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**SUSTAINABLE ENERGY EFFICIENCY AND  
ENERGY SECURITY IN DEVELOPING  
COUNTRIES: A CASE STUDY OF  
AIRPORTS IN SOUTH AFRICA**

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Thesis submitted in fulfilment of the requirements for the degree of  
Doctor of Philosophy in Engineering (PhD)  
(Mechanical Engineering)

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Durban, South Africa

4<sup>th</sup> February 2022

As the candidate's supervisor, I have approved this thesis for submission.

Signed: 

Date: 4<sup>th</sup> February 2022

**Name: Prof. Freddie L. Inambao**

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## Declaration 2 - Publications

This section presents the articles that form part and/or include the research presented in this thesis. The following papers have been published:

### DoHET Accredited Journals

1. Jerusha Joseph, Freddie L. Inambao, Sustainability: The Big Challenge, International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 11 (2020), pp. 3080-3098 © International Research Publication House.  
<https://dx.doi.org/10.37624/IJERT/13.11.2020.3080-3098>  
<http://www.irphouse.com>
2. Jerusha Joseph and Freddie L. Inambao, Trends: Energy Efficiency and Energy Security, International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084–4117 © International Research Publication House.  
[http://www.irphouse.com/ijert20/ijertv13n12\\_06.pdf](http://www.irphouse.com/ijert20/ijertv13n12_06.pdf)  
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3. Jerusha Joseph & Professor Freddie Inambao, Barriers to Sustaining Energy Efficiency and Energy Security in Developing Countries, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD). ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 6, Dec 2021, 165-182 © TJPRC Pvt. Ltd., DOI : 10.24247/ijmperddec202111.  
<http://www.tjprc.org/publishpapers/2-67-1636096243-11IJMPERDDEC202111.pdf>  
URL – <http://www.tjprc.org/view-archives.php>
4. Jerusha Joseph & Professor Freddie Inambao, Principles for Achieving Energy Efficiency in Developing Countries, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD). ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 2, Apr 2021, 265-282 © TJPRC Pvt. Ltd., DOI : 10.24247/ijmperdapr202120.  
<http://www.tjprc.org/publishpapers/2-67-1615791153-IJMPERDAPR202120.pdf>  
URL – <http://www.tjprc.org/view-archives.php>
5. Jerusha Joseph & Professor Freddie Inambao, Energy Consumption and Energy Efficiency of Airports: A Case Study of Airports in South Africa, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 2, Apr 2021, 205-228 © TJPRC Pvt. Ltd. DOI : 10.24247/ijmperdapr202116.  
<http://www.tjprc.org/publishpapers/2-67-1615277314-16IJMPERDAPR202116.pdf>  
URL – <http://www.tjprc.org/view-archives.php>

6. Jerusha Joseph & Professor Freddie Inambao, Energy Efficiency for Airport Infrastructure: A Case Study of the Implementation of Energy Efficiency for Airports in South Africa, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 2, Apr 2021, 383–406 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdapr202118.  
<http://www.tjprc.org/publishpapers/2-67-1616400030-28IJMPERDAPR202128.pdf>  
URL – <http://www.tjprc.org/view-archives.php>
7. Jerusha Joseph & Professor Freddie Inambao, Entrenching Energy Efficiency as a Culture at Airports: A Case Study of the Implementation of Energy Efficiency for Airports in South Africa, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 3, Jun 2021, 405–420 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdjun202134.  
<http://www.tjprc.org/publishpapers/2-67-1621485316-34IJMPERDJUN202134.pdf>  
URL – <http://www.tjprc.org/view-archives.php>
8. Jerusha Joseph & Professor Freddie Inambao, Reducing Energy Consumption at Airports in South Africa: Investigating Technologies that Reduce Electricity Consumption, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 6, Dec 2021, 133-146 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperddec20219.  
<http://www.tjprc.org/publishpapers/2-67-1634800855-9IJMPERDDEC20219.pdf>  
URL – <http://www.tjprc.org/view-archives.php>
9. Jerusha Joseph & Professor Freddie Inambao, Principles for Achieving Energy Security in Developing Countries, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 5, Oct 2021, 155–178 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdoct202111.  
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URL – <http://www.tjprc.org/view-archives.php>
10. Jerusha Joseph & Professor Freddie Inambao, Energy Security: Conceptualising a Low-Carbon Energy Mix for Airports in South Africa, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 6, Dec 2021, 29-56 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperddec20213.  
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URL – <http://www.tjprc.org/view-archives.php>
11. Jerusha Joseph & Professor Freddie Inambao, Energy Security: Investigating Wind Energy for Airports in South Africa – A Technoeconomic Assessment, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN

- (E): 2249-8001 Vol. 11, Issue 4, Aug 2021, 203-228 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdaug202117.  
<http://www.tjprc.org/publishpapers/2-67-1625050719-IJMPERDAUG202117.pdf>  
URL – <http://www.tjprc.org/view-archives.php>
12. Jerusha Joseph & Professor Freddie Inambao, Energy Security: Investigating Anaerobic Digestion for Airports in South Africa – A Technoeconomic Assessment, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 4, Aug 2021, 319-340 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdaug2021.  
<http://www.tjprc.org/publishpapers/2-67-1626781633-25IJMPERDAUG202125.pdf>  
URL – <http://www.tjprc.org/view-archives.php>
13. Jerusha Joseph & Professor Freddie Inambao, Energy Security: Investigating Natural Gas for Energy Generation at Airports in South Africa – A Technoeconomic Assessment, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 5, Oct 2021, 193-214 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdoct202113.  
<http://www.tjprc.org/publishpapers/2-67-1632896505-13IJMPERDOCT202113.pdf>  
URL – <http://www.tjprc.org/view-archives.php>
14. Jerusha Joseph & Professor Freddie Inambao, Energy Security: Investigating Geothermal Heat Sinks for Air Conditioning Systems at Airports in South Africa – A Technoeconomic Assessment, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 5, Oct 2021, 231-246 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdoct202116.  
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URL – <http://www.tjprc.org/view-archives.php>
15. Jerusha Joseph & Professor Freddie Inambao, Energy Security: Standards and Guidelines for Solar Photovoltaic Installations including Technical Plan to Transition Solar Photovoltaic Plant Maintenance to be Performed In-house for Airports in South Africa, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 5, Oct 2021, 101-122 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdoct20218.  
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URL – <http://www.tjprc.org/view-archives.php>
16. Jerusha Joseph & Professor Freddie Inambao, Energy Security: Establishing a Low Carbon Energy Mix and Roadmaps to Carbon Neutrality in Electricity Consumption for Airports in South Africa, International Journal of Mechanical and Production Engineering Research and

Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 6, Dec 2021, 91-106 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdddec20216.

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URL – <http://www.tjprc.org/view-archives.php>

17. Jerusha Joseph & Professor Freddie Inambao, Ensuring Sustainability of Energy Efficiency and Energy Security in Developing Countries: A Case Study of Airports in South Africa, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 6, Dec 2021, 219-236 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdddec202114.

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URL – <http://www.tjprc.org/view-archives.php>

18. Jerusha Joseph & Professor Freddie Inambao, Sustainability of Energy Efficiency and Energy Security for Airports in South Africa: Guidelines for Adopting Green Building Status for New Infrastructure, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 5, Oct 2021, 123-144 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdoct20219.

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URL – <http://www.tjprc.org/view-archives.php>

19. Jerusha Joseph & Professor Freddie Inambao, Sustainability of Energy Efficiency and Energy Security for Airports in South Africa: Guidelines for Transitioning Existing Terminal Buildings to Green Building Status, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 6, Dec 2021, 119-132 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdddec20218.

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URL – <http://www.tjprc.org/view-archives.php>

20. Jerusha Joseph & Professor Freddie Inambao, Leveraging Fourth Industrial Revolution Technologies and Designs for Realising Energy Efficiency and Energy Security in Developing Countries, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 11, Issue 6, Dec 2021, 257-274 © TJPRC Pvt. Ltd. **DOI** : 10.24247/ijmperdddec202116.

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## **Dedication**

I dedicate this thesis to the “Energy of the Universe” whose nature and design enabled this work to be completed for the progression and purpose that is unfolding.

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I convey my thanks to Airports Company South Africa (ACSA) for supporting my studies, allowing me to use the airports as a case study for this thesis and most importantly promoting my work for implementation in ACSA.

My sincerest gratitude to my Creator for making the completion of this PhD thesis possible and allowing that this be in His Will for me. It is always my greatest fulfilment to do that which is in His Will. My greatest desire is for His purpose and calling for my existence to be complete in respect of this thesis and the reason of my being a human being.

## Abstract

When looking at the penetration of energy efficiency into the built environment and progress in the decrease in reliance on fossil fuel sources for energy generation, there is a definite challenge in obtaining the priority it requires to arrest the exponential increase in carbon emissions. Energy being key to economic development and improvement of the human way of life, developing countries face unique challenges to secure and sustain low carbon energy sources and effectively inculcate energy efficiency. This study aimed to present a solution in the form of an engineering approach entrenched in the three dimensions of business sustainability, i.e., environmental, social, and economic, to ensure that efforts towards energy efficiency and energy security in developing countries are effective and sustained in reducing carbon emissions. This solution was implemented in a live environment for nine airports in South Africa, and the results are presented in the form of case studies. The thesis investigated the global context of the climate change challenge and the global trends regarding carbon emissions from energy generation. The barriers that developing countries face with respect to achieving energy efficiency and energy security are presented together with the focuses required to overcome the barriers. Energy efficiency is investigated from the point of resource extraction to the point of energy end use, investigating energy conversion efficiencies, showing its best-matched end-use, resulting in the determination of principles for energy efficiency from component to system to infrastructure ecosystem. The principles developed were used to write an energy efficiency policy for all new infrastructure adopted at Airport Company South Africa's (ACSA's) nine airports in South Africa. An approach to interpreting onsite low carbon energy sources and their generation potential using available commercial technologies is proposed. Principles are created to determine an optimum low carbon energy mix that is suitable to available resources, business focus, operating environment and efficiently matching the site energy demand. The resulting energy mix based on these principles is presented as a case study for ACSA's airports. The technologies identified for implementation to reduce energy consumption of the airports as well as their carbon footprint through the energy mix are tested for their financial viability using an economic model run via Microsoft Excel. These initiatives are SMART (specific, measurable, achievable, relevant, timed) in that they are specifically chosen for an organisation in a developing country, measurable in economic return and environmental benefit, achievable for the business, relevant to the airports' geographical location and timed to map a pathway to carbon neutrality in electricity consumption for the airports by 2030. To ensure that the principles defined are sustained through the necessary changes in legislation, personnel and technologies, a set of key factors that underpin energy efficiency and energy security were determined and are presented. A case study of the implementation of these factors for airports in South Africa are presented. The thesis concludes with leveraging the fourth industrial revolution for innovative engineering solutions, presenting smart solutions to close the large development time gaps required for building human capacity, engineering capability and costly

storage technologies to mature due to inherent intermittency of renewable energies. The results of the study and its implementation show that the solutions presented for energy efficiency and a low carbon energy mix are realistic and successful, while being grounded in sound scientific and engineering principles and sustained through inevitable changes. This is evident in the various strategies, company policies, technical guidelines and other programmes being approved and implemented by the senior management of the organisation that owns and operates the nine South African airports presented in this case study. The findings of the implementation show that a low carbon energy mix makes business sense, provides energy security and that achieving carbon neutrality is possible through the adoption of carbon offsetting. The “acid test” showing the solution presented in this thesis is being implemented for the nine airports in South Africa is that it still remains as a valid and a business focus even in the financial crisis faced by the aviation industry since the COVID-19 pandemic.

**Keywords:** *Sustainable Energy Efficiency, Sustainable Energy Security, South African Airports low-carbon Energy Mix, Leveraging Fourth Industrial Revolution for reducing carbon emissions, green airport buildings, renewable energy for airports*

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# CHAPTER 1. INTRODUCTION

## 1.1 Introduction

Climate change due to the increased concentration of carbon-dioxide emissions in the earth's atmosphere from human activity is a major concern globally. Over the last two decades, considerable effort has been made by most countries around the world to reduce carbon-dioxide and other greenhouse gas emissions that accelerate global warming. Technology advancements towards greater efficiency and conservation of resources in energy generation and energy usage in all sectors including industrial, domestic, commercial, transportation and travel have contributed towards reducing carbon dioxide emissions. Governments of many countries have pledged to reduce carbon emissions and have issued and implemented various policies and legislation to promote reduced carbon emissions. Governments of wealthier countries, primarily those classified as having developed economies, have gone a step further by providing incentives and subsidies to promote the adoption of less carbon intensive energy sources, technologies and fuels. State owned entities have begun including environmental considerations in their strategies and developments in an effort to influence the private sectors to include environmental considerations in urban, commercial and industrial sectors. Despite these efforts, carbon-dioxide emissions have been steadily increasing (Fig. 1).

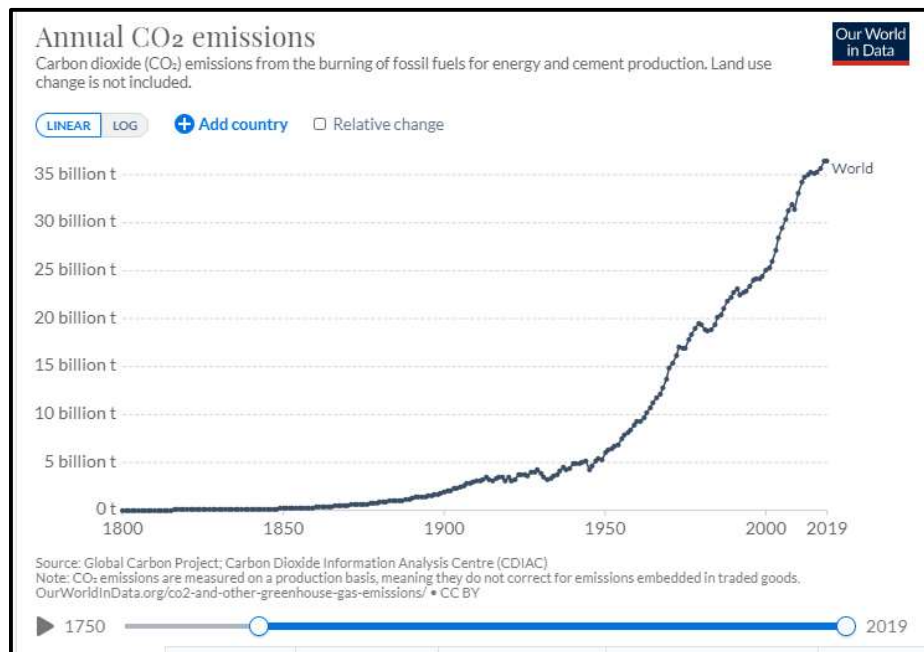


Figure 1: Global annual CO<sub>2</sub> emissions (1800-2019) [1]

The four industrial revolutions that made the human way of life convenient together with the advancement in medicine has contributed to the explosion of the human population (Fig. 2). By superimposing the growth of the human population (Fig. 3) and marking the start of the industrial

revolutions (Fig. 4), the correlation of the industrial revolutions with the accelerated growth of the human population can be observed.

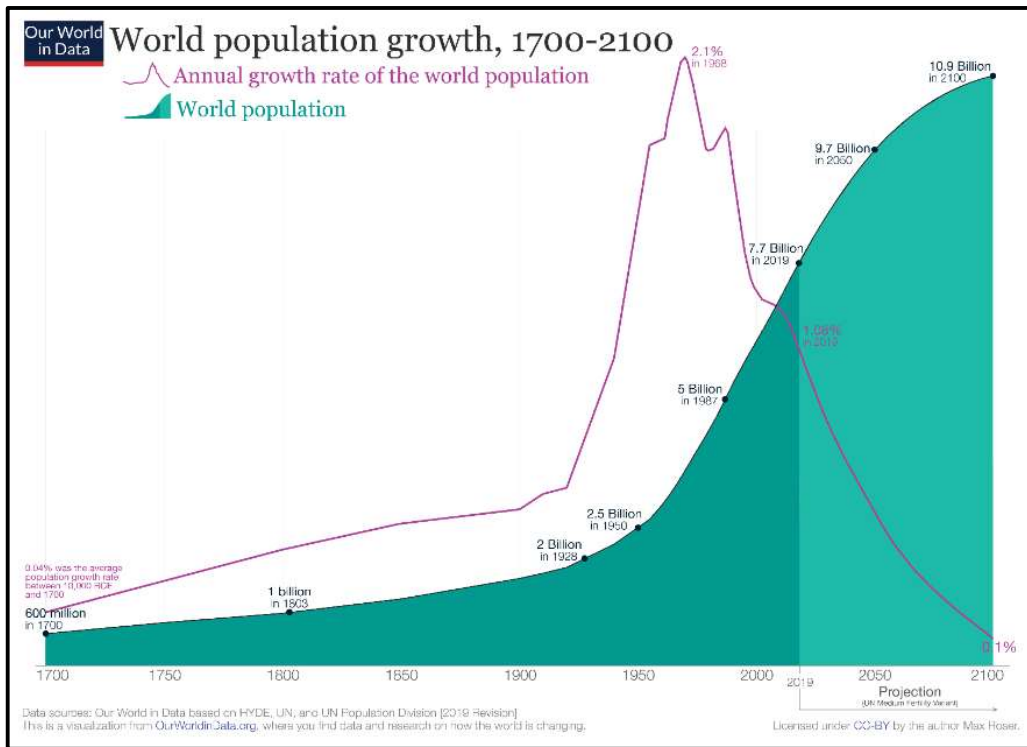


Figure 2: World population growth [2]

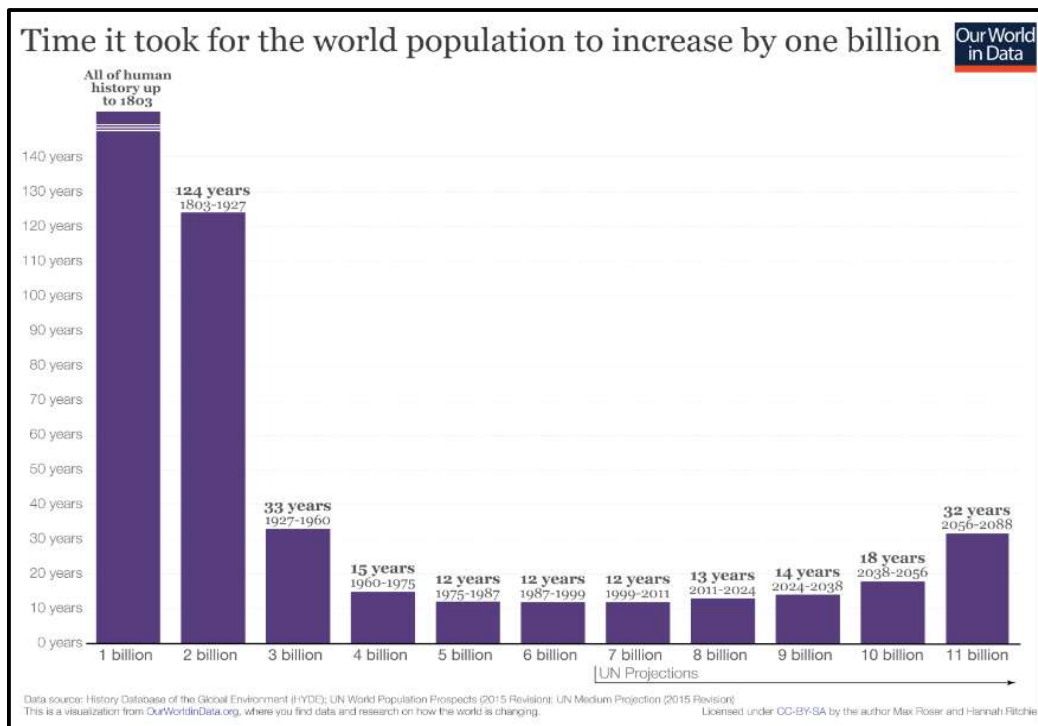


Figure 3: Population growth rates [2]

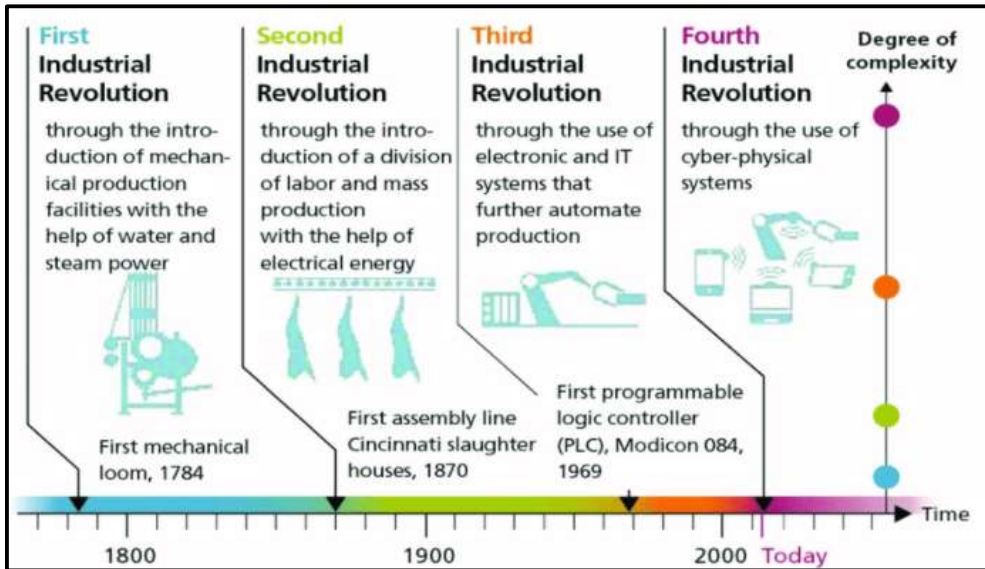


Figure 4: Timeline showing the four industrial revolutions [3]

Energy has played a key role as a catalyst in the industrial revolutions with steam energy in the first industrial revolution, electricity in the second industrial revolution and semiconductor material in electronics (light current), controllers and computing in the third industrial revolution, which enabled the fourth industrial revolution based on artificial intelligence. The energy consumption profile of the world has been increasing since the first industrial revolution (Fig. 5).

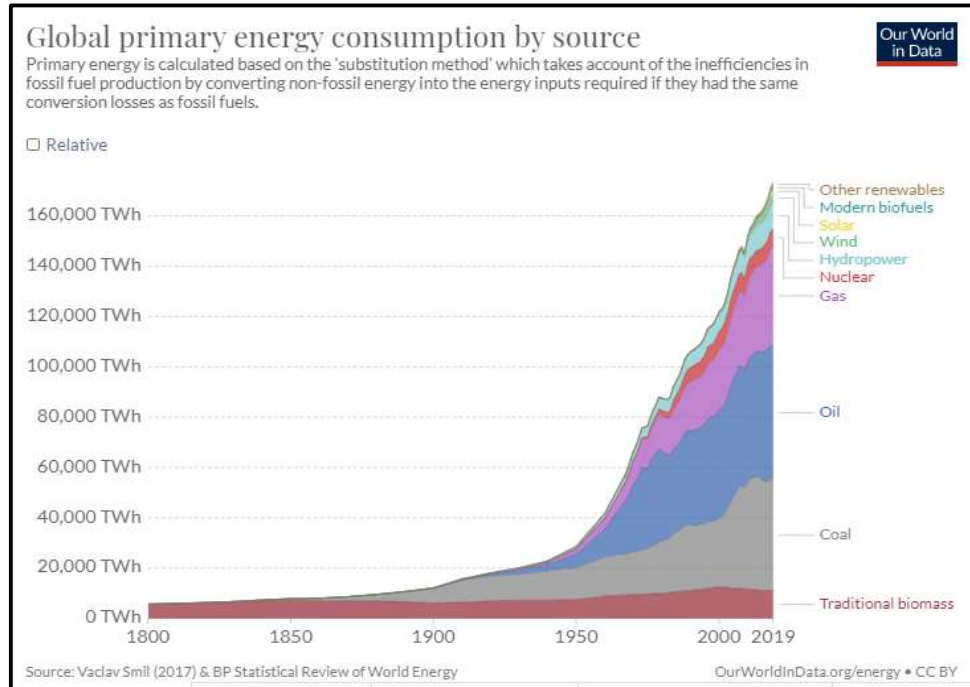


Figure 5: Energy consumption of the world (1800-2019) [4]

Energy is a key ingredient in economic growth and development. Access to energy thus plays a role in developing the financial economy of countries in the world. A comparison of the GDP of countries in

the world in 1950 to 2016 shows that most of the countries in the world are richer in 2016 compared to 1950 (Fig. 6) and a closer view shows that the global average indicates that the world was 4.4 times richer in 2016 compared to 1950 (Fig. 7). Fig. 8, which is a zoom in of Fig. 7, shows that most developing countries have increased in wealth way beyond the global average. Most of the developed countries are around the global average.

Energy consumption around the world contributes to 73.2 % of the global greenhouse gas emissions. (Fig. 8) This accounts for the majority of the greenhouse gas emissions and thus focussing efforts on reducing greenhouse gas emissions from energy consumption will be most significant in our fight against climate change. Energy use in industry contributes 24.2 %, in buildings 17.5 %, and in transport 16.2 %. Focusing efforts on reducing emissions in buildings will thus prove significant in reducing greenhouse gas emissions and the principles adopted can be shared with the industrial sector.

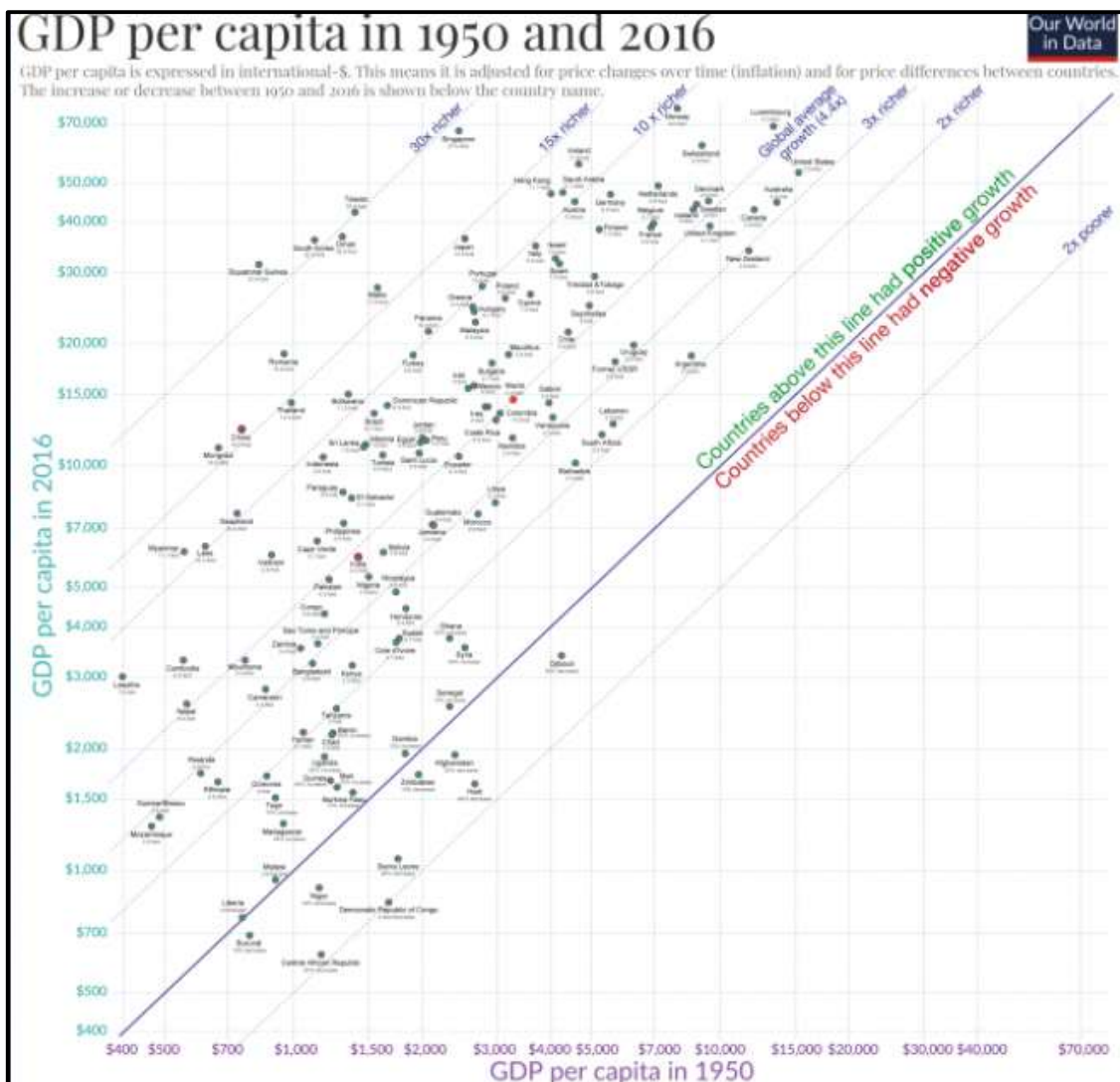


Figure 6: Comparing the economies of the countries of the world in 1950 vs 2016 [5]

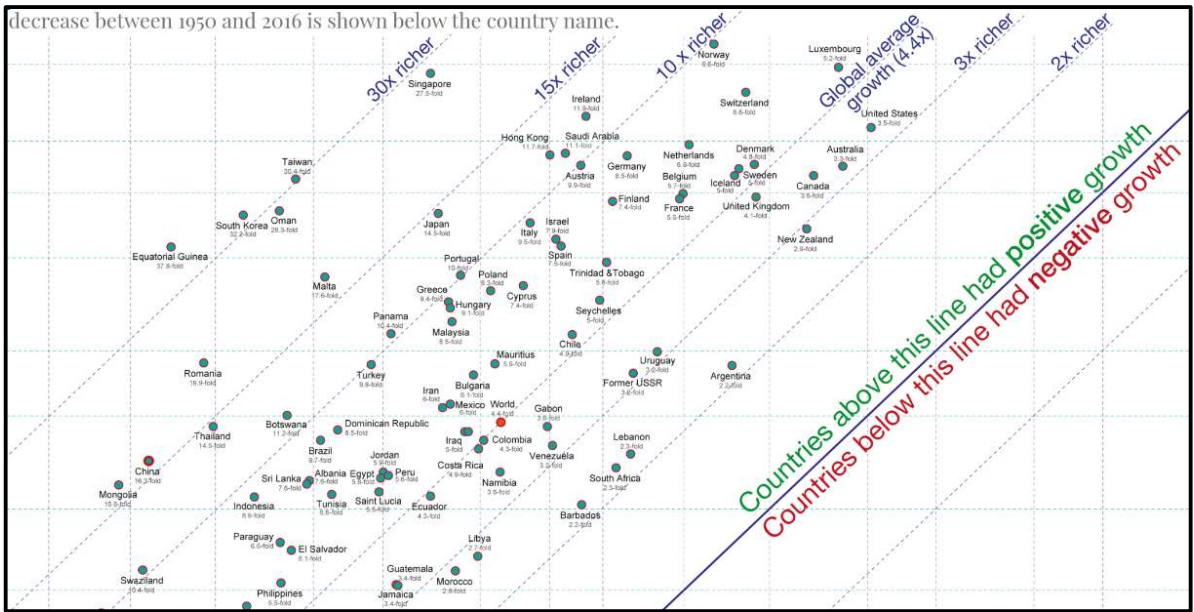


Figure 7: A closer view of Fig. 6 showing countries' economic growth in relation to global average economic growth [5]

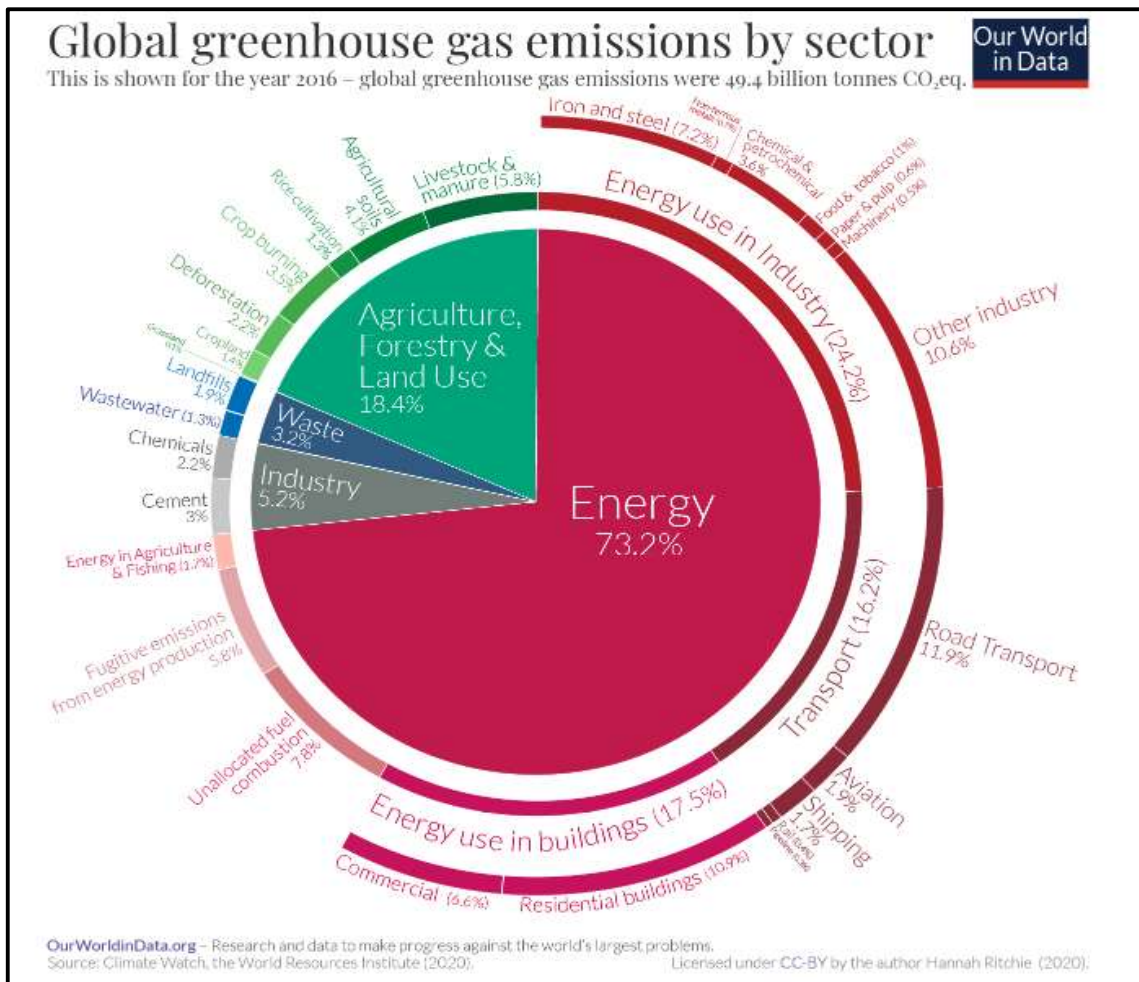


Figure 8: Global greenhouse gas emissions by sector [6]

Reduction in greenhouse gas emissions have been gaining global attention over the last three decades. Much effort has been put into global cooperation in reducing carbon emissions. For the first time in June 1988 at the World Conference on the Changing Atmosphere in Toronto, politicians and scientists concluded that “humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war.” The conference recommended reducing carbon dioxide emissions by 20 % by 2005. In the same year, the Intergovernmental Panel on Climate Change (IPCC) published its First Assessment Report, which highlighted the increasing accumulation of human-made greenhouse gases in the atmosphere. The first Conference of the Parties (COP) in Canada in 1995 recognized that there is a need for binding commitments by industrialized countries to reduce emissions. In December 1997 around 150 countries signed the Kyoto Protocol, which binds 38 industrialized countries (called Annex 1 countries) to reduce greenhouse gas emissions by an average of 5.2 % below 1990 levels in the period of 2008 to 2012. The Kyoto Protocol became international law on 16 February 2005. [7]

In December 2007 the United Nations (UN) Climate Change Conference in Bali, Indonesia, which was attended by representatives from over 180 countries, together with observers from intergovernmental and nongovernmental organisations, agreed on a “Bali roadmap”. This document provided guidelines to reach a treaty by the end of 2009 to replace the Kyoto Protocol. That year in April during the UN Climate Talks in Bangkok – the first meeting after the Bali conference – an ambitious timetable was developed to complete the complex negotiations on a new climate deal in time for the UN Climate Conference in Copenhagen in December 2009. [7]

Another significant agreement was the Paris Agreement which is a legally binding international treaty on climate change adopted by 196 parties at COP 21 in Paris, on 12 December 2015, and which entered into force on 4 November 2016. Its goal is to limit global warming to below 2 °C, preferably to 1.5 °C, compared to pre-industrial levels, by 2100. To achieve this long-term temperature goal, countries aim to reach global peaking of greenhouse gas emissions as soon as possible to achieve a climate neutral world by mid-century. The Paris Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects. [8]

The countries that are committed to the Paris Agreement are from different socio-economic backgrounds with varying political and governmental dynamics thus the climate change challenge is not equal nor is it ranked the same in terms of a country’s priorities. Basic human needs that must be met as well as other human rights issues in many developing countries take priority and this prioritization can be seen in the United Nations sustainable development goals (SDG) (Fig. 9).



Figure 9: United Nations Sustainable Development Goals (SDGs)

Energy is key in the economic development that is needed to address poverty and provide for basic human needs, which is a challenge for developing countries. Mature energy technologies characteristically are at peak efficiency and these technologies are primarily fossil fuel based. They have reached economies of scale and thus can be secured at competitive rates which is key in access to cheap energy for much needed economic growth. Transitioning developing countries towards reducing carbon emissions to reach the goal to limit global warming to well below 2 °C, preferably to 1.5 °C, compared to pre-industrial levels by 2100, necessitates a drastic change that threatens their ability to meet basic human needs, as outlined by the first 12 SDGs in Fig. 9, within the near future. This challenge varies from country to country and the result 80 years from now could go one of three ways, as depicted in Fig. 10.

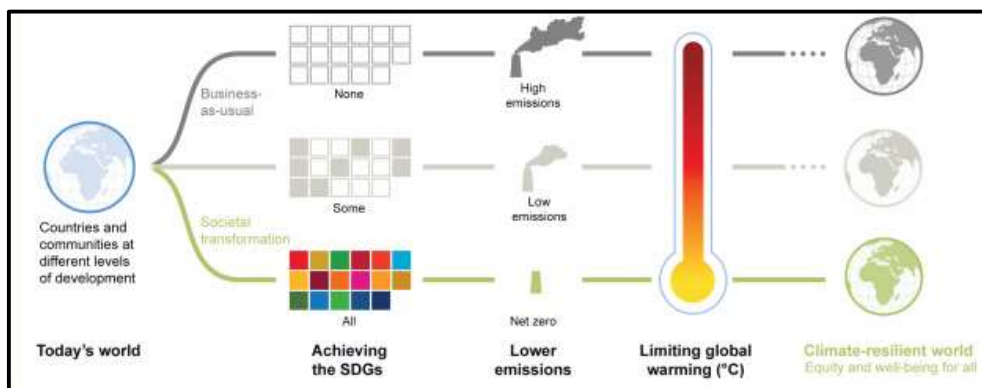


Figure 10: Climate-resilient development pathways (CRDPs) describe trajectories that pursue the dual goals of limiting warming to 1.5 °C while strengthening sustainable development [10]

When looking at the consequences of climate change and the priority of meeting the basic needs of citizens from developing countries, developing countries are placed in an awkward position such that if they do not innovatively address these issues now, the result could be the business-as-usual scenario

(Fig. 10) and not the climate-resilient world that secures the future of citizens without compromising their ability to meet immediate needs.

## 1.2 Problem Statement

With the challenges facing the countries of the world, the attempts to reduce carbon emissions to keep the global temperature rise to below 2 °C (Fig. 11) or below 1.5 °C (Fig. 12) will require consistency of efforts and the capacity to sustain the impact of efforts made to ensure this transition to a low carbon economy. The peaking of the global CO<sub>2</sub> emissions between 2020 and 2030 for the 2 °C pathways and between 2020 and 2025 for the 1.5 °C pathways before the steep drop in global CO<sub>2</sub> emissions, implies that our CO<sub>2</sub> emissions should be capped off now within this decade and so as to result in the required steep drop in CO<sub>2</sub> emissions within the next two decades. The various curves in the scenarios contained in Fig. 11 and Fig. 12 show the impact of a delay in the peaking of CO<sub>2</sub> emissions. Delays in peaking of CO<sub>2</sub> emissions show that a quicker dropping off of CO<sub>2</sub> emissions is then required to ensure that global CO<sub>2</sub> emissions start dropping off by mid-century and complete the desired drop off by the end of the century.

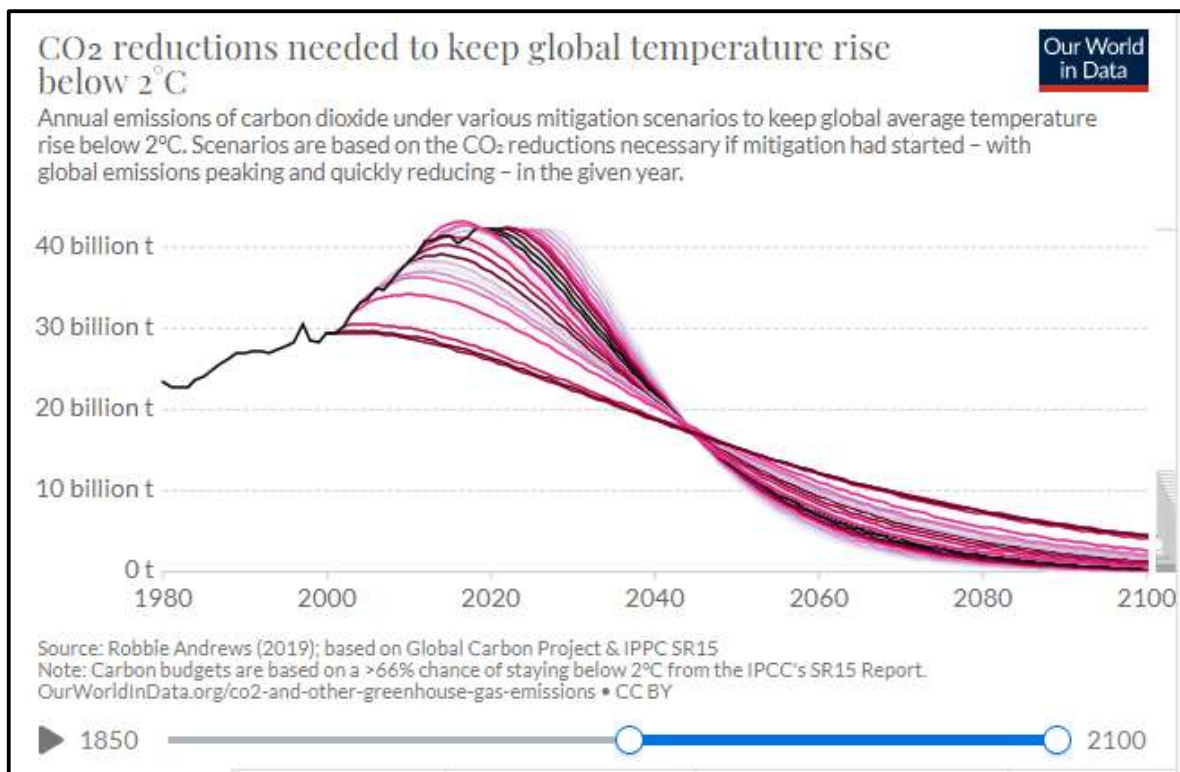


Figure 11: CO<sub>2</sub> reductions needed to keep global temperature rise below 2 °C [11]

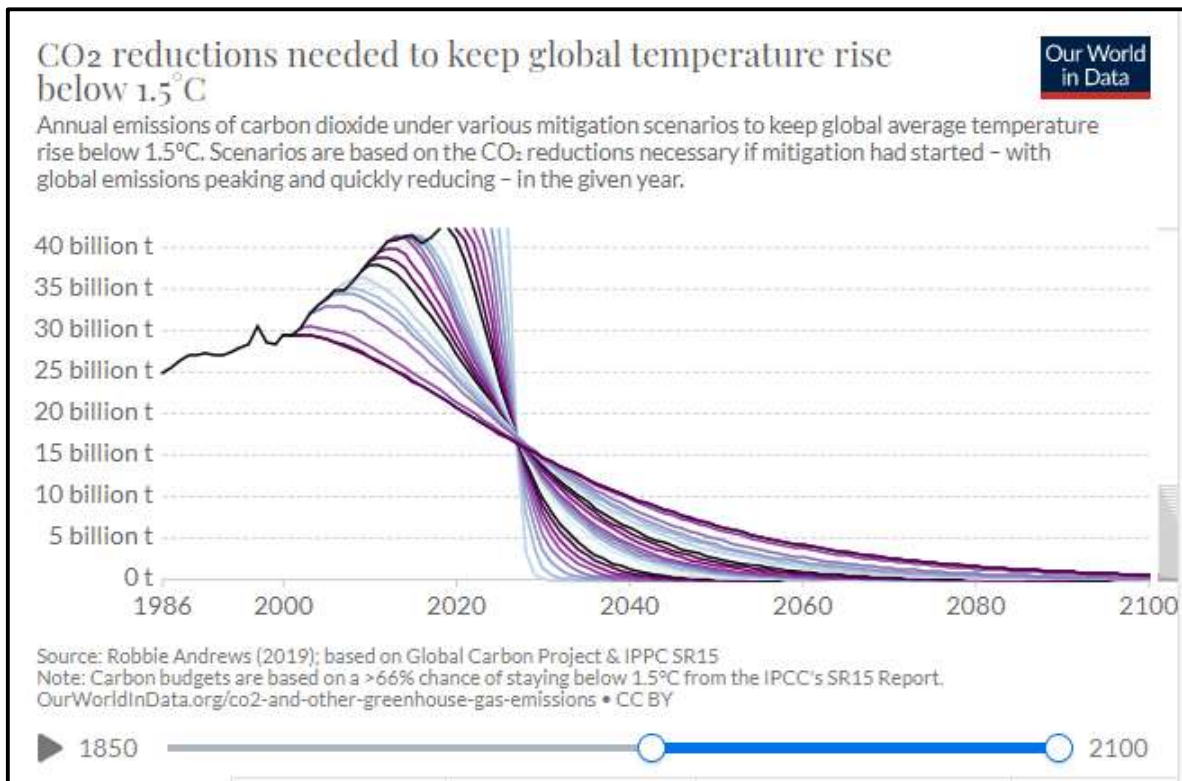


Figure 12: CO<sub>2</sub> reductions needed to keep global temperature rise below 1.5 °C [12]

Developing countries need to find a solution that allows them to transition to a low carbon economy without compromising their ability to address their immediate priorities. The challenge lies in how to transition developing countries to a low carbon economy that is sustained, effective and within their socio-economic means.

### 1.3 Research Motivation

Reducing carbon emissions to prevent climate change is a global aim with many countries around the world uniting in doing their bit to achieve this goal. The goal may be the same, however, the effort required to achieve the goal differs. Coal and oil resources are well established in all sectors of energy usage with related technologies being well established and mature in the market, making them cheaper and easier to operate and maintain compared to newer technologies that use renewable energy. There is therefore more opportunity and motivation for developing countries to transform their economies using traditional technologies and energy sources.

This dynamic has many implications that can be seen in the scenarios presented in Fig. 13 which provides a graphic picture of the content of the Paris Agreement. Pledges and targets of various countries in the world show a 2.5 °C to 2.8 °C change by 2100 in the global warming scenario compared to the present day global temperature. Lagging behind this scenario is the warming scenario that shows

the current policies in place to achieve the reduction in carbon emissions indicating a global warming change of 2.8 °C to 3.2 °C by 2100. This means that the policies we have today which are meant to bring about a change in climate that is lower than the “no climate policies” scenario indicating a 4.1 °C to 4.8 °C in 2100 are not quite adequate to meet the “pledges and targets” scenario. Furthermore, our pledges and targets together do not meet the desired scenarios of 2 °C pathways or 1.5 °C pathways which indicates warming relative to the pre-industrial base period 1850 to 1900.

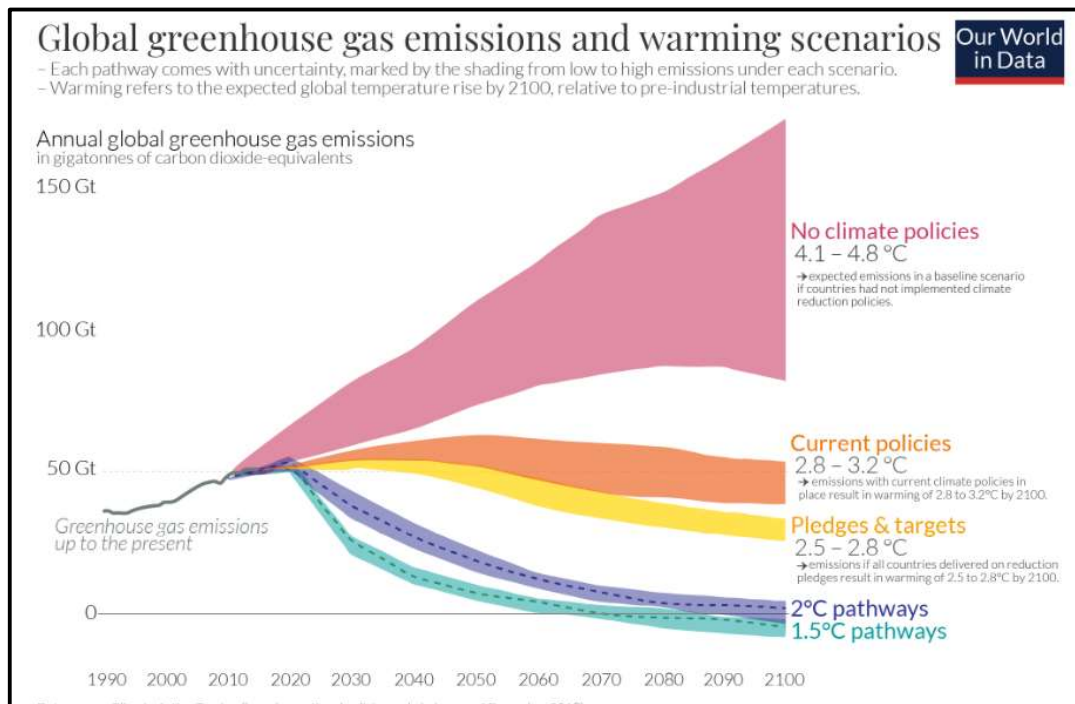


Figure 13: Global greenhouse gas emissions and warming scenarios [9]

There are definite challenges in relation to making commitments to reducing greenhouse gas emissions. This is a serious and global challenge that affects the existence of life as we know it. Consequences of climate change are already visible, for instance, temperatures are rising, polar caps are melting, sea level is rising, desertification is increasing and the winters in Europe are becoming wetter. Mount Kilimanjaro through the years contains less and less snow. The number of natural disasters are increasing, and tsunamis, floods and extreme drought are occurring more frequently than in times past. In the period 1950 to 1960 worldwide, 13 natural disasters were registered compared to 72 in the period 1990 to 1998. [7]

Changes in global climate will have enormous consequences for nature as well as the economy. A small rise in mean annual temperature can have a major impact on a region’s ecology and biological diversity. [13] Biodiversity is of crucial importance for the stability of ecosystems as well as for human health. [14] Some researchers estimate that these costs are set to rise to between 5% and 20% of global income. [15]

The human health effects of climate change will vary in complexity, scale and directness and will have different timing. Impacts will vary geographically as a function both of environment and topography and of the vulnerability of the local population. Impacts will be both positive and negative (although expert scientific reviews anticipate predominantly negative) as climatic change will disrupt or otherwise alter a large range of natural ecological and physical systems that are an integral part of Earth's life support system. [7] Human health effects are pictorially represented in Fig. 14.

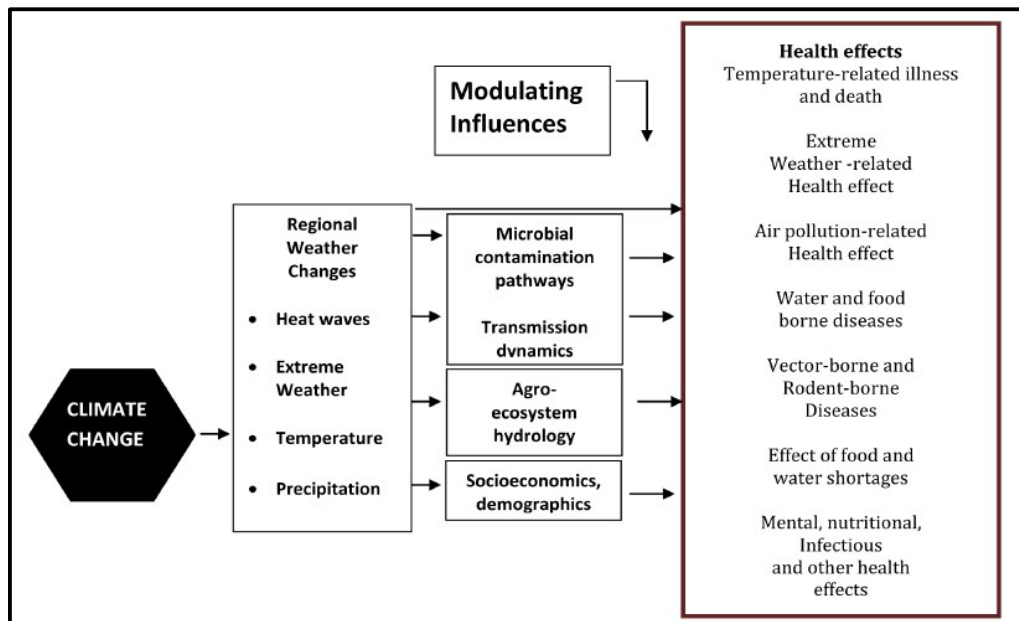


Figure 14: Pathways by which climate change affects human health including local modulating influences and the feedback influence of adaptation measures [7]

Mitigating the effects of climate change requires a global effort regardless of the social, economic and political dynamics, therefore finding inventive and innovative ways to overcome challenges will be key to being successful in reducing carbon emissions. Developing countries do not have the economic strength or the required social and political standing to easily transition towards a low carbon economy through energy efficiency and energy security and thus their challenge will be unique. This study aimed to contribute to the ease and success of developing countries' in achieving and sustaining energy efficiency and energy security.

#### 1.4 Aims and Objectives

The purpose of this thesis was to develop a solution, implement the solution and present the work executed to achieve sustained energy efficiency and energy security in developing countries. To realise this purpose the following objectives were formulated:

1. Define sustainability and the challenges faced in the context of achieving sustained energy efficiency and energy security in developing countries.
2. Identify and present global trends in the achievement of energy efficiency and energy security in developing countries and outline the lack of sustainable progress in reducing carbon emissions.
3. Identify and investigate the barriers faced by developing countries in achieving energy efficiency and energy security.
4. Develop principles for achieving energy efficiency in developing countries.
5. Develop principles to achieve energy security in developing countries.
6. Develop principles for the purpose of sustaining energy efficiency and energy security in developing countries.
7. Develop innovative ways to overcome barriers faced by developing countries in the quest for achieving and sustaining energy efficiency and energy security.

The solution to achieve sustained energy efficiency and energy security in developing countries was implemented at nine airports in South Africa which are owned and operated by Airports Company South Africa (ACSA) SOC Limited. Airports in South Africa owned and operated by ACSA have diverse climates and resource availabilities due to their geographical locations, very different passenger throughput, size of facilities and operational compliment, thus making an ideal setting for implementing the same goal, overcoming the unique consequences, ensuring energy security and energy efficiency are sustained. Airports also have facilities that are similar to mini-cities, especially larger airports, e.g. O R Tambo International Airport, Cape Town International Airport, King Shaka International Airport in the case studies and this makes the implementation from a facilities perspective similar for country wide adoption. The state-owned financially autonomous organisation (ACSA) also provided a unique setting of political- and profit-based platforms on which to derive, gain support for and implement a sustainable solution for energy efficiency and energy security.

To realising this implementation the following objectives were formulated, in relation to ACSA airports in South Africa:

1. Investigate energy consumption and energy performance.
2. Develop standards and guidelines for achieving energy efficiency.
3. Entrench energy efficiency.
4. Investigate technologies that can reduce electricity consumption by performing a technoeconomic assessment of relevant technologies.
5. Investigate energy needs and conceptualise a low carbon energy mix.
6. Investigate the uptake of wind energy by performing a relevant technoeconomic assessment.

7. Investigate the application of anaerobic digestion by performing a relevant technoeconomic assessment.
8. Investigate the use of natural gas for energy generation by performing a relevant technoeconomic assessment.
9. Investigate the use of geothermal heat sinks for air conditioning systems by performing a relevant technoeconomic assessment.
10. Review the lessons learnt from existing solar photovoltaic installations at airports in South Africa and establishing standards and guidelines for further installations.
11. Develop and confirm a low carbon energy mix.
12. Develop and present a solution to sustain energy efficiency and energy security.
13. Develop guidelines for the adoption of green buildings in new infrastructure and for existing terminal buildings to sustain energy efficiency and energy security.

## **1.5 Methodology**

To achieve the aims and objectives, it was necessary to establish an engineering solution which upon implementation suited the operating environment and supported the business imperatives with the current staff complement and commercially available technologies. The following approach was used to achieve the aims and objectives:

1. Understand the context of the environmental challenge of global warming and establish the reason for increasing carbon emissions as well as the urgent need to abate the acceleration of climate change through carbon emissions.
2. Investigate the global challenge of carbon emissions reduction, the progress and ways adopted to reduce emissions.
3. Investigate the barriers faced by developing countries to achieve reduced carbon emissions.
4. Derive principles to sustaining reduced carbon emissions in developing countries by considering ways to entrench globally and locally relevant initiatives that are implementable via a strategy, supporting business imperatives in all three spheres of business sustainability, i.e. environmental, social and economic.
5. Draft a strategy for the nine ACSA-owned and operated airports in South Africa to reduce carbon emissions incorporating elimination of unnecessary carbon emissions, transitioning necessary energy requirements to reduced carbon emissions, offsetting unavoidable carbon emissions and creating an organisational culture to sustain reduced carbon emissions, ensuring that it supports the business sustainability organisational goals.
6. Gain organisational support for the strategy and executive approval for its implementation.

7. Communicate the approved strategy and the plans for its implementation at each airport, forming supporting teams for its implementation.
8. Capacitate teams for implementation of various aspects of the strategy through formal training, sharing of learnings via platforms like workshops and forums.
9. Begin implementation of the approved strategy by deriving principles to achieve energy efficiency in developing countries through the fundamental concept of energy efficiency in practice penetrating every level of the facility and ensuring that it is sustained going forward.
10. Apply the derived principles to achieve energy efficiency in developing countries to the nine airports owned and operated by ACSA including development of a standard and guideline document for achieving energy efficiency in accordance with the approved strategy for implementation.
11. Identify key technologies for energy conservation and energy efficiency at the nine airports, perform financial analysis using economic models used by the business for determining viability of capital investments.
12. Continue implementation of the approved strategy by deriving principles to achieving energy security in developing countries through considering the site's available low carbon energy sources, the site's energy needs, present and future and satisfying the site's energy needs by efficiently matching the available energy source to the need.
13. Identify alternative low-carbon energy generation technologies for implementation at the nine airports, perform financial analysis using economic models used by the business for determining viability of capital investments.
14. Apply the principles to achieving energy security in developing countries to the nine airports owned and operated by ACSA, developing roadmaps to reduced carbon emissions according to the targets and timelines committed to in the approved strategy supporting the business financial goals.
15. In accordance with the approved strategy, prepare for implementation of requirements to meet nationally and internationally recognized environmental standards at existing airport infrastructure at the nine airports and prepare project requirements for future infrastructure compliance.
16. Translate all implementation plans of the objectives of the approved strategy into annual targets, incorporate into all levels of the business, track progress and ensure continuous improvement is incorporated.
17. Upon successful implementation of alternative low-carbon energy generation power plants at one airport, establish standards and guidelines for project implementation of future installations.

18. As part of continuous improvement, identify ways in which barriers to organisational implementation of the approved strategy can be overcome, especially using instruments of the fourth industrial revolution.

## **1.6 Research Significance**

Reducing carbon emissions especially in the quest for energy in developing countries is a unique challenge. Any efforts achieved are not necessarily sustainable due to the challenges faced by developing countries. The increase in global temperature and ever-increasing carbon emissions from energy generation, despite the pledges of countries to reduce carbon emissions and advocacy for climate change, necessitates a solution that works and is consistent in reducing carbon emissions especially in the developing economies of the world where the majority of the increase in carbon emissions over the next few decades is most likely to come from.

The significance of this research is found in the establishment of principles to achieve energy efficiency and energy security in the context of developing countries in South Africa, the implementation of these principles across nine airports in South Africa, and the entrenchment of energy efficiency and energy security within an organisation such that it is sustained successfully through inevitable changes in technologies, personnel, legislation, etc. The process of implementation of these principles at airports in South Africa demonstrates the practicality and workability of these principles. The research demonstrates how to sustain energy efficiency and energy security in developing countries and provides a case study of this implementation for airports in South Africa owned and operated by ACSA. The research also proposes solutions for overcoming barriers faced typically by organisations in developing countries using fourth industrial revolution technologies.

## **1.7 Thesis Outline**

The thesis contains twenty-three chapters. The layout of the thesis is as follows:

Chapter 1 presents the introduction, research motivation, problem statement, research motivation, aims and objectives, research significance, thesis outline, scope of the study and references for the chapter.

Chapter 2 presents the impact of greenhouse gas emissions together with its role in climate change and highlights the key factors to sustain the change in direction towards energy efficiency and minimization of the use of fossil fuel-based energy sources in relation to energy security.

Chapter 3 presents a review of the trends in global energy sources and their evolution and its carbon footprint; the cost-effective modern fuel of energy efficiency together with the approaches and initiatives adopted to achieve energy efficiency and alternative less carbon intensive energy sources in focus. It also reviews South Africa's unique challenges in energy supply and demand, and the role of energy efficiency and an alternative energy mix.

Chapter 4 presents an investigation into the barriers to energy efficiency and energy security in developing countries, contextualising their origins and outlining the required focus to overcome the barriers.

Chapter 5 presents a set of principles to achieve energy efficiency throughout the energy value chain, maximizing financial benefit and reducing carbon emissions.

Chapter 6 presents an investigation of the site energy consumption of the nine ACSA airports, analysing the typical facilities installed at the airports to establish the drivers of the energy consumption, quantify the base load energy consumption, and identify significant energy users constituting more than 70 % of the site's total energy consumption.

Chapter 7 presents the groundwork completed in the process of transitioning the ACSA airports to being energy efficient.

Chapter 8 presents the work done to inculcate the practice of energy efficiency within ACSA with the aim for this to become company culture for the airports in South Africa.

Chapter 9 presents an investigation into the adoption of a solar thermal heat deflective innovative technology to reduce air conditioning in airport terminal buildings in South Africa, providing a technical and economic assessment (or technoeconomic assessment).

Chapter 10 presents an investigation into the technologies that will reduce energy consumption at airports in South Africa, estimating the energy reduction impact, investment and return on investment.

Chapter 11 presents the principles for achieving energy security in developing countries through an approach to defining a developing country's energy mix that overcomes the financial and technological challenges while being suited to its operating environment.

Chapter 12 presents the journey related to conceptualising of a low-carbon energy mix for the nine ACSA airports.

Chapter 13 presents the investigation of establishing a suitable wind energy technology including its technical and economic assessment (technoeconomic assessment) to ensure a reliable and feasible transition for nine ACSA airports.

Chapter 14 presents the technical and financial evaluation (pre-feasibility) or technoeconomic assessment of using waste from the ACSA airports in an anaerobic digestion process producing methane gas to be used as fuel for energy.

Chapter 15 presents the investigation into natural gas as an energy source for the ACSA, providing the technical and financial evaluation (or technoeconomic assessment) of its adoption at airports.

Chapter 16 presents an investigation into the adoption of geothermal heat sinks to serve as a replacements of cooling towers in an airport environment in South Africa, providing a technical and economic assessment (technoeconomic assessment) based on the geothermal heat sink installation at Hotel Verde in the Western Cape of South Africa.

Chapter 17 presents the standards and guidelines relating to technical aspects of the current solar photovoltaic installations at the ACSA airports, and the proposed and supported plan for transitioning the maintenance of all plants to be performed inhouse.

Chapter 18 presents the establishment of a range of energy generation technologies forming a low carbon energy mix that is economically feasible and technically suited to the operating environment to ensure a reliable and feasible transition for nine ACSA airports to realise energy security.

Chapter 19 presents principles that provide an approach to ensuring that climate change mitigation efforts are sustained through implementing relevant technologies, legislation, personnel and markets and shows the application of these principles in an airport environment.

Chapter 20 presents the guidelines for development of green star rated infrastructure at airports in South Africa sustaining energy efficiency and energy security for new terminal, office and commercial buildings, in compliance with the green star rating system of the Green Building Council of South Africa.

Chapter 21 presents the guidelines for transitioning existing airport terminal buildings towards the adoption of a green star rating as per the green star rating system of the Green Building Council of South Africa.

Chapter 22 presents an approach to leveraging the instruments of the fourth industrial revolution to overcome the challenges faced by developing countries in adopting energy efficiency and making provision for their energy security.

Chapter 23 presents the conclusion to this study with recommendations for future work.

## 1.8 Scope

The scope of this thesis covers the main themes represented in Figure 15. The principles for energy efficiency and energy security presented in this thesis can be applied to any organisation in an industry, country-wide, domestic or commercial setting. The application of the principles for energy efficiency and energy security in the case studies presented in this thesis is in the context of a commercial setting within the aviation industry, more specifically, nine ACSA airports in South Africa.

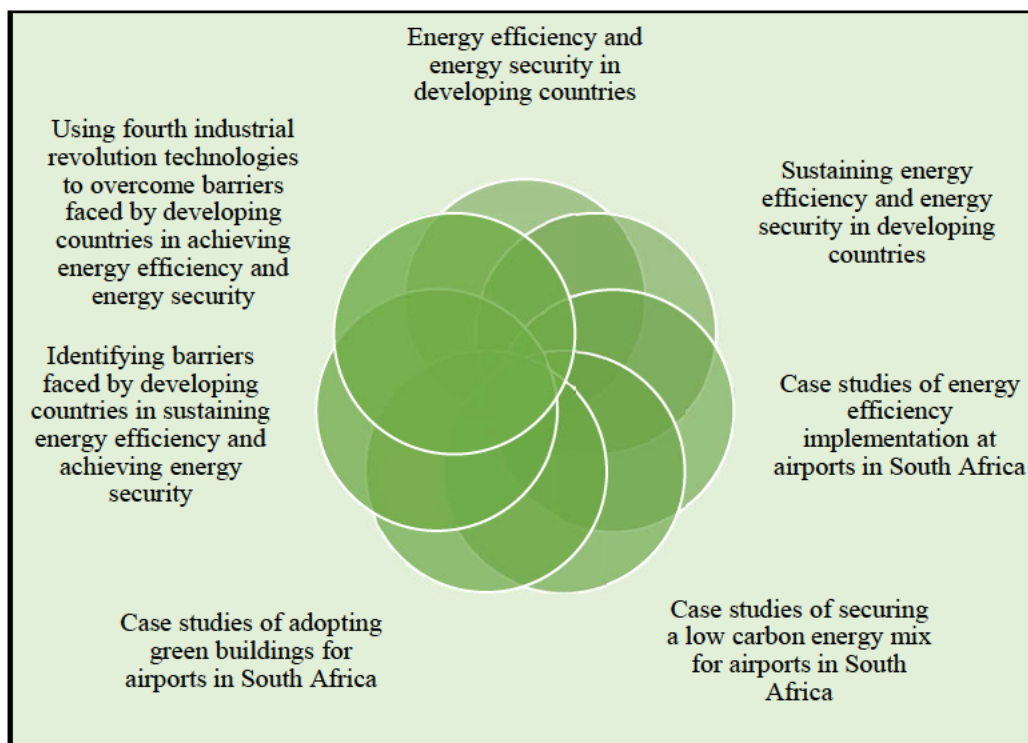


Figure 15: Scope of the themes covered in this thesis

The energy efficiency initiatives presented in the case study cover the energy intensive technologies at airports, particularly the energy conservation technologies related to reducing air conditioning load. The

renewable energy sources and technologies investigated for the airports in the case studies cover solar photovoltaic technology, geothermal heat sinks, and wind energy (vertical axis wind turbines). The low carbon alternative energy sources investigated in the case studies are anaerobic digestion and natural gas. The case studies cover the strategies and frameworks that underpin sustainable energy efficiency and energy security and investigate the adoption of green buildings for existing and new infrastructure in an airport setting.

## References

- [1] Ritchie, H., Roser, M., “CO<sub>2</sub> emissions”, published online at OurWorldInData.org. 2020. Retrieved from <https://ourworldindata.org/co2-emissions?country=>, accessed 01/06/2021.
- [2] Roser, M., Ritchie, H., Ortiz-Ospina, E., “World population growth”, published online at OurWorldInData.org. 2013. Retrieved from <https://ourworldindata.org/world-population-growth>, accessed 01/06/2021.
- [3] Savic, D., Aydin, O., “Rethinking the role of information in the fourth industrial revolution”, In: Ayden, O. et al. (eds), “The impacts of digital transformation” (pp.35-46) Istanbul: EFE Akademi. 2020.
- [4] Ritchie, H., Roser, M., “Energy production and consumption”, published online at OurWorldInData.org. 2020. Retrieved from <https://ourworldindata.org/energy-production-consumption>, accessed 02/06/2021.
- [5] Roser, M., “Economic growth”, published online at OurWorldInData.org. 2013. Retrieved from <https://ourworldindata.org/economic-growth>, accessed 01/06/2021.
- [6] Ritchie, H., Roser, M., “Emissions by sector”, published online at OurWorldInData.org. 2020. Retrieved from <https://ourworldindata.org/emissions-by-sector>, accessed 01/06/2021.
- [7] Adedeji, O., Reuben, O., Olatoye, O., “Global Climate Change”, Journal of Geoscience and Environment Protection, 2014, 2, 114-122. Retrieved from <http://www.scirp.org/journal/gep> <http://dx.doi.org/10.4236/gep.2014.22016>, accessed 04/06/2021.
- [8] United Nations Climate Change, “The Paris agreement”. Retrieved from <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>, accessed 04/06/2021.
- [9] Ritchie, H., Roser, M., “CO<sub>2</sub> and other greenhouse gas emissions”, published online at OurWorldInData.org. 2020. Retrieved from <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions>, accessed 01/06/2021.
- [10] Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (eds.), “Global warming of 1.5 °C”, Intergovernmental Panel on Climate Change (IPCC) Special Report, 2018.

- [11] Our World in Data, Chart, “CO<sub>2</sub> reductions needed to keep global temperature rise below 2 °C”, Retrieved from <https://ourworldindata.org/grapher/co2-mitigation-2c?country=>, accessed 18/06/2021.
- [12] Our World in Data, Chart, “CO<sub>2</sub> reductions needed to keep global temperature rise below 1.5 °C”, Retrieved from <https://ourworldindata.org/grapher/co2-mitigation-15c?country=>, accessed 18/06/2021.
- [13] Pounds, J.A., Puschendorf, R., “Clouded Futures”, *Nature*, Vol. 427, 8 January 2004.
- [14] Harvard Medical School, Chivian, E., “Biodiversity: Its Importance to Human Health”, Harvard Medical School, 2002.
- [15] Stern, N., “The Economics of Climate Change—The Stern Review”, Cambridge: Cambridge University Press, 2006.

## CHAPTER 2. SUSTAINABILITY: THE BIG CHALLENGE

This chapter presents the impact of greenhouse gas emissions together with its role in climate change and highlights the key factors to sustain the change in direction towards energy efficiency and minimization of the use of fossil fuel-based energy sources in relation to energy security.

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<http://www.irphouse.com>

## Sustainability: The Big Challenge

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### Abstract

Reducing greenhouse gas emissions, especially carbon-dioxide emissions, has been an agenda adopted by organizations, governments, businesses and citizens alike all over the world over the last few decades. Energy efficiency, energy conservation and renewable or alternative energy sources to lower in greenhouse gas emissions has been the most popular approach taken by various organizations, governments and individuals to reduce their carbon footprint. Being energy efficient and reducing energy consumption has not only started making business sense but increases reliability and availability of infrastructure. Introducing an environmentally friendly energy source provides a certain level of energy security by reducing dependence on depleting fossil fuel energy sources and purely by diversifying the approach of diversity in the utilization of energy sources (energy mix). However, when looking at the penetration of energy efficiency into the world's built environment and the much needed decrease in reliance on fossil fuel sources for driving energy, there is a definite challenge in that it does not seem to get the priority that it requires to arrest the exponential increase in carbon emissions causing climate change. This paper presents the impact of greenhouse gas emissions together with its role in climate change and highlights the key factors to sustain the change in direction towards energy efficiency and minimization of the use of fossil fuel-based energy sources towards energy security. The result of application of the approach presented will be a reduction in carbon emissions through changing technologies, markets, legislation, personnel and resource availability

**Keywords:** Energy efficiency, energy security, developing countries, sustainability

### I. INTRODUCTION

The challenge of climate change needs to be contextualized for it to be given the priority it requires to ensure that its potential effects do not become a reality in the near future. Climate change threatens the delicate balance in the earth's biosphere to sustain biological life and thus the survival of the human species as we know it.

The conditions required for the viability of are summarized by [1] as follows: "Liquid water is the common ecological requirement for earth life. Temperature on an exoplanet is the first parameter to consider both because of its influence on liquid water and because it can be directly estimated from

orbital and climate models of exoplanetary systems. Life needs some water, but deserts show that even a little can be enough. Only a small amount of light from the central star is required to provide for photosynthesis. Some nitrogen must be present for life and the presence of oxygen would be a good indicator of photosynthesis and possibly complex life" [1]. An essential component to life as we know it is temperature. The term "climate change" is used in reference to the upsetting of this delicate temperature balance which is the main reason for the focus on reducing our impact on climate change.

The earth's average temperature has been experiencing anomalies threatening the sustainability of life as we know it. Fig. 1 shows that since 1980 we have been experiencing an increase in temperature without any signs of a recovery. The earth's temperature is regulated by the presence of greenhouse gases in its atmospheric layer. The increase in the earth's temperature can be accounted for by an increase in concentration of greenhouse gases in the earth's atmosphere earlier in earth's history. Fig. 2 shows the corresponding increase in carbon dioxide (CO<sub>2</sub>) emissions.

On earth, an atmosphere containing naturally occurring amounts of greenhouse gases causes air temperature near the surface to be warmer by about 33 °C (59 °F) than it would be in their absence [2]. Without the earth's atmosphere, the earth's average temperature would be well below the freezing temperature of water [3]. The major greenhouse gases are water vapor, which causes about 36 % to 70 % of the greenhouse effect; CO<sub>2</sub>, which causes 9 % to 26 %; methane (CH<sub>4</sub>), which causes 4 % to 9 %; and ozone (O<sub>3</sub>), which causes 3 % to 7 % [4][5][6].

"Carbon dioxide (CO<sub>2</sub>) is known as a greenhouse gas (GHG)—a gas that absorbs and emits thermal radiation, creating the 'greenhouse effect'. Along with other greenhouse gases, such as nitrous oxide and methane, CO<sub>2</sub> is important in sustaining a habitable temperature for the planet: if there were absolutely no GHGs, our planet would simply be too cold. It has been estimated that without these gases, the average surface temperature of the Earth would be about -18 degrees Celsius." [12]

"Since the Industrial Revolution, however, energy-driven consumption of fossil fuels has led to a rapid increase in CO<sub>2</sub> emissions, disrupting the global carbon cycle and leading to a planetary warming impact. Global warming and a changing climate have a range of potential ecological, physical and health impacts, including extreme weather events (such as floods, droughts, storms, and heatwaves); sea-level rise; altered

crop growth; and disrupted water systems.” [12]

To ensure that we are addressing the cause of climate change, it is essential that we are aware of which of the greenhouses gas or gases are responsible for this and then look for which activities are contributing to the unnatural increase in concentration. Fig. 3 shows the history of concentrations of greenhouse gas emissions in the atmosphere. Fig. 4 shows the

global warming potential (GWP) of each greenhouse gas relative to carbon-dioxide. From these figures one can see that CO<sub>2</sub> has increased at a rate exceeding those of the other greenhouse gases, indicating the likelihood of gas being the cause of the increase in global temperature. Now that we have established that the release of CO<sub>2</sub> is responsible for the temperature increase through global warming, it is the next step to investigate the cause of the increase in CO<sub>2</sub>.

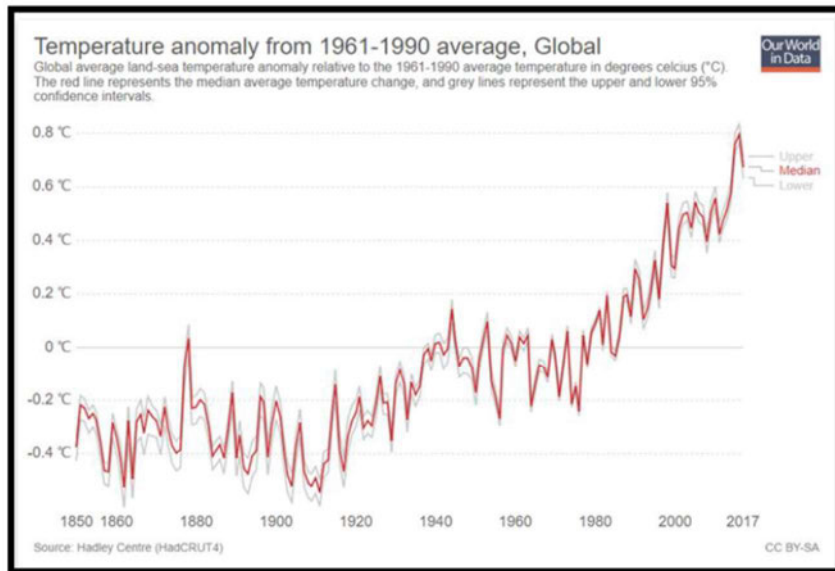


Fig. 1. Earth's temperature anomaly over time [12]

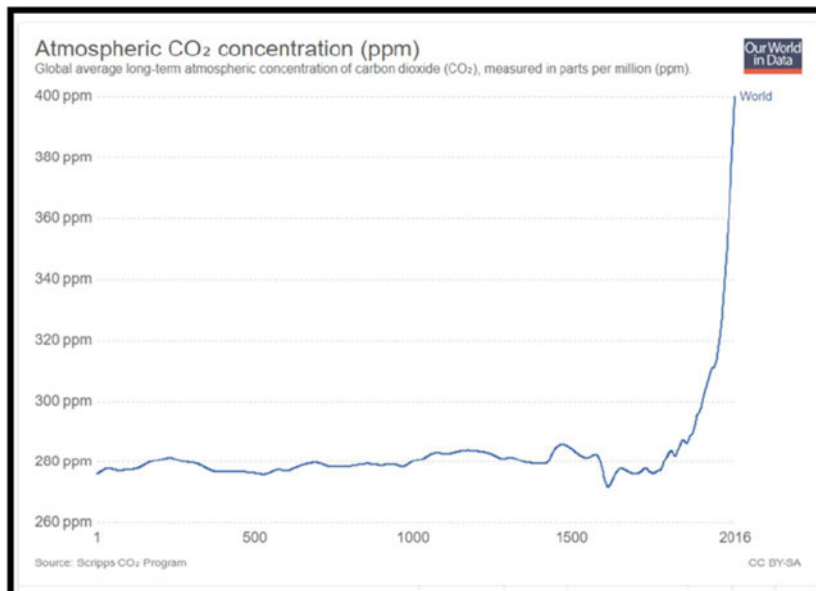


Fig. 2. Increase in concentration of CO<sub>2</sub> in the atmosphere [12]

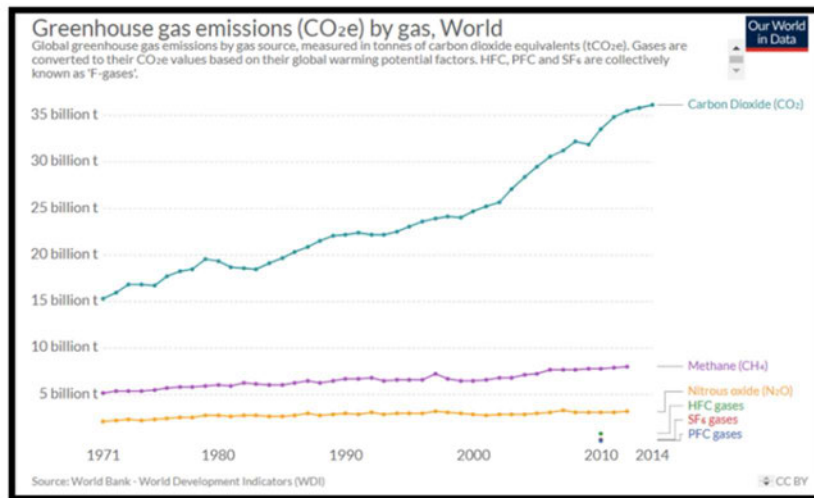


Fig. 3. Global greenhouse gas emissions by gas source [12]

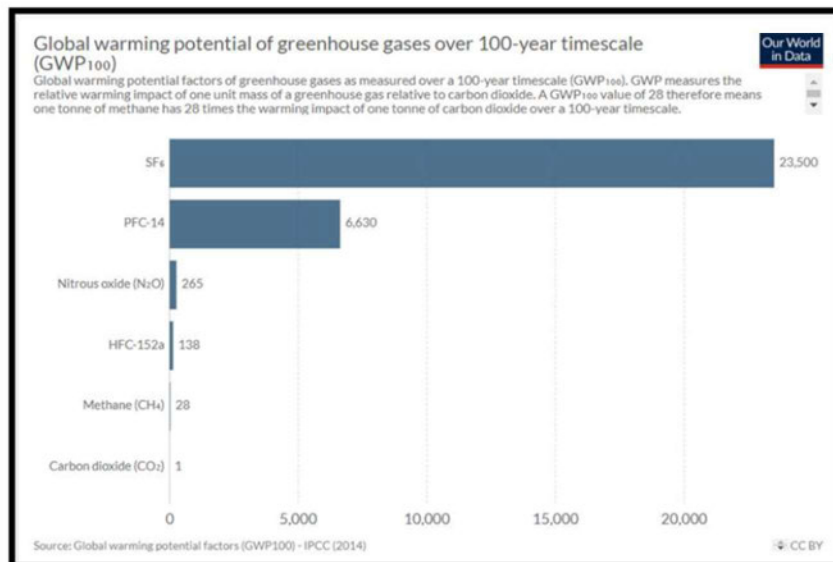


Fig. 4. Global warming potential of greenhouse gases relative to carbon-dioxide [12]

Human activity since the industrial revolution has increased the amount of greenhouse gases in the atmosphere, leading to increased radiative forcing from CO<sub>2</sub>, methane, tropospheric ozone, CFCs, and nitrous oxide. According to work published in 2007, the concentrations of CO<sub>2</sub> and methane have increased by 36 % and 148 % respectively since 1750 [7]. These levels are much higher than at any time during the last 800 000 years, the period for which reliable data has been extracted from ice cores [8][9][10][11]. Less direct geological evidence indicates that CO<sub>2</sub> values higher than this were last seen about 20 million years ago. From Fig. 3, one observes the change in CO<sub>2</sub> levels

and methane levels from 1971 to 2014.

The industrial revolutions experienced in our known history of civilization can be pictorially seen in Fig. 5. In the pre-industrial era natural power (wind, water, draft), animal and human muscle power were used for the manufacturing of goods for human consumption. The need for convenience coupled with key discoveries of energy sources and technologies started the industrial revolution. Over time this “created energy” became more intense and created greater efficiencies in that more human activity was possible per unit of energy available.

This journey, however, has led to the disruption of the natural balance of the fundamental parameters for earth life to sustainably sustain itself.

With the birth of the industrial revolution competitiveness in survival moved from physical conquering (or overpowering through physical force) and colonization to trading and

negotiations of relative worth of goods and services. Figure 6 shows the description of the constituent parts of business sustainability. "Business sustainability is often defined as managing the triple bottom line - a process by which companies manage their financial, social and environmental risks, obligations and opportunities. These three impacts are sometimes referred to as profits, people and planet." [14].

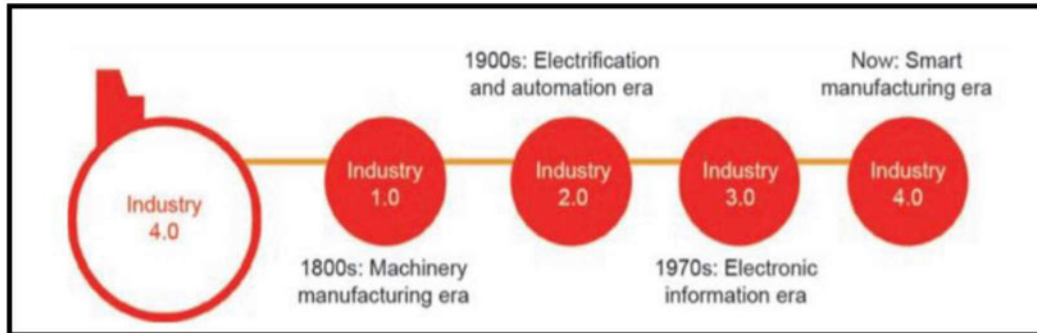


Fig. 5. Four stages of the industrial revolution [13]

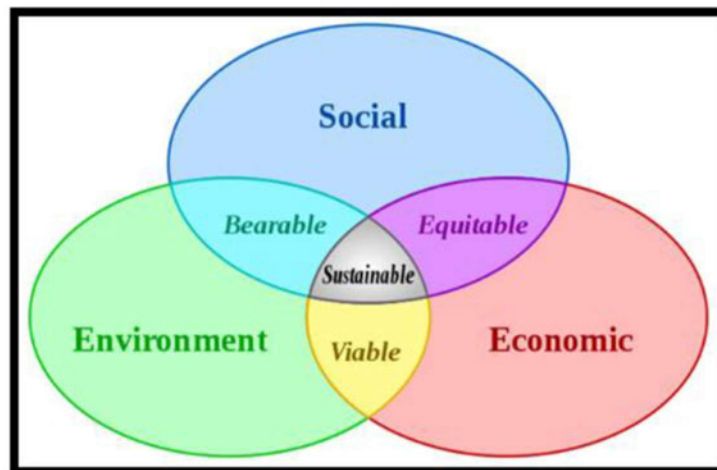


Fig. 6. Venn diagram – elements of business sustainability [15]

## II. DEFINING SUSTAINABILITY

The heart of sustainable development and business sustainability requires the sustainability in each dimension of economic, social and environmental factors to merge on common ground and operate in the "sustainable" zone as can be seen in Figure 6. Currently, the majority of the world's countries, policies, strategies and legislation favor trade and investment to enable their citizens and inhabitants to have a competitive advantage without much consideration for the constraints of the natural resources that make trade and investment possible.

The current business sustainability mesh works such that the economic wheel is designed to serve the social dimension of human needs and desires while environmental considerations have a low priority. Recently there has been an increasing awareness of the sustainability of human society hinging on the precise balance of the ecological environment.

The distribution of the earth's natural resources to the human species for their survival, convenience and competitive advantage is regulated by the created human financial economy where trading power is at the heart of the economy. Prior to civilization, colonization and physical force on existing

inhabitants were used to secure resource abundant land which would enable goods and services and consequently competitive advantage as can be seen with the first and second world wars. With the scientific discoveries that led to the birth of technology, trading power became the new competitive advantage as war that resulted in physical death of the opposition was not an effective way to gain economic advantage. This adaptation of the human species was a shift in their method of sustaining their social and economic status. The

following three sections will investigate the key factors at play in the environmental, social and economic dimensions.

*A. Environmental factors*

Environmental science is the study of the interaction between natural and human systems. Humans use the land, water elements and energy for their needs, survival and convenience, in the process causing pollution and resulting in the acceleration of climate change (Fig. 7).

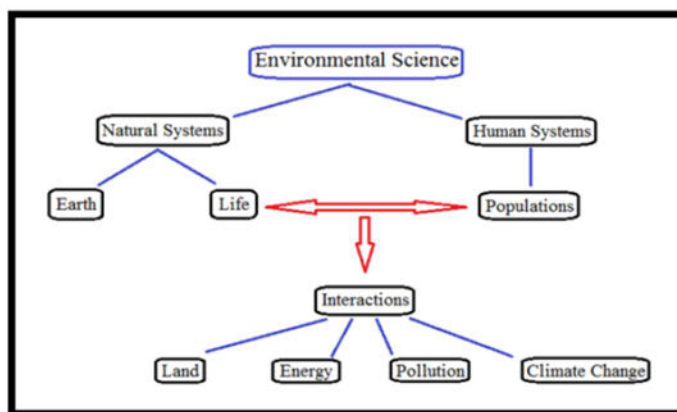


Fig. 7. Environmental Science: the interaction between Natural and Human Systems

Humans, purely by their presence, leave an environmental footprint on this planet, and industrialization increases this environmental impact as they manipulate the environment to suit their needs. Scientists over the years have developed what we call “planetary boundaries” that allow us to benchmark the

impact of our existence and activities on a scale that compares the key planetary parameters that regulate life as we know it to before the significant impact of human existence and how far away we are from significantly altering the current planetary life (Fig. 8).

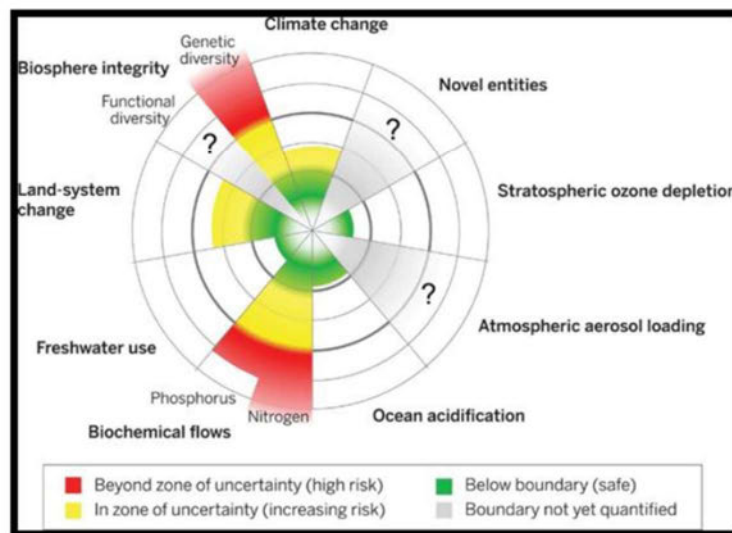


Fig. 8. Current status of the control variables for seven of the planetary boundaries [16]

The planetary boundaries framework defines a safe operating space for humanity based on the intrinsic biophysical processes that regulate the stability of the earth system [16]. As can be seen in Fig. 8, there are nine planetary boundaries which, if altered for a period of time, will cause our planet to change compared to how we know it now. These nine boundaries, climate change, novel entities, stratospheric ozone depletion, atmospheric aerosol loading, ocean acidification, biochemical flows, freshwater use, land system change, biosphere integrity have close interactions with each other in that a change in one planetary boundary will automatically mean changes in another planetary boundary. Fig. 9 shows the interactions between the biosphere and the nine planetary boundaries.

An analysis of the many interactions among the boundaries

suggests that the parameters of climate change and biosphere integrity are highly integrated, emergent system-level phenomena that are connected to all the other planetary boundaries. They operate at the level of the whole earth system and have co-evolved for nearly 4 billion years. They are regulated by the other boundaries and, on the other hand, provide the planetary-level overarching systems within which the other boundary processes operate. Furthermore, large changes in the climate or in biosphere integrity would likely, on their own, push the earth system out of the holocene state. The Holocene state refers to the current geological state that the earth finds itself in. Transitions between time periods in earth history have often been delineated by substantial shifts in climate, the biosphere, or both [16].

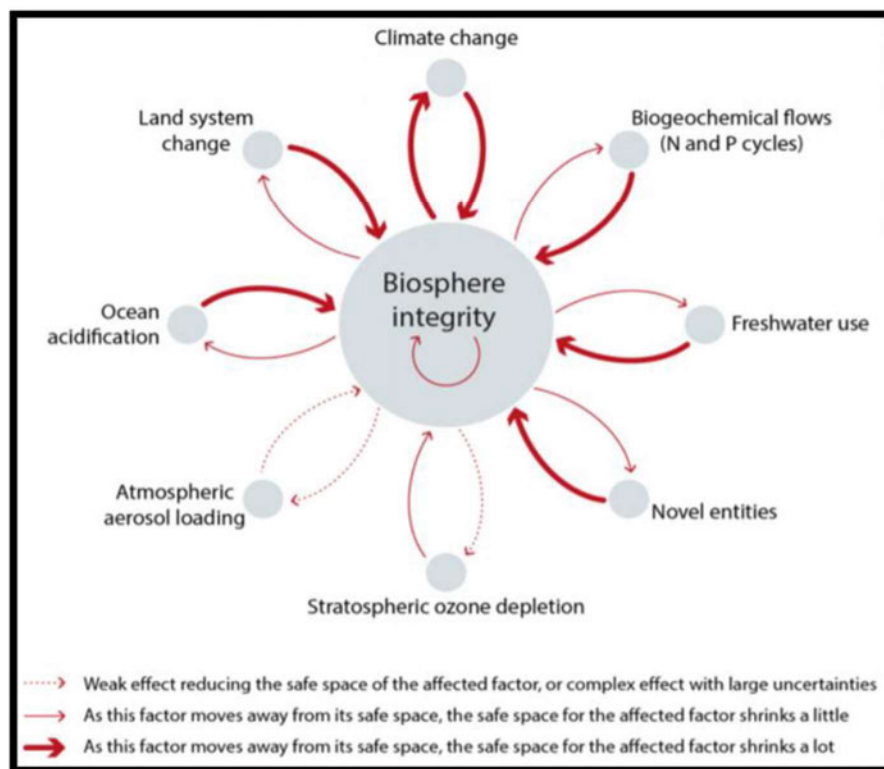


Fig. 9. The interaction between the biosphere integrity planetary boundary and other planetary boundaries [16]

One can see from Fig. 9 that the interaction with the planetary boundary of the biosphere integrity is linked directly with six other planetary boundaries the strongest of which is climate change, in both directions, i.e. climate change causes biosphere change and biosphere change causes climate change.

The key variable influencing climate change is generally expressed as a maximum concentration of CO<sub>2</sub> in the atmosphere of 350 ppm, a value that would likely preserve the climate in a Holocene-like state. Atmospheric CO<sub>2</sub>

concentrations currently exceed 400 ppm. As an alternative boundary to 350 ppm, one can use the 2 °C temperature stabilisation goal emphasised in the Paris Agreement. [17] The Paris Agreement proposed to keep the increase in global average temperature to below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels.

The other variable causing climate change is the increase in top-of-atmosphere radiative forcing of +1.0 W/m<sup>2</sup> relative to

preindustrial levels. Radiative forcing or climate forcing is the difference between insolation (sunlight) absorbed by the earth and energy radiated back to space. There are other greenhouse gases that have global warming potential, however, the one most prevalent in terms of human activity and increase over the past century is CO<sub>2</sub> (Fig. 2 and Fig. 3). The increase in CO<sub>2</sub> emissions in earth's atmosphere is due to the combustion of fuels from which the human species derive energy to drive their machinery, produce goods and commute across the planet.

### B. Social Factors

The dictionary definition relates the term 'social factors' is "human society, the interaction of the individual and the group, or the welfare of human beings as members of society" [18]. A social construction is built around serving human needs and wants and these are characterized in Maslow's hierarchy of needs as depicted in Figure 10.

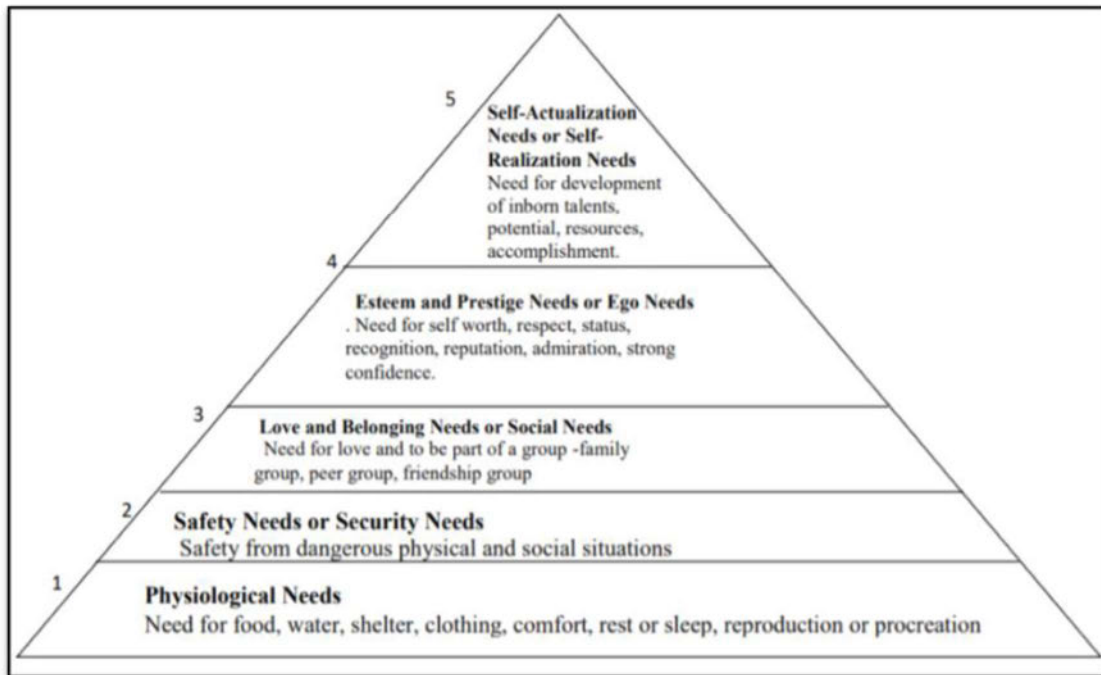


Figure 10: Abraham Maslow's hierarchy of needs [19]

There are several descriptive definitions of what social sustainability entails. Social sustainability can be described as equity in resource distribution, which, from a livelihood perspective, is regarded as the capacity of the human species not only to get access to but also to maintain an adequate and decent livelihood. There are two dimensions of the definition of social sustainability, namely the proactive approach that indicates the capabilities of adapting to, exploiting and creating change and ensuring continuity (positive dimension). The reactive dimension highlights the coping ability to deal with shocks and stresses (negative dimension) [20].

Social sustainability can be visualized as the improvement of living conditions for people and future generations and the quality of governance of the development process. The social pillar of sustainable development can thus be seen as including both procedural aspects and substantive aspects. The procedural aspects include the role of democratic

representation, participation, and deliberation and the substantive aspects focus on "what" is to be done (i.e., the social goals of sustainable development). The procedural aspects include the "how" or the means to achieve these goals. Procedures cannot be static but should always include a temporal dimension. Aspects overlap, and it is also not always easy to distinguish between substantive and procedural issues as they may reinforce one another. For example, by achieving certain social sustainability goals such as providing opportunities for learning or improving the participatory capacities of local civil societies, one is simultaneously improving opportunities for actors to take part in sustainability projects and planning [21]. Social sustainability is all about human welfare including quality of life, social justice, social cohesion, cultural diversity, democratic rights, gender issues, human rights, participation, social capital development and human capability [22]. Fig. 11 shows the factors that are involved with social sustainability as described above.

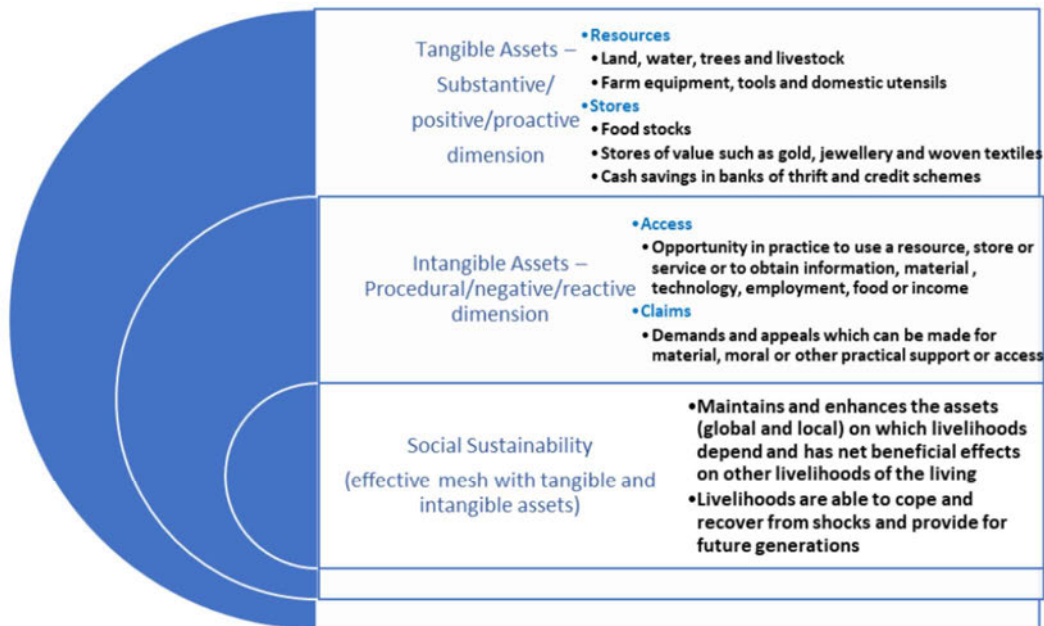


Fig. 11. Social factors and their sustainability, adapted from understanding of [20-22]

Out of these tangible and intangible assets people construct and contrive a living, using physical labor, skills, knowledge, and creativity. Capabilities, equity and sustainability combine in the concept of sustainable livelihoods. A livelihood fundamentally is a means of gaining a living. Capabilities are both an end and means of livelihood: a livelihood provides the support for the enhancement and exercise of capabilities (an end); and capabilities (a means) enable a livelihood to be acquired. Equity is both an end and a means: the minimum definition of equity must include adequate and decent livelihoods for all (an end); and equity in assets and access are preconditions (means) for gaining adequate and decent livelihoods. Sustainability, too, is both end and means: sustainable stewardship of resources is a value (or end) in itself and provides conditions (a means) for livelihoods to be sustained for future generations [20].

### C. Economic Factors

“Economics is the study of how societies use scarce resources to produce valuable commodities and distribute them among different people” [23]. Each country can be seen as having natural resources and skilled personnel which can be used to build their economy. The economic factors in a country include accessibility of natural resources, power and energy resources, capital accumulation, technological resources, available labor force, transportation and communications, education and training. Natural resources may be trees, soil, water, minerals,

coal, oil and anything else naturally occurring within a country. Natural resources have the potential to develop countries through creation of jobs and increasing wealth through sales or trading. The value of the natural resources depends on the international interest in the natural resources. The process of converting economic inputs – capital, labor, and various forms of energy such as oil, coal etc. – into economic outputs such as manufactured goods and services can be expressed using an equation called production function.

Production is the heart of the economy which is the manufacture of goods and enabling of services. There are four factors that make production possible, i.e. capital, land, labor and entrepreneurship. These factors give the ability to satisfy needs and start the circulation of income (enable trade). Microeconomics is the study of basic elements in the market (microeconomy) that includes households, firms, buyers and sellers. The dynamics of demand and supply, optimal production, finance and the stock market and strategies that are involved with competition for customers and resources is called game theory. Macroeconomics is the study of the entire economy (macroeconomy) that includes the aggregation of production, consumption, saving and investment and the issues affecting it which includes the resources (labor, capital, land), inflation, exchange rates, economic growth and the public policies that address these issues. Fig. 12 is a pictorial representation of the micro and macroeconomy.

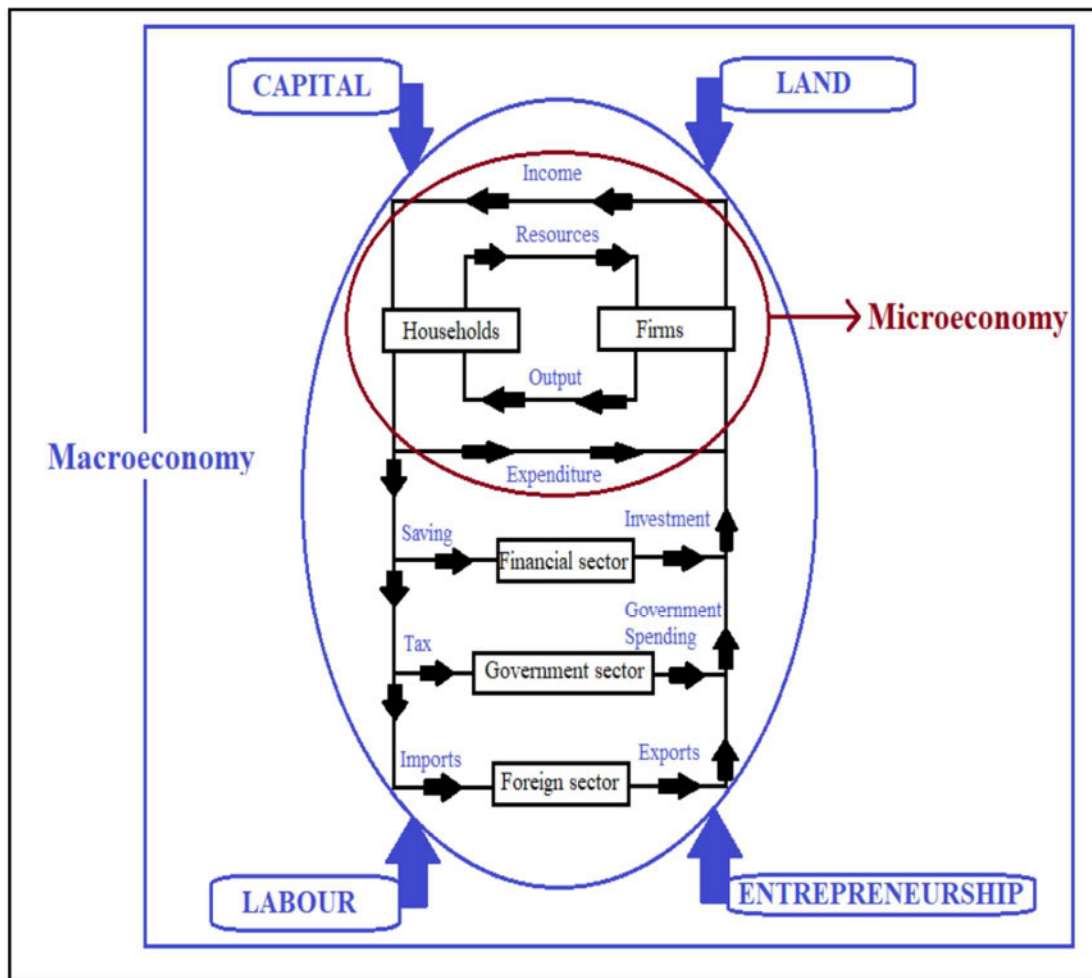


Fig. 12. Schematic of aspects in the economic dimension (the flow of money)

Production being at the heart of the economy involves the conversion and hence manipulation of natural resources. To manipulate natural resources, one requires energy, hence energy and its resources are key to production. The combination of technology and innovation provides the design basis upon which resources are manipulated into something useful and fit for purpose.

### III. THE IMBALANCE IN THE CURRENT INTENDED SUSTAINABILITY MESH

There is clearly an imbalance in the business sustainability mesh. The imbalance in the environmental dimension can be seen by the results in the previous sections regarding the environmental, social and economic dimensions. The

environmental dimension imbalance can also be seen in section IIA. The inequality across the world that can be seen in Fig. 13, Fig. 14 and Fig. 15 and is an indication of the imbalance in the economic dimension which also implies inequitable distribution in resources such as food, shelter due to the trading power being which is able to distribute these resources being imbalanced. The imbalance compromises business sustainability and if it wants to achieve sustainability again, the three dimensions need to be contextualized to the prevailing conditions. Inequality which gives rise to poverty and other social challenges are characteristic of developing countries who have yet to effectively manipulate their natural capital to achieve adequate economic growth and distribution of wealth. Access to a secure supply of energy is key in manipulation of resources for production and creation of wealth as well as for livelihoods to improve.

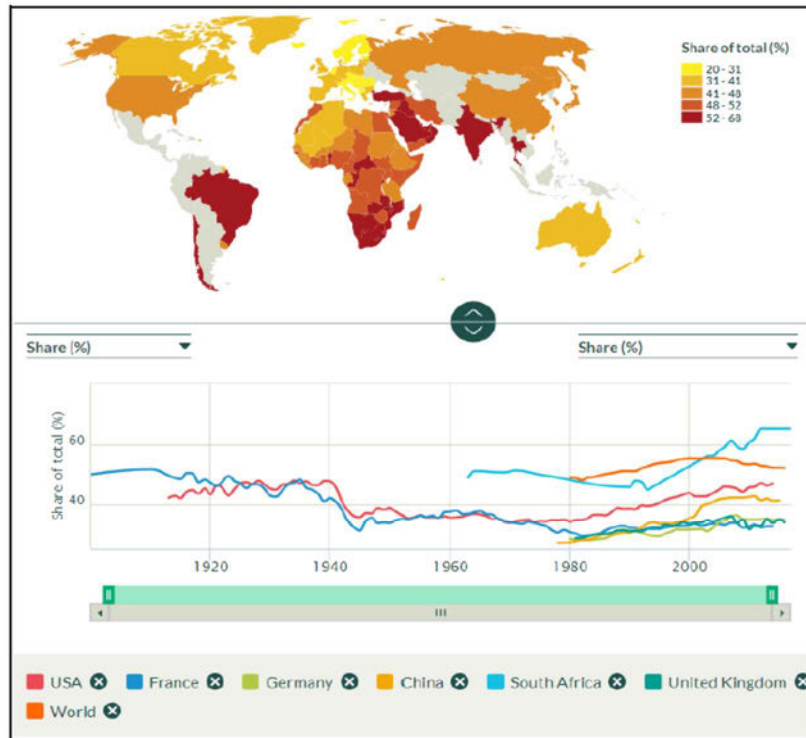


Fig. 13. Top 10 % national income share [24]

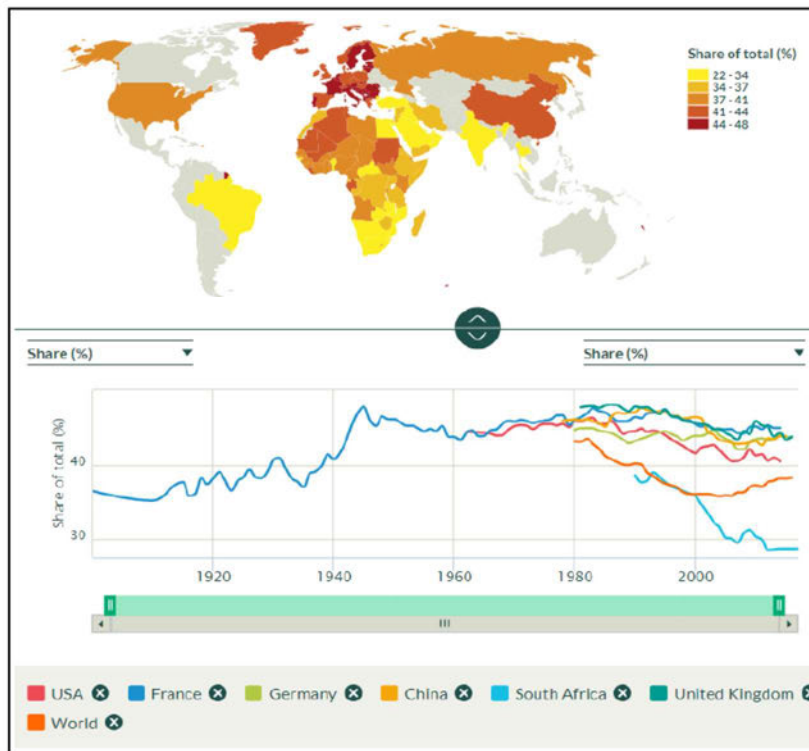


Fig. 14. Middle 40 % national income share [24]

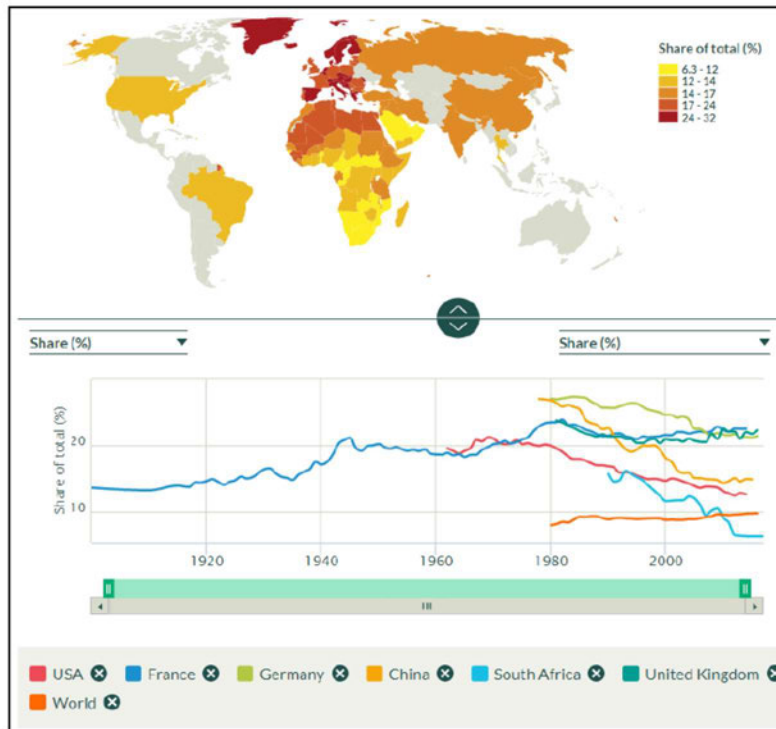


Fig. 15. Bottom 50 % national income share

There are various reasons for the imbalance in the business sustainability mesh. The World Wars I and II which involved military force used for subjugating countries and their citizens for reasons of racism, owning resources that a country possesses, fraud and corruption, etc. played a role in creating inequitable conditions amongst humans, based on race, gender, ethnic groups, religious sects, or wealth hierarchy. The subsequent post-World Wars economies were built with various strategies and underlying themes in mind which differed from country to country over the years, resulting in the inequality we see today with the differences of trading power (or inequality gap) between the most wealthy to the least wealthy being significantly large. One can observe that these are topics in focus of government policies today and other mechanisms adopted to bring about equality, economic freedom, in countries that are most affected. The topic of this paper is the sustainable reduction of carbon emissions through energy efficiency and energy security such that the planetary boundaries are kept within limits for now and future generations. The journey of sustaining energy efficiency and energy security has the potential as per its pivotal role in all three dimensions of economic, environmental and social to allow the achievement of a common ground for existence in the sustainable zone as depicted in Fig. 6. Successfully integrating energy efficiency and energy security within the existing framework of social, economic and environmental factors will result in the creation of new markets with the potential of positively impacting economic growth, which has

the potential for decreasing the economic inequality gap and meeting the human needs in the social dimension.

#### IV. ACHIEVING SUSTAINABILITY

The definition of sustainability is captured in the 1987 Brundtland Report and has been the basis upon which many sustainable development plans have been built. "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" [25]. In the United Nations publication entitled, "Transforming our world: 2030 Agenda for Sustainable Development", 17 goals (Sustainable Development Goals or SDGs) were highlighted in order of priority and focus. The first six goals focused on eradicating poverty, hunger, and focus on education, health and well-being, achieving gender equality and providing clean water and sanitation. The remaining goals focus on environmental sustainability and the growing of the financial economy. The order of priority of the goals tells the story of the imbalance we currently see in the sustainability mesh and what is the focus of governments and businesses from a fundamental perspective. The priorities of these goals show where effort, financial support, education and funding, will be allocated from a strategic point of view.

If humanity at the outset designed and implemented an economic system around environmentally sustainable

parameters, our social tastes and needs would have evolved around these factors and the three dimensions of social, economic and environmental would have been sustainable. Carbon emissions and its effect on climate change would not be an issue at this point in the existence of the human species. In order to implement such a designed system, there is a need to have a fundamental understanding of how all three dimensions work together. Knowledge of our planet, its environment and ecosystems have increased significantly over time. When industrialization began, the knowledge of the environment was limited, the planet's resources was seemingly inexhaustible by the human species. As knowledge of the planet's ecosystems delicate balance increased, coupled with the awareness of the exponential increase in human population numbers, the perception that the planet and its resources are inexhaustible by the human species changed and this awareness gave birth to sustainability and the definitions of the famous 1987 Brundtland report.

Today there are new challenges being faced by the human species and the Brundtland definition of sustainability and its application must be interpreted and applied to meet these challenges should humanity want to achieve sustainability of our planet and of the human species as we know it. The economic dimension was designed to extract and convert an infinite amount of resources to stimulate trade and investment as well as create wealth for humans. With this, human population grew exponentially and demand for resources and hence on the environment increased to a tipping point where planetary boundaries are being threatened. This being the new challenge, the environmental dimension can no longer be perceived as limitless. There are still many things to be uncovered about our environment and its delicate balance, hence the achievement of a sustainable mesh between social, environmental and economic is progressive. Unfortunately, the results of the evolution of the three dimensions over the years (when the earth was seen as inexhaustible), has created a very rigid and delicate financial economy that has allowed the human species to thrive in terms of population numbers due to the conveniences that came with industrialization. These two factors have created a time lag between when we have knowledge of our adverse impact on our planet to seeing the necessary change required, even though we may have resolved to do this at a policy level.

The business sustainability mesh should be progressive and agile due to our knowledge of the planet being progressive. The characteristics of a progressive business sustainability mesh (Fig. 5) is that it should respond to imbalances as they arise. However, our current response is that when results of the imbalance materializes in all dimensions, there is a tendency to prioritize short term wellness of the human species, i.e. prioritize needs in the social dimension (Fig. 10, level 1 of the pyramid) and those elements in the economic dimension that support the needs in the social dimension. Prioritizing a single dimension further perpetuates the imbalance as there must be a sacrificial dimension. In this case, our planet's natural ecosystems in the environmental dimension is the sacrificial

dimension. Fig. 16 depicts this mindset.

There is a need to evolve the human business sustainability mesh as seen in Fig. 6 so as to reach sustainability. The following objectives towards achieving sustainability, unbiased to any one of the three dimensions (social, economic and environmental) need to be incorporated in the human species way of life:

- Maintain the delicate balance of planetary boundaries within restricted limits
- Ensure that human needs and requirements are met within planetary boundaries
- Ensure that the economic models that thrive on the current environmental resources are transitioned to maintain limits within planetary boundaries

The fourth industrial revolution coupled with the various new market entrants from energy efficiency and clean energy sources have converged and have the potential to address the imbalance in the business sustainability mesh, particularly in developing countries, while fulfilling its purpose of reducing carbon emissions. In fact, by fulfilling its purpose in addressing climate change within the existing business sustainability mesh, the potential of bringing about fulfilment in other dimensions will result in significant progress towards a balanced business sustainability mesh. Fig. 17 shows the culmination of the key factors in each dimension being met in the solution of energy efficiency and energy security, to meet living in what Kate Raworth calls the "Safe and Just Space" for humanity.

This leveraging of energy efficiency and clean energy for creating new market entrants in developing countries will address the following biases currently prevalent in the business sustainability mesh:

- Considering just the social and economic dimensions in the quest for being equitable, where resources are distributed equally to humans, eradicating poverty, social inequality and raise the standard of living.
- Considering just the social and environmental dimensions in the quest for making human life bearable by humans adjusting their lifestyle such that they consider the environment, contributing to a healthier environment and well-being.
- Considering just the economic and environmental dimensions in the quest for being viable by striving to meet economic growth and development with consideration for the environmental effects

The achievement of the above highlighted objectives and addressing of biases will achieve the mindset shift from the mindset depicted in Fig. 16 to the desired mindset captured in Fig. 18. We will no longer be serving our needs first and then considering the environment but will consider first what our environment can sustain within planetary boundaries and then use it innovatively such that our needs are met.

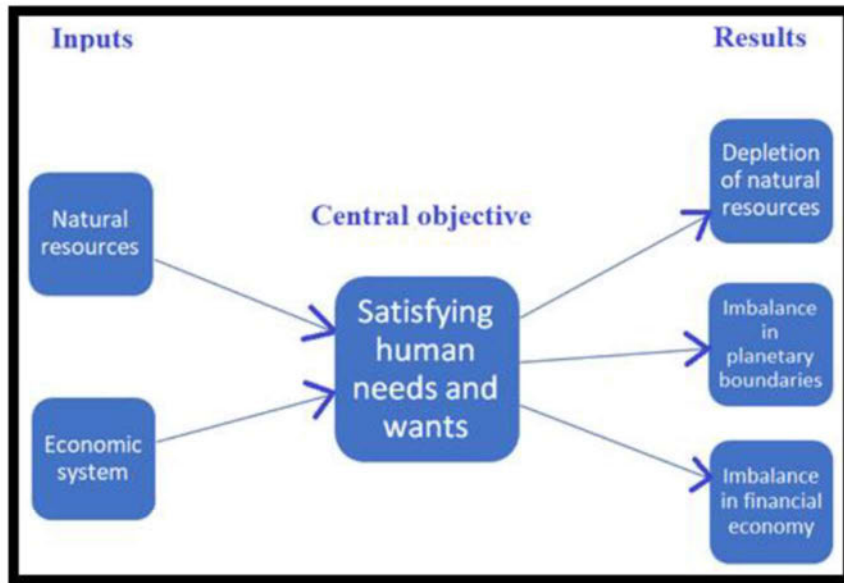


Fig. 16. 'As is' mindset of our current "sustainability" development focus

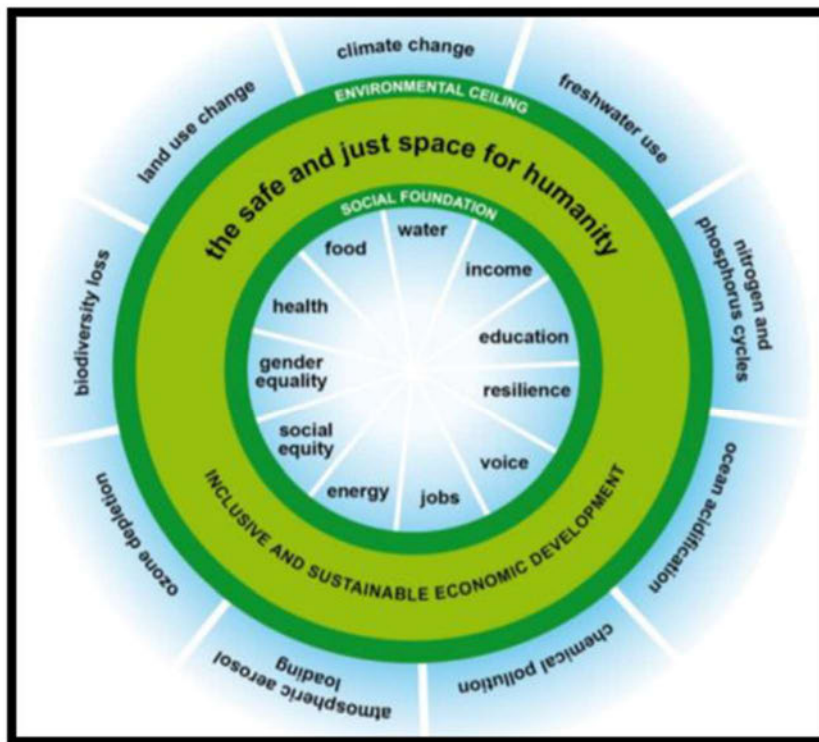


Fig. 17. A safe and just space for humanity to thrive in [26]

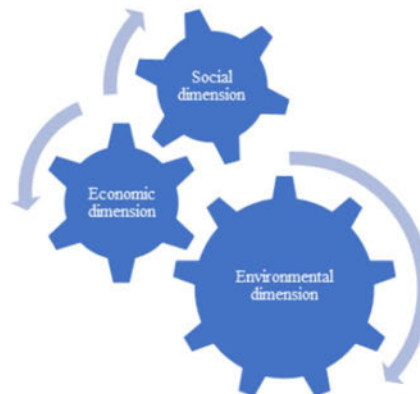


Fig. 18. The desired mindset (“To be” mindset)

To create the “to be” mindset as shown in Fig. 17 would have been easier if we had the knowledge we have now about our planet before industrialization and applied it then, however, we find ourselves in an existing economic system with established product markets and flow of money, satisfying the existing host of human needs and wants that we have become accustomed to. The challenge to achieve sustained energy efficiency and energy security requires a deep knowledge of how to motivate targeted objectives within the financial economy and organizations such that energy efficiency and energy security shifts offer a better solution as well as how to innovate in a way that will lead to new ways of satisfying the desires currently being satisfied by the industry.

Motivating the targeted objectives highlighted for sustained energy efficiency and energy security will require action via the social and economic levers of technology and innovation which will have the effect of transforming the market, opening the circulation of money to developing economies. This solution sustains the environmental planetary boundaries and has a “knock-on” effect in terms of potential to turn the dial of social imbalances through the stimulation of the economy by new entrants in the market. New entrants are market participants that have recently entered a market or industry sector [27].

New entrants in the market come via innovation and technological break throughs. New entrants have the effect of creating potential for “resetting the dial” to allow those in the bottom 50 % national income share (Fig. 15) to have access to a greater share of the national income, thus in a position to satisfy the needs as in Abraham Maslow’s hierarchy of needs (Fig. 10). Technology is the application of knowledge to the world that allows people to affect their environment by controlling or changing it. Technological change is improvement in the art of making products or developing processes. Technological products are something that human create using the application of knowledge to improve a person’s life, environment or society. A technological process is a means to make and improve products and services.

The rapid pace of technological developments played a key role in previous industrial revolutions [28]. Every industrial

revolution brought with it benefits and challenges to the socioeconomic status of the countries that have engaged in such transformation. For instance, Great Britain led the first industrial revolution with the invention of the commercial steam engine, which revolutionized communication and transportation and led to many other industrial developments. In the second industrial revolution, the United States was primarily in the lead, with the telephone revolutionizing communication. In the third industrial revolution, the internet was the key factor and succeeded because it was conceived as a public infrastructure technology rather than a proprietary technology [29]. The industrial revolution history and synopsis is depicted in Fig. 5.

Industry 4.0 is not an exception to the previous eras of industries and is expected to bring immense benefits and many challenges. Social challenges are mainly the risk of cybercrime due to increased connectivity, and job losses due to the automation of large segments of operations in many industries. Technological and business-driven innovative solutions are not going to be enough. Innovation in its broadest sense is the key solution, in particular social innovation. The same drive to innovate technologies to increase productivity can also be utilized to improve the welfare and social needs of the world population [28].

Many innovations tackle social problems or meet social needs, but only for social innovation is the distribution of financial and social value tilted toward society as a whole. A social innovation is a novel solution to a social problem that is more effective, efficient, sustainable, or just than existing solutions and for which the value created accrues primarily to society as a whole rather than private individuals. A social innovation can be a product, production process, or technology (much like innovation in general), but it can also be a principle, an idea, a piece of legislation, a social movement, an intervention, or some combination of all of them. Indeed, many of the best recognized social innovations, such as microfinance, are combinations of a number of these elements [30]. Technological and social innovation are key drivers in providing sustainable solutions that meet the three key criteria of sustainability and can act as an assessment mechanism to

any related developments of Industry 4.0, as shown in Fig. 19 [28].

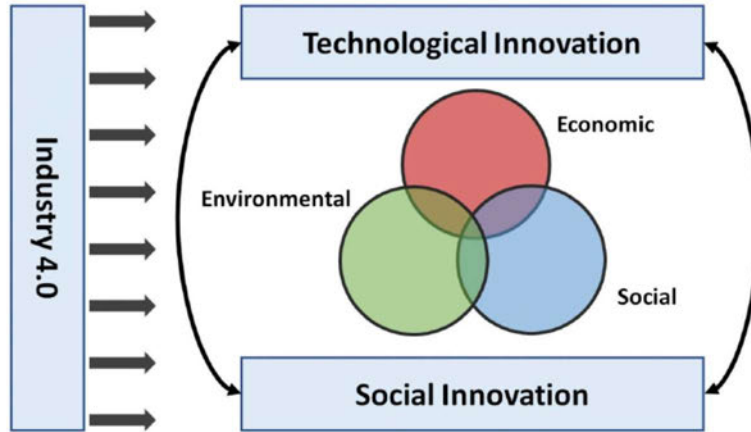


Figure 19: A framework to safeguard the potential of a sustainable Industry 4.0 [28]

Energy is a fuel source enabling the economy. The earth's natural capital is the available material for production. Technology and innovation are the transforming tools. Funds are the bargaining mechanism and people are the designers. The real challenge to sustainability is in achieving the paradigm shifts required in an existing economy with established drivers, existing societal expectations and requirements that humans have become accustomed to with the earth supplying the seemingly unending demand for materials. As can be seen with SDGs, sustainability of the earth's natural resources is not a

priority focus, neither are the SDGs structured to eliminate the biases that may occur in the sustainability mesh highlighted earlier. Human needs are unending and the more that they are satisfied, the more the human species thrive in population growth and the greater the demand on earth's resources. One can see how the industrial revolutions timeline, the timeline of the planet's increase in temperature (and CO<sub>2</sub> levels) and the timeline of the population growth corroborates. Compare Fig. 1, Fig. 2 and Fig. 5 with Fig. 20.

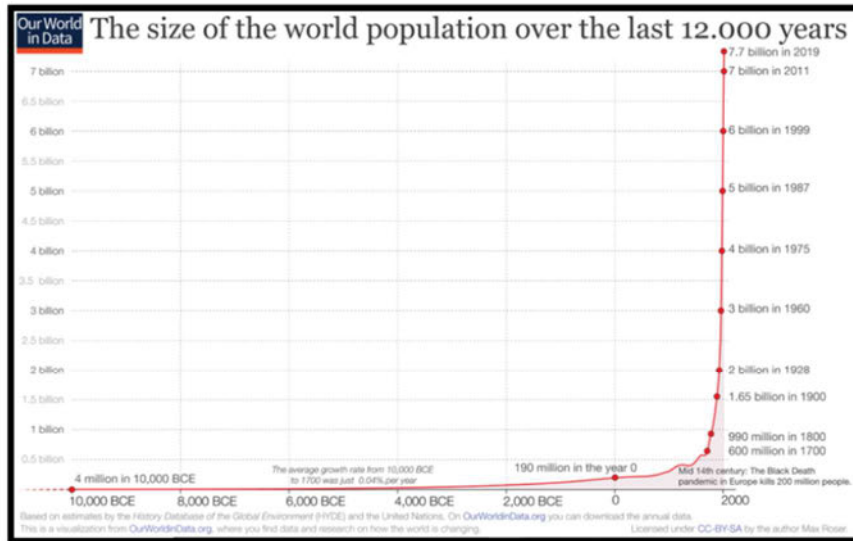


Fig. 20. Population growth over the last 12 000 years [31]

There are countries in the world where inequality, poverty and unemployment are not as bad as others. These countries have more developed economies than others and there is a distinction between countries that are 'developed' and countries that are 'developing'. The Human Development Index (HDI) is an index that measures key dimensions of human development considering three main factors, life expectancy, access to education and standard of living as measured by the gross national income per capita adjusted for the price level of that country [32]. Countries that are classified as developing have a poor Human Development Index (HDI) and thus will have opportunity for development of their economy and other related factors such as infrastructure, health care systems, etc.

Energy plays a key role in enabling development. Leveraging on developing countries' need for achieving a better livelihood and the need for access to a secure supply of energy to enable a better livelihood will be pivotal in shifting the paradigm towards development that meets in the sustainable zone of the social, economic and environmental spheres of the business sustainability mesh. It is imperative that this opportunity be used. Failing to use this opportunity will result in accelerating climate change in order to meet the developing world's needs.

Given their extensive experience with older technologies, leading nations may have no incentive to adopt new ideas, especially those new ideas that do not initially seem to produce an improvement. Developing nations, however, have less experience; the new techniques offer them an opportunity to use their lower wages to break into the market. If the new techniques eventually prove to be more productive than the old, there is a reversal of leadership [33]. Using technological breakthroughs of the fourth industrial revolution, the developing world should engineer a built environment that is in harmony with nature, mitigating the effects of climate change while securing access to sustainable sources that are renewable. This will produce new market entrants; these new market entrants must be economically competitive to be sustained and also be fit for purpose competing with the products that they are trying to replace because of their contribution to the acceleration of climate change.

Energy efficiency and the need for energy security in developing countries need to be viewed differently from just being an environmentally sustainable initiative in order to be sustained as a focus of the human species. This is evident in the focus of the Sustainable Development Goals (SDGs) being on serving humans immediate needs first. The first five SDGs are eradicating poverty, hunger, focus on education, health and well-being, achieving gender equality. These need to be viewed in context of the opportunity that energy efficiency and energy security offer to fulfil these goals. New market entrants can potentially be created in the form of innovative market solutions and products to enable energy efficiency and energy security, and job opportunities for those specializing in energy efficiency and alternative energy technologies. These market entrants will find a place in the less developed countries and will serve to better their HDIs.

As organizations see the business case in energy efficiency and as alternative energy grid parity is met, the demand for reliable alternative solutions for energy supply based on sound engineering and science principles arise. This will feed the demand for new and revised educational programmes, creating more jobs and giving developing countries an opportunity to get a market share in energy supply. The realized profits of energy efficiency and business security offered by alternative energy supply, together with the positive public image of an environmentally responsible organization, will put pressure on all organizations to follow suite in order to remain relevant and competitive. From this point, the flow of money will gain momentum as per the depiction in Fig. 12. Pressure will be on the ruling or governing body of the country to be seen as promoting environmental sustainability and the knowledge gained on planetary boundaries will take the form of government policies. This will lead to maintaining the planetary boundaries as outlined in Fig. 9.

The solution that will ensure that sustainable energy efficiency and energy security will be established in the business sustainability mesh is as follows:

**Step 1:** Technologically innovate for energy efficiency and security of energy supply in a way that:

- Is designed to save costs and be a better commercial alternative
- Creates new opportunities for jobs
- Gradually creates a market for new products and solutions that support local participation
- Appeals to the convictions of the population at large, creating a campaign for itself

**Step 2:** Ensure that energy efficiency and energy security (a mix of alternative energy solutions) are focused on eradicating poverty, hunger and other priority focuses of most countries in the developing world as per the SDGs

**Step 3:** Ensure that energy efficiency and energy security create new markets that support local economic growth

**Step 4:** Being now established as an operational cost saving, energy efficient practices and energy security approaches be entrenched into organizational strategies and way of conducting business

**Step 5:** Being now established as a tool to improve the HDIs of developing countries, they form part of government policies

The above five steps show the creation of the affinity that energy efficiency and energy security will have to fit into the business sustainability mesh (Fig. 22).

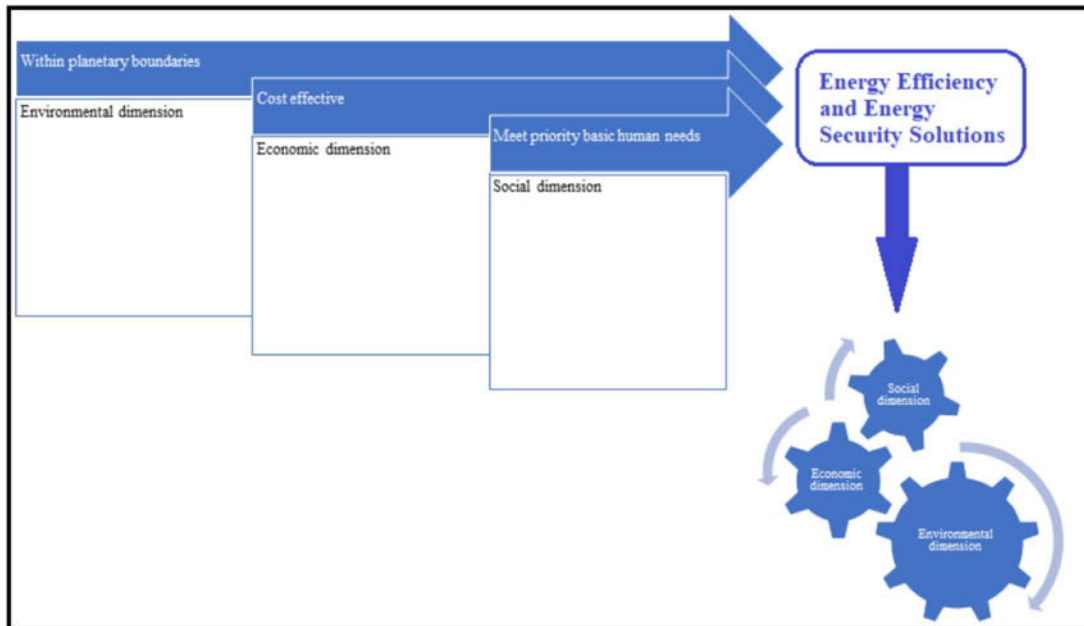


Fig. 21. Natural affinity of energy efficiency and energy security to the business sustainability mesh

Many countries and businesses tend to approach energy efficiency and energy security from Step 5 and expect to get to Step 1. This is the key reason that energy efficiency and energy security have a shallow penetration and slow-moving pace into and sometimes stagnate in developing countries. They are punted as “the right thing to do” instead of showing value that addresses the fundamental needs of society.

There is an interdependency of developing countries economic growth and improvement of HDIs and the role of energy efficiency and energy security. Energy efficiency and energy security is key to enabling economic growth and improvement of HDIs. Similarly, in order for energy efficiency and energy security to be sustained, it must be established as a tool of economic growth and improvement of HDIs.

## V. CONCLUSION

For the sustainability of our planet to be realized, we need to give much consideration to keeping within the planetary boundary of climate change, focusing our effort on the carbon footprint of the sources we derive our energy from. For sustainability of human livelihoods, the manipulation of resources for human use and its access must be evolved such that it allows our survival and supports our way of life without hindering the planetary boundaries that maintain the biosphere integrity. The manipulation of resources for human use is achieved with the use of energy sources, whether these be in the form of heat, electricity or others. These energy sources must be carefully chosen, and the methods chosen to derive energy from the energy source for meeting our needs must be designed to reduce impacts on planetary boundaries. Energy efficiency and energy security must be woven into the fabric of

social factors for it to be sustained. Access to energy is key to production and thus economic growth. Energy combined with technology and innovation makes production possible. The requirement that energy is used efficiently, and CO<sub>2</sub> emissions are reduced from energy sources must be integrated into the economic framework already established to ensure that there is a sustained reduction in carbon emissions. This means energy efficiency and clean energy sources must make business sense and offer competitive advantage for it to be chosen over traditional and established energy sources and energy consumption methodologies.

If the developing world seeks to make good their HDI through the old and long-established technologies and ways, there is lack of acknowledgment of the climate change dilemma and the perpetuation of the economic imbalances and this will result in a worsening of their HDIs. The motivation for reduction in carbon emissions through energy efficiency and secure, clean energy sources must be through established means of the built environment, i.e. the social and economic factors, and must have adequate penetration into the engineering of the built environment, into organizations’ ways of working, be economically competitive and meet fit for purpose requirements with added advantages over its competitors.

The sustainable solution for ensuring that energy efficiency and energy security has lasting and established penetration in developing countries is the solution that can achieve sustainability in all three spheres of the environmental, economic and social constructs. By addressing the priority social concerns and make for an attractive economic alternative, it will be sustained through changing markets, technologies, legislation, personnel and resource availability.

## REFERENCES

- [1] C.P. McKay, "Requirements and limits for life in the context of exoplanets," *Proc. Natl. Acad. Sci. U.S.A.*, vol. 111, no. 35, pp 12628–12633, 2014.
- [2] H. Le Treut, et al., "Historical overview of climate change science," in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon et al. Eds, 2007, pp. 93-127.
- [3] J. Blue, "What is the natural greenhouse effect?" *National Geographic*, 15 April 2016.
- [4] J.T. Kiehl, and K.E. Trenberth, "Earth's annual global mean energy budget," *Bull. Am. Meteorol. Soc.*, vol. 78, no. 2, pp 197–208, 1997.
- [5] G. Schmidt, "Water vapour: feedback or forcing?" *RealClimate*, 6 April 2005.
- [6] R. Russell, "The greenhouse effect & greenhouse gases," University Corporation for Atmospheric Research Windows to the Universe, 16 May 2017.
- [7] Environmental Protection Agency, "Recent climate change: atmosphere changes," United States Environmental Protection Agency Climate Change Science Program, 2007.
- [8] S., Renato, J., Chappellaz, T.F., Stocker, L., Loulergue, G., Hausammann, K., Kawamura, J., Flückiger, J., D., Schwander, Raynaud, V., Masson-Delmotte, J., Jouzel, "Atmospheric methane and nitrous oxide of the Late Pleistocene from Antarctic ice cores," *Sci.*, vol. 310 no. 5752, pp 1317–1321, 2005.
- [9] U. Siegenthaler, et al., "Stable carbon cycle–climate relationship during the Late Pleistocene," *Sci.*, vol 310, no. 5752, pp 1313–1317, 2005.
- [10] J.R. Petit, et al., "Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica," *Nat. Sustainability*, vol. 399, no. 6735, pp 429–36, 2009.
- [11] D. Lüthi, M. Le Floch, B. Bereiter, T. Blunier, J-M. Barnola, U. Siegenthaler, D. Raynaud, J. Jouzel, H. Fischer, K. Kawamura and T.F. Stocker, "High-resolution carbon dioxide concentration record 650,000–800,000 years before present," *Nat. Sustainability*, vol. 453, no. 7193, pp 379–382, 15 May 2008.
- [12] Our world in data, <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions#the-long-run-history-cumulative-co2>; accessed 20/03/2019.
- [13] F. Qian, W. Zhong and W. Wenli, "Fundamental theories and key technologies for smart and optimal manufacturing in the process industry," *Eng.*, vol. 3, pp 154-160, 2017.
- [14] The Financial Times, "Definition of business sustainability," <http://lexicon.ft.com/Term?term=business-sustainability>, accessed 21/03/2019.
- [15] Wikipedia, "Sustainable development," [https://en.wikipedia.org/wiki/Sustainable\\_development](https://en.wikipedia.org/wiki/Sustainable_development), accessed 21/03/2019.
- [16] W. Steffen, K. Richardson, J. Rockstrom, S.E. Cornell, I. Fetzer, E.M. Bennett, R. Biggs et al., "Planetary boundaries: Guiding human development on a changing planet," *Sci.*, vol. 347, no. 6223, 2015.
- [17] D.W., O'Neill, A.L., Fanning, W.F., Lamb et al., "A good life for all within planetary boundaries," *Nat. Sustainability*, vol. 1, pp. 88–9, 2018.
- [18] Merriam Webster dictionary definition of "Social," 2019.
- [19] E.O Aruma and M.E., Hanachor, "Abraham Maslow's hierarchy of needs and assessment of needs in community development," *Int. J. Dev. Econ. Sustainability*, vol.5, no.7, pp.15-27, 2017.
- [20] R. Chambers, and G.R., Conway, "Sustainable rural livelihoods: practical concepts for the 21st century," *IDS Discussion Paper*, issue 296, ISBN 0 903715 58 9, October 1992.
- [21] M. Boström, "A missing pillar? Challenges in theorizing and practicing social sustainability: introduction to the special issue," *Sustainability: Sci., Practice Policy*, vol. 8 no. 1, 3-14, DOI: 10.1080/15487733.2012.11908080, 2012.
- [22] G. Baffoe and E. Mutisya, "Social sustainability: A review of indicators and empirical application," *Environ. Manage. Sustainable Dev.*, vol. 4, no. 2, 2015.
- [23] P.A. Samuelson and W.D. Nordhaus, *Economics*, The McGraw-Hill Companies, Inc., Boston, Chapter 1, pages 3-7, 1998.
- [24] Taken from the "World Inequality Database" [https://wid.world/world/#sptinc\\_p0p50\\_z/US:FR:DE:CN:ZA:GB:WO/last/eu/k/p/yearly/s/false/5.2195/30/curve/false/country](https://wid.world/world/#sptinc_p0p50_z/US:FR:DE:CN:ZA:GB:WO/last/eu/k/p/yearly/s/false/5.2195/30/curve/false/country), Accessed 23/12/2019.
- [25] G.H. Brundtland. United Nations Chairperson 1987, "Report of the World Commission on Environment and Development, Our Common Future," NGO Committee on Education of the Conference of NGOs, Oslo, 20 March 1987.
- [26] K. Raworth, *A Safe and Just Space for Humanity: Can we Live Within the Doughnut?* Oxfam, Oxford, UK, 2012.
- [27] Taken from <http://www.businessdictionary.com/definition/new-entrants.html>, accessed 30/12/2019.
- [28] R. Morrar, H. Arman, and S. Mousa, "The Fourth Industrial Revolution (Industry 4.0): A social innovation perspective," *Technol. Innovation Manage. Rev.*, vol 7, no. 11, pp. 12-20, 2017.
- [29] N.G. Carr, "IT doesn't matter," *Harvard Bus. Rev.*, May 2003.

- [30] J.A. Phills Jr., K. Deiglmeier, D.T. Miller, "Rediscovering Social Innovation," *Stanford Soc. Innovation Rev.* pp 39, Fall, 2008.
- [31] Our World in Data, <https://ourworldindata.org/uploads/2018/11/Annual-World-Population-since-10-thousand-BCE-for-OWID.png>, accessed 06/01/2020.
- [32] M. Roser, "Human Development Index (HDI)," published online at [OurWorldInData.org](https://ourworldindata.org). Retrieved from: '<https://ourworldindata.org/human-development-index>', accessed 07/01/2020.
- [33] E. Brezis, P. Krugman and D. Tsiddon, "Leapfrogging: A theory of cycles in national technological leadership," *American Econ. Rev.*, vol. 83, 1993.

### CHAPTER 3. TRENDS: ENERGY EFFICIENCY AND ENERGY SECURITY

This chapter presents a review of the trends in global energy sources and their evolution and its carbon footprint; the cost-effective modern fuel of energy efficiency together with the approaches and initiatives adopted to achieve energy efficiency and alternative less carbon intensive energy sources in focus. It also reviews South Africa's unique challenges in energy supply and demand, and the role of energy efficiency and an alternative energy mix.

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## Trends: Energy Efficiency and Energy Security

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### Abstract

As awareness is growing that the carbon emissions on our planet are excessive, there are ongoing efforts to arrest the increase. The nature of the initiatives and methodologies used to curb emissions vary due to the dynamics present in each country. Replacing incandescent and fluorescent lighting technologies with light emitting diode (LED) technology is one of the most popular energy efficiency initiative implemented by businesses, organisations and citizens. Insulating pipelines and furnaces, fixing leaks on compressed air lines and implementing controls on energy consuming equipment and systems are some of the initiatives employed by industry. There are organisations in the commercial sector such as hotels, airports, hospitals, banks and businesses that go a step further to employ renewable energy sources as a matter of corporate responsibility and for marketing purposes. Increasingly, such strategies make business sense as well. Governments have committed themselves to various climate change agreements and policies, as well as legislation regarding "green buildings". This paper reviews the trends in global energy sources, its carbon footprint and evolution, the cost-effective modern fuel of energy efficiency together with the approaches adopted and the alternative "less carbon intensive" energy sources in focus. This paper reviews South Africa's unique challenges in energy supply and demand, and the role of energy efficiency and an alternative energy mix. Trends are highlighted and motivations for specific trends are explored and investigated, distinguishing between the world's developed and developing economies. The shallowness of the penetration of energy efficiency and the adoption of environmentally sustainable energy sources, despite the efforts and resolutions of many countries, highlights the fundamental challenge of the need for a solution that will entrench a culture of energy efficiency and sustainable energy in our way of life.

**Keywords:** Energy efficiency, energy security, carbon emissions, renewable energy, green buildings, sustainability, climate change

### I. INTRODUCTION

Energy is a basic human need and is required to power our technologies and drive our economies. Energy is needed to grow, process and prepare food, in manufacturing processes, for health purposes, in transportation and communication as well as in our homes for daily conveniences. Energy is used to

drive machinery that manufactures goods for human consumption and the construction of infrastructure that drives the financial economy. Transportation and our buildings use a significant amount of energy to keep us mobile and sheltered from the elements of the weather (such as wind, temperature, humidity, solar radiation, precipitation).

Globally, energy used can be categorised into four main sectors namely transport, industry, buildings and non-combustion uses such as lubricants, bitumen, plastics and feedstocks for petrochemicals, as shown in Fig. 1. The industrial sector is the most energy intensive of the four sectors for the time period 1970 to 2020. This is indicative of the industrial revolution starting in the 1800s with the machinery era, continuing in the 1900s the electrification era, the 1970s with the electronic information era to the present with the smart manufacturing era. By the 1970s much of the world had caught on to industrialisation with developed economies maturing energy hungry technologies and developing economies adopting the least-cost industrial revolution technologies for economic development, resulting in an exponential increase in carbon emissions.

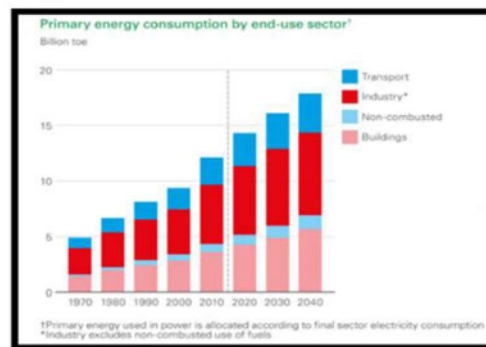


Fig. 1. Energy source breakdown of four main end-use sectors [1]

Fig. 2 shows that coal, oil and natural gas were popular choices in the industrial sector throughout the 1990s and at the turn of the 21st century, however, it seems that gas is becoming the energy source of choice from 2020 and beyond, with coal and oil stagnating in terms of growth. Fig. 2 also shows that oil is most commonly used for transport due to crude oil being the basis of fuels such as petroleum, diesel and aviation fuel. Oil is also used as an input for manufacturing products in plastics,

lubricants, etc. Electricity is the most popular energy source in buildings according to Fig. 2.



Fig. 2. Energy source breakdown of four main end-use sectors [1]

Fig. 3 shows the growth in primary energy alongside the inputs to power. Almost all growth in power demand stems from developing economies, led by China and India. Demand growth in the Organisation for Economic Co-operation and Development (OECD) is much smaller, reflecting both slower economic growth and a weaker responsiveness of power demand to economic growth in more mature, developed economies.

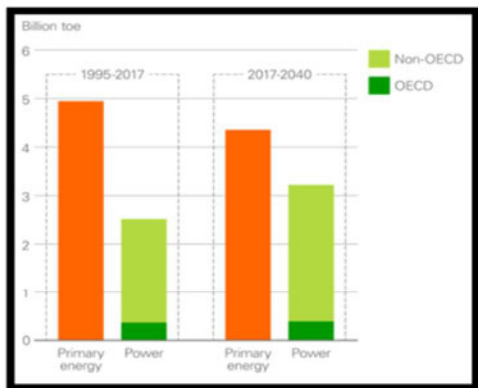


Fig. 3. Growth in primary energy and inputs to power [1]

The mix of fuels in global power generation has shifted significantly, with renewables gaining share at the expense of coal, nuclear and hydro. The share of natural gas is broadly flat

at around 20 % [1]. The economy of the United States of America (USA), one of the largest if not the largest economy in the world, is powered by a mix of petroleum, natural gas, coal, renewable energy and nuclear electric power. Petroleum makes up 37 % of energy demand in the USA and serves the largest end-use sector of energy, i.e. transportation (37 %). Natural gas powers the industrial, residential and commercial sectors (Fig. 4).

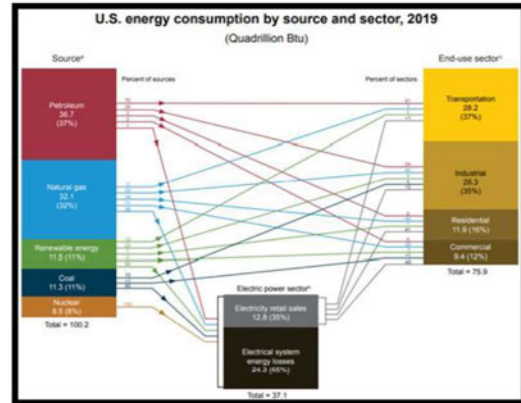
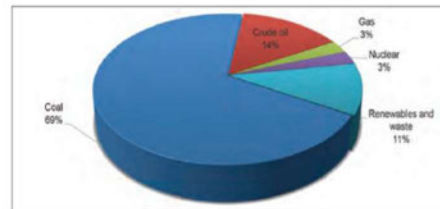
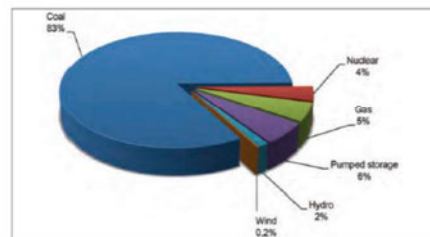


Fig. 4. US Energy Consumption by source and sector, 2019 [2]

South Africa is a developing economy. As per 2016 data, its energy supply is dominated by coal with 69 % of the primary energy supply followed by crude oil with 14 %, renewables and waste with 11 %, and natural gas and nuclear with 3 % each. Eskom is South Africa's national electricity provider whose main energy source is coal. The energy mix to produce electricity can be seen in Fig. 5.



(A) Source: DoE Energy Balances, 2016



(B) Source: Eskom Integrated Results, 2018

Fig. 5. South African primary energy supply by source (A) and electricity energy mix by source (B) [3]

The largest energy end-use sector is industry at 52 % followed by the transport sector at 19%, the commercial and public sectors at 14 %, residential sector at 8 % and agricultural sector at 6 %. The industrial sector is a heavy user of coal, using it in

its natural form and in the form of electricity. Coal is also dominant in the residential sector. Petroleum is naturally dominant in the transport and agricultural sector (Fig. 6).

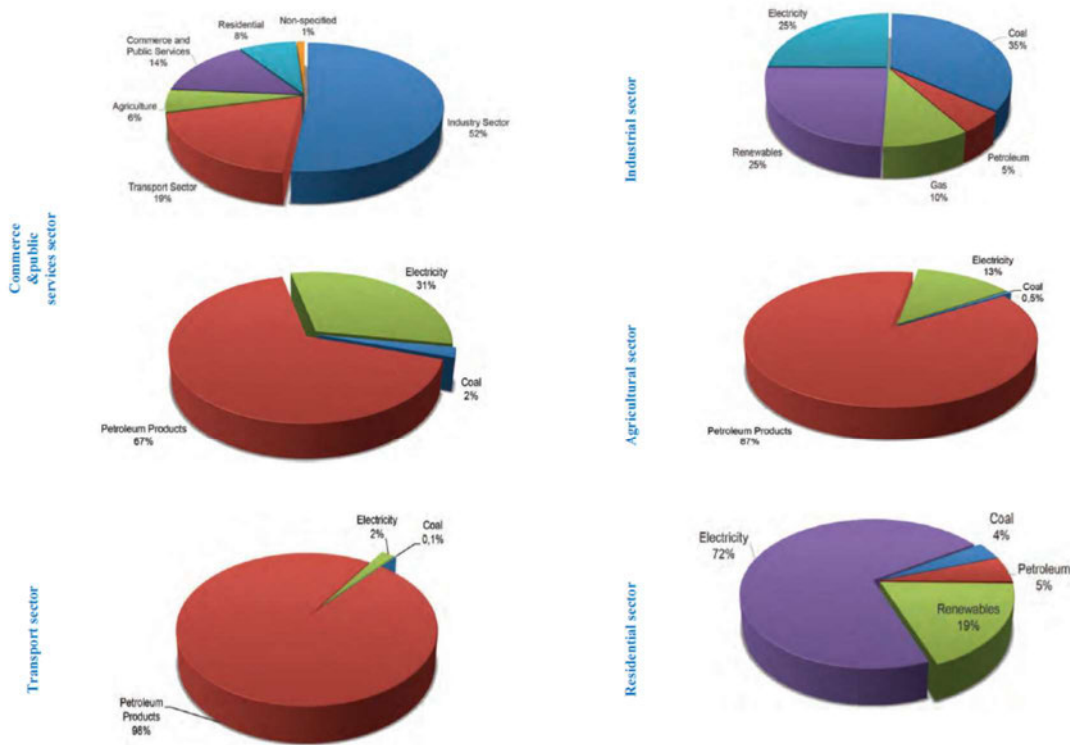


Fig. 6. Energy use by end-use sector and energy mix for each energy end-use sector [3]

Energy consumption will differ from country to country based on various factors such as stage of industrial development, size and type of industry, penetration of urbanisation, etc. Energy sources employed will have similarities (such as petroleum being popular for the transport sector) and differences (such as natural gas being a popular energy choice for America and coal for South Africa). There is a strong correlation between energy consumption and the development of countries' economies. Developed economies are highly carbonised while developing economies have a less intense carbon footprint. This is not due to developing countries being more environmentally conscious, but due to less economic and industrialised activities. Fig. 7 shows that CO<sub>2</sub> emissions per capita are generally higher for countries with more developed economies like the US, Canada, Germany, and Japan, while countries like India, Brazil, Mexico, and South Africa with transitional/developing economies have lower CO<sub>2</sub> emissions per capita.

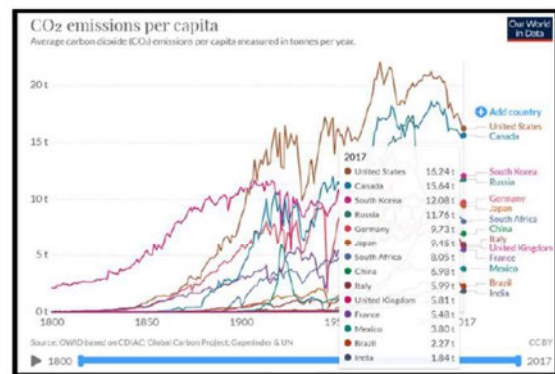


Fig. 7. CO<sub>2</sub> emissions per capita [4]

Energy available across the planet varies due to the energy sources available in each country and the ease of extraction and processing for usable energy. The costs that the extraction and processing of energy sources comes with includes the risks to human health and cost of mitigation. The following sections will review the world's energy consumption and the associated carbon footprint, and examine the shifts in energy sources following climate change imperatives. This includes the world's renewable energy uptake, renewable energy potential and various initiatives employed by countries to reduce their carbon footprint. The review focuses on the unique challenges faced by South Africa, a country with a developing economy, showcasing the dynamics of securing energy supply for economic development while satisfying the requirement to decarbonise. The paper concludes by highlighting the three scenarios of our continued economic activity and their impacts as well as two scenarios for desired pathways that the energy landscape of our globe can take to arrest climate change, ultimately showing the need for a lasting approach which is embedded in our way of life as opposed to the current approach as revealed in this literature review.

## II. ENERGY TRENDS

Understanding what has lead up to the current global warming crisis is key to moving towards a solution that will make a difference. This section outlines the history of the use of the traditional energy sources of coal, oil and natural gas which are not only the primary energy sources of the majority of the countries of the world fueling the first three industrial revolutions, but also are responsible for the resulting carbon footprint.

### A. The World's Carbon-Intensive Energy History

The world's first oil wells were drilled in China around the 4th century AD. The Chinese used simple bamboo poles to drill these wells. The material they extracted was then used primarily as a source of fuel. In later centuries, oil was found across Asia and Europe. The modern oil industry began in the mid-19th century. On August 27, 1859, Colonel Edwin Drake discovered the first underground oil reservoir near Titusville, Pennsylvania (USA) after drilling a well just 21 metres deep. Drake worked for the Pennsylvania Rock Oil Company which wanted to use the oil to light streetlamps. Drake's well initially produced 30 barrels of oil per day (b/d) (one barrel is equal to 159 litres or 42 US gallons). Its success marked the beginning of the modern oil industry. Oil soon began to receive more attention from the scientific community. After some research, a variety of products were eventually developed from crude oil. For example, kerosene for heating was one of the first products [5].

In 1870, John D. Rockefeller incorporated Standard Oil Co. in Ohio. The company quickly emerged as the dominant player, driving prices down and buying up competition. Standard Oil expanded across the country and began exporting to overseas markets including China. It was so successful that by 1890 it controlled nearly 90 % of refined oil in the US [6]. Soon other products like gasoline and diesel to run engines were also on

the market. In 1890, the mass production of automobiles began creating a huge demand for gasoline and pushing companies to find more oil fields [5].

Many of the major petroleum companies that are recognisable today can trace their origins to events that occurred over the next decade:

- Gulf Oil and Texaco were established in 1901, following the discovery of oil at Spindletop, Texas.
- Royal Dutch and Shell merged in 1907 to form Royal Dutch/Shell, with the aim of remaining competitive in the face of increased price competition from US firms.
- The Anglo-Persian Oil Company (now BP) was formed in 1908, following the discovery of oil in the south-west of modern-day Iran.
- Chevron, Exxon and Mobil (now Exxon Mobil) were formed in 1911 when Standard Oil was split up by the Supreme Court of the United States as a result of antitrust violations.

These international oil companies (IOCs) (BP, Chevron, Exxon, Gulf Oil, Mobil, Royal Dutch/Shell and Texaco) became known as the 'seven sisters' and went on to control 85 % of the world's oil reserves at their peak in the early 1970s [6].

Officials from Kuwait, Iran, Iraq, Saudi Arabia and Venezuela met in Baghdad in 1960 to discuss how to handle the price cuts imposed by the IOCs. They agreed to form the Organization of Petroleum Exporting Countries (OPEC), with the aim of reducing competition between their nations and controlling prices. Over the next two decades OPEC expanded to include Qatar, Indonesia, Libya, United Arab Emirates, Algeria, Nigeria, Ecuador and Gabon. Many of these nations also took control of their oil reserves between 1960 and 1976, by buying out or forcibly taking shares from the IOCs [6].

From 30 b/d of oil produced in the mid-19<sup>th</sup> century, the rate of extraction rose to close to 100 million b/d (Fig. 8). The total world average annual growth of oil production over the last decade (2008-2018) was around 1.4 %, with 2019 seeing an overall decline of about 0.1 % to about 95 million b/d. It can be observed from Fig. 8 that the Middle East is the largest producer of oil contributing 32 % of the global share followed by North America (US, Canada and Mexico) at 25.9 % and the Commonwealth of Independent States (CIS) made up of Armenia, Azerbaijan, Belarus, Kazakhstan, Russian Federation and other states at 15.4 %. The CIS and the Middle East were among the lowest oil consumers at 4.3 % and 9.6 % respectively in 2019. The largest oil consumer in 2019 was the Asia Pacific at 36 million b/d or 36.8 % of global consumption, followed by North America at 23.5 million b/d (23.9 %). South Africa consumed 569 thousand b/d constituting 0.6 % of the global share. The total world average growth rate of oil consumption over the last decade (2008-2018) was 1.3 % and in 2019 was 0.9 % which is below the average annual growth rate of the last decade.

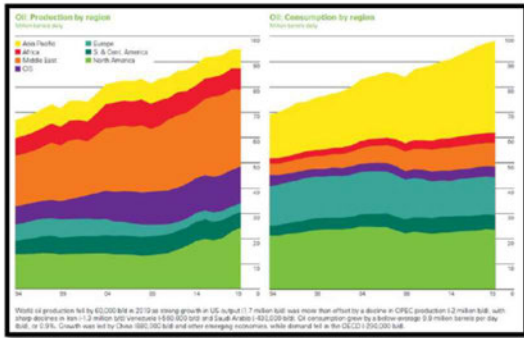


Fig. 8. World oil production and consumption by region from 1994 to 2019 [7]

Since primitive humans first began to use fire, energy has been an essential resource for human survival. Easily accessible timber satisfied heating, cooking and other basic needs for the survival of primitive humans. With technological advances in coal mining, coal, which had higher energy density, was widely used. In 1769, Watt invented the steam engine. In 1875, the French built the first coal-fired power plant in the world. The progress of human civilisation accelerated the development of the coal industry, and coal accounted for the largest share in primary energy mix in the 1780s, surpassing wood for the first time. This was the first transformation – from wood to coal. [8]

In 2019 China, Indonesia, Australia and India made up the majority of the Asia Pacific's 74.4 % (124,72 EJ) contribution to the global total production of 167,58 EJ (Fig. 9). South Africa's 6 EJ energy production in 2019 contributed to 3,6 % of the world's coal energy production. The average annual growth rate of coal energy production over 2008-2018 was 1,4 % and in 2019 the growth rate was 1,5 %, higher than the decade average [7]. World coal energy consumption was 157,86 EJ in 2019 which represented a decrease in the annual growth rate by 0,6 % as opposed to an average annual growth rate of 0,8 % over 2008-2018. The Asia Pacific coal energy consumption of 122,22 EJ makes up 77,4 % total world energy consumption and South Africa consumed 3,81 EJ making up 2,4 %. The figures indicate that there is a slower growth rate and notable decline in the use of coal as an energy source.

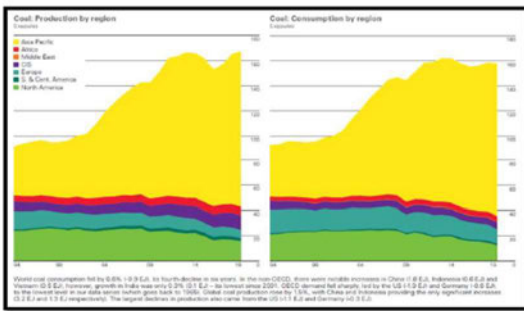


Fig. 9. World coal production and consumption by region from 1994 to 2019 [7]

Naturally occurring natural gas was discovered and identified in America as early as 1626, when French explorers discovered natives igniting gases that were seeping into and around Lake Erie. The American natural gas industry got its beginnings in this area. In 1859, Colonel Edwin Drake (a former railroad conductor who adopted the title 'Colonel' to impress the townspeople) dug the first well. Drake hit oil and natural gas at 69 feet below the surface of the earth [9].

The world produced 3989,3 billion cubic metres of natural gas which is around 143,62 EJ in 2019 (Fig. 10). 28,9 % came from North America (23 % by the US) followed by the CIS producing about 21,1 %, and the Middle East and Asia Pacific 17,4 % and 16,8 % respectively. The growth rate of natural gas production per annum over the last decade (2008-2018) has been 2,4 % with a significant increase in 2019 to 3,4 %. The world consumption of natural gas has been 3929,2 billion cubic metres (141,45 EJ) in 2019 (growth rate of 2 % versus an average annual growth rate of 2,5 % over 2008-2018). The North American region used 26,9 % of this followed by the Asia Pacific at 22,9 % and three regions around 14 % each, i.e. CIS (14,6 %), Middle East (14,2 %) and Europe (14,1 %). South Africa consumed 4,3 billion cubic metres of natural gas in 2019, representing 0,1 % of the total world consumption.

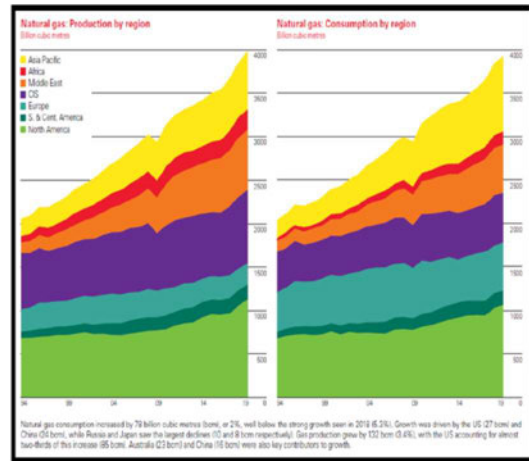


Fig. 10. World Natural Gas production by region from 1994 to 2019 [7]

From the trends of oil, coal and natural gas production and consumption, one can see that the highest production and consumption growth rate over the period 2008-2018 is natural gas and the lowest production and consumption rate is coal. The world's energy mix used to be dominated by oil in the 1970s and has evolved to an almost balanced amount of coal, oil and natural gas as can be seen in Fig. 11.

Other trends that can be observed are that most of the countries with developed economies in the world consume a lot of energy (whether it be in the form of coal, oil or natural

gas) and produce a significant amount of energy as well. The sources of primary energy consumption per region can be seen in Fig. 12. Oil is the dominant primary energy consumption source for all of America, the Europe and Africa, coal is the dominant primary energy consumption source for the Asia Pacific region, notably in China, India and Indonesia, and natural gas is the dominant primary energy consumption source for the Middle East and CIS. It can also be observed from the trends that even though the Middle East produces a significant amount of oil, they have a small oil consumption footprint; this implies that oil exports are significant and *vice versa* for South and Central America where much less oil is produced and yet their oil footprint is larger in relation, thus oil imports are significant.

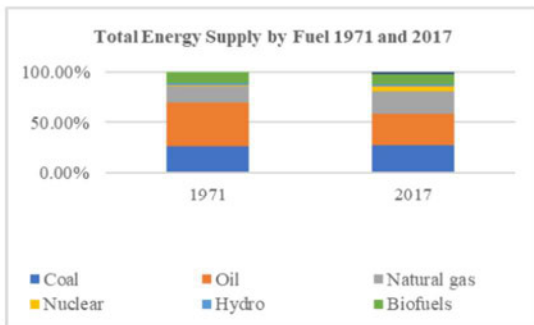


Fig. 11. Total Energy Supply by fuel, 1971 and 2017 [10]

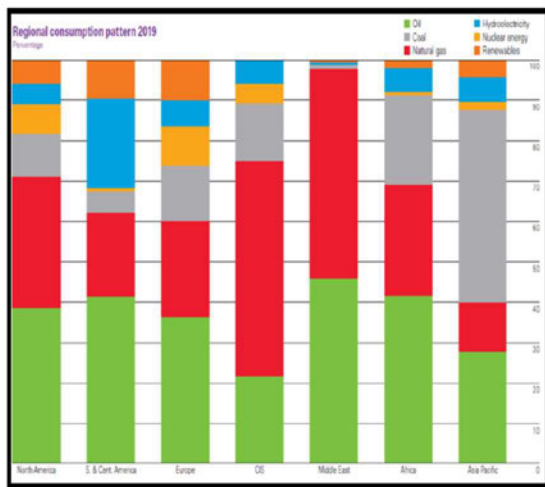


Fig. 12. Primary energy consumption sources per region [7]

The production and consumption of coal, oil and natural gas has shaped the carbon footprint for the world over the industrial revolution era as is described in the following section.

### B. World's Carbon Footprint

In 2017, thirty-six billion tonnes of CO<sub>2</sub> were emitted, reaching a concentration of over 400 ppm. This number has increased exponentially from the 2 billion tonnes of emissions in 1900, just 117 years ago. The growth of CO<sub>2</sub> emissions since the 1750s to the present can be seen in Fig. 13. The energy intensity varies across continents according to dynamics at play such as the economy and economic activity, the geopolitics and history, natural environmental endowments and types of control over the resources through governments, monarchies and other regimes, etc. Fig. 14 shows the share of the world's global carbon emissions over half-century periods (1750 to present) and tells the story of industrialisation via coal, oil and natural gas across the world as the various countries' economies began developing.

In 2017 China, an emerging economy, was the world's largest CO<sub>2</sub> emitter accounting for more than 25 % of the global emissions, followed by the USA (a developed economy) accounting for about 15 %, the European Union (EU) about 10 %, India (an emerging economy) about 6 %, and Russia (a developed economy) about 5 %. South Africa, a developing economy, contributed 1,26 % of the carbon emissions (Fig. 15).

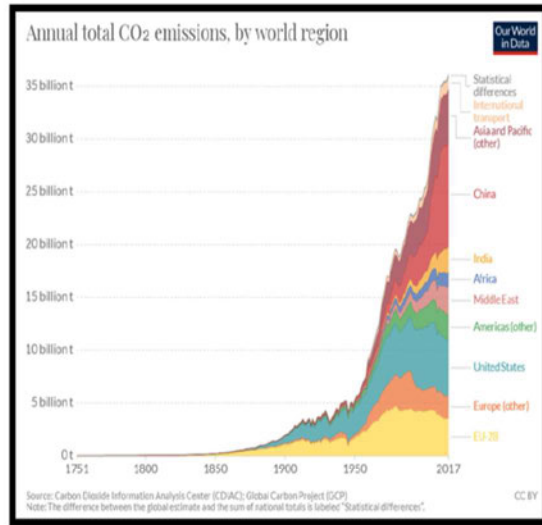


Fig. 13. Annual CO<sub>2</sub> emissions [12]

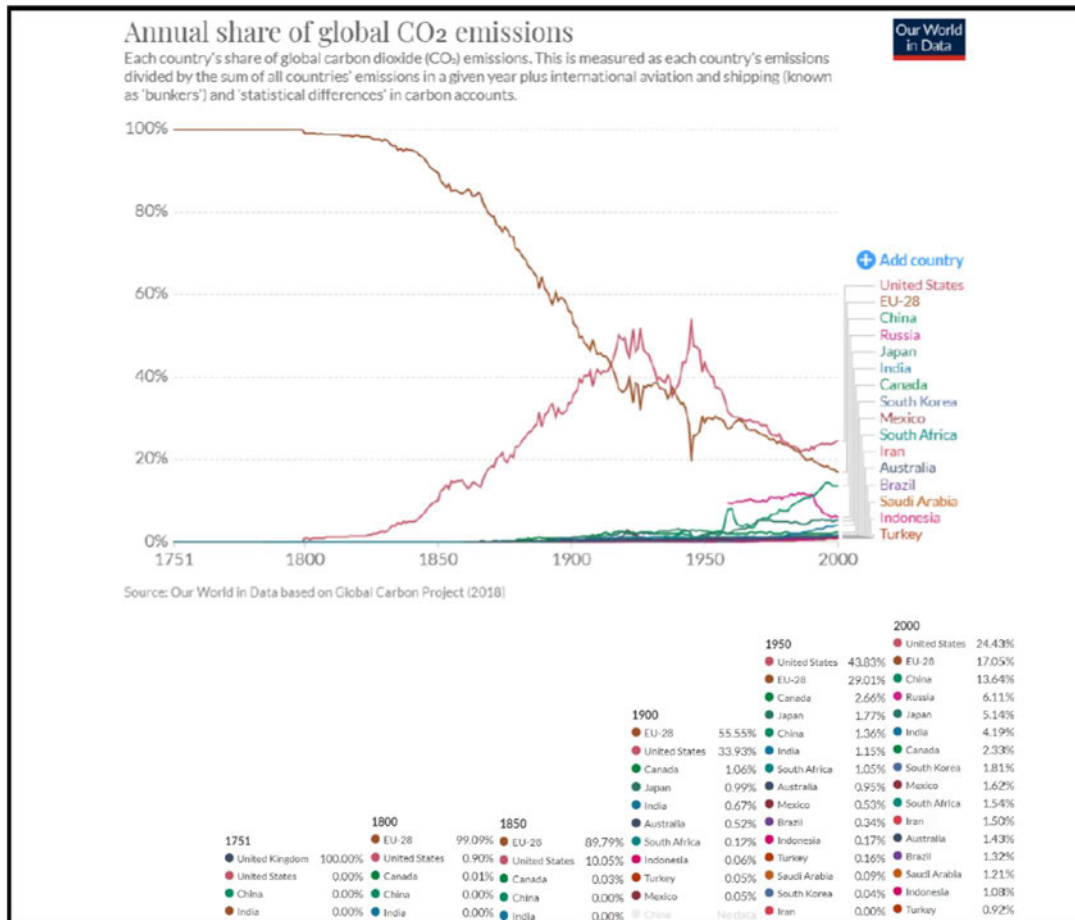


Fig. 14. Share of the world's global carbon emissions over half-century periods [12]

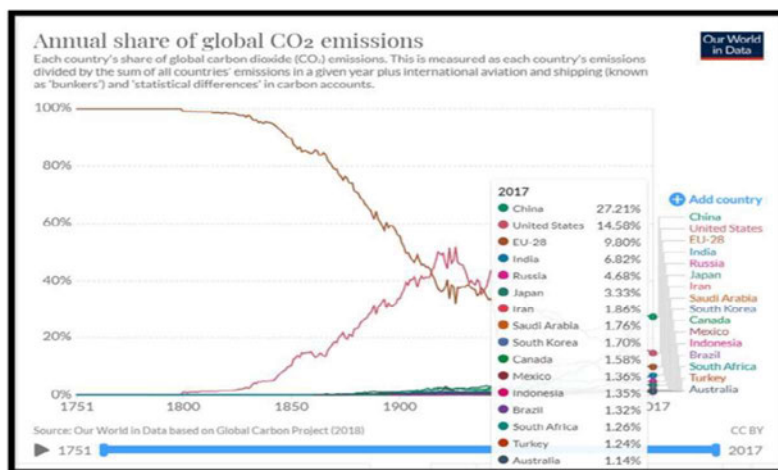


Fig. 15. 2017 Carbon-dioxide emissions of the world [12]

The International Monetary Fund (IMF) and the United Nations (UN) classify the world's countries into developed, developing and least developed categories based on their industrial base development and their human development index (HDI) in relation to other countries. It is not a universally accepted definition though; in 2015, the World Bank declared that the "developing/developed world categorization" is becoming less relevant and that they will phase out the use of that descriptor. The term "developing" describes a currently observed situation and not a changing dynamic or expected direction of progress. Since the late 1990s, developing countries tended to demonstrate higher growth rates than developed countries. Developing countries include, in decreasing order of economic growth or size of the capital market: newly industrialised countries, emerging markets, frontier markets, "least developed countries". Therefore, the least developed countries are the poorest of the developing countries [11] (Fig. 16). It is not a hard and fast rule that countries with high HDIs are developed countries. As can be seen from Fig. 17, Russia is indicated to have a high HDI but is classified as a developing country according to Fig. 16.

What is clear from Fig. 14 is that in the 18<sup>th</sup>, 19<sup>th</sup> and 20<sup>th</sup> centuries (during the industrial revolution), the developed countries of the world dominated the emission of carbon. The United Kingdom (UK), a developed country was the highest contributor of carbon emissions recorded in 1751 through to the 1800s with USA and Canada then appearing and growing to around 10 % of the world's carbon emissions by 1850. By the 1900s, the EU (the UK is captured in this number) share dropped to just over 50 % and the USA rose to just over 30 %. Emerging countries such as Canada, Japan, India, Australia, South Africa started appearing with the spread of industrialisation. The USA took over as the largest contributor in 1950 with almost half of world carbon emissions in the years leading up to the turn of the millennium, but now its contribution is proportionately less largely due to China. In 2017, China became the world's largest carbon emissions contributor in the world. Reduced proportion of carbon emissions does not imply a decrease in carbon emissions, but rather an indication of carbon emissions in relation to other countries of the world. Fig. 7 shows that the USA is still the largest carbon emissions contributor if one looks at the per capita amount. Fig. 7 is an indication of the carbon intensity of some of the countries of the world. The common trend here is that developed countries have high carbon intensities. The further implication that can be drawn is that if developing countries continue to grow their industrial bases and improve their HDIs through the methods and sources of energy adopted by the developed world, the situation will be a lot worse as industrialisation expands to all parts of the globe, with the added characteristic of developing countries being densely populated.

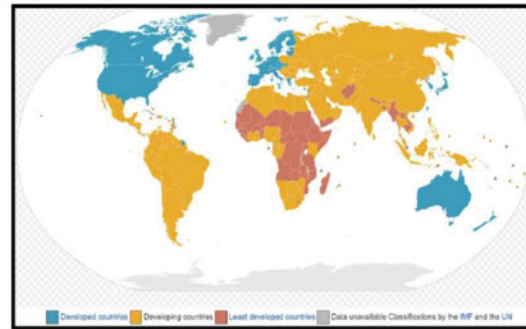


Fig. 16. Classification of the world's countries into developed, developing and least developed [11]

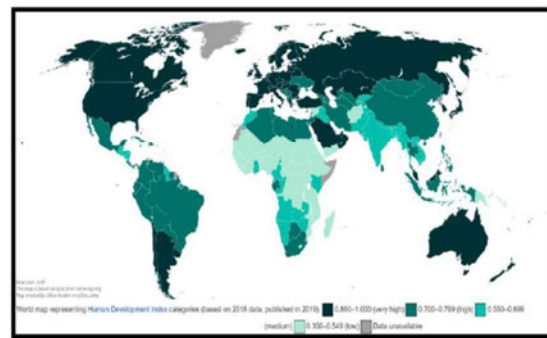


Fig. 17. World Human Development Index [11]

The world's governments and ruling entities have now agreed that these numbers are not sustainable and have joined efforts in the form of various task forces to bring about sustainable development. The sustainable development goals of the United Nations as well as the Intergovernmental Panel for Climate Change (IPCC) are a product of these efforts. The sustainable development goals (SDGs), adopted by the United Nations General Assembly (UNGA) in 2015 provide a powerful framework for international cooperation to achieve a sustainable future for the planet. The 17 SDGs and their 169 targets are at the heart of Agenda 2030, and define a path to end extreme poverty, fight inequality and injustice, and protect the planet's environment. Sustainable energy is necessary for the success of Agenda 2030. The global goal on energy – SDG 7 – encompasses three key targets: ensure affordable, reliable and universal access to modern energy services; increase substantially the share of renewable energy in the global energy mix; and double the global rate of improvement in energy efficiency [13]. The IPCC, made up of hundreds of countries both from the developed and developing economies of the world, released a report in 2011 that will guide policy makers on renewable energy to arrest the CO<sub>2</sub> concentrations in the earth's atmosphere. "There are multiple options for lowering GHG emissions from the energy system while still satisfying the global demand for energy services. Some of

these possible options, such as energy conservation and efficiency, fossil fuel switching, renewable energy, nuclear and carbon capture and storage (CCS) were assessed. A comprehensive evaluation of any portfolio of mitigation options would involve an evaluation of their respective mitigation potential as well as their contribution to sustainable development and all associated risks and costs." [14].

The challenge of arresting the CO<sub>2</sub> concentration in the atmosphere can be anything but equal among the continents of the planet as the various continents have made unequal contributions to the CO<sub>2</sub> concentration and have benefited economically from this unequally as well.

Even though the total energy supply has grown 2.5 times its size over the last four decades or so, there has been a shift in the sources of energy as a result of various dynamics. Fig. 11 shows that there has been a negligible increase in the use of coal, biofuels and hydro, and there has been a significant decline in the adoption of oil, a gradual increase in the adoption of natural gas and an exponential increase in the

uptake of nuclear energy (0,5 % in 1971 to 4,9 % in 2017) and renewable energy (0,1 % in 1971 to 2 % in 2017). Fig. 11 also shows a shift from the traditional fuels of coal and oil being in the majority in 1971 to natural gas, and a stagnation of the use of coal.

The shift away from oil could be related to the geopolitical dynamics of the Middle East and the USA and the effect this has on the cost of doing economic activity which is not sustainable for the world. Fig. 18 shows a history of crude oil prices and the various dynamics at play. The shift from coal has a lot to do with its decreasing popularity due to its CO<sub>2</sub> emissions coupled with the knock-on effect of the cheaper, less carbon intensive alternative of natural gas becoming available and the evolution of nuclear technology becoming less controversial. The emerging pattern among countries (both developing and developed economies) is the consideration of investment in either natural gas or nuclear power for their baseloads and adoption of renewable energy plants instead of renewing old coal powered plants or adoption of new coal powered plants for supplying energy demand.

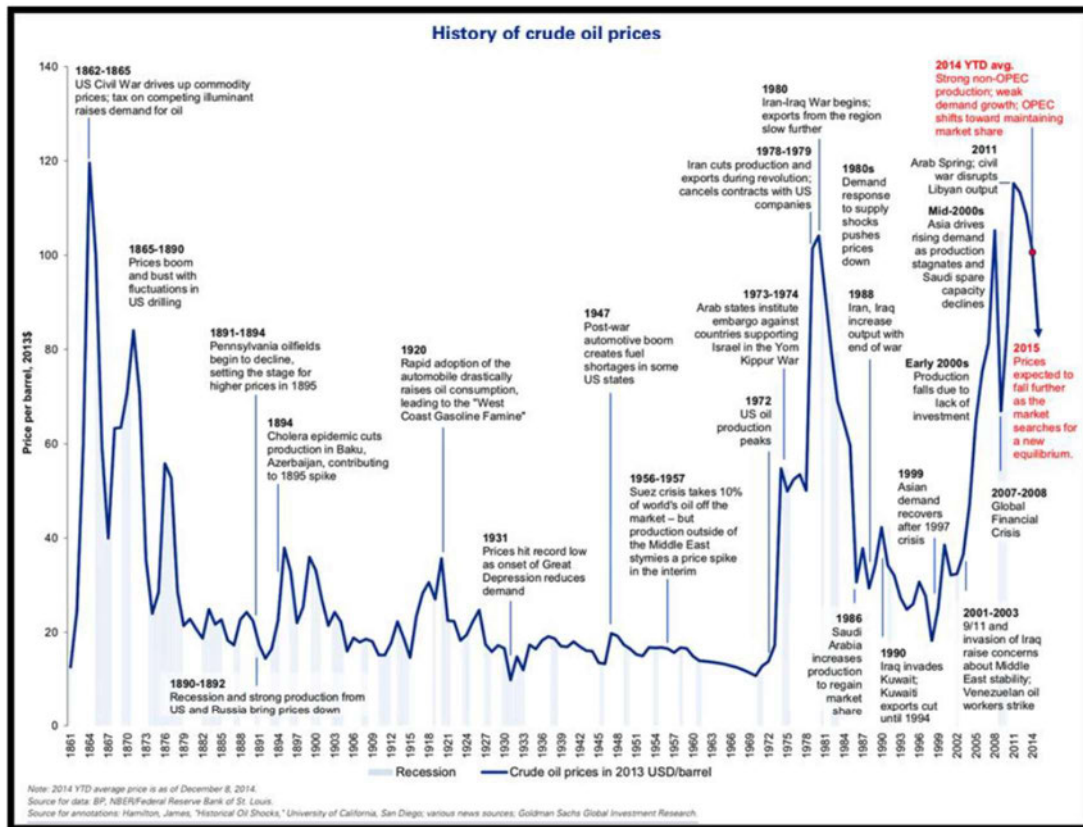


Fig. 18. History of crude oil prices [15]

Energy efficiency and introduction of alternative energy sources that are less carbon intensive have been the two main vehicles in arresting the exponential increase in CO<sub>2</sub> emissions. There have been many government incentives, economic packages and programmes driven by various reasons, not just environmental and climate change, but also energy demand and supply mismatches, energy baseload grid parities being met and exceeded, international markets for various products, international investors and international aid, and more. The following sections will review the various climate change imperatives of energy efficiency, renewable energy, green buildings and the policies surrounding some of these.

### III. CLIMATE CHANGE IMPERATIVES

Countries with developed economies usually make the transition to alternative energy from traditional sources of coal, oil and natural gas sooner not only because it allows for

transition to a lower carbon footprint, but also because this brings additional benefits of energy security through reduced dependency on energy sources not found locally, breaking dependence on imported energy sources and thus reliance on other countries for its energy supply. They also had the finances to pay the additional premium that renewable energy came with when this movement started a few decades ago.

Renewable energy technology has gained momentum over time, bringing greater efficiency and benefits such as energy sources being freely available and abundant, not being logistics or process intensive like coal, oil and natural gas which must be transported and processed for the energy to be extracted. For these reasons renewable energy technology has come to be regarded as a viable alternative especially for developing countries who do not particularly have well developed and all-encompassing national electricity grids (Fig. 19). Decentralized power is now being viewed as a way to stimulate economic development outside urban areas.

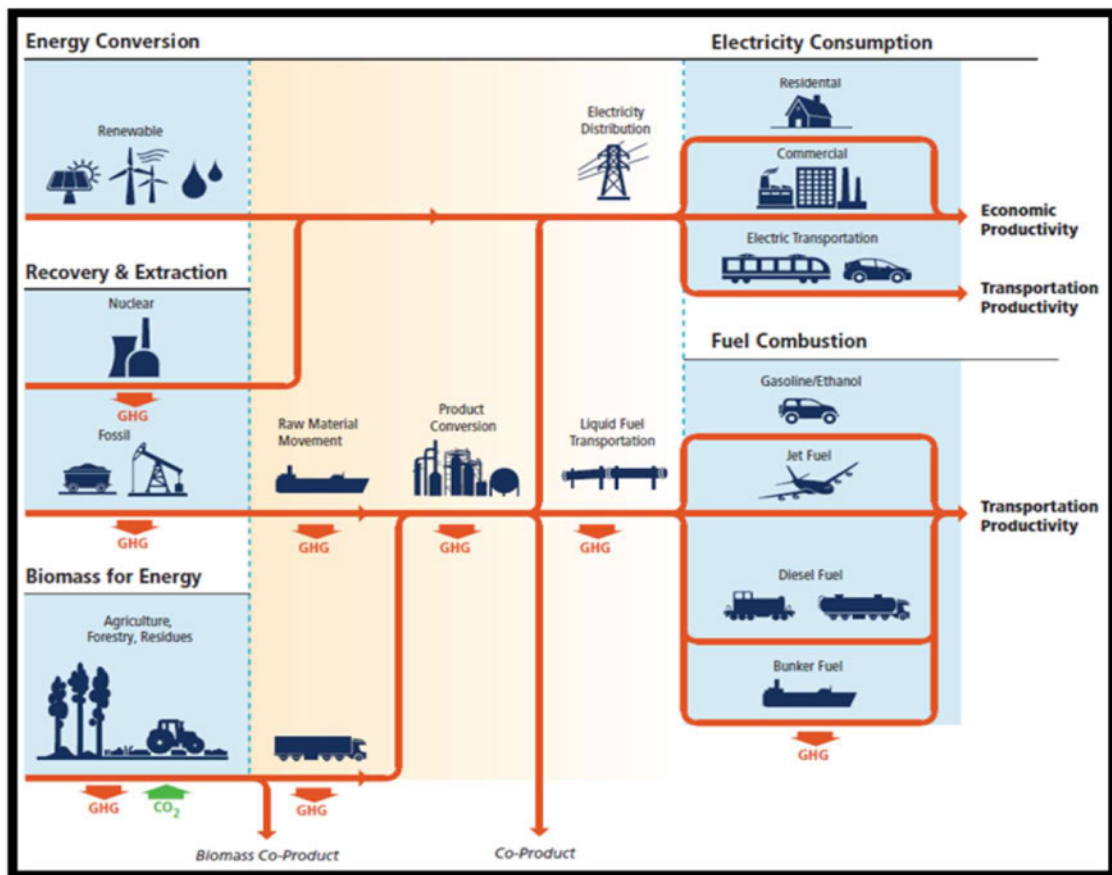


Fig. 19. Illustrative system for energy production and use illustrating the role of renewable energy along with other options [16]

For urban areas whose growth has been exponential causing electrical demand to exceed electrical supply, energy efficiency has become the most popular "fuel" as it not only saves costs, but also makes operations more efficient, having a ripple effect of benefits. For example, changing to LED technology saves on electricity costs and has the benefit of increased lifespan, thus lowering maintenance costs and disposal cost if the LED technology replaces compact fluorescent lighting (CFLs). Similarly, fine tuning of HVAC systems and keeping filters and heat exchangers clean results not only in decreased electricity costs, but also decreased load on chillers, increase in longevity of equipment, etc. Awareness of fresh-water shortage as well as the growing issue of waste disposal for about 8 billion people on our planet among other environmental issues prompted the development and popularity of sustainable or "green" buildings in the built environment. Building infrastructure is constantly under scrutiny as it is a water intensive, electricity demanding and waste producing activity yet it is necessary for economic development.

The following sections review the renewable (and alternative) energy uptake of the world, their energy efficiency activities and the adoption of green buildings in construction of infrastructure which all collectively play a role in addressing the reduction of greenhouse gas emissions through energy efficiency and energy security.

#### A. The World's Renewable Energy Uptake

The world's renewable energy uptake has increased significantly since 1965, from 1000 TWh to over 6000 TWh. Exponential increase can be observed from the turn of the century (Fig. 20). The main renewable energy source has been hydropower. Solar energy began gaining popularity around 2010 and wind energy around 2000.

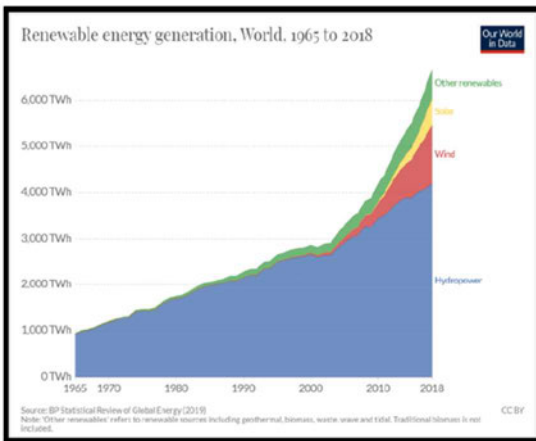


Fig. 20. Renewable energy generation 1965 to 2018 [17]

Today, hydropower is most popular in China and parts of Korea. Other countries where hydropower is installed are India, Russia, Canada, the USA and Brazil (Fig. 21). The USA, Canada, Germany, France, Sweden, Finland, Norway, Japan had major hydroelectric installations in 1965, followed by

Brazil in 1978, Russia in 1985, China in 1987 and India in 1995.

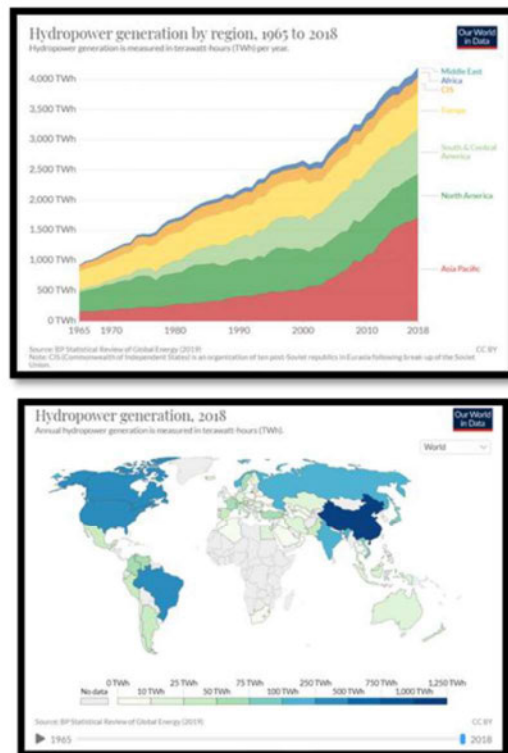


Fig. 21. Hydropower generation by region [17]

The hydropower potential of the world has not yet been tapped in Africa, Australia and parts of South America as can be seen in the world map of hydropower potential of the world in Fig. 22.

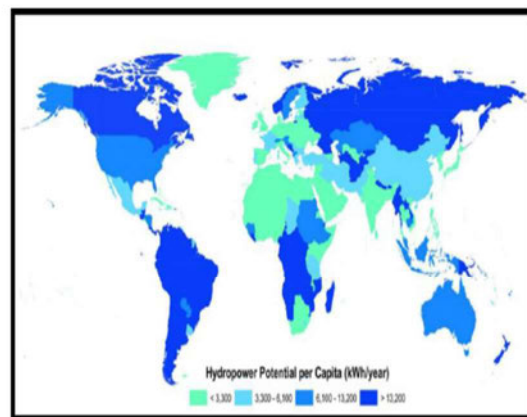


Fig. 22. World Hydropower Potential [18]

Wind energy is most popular in China and parts of Korea. Parts of Europe including the UK, parts of Asia, India, the USA, Brazil, Canada and Australia have wind installations (Fig. 23). Wind energy generation started becoming popular in 2000 with the USA, Germany, Spain and ten years later, China, India, Brazil and Australia.

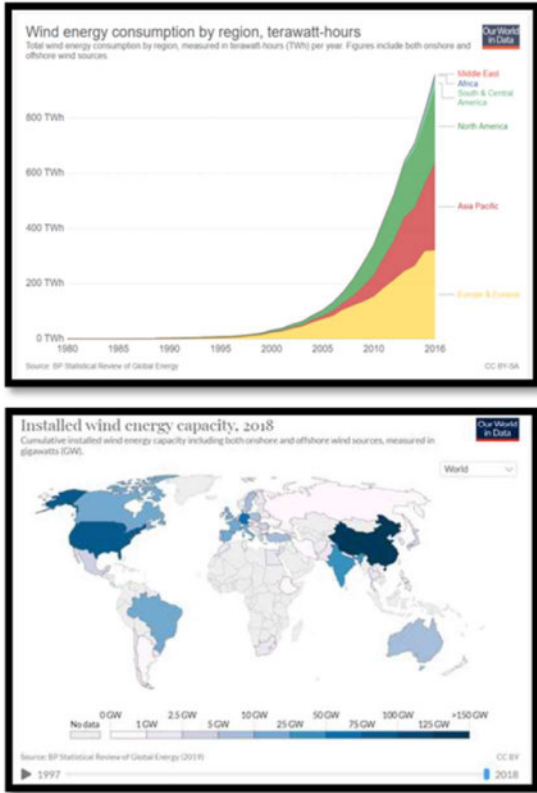


Fig. 23. Wind energy generation [17]

The wind energy potential of the world can be seen in Fig. 24. When one compares the wind energy potential of both onshore and offshore wind energy installations, there is clearly a significant potential still to be tapped into. Russia and parts of South America have not yet tapped into their abundantly available wind energy sources. Similarly, with solar energy which is abundantly available throughout the world, if one compares the solar energy installations around the world (Fig. 25) with the global solar insolation (Fig. 26), South America, Africa and Australia, which account for almost 50 % of the world's landmass, are not using this solar energy. It is clear that in the early years (before 2000) when renewable energy did not reach economies of scale, it was popular only in the developed economies of the world, but since 2000 the uptake of renewable energy is increasing rapidly in the developing economies of China, India, Brazil and South Africa. Fig. 27 shows the renewable energy investment as a percentage of GDP in 2015. South Africa, South America and China have

been making significant investments in renewable energy.

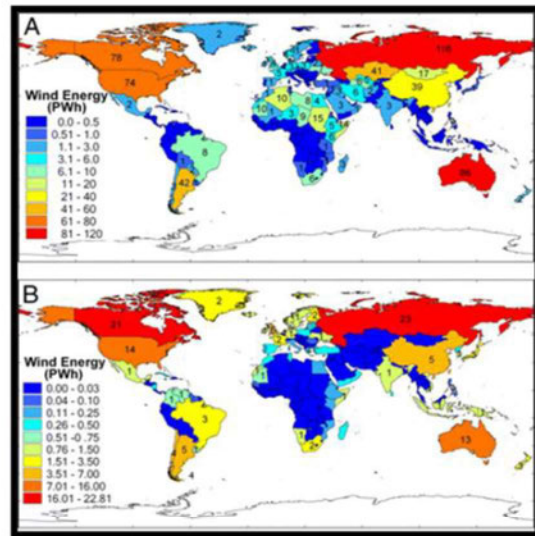


Fig. 24. Annual wind energy potential country by country, restricted to installations with capacity factors >20% with siting limited. (A) Onshore. (B) Offshore [19]

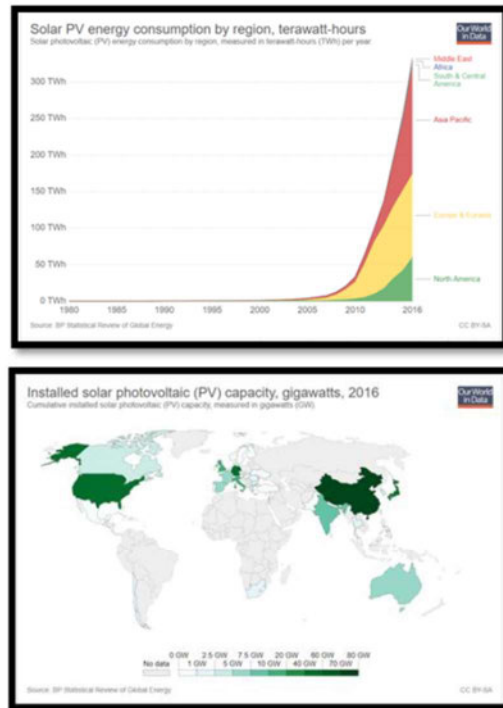


Fig. 25. Solar energy installations by region [17]

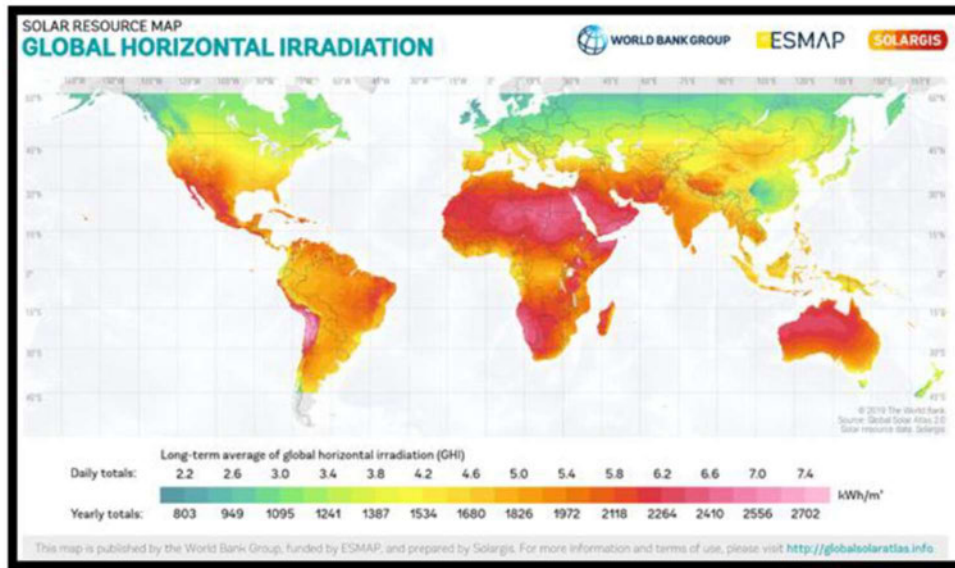


Fig. 26. Global horizontal solar irradiance [20]

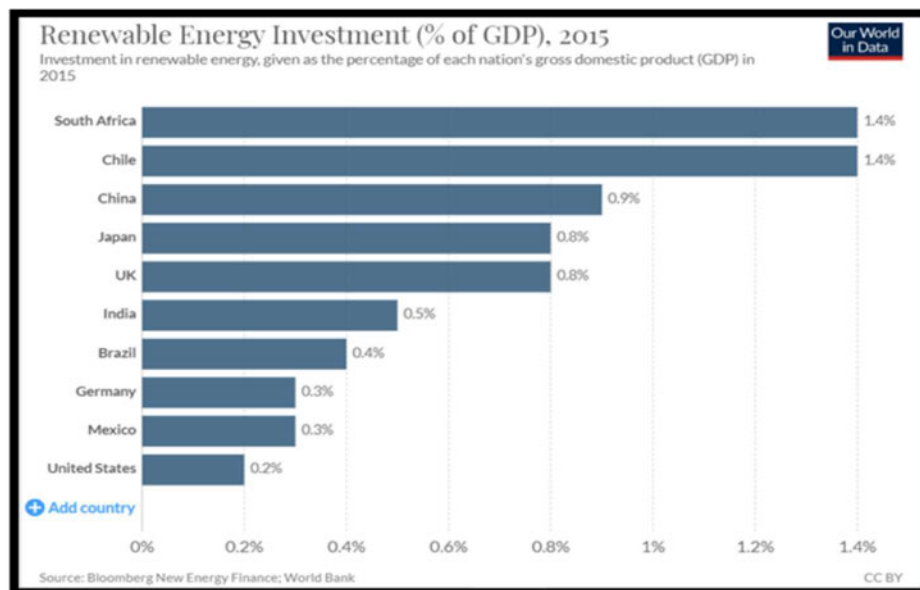


Fig. 27. 2015 Renewable energy investment as a percentage of GDP [17]

The promotion of renewable energy in developed economies are supported by tax arrangements, incentives and promotion programmes, and its uptake is ensured by laws, regulations and environmental policies promulgated by the developed

countries' governments. Table 1 lists the laws, regulations, promotion programmes, tax arrangements and environmental policies in place in developed countries.

**TABLE I.** DEVELOPED COUNTRIES' INSTRUMENTS FOR PROMOTION OF RENEWABLE ENERGY [21]

Laws/Regulations	Promotion Programmes	Tax Arrangements/Incentives	Environmental Policies
<p><b>European Union (EU)</b></p> <ul style="list-style-type: none"> <li>• Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources 22.1 % of electricity from REN sources in 2010</li> <li>• Directive on Energy Savings in Buildings (proposal) COM (2001) 226</li> </ul> <p><b>United Kingdom (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Renewable Obligation (RO) obliges licensed electricity supplies to supply specified proportion of their electricity from renewable sources</li> <li>• Target: 5 % of electricity by renewables in 2003; 10 % in 2010</li> <li>• Renewable Obligation Certificates (ROCs) (current value over £40 /MWh)</li> </ul> <p><b>Denmark (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Electricity Act (1999) subsidies for wind energy are to be replaced by Green Certificates</li> </ul> <p><b>France (EU Member)</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul> <p><b>Germany (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Renewable Energy Sources Act (2000)</li> <li>• Purchase obligation</li> <li>• Premium guaranteed prices</li> <li>• Co-Generation Act (2000)</li> </ul> <p><b>Australia (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Australian Renewable Energy (Electricity) Act</li> <li>• Mandated Renewable Energy Target (MRET)</li> <li>• The Office of the Renewable Energy Regulator (ORER) sets up mandated portions of renewable energy sources utilization for electricity suppliers and issues RECs (Renewable Energy</li> </ul>	<p><b>European Union (EU)</b></p> <ul style="list-style-type: none"> <li>• White Paper for a Community Strategy and Action Plan [COM (97) 599 final (29/11/1997)]</li> <li>• Green Paper: Towards a Europe Strategy for the Security of Energy Supply [COM (2001) 769 final (29/11/2000)]</li> <li>• "Intelligent Energy – Europe" EIE program (2003-2006)</li> </ul> <p><b>United Kingdom (EU Member)</b></p> <p>None noted</p> <p><b>Denmark (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Target for renewables – 20 % of primary energy sources by 2020 should be renewable</li> <li>• Obligation to buy electricity produced from renewables</li> <li>• Until 1999 production subsidy for wind (€0.03/kWh) was paid</li> </ul> <p><b>France (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Obligation to buy electricity produced from renewables</li> <li>• National Programme for Energy Efficiency Improvement (2000): feed-in tariffs for renewable energy electrical production</li> <li>• Wind energy promotion</li> <li>• "Eole 2005" – competitive tendering</li> <li>• Solar Heat – "Helios 2006"</li> </ul> <p><b>Germany (EU Member)</b></p> <ul style="list-style-type: none"> <li>• "100 000 Roof" program for PV promotion (1999)</li> <li>• Loans at low interest rates target 300 MWp in 2003</li> <li>• State funded programmes for bioenergy (subsidies)</li> </ul> <p><b>Australia (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Prime Minister's Measures for a Better Environment (1999)</li> <li>• The Renewable Remote Power</li> </ul>	<p><b>European Union (EU)</b></p> <ul style="list-style-type: none"> <li>• Indicative financial framework for EIE €200m (69.8m for SAVE, 80m for ALTENER, 32.6m for STEER and 17.6m for COOPER).</li> <li>• Contributions from expected EU enlargement is expected ~€50m</li> </ul> <p><b>United Kingdom (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Capital grants for offshore wind and energy crops projects</li> <li>• Landfill tax credit scheme (Landfill Regulations 2002)</li> </ul> <p><b>Denmark (EU Member)</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul> <p><b>France (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Tax credit for renewables installation</li> <li>• Grants for off-grid renewables (up to 95 % in rural zones and 60 % urban zones.</li> <li>• Reduced VAT and income tax credit (15 % in 2002) for household expenses</li> <li>• Loan guarantees of up to 70 % of the amounts of loans</li> <li>• Germany (EU Member)</li> <li>• Low interest loans for small renewable projects</li> <li>• Feed-in tariffs for wind energy (€91 /MWh), biomass (€87 /MWh to 102 /MWh), geothermal energy (€71.6 /MWh to 89.5 /MWh), small hydro, up to 5MW (€76 /MWh) and solar (€506 /MWh)</li> <li>• Soft loans from KfW for small (up to 500 kW) hydro plants and small CHP biomass plants</li> </ul> <p><b>Australia (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul>	<p><b>European Union (EU)</b></p> <ul style="list-style-type: none"> <li>• European Climate Change Program (ECCP)</li> <li>• European strategy to implement the Kyoto Protocol</li> <li>• To cut emissions by some 122 to 178 million tons of CO<sub>2</sub> equivalent</li> <li>• Renewable certificates trade support</li> </ul> <p><b>United Kingdom (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Climate Change Levy (CCL) defines various "taxable commodities" and applies different tax rates (LPG - 0.07 p/kWh; natural gas, coal – 0.15 p/kWh, electricity 0.43 p/kWh). Those meeting reduction targets will receive 80 % levy discount</li> <li>• Emissions Trading Scheme (ETS) – launched in April 2002</li> <li>• For emissions trading</li> </ul> <p><b>Denmark (EU Member)</b></p> <ul style="list-style-type: none"> <li>• Emissions trading program (2002) – to comply with a 21 % GHG reduction target from 1990 levels</li> <li>• Total caps for power company emissions (quota system)</li> <li>• Every ton of excess emission is fined with non-compliance tax (\$5)</li> </ul> <p><b>France (EU Member)</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul> <p><b>Germany (EU Member)</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul> <p><b>Australia (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Renewable Energy</li> </ul>

<p>Certificates) to demonstrate compliance with the requirements.</p> <ul style="list-style-type: none"> <li>• Penalty for non-compliance \$40 /MWh</li> </ul> <p><b>USA (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Energy Policy Act (1992) EPACT</li> <li>• Clean Air Act and amendments (tradeable permits for SO<sub>2</sub> allowance)</li> <li>• Renewable Portfolio Standards (RPS) – expected on the federal level in 2005. Target: by 2019/20 – 10 % of electricity from renewable sources</li> </ul> <p><b>Korea (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Promotion Act of New and Renewable Energy Development, Utilization and Dissemination</li> </ul> <p><b>Canada (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul>	<p>Generation Program (RRPGP) funded from excise paid on diesel. Support up to 50 % of the capital cost</p> <ul style="list-style-type: none"> <li>• Photovoltaic Rebate Program (PVRP) – rebates for households</li> </ul> <p><b>USA (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Export Promotion. Special Advisory committee at US ExIm Bank to promote renewable industry exports</li> <li>• “Wind Powering America” – US DOE program. Goal – 5 % of US electricity powered by wind</li> <li>• Strategic Plan for Geothermal Energy (June 1998) prepared by the US DOE Office of Geothermal Technologies (OGT)</li> <li>• GeoPowering the West goal: 10 % of electricity in 8 states in US west powered by geothermal sources; 7 million homes</li> <li>• US Geothermal Resource Exploration Definition (GRED) program – joint program of US DOE and geothermal industry. DOE funds portion of initial risks</li> <li>• “Million Solar Roofs”, PV promotion program of the US DOE Office of Solar Energy Technology</li> <li>• Zero Net Energy Buildings (ZEB)</li> </ul> <p><b>Korea (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Target for renewables – 2 % of total primary energy supply by 2003</li> </ul> <p><b>Canada (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Action Plan on Climate Change and Wind (feed-in tariffs for wind)</li> <li>• Wind Energy Research and Development Program (WERD) coordinated by Natural Resources Canada (including financial incentives)</li> <li>• Small hydro promotion accelerated tax write-off for equipment of hydro-electric installations not exceeding 15 MW</li> </ul>	<p><b>USA (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Section 45 Production Tax Credit (PTC) for renewable energies (biomass, wind, geothermal, solar)</li> <li>• Investment Tax Credits (ITC)</li> <li>• Sales Tax Reductions Property Tax Reductions (on state level different incentives exist, for example investment grants, production incentives, loan subsidy Programmes, grants for demonstration projects)</li> <li>• Net metering in several states</li> </ul> <p><b>Korea (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Low interest loans for renewable projects</li> <li>• Tax credit for renewables installation</li> <li>• Feed-in tariffs</li> </ul> <p><b>Canada (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Tax incentives for business investments in energy conservation and renewable energy (Canadian Renewable and Conservation Expenses [CRCE])</li> <li>• At least 50 % of the capital cost eligible for income tax write-offs</li> <li>• Support for renewables – foreign entities get 20 % investment credit against future tax payments</li> </ul>	<p>Certificates (RECs)</p> <ul style="list-style-type: none"> <li>• Australian Greenhouse Office (AGO) looks after GHG matters/runs certification program “greenhouse friendly”</li> </ul> <p><b>USA (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• Green certificates (tradeable in several states)</li> <li>• SO<sub>2</sub> allowances trade</li> <li>• Renewable Energy Certificate System (RECs) pilot scheme</li> <li>• More than third of consumers have option to purchase green power GHG trading – voluntary</li> <li>• trading scheme – US Chicago Climate Exchange (CCX)</li> </ul> <p><b>Korea (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul> <p><b>Canada (OECD Country)</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul>
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The trend within developed countries is that they are driven by clear strategies. For example, the EU provides guidance for all its member states. Each member state has a programme, backed up by environmental policy and legislation, some even to the point of making it an obligation for citizens to purchase

electricity from renewables (Denmark) to ensure the uptake of renewable energy happens as well as providing the financial backing through incentives and financial aid. There are clear targets for reduction in carbon emissions as well as emissions trading programmes to promote this target. The OECD

countries make use of laws and legislation with the financial backing of incentives and other programmes such as feed-in tariffs to make renewable energy a viable business investment. A point to note is that most programmes were established in the first decade of the 21st century/last decade of the 20th century.

The prime reason for the need for policies and legislation combined with incentives is that new technologies are bound to be more expensive than their competitors (coal, oil and natural gas) which are established in the market and have economies of scale to make them affordable and competitive.

Comparing these initiatives to encourage renewable energy uptake with programmes run by developing countries, referring

to Table 2, it can be observed that programmes are still in the development phase. There are few to no policies from the countries included in the table that are reliant on foreign investment (as can be seen with India). Chile, Morocco, Argentina, Vietnam have a rural electrification focus which is characteristic of developing countries. Two barriers for establishing renewable energy in developing countries can be seen here, i.e. financial barriers and the barrier of lack of policies and legislation to drive the establishment of renewable energy.

In this respect, foreign aid is available for developing economies, some for specific countries and others applicable to a wider category. Table 3 shows the financial instruments available especially for developing countries.

**TABLE II. PROMOTION OF RENEWABLES IN DEVELOPING COUNTRIES [22]**

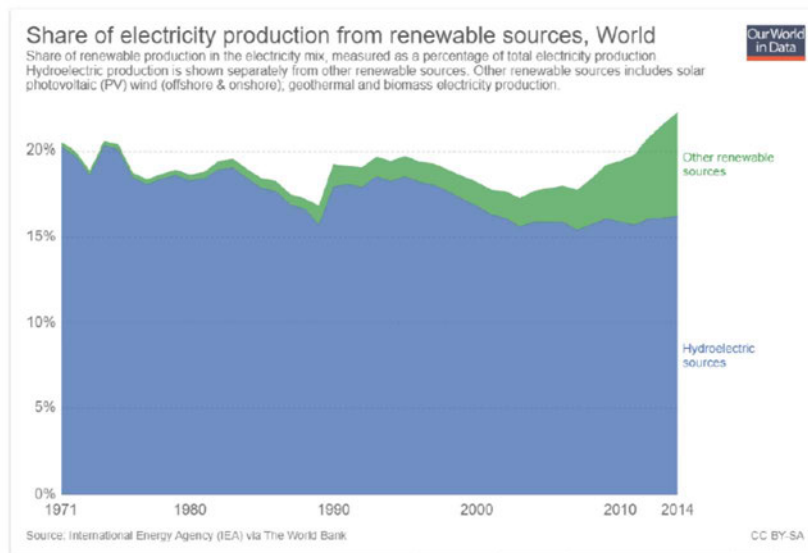
Laws/ Regulations	Promotion Programmes	Tax Arrangements/ Incentives	Environmental Policies
<p><b>Chile</b></p> <ul style="list-style-type: none"> <li>• Project GEF: Barrier removal for rural electrification with renewable energies</li> </ul> <p><b>Brazil, South Africa, Bolivia, Vietnam</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul> <p><b>China</b></p> <ul style="list-style-type: none"> <li>• Renewable energy plan</li> <li>• Government is considering</li> <li>• "Mandated market share" for renewable energy</li> </ul> <p><b>India</b></p> <ul style="list-style-type: none"> <li>• Renewable energy program issued by Ministry of Non-Conventional Energy Sources (MNES)</li> </ul> <p><b>Argentina</b></p> <ul style="list-style-type: none"> <li>• Regimen Nacional de Energia Eolica y Solar – law from end of 1999 to transfer resources for development of wind and solar projects</li> </ul> <p><b>Morocco</b></p> <ul style="list-style-type: none"> <li>• Global Rural Electrification Program (PERG) by Office National d'Electricité (ONE) to boost rural electrification from 20% in 1995 to 80 % in 2008</li> </ul>	<p><b>Chile</b></p> <ul style="list-style-type: none"> <li>• Goal – 90 % coverage for households at a national and regional level by 2006</li> </ul> <p><b>Brazil, Morocco</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul> <p><b>China</b></p> <ul style="list-style-type: none"> <li>• Program on New Renewable Energy from 1996-2010</li> <li>• "Sunlight programme" to promote solar energy</li> </ul> <p><b>India</b></p> <ul style="list-style-type: none"> <li>• Solar Energy Center of MNES initiates:                             <ul style="list-style-type: none"> <li>• – Solar thermal program</li> <li>• – Solar PV program</li> <li>• – Solar building program</li> </ul> </li> <li>• Center for Wind Energy Technology of MNES coordinating foreign funding for wind projects</li> </ul> <p><b>South Africa</b></p> <ul style="list-style-type: none"> <li>• Implementation Strategy for Renewable Energy in South Africa (consultative draft document published by Department of Minerals and Energy). Target – solar energy promotion including off-grid electrification by PV (PV in 1.5 million homes in 10 years)</li> </ul> <p><b>Argentina</b></p> <ul style="list-style-type: none"> <li>• Renewable Energy and Rural Markets program (PERMER) rural electrification: concessions and funding of rural electrification (wind, PV, etc.)</li> </ul> <p><b>Bolivia</b></p> <ul style="list-style-type: none"> <li>• National rural electrification program (PRONER)</li> </ul> <p><b>Vietnam</b></p> <ul style="list-style-type: none"> <li>• National rural electrification program to electrify 90% of rural households by 2005 10% is likely to be by renewable energy</li> </ul>	<p><b>Chile</b></p> <ul style="list-style-type: none"> <li>• Subsidies to investments</li> <li>• Institutional framework</li> </ul> <p><b>Brazil</b></p> <ul style="list-style-type: none"> <li>• Financial incentives to owners and/or developers of small hydro schemes</li> </ul> <p><b>China</b></p> <ul style="list-style-type: none"> <li>• Wind development incentives halving the current 17% VAT duty</li> <li>• Tax reductions, interest rate</li> <li>• Subsidies</li> <li>• Demonstration project</li> <li>• Development</li> </ul> <p><b>India</b></p> <ul style="list-style-type: none"> <li>• Incentive package to accelerate commercialization of renewable energy technologies                             <ul style="list-style-type: none"> <li>• – soft loans, funding, subsidies</li> <li>• – encouraging BOO projects</li> <li>• – 100% foreign direct investment possible (by IREDA – Indian Renewable Energy Development Agency)</li> <li>• PV purchase and subsidy</li> </ul> </li> </ul> <p><b>South Africa, Bolivia, Morocco, Vietnam</b></p> <ul style="list-style-type: none"> <li>• None noted</li> </ul> <p><b>Argentina</b></p> <ul style="list-style-type: none"> <li>• Tax relief</li> </ul>	<p><b>Chile, Brazil, China, India, South Africa, Argentina, Bolivia, Morocco, Vietnam,</b> None noted</p>

**TABLE III.** SCHEMES BY INTERNATIONAL ORGANIZATIONS TO PROMOTE RENEWABLE ENERGY IN DEVELOPING COUNTRIES [23]

Organisation	Continent of Operation	Renewables Category	Programme	Remarks
Global Energy Facility (GEF)	General	General	Of-grid renewable energy support	US\$200m in grants and over US\$1bn co-financing
GEF/ United Nations Environmental Program (UNEP)	General	General	Sustainable Alternatives Net (SANet)	Sustainable technologies in emerging markets (including information and guidance on project finance, co-funding, pre-investment and feasibility studies)
World Bank/GEF	General	General	Strategic Partnership for Renewable Energy	Target-financing \$150m annually; simplified approval process
US Government	Africa	General	African Growth and Opportunity Act (AGOA)	Goal: to expand US exports to Africa
European Commission (EC)	Asia	General	Promotion of Renewable Energy Systems in South-East Asia (PRESSEA)	Renewable energy network. Gathering and disseminating information to attract investments
Inter-American Development Bank (IDB)	Latin America	General	Sustainable markets for Sustainable Energy (SMSE)	Hemisphere Sustainable Energy and Transportation (HSET) Funds for support of renewable energy and energy efficiency projects

From all the programmes shown in Table 1, Table 2 and Table 3, it is evident that the penetration of renewable energy over time has been fluctuating, and hydroelectric sources have been dwindling. This could be due to the lifecycle of existing stock

as well as an increase in energy consumption from traditional fossil fuel energy. However, renewable energy sources excluding hydroelectric sources, have been steadily increasing since the turn of the century (Fig. 28).



**Fig. 28.** World share of electricity production from renewable sources [17]

Whichever way the picture is interpreted, the penetration of renewables is not yet at the point of making a significant difference in addressing climate change, even though there has been a notable increase in adoption of renewables over the past two decades. There has been a pattern of moving towards a less carbon intensive energy mix through the use of natural gas.

**B. Making way for Natural Gas as the new Baseload Energy Source**

Natural gas is one of the mainstays of global energy. Worldwide consumption is rising rapidly and in 2018 gas accounted for almost half of the growth in total global energy demand. Gas plays many different roles in the energy sector and, where it replaces more polluting fuels, it also reduces air pollution and limits emissions of carbon dioxide [24]. Coal to gas switching in the world since 2010 has helped prevent faster growth in carbon dioxide emissions by around 525Mt CO<sub>2</sub> between 2010 and 2018, using 2010 as a baseline (Fig. 29) [25]. These emissions would have been closer to 40 Gt without changes in the global economic and energy system since 2010. These include reductions in the energy intensity of the world economy, in part due to greater efficiency, as well as reductions in the carbon intensity of the energy sector related to the rise of renewables and switching to less carbon-intensive fuels. Fig. 30 shows the CO<sub>2</sub> emissions of coal, oil, gas, biofuel and non-combustible sources. Gas has the lowest fossil fuel impact in CO<sub>2</sub> emissions when combusted to release energy and is much cleaner in terms of particulate matter than any other fuel.

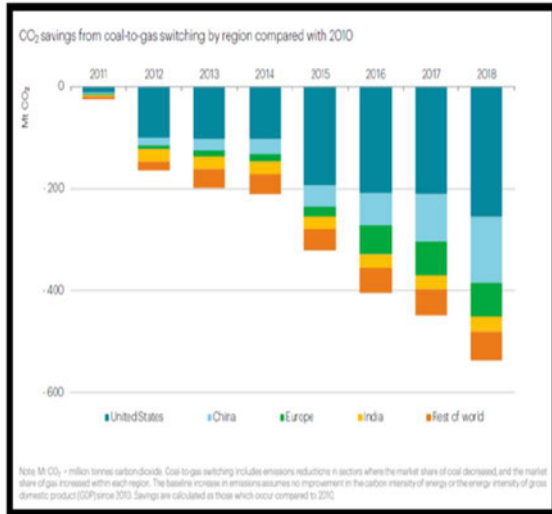


Fig. 29. CO<sub>2</sub> savings from coal to gas switching between 2010 and 2018 (2010 baseline) [25]

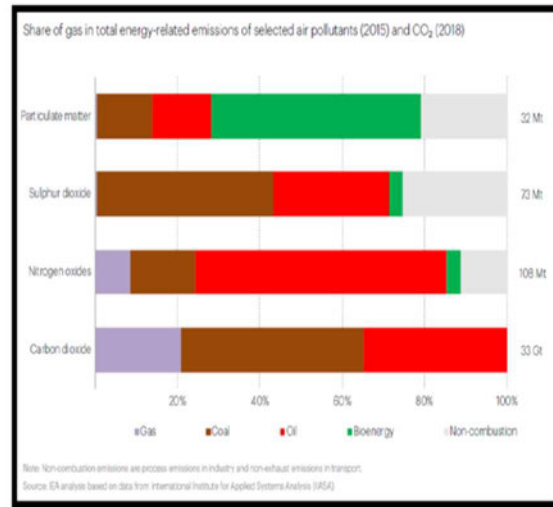


Fig. 30. Share of gas in environmental impact including CO<sub>2</sub> emissions of gas [25]

Coal-to-gas switching avoided more than 500 million tonnes of CO<sub>2</sub> emissions over this period. The majority of the coal to gas switching can be noted in USA and China. The largest emissions savings from coal-to-gas switching occurred in the USA. The remarkable rise of shale gas has pushed down natural gas prices and underpinned large-scale switching from coal to gas in the power sector, where emissions have dropped by a fifth since 2010. In China, gas demand has risen very quickly in recent years because of a major policy push to improve air quality. Gas has substituted for coal-fired industrial and residential boilers in many urban areas; however, switching is much less evident in the power sector [25].

With the notable exception of the UK, coal-to-gas switching has not been a major factor in Europe in recent years, but today's configuration of low gas prices and higher CO<sub>2</sub> prices in the EU is now giving this process renewed momentum (Fig. 31). In India, gas currently has a small share of the energy mix. Large-scale switching has been held back by supply constraints and affordability issues, as well as a lack of infrastructure [25]. In mature markets like the USA and the EU, coal-to-gas switching is a compelling near-term option for reducing emissions, given existing infrastructure and spare capacity (Fig. 32). The cost of coal-to-gas switching has not only to do with the availability of gas, but also the availability of infrastructure, the agility of available infrastructure and the cost of competitor energy sources. The ageing coal powered infrastructure of the USA (more than 80 % being over 30 years old) means that large amounts of coal-to-gas switching can be done at much lower gas prices. More than 50 % of Europe's coal powered infrastructure is over 30 years of age, but the price of coal is very competitive which makes the transition to gas more highly priced.

Gas plays a more prolonged role in emerging economies that are very carbon-intensive today, helping to push more

polluting fuels out of the system, notably in China and India's industrial sectors. [25] One can see from Fig. 31 that the transition to gas for Asia's young coal powered fleet (almost 50 % of China's fleet and over 50 % of India's fleet is under 10 years – Fig. 32) is more limited.

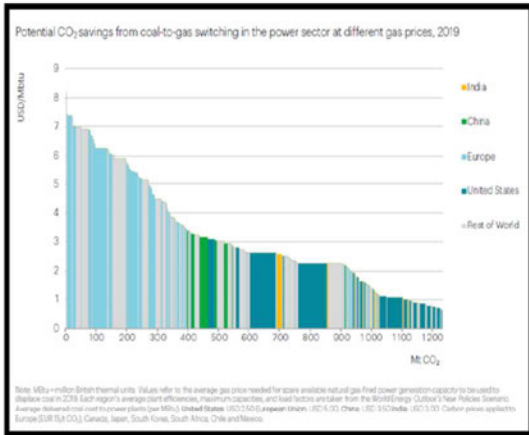


Fig. 31. Potential CO<sub>2</sub> savings from coal-to-gas switching in the power sector at different gas prices, 2019 [25]

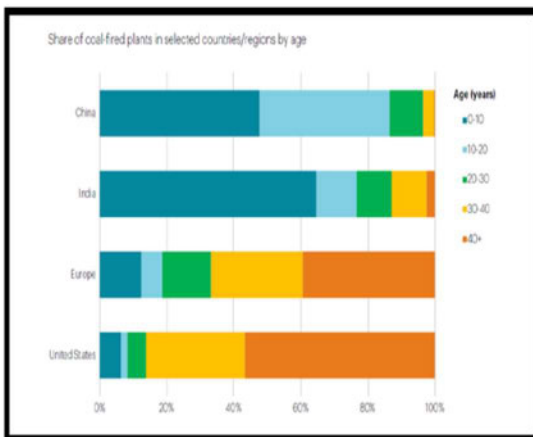


Fig. 32. Share of coal fired plants in selected regions, classification by age [25]

Given the need for decarbonisation efforts to intensify, a role for unabated gas in the energy mix becomes increasingly challenging beyond 2030 [25]. Some countries can use policy instruments and even CO<sub>2</sub> taxes to promote the switch from coal to gas, while other countries may need infrastructure support as well as human capability of building in order to successfully facilitate the transition, especially in developing countries.

Other efforts to decarbonise are occurring in the built environment (construction of infrastructure) where building sustainably reduces overall environmental impact.

### C. Green Star Rated Buildings

Green buildings incorporate design, construction and operational practices that significantly reduce or eliminate the negative impact of development on the environment and people. Green buildings are:

- Energy efficient;
- Resource efficient;
- Environmentally responsible; and
- Healthy and productive environments for people.

In short, a green building approach ensures that whatever the development is, whether office, public building, commercial building, etc. it is built to reduce demand and impact on the environment and health of humans. This means rainwater harvesting, onsite processing of waste into useful products, generation of energy, reducing energy and water consumption, using recycled building materials and materials low in greenhouse gas emissions, better air quality, etc. Fig. 33 is a pictorial representation of a typical green building.

There are over 98 individual and recognised green building councils worldwide whose mission is to abate climate change through green building. The World Green Building Council is an umbrella organisation that gives guidance to the different green building councils, of which the Green Building Council South Africa (GBCSA) is a member, alongside Australia, the USA and the UK among others. Green buildings or environmentally sustainable buildings are already widely adopted globally, with strong growth expected in most countries. Fig. 34 shows the increase in green building activity from findings in a report entitled World Green Building Trends 2018 which reveals that more than 47 % of respondents plan to build more than 60 % of their projects green by 2021. The results in this report are drawn from over 2000 survey respondents in 87 countries spanning 5 continents, with statistically significant results on 19 countries.



Fig. 33. Typical green building features [26]

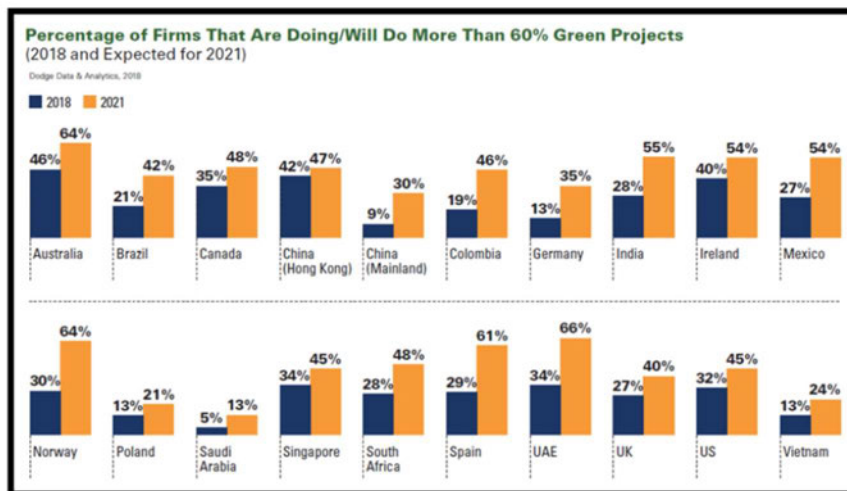


Fig. 34. Anticipated growth in green buildings [27]

South Africa, a developing country, expects to do a significant amount of certification of infrastructure projects, i.e. 48 % of respondents plan to have more than 60 % of their buildings green by 2021. The GBCSA has adopted, adapted, and contextualised the Green Star rating system. Originally

developed by the Green Building Council of Australia, this rating system has been used as a base and has been significantly modified to fit the local market and environmental context. The GBCSA is an independent, non-profit member-based company that was formed in 2007 to lead

the greening of South Africa's commercial property sector. GBCSA provides the tools, training, knowledge, connections and networks, to promote green building practices across the country and build a national movement that aims to change the way the world is built.

The GBCSA started off with the Green Star rating tools for residential, office, public and education buildings, retail developments and existing buildings as well as Green Star rating of interiors of developments. Their tools have extended to rating sustainable precincts, net zero (carbon, water, waste, ecology) rating tools, energy and water performance tools and many more that meet the South African market demand. There have been over 400 green star certifications between 2007 and 2018 in South Africa. As can be seen in Fig. 35, the conceptual market diffusion for net zero energy targets will reach 100 % market saturation by 2030 for new construction.

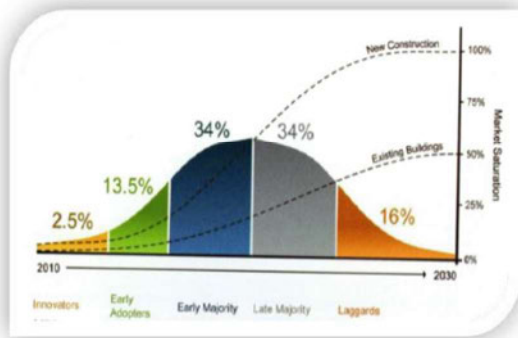


Fig. 35. Conceptual Market diffusion for Zero Net Energy Targets [28]

Fig. 36 shows that the top triggers for green buildings in South Africa are reduced operating costs, healthier buildings and "the right thing to do" which exceeded the global average triggers, whereas the triggers of legislation and client demand seems to be lagging behind the global average triggers. Fig. 37 shows that the payback period for new green buildings is 7 years and for retrofitted green buildings is 5 years (in 2018). The corresponding savings in operational cost in 2018 is 23 % (new buildings) and 22 % (retrofitted buildings) over a five-year period. The top reasons that South Africans selected for going green is reduction in energy consumption and reduction in water consumption, the third reason being protection of natural resources.

The main challenges reported by South Africans with going green is the perceived high initial costs associated with going green which originates from the second challenge of the perception that going green is for high-end projects only and the third challenge is making a business case due to capital and operating expenses being split and the lack of political support and incentives [27].

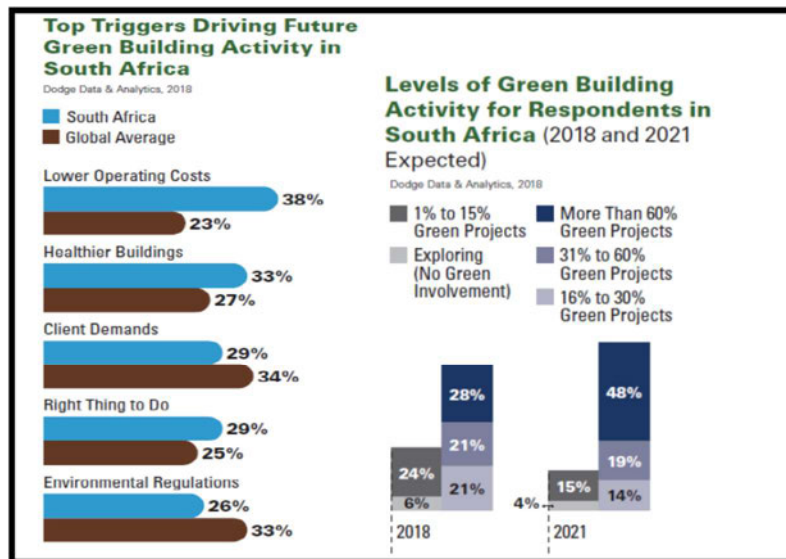


Fig. 36. Green building activity and top triggers for green building activity in South Africa [27]

<b>Expected Business Benefits of Green Building in South Africa</b>				
	<b>New Green Building</b>		<b>Green Retrofit</b>	
	<b>2015</b>	<b>2018</b>	<b>2015</b>	<b>2018</b>
Decreased Operating Costs Over One Year	<b>18%</b>	<b>8%</b>	<b>9%</b>	<b>8%</b>
Decreased Operating Costs Over Five Years	<b>19%</b>	<b>23%</b>	<b>29%</b>	<b>22%</b>
Payback Time for Green Investments (Years)	<b>8</b>	<b>7</b>	<b>6</b>	<b>5</b>

Fig. 37. Benefits of Green Buildings in South Africa [27]

The GBCSA has trained more than 7 000 professionals; however, the growing green building industry is also experiencing challenges. Locally and internationally, research has indicated that there is a widespread perception that green building attracts a cost premium as high as 15 % to 25 % compared to conventional construction. These perceptions hamper the progress of green building.

The GBCSA Cost and Trends report 2019 includes a sample of 91 office buildings owned by 52 companies that were certified from 2015 to 2018. The profile of the combined study population size of 146 projects provides context for the study results which follow. The study population size is made up of 54 projects (37,0 %) certified from 2009 to 2014 and 92 projects (63,0 %) certified from 2015 to 2018. A total of 99 projects (67,8 %) have a 4 Star Green Star certification, 38 projects (26,0 %) have a 5 Star Green Star certification and 9 projects (6,2 %) have a 6 Star Green Star certification. Fig. 38 shows the cost premium of green buildings in the period 2009 to 2018 [2].

Fig. 38 is representative of costs two years ago. A recent study (2020) of going green for an actual project in Airports Company South Africa has been conducted and is included in Table 4. From Table 4, the cost of going for a 4-star green star rating of Terminal 2 in Cape Town International airport (approximately 46 000 m<sup>2</sup> gross construction area to be completed in November 2023) is 0,3 % at R7.2m of the total project budget of R2,4bn and for a 5-star rating 0,61 % at R14,7m. These cost indications are way below the GBCSA study indicated in Fig. 38. These figures include GBCSA certification costs, management and consulting fees, capital and specialist modelling costs for the additional technologies and design features for the green star ratings.

The analysis of the operational cost savings is given together with the additional operational expenditure (OPEX) requirements for the Terminal 2 Development project in Cape Town International Airport (CTIA). Using a simple payback for the 4-star green rating, payback can be achieved within two years, considering the 5-star green rating, simple payback can be achieved in just within four years.

<b>GREEN COST PREMIUM – CONSTRUCTION AREA</b>			
Construction area – Green cost premium (%)	<b>MIN</b>	<b>AVERAGE</b>	<b>MAX</b>
<b>TOTAL</b>	<b>1,1%</b>	<b>3,9%</b>	<b>14,2%</b>
< 5,000 m <sup>2</sup>	3,4%	5,1%	12,2%
< 10,000 m <sup>2</sup>	1,7%	4,0%	14,2%
< 25,000 m <sup>2</sup>	2,7%	5,2%	12,0%
< 50,000 m <sup>2</sup>	1,1%	3,2%	5,0%
> 50,000 m <sup>2</sup>	2,0%	2,4%	3,9%

Fig. 38. The South African cost perspective from GBCSA [29]

TABLE IV. COSTS AND SAVINGS BETWEEN 4-AND 5-STAR GREEN RATING FOR TERMINAL 2 DEVELOPMENT (CTIA)

	4-star green rating	5-star green rating	Salient points
Electricity savings per annum	R4 105 550	R4 935 585	Difference between 4 and 5-star is a Solar PV plant of 500 kWp producing 810 kWh/annum to 185 kWh/annum
Water savings per annum	R 251 972	R 251 972	Air conditioning condensate recovery, rainwater harvesting, low flow toilets and urinals
Sewerage handling savings per annum	R 96 795	R 96 795	Volume of water for flushing of toilets reduced
Total OPEX savings per annum	R4 454 317	R5 284 352	Difference in savings is R 830 035 per annum between a 4-star and 5-star (owing to Solar PV plant)
Capital outlay required	R 7 228 920	R14 728 920	Approximately double the amount capital outlay between a 4-star and 5-star owing to Solar PV plant
Additional OPEX required per annum	R0 (From conventional building to 4-star building)	~R 400 000 (From 4-star to 5-star building)	Calculated using R800 /kW installed of solar PV per annum  Note: no additional OPEX required for 4-star green rating
<p>Both options make financial sense and both options can be considered when it comes to green buildings, the advantages points are as follows:</p> <ul style="list-style-type: none"> <li>• 5-star green rating supports the organizational goal of ACI carbon accreditation and Carbon Neutrality Roadmap stronger than the 4-star green rating for Cape Town International Airport (CTIA).</li> <li>• 5-star green rating gives a larger operational cost saving overall, even if payback takes a little longer than the 4-star green rating.</li> </ul>			

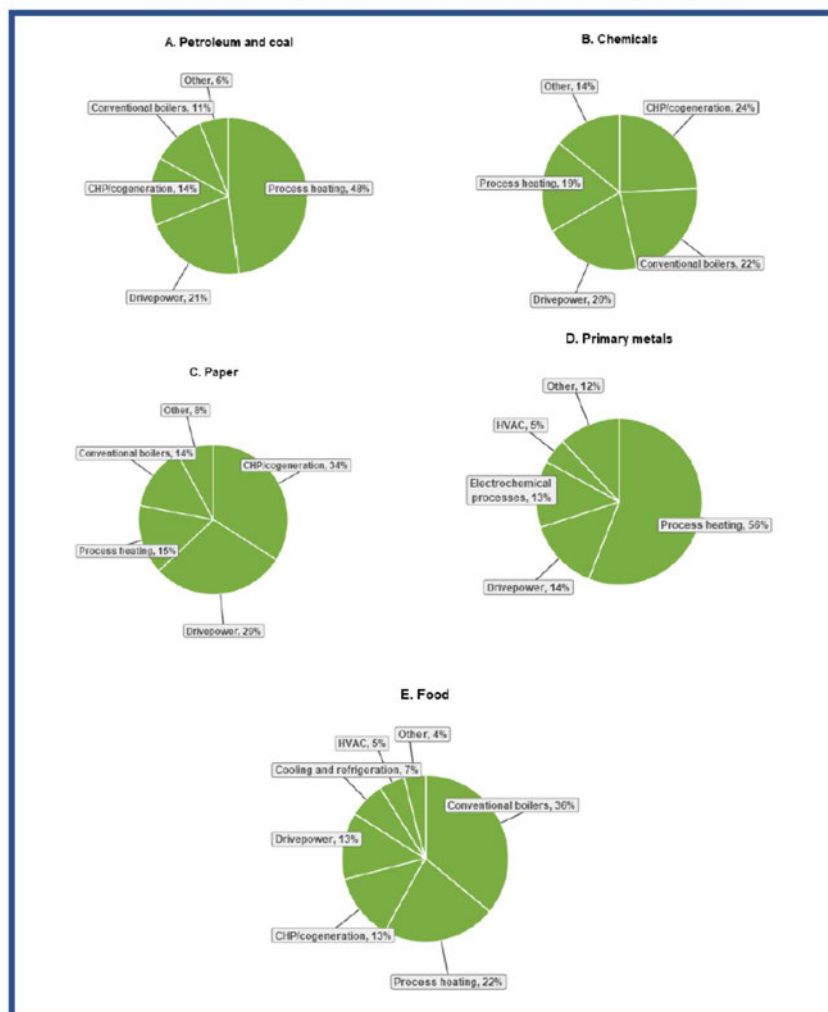
The 4-star green rating model electricity savings involves energy conservation and energy efficiency which is the first "fuel" of developed economies who leverage low hanging fruit with best available technologies and well run engineering building infrastructure as opposed to projects requiring vast amounts of capital outlay, human capability as well as infrastructure capacity to transition energy generation to low carbon (renewable energy), so this makes business sense.

#### D. The Fuel of Energy Efficiency

Energy is commonly used to produce heat that is needed for transformation of raw materials into usable goods. The industrial sector accounts for approximately 31 % of all energy consumption in the USA (consuming just over 21 000 trillion

Btu annually) and much of this energy is used for manufacturing processes. On average, manufacturing facilities use 95.1 kWh of electricity and 536 500 Btu of natural gas per square foot annually, though actual consumption varies widely depending on the subsector.

Fig. 39 shows a breakdown of energy use for the five manufacturing subsectors that consume the most overall energy in the USA. The petroleum and coal subsectors are the largest consumers of energy, accounting for 25 % of the entire manufacturing sector's energy use. The chemicals subsector is second, consuming about 20 % of the sector's energy. The paper subsector accounts for about 10 % of sector energy use, followed by primary metals and food, each of which represent about 5 % of consumption [3].



Notes: CHP = Combined Heat and Power. Sectors shown are in order of total energy use. The "Other" category combines all end uses that consume less than 5% of the overall energy for this sector, including lighting.

Fig. 39. Breakdown of energy use for 5 manufacturing subsectors consuming the most overall energy in the USA [30]

In South Africa, the industrial sector accounted for 52 % of energy consumption in 2016 (Fig. 6). The domestic or residential sector share was 8 %. The typical energy sources for the industrial sector and their industrial sub-sectors can be seen in Fig. 6. The industrial sector is mainly powered by coal (electricity is also primarily from coal sources) and the industrial subsectors of iron and steel, mining and quarrying and the petrochemical industry make up almost half of the energy demand in the industrial sector as seen in Fig. 40 and Fig. 6. The energy use breakdown for the residential sector can be seen in Fig. 41. The rural residential sector primarily uses energy for cooking, water heating and space heating, whereas the middle income-high income residential sector uses energy for a range of different purposes such as pool pump, cool

storage, etc. as captured in Fig. 42.

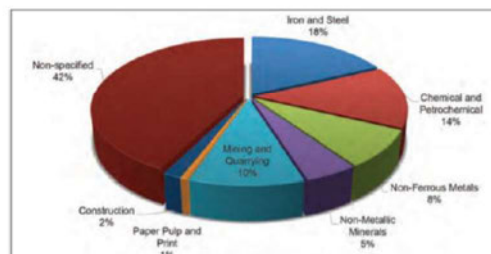


Fig. 40. Energy Demand in the industrial sector, including their subsectors (2016) [31]

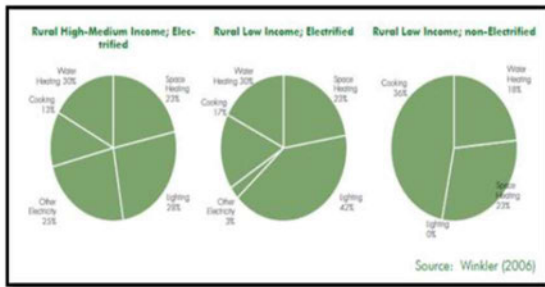


Fig. 41. Rural Residential sector energy use breakdown, 2006 [32]

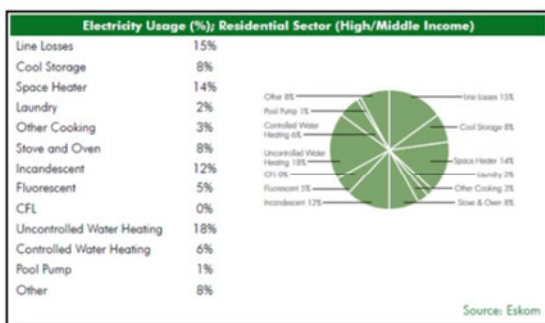


Fig. 42. High/Middle Income Residential Sector energy use breakdown, 2006 [32]

Eskom is South Africa's primary electricity supplier, generating more than 90 % of the electricity in South Africa, and about 40 % of that in Africa [33]. Owned by the South African government, Eskom has been facing demand and supply challenges and investing in energy efficiency to reduce demand has been the focus over the last decade or so. There are many projects funded to reduce electrical energy demand. One of such programmes is the Industrial Energy Efficiency (IEE) Project co-ordinated by the United Nations, funded by various international institutions. The Industrial Energy Efficiency (IEE) Project was established in South Africa in 2010 in response to the need to improve energy efficiency. The United Nations Industrial Development Organization (UNIDO),

along with the Swiss Secretariat for Economic Affairs, the UK Department of International Development and partnered by the Department of Trade and Industry (the DTI) and the Department of Energy (DoE) of South Africa, embarked on a program to address the need for greater energy efficiency.

The UNIDO programme on energy management system implementation (EnMS) combines capacity-building and pilot implementation. It builds understanding, expertise and skills of consultants and enterprises for implementing EnMS in line with ISO 50 001 and provides the expert advisory services needed to ensure implementation [34]. Providing three elements, the EnMS uses an awareness seminar targeted at executive management, user training tailor-made for engineers and operators of energy intensive equipment and systems, as well as an advanced expert level training aimed at the technical specialist or implementer of an ISO 50 001 aligned EnMS within an organisation. This UNIDO programme has an active portfolio across the world and its footprint can be seen in Fig. 43. Since Fig. 43, Durban in South Africa has been an active participant in the UNIDO EnMS programme.



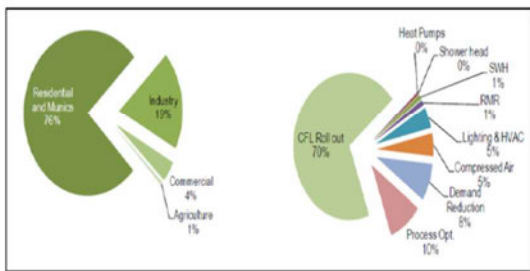
Fig. 43. Overview of UNIDO's EnMS footprint [34]

The programme has since produced results of which five case studies can be seen in Table 5. The first case study is from a hot-rolled coil steel products producer in South Africa (ArcelorMittal Saldanha Works Plant), the second from a milk processing and dairy producing company in Moldova (S.A. Lactis), the third from a petrochemicals company in Egypt (SIDPEC), the fourth from a food processing company using wheat products in Vietnam (Colusa Miliket Foodstuff) and the fifth from an automotive parts producer in Ecuador (INDIMA S.A.).

**TABLE V. CASE STUDIES OF ENERGY EFFICIENCY FROM THE UNIDO ENMS PROGRAMME [34]**

ArcelorMittal Saldanha Works Plant (Energy Efficiency Achievements, 2011-2012) (South Africa)	S.A. Lactis achievements through the implementation of an EnMS, 2011-2012 (Moldova)	SIDPEC achievements through the implementation of an EnMS in 2014 (Egypt)	Colusa Miliket Foodstuff achievements through the implementation of an EnMS in 2012 (Vietnam)	INDIMA S. A. achievements through the implementation of an EnMS in 2014 (Ecuador)
Total number of EnMS measures: 12	Total number of projects: 11	Total number of projects: 6+	Total number of projects: 5	Total number of projects: 3+
Total investment (US\$): 50 000	Total investment (US\$): 6 900	Total investment (US\$): 367 000	Total investment (US\$): No data	Total investment (US\$): 66 500
Gross financial savings in 2011 (US\$): 9 000 000	Gross financial savings (US\$): 22 000	Gross financial savings (US\$): 1 171 000	Gross financial savings (US\$): 46 805	Gross financial savings (US\$): 82 213
Overall payback period (in years): 0.01	Overall payback period (in years): 0.32	Overall payback period (in years): 0.3	Overall payback period (in years): <1	Overall payback period (in years): 0.8
Energy savings for 2011 (GWh): 80	Energy savings for 2011 (MWh): 328	Energy savings in 2014 (MWh): 40 000	Energy savings compared to 2011 (%): 12	Energy savings for 2014 (MWh): 394
GHG emission reduction (tons CO <sub>2</sub> ): 77 222	GHG emission reduction (tons CO <sub>2</sub> ): 160	GHG emission reduction (tons CO <sub>2</sub> ): 53 000	GHG emission reduction (tons CO <sub>2</sub> ): 1 700	GHG emission reduction (tons CO <sub>2</sub> ): TBD

Eskom also ran a few programmes when South Africa’s energy demand exceeded their generation capacity leading to rolling blackouts in the country in 2008. Their Integrated Demand Management (IDM) programmes typically involved incentivizing geyser improvements, solar geysers, heat pumps and replacing incandescent light bulbs with CFLs. According to Eskom, a total of 3,707 MW has been saved since the implementation of their IDM programmes. Fig. 44 shows the breakdown of performed savings per funding model until the end of 2012. The largest savings come from the first mass roll out programme which consisted of distribution of CFL in exchange of incandescent bulbs. A total of 2,137 MW has been saved by replacing over 53 million incandescent bulbs with efficient CFL bulbs. Savings from this programme have contributed to 70 % of all savings claimed by the Eskom IDM unit [35].



**Fig. 44. Energy savings per consumer sector (left) and per technology category (right) [35]**

Energy efficiency since 2008 has been the focus of the South African electricity sector due to the demand and supply dilemma that Eskom has faced which has resulted in rolling blackouts even today. South Africa’s power station fleet has aged with most of them reaching the end of their lifespan or requiring major upgrades. Output of the power plants can dip to as low as 70 % due to inefficiencies and aged infrastructure.

**IV. SOUTH AFRICA’S UNIQUE CHALLENGE**

South Africa has a unique challenge in that demand has increased and the materialisation of required power plants in time for the uptake of new demand as well as to serve as a replacement for the demand served by ageing coal powered plants that have reached the end of their lifespan, has failed. South Africa has the added complication of legislation that protects the monopoly of its energy supplier, Eskom, for both political as well as economic advantage reasons, which prevents the markets, organisations and investors from naturally solving this challenge.

In 1998, just four years after the apartheid regime which practised racial discrimination ended, and the first democratic government was sworn in, the Department of Minerals and Energy released its much awaited White Paper on Energy Policy which contained a broad set of policy objectives, organised under five main themes: increased access to affordable energy services, improving energy governance, stimulating economic development, managing energy related environmental impact, and securing energy supply through diversity. One of the factors that led to the demand and supply gap was the mass electrification of around 3.4 million homes

between 1994 and 2002 that added demand without a responsive energy generation programme that did not just cater for additional demand but also for the declining efficiency of aging power plants and their decommissioning [36]. The current gap in energy supply and demand can be seen in Fig. 45. The supply gap has two scenarios that were analysed by the Council for Scientific and Industrial Research (CSIR). The "business as usual" scenario looks at converting the coal baseload power stations to nuclear energy as per the Integrated Resource Plan (IRP) 2010 with a small component of renewable energy and new coal developments. The second scenario looks at an optimised electricity mix that utilises the sources of coal, nuclear, gas and renewable energy based on the least cost option as per the demand being catered for [37].

Fig. 46 shows how the two scenarios fill the demand gap and one can see that the primary difference between the scenarios is the significant adoption of renewable energy in the second scenario as opposed to coal and nuclear energy in the first scenario. If renewable energy is considered from a cost basis against nuclear and coal, it makes for a competitive business sense. At 2016 values cost savings would be R330 billion between the two scenarios as can be seen in Fig. 47. Fig. 48 provides the R/kWh generated between the two scenarios if a CO<sub>2</sub> tax was legislated as per the draft legislations being circulated. There is an 18 % cost savings between the scenarios and 21 % if CO<sub>2</sub> tax is legislated.

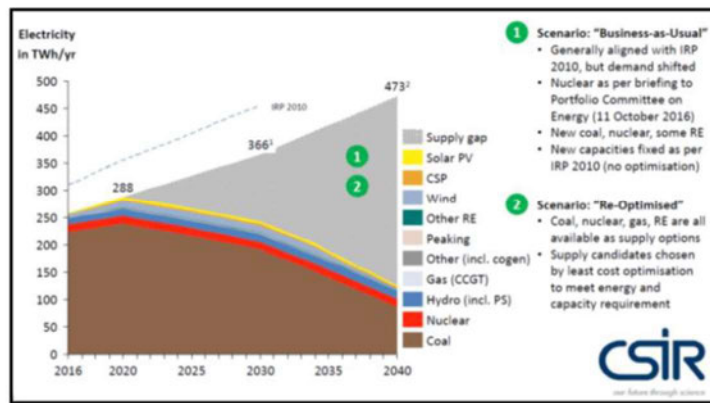


Fig. 45. : Eskom's electricity supply and demand gap and two scenarios for closing this gap [37]

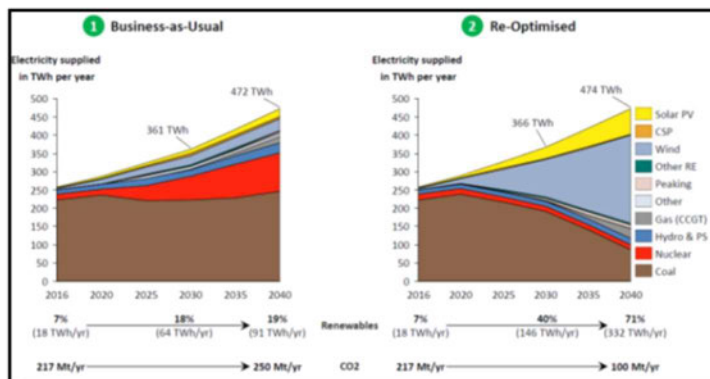


Fig. 46. The two scenarios expanded for meeting the Eskom electricity demand gap [37]

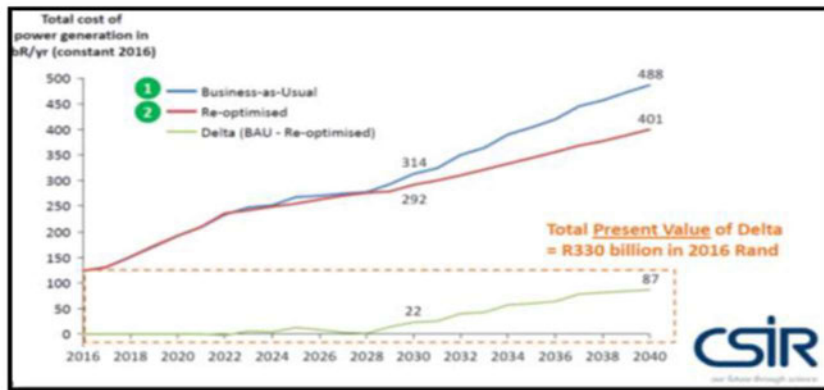


Fig. 47. Cost difference between Scenario 1 and 2 for filling Eskom’s electricity supply gap [37]

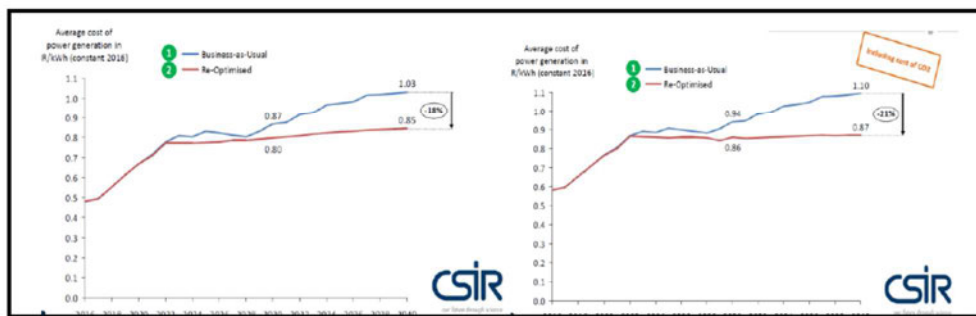


Fig. 48. Cost savings in R/kWh between the two scenarios to satisfy Eskom’s electricity supply gap [37]

The production of electricity being mandated to Eskom in South Africa prevents private development and sale of power generation. The South African government expedited the plan for Eskom to purchase power at competitive rates from the private market for resale to the country, this phase was termed the "Bid Window" where wind power and solar energy (solar PV) were purchased from independent power producers and resold to the country. Fig. 49 shows the impact this bid window made in the context of both scenarios of filling

Eskom’s supply gap. Fig. 50 shows the generation impact in the context of South Africa’s existing electricity generation and Fig. 51 shows the geographical locations of the renewable energy plants and this includes hydropower, biomass, landfill gas and concentrated solar thermal plants (CSP). The geographical location of South Africa gives it an advantage of access to a wide range of renewable energy forms available for electricity generation.

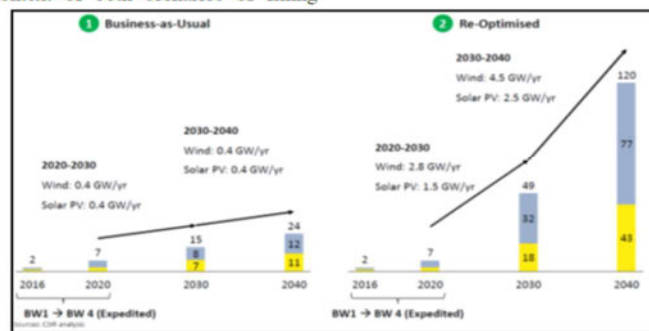


Fig. 49. Eskom’s progress with adopting renewable energy in the context of the two scenarios [37]

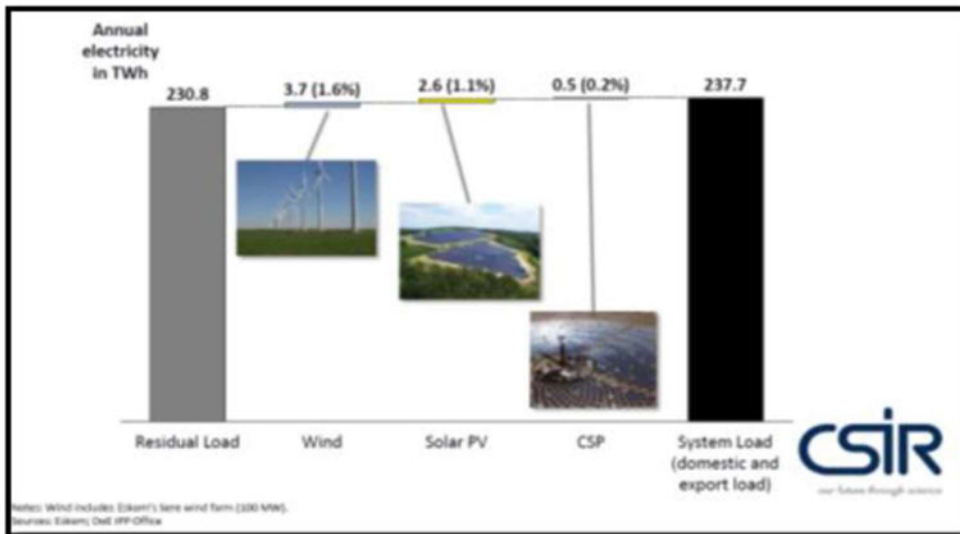


Fig. 50. South Africa's renewable energy installed [37]

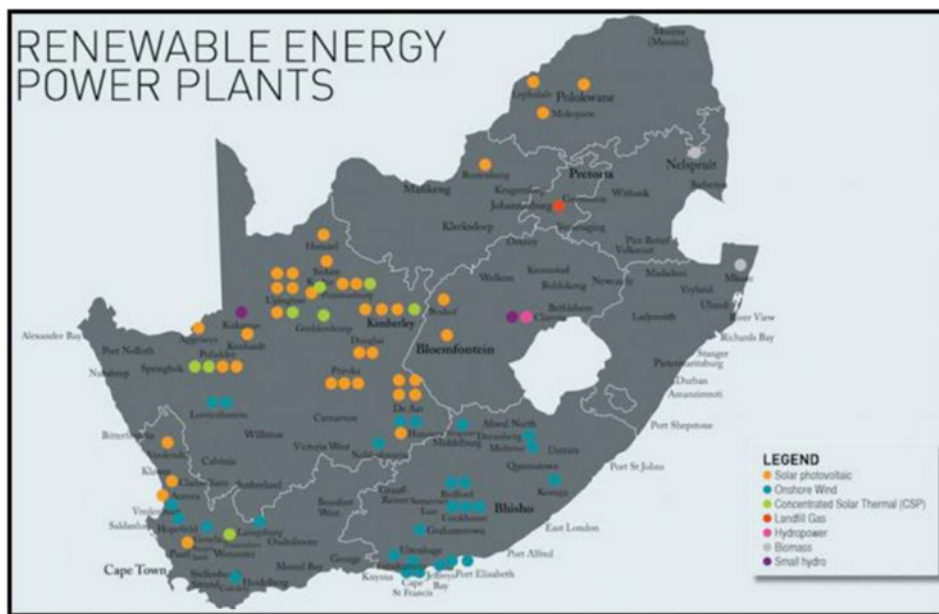


Fig. 51. Geographical location of South Africa's renewable energy plants[38]

The challenge that must be addressed with renewable energy is the capacity factor and the way this plays into the electricity demand profile. At present renewable energy generation

mainly serves the fluctuating load and new load in the South African electricity demand profile (Fig. 52).

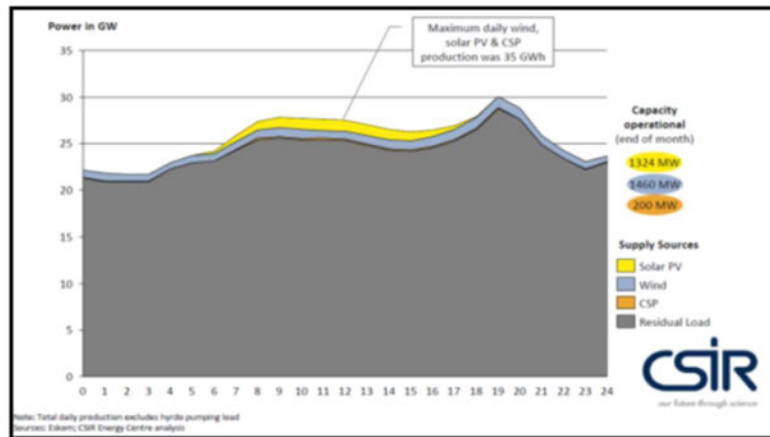


Fig. 52. The installed renewable energy serving the electricity demand within a 24-hour day [37]

Due to the limitation of intermittency due to the nature of renewable energy, the electricity mix is currently designed to incorporate nuclear, coal and natural gas energy sources. In order for Scenario 2 to be realised in South Africa, lots of work remains to be done regarding legislation evolution related to generation entities, the market for energy sources, barriers in relation to the manufacturing sector and capability, and financial barriers.

## V. CONCLUSION

The rise of natural gas has been accompanied by a strong increase in renewable energy over the past two decades as a solution to lower overall carbon emissions, particularly in the power sector, where renewables accounted for 45 % of the growth in power generation in 2018. Renewables now account for around one-quarter of total power generation worldwide, second only to coal (at 38 %). Expanding the use of low-carbon electricity is a major vector for energy transitions. There have been noticeable shifts in individual sectors and countries, but the growth in renewables and gas – alongside steady improvements in energy efficiency – has not yet pushed the consumption of other fuels into decline. Global coal use did fall over 2015 to 2016 but has since bounced back. Oil demand has been robust, rising at an annual rate of well above 1 million barrels per day. In 2011, a World Energy Outlook special report asked whether the world might be poised to enter a "golden age of gas" (Fig. 53). This upside scenario for gas was based on supportive assumptions about gas availability and price, as well as policies on the demand side that could promote its use in certain countries, notably China [25].

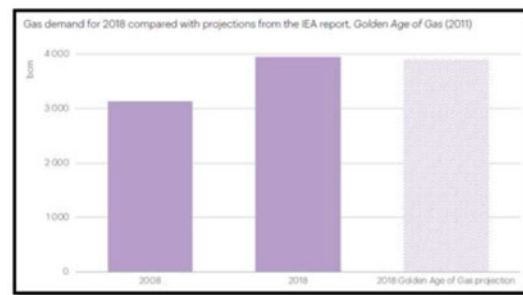


Fig. 53. The golden age of gas reached as per the prediction in 2011 [25]

After three flat years, global energy-related CO<sub>2</sub> emissions resumed growth in 2017 and 2018; annual emissions of more than 33 Gt represent a dangerous disconnect with global climate goals (Fig. 54). This is not good news in the context of climate change. If one observes the energy reserves of fossil fuels throughout the world (Fig. 55, Fig. 56 and Fig. 57), there is enough proved reserves to keep us going for the next two decades only.

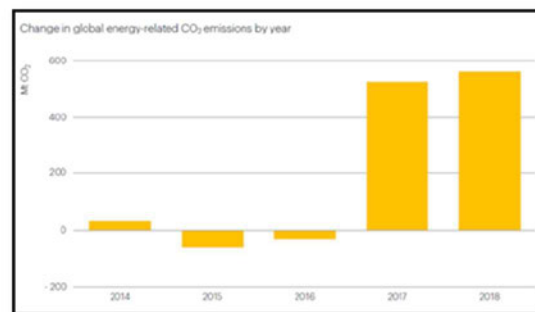


Fig. 54. Change in global energy related CO<sub>2</sub> emissions [25]

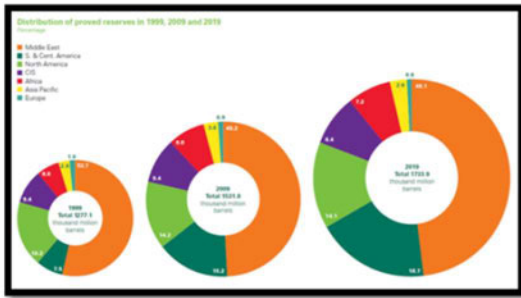


Fig. 55. World distribution of proved crude oil reserves over a 20-year period [39]

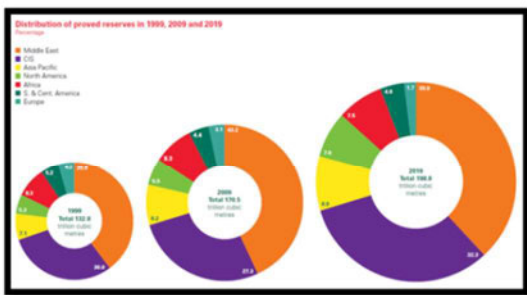


Fig. 56. Distribution of proved natural gas reserves over a 20-year period [39]

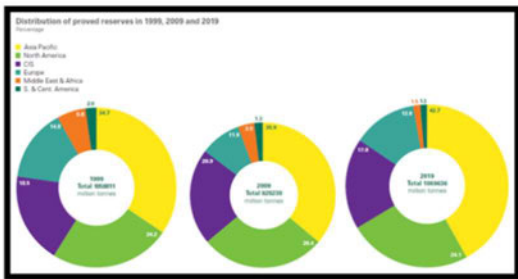


Fig. 57. World distribution of proven coal reserves over a 20-year period [39]

Without restraint or the intervention of climate change policies, a scenario of 4.1 °C to 4.8 °C warming by 2100 relative to preindustrial temperatures is likely (Fig. 58). Should current climate change policies be applied, the projected warming will be 3.1 °C to 3.7 °C and if all countries achieve their current

targets and pledges set within the Paris climate agreement, the average warming will be in the region of 2.6 °C to 3.2 °C by 2100. The impact of global warming above 2 °C can be seen in Fig. 59. The impact will include falls in crop yields; rising sea levels; reduced availability of water; damage to coral reefs; intensified weather patterns and phenomena such as drought, fires, flooding, heat waves; irreversible melting of the Greenland ice sheets; destruction of Amazon forests and many more.

There is a need to consider two scenarios as depicted in Fig. 58, i.e. a consistent 2 °C warming by 2100 and a 1.5 °C consistent warming by 2100.

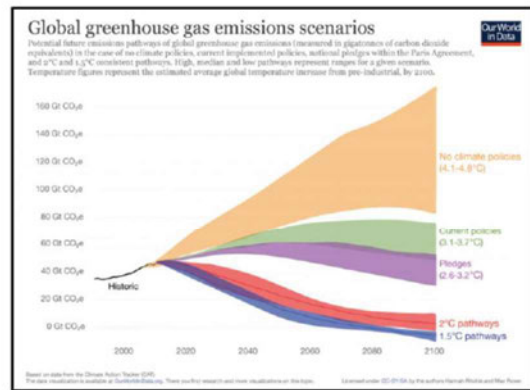


Fig. 58. Global Greenhouse Gas emissions scenarios [12]

The 2 °C consistent warming by way of indication will require a significant increase in ambition of the pledges within the Paris Agreement. To achieve the 1.5 °C consistent warming pathway, there is an urgent need to aggressively and consistently reduce global greenhouse gas emissions. The behaviour highlighted in Fig. 54, where an increase in greenhouse gas emissions (2017 and 2018) after a period of no or little increase in greenhouse gas emissions (2015 and 2016) is observed, cannot be tolerated in the scenarios of the 2 °C and 1.5 °C consistent warming pathways. There is clearly a lack of support for sustaining a reduced carbon emissions design and the need for grounding carbon reduction emissions initiatives within the existing business sustainability mesh of economic, social and environmental constructs such that carbon reduction is consistent and naturally achieved. The 2 °C and 1.5 °C consistent warming pathway scenarios will both require energy efficiency strategies to reduce wastage in energy consumption as well as decarbonising the energy mix generating energy; however, it will need to be achieved naturally, i.e. in the way we do business building and grow our economies.

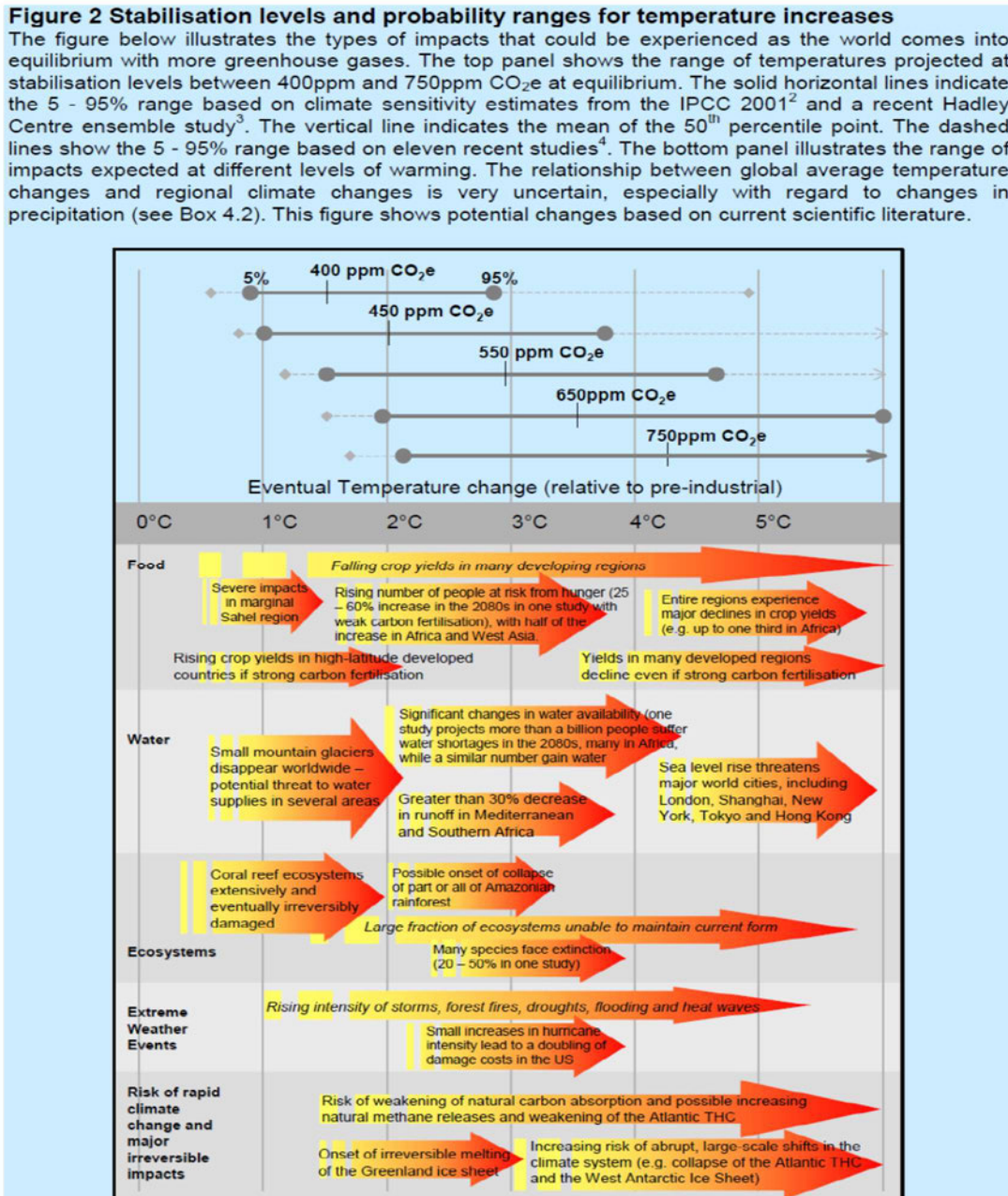


Fig. 59. Adverse effects at various global warming temperature stages [40]

The sustainable solution for ensuring that energy efficiency and energy security has lasting and established penetration in developing countries is the solution that can achieve sustainability in all three spheres of environmental, economic and social constructs. By addressing the priority social concerns and providing an attractive economic alternative, it

will be sustained through changing markets, technologies, legislation, personnel and resource availability [41]. This approach to a sustained reduction in carbon emissions must be investigated so as to develop a design that ensures carbon reduction regardless of the dynamics at play in each country across the globe.

## REFERENCES

- [1] BP Energy Economics, "BP energy outlook 2019 edition," data compilation: Centre for Energy Economics Research and Policy, Heriot-Watt University, 2019.
- [2] US Energy Information Administration (EIA), "Consumption by source and sector", <https://www.eia.gov/totalenergy/data/monthly/index.php>, accessed 12 July 2020.
- [3] Republic of South Africa, "The South African Energy Sector Report 2019", Department of Energy. Pretoria: Government Printer, 2019.
- [4] Our World in Data, <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions>, accessed 12 July 2020.
- [5] Organization of the Petroleum Exporting Countries, "Introduction to the Oil Industry and OPEC." Vienna: OPEC, 2013.
- [6] Investors Gold (IG) Group, "History of Crude Oil", <https://www.ig.com/za/commodities/oil/history-of-crude-oil-price>, accessed 12 July 2020.
- [7] Centre for Energy Economics Research and Policy, Heriot-Watt University, "Statistical Review of World Energy 2020," 69th Edition. London: Pureprint Group, 2020.
- [8] C. Zou, Q. Zhao, G. Zhang, and B. Xiong, "Energy revolution: From a fossil energy era to a new energy era," *Nat. Gas Ind. B*, vol. 3, no. 1, pp. 1-11, 2016.
- [9] W.A. Bakar, R. Ali, "Natural Gas", [https://www.researchgate.net/publication/221909211\\_Natural\\_Gas](https://www.researchgate.net/publication/221909211_Natural_Gas), accessed 13 July 2020, August 2010.
- [10] Constructed with data from International Energy Agency, <https://www.iea.org/data-and-statistics/charts/total-primary-energy-supply-by-fuel-1971-and-2017>, accessed 28 April 2020.
- [11] Wikipedia, [https://en.wikipedia.org/wiki/Developing\\_country#:~:text=Along%20with%20the%20current%20level,a%20specific%20period%20of%20time.&text=Low%20income%20countries%3A%20%241%2C035%20or,income%20countries%3A%20%244%2C046%20to%20%2412%2C535](https://en.wikipedia.org/wiki/Developing_country#:~:text=Along%20with%20the%20current%20level,a%20specific%20period%20of%20time.&text=Low%20income%20countries%3A%20%241%2C035%20or,income%20countries%3A%20%244%2C046%20to%20%2412%2C535), accessed 19 July 2020.
- [12] Our world in data, <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions#annual-co2-emissions>, accessed 28 April 2020.
- [13] D. Gielen, F. Boshell, D. Saygin, M.D. Bazilian, N. Wagner, and R. Gorini, "The role of renewable energy in the global energy transformation," *Energy Strategy Rev.*, vol. 24, pp. 38-50, 2019.
- [14] O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, and C. von Stechow (eds), "Summary for Policymakers. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation". Cambridge: Cambridge University Press, 2011.
- [15] Business Insider Intelligence, <https://www.businessinsider.com/timeline-155-year-history-of-oil-prices-2016-12?IR=T>, accessed 28 April 2020.
- [16] O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, and C. von Stechow (eds), Special Report of the Intergovernmental Panel on Climate Change, "Renewable Energy Sources and Climate Change Mitigation". Cambridge: Cambridge University Press, 2011.
- [17] Our World in Data, <https://ourworldindata.org/renewable-energy>, accessed 25 July 2020.
- [18] O.A.C. Hoes, L.J.J. Meijer, R.J. van der Ent, and N.C. van de Giesen, "Systematic high-resolution assessment of global hydropower potential," *PLOS One*, vol. 12, p. 5, 2017.
- [19] X. Lu, M.B. McElroy, and J. Kiviluoma, "Global potential for wind-generated electricity," *Proc. Natl. Acad. Sci. U.S.A.*, vol. 106, no. 27, pp. 10933-10938, 2009.
- [20] World Bank 2017, Global Solar Atlas 2.0, [https://en.wikipedia.org/wiki/Solar\\_irradiance#/media/File:Global\\_Map\\_of\\_Direct\\_Normal\\_Radiation\\_01.png](https://en.wikipedia.org/wiki/Solar_irradiance#/media/File:Global_Map_of_Direct_Normal_Radiation_01.png), accessed 26 July 2020.
- [21] World Energy Council, Renewable Energy Projects Handbook. London: World Energy Council, 2004, pp 51-59 extract.
- [22] World Energy Council, Renewable Energy Projects Handbook. London: World Energy Council, 2004, pp 67-69 extract.
- [23] World Energy Council, Renewable Energy Projects Handbook London: World Energy Council, 2004, pp 64-66 extract.
- [24] International Energy Agency (IEA), "The Role of Gas in Today's Energy Transitions", Paris: IEA, 2019, p. 2.
- [25] International Energy Agency (IEA), "The Role of Gas in Today's Energy Transitions", Paris: IEA, 2019, pp. 7-93.
- [26] Green Building Council of South Africa, "The Green Building Handbook", South Africa, Volume 5. Cape Town: alive2green, 2012.
- [27] Dodge Data and Analytics, "World green building trends 2018: developing markets accelerate global green growth", Design and Construction Intelligence SmartMarket Report, 2018.
- [28] Green Building Council South Africa, The Green Building Handbook, South Africa, Volume 5. Cape Town: alive2green, 2012.

- [29] Green Building Council of South Africa, Green Building in South Africa: Guide to Costs and Trends. Cape Town: alive2green 2019, p. 22.
- [30] Business Energy Advisor: Manufacturing industries, <https://snopud.bizenergyadvisor.com/article/manufacturing-facilities#toc-0>, accessed 17 May 2020.
- [31] South Africa Department of Energy, "The South African Energy Sector Report 2019", Pretoria: Government Printer, 2019.
- [32] R. Milford, Greenhouse Gas Emission Baselines and Reduction Potentials from Buildings in South Africa. Nairobi: United Nations Environment Programme, 2009.
- [33] Eskom, "Eskom Integrated Annual Report 2019". [www.eskom.co.za](http://www.eskom.co.za), accessed 11 August 2020, March 2019.
- [34] United Nations Industrial Development Organization (UNIDO), The UNIDO Programme on Energy Management System Implementation in Industry. Vienna: UNIDO, 2015.
- [35] Rue du Can, S., Letschert, V., Leventis, G., et al., "Energy Efficiency Country Study: Republic of South Africa." LBNL Report 6365E. Berkeley, CA: Lawrence Berkeley National Laboratory, 2013.
- [36] R. Spalding-Fecher, "Energy and energy policies in South Africa: an overview", NER Quarterly J., vol. 1, no. 1, p. 6, 2002.
- [37] J. Wright, J.T. Bischof-Niemz, J. Calitz, and C. Mushwana, "Least-cost electricity mix for South Africa until 2040." Pretoria: CSIR Energy Centre, 2016.
- [38] Alternative Information & Development Centre, Renewable-Energy-South-Africa-Electricity-Power-Plants, <http://aidc.org.za/renewable-energy-south-africa-electricity-power-plants/>, accessed 12 August 2020.
- [39] Centre for Energy Economics Research and Policy, Heriot-Watt University, Statistical Review of World Energy 2020, 69th Edition, London: Pureprint Group, 2020.
- [40] N. Stern, and M. Jacobs, Stern Review on the Economics of Climate Change. London: Government of the United Kingdom, 2006.
- [41] F.L. Inambao and J.S. Joseph, "Sustainability: The big challenge." Int. J. Eng. Res. Technol., International Research Publication House. <http://www.irphouse.com> (Accepted for publication).

## **CHAPTER 4. BARRIERS TO SUSTAINING ENERGY EFFICIENCY AND ENERGY SECURITY IN DEVELOPING COUNTRIES**

This chapter presents an investigation into the barriers to energy efficiency and energy security in developing countries, contextualising their origins and outlining the required focus to overcome the barriers.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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<http://www.tjprc.org/view-archives.php>

## BARRIERS TO SUSTAINING ENERGY EFFICIENCY AND ENERGY SECURITY IN DEVELOPING COUNTRIES

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### ABSTRACT

*The uptake and investment in renewable and other less carbon intensive energy sources including the impact of energy efficiency have not shown the required consistency to transform our carbon-intensive energy generation to mitigate climate change. This lack of consistency is due to climate change efforts having to work through multiple barriers in various dimensions of our created economic world with its political and social dynamics. Some climate change efforts overcome these barriers and some efforts are not being realised due to their inability to move past the barriers. These barriers exist in greater measure for developing economies of the world than in developed economies largely due to the dynamics of the political, technological and financial dimensions. Understanding the origins of these barriers is necessary to understand the current barriers well enough to find ways to overcome them. This paper investigates the barriers to energy efficiency and energy security in developing countries, contextualising their origins and outlining the required focus to overcome the barriers.*

**KEYWORDS:** *Barriers to Energy Efficiency; Barriers to Energy Security in Developing Countries; Policy and Regulatory Barriers to Energy Efficiency and Energy Security; Technical Barriers to Climate Change in Developing Countries & Financial Barriers to Climate Change*

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### 1. INTRODUCTION

As climate change adaptation moves from theory to practice, barriers may make it difficult for individuals, businesses and governments to plan and implement adaptation actions. Addressing these barriers is critical to advancing climate compatible development. Adaptation refers to actions to prepare for, or reduce the harm from, the effects of climate change. It involves a wide range of measures undertaken by multiple actors and at differential spatial levels, including subnational, national and regional levels. Planned adaptation is important for future economic development, especially for developing countries, where adaptation strategies need to be built into emerging development paths, given the current momentum of rapid growth, investment and urbanisation [1].

Energy management is widely recognised as a primary means to overcome barriers to energy efficiency. Research shows that the adoption of energy management practices in industries may save up to 40 % of the total energy used, half being derived from energy management practices and half from investments in energy-efficient technologies. Energy services is a relatively new term that refers to contractual arrangements that aim to measurably improve energy efficiency. Apart from energy audits, an energy service company (ESCO) can offer financial support in the investments in new technology, as well as additional services, e.g., support in managing the intervention within the plant and providing information about existing opportunities. Energy performance contracting (EPC) and third-party financing (TPF), as well as energy audits, are key means, according to the

European Commission, to improve energy efficiency in the economy. Energy services have been mentioned both in academic literature and in political directives as a tool to overcome many of the barriers to energy efficiency in organisations whose core business is not related to energy. Consulting an ESCO is a way for organisations to out-source energy management [2].

ESCOs help in overcoming informational and financial barriers since an ESCO's core business is energy management, and their services require them to stay well informed about technical and economic energy management solutions. Since ESCOs are specialised in energy savings they have the advantage of economies of scale and making use of their knowledge multiple times, thus reducing the costs for knowledge assimilation per kWh of improved energy efficiency. TPF helps to overcome capital shortages. Energy services are provided in performance-based contracts, which also reduces the risk since the ESCO shares the project risk. However, consulting an external party to manage something as complex as an industrial energy system also implies transaction costs. What an ESCO gains in scale advantage and reduced risk must be compensated for by the extra costs generated from transferring some or all of the responsibility for energy management to an external party. Since transaction costs are not necessarily related to the size of the contract, this results in complex energy services being more profitable in large contracts [2].

A case study on driving forces for improved energy efficiency in the foundry industries in Finland, France, Germany, Italy, Poland, Spain, and Sweden found that in at least 50 out of the 65 investigated foundries, the primary drivers were rising energy prices, cost reductions resulting from lowered energy use, commitment from top management, energy and emission taxes, people with real ambition, a long-term energy strategy, and international [2].

The services that ESCOs offer in most developed countries are not easy to find in developing countries. Even rarer to find is expertise in alternative energy such as natural gas power plants which have about 50 % of the carbon footprint of traditional coal-fired power plants and renewable energy such as solar PV, solar thermal energy, geothermal energy, wind energy, ocean energy, hydro energy, etc. The lack of expertise and familiarity with these technologies form barriers to their adoption. Developing countries face another barrier in the financial dimension in that the necessary capital required to transition towards energy efficient technologies, alternate and renewable energy technologies is not available. The capital funds that most developing countries have are locked in social development such as health infrastructure, education and its platforms, food and the agricultural industry and government efforts are locked into the lowest first cost initiatives.

Traditional fossil fuel energy and its technologies are established market technologies that are mature and thus can be secured at competitive prices. The technology maturity has also allowed the operations and maintenance skills to proliferate, with experience of operating and maintaining the technologies being preserved. This provides a platform that is affordable, reliable and familiar with fossil fuel intensive energy sources, making the transition to cleaner energy sources more difficult. The following sections describe the origin of the barriers that developing countries face in the journey of transitioning towards energy efficiency and energy security, followed by a focus on the specific barriers in the political, technological and financial dimensions and the focus required to overcome these barriers.

## **2. THE ORIGIN OF ALL BARRIERS TO ENERGY EFFICIENCY AND ENERGY SECURITY IN DEVELOPING COUNTRIES**

“The heart of sustainable development and business sustainability requires sustainability in each dimension of economic,

social and environmental factors to merge on common ground and operate in the 'sustainable' zone." [3]. These three dimensions of sustainability work with each other to satisfy human needs (Fig. 1). The social dimension encapsulates the way in which humans relate to each other, the natural environment and the various interactions required for the fulfilment of their needs and wants in the created financial economy. "A social construction is built around serving human needs and wants and these are characterised in Maslow's hierarchy of needs." [3]. This social construction is the origin of the regulations, policies, legislation and political frameworks. "Social sustainability can be described as equity in resource distribution, which, from a livelihood perspective, is regarded as the capacity of the human species not only to get access to but also to maintain an adequate and decent livelihood." [3]. Resource distribution and access is regulated through the economy. "Production is the heart of the economy which is the manufacture of goods and enabling of services. There are four factors that make production possible, i.e. capital, land, labour and entrepreneurship. These factors give the ability to satisfy needs and start the circulation of income (enable trade)." [3]. With time, the created economy, in turn, has an impact on the social dimension as well as the natural environment, making the dimensions represented by Fig. 1 intrinsically dependant on each other. The use of natural environmental resources (environmental dimension) requires building human capability (social dimension) as well as capital accumulation (economic dimension) for the fulfilment of human needs.

"Each country can be seen as having natural resources and skilled personnel which can be used to build their economy. The economic factors in a country include accessibility of natural resources, energy and energy resources, capital accumulation, technological resources, available labour force, transportation and communications, education and training." [3] Each country is endowed differently in terms of its natural resources and this characteristic has led to the history of colonisation and the use of forced rule over certain countries to get control over their natural endowments and geographical location for trade routes and enabling markets. The political framework that each country in the world finds itself in has been shaped through times of war largely due to the battle for economic security.

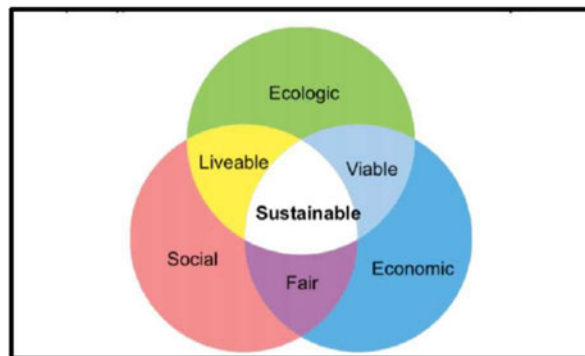
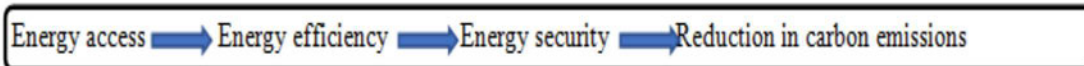


Figure 1: Business Sustainability Mesh [4].

The governments or ruling entities of a country play a key role in shaping the economy, including making choices for trade and investment markets and having in place agreements with other countries for imports and exports which have a knock-on effect resulting in financial investment being made for education and training programmes, manufacturing and other infrastructure, etc. in the line of technologies they wish to promote and proliferate. The government or ruling entities regulate these through various strategies, legislation, policies and frameworks. The barriers that climate change face are based on and related to the economic competition posed by current matured solutions in the commercial market. The overcoming of these barriers to allow for climate change considerations in technology take time depending on the nature of

the existing market as well as the dynamics of the factors supporting it such as the technology lifespan, labour market, price, reliability, etc. Some changes fail in penetrating the market to the intended level or taking over competition as legislation, policies, government strategies and foreign investment protect and support the existing markets and may even directly stop any developments that support climate change mitigation. This is evident in the long reign of Eskom, South Africa's energy service provider which is a monopoly; their investment in renewable energy is largely through invitation to private companies and investors and this limited in installed capacity. When Eskom failed to bring in more capacity to support the country's growing electricity demand, the government adjusted policies to allow certain businesses and domestic households to produce their own renewable energy, only up to a specific installed capacity, limiting the proliferation of renewable energy throughout the country.

This implies that technological changes necessary to mitigate climate change and preserve human life need assistance to overcome market and other dynamics. In the context of technologies and changes necessary for energy efficiency and energy security in the face of climate change, there are unique barriers in developing economies of the world. In developed economies, the need for energy access, the benefits of energy efficiency and in many cases energy security have already been satisfied prior to the dilemma of climate change becoming urgent, thus the change to reduction in carbon emissions will mean taking one step according to Fig. 2. For developing economies where most of the country is yet to be electrified, this means making a leap from a focus on energy access to a focus on reduction in carbon emissions (Fig. 2).



**Figure 2: Energy Efficiency and Energy Security Value Chain in the Context of Climate Change.**

It may be argued that developed countries will have a harder journey transitioning to reduction in carbon emissions due to their energy generation technology base being already in place and developing countries who largely do not have their energy generation in place will have the opportunity to “leapfrog” into a reduced carbon emissions energy generation base. This may be true from the perspective of infrastructure establishment where existing carbon-intensive energy generators will have to “run their course” to be replaced in developed countries and developing countries will not have to face this problem giving them an advantage to realise low carbon energy generation sooner. What developed economies have gained through the journey of energy efficiency and energy security places them in a better financial and political position having developed human resource capacity to realise the transition to low-carbon energy generation. Developing energy security before the climate change dilemma emerged meant diversification of the energy generation base, which developed countries have managed to do effectively, meaning that they have gained the experience required for incorporating multiple energy sources.

The uniqueness of barriers faced by developing countries are due to the journey that they must take to achieve both energy efficiency and energy security in reducing carbon emissions while satisfying energy access. The barriers associated with achieving energy efficiency and energy security in developing countries are presented in this paper and classified according to the three main categories of barriers (Fig. 3).

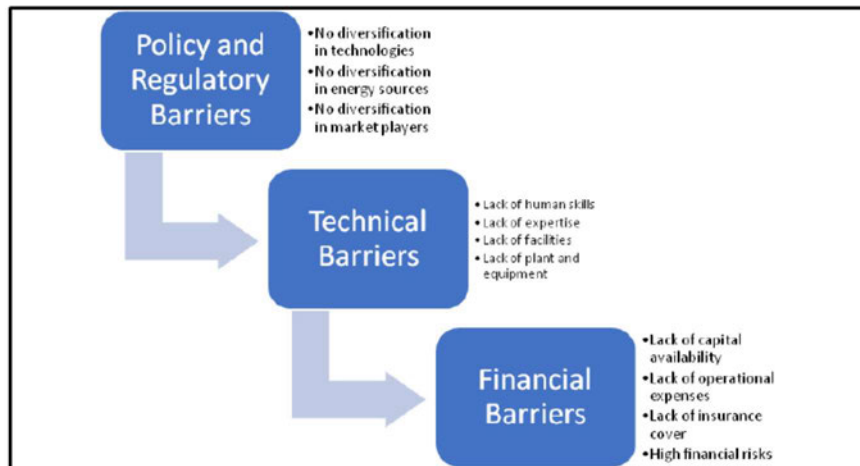


Figure 3: Categories of Barriers to Energy Efficiency and Energy Security.

Most of the barriers originate from the role of the government to ensure safe and good living conditions for citizens using regulation where “Policy and Regulatory Barriers” will be faced, stimulation of technology changes where “Technical Barriers” are faced, and circulation of money where “Financial Barriers” are faced.

### 3. POLICY AND REGULATORY BARRIERS

Consistent and accessible information and the capacity to apply it is essential for effective adaptation [5]. Information barriers are associated with the development, useability of and access to information, data and knowledge [6]. Access to reliable and usable information is key to its integration into policy and regulations. Governance and policy barriers are associated with policy, processes and their level of integration and collaboration on cross-cutting and multi-scaled adaptation planning [6]. Organisational and institutional barriers are within the structures, processes and behaviours of society and organisations that limit the agility and viability of adaptation plans and implementation success [6]. Psychological factors influence our ability to act on information about climate change, including our perception of how urgent adaptation is [5]. Psychological and social barriers are associated with cognitive ability, denial, cultural and behaviour norms of individuals and collective organisations that limit awareness or willingness to act on adaptation measures [6].

Our knowledge of human impacts and their effects on the climate of our planet is progressive which can serve to undermine the information already uncovered. Many times in the history of scientific research, the understanding seemingly established by certain information could be changed by uncovering new information. Added to this is the effects of climate change being gradual relative to the everyday poverty, hunger, economic challenges and crime we experience on a daily basis, therefore the challenge of climate change is not perceived as urgent enough for governments to expend effort and investment into climate change mitigation. Even though the number of papers published on climate change have been increasing since the turn of the century (Fig. 4), awareness of these issues still needs to penetrate into the social, economic and built environment (Fig. 5). Only 5 % of these papers relate to energy, with most relating to environmental science (25 %) followed by earth and planetary science (22 %), agricultural and biological sciences (16 %), social science (8 %), engineering (5 %), and economics (2 %).

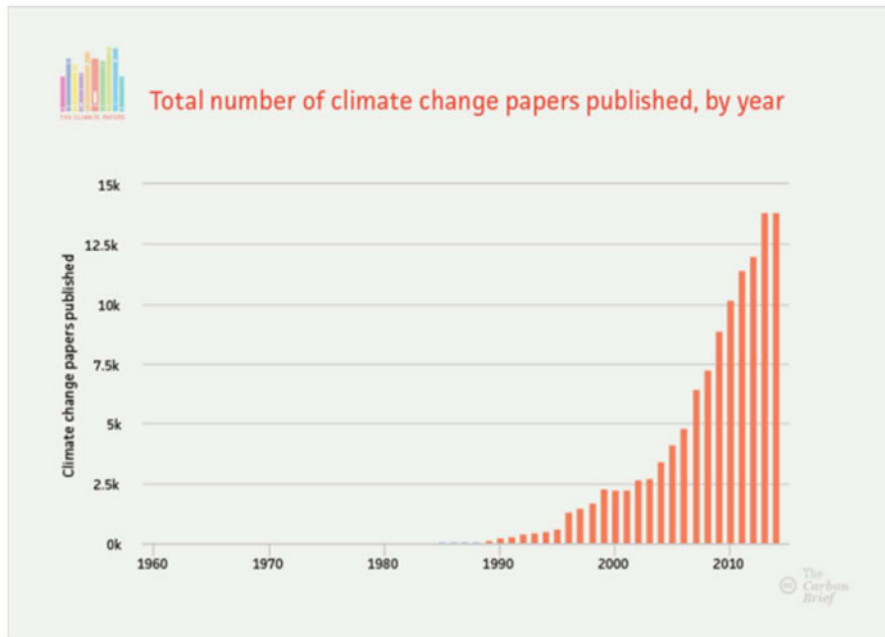


Figure 4: Total Number of Climate Change Papers Published, by Year [7].

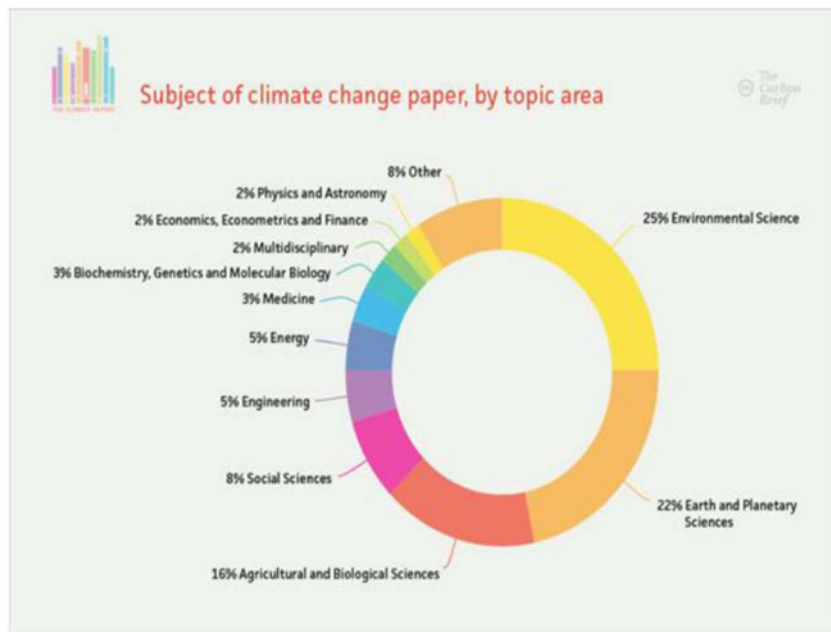


Figure 5: Subject of Climate Change Papers, by Topic Area [7].

When there is an urgency about the threat of climate change, like the urgency that changed the lives of all people of the world when the COVID-19 pandemic hit the world towards the end of 2019, then sustained efforts are seen. Only when people in government are convinced that climate change is a real threat will policies and action be implemented for its mitigation. Government policies and regulations usually protect a country’s interests and are meant to influence and control economic activity in a specific way, and influence social perceptions and behaviour in a way that protects people

adaptation. Adaptation is associated with an additional challenge since people generally find it difficult to make trade-offs across time and between options with uncertain benefits. This includes 'time inconsistency' between the short-and long-term decisions. It is also clear that when people make choices, their current reference point matters; notably, people dislike losing goods more than they like gaining them (this is termed 'loss aversion'). At the organisational level, this also makes it difficult to implement reforms and policy changes that transfer resources from one interested group to another, even if it will lead to overall societal gains" [1].

Two of the institutional barriers faced by the United Nations Industrial Development Organization's (UNIDO's) Industrial Energy Efficiency (IEE) project is the mindset of managers whose thinking is that a focus on energy efficiency costs money and time, and the mindset of plant managers who, even though agreeing with energy efficiency, will not give effect to plant adjustments for more efficient running for fear of losing their jobs because of the many years they have run the plant inefficiently. Some managers who initially agree on climate change mitigation may turn their efforts to fight it purely because it does not bring the desired acknowledgement or advantage to themselves or their allies. These are complex psychological barriers that play out in institutional environments at all levels which suffocate efforts towards climate change mitigation.

Resource barriers relate to implementing adaptation due to the development or deployment of financial, technological, human or informational resources [6]. If South Africa has to change all its policies tomorrow, with all the finances and infrastructure in place to implement renewable and alternative energy, it still does not have the technical capacity in terms of human skills and expertise in the magnitude needed to design, operate and maintain alternative and renewable energy technologies.

#### **4. TECHNICAL BARRIERS**

Technical barriers to realising energy efficiency and energy security in developing countries start with settling for a few selected matured technologies (Fig. 6) and benefitting from their competitively low cost. While this is important for mass development, it can be a limiting factor for exploiting the market for developing technologies that are important for progress. It makes for a rigid structure of sticking to well-known commercially available technologies mostly with manufacturing and designs being owned by parties in foreign countries and or funded by foreign investment. This forms a 'safe zone' in established and matured markets and any new technologies create anxiety that comes with unfamiliarity. This practice has also created a culture of separation and disconnect between the academic and research institutions and technology development.

Education and training are usually aligned to support the endeavours of a country and its commercial market demand. Educational programmes and training are usually based on a market pull. In most cases where the cost of technologies means everything to an investment that looks for lowest first costs, the market pull will always win over any attempt to establish different technologies. However, when looking at climate change mitigation and renewable energy technologies, most commonly this needs to be done through a technology push, aided with policies and legislation to support it. The "technology push" approach attempts to interest the market in new products based on new solutions. The technology cycle can be seen in Fig. 7.

Estimate Rating	Description
Mature	Significant commercial experience (several operating commercial units)
Commercial	Nascent commercial experience
Demonstration	Concept verified by integrated demonstration unit
Pilot	Concept verified by small pilot facility
Laboratory	Concept verified by laboratory studies and initial hardware development
Idea	No system hardware development

Figure 6: Technology Development Description [9].

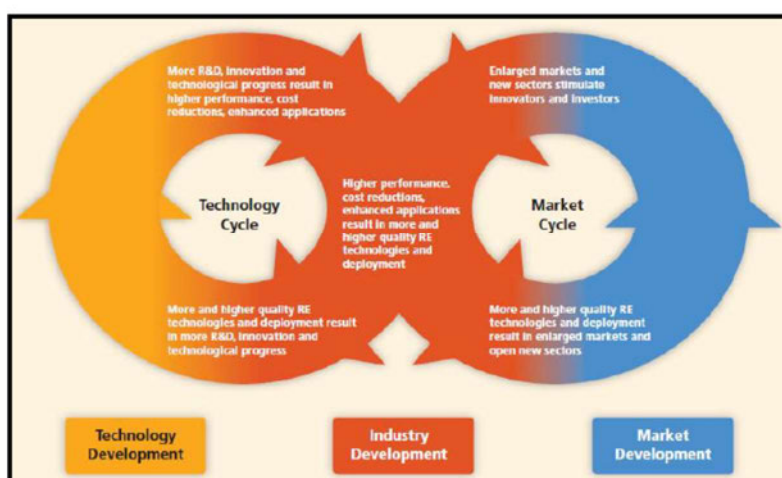


Figure 7: The Mutually Reinforcing Cycles of Technology Development and Market Deployment Drive down Technology costs [10].

Cycles of technology development, industry development and market development usually occur in developed countries first. This means that the learnings and skills associated with the cycles are also mainly in developed countries. Thus, market exploitation of the technologies, manufacturing plants and equipment, their operations and maintenance markets are located in developed countries. The developing countries buy technologies and services from developed countries, and it could be decades until a plant is established in a developing country, and even then, the designs and patents will be held within the developed countries. Therefore, developing countries will always lag developed countries in the technology cycle.

It takes even longer for skills and expertise to transfer to the local communities in developing countries. Most educational programmes and training revolve around the learnings and unique experiences of developed countries where the technologies were established. Thus many technologies when introduced into another country have to live for a few life cycles before their designs capture local design modifications for suitability to the operating environment. This knowledge is also vested in the developed countries research and development experience such that they know more about the operating conditions of a developing country than the developing country knows about its own surroundings. Research and development, tertiary education institutions and the commercial markets are closely linked and have a relationship allowing them to grow their technology and plant base, while this is notably absent in many developing countries.

The disconnect in developing countries between the tertiary education sector and commercial markets undervalues research and development. An investor (including local investors) would choose to invest in something developed by or in development in a developed country rather than to build from scratch their own technology in their own country. This undermining of local talent and regard for tertiary education is deep, to the extent that, for simple things like energy efficiency practices of established technologies, it often takes foreign programmes with foreign consultants to kick-start an industrial energy efficiency programme (UNIDO's Industrial Energy Efficiency Project), while these could have easily been identified with current established engineering programmes and degrees which South African graduates possess.

The lack of capturing institutional knowledge and learnings on existing engineering systems also contributes to the technology barrier to achieving energy efficiency and energy security in developing countries. When electricity is needed, efforts to investigate various energy sources available and energy generation technologies and performing a technical assessment to decide which technology option is best for the site, is a rare occurrence in developing countries. The practice is to have a default energy source and energy generation technology for supplying energy needs.

It is very important to note that every technology type is based on basic engineering and scientific principles which, if applied, can lead to locally designed technologies suited to the operating environment where skills are locally grown. For new technologies to emerge, sound investigations need to be conducted, and for local people to be committed to all phases of the project to ensure that skills and knowledge transfer is facilitated. This may require capital outlay for investment into small scale test projects and pilot plants, field investigations and design cost for scale up projects.

## **5. FINANCIAL BARRIERS**

Certain developing countries do not have the finance or resources to spend whether it is for food security or for climate change mitigation. However, there are developing countries that have finances, but these are tied up in other commitments and priorities. The financial barriers faced by developing countries are two-fold, in that there is a limitation of funds and there is an inefficient allocation of funds which neglects facilitation of innovation, proper investigation and consideration of the bigger picture.

A notable pattern is that developing countries tend to "follow" developed countries when it comes to policy, legislation, commercial markets and technology. This is good in the context of avoiding "reinvention of the wheel", avoiding risk and costly development investment, but also means that developing countries lose out on mobilising profits associated with new technologies. This thinking has led to and widens the gap between the wealth of developed countries and developing countries. Many raw materials exported to developed countries (from developing countries) find financial returns in processed goods from sales to developing countries.

Economic activity is founded upon demand for goods or services. Developing countries find themselves in challenging positions where satisfying their countries' demand for goods and services relies heavily on developed countries. Figure 8 shows the imported and local content for various technologies, materials and labour.

Technology	Imported	Local	Materials (Local)	Labor (Local)
PC	35%	65%	50%	50%
Integrated Gasification Combined Cycle	35%	65%	60%	40%
FBC	35%	65%	50%	50%
Nuclear	35%	65%	60%	40%
CCGT	35%	65%	60%	40%
OCGT	35%	65%	85%	15%
Wind	70%	30%	75%	25%
Solar Thermal	50%	50%	45%	55%
Solar PV	70%	30%	60%	40%
Biomass	35%	65%	50%	50%

Figure 8: Local and Imported Content for Technologies in South Africa [9].

Renewable energy is still significantly reliant on imported content, yet it is needed not just for climate change mitigation, but for additional capacity to satisfy South Africa's growing energy demand. It is key that investment is made in renewable and alternative clean energy education, training, manufacturing, research and development. Also important is that the true cost of coal fired power station electricity generation which includes the mining of coal and its logistics should be used when comparing it to renewable and alternative energy sources electricity generation.

There is a culture in developing countries, especially in state-owned and controlled entities where sound economic analysis that includes quantifiable expenses and benefits over the economic lifespan of the targeted technology is not considered nor are they traded off against a variety of options.

Ensuring that economic models are attempted for each investment is crucial to making the most efficient and effective investment decision. Many times, perceptions and opinions are followed rather than sound scientific investigation and financial modelling providing the best solution.

## 6. THE FOCUS REQUIRED TO OVERCOME THE BARRIERS

The focus to overcome barriers to energy efficiency and energy security in developing countries may be different based on specific challenges experienced by the country and its institutions. Fig. 9 shows the key characteristics of the five shared socio-economic pathways for climate change adaptation and mitigation. From the characteristics given, many countries can be associated with these scenarios. The developing countries are usually in the bottom right hand corner (SSP4) while the developed economies (SSP5) are in the top left hand corner with transitioning economies (SSP2) in the middle. The desired pathway is to be in is SSP1, at the bottom left hand corner.

Socio-Economic Challenges to Mitigation	Socio-Economic Challenges to Adaptation		
	Low	Medium	High
High	<b>SSP5: Fossil-fuelled development</b> <ul style="list-style-type: none"> <li>• low population</li> <li>• very high economic growth per capita</li> <li>• high human development</li> <li>• high technological progress</li> <li>• ample fossil fuel resources</li> <li>• very resource intensive lifestyles</li> <li>• high energy and food demand per capita</li> <li>• economic convergence and global cooperation</li> </ul>		<b>SSP3: Regional rivalry</b> <ul style="list-style-type: none"> <li>• high population</li> <li>• low economic growth per capita</li> <li>• low human development</li> <li>• low technological progress</li> <li>• resource-intensive lifestyles</li> <li>• resource-constrained energy and food demand per capita</li> <li>• focus on regional food and energy security</li> <li>• regionalization and lack of global cooperation</li> </ul>
Medium		<b>SSP2: Middle of the road</b> <ul style="list-style-type: none"> <li>• medium population</li> <li>• medium and uneven economic growth</li> <li>• medium and uneven human development</li> <li>• medium and uneven technological progress</li> <li>• resource-intensive lifestyles</li> <li>• medium and uneven energy and food demand per capita</li> <li>• limited global cooperation and economic convergence</li> </ul>	
Low	<b>SSP1: Sustainable development</b> <ul style="list-style-type: none"> <li>• low population</li> <li>• high economic growth per capita</li> <li>• high human development</li> <li>• high technological progress</li> <li>• environmentally oriented technological and behavioural change</li> <li>• resource-efficient lifestyles</li> <li>• low energy and food demand per capita</li> <li>• economic convergence and global cooperation</li> </ul>		<b>SSP4: Inequality</b> <ul style="list-style-type: none"> <li>• Medium to high population</li> <li>• Unequal low to medium economic growth per capita</li> <li>• Unequal low to medium human development</li> <li>• unequal technological progress: high in globalized high-tech sectors, slow in domestic sectors</li> <li>• unequal lifestyles and energy /food consumption: resource intensity depending on income</li> <li>• Globally connected elite, disconnected domestic work forces</li> </ul>

Figure 9: Key Characteristics of the Five Shared Socio-Economic Pathways [11].

The desired pathway (SSP1) for sustainable development highlights technological progress, economic growth and human development as key characteristics, and low energy demand and resource-efficient lifestyles are included as ingredients. This implies a complete shift of lifestyle, thinking, and creation of wealth that is in harmony with the natural environment. If one looks at the current renewable energy policies and barriers (Table 1), it can be seen that much work has been identified and done to remove barriers to renewable energy adoption. Nonetheless, this does not give an indication of the creation of an economy that is in harmony with the natural environment.

Table 1: Summary of Renewable Energy Policies and Barriers [12]

	Policies	Description	Key Barriers Addressed
Renewable energy promotion policies	Price-setting and quantity forcing policies	Mandates prices to be paid for renewable energy, or requires a fixed amount or share of generation to be renewable	High costs, unfavourable power pricing rules, perceived risks
	Cost reduction policies	Reduces investment costs through subsidies, rebates, tax relief, loans, and grants	High costs, perceived risks
	Public investments and market facilitation activities	Provides public funds for direct investments or for guarantees, information, training, etc. to facilitate investments	Transaction costs, perceived risks, lack of access to credit, information, and skills
	Power grid access policies	Gives renewable energy equal or favourable treatment for access to power grids and transmission systems	Independent power producer frameworks, transmission access, inter-connection requirements
Transport biofuels policies	Biofuels mandates	Mandates specific shares of transport fuel consumption from biofuels	Lack of fuel production or delivery infrastructure
	Biofuel tax policies	Provides tax relief for biofuels	High costs

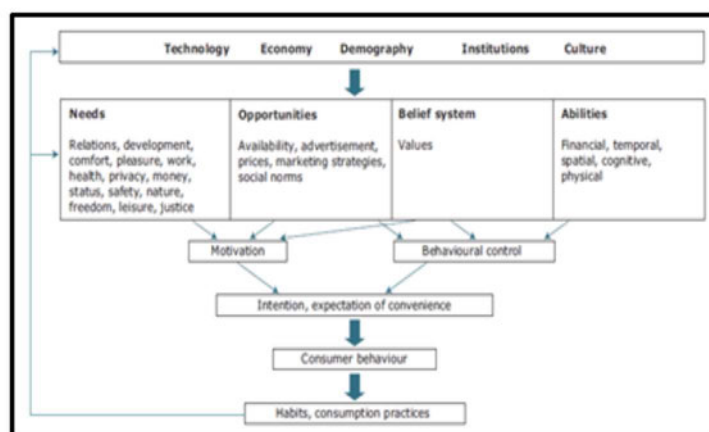
<b>Emissions reduction policies</b>	Renewable energy set-asides	Allocates, or sets aside, a percentage of mandated environmental emissions reductions to be met by renewable energy	Environmental externalities
	Emissions cap and trade policies	Allows renewables to receive monetary credit for local pollutant emissions reduction	Environmental externalities
	Greenhouse gas mitigation policies	Allows renewables to receive monetary credit for greenhouse-gas emissions reduction	Environmental externalities
<b>Power sector restructuring policies</b>	Competitive wholesale power markets	Allows competition in supplying wholesale generation to the utility network and eliminates wholesale pricing restrictions	May heighten barriers of high costs, lack of fuel price risk assessment, unfavourable power pricing rules
	Self-generation by end-users	Allows end-users to generate their own electricity and either sell surplus power back to the grid or partly offset purchased power	May reduce barrier of interconnection requirements, but heighten barriers of high costs, lack of fuel price risk assessment
	Privatised and/or commercialisation of utilities	Changes government-owned and operated utilities into private or commercial entities	May reduce barrier of subsidies, but heighten barriers of high capital costs and perceived risks
	Unbundling of generation, transmission and distribution	Eliminates monopolies so that separate entities provide generation, transmission, and distribution	May provide greater incentives to self-generate, including with renewable energy
	Competitive retail power markets	Provides competition at the retail level for power sales, including "green power" sales	May reduce barriers of high costs, lack of information, transaction costs
<b>Distributed generation policies</b>	Net metering	Values renewable energy production at the point of end-use and allow utility networks to provide "energy storage" for small users	Unfavourable power pricing rules
	Real-time pricing	Values renewable energy production at the actual cost of avoided fossil fuel generation at any given time of the day	Unfavourable power pricing rules
	Capacity credit	Provides credit for the value of standing renewable energy capacity, not just energy production	Unfavourable power pricing rules
	Interconnection regulations	Creates consistent and transparent rules, norms, and standards for interconnection	Interconnection requirements, transaction costs
<b>Rural electrification policies</b>	Rural electrification policy and energy service concessions	Makes renewable energy part of rural electrification policy and planning and creates regulated businesses to serve rural customers	Subsidies for competing fuels, lack of skills and information, high costs, lack of access to credit
	Rural business development and microcredit	Supports private entrepreneurs to provide renewable energy products and services to end-users and offer consumer credit for purchases	Lack of skills, lack of access to credit
	Comparative line extension analyses	Analyses the relative costs of renewable energy with conventional fuels and power delivery	Subsidies for competing fuels, lack of information

The focus required to overcome the barriers starts with the acknowledgement of the need to consider climate change mitigation in all commercial activities. Following this, it is necessary to identify the benefits that climate change

mitigation can offer to developing countries who need to exploit the market benefits of new technologies, designs, manufacturing and commercialisation.

Following this, a clear strategy that will allow proliferation of climate change mitigation into the country must be formulated, workshopped and supported by all stakeholders affected and involved. Input should be captured and taken into consideration before a final strategy is approved and concluded for implementation. The strategy must be reasonable, support the needs of the people, and its achievability must be measured.

Policies and regulations should be well structured and coordinated to ensure that they do not conflict with each other. Neglecting to promulgate policies and regulations that support climate change is as much of a barrier as is leaving in place policies that restrict the technology proliferation that support renewable energy. Ensuring that policies and regulations are put in place as a result of a clear, strong and supported strategy for climate change mitigation is key to sustaining energy efficiency and energy security in developing countries. The economy, education, social aspects and political aspects are deeply linked (Figure 10). Making climate change adaptation a source of wealth generation will gain momentum and has the potential to solve many inequality challenges, poverty and other socio-economic challenges faced by a developing country. This will also serve to change the thinking and behaviour of the citizens when they see the potential that climate change mitigation offers.



**Figure 10: Main Factors Influencing Consumer Behaviour and Emergence of Consumption Practices [13].**

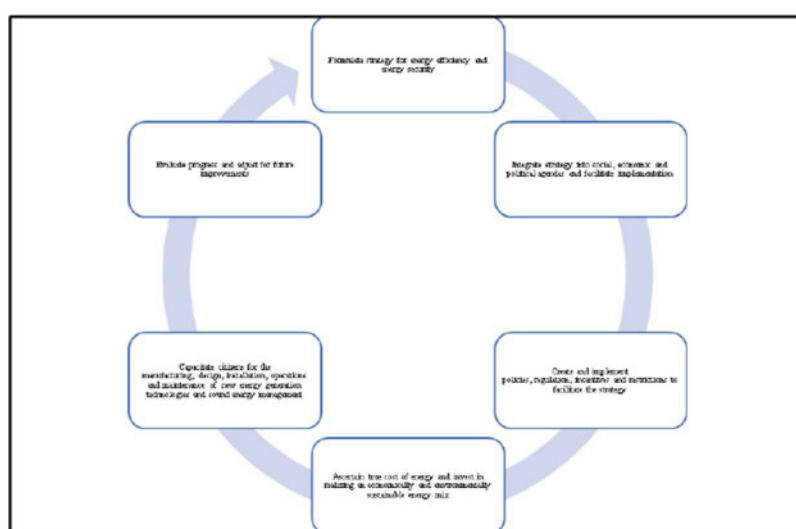
Designing the future economy to exploit the market and financial value while capacitating the local workforce will go a long way to closing the inequality gap faced by many developing countries. Planned adaptation can consider future climate risks in locating and designing infrastructure, urban and rural land-use planning, and in managing ecosystem resources such as water and natural systems [1]. In all these cases, investment decisions made today have long lifetimes (5 to 40 years) and will be exposed to climate change in the future, thus the absence of early action may lock in future risks [1]. There is therefore an opportunity to make these early investment decisions 'climate-smart' by considering future risks now and looking at early adaptation options [1].

The focus of overcoming the barriers to energy efficiency and energy security in developing countries should be (figure 11):

- To formulate a strategy that will mitigate climate change with continuous updates as per the progress and context

of the implementation

- To integrate energy efficiency and alternative energy sources into social, economic and political agendas and facilitate implementation
- To create policies, regulations, incentives and restrictions appropriately as well as align existing regulations and policies such that they support and facilitate energy efficiency and energy security into the country at all levels
- To use sound economic principles for evaluations and investigations that inform real costing of energy from the different power generation sources and allocate raw materials, land, finances and other resources accordingly to realise a new energy mix that is economically and environmentally sustainable
- To capacitate the citizens for the design, manufacturing, installation, operation and maintenance of new energy generation technologies and sound energy management principles



**Figure 11: Focus Required to Overcome Barriers Related to Energy Efficiency and Energy Security in Developing Countries.**

Constant evaluation of progress as well as consideration of the social and economic context of the strategy implementation, including re-alignment when needed, will ensure that climate change adaptation is relevant to the challenges faced by developing countries. Using climate change adaptation as a means and vehicle to alleviate poverty, create wealth through new markets and capacitate the citizens for increased local labour and monetisation, will serve to overcome barriers to energy efficiency and energy security while meeting socio-economic and political goals.

**7. CONCLUSIONS**

This paper presented the origin of barriers to energy efficiency and energy security faced by developing countries as well as analysed the political, technological and financial barriers faced. The focus required to overcome these barriers is to have a strategy to mitigate climate change and achieve implementation through integration of the strategy in social, economic and political agendas as a vehicle to achieve the developing country’s focus on socio-economic and political interests. In this way, climate change mitigation will be sustained due to the benefits they provide which fulfil a developing

country's key focus areas.

#### REFERENCES

1. Cimato, F., Watkiss, P., "Overcoming the barriers to climate change adaptation", *Future Climate for Africa*, May 2018. Retrieved from [https://media.africaportal.org/documents/fcfa\\_ecap\\_economics-guide.pdf](https://media.africaportal.org/documents/fcfa_ecap_economics-guide.pdf), accessed 17/08/2021.
2. Thollander, P., Backlund, S., Trianni, A., Cagno, E., "Beyond barriers - A case study on driving forces for improved energy efficiency in the foundry industries in Finland, France, Germany, Italy, Poland, Spain, and Sweden", *Applied Energy*, (111), 2013.
3. Joseph, J., Inambao, F.L., "Sustainability: The big challenge" *International Journal of Engineering Research and Technology (IJERT)*, Vol 13, Number 11, 2020, pp. 3080-3098.
4. Arpin, M.L., "Circular economy: A critical literature review of concepts", *International Reference Centre for the Life Cycle of Products, Processes and Services*, August 2015.
5. Australian government Department of Climate Change and Energy Efficiency, "Barriers to effective climate change adaptation", 23 December 2011. Retrieved from <https://www.environment.gov.au/system/files/resources/c8e1fa00-3d14-4e3b-98a4-b5b338700042/files/barrierstoadaptation.pdf>, accessed 17/08/2021.
6. Mackay, S., Hennessey, N., Mackey, B., "Barriers to the implementation of climate change adaptation plans and action: Considerations for regional Victoria", Griffith University, Brisbane, 2019. Retrieved from [https://www.climatechange.vic.gov.au/data/assets/pdf\\_file/0038/489476/Policy-Brief-1-Barriers-to-the-implementation-of-climate-change-adaptation-plans-and-action.pdf](https://www.climatechange.vic.gov.au/data/assets/pdf_file/0038/489476/Policy-Brief-1-Barriers-to-the-implementation-of-climate-change-adaptation-plans-and-action.pdf), accessed 17/08/2021.
7. <https://www.carbonbrief.org/analysis-the-most-cited-climate-change-papers>, accessed 19/08/2021
8. Beck, F., Martinot, E., "Renewable energy policies and barriers", *Encyclopaedia of Energy*, Volume 5, 2004, pp 365-383. Retrieved from [http://www.martinot.info/Beck\\_Martinot\\_AP.pdf](http://www.martinot.info/Beck_Martinot_AP.pdf), accessed 18/08/2021.
9. Lyon, C., "Power generation technology data for integrated resource plan of South Africa", *Technical Update by Electric Power Research Institute (EPRI) prepared for Department of Energy South Africa*, April 2017.
10. Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C., "Renewable energy sources and climate change mitigation", *Special Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press, 2011.
11. Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield, "Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty", *Intergovernmental Panel on Climate Change*, 2018. Retrieved from [https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15\\_Full\\_Report\\_High\\_Res.pdf](https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf), accessed 04/06/2021.
12. Beck, F., Martinot, E., "Renewable energy policies and barriers", *Encyclopaedia of Energy*, Volume 5, 2004, pp 365-383. Retrieved from [http://www.martinot.info/Beck\\_Martinot\\_AP.pdf](http://www.martinot.info/Beck_Martinot_AP.pdf), accessed 18/08/2021.
13. European Environment Agency, "Achieving energy efficiency through behaviour change: what does it take?", *EEA Technical report*, 2013.

14. Aderonmu, P. A., et al. "Sustainability Parameters in Knowledge Construction: Energy Efficiency Issues of Architectural Design Studio Space." *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD)* 4.6 (2014): 11-18.
15. Joshi, Krishna. "Application of Energy Concepts for Green Buildings." *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) ISSN (P)* (2016): 2249-6866.
16. Usikalu, M. R., Anuoluwapo H. Shittu, and Leke N. Obafemi. "Construction of an intelligent and efficient light control system." *International Journal of Mechanical and Production Engineering Research and Development* 8.4 (2018): 1025-1034.
17. Premkumar, M., et al. "Design, analysis and fabrication of solar pv powered bldc hub motor driven electric car." *Inter. J. Mecha. Produc. Engi. Res. Develop* 8.1 (2018): 1255-1270.

## CHAPTER 5. PRINCIPLES FOR ACHIEVING ENERGY EFFICIENCY IN DEVELOPING COUNTRIES

This chapter presents a set of principles to achieve energy efficiency throughout the energy value chain, maximizing financial benefit and reducing carbon emissions.

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<http://www.tjprc.org/view-archives.php>

## PRINCIPLES FOR ACHIEVING ENERGY EFFICIENCY IN DEVELOPING COUNTRIES

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### ABSTRACT

*Energy efficiency is key in the plan to mitigate climate change and in most cases, it is the less expensive option when compared to changing energy generation plants to a less carbon intensive energy source and thus popular among developing economies of the world. The approaches to energy efficiency traditionally involve examining energy consumed at the point of component or device consuming the energy. The aim of this study is to present principles for developing countries' established sites and businesses that primarily rely on fossil fuels for its energy needs that will ensure energy efficiency is successfully achieved throughout the value chain for an operational site. This paper presents the traditional approaches of energy efficiency and shows how these approaches while achieving energy efficiency at the point of the energy demand where the energy consuming component or device is installed, it is quite inefficient in the wider picture of the energy value chain. From these observations, a set of principles are presented to achieve energy efficiency throughout the energy value chain maximizing financial benefit and reduction in carbon emissions. A third principle is presented to ensure that energy efficiency is sustainably achieved at an operational site through transitioning existing infrastructure to being energy efficient over a defined period of time and ensuring that new capacity adheres to energy efficiency in the future.*

**KEYWORDS:** *Energy Efficiency in developing countries, Energy savings, Energy conservation, Forms of energy, Energy conversion efficiencies & Energy management*

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### INTRODUCTION

The potential for energy efficiency to simultaneously address economic development, energy security, and environmental protection in countries around the world is well known. Energy efficiency can have even more pronounced impacts in developing countries, where citizens need increased access to energy, utilities might struggle to keep up with demand, and public and private capital to expand availability of energy and improve quality of service is scarce. [1] Energy efficiency policies in Turkey increase energy security to benefit from growing economy and reduce greenhouse gas emissions. Turkey has established a comprehensive, strategic, and legal framework to promote energy efficiency. The energy efficiency law in Turkey has a wide coverage area, including related regulations. These areas include increasing and supporting energy efficiency, setting up energy efficiency consulting companies, establishing energy management systems, promoting energy efficiency investments, increasing energy efficiency in transport and buildings, preventing the sale of inefficient devices and raising awareness. Luxembourg implemented energy performance regulations in 2008 for residential buildings and in 2011 for non-residential buildings. These regulations establish a methodology to calculate energy performance of buildings, to determine minimum energy requirements for new buildings, extensions and renewed elements of existing buildings. Luxembourg is promoting the energy efficiency of buildings with the introduction of energy

performance certificates. New Zealand's "Smart Warming Program" aims to increase the number of hot, dry, and energy-efficient homes to protect patient health and prevent loss of productivity. The first "New Zealand Energy Strategy" and the second 5-year "New Zealand Energy Efficiency and Conservation Strategy" were published in October 2007. However, after the National Party government was elected in 2008, both of these documents were audited. The purpose of doing this is to present a clearer link between energy policies and economic growth. The program of energy saving targets for energy suppliers is a central component of Ireland's energy efficiency policy. The first "National Energy Efficiency Action Plan" identified potential energy saving programs targeting energy suppliers in 2009. [2]

Typical initiatives in energy management to achieve energy efficiency include lighting changes to LED (light emitting diode) technologies, lighting demand control, air-conditioning demand control, eliminating energy wastage in engineering process plants from compressed air and steam leaks, pump and motor operations and other mechanical equipment. Figure 1 shows the approach used by low-income residents in developed countries from a study undertaken by the National Renewable Energy Laboratory.

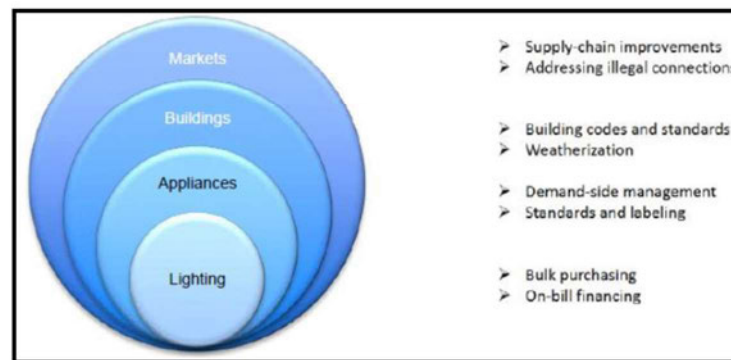


Figure 1: Increasing Levels of Energy-efficiency Intervention [1]

Usually energy efficiency is addressed from the point of the end user, i.e. where the energy is used for lighting, space conditioning, refrigeration, heating needs, engineering process plants and on the efficiency of the respective technologies, this is where efficiency of components such as heat exchangers, motors, pumps, etc. are the most common choice for energy efficiency and energy conservation. Figure 2 shows a snapshot of the typical energy efficiency improvements contained in the Energy Efficiency Baseline Report of the Department of Minerals and Energy (South Africa). Figure 3, Figure 4 and Figure 5 are some of the energy efficiency potential identified for energy savings in the Iron and Steel Industry, Pulp and Paper Industry and the Mining Industry. The same report also contains energy efficiency potentials identified for the Chemical and Petrochemical Sector, the non-Metallic Minerals Sector, non-Ferrous Metals Sector and the Textile and Textile Products Sector. It is observed that the common ground between all the energy efficiency potentials is the "components" identification to be energy efficient.

Energy efficiency, however, does not rely solely on the energy at point of supply to the component requiring the energy. There are drivers that influence energy demand. This is very evident in the case of air conditioning demand, Refer to Figure 6 and Figure 7. Energy consumption per square meter varies across geographical locations, and based on the type of space conditioning system, Figure 7.

Measure	Fuel affected	Fuel Saving potential	Fraction of total for that fuel (Industry)	When economic <sup>25</sup> ?	Assumed payback period	Jobs-years over a ten year period: note this is <i>indicative only</i> . Assumptions are stated in Appendix: D, I/O model for industry electricity options.		
						80% local	20% local	
VSD	Electricity	30%	<1%	2000-2010	4 year	3700	-1500	
Motors	Electricity	5%	1% (2%)	2006-2010	5 year	7600	-1300	
Comp air	Electricity	20%		Immediately	1 year	7500 (100% local)		
Lighting	Electricity	35%	2% (1%)	2002-2006	3 year	3200	900	
HVAC includes some VSDs	Electricity	25%	0.5% (0.1%)	2002-2010	3 year	270	60	
Energy Star Equipment	Electricity	30%	0.1 (2%)	Immediately				
Commercial building design	Electricity <sup>26</sup>	40%	<1%(3%) <sup>27</sup>	Immediately <sup>28</sup>				
Thermal Fuel: Industry, Agriculture and commerce.	Solid	Bagasse	15%	8%	Immediately			
		Coal		7%	Immediately			
		Vegital waste		10%	Immediately			
		Wood		1%	Immediately			
	Liquid	HFO	13%	5%	Immediately			
		LPG		3%	Immediately			
		Kerosene		0.5%	Immediately			
	Gas		11%	3%	Immediately			
	Electricity		10%	1%	Immediately	6-9month	4400	3200
	(Electricity to coal)		55% system efficiency		Immediately			
(Electricity to natural gas)		61% system efficiency		2006-2012				
(Electricity to LPG)				Not economic				
Household CFL use	Electricity	65%	1% (6%)	2002-2010				
	Coal	30%	1% (8%)	Immediately				
Efficient stoves	Wood		<1% (7%)	Immediately				
Electricity to LP gas	Electricity		50% system efficiency.	Immediately				
Solar hot water heater (residential)	Electricity	75% <sup>29</sup>	<1% (3%)	2002-2010 <sup>30</sup>				
Geyser insulation	Electricity	5%	<1%(1%)	2002-2010 <sup>31</sup>				
Add ceilings to RDP houses and insulation to existing houses.	Thermal fuels	15-40% (15%) <sup>32</sup>	<1% (1%)	Immediately <sup>33</sup>				

Figure 2: Summary of Easily Implemented Energy Efficiency Improvements [3]

PJ	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Lighting	0	0	0.2	0.3	0.4	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9
Motors	0	0	0.1	0.2	0.3	0.4	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
VSD	0	0	0	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Compressed air	0	0	0.2	0.4	0.5	0.7	0.9	0.9	0.9	1	1	1	1.1	1.1	1.1
Thermal measures	0	0	5.4	11.1	16.9	22.9	29.1	29.9	30.7	31.7	32.6	33.5	34.3	35.2	36.7
<b>Total</b>	<b>0</b>	<b>0</b>	<b>5.9</b>	<b>12.1</b>	<b>18.2</b>	<b>24.8</b>	<b>31.6</b>	<b>32.4</b>	<b>33.3</b>	<b>34.4</b>	<b>35.3</b>	<b>36.3</b>	<b>37.3</b>	<b>38.2</b>	<b>39.7</b>

Figure 3: Potential Energy Savings in the Iron and Steel Industry (PJ) [3]

PJ	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Lighting	0	0	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Motors	0	0	0.1	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
VSD	0	0	0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Compressed air	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Thermal measures	0	0	1.6	3.1	4.5	6	7.4	7.4	7.4	7.5	7.5	7.5	7.5	7.6	7.6
<b>Total</b>	<b>0</b>	<b>0</b>	<b>1.8</b>	<b>3.7</b>	<b>5.3</b>	<b>6.9</b>	<b>8.5</b>	<b>8.5</b>	<b>8.5</b>	<b>8.6</b>	<b>8.6</b>	<b>8.7</b>	<b>8.7</b>	<b>8.8</b>	<b>8.8</b>

Figure 4: Potential Energy Savings in the pulp and Paper Industry (PJ) [3]

PJ	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
lighting gold mining	0	0	0.1	0.3	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5
lighting other mining	0	0	0.1	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
VSD gold	0	0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
VSD other	0	0	0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Compressed air gold	0	0	0.6	1.2	1.7	2.2	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.5	2.5
Compressed air other	0	0	0.5	1	1.4	1.9	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7
Thermal measures gold	0	0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Thermal measures other	0	0	0.3	0.6	1	1.3	1.7	1.7	1.8	1.8	1.9	1.9	2	2	2.1
motors gold mining	0	0	0.3	0.7	1	1.4	1.7	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6
motors other mining	0	0	0.3	0.6	0.9	1.2	1.5	1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.7
Total	0.0	0.0	2.4	4.9	7.2	9.5	11.5	11.5	11.7	11.8	11.9	11.9	12.2	12.2	12.4

Figure 5: Potential Energy Savings in the Mining Sector (PJ) [3]

	MJ/m <sup>2</sup>
U.S.A.	
Northeast	989.1335
Midwest	1186.733
South	917.5888
West	1069.763
South Africa	1082

Figure 6: Energy Consumption in commercial buildings in the USA [3]

Naturally ventilated cellular		Naturally ventilated open plan		A/C Standard		A/C Prestige	
Typical	Good practice	Typical	Good practice	Typical	Good practice	Typical	Good practice
738	403	849	478	1454	810	2045	1253

Figure 7: Energy Consumption in Commercial Buildings in the UK [3]

One of the more rigorous approaches known in the South African industry over the last decade is practiced and taught by the Industrial Energy Efficiency (IEE) Project of South Africa whose energy efficiency programme culminates in an energy management system aligned to the Energy Management Standard (ISO 50001). This programme also concentrates on Energy Systems Optimization (ESO) for pumps, compressors, motors, boilers and other energy intensive plant equipment. Significant energy savings can be realized, especially if consideration for using energy effectively has not been made before. Some of these energy savings are contained in Table V: Case Studies of Energy Efficiency from the UNIDO EnMS Programme of the "Trends: Energy Efficiency and Energy Security" written by J Joseph and F.L Inambao. These savings are focused on component efficiency and in some cases go into plant level energy efficiency.

To thoroughly achieve energy efficiency and capitalize on the benefits that eliminating energy wastage can bring, one must understand both the scientific principles involved with deriving and using energy in its different forms as well as understanding how this energy supply serves the energy demand. This value chain must be reviewed from the point of the activities and logistics required to harvest the energy source or the supply side to how it is transformed to derive energy and how this energy is used in the demand side of the value chain. This paper investigates energy efficiencies involved with forms of energy of traditional fossil fuel energy sources in their conversions to serve the energy demand for various end uses. This paper also examines satisfying energy demand efficiently in existing energy intensive sites and proposes a

sustainable way to transform an operational/live site towards full compliance with energy efficiency and maintaining this energy efficiency. From these investigations, principles to promote energy efficiency are derived.

## 1. Deriving the three key principles for energy efficiency in Developing Countries

### a. Forms of Energy

Energy exists all around us in various forms which we release through combustion or harness through carefully designed technology using the laws of physics and chemistry. One of the most common forms of energy is chemical energy stored in coal, oil, gas which we combust to release energy. This stored energy together with nuclear energy, elastic energy and gravitational energy is referred to as potential energy. When the chemical energy is released through combustion, they take the form of heat energy which through designed technology is used to turn the shafts of electrical generators, producing electricity. This process releases thermal energy, through mechanical energy and magnetic energy, electrical energy is released. These are forms of kinetic energy. Sound energy and light energy are also experienced in these energy conversions. Refer to Figure 8.

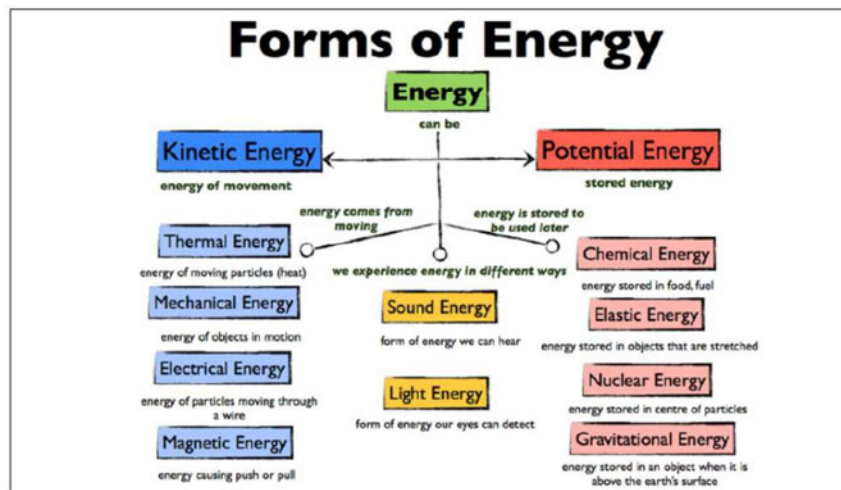


Figure 8: Forms of Energy [4]

Coal, oil and natural gas are forms of stored energy (Chemical energy) that is then released in the form of thermal energy in combustion of these fuels for the production of mechanical energy (the turning of a shaft within an electrical generator from which electricity is then produced, being stepped up, transmitted over long distances, stepped down and used for running of motors that drive pumps, lighting technologies, heat exchangers in chillers and much more. Figure 9 shows the pathways of primary energy to electricity (the most common end use today). Coal, oil and natural gas must be extracted, processed, transported and released to produce electricity. The efficiency of the stages shown in Figure 8 for China, a developing country is shown in Figure 10 for coal extraction, processing and transportation, Figure 11 for crude oil extraction and transportation, Figure 12 for oil refinery processes and Figure 13 for natural gas extraction and processing.

	<i>i</i> (primary energy)	<i>j</i> (secondary energy (SE))	<i>m</i> (stage)	<i>n</i> (electricity pathways)
1	Crude coal	Raw coal	Feedstock production	Coal
2	Crude NG	Raw NG	Feedstock Transportation	NG
3	Crude oil	Raw oil	Fuel production	Oil
4		Final coal	Fuel transportation	Wind
5		Final NG		Hydro
6		Diesel		
7		Gasoline		
8		Residual oil		
9		Electricity		

Figure 9: The Unified Structure of Fuel Pathways [5]

Process	Efficiency ( $\eta$ )
Coal extraction	97%
Coal processing	97%
Coal transportation (percentage and distance)	Railway: 49% (642 km) Barge: 26% (650 km) Long-distance road: 30% (310 km) Short-distance road: 100% (50 km) Coal: 81%
Secondary energy for extraction and processing	Electricity: 15% Diesel: 3% NG: 1%

\* The shares of transportation can add up to more than 100% because two modes of transportation can be used in series.

Figure 10: Efficiency of Coal Extraction, processing and Transportation [5]

Process	Efficiency ( $\eta$ )
Crude oil extraction	93%
Crude oil transportation	Sea tanker: 50% (11000 km) Railway: 30% (942 km) Pipeline: 78% (440 km) Barge: 10% (250 km) Short-distance road: 10% (50 km)
Secondary energy for crude oil processing	NG: 44% Crude oil 28% Electricity 14% Diesel 1% Coal 3% Residual oil 1% Gasoline 1%

Figure 11: Efficiency of Crude oil Extraction and Transportation [5]

Process	Efficiency ( $\eta$ )
Gasoline refining	89.1%
Diesel refining	89.7%
Residual oil refining	94.0%
Secondary energy mix for refinery	Crude oil: 69% Refinery still gas: 10% Coal: 9% NG: 4% Residual oil: 1%
Residual oil transportation	Sea tanker: 52% (7000 km) Railway: 50% (900 km) Pipeline: 15% (160 km) Barge: 10% (1200 km)
Gasoline and diesel transportation	Sea tanker: 25% (7000 km) Railway: 50% (900 km) Barge: 15% (1200 km) Short-distance road: 10% (50 km)

Figure 12: Efficiency of oil Refinery Processes [5]

Process	Efficiency ( $\eta$ )
NG extraction	96%
Secondary energy mix for NG extraction	NG: 44% Crude oil: 28% Electricity: 14% Diesel 1% Coal 3% Residual oil 1% Gasoline 1%
NG processing	94%
Secondary energy mix for NG processing	NG: 99% Electricity: 1%

Figure 13: Efficiency of Natural Gas Extraction and Processing [5]

From these figures, it can be clearly seen that due to process inefficiencies and logistics, a fair amount of energy cannot be recovered in the process. In the real world, certain inefficiencies are unavoidable and inevitable due to the laws of the conservation of energy and the process of energy conversions. Within our control, however, is the how the energy is transformed for use in the value chain, this includes the energy spent on logistics. Electricity being the preferred form of energy since the 20<sup>th</sup> century, has revolutionized power generation. Global warming not yet acknowledged as a concern when electricity began becoming popular. Wherever electricity was available, a device or plant was “plugged in” without consideration of limitations that this might have in the future. When Eskom, South Africa’s national electricity provider began with its coal fired power plants, to run the plants at 100% load factor, the citizens were encouraged to “plug in”. A few decades later, the desperate request to citizens is to now switch off as Eskom’s demand exceeded its capacity to supply resulting in the first rolling blackouts in South Africa in 2008. To get temporal relief while a longer-term solution was being put in place, Eskom went on energy efficiency drive to eliminate wastage within its demand. Figure 44: Energy savings per consumer sector (left) and per technology (right) in “Trends: Energy Efficiency and Energy Security” written

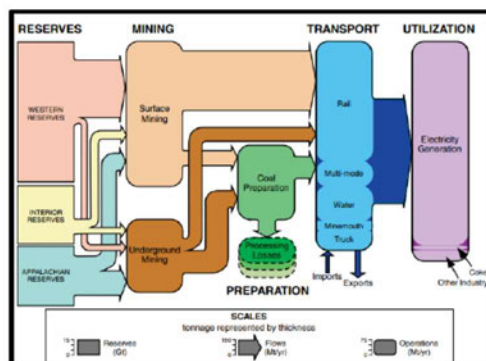
by J Joseph and F.L Inambao shows the energy saving initiatives done by Eskom. Today, we find ourselves having to relook at the way we derive energy for use and the way it is used, not just for demand and supply challenges in developing countries like South Africa, but for the urgent need to reduce carbon emissions against the every growing need for energy due to the effect it has on climate change.

**a. The Implications of the laws of energy to derive Energy for various end uses**

Since the discovery of electricity and the science behind direct and alternating current in the 20<sup>th</sup> century, humans have largely moved away from piping natural gas and oil as fuel for light, heating and other household uses. Appliances and industrial machines use electrical energy which is produced traditionally in a centralized power plant and distributed throughout cities, used in households, manufacturing. We use electrical energy for almost everything in our daily lives, whether it is for lighting, cooling, heating, motion as we find in pumps, motors, etc. The law of conservation of energy states that energy cannot be created nor destroyed but converted from one form to another. The second law of thermodynamics states that the entropy of an isolated system always increases. This implies that as energy is converted from one form to another, we lose some of the energy with each conversion, leaving the amount of usable energy much smaller in quantity.

Energy in its usable form is limited and costly to produce, thus reducing the demand for it will be the first point of interest when it comes to ensuring energy efficiency. Reducing energy wastage in homes, engineering plants, offices, commercial and industrial facilities saves costs and reduces carbon footprint. Understanding the energy need and then matching the energy need with an energy source that ensures the shortest path to energy conversion is the first step in the value chain to ensure energy efficiency.

Examining energy use from energy source to end use for coal, oil and natural gas, it can be seen that from resource extraction from its natural state, there is a significant amount of work that must be done on the natural resource before it is used in power plants or electrical generator to produce usable electricity. Figure 14 shows the process from extraction of coal to its use in electricity.



**Figure 14: Schematic showing the coal fuel cycle in United States, illustrating the Flow Paths and relative quantities of coal as it moves from reserves through the various operations—mining to processing (if applicable) to transport to utilization [6]**

At each stage energy is used, i.e. energy is used by mechanical machines and vehicles to mine the raw coal resources, energy is used for various coal preparation purposes, energy is used to transport the coal to various geographical

locations to be used and in this case to produce electricity. This very simplified process in Figure 14 shows that before the coal is used to produce electricity for end users, already at this stage energy has been used. Figure 15 shows the journey of electricity generated at power stations before it reaches the end user. The electricity generated must go through transmission (voltage step up) for travel over long distances before it is stepped down for distribution to the end user.

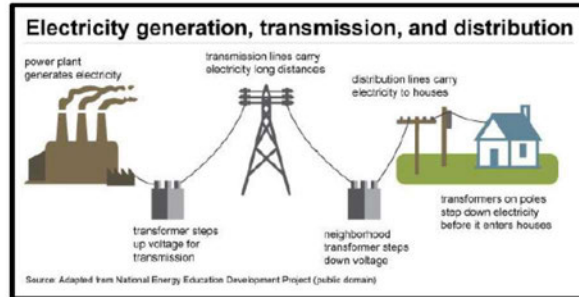


Figure 15: The Journey of Generated Electricity to the End user [7]

The end user then utilizes electricity for various household, commercial and industrial uses. The electricity is used to energize electrically powered devices such as computers, electronic, lighting and many other devices that producing heat for cooking, water heating also powering the refrigeration and space air-conditioning processes.

From the description of the journey that raw coal takes to reach its end use, we can see the many energy conversions in Figure 16. Figure 16 depicts some of the end uses of energy mainly found in commercial and domestic end users. If we simplify the coal journey to focus just on the energy resource conversion into the various forms of energy before it is finally reached its intended state for use by the end user, we get Figure 17 (heating purposes), Figure 18 (air-conditioning), Figure 19 (Motor Driven Pumps), Figure 20 (lighting), Figure 21 (computers and control circuitry).

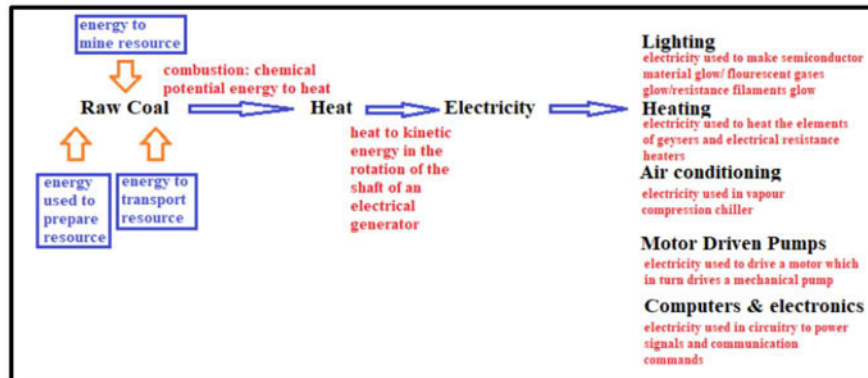


Figure 16: Coal to Energy Pathways from Natural Resource to End Use

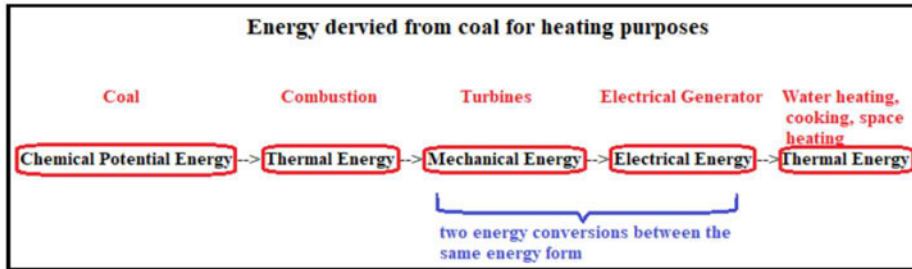


Figure 17: Forms of Energy for: Energy derived from coal for Heating Purposes

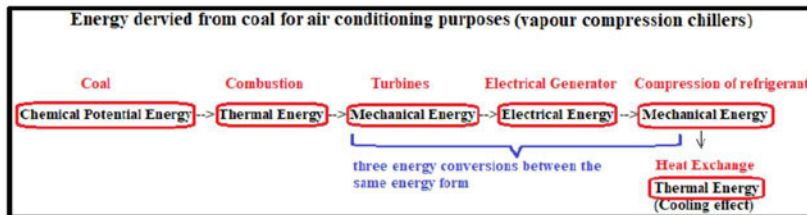


Figure 18: Forms of Energy for: Energy derived from coal for air conditioning purposes

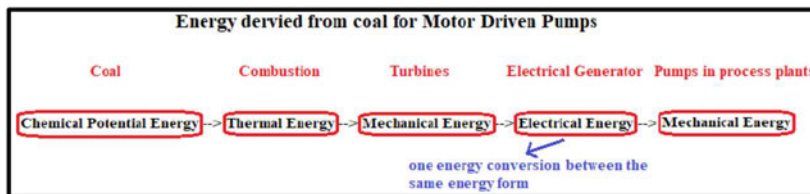


Figure 19: Forms of energy for: Energy derived from coal for Motor Driven Pumps

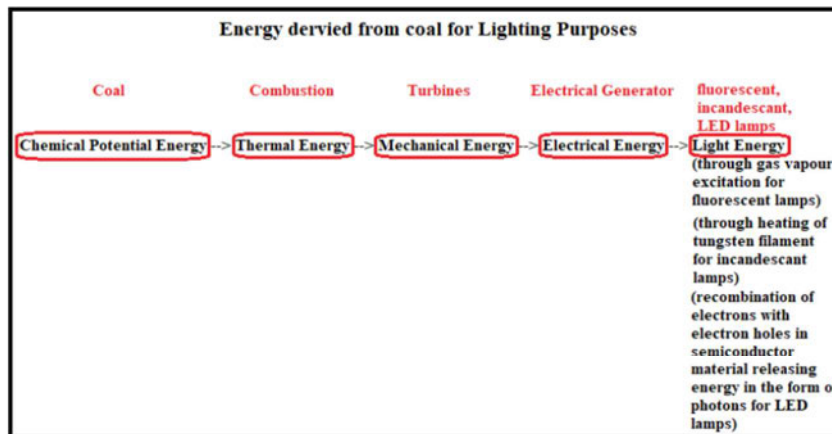


Figure 20: Forms of Energy for: Energy derived from coal for Lighting Purposes

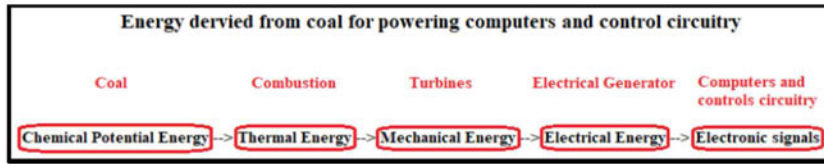


Figure 21: Forms of Energy for: Energy derived from Coal for Powering Computers and Control Circuitry

It can be seen that for heating purposes (Figure 17) there are two energy conversions between the same energy forms, i.e. thermal energy. In other words, coal being combusted to release thermal energy for electricity generation (via mechanical energy) is then used to generate thermal energy via traditional geyser elements and electrical resistance heaters which are common technologies used today.

Recall the law of conservation of energy and the second law of thermodynamics implies that there is less usable energy for the next stage with each energy conversion. Figure 18 shows three energy conversions between the same energy form, i.e. thermal energy for air conditioning purposes and Figure 19 shows an energy conversion between the same energy form, i.e. mechanical energy for Motor Driven Pumps. For the technologies currently being used for lighting and computers & control circuitry (Figure 20 and Figure 21 respectively), there are no energy conversion between the same energy form. In this context this may be energy efficient. Using energy efficiently, i.e. getting maximum output for a given input requires that the shortest energy conversion route, preferably with no repeats within the form of energy from its source to the intended use.

In the current global challenge of climate change, reconsidering the source of fuel for energy is important to reduce carbon emissions that is a significant contributor to global warming. Considering the suitable energy source (or fuel) for deriving energy wherein it is key that energy sources available at the point of demand is considered with the least carbon footprint and any synergies identified solves not just the global climate change challenge from carbon emissions, it also within this process introduces energy efficiency. Recall that energy efficiency is getting the maximum energy output for a given energy input. From these aspects, the first principle of energy efficiency is derived as follows:

**Principle One: Efficiently matching the energy source and the energy need such that it is the shortest route from the energy source to the energy end use and that its energy source is the best choice for cost effectiveness, suitably satisfying the need and closest to zero carbon emissions.**

#### **b. Taking a wholistic approach for Efficiently Satisfying Energy demand**

Now that we have dealt with the supply side of the energy value chain, we examine the demand side of the value chain. As highlighted, much emphasis is put on the component energy efficiency, however, there are various factors before we get to the component using the energy that significantly contribute to the magnitude of energy demand.

In providing air conditioning or HVAC (Heating, Ventilation and Air Conditioning), the energy consumption the chiller (compressor and evaporator), cooling tower, air handling unit, associated pumps and motors (Figure 22) are the focus of energy efficiency.

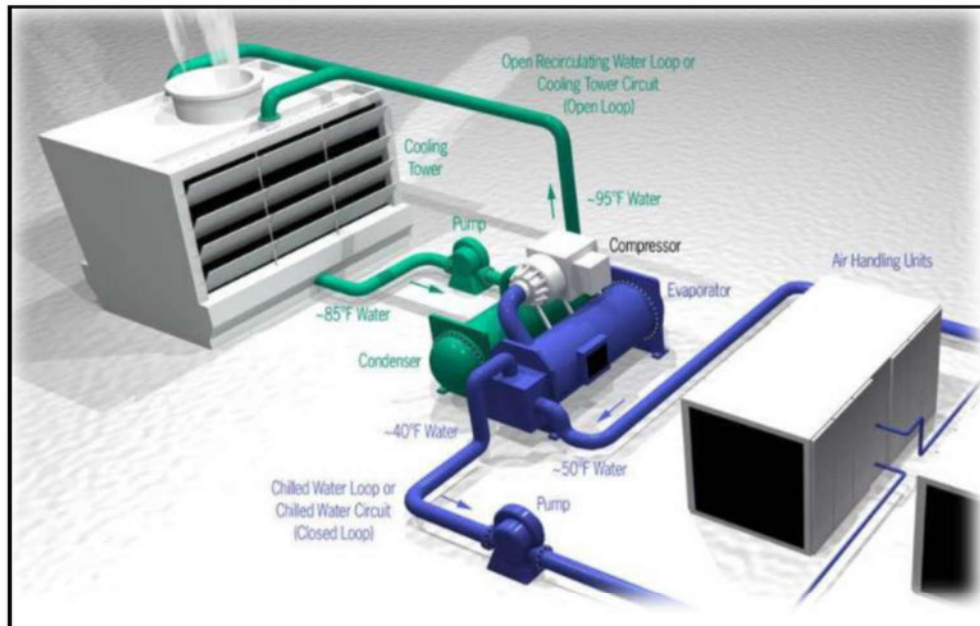


Figure 22: HVAC System Basic components [8]

While the components in an air condition system are quite important in terms of their technology type, and the way in which they were designed and manufactured, etc., equally is the system wherein they serve to provide the air conditioning cycle important. Ensuring that proper controls are in place between components and that they are working effectively is not only important for serving the air conditioning load, but it is paramount for energy efficiency.

Taking a wider view than the system, we look at the drivers of the demand for air conditioning. The weather is an obvious driving factor for the need of air conditioning, i.e. the need for HVAC is driven by the seasons and daily weather which fluctuates. For humans to be comfortable, a specific air temperature and humidity is preferable at places of activity or homes. Certain equipment such as computers, preservation of food and other processes also require a specific air temperature and humidity control. It is true that the weather is a factor not within our control, however, the demand for air conditioning can be reduced if one looks at the factors of building design and operations.

Examples of building design factors that affects air-conditioning design are the building orientation and architecture, the materials of construction, insulation and other convective boundaries, the sizing of doors and windows (fenestration), etc. Examples of building operation factors that affect air conditioning load is the operation of entrances and exits of the air conditioning facility, ventilation demand of the facility and how this is determined and controlled. Another factor affecting air conditioning demand is lighting load. To satisfy lighting needs, adopting LED lighting is popular and their heat sinks are usually contained in ceiling voids, this added heat can contaminate the feedback control if the feedback control sensor is placed such that the reading is contaminated by the heat load within the ceiling void. This causes the air conditioning system to respond to an incorrect input of the air-conditioned space and this causes overcooling resulting in increased energy demand. When one introduces increased skylights and other features to introduce daylight into a building, the air conditioning load usually increases due to the conductance of glass. If all the factors listed here are considered, one

can see that the component energy efficiency is just one aspect in the bigger picture.

If one considers energy demand for lighting, the usual inclination is to ensure that LED is the technology of choice over fluorescent, halogen or incandescent lighting technologies. However, there are other factors involved to ensure that lighting demand is truly efficient. In microchip manufacturing for LED lighting, there are superior designs and materials and sub-standard types. Ensuring that the efficacy of the light, its distribution, colour temperature, colour rendition index, LED driver efficiency, the coefficient of utilization of the lighting fixture is also examined to serve the lighting function efficiently is critical. Some of these factors are depicted in Figure 23.



Figure 23: Left [9]: Typical components of LED Technology, Right [10] LED Lighting within an Environment

When these are overlooked, it can be that more lighting is installed due to lux levels not being met or the lighting need not being met. Other factors that drive the need for lighting is the interior design, such as colour of wall and ceiling paint and furnishings, height at which light is installed and whether there is a conducive space for effective heat exchange from the heat sinks of LED lighting. Factors such as daylight and control of lighting according to demand through occupancy sensor and variation in lighting intensity (day and night lighting demands differ).

These are just two examples (lighting and air conditioning) of energy demand where when considering energy efficiency from a wholistic perspective, one must consider the component efficiency, the system efficiency, the factors affecting the system and component and the factors affected by the system and component. This is depicted in Figure 24. This then gives birth to the second principle in achieving energy efficiency.

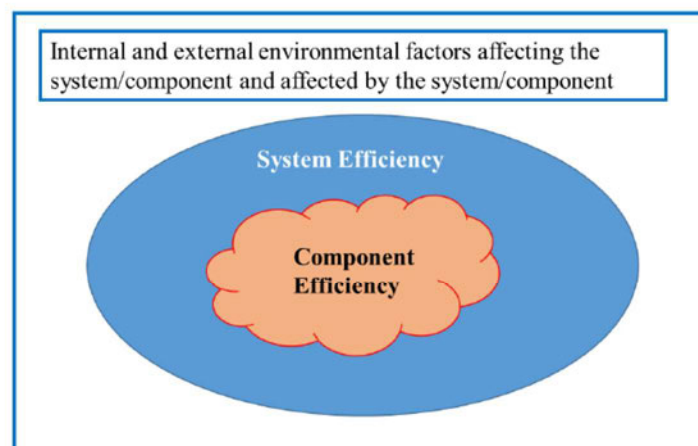


Figure 24: Wholistic Approach to achieving Energy Efficiency

**Principle Two: Take a system approach when it comes to energy efficiency, this means considering the energy consuming device or technology, the system that the device or technology is a part of as well as factors affecting the system and factors affected by the system.**

**c. Timing that supports successful and Effective Implementation of energy efficiency for an operational site**

When achieving energy efficiency in an established site that is operational and thus changing over time and with multiple stakeholders such as tenants that use or influence the site's energy consumption, an approach that serves the need of the energy users while achieving energy efficiency is paramount to success.

In a typical business setting, existing installed technologies that are not the best available technologies (BAT) on the commercial market, needs to be changed and where the capacity of the site is being expanded with the adoption of new buildings and facilities, there arises a need for an approach that will ensure that the new capacity is aligned to energy efficient practices in best available technologies and designs while ensuring that existing technologies are either being retrofitted (typically where it makes business sense) or with replacement cycles (when these technologies have reached the end of their lifespan) where they must be replaced.

It is the tendency of management, staff, consultants and design engineers of employing the same technologies and designs across a site and thus to ensure that preferred energy efficient technologies and designs are adopted when replacing old technologies and installing new capacity, a "Standards and Guidelines for Energy Efficiency" document must be drafted, approved and adopted as a company policy. This "Standards and Guidelines for Energy Efficiency" document must cover preferred technologies for all significant energy using device types, system types and preferred designs that will apply when new buildings and facilities are constructed. Where tenants occupy, fit out and maintain a space onsite, energy efficiency obligations must be included in tenant lease agreements and these obligations must be audited for compliance. It may be difficult to include energy efficiency obligations in an existing lease that has not been agreed upon when the lease was signed. In cases like this, the landlord can attempt to get buy-in for energy efficiency and upon renewal of the lease or when a new tenant occupies the space, energy efficiency obligations can be enforced.

This approach ensures that in an expected space of time, typically when the end of the replacement cycle of infrastructure has expired, and when the current round of all tenant lease agreements have expired, all components and systems will be transformed to be energy efficient. Figure 25 captures this approach to transitioning an established and operational site towards compliance with energy efficiency.

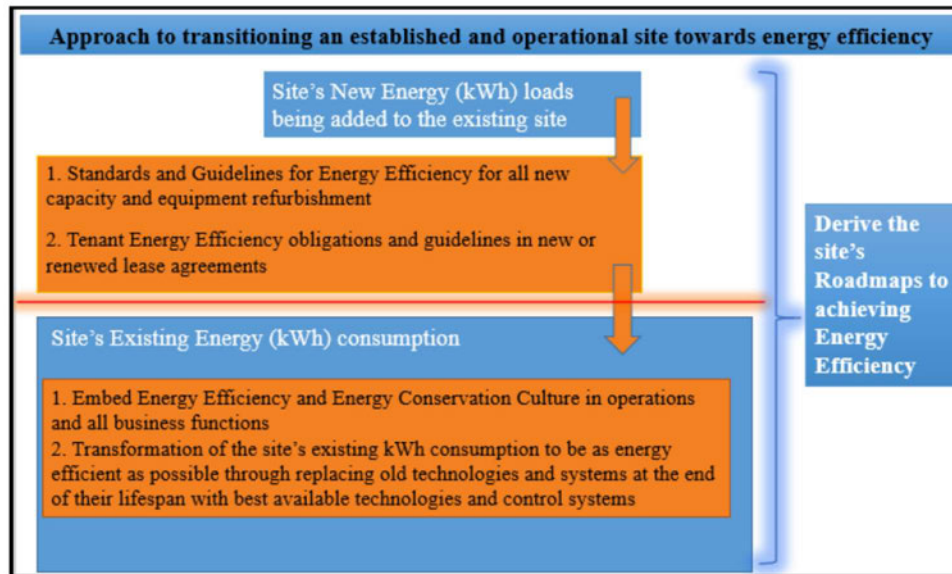


Figure 25: Approach to Transitioning an established and operational site towards Energy Efficiency

To secure the execution of all the initiatives identified over the time required to transition the site towards energy efficiency, derive a roadmap to energy efficiency for the site that can be tracked and used for auditing the compliance towards energy efficiency. The third principle to achieve energy efficiency is as follows.

**Principle Three: Ensure that the approach to implementation of energy efficiency meets business imperatives and supports operations, deriving “Standards and Guidelines for Energy Efficiency”, including energy efficiency obligations in tenant lease agreements as well as embedding energy efficient culture in operations and business functions, transforming the existing stock to best available technology, including all these initiatives in the site’s roadmap to energy efficiency.**

To achieve these three principles to achieve energy efficiency, there are factors that must be investigated and established for the site concerned.

## 2. Key Factors to Successfully applying the principles of Energy Efficiency for an existing site

To apply the principles of energy efficiency successfully as outlined here, one must have knowledge of the site’s energy consumption. It is imperative to know the quantity of energy demand and identify drivers for the energy consumption. This will allow determination of whether energy consumption is controlled or out of order, so that action can be taken accordingly to restore order or bring clarity around the energy consumption of the site such that it is predictable. Knowing the technologies that make up the energy demand including their contribution to the total energy demand is imperative to allow focus of effort, investment, and policy to achieve energy efficiency. It is also key to understand and consider the organization that owns the site, their culture, financial imperatives, business focus, technical acumen of operational and engineering staff.

In summary, the following key factors are vital in preparation for applying the principles of energy efficiency:

3.1 Know the energy consumption of the site:

- (a) Identify drivers of energy consumption of the site
- (b) Identify the baseload energy demand of the site
- (c) Identify the significant energy users of the site (technical) making up over 70% of the site

This can be particularly challenging where large sites that lack sub-metering are concerned. Rendering a site even more complex is when there are multiple stakeholders utilizing energy in the case of landlord and tenants are concerned

3.2 Know the significant energy using technologies installed at the site together with the installation context

- (a) Lighting technologies (CFLs, halogens)
- (b) HVAC (heating or no heating) – put in emails of the visits from each airport in the next paper
- (c) Steel and glass structures with three “triple volume”

3.3 Know the site’s management/organization’s appetite for the implementation of energy efficiency

- (a) Company culture and business focus
- (b) Financial aspects such as return on investment, feasibility, internal rate of return
- (c) Technical aspects such as maintenance support for the technology and the ability of internal staff to operate the technology

### 3. CONCLUSIONS

Addressing energy efficiency in developing countries goes beyond component optimization or optimization of the system that the component forms a part of, it involves looking at the entire value chain from where energy is derived, including reviewing the energy source itself especially in the context of global warming due to increasing carbon emissions from traditional fossil fuel energy sources. The approach to energy efficiency when addressing the demand side, must be from a component, to system that the component operates within and the drivers of the system’s energy consumption.

To ensure that energy efficiency is achieved for a living site, it is vital to chart a roadmap to energy efficiency that ensures:

- no inefficient energy loads are added to the site’s energy grid,
- tenants occupying space on site comply with energy efficiency obligations
- existing technologies consuming energy are migrated towards best available technology and
- energy efficient culture is embedded in the business and its processes.

To apply these principles to achieve energy efficiency, it is important that the quantity of energy consumed at the respective site, the significant energy using technologies as well as their contribution to the total energy consumption is known. This will allow focus for efforts, policies, development of “Standards and Guidelines for Energy Efficiency” and which tenants will need audits towards compliance with energy efficiency. Understanding what motivates the business and the culture of the owners of the site will guide the nature of interventions to be motivated for successfully applying energy

efficiency. Investigating these factors will allow the application of the principles for achieving energy efficiency resulting in an energy efficient site within a defined duration of time.

#### REFERENCES

1. Aznar, A., Logan, J., Gagne, D., Chen., E., "Advancing Energy Efficiency in Developing Countries", National Renewable Energy Laboratory, April 2019.
2. Surekha, B., Hegde, M. N., & Jagadish, K. S. (2016). Energy and building materials. *International Journal of Civil Engineering*, 5, 13-24.
3. Türkoğlu, S.P., Karadoğan, P. S. O., "The Role and Importance of Energy Efficiency for Sustainable Development of the Countries", *Proceedings of 3rd International Sustainable Buildings Symposium (ISBS 2017)*, January 2018.
4. Kumar, A. P., & Manieah, D. (2019). Crashworthiness behaviour of capped cylindrical aluminium tubular structures subjected to lateral compression. *Int J Mech Prod Eng Res Dev*, 9, 1167-1172.
5. "Energy Efficiency Baseline Study", Department of Minerals and Energy Pretoria, Report number 2.3.4 – 03 Final Report October 2002
6. <https://www.quora.com/How-many-forms-of-energy-are-there-in-the-universe>, accessed 16 October 2020
7. KUMAR, C., Vijayalakshmi, B., Ramesh, C., & Pandian, S. C. IMPROVEMENT IN ENERGY AND AVOIDING PACKET ERRORS IN TCP BY CODA MECHANISM.
8. HeWu, W., XiaoBin, Z., MingGao, O., "Energy and environmental life-cycle assessment of passenger car electrification based on Beijing driving patterns", *Technological Sciences*, April 2015 Vol.58 No.4: 659–668
9. Kumar, A. P., & Sundaram, M. S. (2018). An axial crushing characteristics of hybrid kenaf/glass fabric wrapped aluminium capped tubes under static loading. *Int J Mech Prod Eng Res Dev*, 8(6), 201-206.
10. National Research Council 2007. *Coal: Research and Development to Support National Energy Policy*. Washington, DC: The National Academies Press. ISBN 978-0-309-11022-8
11. United States Energy Information Administrator, <https://www.eia.gov/energyexplained/electricity/delivery-to-consumers.php>, accessed 27 October 2020
12. <https://instrumentationtools.com/what-is-hvac-system/>, accessed 13 November 2020
13. <https://www.ledrise.eu/blog/led-linear-lamp-design/>, accessed 13 November 2020
14. <https://cobus-spaces.com/can-classroom-design-affect-focus-and-productivity/>, accessed 13 November 2020

## CHAPTER 6. ENERGY CONSUMPTION AND ENERGY EFFICIENCY OF AIRPORTS: A CASE STUDY OF AIRPORTS IN SOUTH AFRICA

The chapter presents an investigation of the site energy consumption of the nine ACSA airports, analysing the typical facilities installed at the airports to establish the drivers of the energy consumption, quantify the base load energy consumption, and identify significant energy users constituting more than 70 % of the site's total energy consumption.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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<http://www.tjprc.org/view-archives.php>

## ENERGY CONSUMPTION AND ENERGY EFFICIENCY OF AIRPORTS: A CASE STUDY OF AIRPORTS IN SOUTH AFRICA

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### ABSTRACT

*Energy efficiency is vital as the first step in reducing carbon emissions and, in many cases, it is more cost effective to eliminate energy wastage prior to changing energy generation sources to less carbon intensive energy sources such as renewable energy to mitigate climate change. To achieve energy efficiency for a site, it is key to understand the energy consumption of the site. This study investigates the site energy consumption of nine airports in South Africa. The paper presents the typical facilities installed at the airports, seeks to establish the drivers of the energy consumption, quantifies the base load energy consumption and significant energy users constituting more than 70 % of the site's total energy consumption. From these parameters the technology focus of all energy efficiency initiatives can be identified.*

**KEYWORDS:** *Energy efficiency in developing countries, base load energy consumption, drivers of Energy Consumption & significant energy users*

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### 1. INTRODUCTION

During the 20th century, the age when electricity became the preferred and popular choice for a source of energy for commercial, domestic and even industrial uses, whether derived from coal, oil or natural gas, not much consideration was given to energy efficiency. Energy efficiency is universally defined as getting the maximum output or benefit for a given energy input. Reducing energy wastage is often coupled with energy efficiency. Reducing energy wastage is not just about cost saving; in the bigger picture it allows for decreasing the rate of growth of energy demand considering the ever-growing human population and increase in urbanization in developing countries.

Three key factors point towards the potential for energy efficiency projects in the context of the Clean Development Mechanism:

- High growth in energy demand is forecast for developing countries, with electricity use expected to increase significantly in the future.
- The most cost-effective energy efficiency projects tend to be those implemented as part of new construction or major facility modification efforts and these types of projects are projected to be significant in developing countries.
- Most developing countries did not participate in the wave of energy efficiency investment that occurred (mostly in OECD countries) after the oil price shocks of the 1970s and 1980s. Consequently, there are still numerous opportunities to increase energy efficiency in developing countries (as well as in countries with economies in

transition) [1]

Only a few developing countries have undergone the end-use profiling of energy demand that allows for the successful planning of energy efficiency projects. Independent of the value this information might have for establishing baselines, national end-use energy analyses will be critical to the identification of cost effective, high-impact energy efficiency projects that might be implemented in developing countries[1].

Nearly all OECD countries have seen substantial improvements in the efficiency of their energy using equipment in the past two decades. As a result, they have established markets for energy-efficient products and services with personnel trained in the installation and maintenance of high-efficiency equipment [1]. The oil price shocks of the 1970s highlighted the economic benefits of energy efficiency and developed countries had the capital resources required to make energy efficiency investments. In contrast, the energy efficiency wave of the 1970s largely bypassed developing countries, where national governments lacked the institutional capabilities to implement and promote energy efficiency policies [1]. Today (and in the foreseeable future), new market drivers are expanding the energy efficiency sector in developing countries. Some key trends in the energy efficiency sector include:

- Subsidy removal. In recent years, many developing countries have begun to decrease or remove energy subsidies. This makes the true cost of energy more apparent to end-users and increases the incentives for efficiency.
- Restructuring and privatisation. Restructuring of the electricity sector is typically undertaken to open the power sector to competition and encourage outside investment. In the course of restructuring, many countries are privatising their state-owned utilities and major industries, which generally increases the pressure on companies to cut costs and increase efficiency.
- Demand-side management (DSM). Governments struggling with power supply problems, brown outs, black outs and increasing electricity demand, often encourage energy efficiency through DSM. DSM is viewed as a means of implementing load management and energy conservation initiatives to mitigate these problems.
- Construction boom. Economic growth in developing countries has led to a construction boom, expanding the demand for greenfield energy efficiency projects, specifically those related to building envelope and control technologies.
- Environmental concerns. A growing interest in energy efficiency is coming from the threat local and global environmental problems, including global climate change and concerns for resource scarcity [1].

Increased energy efficiency is one of the highlighted objectives in the European strategy for smart, sustainable, and inclusive growth. Improving energy efficiency in energy-intensive industry is thus becoming increasingly important. From an industrial perspective, improved energy efficiency is recognized as providing several direct economic benefits, apart from indirect benefits such as increased competitiveness and higher productivity. Energy costs for European energy-intensive foundry industries represent about 5 % to 15% of the added value. Two main means of reducing energy costs can be identified. First, enterprises can apply supply side management, e.g. through investments in new electricity production or negotiating lower prices with their energy suppliers. Second, enterprises can apply demand side management, e.g. adopt energy management practices at plant level within four principal areas: energy-efficient technologies, load management, energy conversion, and encouraging more energy-efficient behaviour (energy conservation). Energy management has

received increased attention in regard to policy formulation, both in the form of Long-Term Agreements (LTA) and Voluntary Agreements (VA). Moreover, standards for energy management have been set internationally, e.g. the ISO 50001. Recent research shows that when adoption of energy saving technology goes hand-in-hand with energy management practices the energy efficiency potential is higher [2].

To establish the focus of technologies for energy efficiency initiatives and energy management programmes, it is important to know the site's energy consumption in terms of its drivers, its base load and the significant energy users of the site up to at least 70%. These key factors were investigated and established for nine airports in South Africa, namely, OR Tambo International Airport in Gauteng, Cape Town International Airport in the Western Cape, King Shaka International Airport in Durban, Port Elizabeth International Airport, East London Airport, Bram Fischer International Airport in Bloemfontein, George Airport, Upington International Airport, Kimberley Airport. These nine airports are owned and operated by Airports Company South Africa.

## 2. INVESTIGATING THE ENERGY CONSUMPTION OF NINE AIRPORTS IN SOUTH AFRICA

### 2.1 Describing the nine air ports in the case study

Airports Company South Africa (ACSA) was formed in 1993 as a public company under the Airports Act (No. 44 of 1993) and, although majority owned (74.6%) by the South African Government, is legally and financially autonomous and operates under commercial law. Over the years, the company has transformed a fragmented infrastructural parastatal into a focused, customer driven, efficient and commercially successful business, whose airports have become critical success factors in the Brand South Africa campaign. The company has the South African Government through the Department of Transport as a major shareholder and is thus regarded as a state-owned company (SOC) in terms of the Public Finance Management Act (PFMA). The company owns and manages a network of nine airports in South Africa, including the three main international gateways of O.R. Tambo International, Cape Town International and King Shaka International Airports. Other airports in the Airports Company South Africa network are Port Elizabeth International Airport, East London Airport, Bram Fischer International Airport in Bloemfontein, George Airport, Upington International Airport and Kimberley Airport. These nine airports operated and owned by ACSA facilitated the movement of 42 million passengers and about 380,208 tonnes of cargo between 1 April 2018 and 31 March 2019.

While the airports' passenger numbers pre-COVID-19 pandemic (and global lockdown), have been steadily increasing, their energy consumption has been steadily decreasing. Even with construction activities over the years depicted in Figure 1, the electricity consumption of the airports has been decreasing. Figure 1 depicts actual electricity consumption numbers from the national electricity grid as well as the yield of solar photovoltaic (PV) plants as per their beneficial operation dates as outlined in Table 1. The reduction in grid electricity consumption can be seen in Figure 2.

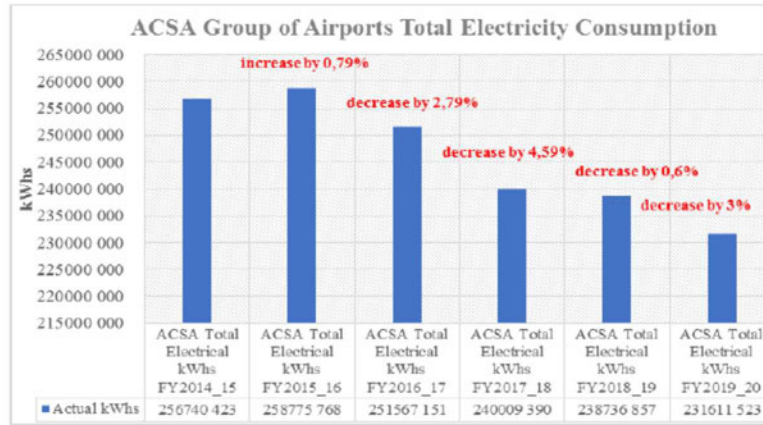


Figure 1: 6-year view of ACSA’s Nine Airports Total Electricity Consumption

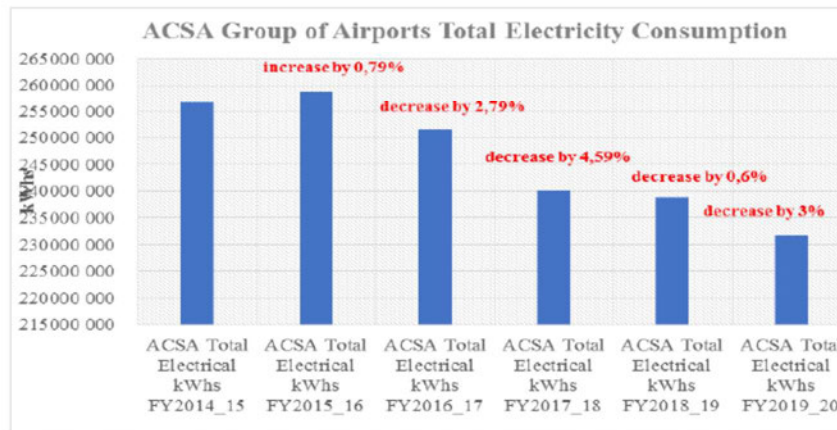
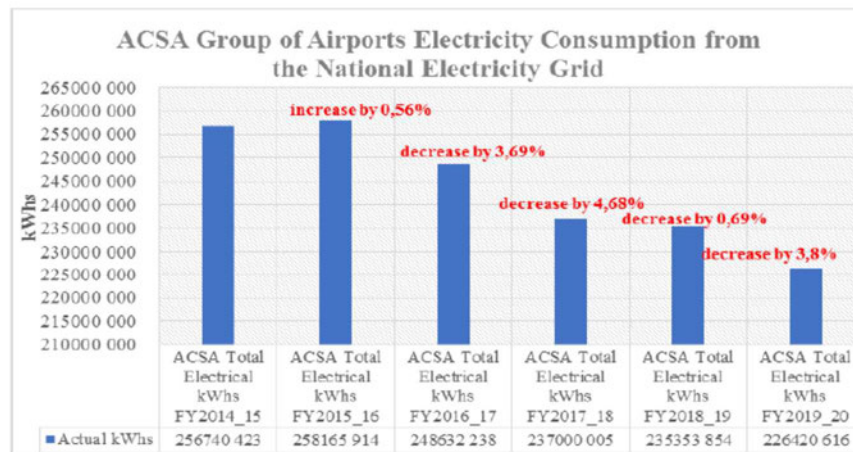


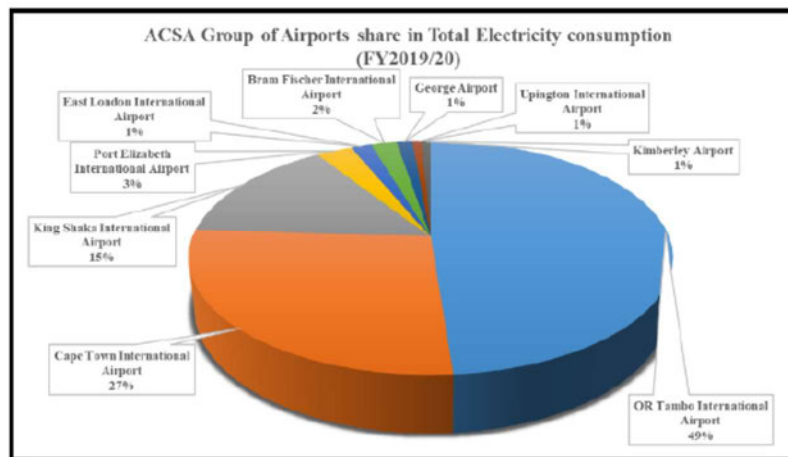
Figure 2: 6-Year View of ACSA’s Nine Airports Electricity Consumption from the National Electricity Grid



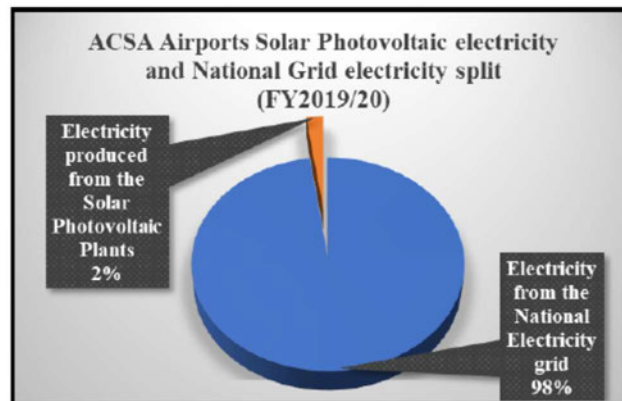
**Table 1: Airports’ Solar Photovoltaic Plant Installations**

Airport	Solar Photovoltaic Plant Peak Capacity	Date of Beneficial Operation
George Airport	750kWp	October 2015
Kimberley Airport	500kWp	May 2016
Uptington International Airport	500kWp	May 2016
Bram Fischer International Airport	750kWp	December 2018
Port Elizabeth International Airport	1MWp	July 2019

The percentage contribution of each airport to the total energy consumption for the period 1 April 2019 to 31 March 2020 (FY2019/20) can be seen in Fig.3, the ratio of solar PV yield to electricity consumption from the grid is in Figure 4.



**Figure 3: Airport split in Electricity Consumption**



**Figure 4: Solar PV and National Electricity Grid Split**

The energy reduction of the airports differs annually, this is due to project execution timing and organizational dynamics involved in the execution. Making a business case is key to ensuring that a project is approved for funding. To determine where energy efficiency efforts should be focussed, it is imperative to understand where most of the energy is consumed. Table 2 shows the typical facilities at the airports.

Table 2: Airports facilities

Airport	Onsite facilities as at 2020	Average of annual maximum energy demand
O R Tambo International Airport	Passenger Terminal Buildings and passenger boarding bridges that include commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, fire fighting facilities, Jet A1 fuel storage and hydrant network, runways, taxiways. Three hotels, car rental facilities and wash bays, car parking lots, office buildings, warehouses, cold storage rooms, maintenance storage and stock rooms, bus staging areas, vehicle fuelling stations.	16 MVA
Cape Town International Airport	Passenger terminal buildings and passenger boarding bridges that include commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, fire fighting facilities, Jet A1 fuel storage and hydrant network, runways, taxiways. One hotel, car rental facilities and wash bays, car parking lots, office buildings, warehouses, cold storage rooms, maintenance storage and stock rooms, bus staging areas, vehicle fuelling stations.	10.5 MVA
King Shaka International Airport	Passenger terminal buildings and passenger boarding bridges that include commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, fire fighting facilities, Jet A1 fuel storage and hydrant network, runways, taxiways. Car rental facilities and wash bays, car parking lots, office buildings, cold storage rooms, maintenance storage rooms, bus staging areas, vehicle fuelling stations.	5.7 MVA
Port Elizabeth International Airport	Passenger terminal building that includes retail stores, restaurants, luggage conveyor belts, waste sorting area, water storage tanks, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, fire fighting facilities, Jet A1 fuel storage and hydrant network, runways, taxiways, car rental facilities and wash bays, car parking lots, office buildings.	1.24 MVA
East London Airport	Passenger terminal building that includes restaurants, baggage conveyor belts, waste sorting area, office areas, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, fire fighting facilities, Jet A1 fuel storage tank, runways, taxiways. Car rental facilities and wash bays, car parking lots, office building.	0.8 MVA
Bram Fischer International Airport	Passenger terminal buildings that include restaurants, baggage conveyor belts, waste sorting area, water storage tanks, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, fire fighting facilities, Jet A1 fuel storage and hydrant network, runways, taxiways. Hospital, car rental facilities and wash bays, car parking lot, office building.	0.66 MVA

George Airport	Passenger terminal building that includes restaurants, baggage conveyor belts, waste sorting area, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, fire fighting facilities, Jet A1 fuel storage tank, runway, taxiways. Car rental facilities and wash bays, car parking lots, office building.	0.7 MVA
Upington International Airport	Passenger terminal building that includes restaurants, baggage conveyor belt and carousel, water storage tank, HVAC packaged plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, fire fighting facilities, Jet A1 fuel storage tank, runways, taxiways. Car rental facilities and wash bays, car parking lot, office building.	0.33 MVA
Kimberley Airport	Passenger terminal building that includes a cafe, baggage conveyor belt and carousel, HVAC decentralized units. Aprons (parking bays for aircraft), air traffic control tower, radar tower, fire fighting facilities, Jet A1 fuel storage tank, runways, taxiways. Car rental facilities and wash bays, car parking lot, office building.	0.3 MVA

**2.2 Determining Drivers of Energy Consumption at the Nine Airports in the Case Study**

The common misconception is that passenger numbers at airports drive the airports’ energy consumption. This can be easily tested using the airports’ passenger throughput and energy consumption data. Figure 5 to Figure 13 shows the airports’ regression analysis of energy consumption against their passenger numbers for a period of 12 months from 1 April 2019 to 31 March 2020.

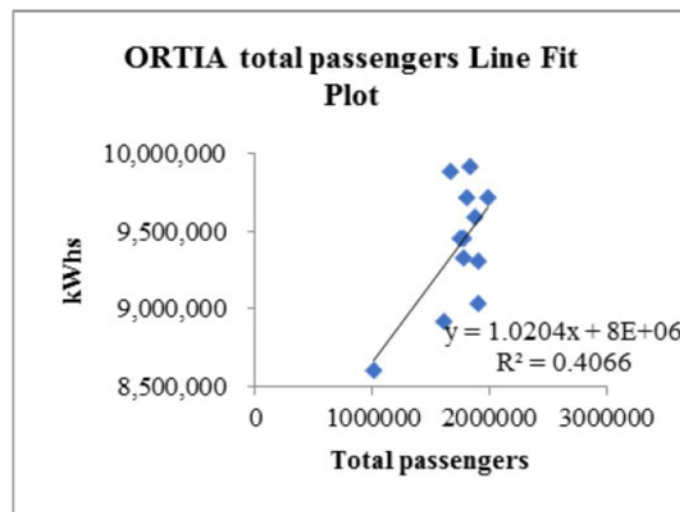
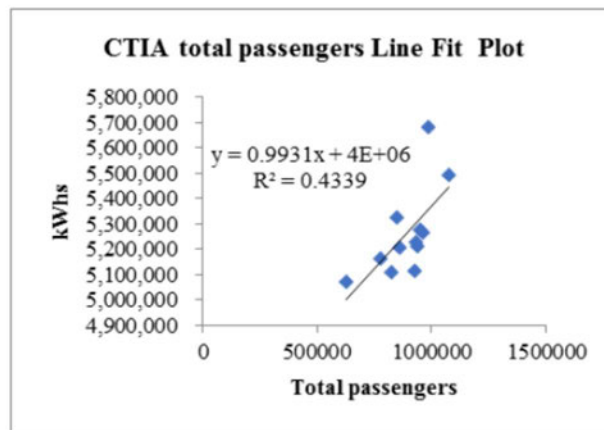
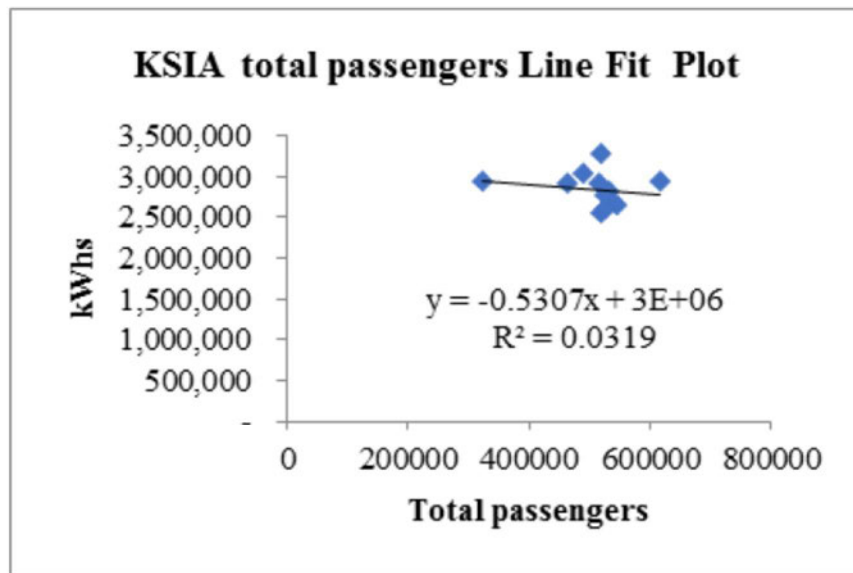


Figure 5: OR Tambo International Airport’s (ORTIA) Energy Consumption Regression Analysis for Passenger Numbers



**Figure 6: Cape Town International Airport’s (CTIA) Energy Consumption Regression Analysis for Passenger Numbers**

Figure 5 shows that the correlation of OR Tambo International Airport’s (ORTIA’s) energy consumption with passenger numbers is not strong. The  $R^2$  value is 0.4066 which means that 40% of the time there is a correlation between energy consumption and passenger numbers. The slope shows energy consumption increases when passenger number increase, but due to the weak correlation, passenger numbers are not a driver for the airport’s energy consumption. Figure 6 shows that there is a weak correlation between Cape Town International Airport’s (CTIA’s) energy consumption and passenger numbers (43.39%,  $R^2 = 0.4339$ ).and for these instances. At these times there is an increase in energy consumption with passenger numbers increase, but due to the weak correlation, passenger numbers are not a driver for the airport’s energy consumption.



**Figure 7: KingShaka International Airport’s (KSIA) Energy Consumption Regression Analysis for Passenger Numbers**

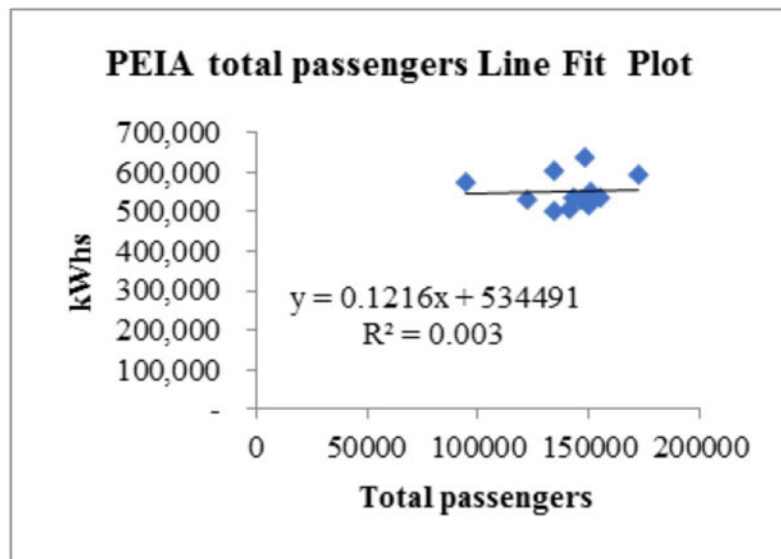


Figure 8: Port Elizabeth International Airport’s (PEIA) Energy Consumption Regression Analysis for Passenger Numbers

Figure 7 shows that for King Shaka International Airport (KSIA), there is almost no correlation (3.19%,  $R^2 = 0.319$ ) between its energy consumption and passenger numbers, in fact the slope is negative, i.e. there is an energy consumption decrease with passenger number increase. Thus, passenger numbers are not a driver for the airport’s energy consumption. Figure 8 shows that for Port Elizabeth International Airport (PEIA) there is 0.3% ( $R^2 = 0.003$ ) correlation between energy consumption and passenger numbers. The slope is almost a vertical line, i.e. there is no increase in energy consumption with passenger numbers. Thus, passenger numbers are not a driver for the airport’s energy consumption.

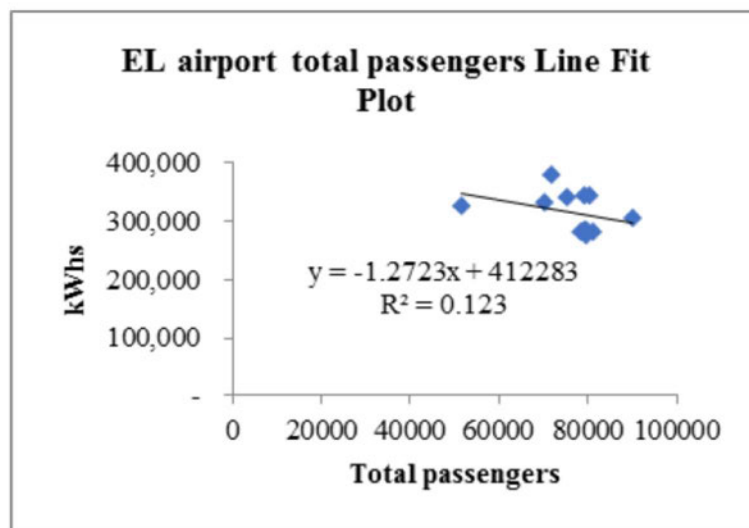
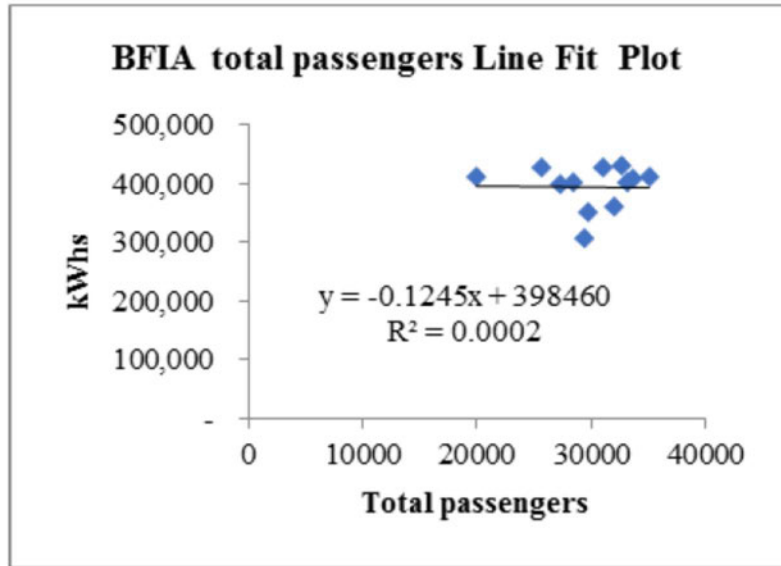
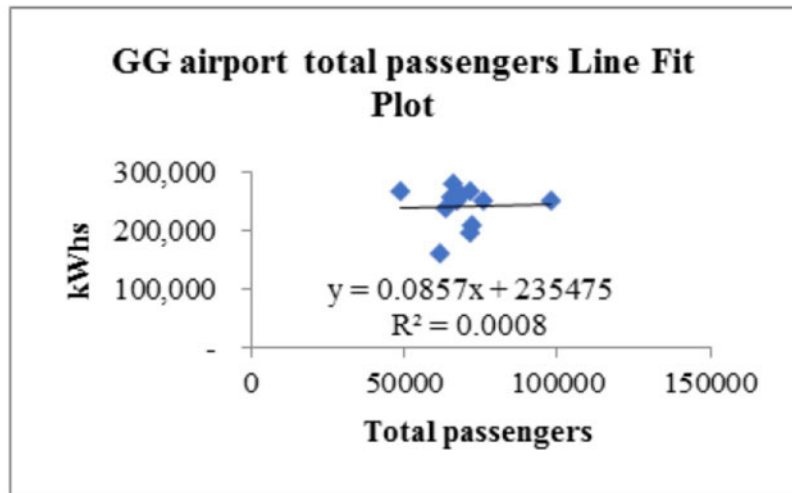


Figure 9: East London Airport’s (EL Airport)Energy Consumption Regression Analysis for Passenger Numbers

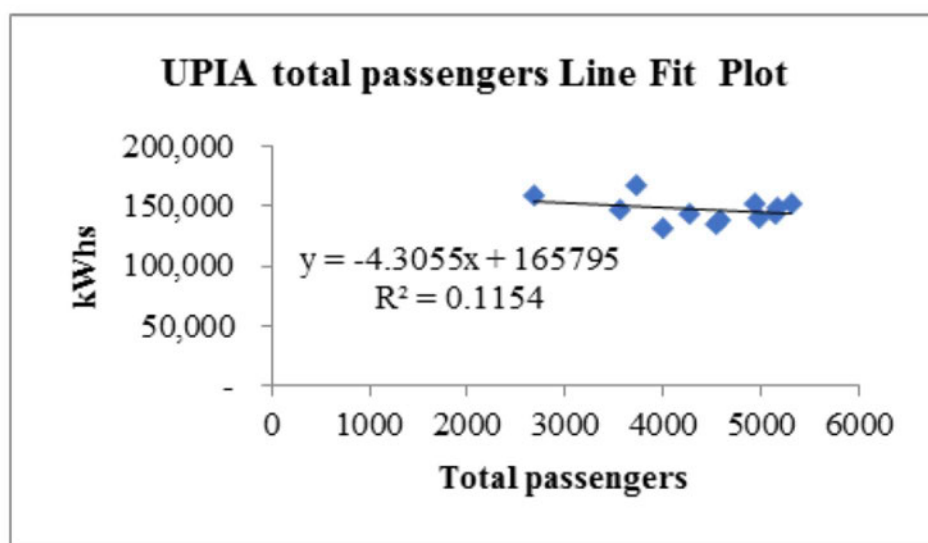


**Figure 10: Bram Fischer International Airport’s(Bfia) Energy Consumption Regression Analysis for Passenger Number**

Figure 9 shows a weak correlation of 12.3% ( $R^2 = 0.123$ ) between East London (EL) Airport’s energy consumption and passenger numbers. The graph shows a negative slope meaning that energy consumption decreases when passenger numbers increase. Due to this weak correlation, passenger numbers are not a driver for the airport’s energy consumption. Figure 10 shows that Bram Fischer International Airport’s (Bfia’s) energy consumption has almost no correlation (0.02%,  $R^2 = 0.0002$ ) with its passenger numbers. From the slope of the graph, energy consumption decreases when passenger numbers increase. Due to the weak correlation, passenger numbers are not a driver for the airport’s energy consumption.

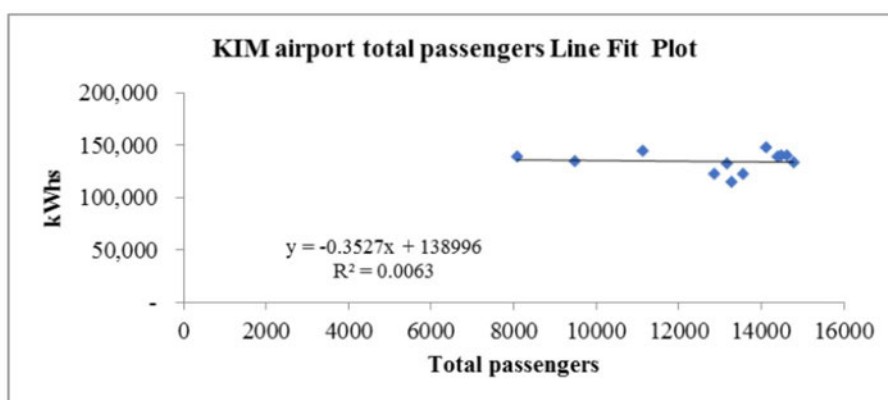


**Figure 11: George Airport’s (GG Airport) Energy Consumption Regression Analysis for Passenger Numbers**



**Figure 12: Upington International Airport’s (UPIA) Energy Consumption Regression Analysis for Passenger Numbers**

George (GG) Airport’s energy consumption correlation with passenger numbers shown in Fig. 11 shows almost no correlation (0.08%,  $R^2 = 0.0008$ ). The slope is also close to zero, showing that there is no real increase or decrease of energy consumption with passenger numbers increase. The very weak correlation shows that passenger numbers is not a driver of the airport’s energy consumption. Figure 12 shows that Upington International Airport’s (UPIA’s) energy consumption has 11.54% ( $R^2 = 0.1154$ ) correlation with passenger numbers. The slope of the graph indicates that energy consumption decreases when passenger numbers increase. Due to the weak correlation passenger numbers are not a driver of energy consumption.



**Figure 13: Kimberley Airport’s (KIM airport) Energy Consumption Regression Analysis for Passenger Numbers**

Figure 13 shows that KIM airport’s energy consumption does not have much correlation (0.63%,  $R^2 = 0.0063$ ) with passenger numbers. The negative slope indicates that the energy consumption decreases with passenger number increase. Due to the low correlation, passenger numbers are not a driver for the airport’s energy consumption.

It can be seen from these graphs that there is no correlation of passenger numbers with energy consumption. The

R<sup>2</sup> values of the regression analysis for all these airports are significantly below 1. This also implies that an increase in passenger numbers does not mean an increase in energy consumption and the converse is true, i.e., if passenger numbers decrease, this does not mean that energy consumption will linearly decrease. This means that greater occupancy does not have a significant effect on energy consumption.

The regression-based approach is the most rigorous approach and can provide the most accurate results when applied effectively. This approach utilizes regression analysis to provide normalized facility-level energy consumption and annual and total changes in energy intensities that account for the effects of variables such as changes in production and weather. This provides facility and corporate energy managers with a better window into how they use energy at the facility, and whether their energy management efforts are succeeding [3].

Due to the large capacity of centralized HVAC systems at airports, the weather is another possible driver that can be tested for correlation. KSIA and CTIA only have cooling functions in their centralized HVAC systems, therefore their regression analyses will only be using cooling degree days (CDD) while the rest of the airports will have a summation of cooling and heating degree days or degree days (CDD + HDD or DD). Refer to Figures 14 to 22.

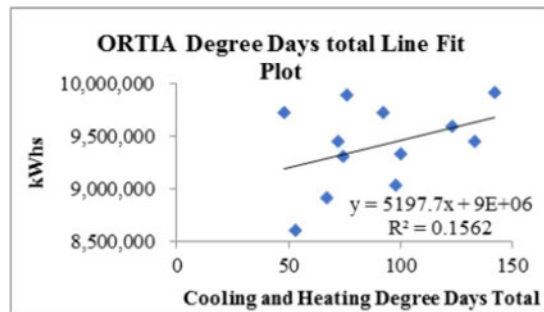


Figure 14: OR Tambo International Airport's(ORTIA) Energy Consumption Regression Analysis for the weather

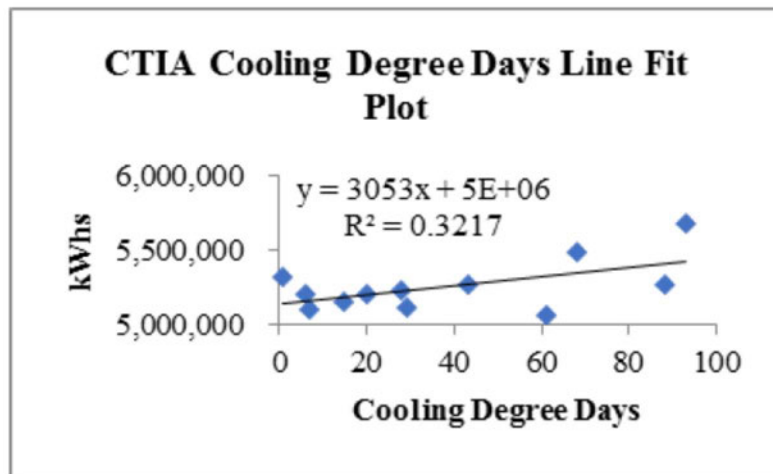


Figure 15: Cape Town International Airport's (CTIA) Energy Consumption Regression Analysis for the Weather

Figure 14 shows that ORTIA’s energy consumption has 15.62% ( $R^2 = 0.1562$ ) correlation with the need for space heating and cooling as provided by its HVAC system. This is a weak correlation and its slope being positive indicates that energy consumption increases with the need for HVAC. The weather, however, is not a driver of ORTIA energy consumption. Figure 15 shows that there is a 32.17% ( $R^2 = 0.3217$ ) correlation between CTIA’s energy consumption and need for space cooling. The slope of the graph indicates that the energy consumption increases with the need for space cooling. The weather is not a driver for CTIA’s energy consumption as the  $R^2$ -value is low.

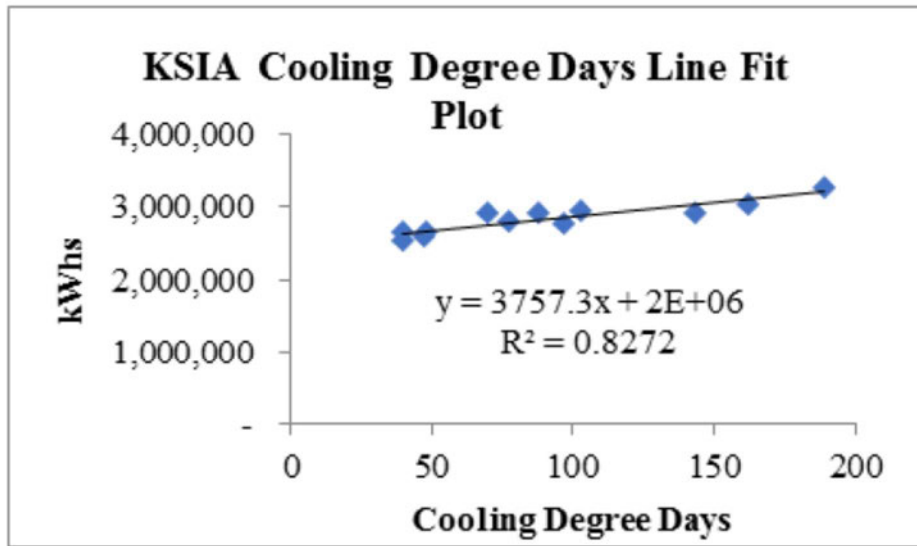


Figure 16: King Shaka International Airport’s (KSIA) Energy Consumption Regression Analysis for the weather

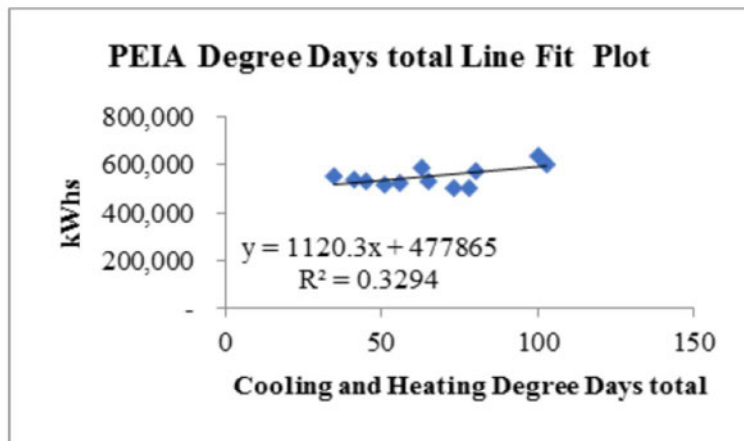


Figure 17: Port Elizabeth International Airport’s (PEIA) Energy Consumption Regression Analysis for the weather

Figure 16 shows a definite and strong correlation (82.72%,  $R^2 = 0.8272$ ) between KSIA’s energy consumption with the need for space cooling. There is a direct relationship, i.e. energy consumption increases with the need for space

cooling. Due to the high  $R^2$  value, the need for space cooling (weather) is a driver of KSIA's energy consumption. PEIA's energy consumption has a 32.94%,  $R^2 = 0.3294$ ) correlation with the need for space cooling and heating, and the slope of the graph (Figure 17) shows that energy consumption increases with the demand for HVAC. The low  $R^2$  value, however, shows that the need for space cooling and heating is not a driver of the airport's energy consumption.

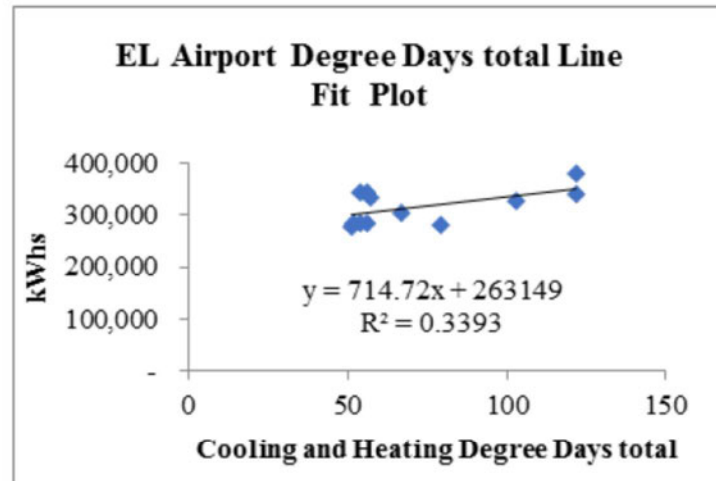


Figure 18: East London (EL) Airport's Energy Consumption Regression Analysis for the Weather

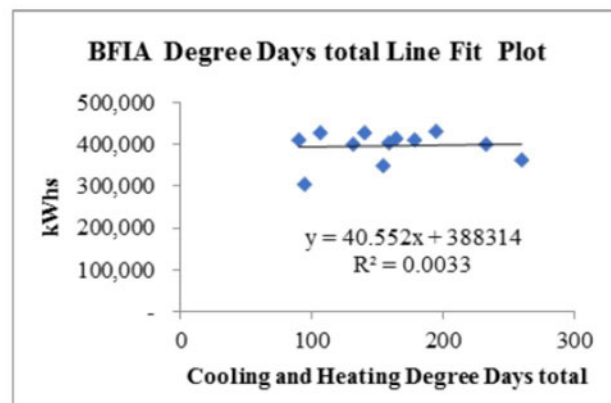


Figure 19: Bram Fischer International Airport's (BFIA) Energy Consumption Regression Analysis for the weather

Figure 18 shows that there is a weak correlation (33.93%,  $R^2 = 0.3393$ ) of EL Airport's energy consumption with the need for space cooling and heating. The positive slope indicates that energy consumption increases with the need for space cooling and heating. Space cooling and heating is not a driver of the airport's energy consumption due to the low  $R^2$  value. Figure 19 shows that there is a 0.33% ( $R^2 = 0.0033$ ) correlation between BFIA's energy consumption and the need for space heating and cooling. The slope of the graph is positive indicating that energy consumption increases with the need for space heating and cooling. However, space heating and cooling is not a driver of the airport's energy consumption due to the very weak  $R^2$  value.

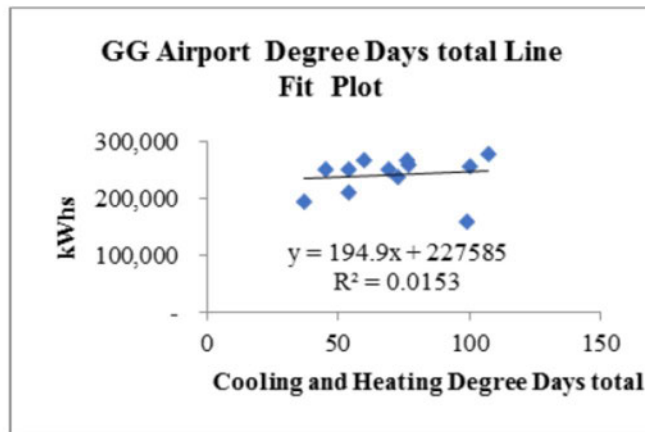


Figure 20: George Airport’s (GG Airport’s) Energy Consumption Regression Analysis for the Weather

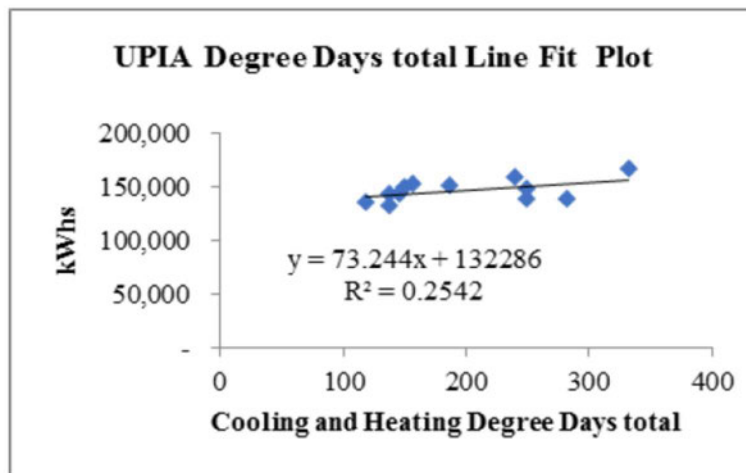


Figure 21: Upington International Airport’s (UPIA)Energy Consumption Regression Analysis for theWeather

Figure 20 shows GG airport’s energy consumption has a weak correlation (1.53%,  $R^2 = 0.0153$ ) with the need for space heating and cooling. The positive slope indicates that energy consumption increases with the need for space heating and cooling. The need for space heating and cooling is not a driver of the airport’s energy consumption due to the low  $R^2$  value. Figure 21 shows UPIA’s energy consumption has a 25.42 % ( $R^2 = 0.2542$ ) correlation with the need for space heating and cooling. The positive slope indicates that energy consumption increases with the need for space heating and cooling. However, space heating and cooling is not a driver for the airport’s energy consumption due to the low  $R^2$  value.

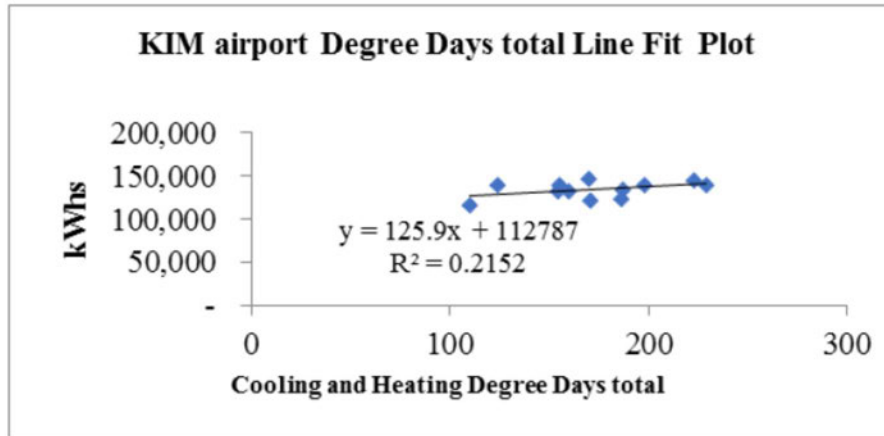


Figure 22: Kimberley Airport's (KIM Airport's) Energy Consumption Regression Analysis for the weather

Figure 22 shows that KIM airport's energy consumption has a weak correlation with the need for space heating and cooling (21.52 %,  $R^2 = 0.2152$ ). The positive slope indicates that energy consumption increases with the need for space heating and cooling. The need for space heating and cooling is not a driver of the airport's energy consumption due to the low  $R^2$  value.

When reviewing the regression analysis of the weather, one can see that KSIA has the most significant correlation to cooling degree days ( $R^2 = 0.8$ ) compared to the rest of the airports in the group. King Shaka International Airport has the newest technology and control systems for their HVAC system.

The general conclusion in energy management when there are no identifiable, clear drivers for energy consumption, is that the energy consumption is not predictable and in some cases is interpreted to be 'out of control'. Being an operational site where many tenants and other stakeholders use energy on the site and join and leave the site without any conscious monitoring of this process from an energy perspective, it is difficult to predict future monthly energy consumption, so one can say the situation is 'out of control' in this regard. When activity and routine is fairly constant or changes are negligible in the context of the total load, it may seem that the energy consumption is predictable and when energy saving projects are undertaken, one can see the difference in the total figures as can be seen in Figure 1 in the energy savings for the airports over the last 5 years. For example, if a Measurement and Verification (M&V) exercise for an energy saving project were to be executed, one will realize that the impact of the energy savings could be significantly reduced in the total energy context caused by unaccounted for increases in electrical loads. The converse is also true in that it could be that no concerted effort has been made to save energy, however, the airports in general reflect energy saving. For the ACSA group of airports, both cases were observed, however, the reduction in energy consumption is largely due to energy saving projects being undertaken over the years.

Figure 23, Figure 24, Figure 25 and Figure 26 show 30-minute interval electricity demand profiles for 4 days of the year in different seasons for OR Tambo International Airport and Figure 27, Figure 28, Figure 29 and Figure 30 for Cape Town International Airport.

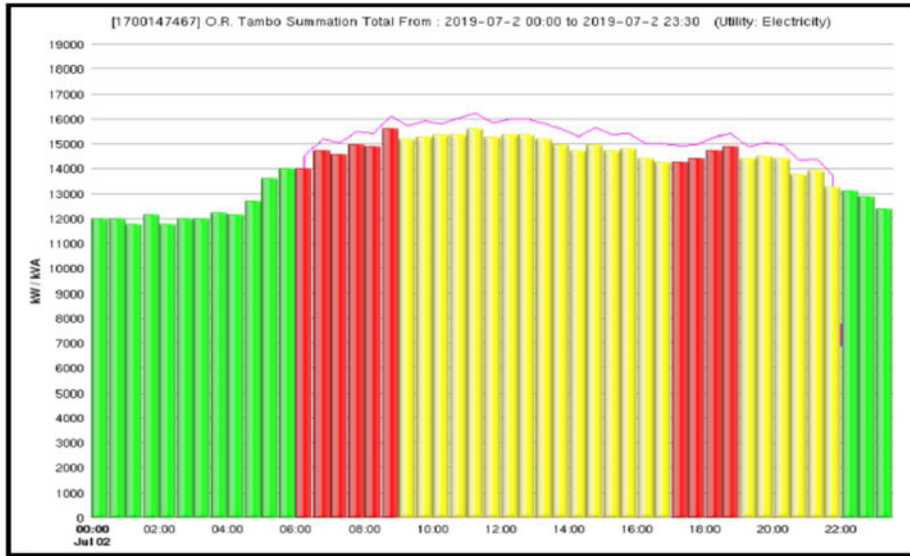


Figure 23: ORTIA 24-hour demand in 30-minute Intervals for the 2<sup>nd</sup> July 2019

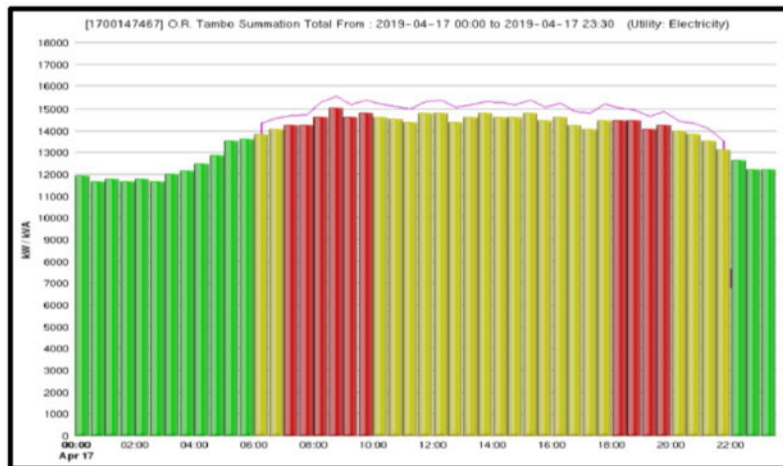


Figure 24: ORTIA 24-hour demand in 30-minute Intervals for the 17<sup>th</sup> April 2019

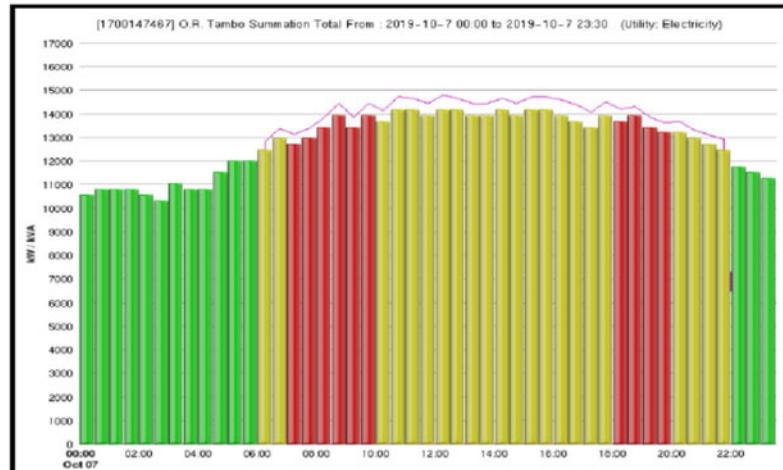


Figure 25: ORTIA 24-hour demand in 30-minute intervals for the 7<sup>th</sup> October 2019

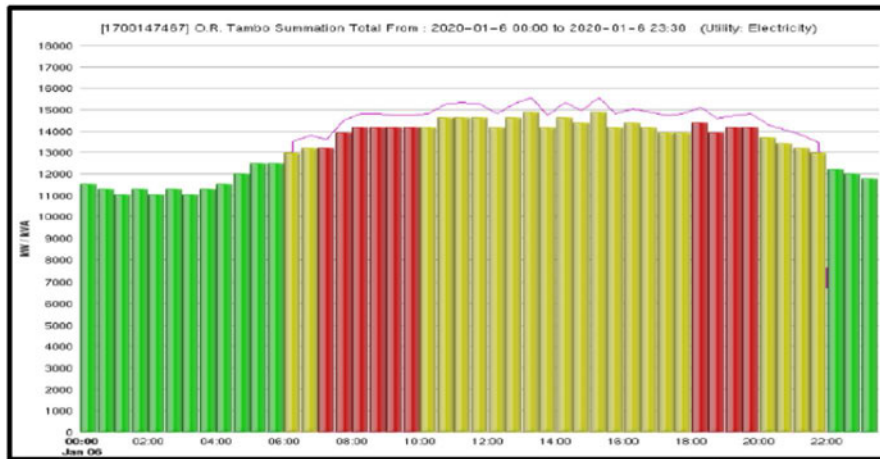


Figure 26: ORTIA 24-hour demand in 30-minute intervals for the 6<sup>th</sup> January 2020

In Figure 23, for ORTIA for the 2<sup>nd</sup> July 2019, the maximum electrical demand is 15.5MVA, the minimum electrical demand and base load is 11.5MVA, which is 74% of the total electrical load. The green bars show the off-peak electricity tariff period, the red bars show the peak electricity tariff period and the yellow bars show the standard electricity tariff period. In Figure 24, the maximum electrical demand is 15MVA, the minimum electrical demand and base load is 11.5MVA, which is around 76% of the total electrical load. Similarly, for the 7<sup>th</sup> October 2019 (Figure), the maximum electrical demand is 14.1MVA, the minimum electrical demand and baseload is 10.3MVA, 73% of the total electrical demand and for the 6<sup>th</sup> January 2020 (Figure 26), the maximum electrical demand is 15MVA, the electrical demand and baseload is 11MVA, 73% of the total electrical load. A similar pattern can be observed for CTIA in the following figures.

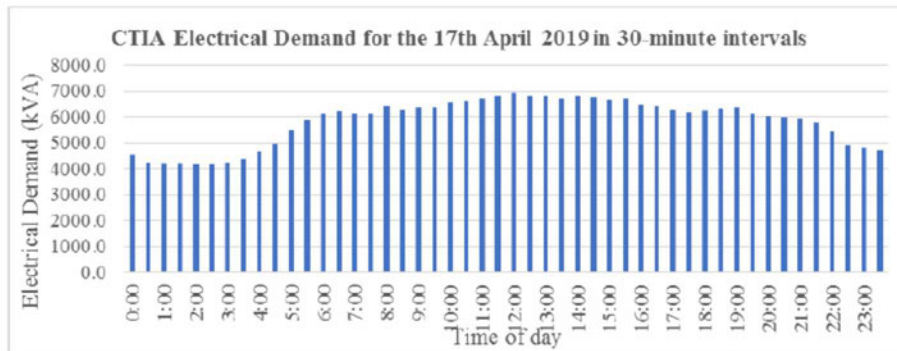


Figure 27: CTIA 24-hour demand in 30-minute intervals for the 17<sup>th</sup> April 2019

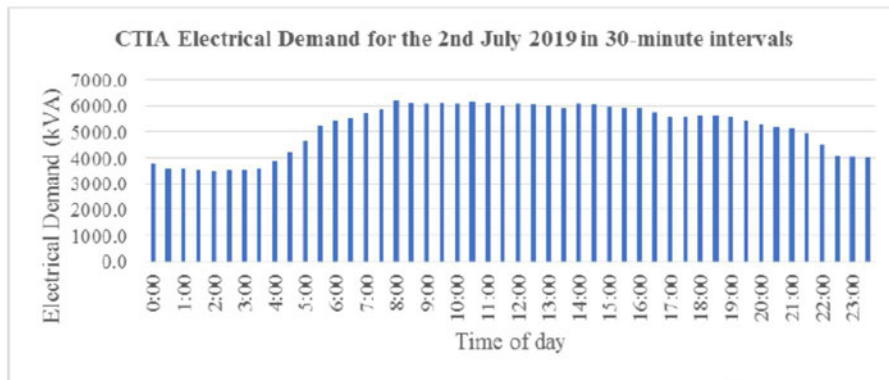


Figure 28: CTIA 24-hour demand in 30-minute intervals for the 2<sup>nd</sup> July 2019

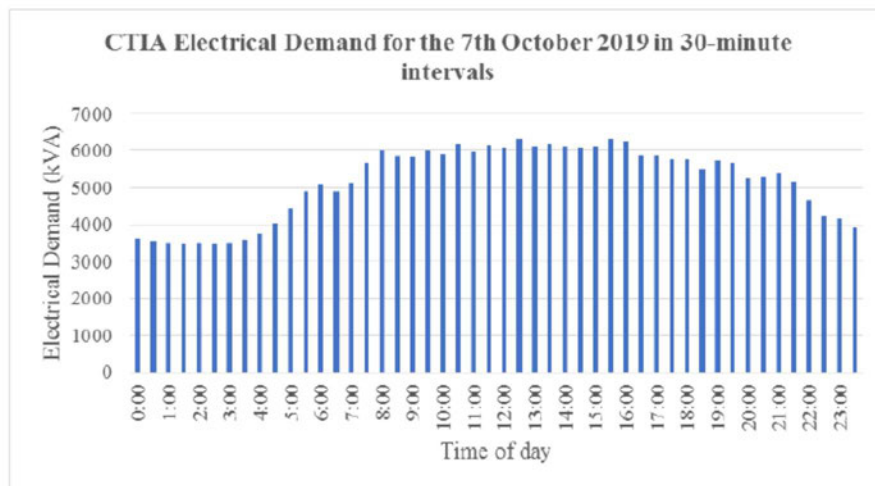
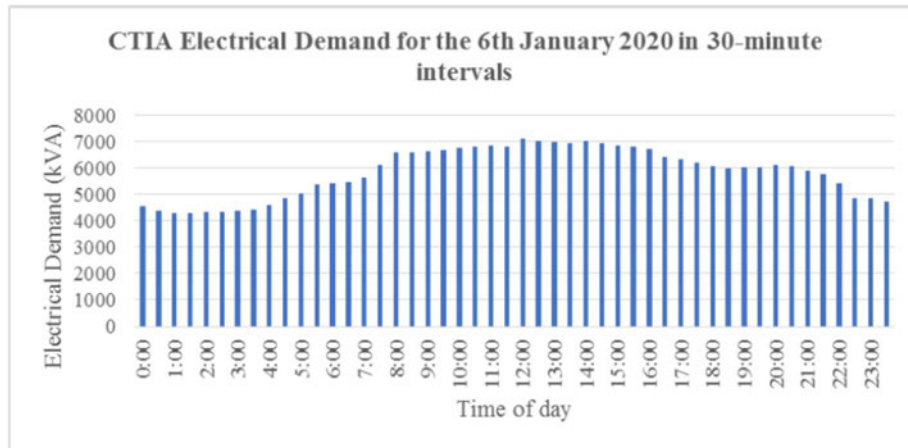


Figure 29: CTIA 24-hour demand in 30-minute intervals for the 7<sup>th</sup> October 2019



**Figure 30: CTIA 24-hour demand in 30-minute intervals for the 6<sup>th</sup> January 2020**

In Figure 27, for CTIA on the 17<sup>th</sup> April 2019, the maximum electrical demand is 7MVA, the minimum electrical demand and baseload is 4.2MVA, which is 60% of the total electrical load. In Figure 28, for CTIA on the 2<sup>nd</sup> July 2019, the maximum electrical demand is 6.3MVA, the minimum electrical demand and baseload is 3.5MVA, which is around 55% of the total electrical load. Similarly, for the 7<sup>th</sup> October 2019 (Figure 29), the maximum electrical demand is 6.4MVA, the minimum electrical demand and baseload is 3.5MVA, 54% of the total electrical demand and for the 6<sup>th</sup> January 2020 (Figure 30), the maximum electrical demand is 7MVA, the electrical demand and baseload is 4.3MVA, 61% of the total electrical load.

The maximum demand and baseload for each airport varies everyday, what was presented here is just a sample of the results and was not meant to show the highest or lowest electrical demands, but to demonstrate the baseload percentage of the total electrical load. Daily electrical demand profiles for the other airports are not available, however, due to the similarity in design, facilities installed and operations of the airports, the electrical energy consumption profile patterns can be inferred to be similar. These electrical demand profiles tell us that airports have a large baseload, at least 50%.

### 2.3 Determining and quantifying significant energy users for airports

From an investigation conducted at King Shaka International Airport in 2013 to determine the airport's significant energy users, the lighting energy consumption was measured at the electrical distribution boards during the day and at night. From the readings, it can be seen that lighting is the most significant energy user, taking up around 61% of the total airport load during the day and around 69% during the night as shown in Figure 31 and Figure 32 respectively.

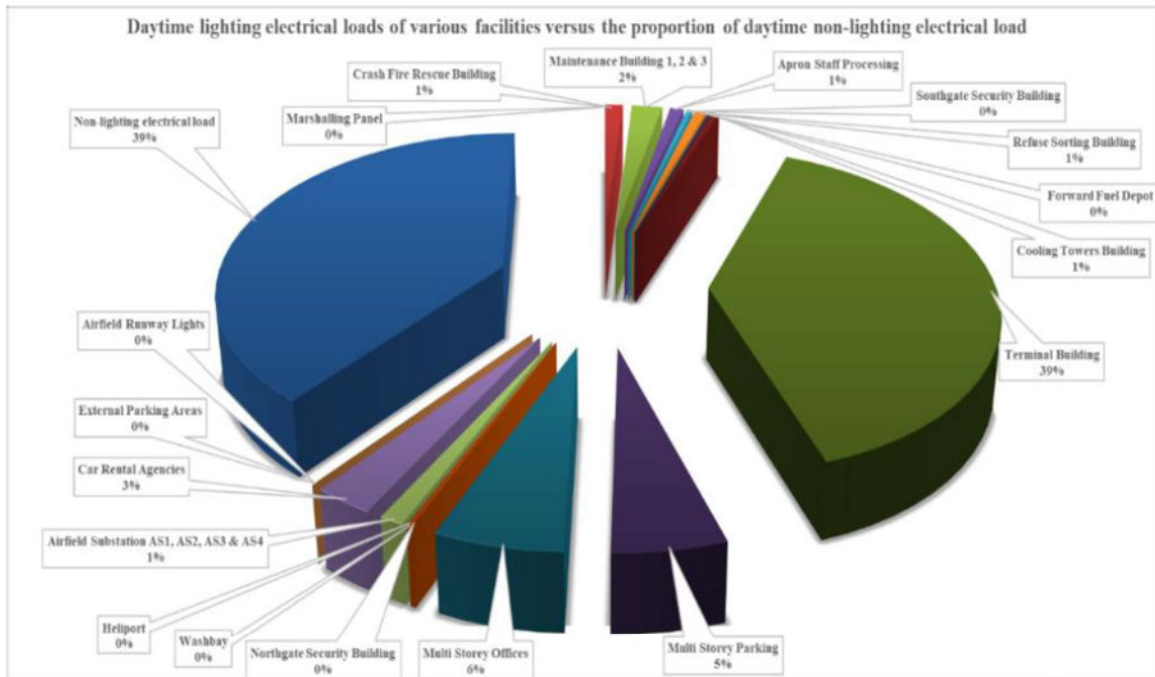


Figure 31: King Shaka International Airport daytime lighting load versus non-lighting load [4]

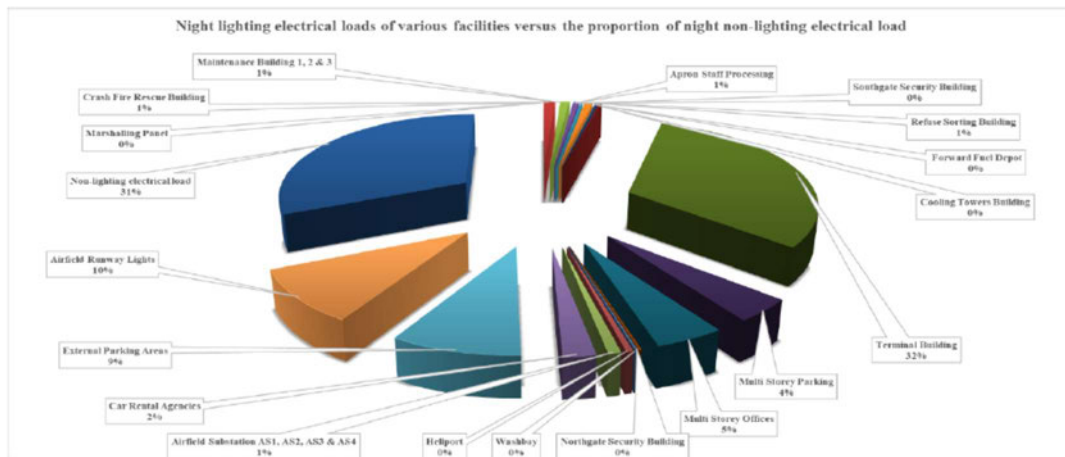


Figure 32: King Shaka International Airport night lighting load versus non-lighting load [4]

A similar study was conducted for KSIA’s air-conditioning load and it was shown that the primary air conditioning plant electrical load makes up at least 19% of KSIA’s total load, as shown in Figure 33. Figure 34 shows the split in energy consumption of the chillers, cooling towers, and the various sets of pumps. Chillers take up 41% of the energy requirement, followed by cooling towers (21%) and the rest are split between the pumps. This means that chiller load is around 8% of the total airport electricity load.

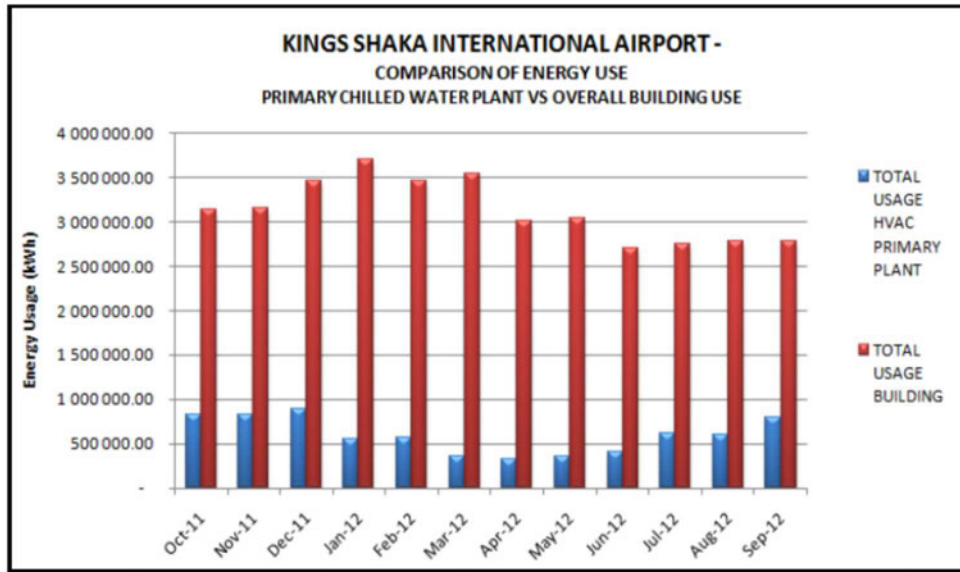


Figure 33: King Shaka International Airport’s HVAC Electricity Load and the Total Electricity Load [5]

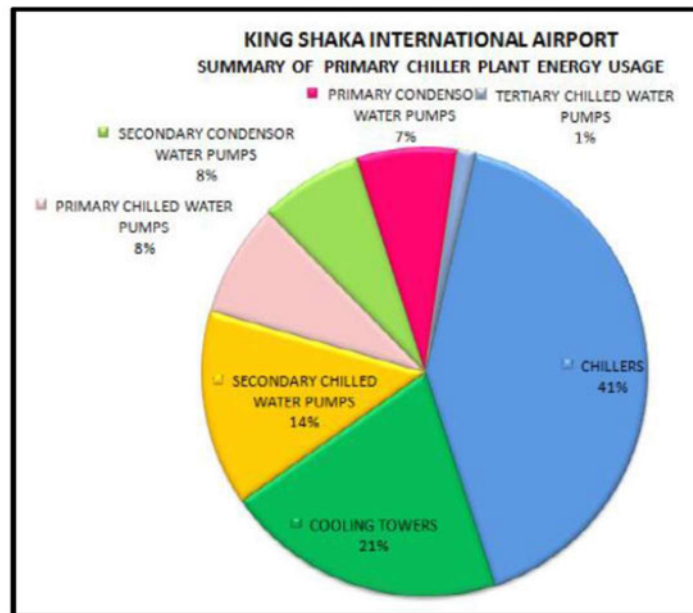


Figure 34: KSIA Chiller Plant Energy Usage Split [5]

Due to the facilities being very similar for the airports as can be seen in Table 2, it is estimated that lighting makes up at least 50% of an airport’s total load for the international airports (ORTIA, CTIA, KSIA) and at least 60% for regional airports (PEIA, EL, BFIA, GG, UPIA, KIM) due to their lack of full baggage handling systems and large onsite HVAC plants. Air conditioning can make up around 20% to 30% of an airport’s electricity consumption depending on whether the airport provides heating as well as cooling. The airports also incorporate a significant motor and pump load due to the various systems such as wastewater systems, Jet A1 fuel systems, baggage handling systems, fire-fighting systems, potable

water systems, irrigation systems, etc. Motors also drive large fans for fire compliance extraction systems and compliance with building ventilation.

In summary, the significant energy users are lighting (around 50%), HVAC (around 30%), and there are also a significant number of pumps, motors and fans within the airport facilities. Achieving energy efficiency requires a focus on the significant energy users, i.e. lighting, HVAC, pumps, motors and fans. It will be beneficial too to address the architecture of new buildings, their envelope and determining the energy sources that will serve their energy demand as these factors also drive the energy demand of the significant energy users.

### **3. CONCLUSIONS**

This study has established that passenger numbers are not drivers for energy consumption for any airport. KSIA's energy consumption showed an 82% correlation with the cooling degree days (CDD). KSIA has the newest air conditioning system (11 years old) in the group and is the best maintained when compared to the other airports.

As seen with the daily electricity demand profiles for ORTIA and CTIA, baseload energy consumption is at least 50% of the total energy consumption. With the services being very similar from airport to airport, it can be inferred that the baseload energy consumption is at least over 50% for each airport. Airports generally by design have high baseloads due to the lighting load of runways and the requirement that they be on at all times during operational hours and due to the general design of the terminal buildings and other facilities which are leased to various external tenants. This makes it extremely difficult to control and standardize lighting technologies and control. Due to the double and triple ("triple volume") glass and steel structure design of terminal buildings, the air conditioning load is significant and demand is driven by weather conditions and not as a result of the number of people within the building. It is evident from the energy consumption of KSIA that lighting is a significant energy user taking up at least 61% of the airport's energy consumption in the day and 69% at night, while air conditioning takes up 19% of the total energy consumption.

Due to facilities across the airports being similar, including designs and operations, it can be concluded that the significant energy consuming items are related to lighting which takes up at least 50% of an airports' energy consumption, and air conditioning which can take up to between 20 % and 30% of an airport's energy consumption, depending on whether the airport's air conditioning system also provides heating. Pumps, motors and fans are also significant energy using technologies as they are used in vast quantities to pump water, fuel, sewerage and storm water and for ventilation (fans).

To achieve energy efficiency across the airports, the focus of energy efficiency initiatives should be on lighting, air-conditioning, pumps, motors, and fans which have been established to be significant energy using technologies. The best available technologies (BAT) should be adopted for lighting, including lighting control technologies. For air-conditioning systems, reducing air-conditioning demand as well as controlling the air conditioning supply to respond to demand should be the focus of energy efficiency initiatives. Pumps, motors, and fans should be sized correctly for the application and be energy efficient technologies. Focussed technology and control of demand will ensure that energy efficiency reduces total energy consumption significantly and effectively.

### **ACKNOWLEDGEMENTS**

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#### REFERENCES

1. *Violette, D., Mudd, C., Keneipp, M., "An Initial View on Methodologies for Emission Baselines: Energy Efficiency Case Study" OECD Environment Directorate and International Energy Agency, 2001.*
2. *Thollander, P., Backlund, S., Triami, A., Cagno, E., "Beyond barriers - A case study on driving forces for improved energy efficiency in the foundry industries in Finland, France, Germany, Italy, Poland, Spain, and Sweden", Applied Energy, (111), 636-643, 2013.*
3. *"Better Plants: Energy Intensity Baseline and Tracking Guidance", US Department of Energy, February 2015.*
4. *Data readings from Pellew, C., National Cleaner Production Centre - South Africa, "Lighting Assessment at King Shaka International Airport", 14 August 2014.*
5. *Kasaval, S., Ferreira, J., Spoomaker and Partners Inc. "Preliminary energy audit report for the HVAC installation at King Shaka International Airport", 22 November 2012.*
6. *Integrated Demand Management Market End-Use Knowledge Base UI 240-66204213 (Eskom Integrated Demand Management, South Africa, August 2014)*

## **CHAPTER 7. ENERGY EFFICIENCY FOR AIRPORT INFRASTRUCTURE: A CASE STUDY OF THE IMPLEMENTATION OF ENERGY EFFICIENCY FOR AIRPORTS IN SOUTH AFRICA**

This chapter presents the groundwork completed in the process of transitioning the ACSA airports to being energy efficient.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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<http://www.tjprc.org/view-archives.php>

## ENERGY EFFICIENCY FOR AIRPORT INFRASTRUCTURE: A CASE STUDY OF THE IMPLEMENTATION OF ENERGY EFFICIENCY FOR AIRPORTS IN SOUTH AFRICA

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### ABSTRACT

*Achieving energy efficiency sustainably for a site involves the elimination of energy wastage, reduction in carbon footprint and reduction in operational costs while at the same time achieving standardization across operations and maintenance practices. Achieving energy efficiency with the current climate change crisis requires that energy efficiency be established from energy source to end user. Energy efficiency for a site also involves ensuring that energy intensive equipment, plant and other devices are consuming as little energy as possible, while maximizing their work output. This paper presents the groundwork completed in the process of transitioning airports in South Africa to being energy efficient.*

**KEYWORDS:** *Energy efficiency in Developing Countries, Energy Savings, Energy Conservation, Forms of Energy, Energy Conversion Efficiencies, Energy Management, Standards and Guidelines for Energy Efficiency & Holistic Approach to Energy Efficiency*

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### 1. INTRODUCTION

One of the most attractive benefits to improvement in energy efficiency in buildings is lower energy costs. Other benefits likely to be realized from energy efficiency investments in buildings are:

- Reducing energy use for space heating and/or cooling and water heating;
- Reduced electricity use for lighting, office machinery and domestic type appliances;
- Reduced maintenance requirements;
- Improved comfort;
- Enhanced property value.

The importance of energy efficiency in the building sector is especially significant in developing countries owing to the increase in new construction with opportunities to employ efficient materials and best practices.[1]

The first principle of energy efficiency as outlined by [2] requires the efficient matching of energy source to energy need resulting in the shortest energy conversion route from the energy source to the energy need and that the energy source is the best choice for cost effectiveness, satisfaction of the need, and closeness to zero carbon emissions. The second principle of energy efficiency as outlined by [2] requires that a holistic approach be taken when it comes to energy efficiency, which means considering the energy consuming device or technology, the

system that the device or technology is a part of, as well as factors affecting the system and factors affected by the system. The third principle states that one must ensure that implementation of energy efficiency meets business imperatives and supports operations, culminating in a “Standards and Guidelines for Energy Efficiency” document that can be adopted as a policy by the site/organization. These standards and guidelines must include device types, system types and preferred designs that will apply when new buildings and facilities are constructed, and replacement cycles for existing buildings and facilities are executed.

This paper presents the application of these principles for the airports in South Africa owned and operated by Airports Company South Africa to begin the transformation of the airports to be energy efficient over the course of a specific period of time. The paper presents the implemented approach to energy efficiency to ensure that airports are transitioned to energy efficient operations and infrastructure reducing energy wastage. The matching of low carbon energy sources to the energy need is presented with consideration of the operating environments, commercial markets, staff technical acumen and business imperatives. The “Standards and Guidelines for Energy Efficiency” document to be adopted as a policy for airports to transition towards energy efficiency is presented together with the principles from which they were derived.

## 2. APPLYING THE PRINCIPLES OF ENERGY EFFICIENCY FOR AIRPORTS

The energy consumption of airports in South Africa, specifically the O R Tambo International Airport, Cape Town International Airport, King Shaka International Airport, Port Elizabeth International Airport, East London Airport, Bram Fischer International Airport, George Airport, Upington International Airport and Kimberley Airport, have a characteristically high base load (at least 50%). Their significant energy users are lighting (about 50% to 60%) and air conditioning (20% to 30%) and a significant number of pumps motors and fans. [3]

The airports’ energy needs for their buildings and infrastructure are primarily satisfied by electricity supplied by South Africa’s national electricity provider, Eskom. Eskom derives most of its power from coal-fired power plants. The airports’ mechanical road vehicles are fuelled with diesel and petroleum. Some of the airport sites use LPG for cooking at the various commercial restaurants. The focus of the application of energy efficiency is on the significant energy users that are carbon intensive, i.e., electricity consumption from the grid and specifically on significant energy users of the electricity.

### 2.1 Finding the Most Suitable Energy Source to Match the Energy Need

The first principle to achieving energy efficiency as per [2] is to ensure that the most suited energy source is selected to serve the energy need.

**Principle One: Match energy source and energy need using the shortest energy conversion route from the energy source to the energy end use and ensure that the energy source is the best choice for cost effectiveness and is as close to zero carbon emissions as possible.**

The airports’ significant energy users are lighting and air conditioning. This principle is applied for these significant energy users.

#### (a) Lighting

The airport’s most significant energy user is lighting. Lighting is used not just for terminal buildings, office buildings,

commercial facilities such as hotels and transportation systems, car parks, streets, roads, and walkways, but also for the crucial purpose of lighting runways to assist aircraft to land and take-off safely. The lighting load being typically at least 50% of the airport's total load, the focus on ensuring that the lighting load is as efficient as possible is the key to reducing capital cost, carbon emissions and operational costs (including maintenance). Lighting is required during the day and at night for the terminal office and multi-storey parkades as well as the airfield including runways.

The best available technology for lighting that satisfies energy efficiency criteria is currently LED lighting. LED lighting technology consists of the same semiconductor materials that are used in solar photovoltaic technologies with different material treatments for performance according to its application (lighting or power generation). It will therefore be ideal to use solar energy to power the LED lighting that is needed during the daytime. It is the most efficient energy source for the energy need as it is the shortest route from the energy source to the energy end use and ensures that the energy source is the best choice for cost effectiveness and is as close to zero carbon emissions as possible (figure 1).

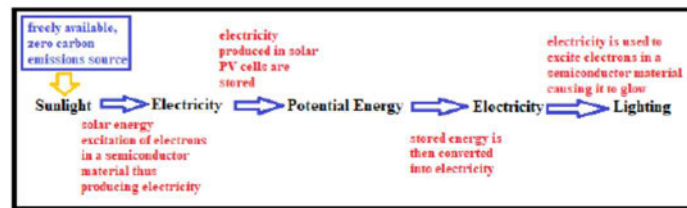


Figure 1: Solar Energy as an Energy Source for Lighting.

Figure 1 shows the typical commercially available solar powered LED lighting. It can be seen from the figure that there is one energy conversion between the same energy type, i.e., electricity is stored and then released. Energy storage is key for renewable energy sources such as solar energy and wind energy due to their availability being intermittent. At this stage, commercial storage options usually involve a battery pack and in commercial solar PV plants, the solar PV plant design includes energy storage or a grid-tie connection arrangement to overcome the intermittency related to solar energy. Technology development and lamp designs are yet to evolve to take advantage of direct conversion from solar energy to LED lighting.

#### (b) Space Conditioning (Heating, Ventilation and Air Conditioning – HVAC)

The second significant energy user at airports is for space conditioning. The demand for air conditioning is typically driven by the weather conditions; the higher the ambient temperature and thermal discomfort (high humidity), the greater the demand for space conditioning. Air conditioning involves two major energy users on the chilled water side, namely, the chillers and the cooling towers.

##### (i) Chillers

To produce chilled water, a refrigerant is compressed in a vapour compression cycle using a mechanical compressor which runs on electricity and is cooled by water (via cooling towers) or air (must be installed in an area where sufficient air intake is facilitated). The cooling output to electricity input (coefficient of performance or COP) of the commercial vapour compression chiller is usually between 3.0 and 3.8. Maintenance is the key to ensure that the COP of the chillers remains consistent during its useful life.

Due to the demand for cooling being proportional to the ambient temperature, this presents an opportunity to use the solar energy causing the demand for cooling to create the cooling effect. This is possible with absorption chiller technology available on the commercial market which uses heat to produce chilled water through the adoption of an absorbent such as lithium bromide and preferably water as a refrigerant for environmental sustainability (although ammonia is another option). The heat needed to drive the absorption cooling cycle can be harnessed from solar energy via solar thermal collectors. Alternately, if waste heat is available from another process on site, this can be harvested to power the absorption cooling cycle. This will be the most efficient energy process as it is the shortest route from the energy source to the energy need and significantly reduces carbon emissions to almost zero in running the chiller, with only a minimal amount of electricity being required to run a small pump that circulates the working fluids (Fig. 2). The absorption chiller adopting water as a refrigerant means that there is no global warming potential associated with the technology as there is with conventional vapour compression chillers.

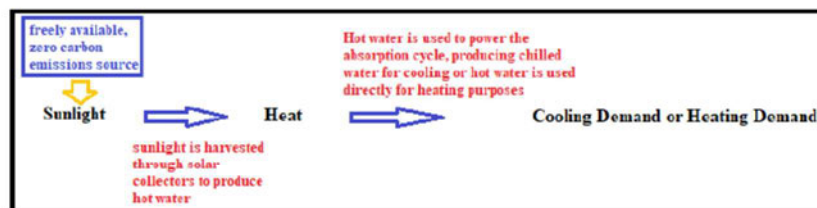


Figure 2: Solar Energy as an Energy source for Chillers in Air Conditioning Systems

A switch over valve within the absorption chiller allows for the solar heat harvested to be used for heating purposes. The technology for the solar thermal collector which harvests the solar heat should be chosen such that minimal heat is lost to the environment. Vacuum tube solar thermal collectors are most efficient in this respect. For larger commercial installations, utilizing solar energy may become a hurdle from a spatial point of view. Utilizing waste heat from a process plant (co-generation or trigeneration) may be a better arrangement to power absorption chillers in larger installations.

#### (ii) Cooling Towers

Cooling towers which are an integral part of ensuring that chilled water production is efficient by cooling the compressor through circulation of condenser water are another significant energy user in the air-conditioning system. Water-cooled chillers are intensive in energy and water consumption. Water loss due to evaporation in evaporative cooling towers in commercial size HVAC systems can make them expensive to operate. The energy consumption can also become increasingly expensive as the demand for cooling the condenser water increases. The energy is used for pumps circulating the water to the top of the cooling tower and the operation of fans for forced air induction when the demand for cooling increases. An environmentally sustainable method to achieve heat exchange is to use the stable ground temperature as a heat sink. This is ideal in South Africa where ground temperatures are stable below a certain ground depth. The configuration of the geothermal heat sink loop requires minimal energy to keep the condenser water moving and there is no water loss due to evaporation, Figure 3.

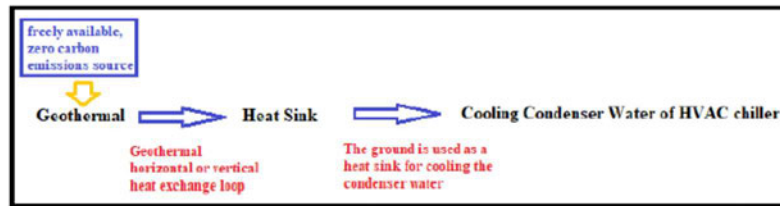


Figure 3: Geothermal Heat Sink used as an Energy Source to Cool the Condenser Water of Air Conditioning Systems.

Using solar heat as an energy source for HVAC absorption chillers with water as refrigerant and geothermal heat sinks in the place of cooling towers saves significantly on electricity and water and eliminates greenhouse gas emissions associated with conventional refrigerants. This type of system could be the most environmentally sustainable HVAC system that can be built with existing commercial technology and materials. It will also be most energy efficient in that when cooling is required, the energy to bring about that cooling is abundantly available.

## 2.2 Taking a Holistic Approach to Achieve Energy Efficiency

Taking a holistic approach to achieving energy efficiency and ensuring that the energy efficiency principles identified are captured in a “Standards and Guidelines for Energy Efficiency” document according to [2] is the next step in ensuring a site’s energy efficiency. These steps are captured across principle two and principle three as follows:

**“Principle Two: Take a holistic/systems approach when it comes to energy efficiency; this means considering the energy consuming device or technology, the system that the device or technology is a part of as well as factors affecting the system and factors affected by the system.**

**Principle Three: Ensure that the approach to implementation of energy efficiency meets business imperatives and supports operations based on “Standards and Guidelines for Energy Efficiency”. These standards and guidelines must include device types, system types and preferred designs that will apply when new buildings and facilities are constructed, and replacement cycles for existing buildings and facilities...”**

The following sections take a holistic approach to the significant energy users of airports, i.e., lighting, HVAC, pumps, motors, fans and “building architecture and envelope”. The “building architecture and envelope” impacts the demand for lighting and HVAC. The following sections will take a holistic/systems approach defining energy efficiency guiding statements that must be adopted by all users of the site. These guiding statements were derived for the airports and are clauses contained in their “Standards and Guidelines for Energy Efficiency” which are being implemented as a company policy for all new infrastructure, refurbishments and replacement projects.

### (c) Lighting Systems

Lighting requirements within buildings are regulated by South African National Standards and the Occupational Health and Safety Act 85 of 1993. Minimum lighting levels are specific and are legally binding in South Africa. It is a common practice for emphasis to be placed on the lighting technology being chosen, and other design factors of the lamp and its surroundings are usually neglected. Factors that affect the light output such as the luminaire, control gear and factors that affect the amount of light required such as the colour of paint, furnishings and surroundings are not always considered (figure 4).

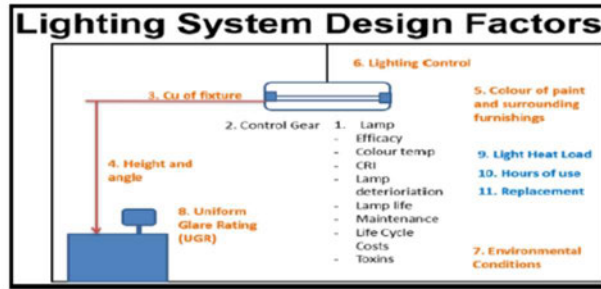


Figure 4: Lighting System Design Factors.

The following energy efficiency guiding statements referred to as “clauses” due to the “Standards and Guidelines for Energy Efficiency” being drafted according to the ISO format supports the organization’s financial, technological, and other business imperatives considering the risks, operational and maintenance requirements including practicality of its implementation. These clauses are derived from the lighting design factors presented in figure 4. The clauses guide new capacity projects, i.e., new office developments, expansions to terminal buildings and other commercial buildings being constructed at the airports to incorporate energy efficiency. The clauses are indicated in italics and the supporting information is not in italics.

- *LED lighting technology shall be used for all applications with respect to lighting and illumination.*
- *LED lighting having a Correlated Colour Temperature above 4000 Kelvin shall only be utilized in areas of transit and is limited to 5600K. Operational areas are recommended to have LED lighting with a Correlated Colour Temperature of 4000K.*
- *Lamps with a colour rendition index (CRI) of less than 65 shall not be used.*

Colour Rendering Indices (CRI) categories are as follows:

- 75 to 100 CRI – excellent colour rendition
- 65 to 75 CRI – good colour rendition
- under 65 CRI – poor colour rendition

(a) Lamp Efficacy shall be Greater than 80 Lumens per Watt

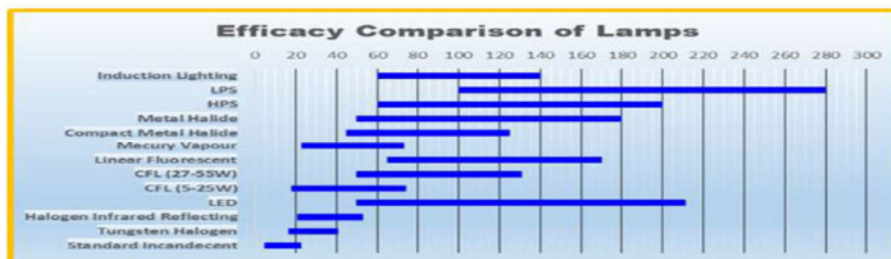


Figure 5: Efficacy Comparison of Lamps [4].

Figure 5 shows a comparison of lighting technologies and their efficacy ranges and that LED lighting has one of the best efficacies of the lighting technologies. The Low Pressure Sodium (LPS) lighting technology which is indicated to

have an efficacy that outperforms LED lighting has a poor CRI and is a popular choice for street lighting. Figure 6 shows the LED lamp key criteria and how these compare with other lighting technologies.

Lamp type	Luminous efficacy (lumens/watt)	Luminous output (lumens)	Wattage	CCT <sup>TM</sup> (typical/dominant wavelength)	CRI <sup>TM</sup>	Lifetime
LED white package (cool)	132 lm/W	139 lm	1.05 W	6500 K	75	50k hours
LED white package (warm)	78 lm/W	87.4 lm	1.12 W	3150 K	80	50k hours
LED lamp (warm)	62 lm/W	650 lm	10.5 W	3000 K	92	50k hours
OLED panel	23 lm/W	15 lm	0.65 W	2800 K	75	5k hours
HID <sup>TM</sup> (high watt) lamp system	120 lm/W 111 lm/W	37800 lm 341 W	315 W 341 W	3000 K	90	20k hours
Linear fluorescent lamp system	111 lm/W 97 lm/W	2890 lm 5220 lm	26 W 54 W	4100 K	85	25k hours
HID (low watt) lamp system	104 lm/W 97 lm/W	7300 lm	70 W 75 W	3000 K	90	12k hours
CFL	63 lm/W	950 lm	15 W	2700 K	82	12k hours
Halogen	20 lm/W	970 lm	48 W	2750 K	N/A	4k hours
Incandescent	15 lm/W	900 lm	60 W	3300 K	100	1k hours

Figure 6: U.S. Department of Energy Comparison of Lumens per Watt for Various Lamp Types [5]

Figure 6 shows that LEDs provide the most illumination, quality and have the longest lifespan for the least amount of power input.

**(b) LED**

Lamps shall only be eligible to be purchased from suppliers offering a five (5) year warranty as a minimum. It is recommended that LED lamps be replaced when their lumen depreciation is at 20%, which corresponds to 80% lumen output, and fluorescent lamps be replaced when their lumen depreciation is at 20%, which corresponds to 80% lumen output.

This clause is due to lamp life and lamp deterioration which depends on the type of microchip that is contained in the LED. There are two classes of microchips contained in LED lamps, one is a substandard efficiency microchip contained in lamps of suppliers who do not offer warranties and a premium efficiency microchip which usually carries a warranty of five (5) years. Refer to figure7 for the Lumen Maintenance Curve for various light types.

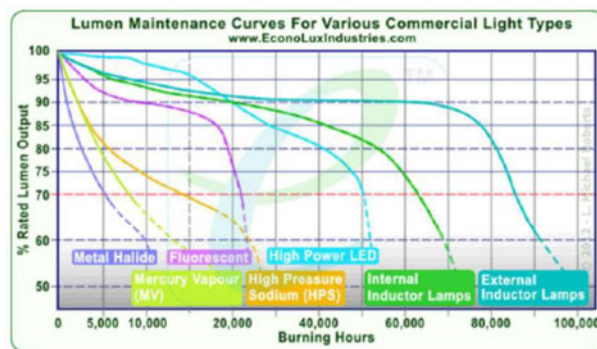


Figure 7: Lumen Maintenance Curves [6]

**(c) Technologies that have Toxic Components shall be Avoided**

Compact Fluorescent Lamps (CFLs) have mercury, phosphors, yttrium, etc. that harm the environment and therefore may

have special disposal requirements which carry significant cost. CFLs exhibit at least 2.5-times and 1.3-times higher human and eco-toxicity potentials than the LEDs, respectively.[7]

*(d) Magnetic ballasts shall not be used. A ballast factor as close as possible to 1 shall be accepted with the lower boundary being a ballast factor of 0.95.*

Electronic ballast factors range from 0.7 to 1.2 and are categorized as follows:

- 0.7 to 0.8 – Low ballast factor
- 0.85 to 1 – Normal ballast factor
- 1.13 to 1.2 – High ballast factor
- *For offices, boardrooms and ablution facilities, lighting shall be controlled according to human occupancy using occupancy sensors that adopt passive infrared and ultrasonic (dual) technology. For indoor passages and walkways, lighting shall be controlled according to motion using occupancy sensors that use passive infrared technology. For car park areas, lighting shall be controlled according to human occupancy, using sensors that increase lighting levels to 100% in human presence and decrease lighting levels to 40% in human absence. Street lighting shall be controlled by photocells according to the daylight levels available. All new projects and infrastructure refurbishments must incorporate a Digital Addressable Lighting Interface (DALI) that controls lighting according to demand. For lighting replacements during maintenance, this is a recommendation.*
- *Uniform Glare Rating (UGR) for lighting systems shall comply with ISO 8995.*
- *Interior furnishings shall have a ceiling reflectance (RC) of not less than 80% and wall reflectance (RW) of not less than 70%*

Figure 8 shows the coefficients of utilization in a room that has ceilings and walls in relationship to the room cavity ratio (RCR).

Report LS1 1101 Lamp: 400 Watt Clear Lumens: 50,000 Mounting Surface/Pendant		COEFFICIENTS OF UTILIZATION Zonal Cavity Method Effective Floor Cavity Reflectance 0.20										
		80			70			50			30	
RC		70	50	30	70	50	30	50	30	50	30	
RCR	1	94	91	89	91	88	86	83	81	78	77	
	2	88	84	80	86	81	78	77	74	73	71	
	3	83	77	72	80	75	70	71	67	67	65	
	4	78	71	65	75	69	64	66	61	63	59	
	5	73	65	59	70	63	58	60	56	58	54	
	6	68	58	52	66	58	52	55	51	53	49	
	7	63	54	48	61	53	47	51	46	49	44	
	8	59	49	43	57	48	43	46	41	45	40	
	9	55	45	39	53	44	38	42	37	41	36	
	10	51	41	35	49	40	35	39	34	37	33	

Figure 8: Photometric Table[4].

$$RCR = \frac{2.5 \times h \times \text{room perimeter}}{\text{room area}}$$

Where:

RCR is the room cavity ratio

$h$  is the room height

- In the case of lighting heat sinks for LED lamps being contained in the ceiling voids, return air systems shall not be taken from ceiling voids.

Lighting internal heat gains from non-industrial facilities are typically between 70% and 400 % that of internal heat gains from people in a typical office space.[9]

- The life of LED lighting shall be a minimum of 50 000 burning hours, except for the removable bulb type as in the GU10, MR16, pin-type and Edison screw type which shall be a minimum of 25 000 hours.
- For ease of maintenance and replacements, lighting installed in areas that are double volume and more shall incorporate a winch or similar mechanism that drops the light fitting down to a height reachable at floor level with a ladder for maintenance purposes, thus negating the need for other plant and machinery to reach up to the light fitting.
- Lighting for architectural and ambiance purposes shall follow the requirements in this document.
- All advertising, illumination and signage shall follow the requirements set out in this document.

### HVAC Systems

Ventilation requirements are regulated by the Occupational Health and Safety Act 85 of 1993 and SANS 10400 Part O is used in designing of HVAC systems for commercial applications. Much effort is placed on ensuring that the HVAC system's cooling and heating delivery meets the demand. This is usually the starting point of HVAC system design. The factors that affect the HVAC demand such as the orientation of the building and the envelope design, the windows and doors (fenestration) are not always addressed to effectively reduce the demand. HVAC design should start when the facility under construction is in planning stages. Figure 9 shows the HVAC system design factors.

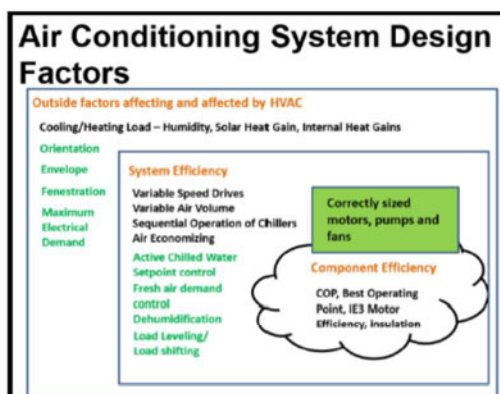


Figure 9: HVAC System Design Factors.

The following statements regarding the designing of HVAC systems are meant to guide projects for incorporation of energy efficiency in HVAC systems.

- To reduce HVAC demand, the following passive cooling interventions must be incorporated for all new buildings

and refurbishments:

- Double glazing or low emissivity glass
- Wind lobbies designed to reduce the amount of outside air entering the air-conditioned space through building entrances/exits
- Use of heat deflective paint to reduce the amount of solar thermal heat gain through the roof and brick/masonry walls.
- Low building overhangs designed to deflect solar thermal gain and yet allow a certain amount of outdoor lighting to reduce daytime lighting demand.
- All centralized HVAC systems shall incorporate fresh air demand control via Air Handling Units (AHUs) to accurately satisfy oxygen requirements within the space.
- All centralized HVAC systems shall incorporate air economizing which is "free air cooling".
- Return air shall be ducted and taken directly from the space and not filtered through the ceiling void; return air temperature shall be measured in the space.
- All centralized space cooling HVAC systems shall integrate Constant Air Volume (CAV) and Variable Air Volume (VAV) for cooling and heating load profiles in the terminal building. CAVs should be used to satisfy the cooling or heating base load whereas VAVs shall supply varying demand. This clause does not apply to air conditioning systems supplying IT core rooms and wire centres.

Figure 10 shows the rationale behind constant air volume and variable air volume feeds. The cooling baseload is the load that is required to always be served and the variable cooling load is meant to be served on demand. Choosing constant air volume and variable air volume in design allows for energy efficient design and technology selection of motors and fans.

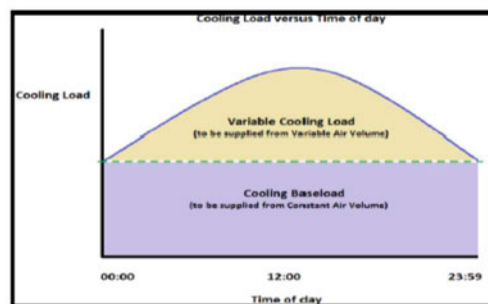


Figure 10: Cooling Load Profile and Type of Air Supply.

- All offices, whether on decentralized or centralized HVAC systems, shall be VAV and all fan coil units and other systems shall be variable refrigerant volume or variable chilled water flow.
- All decentralized systems shall incorporate inverter control for compressor-driven systems to ensure that varying HVAC demand is efficiently satisfied, and the energy rating shall not be less than the "A rating" as per the energy efficiency labelling system.

- All double volume buildings or structures shall be served from centralized HVAC systems.
- For all new buildings / infrastructure, a centralized HVAC system shall reuse condensate at the cooling towers of water-cooled HVAC systems.
- It is recommended that heat recovery from the condenser be considered for reuse according to a cost-benefit analysis. This cost-benefit analysis must be performed, and its results must be discussed and proven not viable with specific data in respect of the application.
- All centralized HVAC systems shall incorporate active chilled water set point control.
- Constant flow chilled water systems shall not be used in any air conditioning system.
- Variable speed drives shall be used to control chilled water flow as opposed to throttling.

There are various methods for controlling chilled water flow. The most common of these are depicted in Fig.11. Throttling involves restricting the outlet flow of a pump and it is commonly achieved by partially closing a valve, this is similar to controlling speed of a motor vehicle with a foot on the brake at constant accelerator position. Bypassing requires installation of piping to divert part of the outlet which is commonly put back into the inlet. A variable speed drive controls the pump to deliver according to the need of the system.

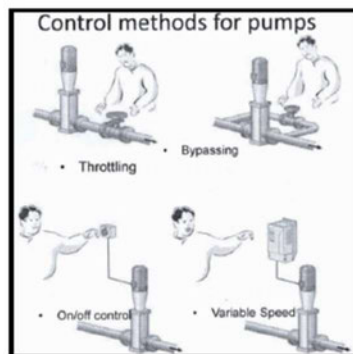


Figure 11: Illustration of Control Methods for Pumps [4].

The difference in these methods of control is the power consumption. Figure 12 illustrates the difference in power consumption between throttling and using a variable speed drive. Figure 13 compares the power consumption of all four methods of control for pumps.

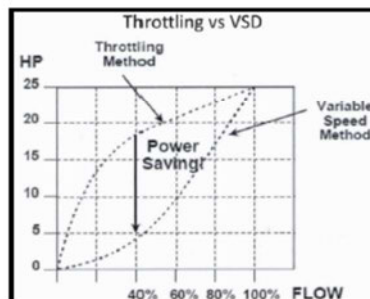


Figure 12: Power Saving with using a Variable Speed Drive Control Instead of Throttling [4].

From figure 12 it is evident that there is significant energy saving using a variable speed drive to control flow as opposed to the throttling method, with the largest saving being around the 40 % flow mark.

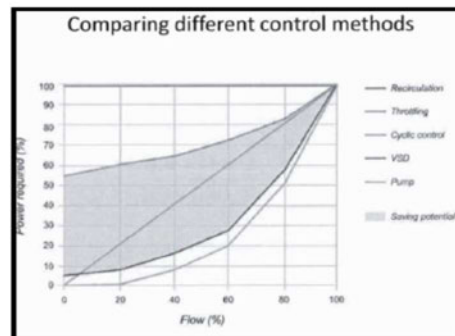


Figure 13: Power Consumption for Various Control Methods for Pumps [4].

From figure 13, it can be seen that the energysaving between the use of VSDs and recirculation, throttling, and cyclic control is significant.

- *To satisfy additional cooling demand, the chiller loading methodology for centralized HVAC systems shall be to start the next chiller only once the running chiller/s has exceeded 90% load and there is yet demand to be satisfied.*
- *All feedback control sensors shall be strategically placed to measure the respective parameter correctly and accurately.*
- *It is recommended that all HVAC systems performing dehumidification consider achieving this by using heat pipe dehumidification. This recommendation must be considered by way of a study done for the application showing the merits through a cost-benefit analysis.*

Refer to Figure 14 for the depiction of the heat pipe dehumidification process. Heat pipes may be described as having two sections: precool and reheat. The first section is located in the incoming air stream. When warm air passes over the heat pipes, the refrigerant vaporizes, carrying heat to the second section of heat pipes, placed downstream. Because some heat has been removed from the air before encountering the evaporator coil, the incoming air stream section is called the precool heat pipe. Air passing through the evaporator coil is assisted to a lower temperature, resulting in greater condensate removal. The “overcooled” air is then reheated to a comfortable temperature by the reheat heat pipe section, using the heat transferred from the precool heat pipe. This entire process of precool and reheat is accomplished with no additional energy use. The result is an air conditioning system with the ability to remove 50 % to 100% more moisture than regular systems.

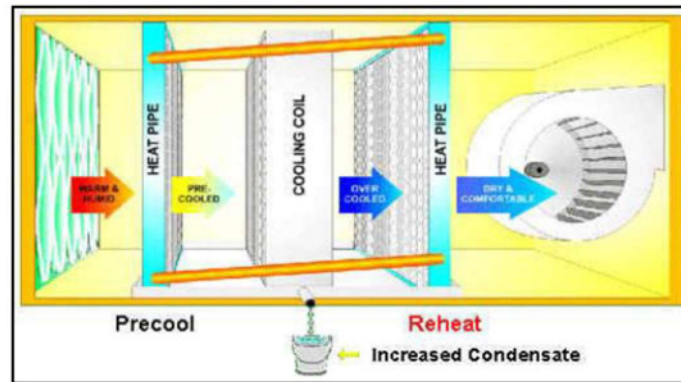


Figure 14: Heat Pipe Dehumidification Process[10].

- If the Coefficient of Performance (COP) of the chiller is less than 2, replacing or reconditioning of the chiller to achieve higher COPs shall be done based on the useful lifespan.
- New buildings and developments shall consider incorporation of alternative energy sources for space cooling or heating needs according to a cost-benefit analysis. This cost-benefit analysis is mandatory and the alternatives that must be considered are heat-pump systems for smaller and decentralized systems, and solar-thermal powered absorption cooling for larger systems (demand of 32kW and over).
- Air-cooled and water-cooled HVAC systems shall be chosen on a cost-benefit analysis. The cost benefit-analysis must be performed and discussed before a decision is made.
- Chilled water piping systems and air ducting systems must be adequately insulated and maintained.
- Provision for active measurement of duct air losses shall be made to monitor air leaks.
- In air handling units (AHUs), variable speed drives (VSDs) shall be used as opposed to damping.

There are various ways to control electric motors for variable air flow. Four of these ways are illustrated in figure 15:

- Outlet damper control (location 1),
- Inlet vane control (location 2),
- Magnetic clutching (location 3) and
- Variable frequency drives (location 4)

The typical power consumption of these various control systems can be seen in figure 16. The increase of fan pressure or air flow can be achieved by the arrangement of fans in series or in parallel. A series arrangement will result in an increase in fan pressure and a parallel arrangement will result in an increase in air flow. This can be seen in figure 17.

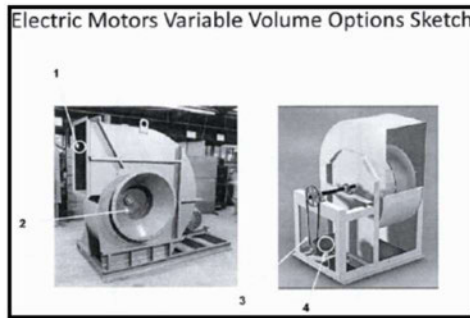


Figure 15: Illustration of Variable Air Control Options[4].

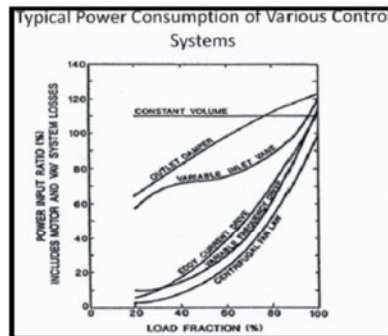


Figure 16: Power Consumption of Variable Air Control Options [4].

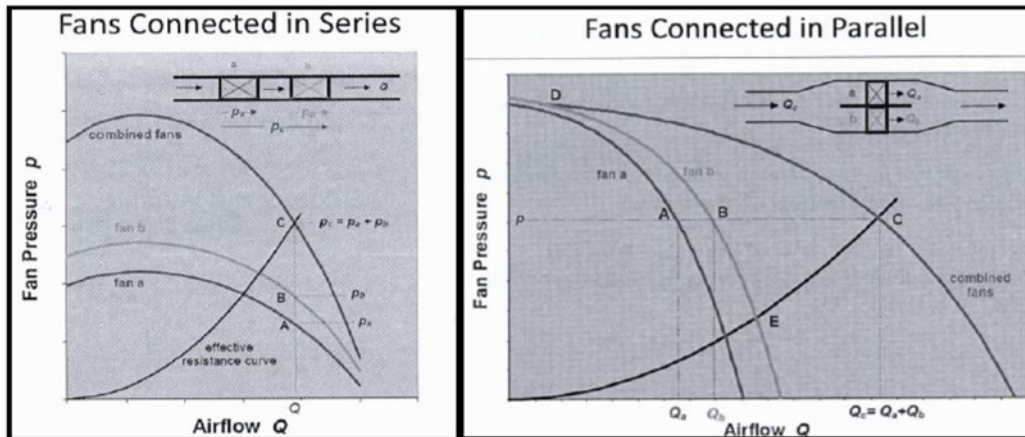


Figure 17: Fans Connected in Series (left) and Parallel[4].

- AHUs shall incorporate filter pressure drop gauges that shall be locally monitored via BMS with alarm remotely.

**Pumps**

At airports, the selection of pumps for pumping potable water, sewerage, stormwater, fuel (Jet A1, diesel), fire-fighting systems, and HVAC working fluids, are usually “unseen” and selected at design stage of all facilities. Often in commercial applications, a pump’s operation and selection are not re-assessed and modified for its operation. The following clause and supporting information ensures that when pumps are selected for facilities and applications, they are correctly sized for

operations, ensuring energy efficiency for all pumping applications.

- For pump selection, critical requirements such flow rate and/or pressure head must be established, and selection of pump shall consider the energy consumption implications.

If a pump is producing more pressure than the application requires, it is also consuming more energy than necessary. Elimination of excess energy consumption can be done by reducing the diameter of the pump impeller to the minimum needed to satisfy the pressure or flow requirement. Trimming the impeller of a centrifugal pump reduces its pressure output, rather than its flow capacity. In many applications, impeller trimming can be used to reduce excess flow as well as excess pressure. Refer to Fig. 18.

For example, in designing a pumping system, it is calculated that the system needs a flow rate of 800GPM and that the pump must produce a pressure of 60 feet of head at this flow rate. These pressure and flow rate requirements are marked by Point "A" in Fig.18. Based on this, a pump with a pump curve "B" is selected. When the system is in operation, the actual system curve turns out to be "C", so the pump actually operates at point "D". At this point, the pump pressure is approximately the same as originally estimated, however, the flow rate is much higher than the system requires. Pump power is proportional to the third power of the flow rate, so a large amount of energy is wasted.[11] The centrifugal fan and pump laws can be found below.

Power (kW) and Flow rate (LPS):

$$\frac{kW_{new}}{kW_{old}} = \frac{[LPS_{new}]^3}{[LPS_{old}]^3}$$

LPS: Litres per second

kW: Kilowatt

Power (kW) and pump impeller diameter (D):

$$\frac{kW_{new}}{kW_{old}} = \frac{[D_{new}]^3}{[D_{old}]^3}$$

Pressure or Head (P) and Speed (RPM):

$$\frac{P_{new}}{P_{old}} = \frac{[RPM_{new}]^2}{[RPM_{old}]^2}$$

RPM: Revolutions per minute

Flow (LPS) and Speed (RPM):

$$\frac{LPS_{new}}{LPS_{old}} = \frac{RPM_{new}}{RPM_{old}}$$

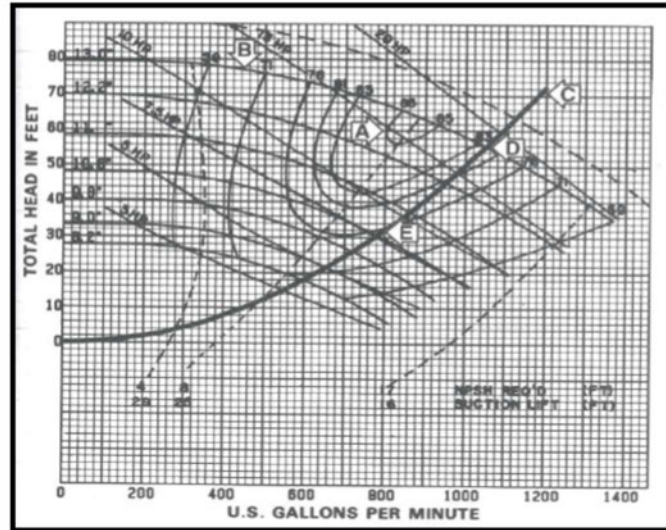


Figure 18: Graph of Pump Impeller Trimming[11].

To eliminate the energy waste, trim the pump impeller so that the pump operates at point “E”. This produces the originally required flow rate of 800GPM, but the pump is able to operate at a lower pressure. The pump curves show that the pumping power has been reduced from about 18 horsepower to about 8 horsepower, this amounts to a reduction of net energy by half, taking some efficiency loss in the pump motor into account. Trimming the impeller usually reduces the efficiency of a pump to an extent. Provided that the diameter reduction is not excessive, the efficiency loss is moderate and the reduction in pump power consumption is substantial. In the example above, the pump efficiency was reduced from 82% to about 77%, but the overall energy consumption was reduced by half. Pump impeller trimming is worthwhile if the application needs only a small reduction of impeller diameter. [11]

One can also increase either the flow rate or the pump head while keeping the other parameters constant by the pump series and parallel arrangements seen in the figure 19.

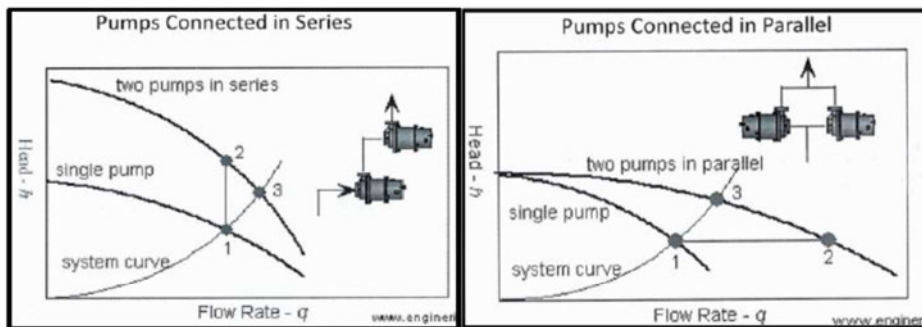


Figure 19: Pumps Connected in Series and Parallel [4].

**Motors**

Motor selection is key to saving energy in pump and fan applications at airports. The following section contains the clauses for optimum motor selection together with its supporting information.

- Optimum motor efficiency shall be derived at design stage.

- If motor output is less than 1kW, motor with efficiency class of International Efficiency 1(IE1) shall not be used. If motor output is greater than 10 kW for a system operating for under 2000 hours per year, motors with the efficiency class of IE1 shall be used. In the case of operation hours exceeding 2000 hours per year, motors with efficiency class of IE1 shall not be used.

The International Electro-technical Commission (IEC) has introduced standards relating to energy efficient motors. IEC 60034-30-1 defines four IE (International Efficiency) classes for all electric motors that are rated for sinusoidal voltage. Standard efficiency is IE1, High efficiency is IE2, Premium efficiency is IE3 and Super premium efficiency is IE4. Figure 20 shows the correlation between efficiency and output for the four efficiency classes of motors.

To achieve the best return on investment, users of production equipment need to apply a life cycle approach when considering investing in major equipment. The life cycle cost (LCC) is the total cost for purchasing, installing, operating, maintaining and disposing of an item of machinery. Life cycle costing comparisons can be seen in Figure 21. Motor selection at design stage shall be such that it operates at not less than 50% load, but not more than 100%. Active system control shall be achieved by using a variable speed drive. The standard IEC 60034-30-1:2014 defines efficiency levels and classes at 50 Hz and 60 Hz for single or three-phased line motors (regardless of the technology).

#### International Efficiency 1, 2, 3, 4

- Number of poles: 2, 4, 6, 8
- Power range: 0.12 kW to 1.000 kW

#### Level

- IE1 - Standard Efficiency
- IE2 - High Efficiency
- IE3 - Premium Efficiency
- IE4 - Super Premium Efficiency

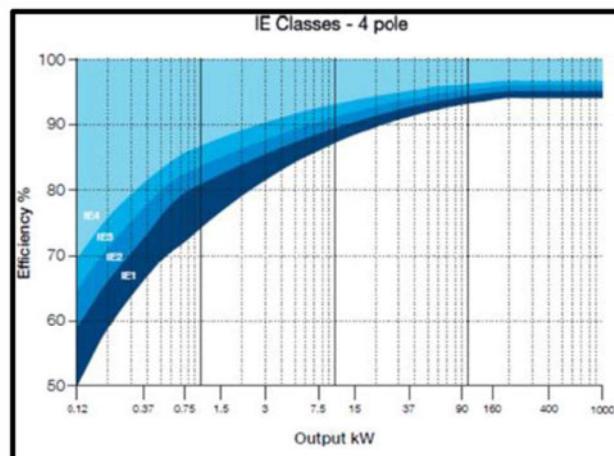


Figure 20: Motor IE Classes and their Efficiencies in Relation to the Power Output[12].

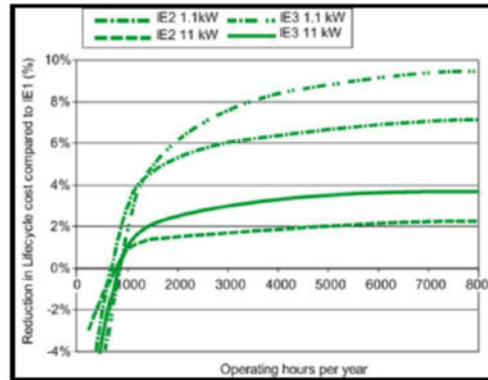


Figure 21: Life Cycle Cost Comparisons for Motor Classes IE1, IE2 and IE3 [13].

At 1000 hours operation, IE2 and IE3 motors give about the same percent reduction in LCC compared to IE1. At 8000 hours operation, IE2 and IE3 percent reduction in LCC compared to IE1 increases to its maximum and thereafter flattens out.

### Building Architecture and Envelope

The building architecture and envelope is the key to reducing energy demand for lighting and air conditioning. Airport terminal buildings in South Africa are at least double volume and this represents a significant lighting and HVAC demand. In South Africa, the SANS 204 energy efficiency standard contains guidelines on building architecture and envelope design. Airports can benefit immensely from the research that supports the clauses in the SANS 204 energy efficiency standard. The following three clauses serve to guide new capacity building projects design of orientation, envelope, and fenestration at airports.

- *The orientation of new buildings shall comply with the optimal building orientation set out in SANS 204: 2011, clauses 4.1 and 4.2.*
- *The envelope of new buildings shall comply with the building design set out in SANS 204: 2011, clauses 4.3.2, 4.3.3, 4.3.5, 4.3.6 and 4.4.*
- *The fenestration of new buildings shall comply with the requirements for fenestration set out in SANS 204: 2011, clause 4.3.4.*

### Ensuring that the Approach to Implementation of Energy Efficiency Meets Business Imperatives

The successful implementation of energy efficiency within a business requires effective integration into existing business processes, communication with executing stakeholders and decision makers, and ensuring its adoption in projects. Airports by nature have multiple stakeholders including airlines, ground handlers, maintenance service providers, operators, concessionaires, government agencies, retailers, and others. The effective implementation and relevance of energy efficiency is the final principle in energy efficiency according to [2].

**Principle Three: Ensure that the approach to implementation of energy efficiency meets business imperatives and supports operations based on “Standards and Guidelines for Energy Efficiency”.** These standards and guidelines must include device types, system types and preferred designs that will apply when new buildings and facilities are constructed, and replacement cycles for existing buildings and facilities.

The following sections contain the steps taken toward effective implementation of energy efficiency to ensure that all airports transform to be energy efficient facilities over a defined period of time.

**Implementation plan for Integrating the Standards and Guidelines for Energy Efficiency**

Now that there is a “Standards and Guidelines for Energy Efficiency” that is adopted as a company policy with clauses that guide the technology selection and design of the significant energy users at airports is the key that the policy is implemented effectively.

Identifying the implementers of the policy and the area that it will be implemented in is key to the success of integrating energy efficiency into the business. One must have a thorough understanding of how the business works and the governance processes. Table 1 shows the key implementers and the area of implementation at ACSA.

**Table 1: Identification of Implementers of the Standards and Guidelines for Energy Efficiency**

Key Implementers of the Policy	Area of Implementation
Project Managers and User Clients	Capital Projects
Operational expenditure budget owners	Refurbishments Projects
Maintenance Engineering Contract Managers	Service Level Agreements
Tenant Contract Managers	Tenant Lease Agreements
Airport Planners	Airport Planning activities
Chief Engineers	Technology Selection and Standards Development
Environmental Compliance Officers	Audits of environmental compliance
Supply Chain Management	Life Cycle Costing Approach
Operations Staff	Daily Operations Requirements
Operational Service Providers	Service Level Agreements

Once the implementers and the area of implementation have been identified, a communication strategy must be prepared for each stakeholder. It is advised that communication be arranged for one group of stakeholders at any time so that communication can be contextualized for their area of implementation. Table 2 shows the communication plan that was executed per stakeholder grouping for the nine airports owned and operated by ACSA in South Africa.

**Table 2: Communication Plan with Various Stakeholder Groupings**

Stakeholder Grouping	Target Date of Policy Communication	Person Responsible
Portfolio Project Management in Technical Services and solutions	13 June to 31 August 2017	Jerusha Joseph
Maintenance Engineering in Infrastructure Asset Management	13 June to 31 August 2017	Jerusha Joseph
Spatial portfolio (Property, Commercial, Advertising)	13 June to 31 August 2017	Jerusha Joseph
Supply Chain Management	13 June to 31 August 2017	Jerusha Joseph
Finance	13 June to 31 August 2017	Jerusha Joseph
Environmental Compliance	13 June to 31 August 2017	Jerusha Joseph
Operations in Airport Management	13 June to 31 August 2017	Jerusha Joseph
Airport Planning	13 June to 31 August 2017	Jerusha Joseph
Chief Engineers	13 June to 31 August 2017	Jerusha Joseph

**Implementing Energy Efficiency in Projects**

To effectively implement energy efficiency in projects, various energy efficiency actions must be introduced at each stage in the project life cycle. Table 3 shows the various project actions that must be taken at general project stages for each implementing function within ACSA. The red text within table 3 indicates the actions regarding energy efficiency that must be taken. There are various forms of project life cycles when it comes to executing infrastructure projects. Table 4

gives the energy efficiency actions at each project stage including the role players for five different project life cycles, i.e., the South African National Treasury, the Engineering Council of South Africa (ECSA), the South African Councils for Quantity Surveying, Project Management, Architectural professions, Construction and Industry Council, ISO 29481-1 and Royal Institute of British Architects Plan of Work.

**Table 3: Actions Required by Projects being Executed by Various Departments for Different Project Stages**

Implementer	Stage 1: Inception	Stage 2: Preliminary Design	Stage 3: Detailed Design	Stage 4: Documentation and Procurement	Stage 5: Contract Management	Stage 6: Close Out
<b>Airport Planning</b>	Passenger Traffic Forecast	Airport Future Capacity	Masterplan Drafting Action: Submit Electrical Demand Planning Request containing future electrical loads and consider orientation of future infrastructure			
<b>Infrastructure, Information Technology, Security, Refurbishment, Projects</b>	Refer to Table 4 following					
<b>Maintenance Projects</b>	Business Case Action: Application of Standards and Guidelines for Energy Efficiency	Project Charter Action: Applications of Standards and Guidelines for Energy Efficiency	Procurement based on Demand Request	NEC/ECC & TSC (3-5 years) Action: Applications of Standards and Guidelines for Energy Efficiency	Project Execution and Service Level Agreements (SLAs)	Measurement and Verification (continuous evaluation of SLAs) Action: Measurement and Verification exercise to determine energy savings and effectiveness of the standard

Spatial Agreements	Commercial Business Case	Project Charter Action: Application of Standards and Guidelines for Energy Efficiency	Procurement based on Demand Request	Tender Document Action: Review of the Tenant's Energy Management Strategy and submit Electrical Load Request to Electrical Department	Contract Negotiation and Signing	Contract Management Action: Measurement and Verification exercise to determine energy savings and effectiveness of the standard
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Table 4: Energy Efficiency Actions and Role Players at Each Stage Gate for the Various Project Life Cycles

ACSA responsible party	Standards and Guidelines for Energy Efficiency	Local and International Project Life Cycle Standards						
		National Treasury (2015)	Engineering Council South Africa (ECSA)	SA Councils for the quantity surveying profession (SACQSP), Project and construction management professions (ACPCMP), landscape and architectural profession (SACLAP) and architectural profession (SACAP)	Construction Industry Council (2007)	ISO 29481-1 (2010), Building Information Modelling	Royal Institute of British Architects Plan of Work (2013)	
		Stage number	Project Life Cycle Stages					
Planning/Spatial functions	Considered at planning stage for cost estimation and where capacities are available, notification of enablement of Electrical, Sewer and water supply services	0	Project Inception				Portfolio Requirements	
Planning functions		1	Infrastructure planning					
Planning functions		2	Strategic resourcing					
Engineering and User Client	Implemented at Scoping Stage	3	Preparation and briefing or prefeasibility	Inception	Inception	Preparation	Concept of need Outline feasibility	Strategic design Preparation and brief
Project Management	Implemented at Feasibility Stage	4	Concept and viability or feasibility	Concept and viability (preliminary design)	Concept and viability	Concept	Substantive feasibility Outline conceptual design	
Project Management	Check implementation of Standards and Guidelines for Energy Efficiency in the design and Electrical Load request submitted to the Engineering department and inclusion of an energy meter	5	Design development	Design development (detailed design)	Design development	Design development	Full conceptual design	Developed design
Project Management and Engineering	Check inclusion of Standards and Guidelines for Energy Efficiency -Final Sign off on Tender preparation	6A	Production information	Documentation and procurement	Documentation and procurement	Production information	Coordinated design and procurement Production information	Technical design
Project Management		6B	Manufacture, fabrication and construction information			Manufacture, fabrication and construction information		
Project Management		7	Works	Contract administration and inspection				Construction
Project Management, Engineering and User Client	Evaluation of Energy Saved as per anticipation at feasibility stage - excel spreadsheet of all Energy consuming equipment specifications handed over to the Engineering department	8	Handover		Construction	Post Practical completion	Construction	Handover and close-out
Project Management	Handover documentation for all energy using infrastructure	9	Close out	Close-out	Close-out			
Engineering	Energy measurement after 1 year							In use

Awareness must be created throughout the organization, including technical support and guidance for the implementation of the standards and guidelines for energy efficiency.

## CONCLUSIONS

The most energy efficient, low carbon energy sources for the airports in South Africa owned and operated by ACSA for their identified significant energy users (lighting and space air conditioning) were presented. The most energy efficient, low carbon energy source for lighting according to the best available technologies on market is solar energy through photovoltaic technology with energy storage. For space air conditioning chillers solar thermal energy as a power source energizing absorption chiller technology and for the cooling towers utilizing stable ground temperature as a heat sink through geothermal heat sink, are the most energy efficient low carbon energy sources.

A holistic/systems approach in the form of a Standards and Guidelines for Energy Efficiency for new infrastructure and refurbishments was presented in relation to the airports' significant energy users, including energy efficiency clauses addressing technology choices, specifications and design features for lighting, HVAC, pumps, motors, building architecture and envelope. Implementing alternative energy sources requires an in-depth analysis that considers the airports' electrical demand, their operations and organizational prerogatives. When alternative energy is considered for the airports, the energy efficiency pathways established in this paper will be taken into consideration.

## REFERENCES

1. K. Syngellakis, S. Taylor, M. Draeck, et al., "Sustainable Energy Regulation and Policymaking for Africa", UNIDO Training Package, Module 18, <http://africa-toolkit.reep.org/>, accessed 05 December 2020.
2. J. Joseph, F.L. Inambao, "Principles for Achieving Energy Efficiency in Developing Countries", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, ISSN (P): 2249-6890; ISSN (E): 2249-8001, Vol. 11, Issue 2, Apr 2021, 265-282.
3. J. Joseph, F.L. Inambao, "Energy Consumption and Energy Efficiency of Airports: A Case Study of Airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, ISSN (P): 2249-6890; ISSN (E): 2249-8001, Vol. 11, Issue 2, Apr 2021, 205-228.
4. Zikhali, W. *Perspectives of Infrastructure Development: An Analysis of Three Wards in Nkayi District, Zimbabwe*
5. American Association of Energy Engineers (AEE), 2014, *Certified Energy Manager Course notes*.
6. DOE Solid-State Lighting Research and Development: Multi-Year Program Plan.
7. <http://www.econoluxindustries.com/Technology.html>, accessed 28th April 2015.
8. <http://www.electronicstakeback.com/2013/01/16/new-research-shows-cfls-and-led-lightbulbs-have-higher-toxicity-and-resource-depletion-than-incandescent>, accessed 28th April 2015.
9. <http://www.standardpro.com/ballasts-info/fluorescent-ballasts/terminology>, accessed 29th April 2015.
10. <http://www.electronicstakeback.com/2013/01/16/new-research-shows-cfls-and-led-lightbulbs-have-higher-toxicity-and-resource-depletion-than-incandescent>, accessed 28th April 2015.
11. Khan, Y., & Ghosh, S. *Spatial Disparities in Health Care Infrastructure in South 24 Parganas District of West Bengal, India*.
12. <http://www.asoinc.com/applications/DH/DHHeatPipe.html>, accessed 29th April 2015.

13. *Energy Efficiency Manual*, by Donald R. Wulfinghoff, Page 1178 – 1179.
14. *Motor Guide February 2014, Low voltage Motors*, ABB, ISBN 952-91-0728-5.
15. [http://www.electrical-installation.org/enwiki/Energy\\_saving\\_opportunities\\_-\\_Motors](http://www.electrical-installation.org/enwiki/Energy_saving_opportunities_-_Motors), accessed 29th April 2015.

## **CHAPTER 8. ENTRENCHING ENERGY EFFICIENCY AS A CULTURE AT AIRPORTS: A CASE STUDY OF THE IMPLEMENTATION OF ENERGY EFFICIENCY FOR AIRPORTS IN SOUTH AFRICA**

This chapter presents the work done to inculcate the practice of energy efficiency within ACSA with the aim for this to become company culture for the airports in South Africa.

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<http://www.tjprc.org/view-archives.php>

## ENTRENCHING ENERGY EFFICIENCY AS A CULTURE AT AIRPORTS: A CASE STUDY OF THE IMPLEMENTATION OF ENERGY EFFICIENCY FOR AIRPORTS IN SOUTH AFRICA

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### ABSTRACT

*The best and most technically correct energy efficiency advice and strategies to reduce energy consumption, namely, eliminate energy wastage and reduce carbon footprint, will not achieve their targets for a specific site without entrenching energy efficiency as a culture within the site or organization where these aims are planned to be achieved. The people within the various departments onsite making decisions for and influencing the decisions taken by the organization as well as executing day to day tasks that affect the site's energy consumption, need to start thinking about energy efficiency in every aspect of their work such that a culture of energy efficiency is created. Requiring compliance with energy efficiency requirements may be necessary to set the standard for the level of energy efficiency required, but as time progresses, it is in the company's best interests to create a culture of energy efficiency where it becomes first nature. This paper presents the work done to inculcate the practice of energy efficiency within the Airports Company South Africa with the aim for this to become company culture for the airports in South Africa.*

**KEYWORDS:** *Energy Efficiency in Developing Countries, Energy Efficiency in Tenant Lease Agreements; Energy Efficiency Culture, Daily Energy Efficiency Tasks for HVAC Systems, Energy Efficiency in Daily Airport Operations & Roadmaps to Energy Efficiency Formation of Energy Teams at Airports*

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### 1. INTRODUCTION

Deciding on the most efficient energy source for the significant energy users as done in [1], and investigating energy efficiency from device to system, and establishing the standards and guidelines for energy efficiency is important, but equally important is ensuring that they are entrenched within the company as a culture. Actively involving all key stakeholders in the process of achieving energy efficiency is the key to getting wider organizational support in covering all bases and consolidating the energy efficiency vision [2]. A study conducted by [3] shows that the studied enterprises valued behaviour-related measures as being as important as technical measures. Raising awareness of energy efficiency and consumption within the organization, therefore, constitutes an essential leadership task, but it is oftentimes perceived as challenging and frustrating in comparison to technical tasks. The embedding of energy efficiency in corporate strategy, the use of a broad spectrum of different practices, and the empowerment and involvement of employees as major drivers in establishing energy efficiency within SMEs are paramount to success [3].

Airports Company South Africa (ACSA) owns and operates nine airports in South Africa, namely, OR Tambo International Airport (ORTIA), Cape Town International Airport (CTIA), King Shaka International Airport (KSIA), Port Elizabeth International Airport (PEIA), East London Airport (EL airport), Bram Fischer International

Airport (BFIA), George Airport (GG airport), Upington International Airport (UPIA) and Kimberley Airport (KIM airport). Standards and guidelines for energy efficiency as well as the principles that give birth to the clauses for achieving energy efficiency were set for the airports [1]. These standards and guidelines for energy efficiency must also filter through the tenants at the airports guiding the activities performed in the spaces they occupy to ensure energy efficiency and reduction in energy consumption. Furthermore, the principles that have been outlined for the technology selection, design and operation of HVAC systems contained in the ACSA Standards and Guidelines for Energy Efficiency must infiltrate daily operations of HVAC systems at the airports. Due to the airports having outsourced HVAC operations and maintenance, it is key that principles of energy efficiency form part of their service level agreements (SLAs).

Due to airports naturally having a large land footprint with many spatial areas, everyday operational issues such as leaking taps, pipes, broken glass, non-operational sliding doors, lighting and HVAC units left on in unoccupied areas, etc. are inevitable. There is an opportunity to start the creation of an energy-efficient culture by making the everyday identification and resolution of these issues an effort of onsite users that extend beyond just the personnel of ACSA.

The three principles for energy efficiency contained in [4] should culminate in the energy efficiency approach initiatives contained in a roadmap to energy efficiency (third principle for energy efficiency). This ensures that the site is transitioned towards energy efficiency in a defined period of time, eliminating energy wastage, increasing efficacy, reducing carbon emissions, saving on operational expenditure, and increasing the operational efficiency of an infrastructure intensive site like an airport. Ensuring that all the initiatives on the roadmap to energy efficiency are realized, it is imperative to have a team that coordinates and facilitates the execution as well as providing feedback regarding the adjustment of the initiatives and approaches to meeting the principles of energy efficiency as outlined in [4]. This paper presents the key initiatives being implemented at airports in South Africa for the realization of energy efficiency as a culture on site at its nine airports in South Africa.

## 2. INCULCATING ENERGY EFFICIENCY AT AIRPORTS

A culture of energy efficiency must be embedded in operations and business functions for success in achieving energy efficiency on site. The following sections present:

- The incorporation of energy efficiency in tenant lease agreements based on the Standards and Guidelines for Energy Efficiency established for airports in South Africa as found in [1].
- Daily HVAC operational cost savings that are focussed on energy efficiency in operations and maintenance of HVAC systems based on the principles established in the Standards and Guidelines for Energy Efficiency for airports in South Africa as found in [1].
- The Energy Efficiency Ambassador programme is meant to incorporate a general culture of energy efficiency onsite as well as eliminate energy wastage from everyday operational issues.
- The roadmap to energy efficiency will transition the airport sites towards compliance with energy efficiency within a defined period of time.
- The establishment of energy teams at the airports to facilitate the execution of all activities contained in the roadmap to energy efficiency.

These steps were followed for the airports owned and operated by Airports Company South Africa as named

earlier. The initiatives were adjusted from airport to airport and implemented based on many factors such as the size of operation, staff complement, infrastructure designs, scale of operations and their impact on energy consumption.

**2.1 Energy Efficiency for Inclusion in Tenant Lease Agreements**

The following clauses are intended for inclusion in tenant lease agreements. The energy efficiency clauses are also designed to be audited for compliance at the tenant’s spaces during defined intervals so that accountability and energy performance tracking is facilitated. Tenants (occupants of spaces at the airports) such as restaurants, offices, warehouses, workshops, etc. usually have the building or space ‘shell’ handed over to them which they must fit out and customize according to their operational needs. Certain buildings such as offices have lighting and air conditioning installed which must be maintained with wear and tear items being the responsibility of the tenants to replace during their lease period. Commercial use spaces are typically provided with electricity and air conditioning, with the lighting and other furnishings being installed by the tenant. Tenant leases can extend to several years and in some instances be renewed and thus the energy consumption becomes significant. To ensure that tenants are aligned to the energy efficiency imperatives of the business, it is important that energy efficiency is binding according to their lease agreements. The following subsections present the extracts that must be included in a tenant’s lease agreement. The extracts must be explained and discussed with the contract manager and the tenant to ensure that there is understanding and agreement in the case of existing tenants. For new tenants, this extract will be a condition of them using the space.

**2.1.1 Documents to be Produced by the Tenant Before Occupation of the Space**

- The tenant must submit their Energy Conservation and Efficiency strategy for all spaces occupied. This strategy must adopt energy consumption control measures, smart and energy efficient technologies, timely maintenance and good housekeeping, the latest energy efficient technology for lighting, water heating and flow control, space conditioning, refrigeration and any other applications for business operations. This strategy must address all energy consuming activities, devices and infrastructure installed and or used by the tenant. This strategy must be submitted to the ACSA Property Manager within 30 days of the signing of this lease agreement.
- A comprehensive report must be drawn up of the space(s) that are occupied by the tenant, detailing the devices/equipment that are drawing energy in their environments. Table 1 is an example.

**Table 1: Report on the Devices/Equipment Drawing Energy on a Particular Site**

Space occupied (e.g. office, cold room, retail)
Location of occupied space, Location of occupied space, floor area (sqm) and volume (single/double/triple/more)
Equipment type occupying and supplying the space (e.g. computer, hydroboil, air conditioner, lamp)
Equipment Manufacturer Specifications (manufacturer name & model)
Quantity of equipment type within the space
Location of Electrical Feed for the equipment (White/red Plug point, Distribution Board (DB) Space occupied (e.g. office, cold room)
Electrical Nameplate Rating of equipment (include nameplate COP for air conditioning)
Operational timeframes/ durations & number of operational days of the equipment
Maintenance frequency of the equipment (where applicable)

- This report must be submitted to the ACSA Property Manager within 30 days of the signing of this lease agreement, accompanying the Energy Conservation and Energy Efficiency Strategy. Any new equipment added, upgrades or refurbishments need to be added to the list in Table 1 and submitted within 30 days of the addition.

upgrade or refurbishment. These updates must be submitted to the ACSA Property Manager.

- A 6-monthly reporting of the Coefficient of Performance (COP) of refrigeration units/plants must be submitted to the ACSA Property Manager. Refer to the section on refrigeration.

#### 2.1.2 Lighting

- Make use of LED lighting as far as possible, with maximum correlated colour temperature (CCT) of 4000K for indoor areas and consumption of not more than 50W per 25m<sup>2</sup> area of office space for office spaces. The only case for an exception where LED lighting is not adopted is when the existing light fitting installed and expected to be retained with the space on expiry of the lease is not compatible with LED lighting. Where the tenant is performing their own lighting fit-out, LED lighting is compulsory.
- Ensure that lux levels are in accordance with the Occupational Health and Safety Act, 1993 Environmental Regulations for Workplaces, 1987 Schedule - Minimum Average Values of Maintained Illuminance (Measured on the Working Plain) and ensure that the lux levels do not exceed 25% of the minimum lux levels stated in this act.
- In all cases, where security is not a risk, lighting must be switched off when not needed for business operations. The adoption of occupancy sensors, timers and other smart technologies must be considered to control the use of lighting. This should be included in the tenant's Energy Conservation and Efficiency Strategy for the occupied space(s).
- Daylight harvesting is recommended where natural lighting can be utilized; this should be adopted in the Energy Conservation and Efficiency Strategy of the tenant for the occupied space(s).

#### 2.1.3 Space Conditioning

- For the common areas cooled via the central air conditioning system in the terminal building, the temperature is usually maintained between 22°C and 24°C. If the tenant has control of air conditioning space temperature, maintain space temperatures within 22°C and 24°C.
- Ensure that the space is enclosed when the air-conditioning is operational, i.e., all windows and doors tightly sealed.
- Use methods such as insulation for a space fitted out by the tenant to keep space heating demand as low as possible.
- Potable bar and fan heaters are not to be used in the space unless permission is granted and this is declared in the report containing the tenant's Energy Conservation and Efficiency Strategy.
- Switch off air conditioners during times when the space is unoccupied. Occupancy sensors and timers are recommended to be adopted. The methods for controlling air conditioning usage must be detailed in the tenant's Energy Conservation and Efficiency Strategy for the space.

#### 2.1.4 Refrigeration

- Where refrigeration is installed by the tenant, refrigeration units/plants should have variable speed control and must be controlled according to a temperature setpoint, i.e., the plant must have feedback control capabilities.

- Regular and timeous maintenance according to the OEMs requirements must be done on the units/ plants to ensure that the Coefficient of Performance (COP) is kept as close as possible to the design nameplate. The COP must be calculated from measured readings and recorded. The results of the COP must be submitted to the ACSA Property Manager every 6 months. Should the COP calculated from measured readings deviate by a difference of 0.7 or more from the manufacturer's design for more than 6 months, action must be taken to restore the COP to within 0.7 of the design nameplate.
- The space that is refrigerated must be well insulated with the integrity of the insulation maintained and the space must be tightly enclosed, except for open refrigerators in the retail space where glass enclosures are advised for energy conservation.
- All energy conservation and energy efficiency measures for the units/plant must be captured in the tenant's Energy Conservation and Efficiency Strategy.

### **2.1.5 Water and Water Heating**

- Ensure that geysers are switched "on" a maximum of one hour before intended use and that hydroboils are switched off when not in use for extended periods such as weekends, holidays, or days away. Timers are effective in achieving this. The control of geysers and hydroboils within the occupied space must be detailed in the tenant's Energy Conservation and Efficiency Strategy.
- For added efficiency, consider insulating the geyser and installing a timer for its operation.
- Refrain from using set points higher than 60°C on the geyser, ensuring that the set point is high enough to prevent the growth of legionella.
- Ensure that the geyser is maintained and that there are always no leaks.
- Where the tenant is responsible for installation and maintenance of faucets, showers and other facilities, ensure that faucets and showerheads are low flow and water efficient. Adopt sensors for faucets in washbasins.
- All energy saving measures are to be detailed in the tenant's Energy Conservation and Efficiency Strategy.

### **2.2 Daily HVAC Operational Cost Savings**

Due to the second largest energy user at airports being HVAC as established in [5], the operators of central HVAC systems are usually the operations and maintenance (O&M) service providers appointed by Airports Company South Africa. The age of HVAC systems across the airports differ and so do their designs and thus capabilities. To ensure energy efficiency in the operation of existing HVAC systems, the guidelines in the following subsections were introduced to the airports' technical teams for implementation. The guidelines promote energy efficiency as an operational cost saving measure for the organization, intending to achieve much-needed cost saving for the financial year especially during the peak summer period when the cost of energy for air conditioning is at its highest.

#### **2.2.1 Air Conditioning Maintenance**

Electricity consumption of HVAC systems increases when heat exchange surfaces are not maintained. Ensure that the following maintenance is done each year before the summer period, i.e., by 1 December:

- Clean heat exchange surfaces
- Inspect ductwork for air leakages and seal all leaks by taping or caulking
- Inspect ductwork insulation – repair or replace as necessary
- Inspect damper blades and linkages – adjust on a regular basis and clean oil
- Clean or replace air filters
- Inspect and clean coils
- Inspect coils and casings for leakage – seal all leaks
- Inspect all room air outlets and inlet (diffusers, grilles) to be free of dirt and obstructions
- Lubricate motor and drive bearings
- Check for over-voltage and low-voltage conditions on motors
- Check excessive noise and vibration
- Keep fan blades clean
- Inspect piping for leaking at joints – repair as and when necessary
- Inspect strainers and cleaning regularly
- Inspect vents and remove all clogs – clogged vents retard efficient air elimination and reduce system efficiency
- Replace leaking dampers on ventilation systems
- Ensure condensing and evaporating devices are clean and well maintained – check that condensers are not obstructed by equipment or vegetation
- Ensure that insulation is installed on refrigerant pipework located outside a building
- Ensure that motors are operating at Best Efficiency Point as per manufacturer data
- Where applicable, check motor and belt drives and ensure that they are operating as per OEM operating conditions

Airports are expected to keep the dates of maintenance for checking and assessment purposes to ensure that the system is performing optimally.

### **2.2.2 Air Conditioning Control**

Ineffective air conditioning control can defeat the purpose of air conditioning altogether. Ensure that the following controls are put in place before the peak summer period to ensure energy savings. Care should be exercised when implementing these controls as their implementation will ensure energy savings without voiding equipment warranties or triggering energy consumption in another part of the HVAC system.

- Lower temperature set-points do not cool a building down more quickly; temperature control should be around 23-24 degrees Celsius. On those exceptionally hot and humid days, ensure that the delta T of temperature set-point

and outdoor environmental temperature does not exceed 10 degrees Celsius. Care should be taken when applying this parameter as central HVAC systems in, for example, ORTIA, may need some discretion with respect to variable air volume and constant air volume systems. With Constant Air Volume Air Handlers, you may find that the unit responds to a higher setpoint by heating the air as a fixed delta T across the coils which is the only capability of the system, but this negates energy savings. With KSIA's HVAC system, this increase in setpoint can be achieved efficiently by increasing the Chilled Water Leaving Temperature Setpoint (as it has this capability).

- If heating is available in your centralized air conditioning system, ensure that heating and cooling is not allowed at the same time by setting controls to give a wide temperature gap within which heating and cooling systems turn on – a gap of around 4-5 degrees Celsius between the heating and cooling thermostat set-point will create a comfortable 'dead band'. For ORTIA, a sure way of guaranteeing that heating and cooling is not activated at the same time is to check that the contactor supplying the heating elements is not activated at the same time when the two/three valve supplying chilled water to the AHU is open.
- Ensure that fresh air intake is compliant with building regulations, prevent fresh air intake dampers from being in full open position unnecessarily. For constant air volume systems, fresh air intake dampers should be fully open to avoid the motor pulling air against a closed damper. For ORTIA, CTIA and KSIA, carbon dioxide sensors are installed that vary the damper position to allow sufficient fresh air while maximising efficiency through returned air. These should be checked for correct functioning.
- Ensure that the feedback control sensors are correctly reading the temperature of the space, not the ceiling void or the air duct temperature.
- If the system can tolerate a little increase in temperature at the evaporator, the opportunity exists to reduce compressor power. This evaluation and adjustment must be done through a qualified air conditioning specialist, bearing in mind equipment warranties.
- If the system can tolerate a decrease in condensing temperature, an opportunity exists to decrease compressor power consumption. This evaluation and adjustment must be done through a qualified air conditioning specialist, bearing in mind equipment warranties.
- For centralized air conditioning systems, chiller sequencing operations should be such that the next chiller is brought online only when the current operational chiller has exceeded 95% loading. There should never be more than one chiller part loading at any time.
- Check the energy balance between primary and secondary circuits – check the flow rate through the bypass line. The flow rate through the bypass line should never exceed the flow rate through one chiller. If it does there is excess demand or excess supply of chilled water. If the flow rate is not known, it can easily be calculated knowing the cooling capacity of the chiller.

### **2.2.3 Air Conditioning System Time Schedule**

HVAC time schedules help air conditioning systems to cope better with outdoor environmental temperatures experienced in summer which are outside their design as energy efficiently as possible when combined with proper maintenance and air conditioning control.

- For centralized air conditioning systems that have the capability of implementing time schedules, begin chiller operation before airport operations (earlier than 6 am) to give the HVAC system a better chance of responding to the internal heat gains and solar heat gains of the day. This will also lower the operational cost of energy as energy at that time is on standard or off-peak tariffs.
- Ensure that all air conditioning units and systems are shut down when they are not required, i.e., outside operational hours.

#### 2.2.4 Envelope, Fenestration and Equipment Care

The following must be performed to ensure that the air conditioning provided for the comfort of occupants is maximized and not wasted through comprises in the facility's envelope, fenestration and improper maintenance of other engineering systems that contribute to the heat loading of the facility.

- Report and ensure repair of all broken windows and openings that allow unintended environmental exposure, including sliding doors that are defective and stay in the open position.
- Report and ensure repair of all lighting containing ballasts that have fused as these fuses consume electricity and produce heat without lighting up the environment. Either disconnect the fixture or replace the lamp.
- Report and ensure resolution of areas that are overcooled or areas that are in heating mode, when cooling is intended.

During daily operations a water leak, overlooked or unseen broken windows, open sliding doors in air-conditioned spaces, neglecting the switching off of lighting and air conditioning can all lead to energy wastage; thus, resolving these issues and keeping daily energy wastage to a minimum is key.

#### 2.3 Energy Efficiency in Daily Operations

Each of the international airports (ORTIA, CTIA, KSIA) has a dedicated Infrastructure Management Centre (IMC) which coordinates all daily operations and maintenance tasks with respect to the airport infrastructure. At its core, the IMC is the airports' infrastructure call centre/helpdesk, with their duties extending to ensuring the work needed to resolve the call is executed by the respective party; measuring, recording and reporting turn-around times on resolved calls. The regional airports have decentralized IMC functions in that they have shared responsibilities where the functions of the IMC are undertaken by one or two persons who are part of the airports' maintenance team. In the course of their duties, the IMC team also coordinates the work tasks of a host of service providers such as cleaning services, HVAC operations, recycling and waste services operations and maintenance, Jet A1 fuel farm operations and maintenance service providers, people movers service providers, sewerage waste operations and maintenance service providers, thus ensuring that all operations and maintenance requirements are met. These service providers and in-house maintenance personnel collectively have "eyes and ears" on all infrastructure at every location of the airport every day.

To leverage the opportunity of the "eyes and ears" of operations and maintenance personnel at every location of the airport for the purposes of energy efficiency, it is key to establish an energy efficiency platform through which energy efficiency issues can be reported to be resolved via the airports' existing IMC. Certain behaviours such as switching off lighting and air conditioning for offices and other occupied areas in buildings can be achieved through the various service providers, especially the janitors of buildings as they naturally are "looking after" the buildings daily. Issues that cause a

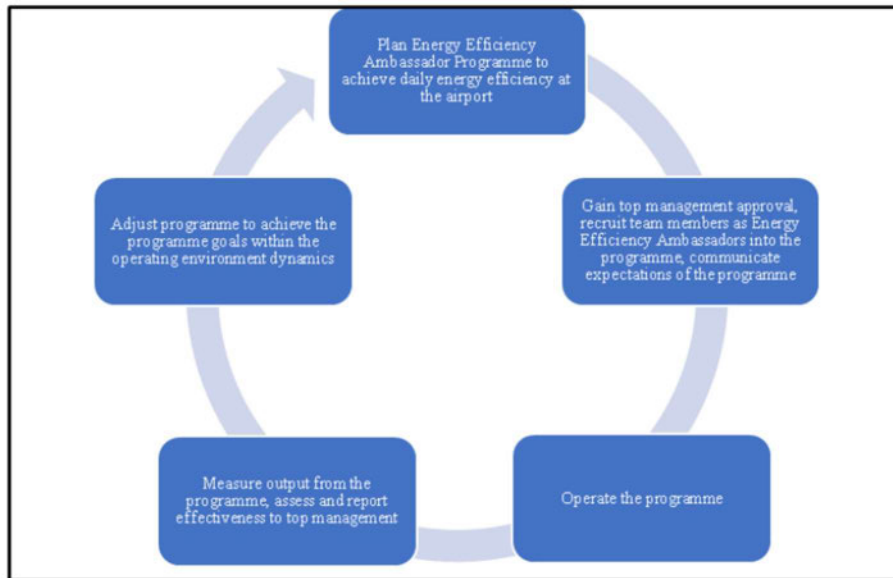
loss in energy efficiency such as dirty air filters, leaking air ducts, potable water pipe bursts to broken windows and leaking faucets can be reported promptly to the IMC by various individuals working for service providers and this can be resolved within a day or within the week depending on the complexity of the resolution of the issue.

The energy efficiency programme can be set up with the intention of creating a lasting energy efficiency culture, or through behaviour expectations contained in SLAs, tenant obligations and even individuals' Key Performance Indicators (KPIs). Either way, in an organization as complex as an airport authority by virtue of the number of role players, it is best that commitment and support from top management is gained for such a platform. It is key to have a programme that is well defined, its outputs measured, assessed and programme adjusted to meet the intended goals within the airport sites' operating culture and infrastructure environment. The following section outlines the steps taken to establish an "Energy Efficiency Ambassador Programme" to promote energy efficiency in daily activities.

### **2.3.1 Steps to Rolling out an Operational Energy Efficiency Ambassador Programme**

The following steps outline the process to establish and operate an Energy Efficiency Ambassador Programme aimed at achieving energy savings through the elimination of energy wastage from daily operations. Figure1 depicts these steps.

- Step 1: Plan the Energy Efficiency Ambassador Programme to achieve daily energy efficiency at airport sites.
- Step 2: Obtain permission and commitment from management team.
- Step 3: Call for voluntary Energy Efficiency Ambassadors who may be employees of Airports Company South Africa or employees of its tenants and service providers. Include within the team mandatory participation of new tenants, maintenance and other service providers who have service level agreements with the organization. Gain buy-in for participation from existing tenants.
- Step 4: Communicate expectations of the programme to the Energy Efficiency Ambassadors.
- Step 5: Communicate plan to all parties involved in executing the various operational corrective actions that will eliminate energy wastage, such as the IMC, decision-makers and executors of the tasks to be resolved.
- Step 6: Operate the programme.
- Step 7: Evaluate energy savings and effectiveness of programme and report to top management.
- Step 8: Adjust plan accordingly.



**Figure 1: Process to Establish and Run the Energy Efficiency Ambassador Programme.**

The actions to be performed by the energy efficiency ambassadors must be listed and the work tasks divided amongst the ambassadors.

### 2.3.2 Tasks to be Performed by the Energy Efficiency Ambassadors

Identify specific instances where energy (and water) is wasted daily through usual activities and unavoidable occurrences.

(a) Report the following to be addressed by the IMC Helpdesk as and when they occur and when they are identified on daily site walkabouts:

- Fused lamps
- Leaking taps and pipes
- Overcooled areas
- Broken windows in an air-conditioned area
- Lighting schedules not working

(b) Perform the following actions onsite as needed and identified during daily walkabouts:

- Switch off lighting not needed and at the end of the workday
- Unplug devices not needed/in use
- Switch off air conditioning when the space is unoccupied
- Close taps

### **2.3.3 Recruitment of Team Members for the Energy Efficiency Ambassador Programme**

Guidelines for constituting the team of Energy Efficiency Ambassadors:

- Call for Energy Efficiency Ambassadors on a voluntary basis, do not limit the call to internal staff, or
- Call for Energy Efficiency Ambassadors by invitation to specific departments or job descriptions where the operational issues causing energy wastage is more likely to occur within their job functions, under their control or are identified by them, e.g., cleaning staff, guarding services personnel, maintenance personnel, safety staff, etc., or
- A hybrid approach of (a) and (b) that calls for volunteers but also makes targeted invitation to specific departments.
- Start with a few energy ambassadors and scale the team and their duties such that it suits the goal of the energy Efficiency Ambassador Programme.

By its nature, an airport as an organization does not have full influence over its energy consumption by virtue of areas being occupied by tenants and energy intensive infrastructure being maintained and operated by service providers (i.e., outsourced), therefore it is essential that service providers and significant energy be included in the Energy Efficiency Ambassador Programme. For this reason, the outcomes of the Energy Efficiency Ambassador Programme should be incorporated into tenant lease agreements and Service Level Agreements (SLAs). Cleaning services and guarding personnel are key in a programme such as this, so it would be most beneficial to get them onboard. At airports, safety personnel perform daily walkabouts to identify hazards and reportable incidents, so ensuring their inclusion in the programme will be beneficial. In summary, the following functions/categories of people should be included in the programme:

- Service providers having custodianship of maintenance and operations of energy intensive infrastructure or infrastructure that affect or influence the site's energy consumption;
- Top ten significant energy using tenants that constitute over 50% of the share of tenant energy consumption;
- Janitorial/cleaning staff;
- Security personnel; and
- Staff that perform inspections and walkabouts as per their usual work duties.

### **2.3.4 Communication**

Communication is key to bringing about a sense of community and common motivation for the execution of tasks. Keeping team members informed of the progress in meeting the goals of the Energy Efficiency Ambassador Programme as well as bringing about awareness of energy wastage and its impact on the company, country and planet will be one of the many ways to bring about motivation and gain momentum for the programme. Communication around awareness should seek to build a culture of energy efficiency within the company. In this respect, topics and modes of communication with the audience should be relevant to their daily life and work experience. Communication should be two-way in that team members should be invited to provide feedback and be encouraged to co-create the next cycle of the programme towards an improved solution. In summary, communication should be related to:

[www.tjprc.org](http://www.tjprc.org)

[editor@tjprc.org](mailto:editor@tjprc.org)

- Progress on energy savings;
- Awareness of energy and implications for the company, country, planet;
- Information sharing amongst team members around energy and how it affects the team members' daily lives; and
- Suggestions on how to improve the Energy Efficiency Ambassador Programme.

Methods and channels of communication should be varied based on what appeals to the various functions/categories of people on the programme. The following methods should be considered:

- Periodic (monthly, weekly) meetings using both virtual and face-to-face interactions;
- Group email or Microsoft Teams;
- Social networking (social media such as WhatsApp groups, targeted team building);
- Logbooks and formal progress reporting; and
- Internal newsletters.

Care must be exercised to provide just the right amount of information at the right time, suitable to team members, to avoid causing fatigue and loss of motivation for the Energy Efficiency Ambassador Programme. Encouraging team members to be active in the administration of the programme will go a long way towards creating a lasting culture of energy efficiency within the company.

### **2.3.5 Incentives to Motivate Team Members of the Energy Efficiency Ambassador Programme**

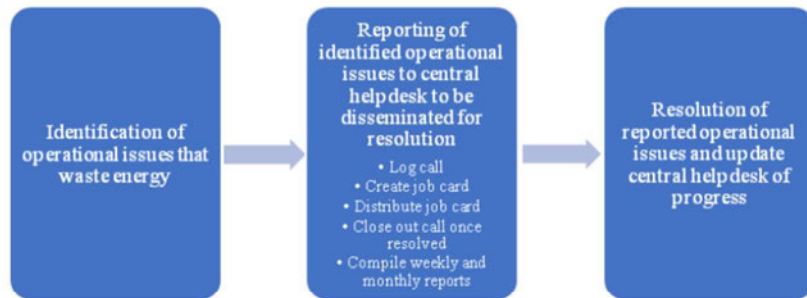
Varying company cultures may pose various degrees of difficulty in getting a programme such as the Energy Efficiency Ambassador Programme off the ground and keep it running successfully. Certain organizations may need to offer incentives to get volunteers and keep team members motivated. When approaching the launching of a programme such as this, it will be beneficial to consult with personnel who have launched other types of awareness and other programmes such as safety, security, environmental, and customer service programmes that seek to create culture and community in the organization. The personnel running these programmes can provide useful input to the successful launching and running of the Energy Efficiency Ambassador Programme. Whether the programme starts out as being incentive or voluntary, there must be plans over time to get the tasks of the programme formalized as obligations of tenants, service providers and even employees of the company. The following options can be considered so as to ensure that the programme is successful:

- Include in annual performance contracts as KPIs (Key Performance Indicators) for ACSA employees;
- Include in SLAs for service providers;
- Monthly recognition for "top achievers" such as "Energy Efficiency Ambassador of the Month"; and
- Latch onto ACSA's existing "rewards and recognition" programme or create a new programme.

It is important to not focus rewards on monetary gains unless the model of the company is designed for such where energy savings can be quantified, and cost savings can be associated with a certain individual. Incentives must also be fair and impartial so that team members do not become aggrieved, or competition becomes unfriendly.

**2.3.6 Process of the Energy Efficiency Ambassador Programme**

Much of the success of the Energy Efficiency Ambassador Programme will depend on effective identification, communication and successful resolution of daily operational issues that lead to energy wastage. The recruited Energy Efficiency Ambassadors are the identifiers of the daily operational issues that waste energy. It is useful to channel all issues to a central station from which the dissemination of the issues for resolution is undertaken and from which there is a report back on the repair status of the tasks reported. If the organization has an existing helpdesk, it is advisable to make use of this helpdesk. The process of the programme will then be as depicted in Figure 2.



**Figure 2: Process of the Energy Efficiency Ambassador Programme.**

It is important to plan the ‘voluntary’ nature of the Energy Efficiency Ambassador Programme for a defined period of time after which it becomes part of all business activities as a requirement, i.e. SLAs in tenant lease agreements, KPIs in staff performance contracts, and reporting being part of top management focus and company dashboards.

**2.4 Roadmaps to Energy Efficiency**

An energy efficiency road map must be drafted for every site to ensure that all identified energy efficiency initiatives and desired behavioural changes are realized, transforming sites towards energy efficiency over a defined space of time and maintaining this trajectory. This roadmap must be revised annually. The roadmap should include all tasks that must be executed, the dates that they should be executed by, and by whom. Table 2 contains all the type of activities that have been included in plans so far for implementation at the airports. Individual airports develop their individual road maps based on their infrastructure replacement and refurbishment cycles, age of infrastructure, impact of tenants on energy consumption and other organizational factors.

**Table 2: Types of Activities Included in Roadmaps to Energy Efficiency**

Strategic Objective	Task/Project	Date (year) to be Realized	Executing/ Facilitating Department
Reduce Energy Consumption in existing infrastructure	Energy efficient lighting retrofits: <ul style="list-style-type: none"> <li>• LED lighting for all buildings’ facilities</li> <li>• LED lighting for all signage and advertising</li> <li>• LED for the airfield and outdoor applications</li> </ul>	All airport systems compliant by 2025	Electrical Maintenance Departments
	Lighting control projects: <ul style="list-style-type: none"> <li>• Occupancy sensors,</li> </ul>	All airport systems compliant by 2025	Electrical Maintenance

	<ul style="list-style-type: none"> <li>• Photocells and dimming functions to modulate according to lighting the need</li> <li>• Timers</li> </ul>		Departments
	HVAC demand reduction projects: <ul style="list-style-type: none"> <li>• Heat resistant coating on roof/ solar thermal roof/ green roof.</li> <li>• Solar thermal walls OR heat deflection facades</li> <li>• Building envelope and fenestration projects</li> </ul>	All airport systems compliant by 2025	Mechanical Maintenance and Facilities Management Departments
	HVAC systems redesign with replacement and refurbishment cycles to ensure a smooth notified maximum demand curve (load levelling techniques and load shifting techniques): <ul style="list-style-type: none"> <li>• Heat pipe dehumidification</li> <li>• Re-use of condensate as make-up water to aid in achieving temperature required for cool chillers</li> <li>• Re-use of condenser water in a heat exchanger as a pre-heater to the geysers or any other process requiring a heated fluid</li> <li>• Active chilled water set-point control, variable speed drives, air economizing, fresh air demand control</li> <li>• Ice storage or chilled water storage</li> </ul>	All airport systems compliant by 2027	Maintenance Engineering Projects
Embedding Energy Efficiency culture	Application of the Standards and Guidelines for Energy Efficiency in all new projects, refurbishments and replacements	All airports fully compliant by 2018	Engineering and project execution departments
	Application of energy efficiency in daily activities: <ul style="list-style-type: none"> <li>• Energy Efficiency Ambassador programme</li> <li>• Energy efficiency in maintenance</li> </ul>	All airports fully compliant by 2023	Facilitated by Energy and Demand Management
	Application of energy efficiency in tenant leases	All airports compliant by 2018 for new tenants and upon lease renewals for existing tenants (~2023)	Facilitated by Energy and Demand Management, executed by commercial departments

The implementation of energy efficiency in relation to the sources of energy requires an in-depth analysis that seeks the most suitable energy sources for the airports' electrical demand suiting its operations as well as fulfilling key organizational prerogatives. In this analysis of alternative energy sources for the airports, energy efficiency implementation as outlined in this paper will need to be taken into consideration.

### 2.5 Formation of Energy Teams at each Airport to Facilitate the Inculcation of Energy Efficiency

An Energy Team should be established onsite at each facility that coordinates and facilitates the execution of the initiatives that transition the site towards energy efficiency as well as lead the creation and track the progress of establishing a culture

of energy efficiency at each site. In essence, the roadmap to energy efficiency will be the guiding principle of the constitution of the airports' Energy Teams. Refer to Table 3 for the constitution of the Energy Teams at the airports.

**Table 3: Constitution of Energy Team**

#	Energy Team Members	Roles Played on the Team
1	Electrical Engineer/Electrical Technician	Facilitate and execute LED lighting retrofits; lighting control initiatives; lighting conservation initiatives. This includes scoping and budgeting of project activities
2	Mechanical Engineer/Mechanical Technician	HVAC energy conservation in operations, design retrofits towards energy efficiency
3	Project Manager/ Project Programme Manager	Incorporation of Standards and Guidelines for Energy Efficiency and ensuring that project budgets are aligned to achieve this
4	Commercial Key Accounts Manager	Incorporation of energy efficiency in the tenant lease agreements
5	Environmental Compliance Officer	Checking compliance of all tenant lease agreements with their energy management strategies
6	Safety Compliance Officer	Checking that all practices are compliant with safety requirements as per the Occupational Health and Safety Act 85 of 1993
7	Energy Management Engineer	Lead the energy team and the Energy Efficiency Ambassadors; coordinate and track success of realizing the roadmaps to energy efficiency
8	Infrastructure Management Centre (IMC) Helpdesk Agent	Collation of all calls resolved that affect energy consumption to quantify energy savings
9	Information Technology (IT) officer	Introduce new and innovative ways to stimulate awareness and introduce convenience to achieve energy efficiency monitoring, tracking and evaluation of results to compare them with targets
10	Procurement Manager	Ensure that energy efficiency is considered in all project procurements.
11	Maintenance function heads of department	Ensure that for all infrastructure refurbishments and replacements, energy efficiency is considered in the new/refurbished designs and equipment specifications, as well as alignment of respective budgets to perform this

The above airport-based Energy Teams will vary based on the airport structure, infrastructure onsite and the scale of operations. For instance, project execution for regional airports (PEIA, EL airport, BFIA, GG airport, UPIA, KIM airport) are centralized and based at corporate office, so most of the team members will be shared. The concept of the Energy Teams will be consistent, but the energy team constitution will vary. Energy teams should decide on their methods of communication, communication frequency and coordination. Meeting on a monthly basis in relation to the results of the sites energy consumption is essential and the energy efficiency ambassadors should communicate at least weekly with the Energy Team to accurately track progress on elimination of energy wastage.

### 3. CONCLUSIONS

Due to the airports having a significant number of tenants utilizing and influencing the use of energy at the airports, clauses for energy efficiency were presented to be included as an extract in tenant lease agreements to ensure energy efficiency in tenant spaces. To eliminate energy wastage in HVAC systems daily operations, a guideline for HVAC maintenance and operations operational cost savings that largely address energy conservation and efficiency was introduced. To achieve energy efficiency in daily airport operations, the Energy Efficiency Ambassador Programme should be implemented. These initiatives are in accordance with [4] i.e., fulfilling the principles of energy efficiency so as to achieve energy efficiency sustainably for airports.

These energy efficiency initiatives are all included in each airports' roadmap to energy efficiency for implementation with the alternative energy sources requiring a further analysis prior to implementation. Now that there is a plan in place to realize energy efficiency at all airport sites for existing infrastructure and new infrastructure, there is an

expectation and standard set for the creation of an energy efficiency culture within the organization. In due course, further carbon reduction activities can be explored that will ensure energy security in the current global warming crisis faced by the world today.

#### REFERENCES

1. J. Joseph, F.L. Inambao, "Energy Efficiency for Airport Infrastructure: A Case Study of the Implementation of Energy Efficiency for Airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, ISSN (P): 2249-6890; ISSN (E): 2249-8001, Vol. 11, Issue 2, Apr 2021, 383-406.
2. United Nations Economic and Social Commission for Asia and the Pacific Environment and Development Division, "Guidelines for Strengthening Energy Efficiency Planning and Management in Asia and the Pacific" April 2011.
3. W. König, S. Löbbe, S. Büttner, C. Schneider, "Establishing Energy Efficiency—Drivers for Energy Efficiency in German Manufacturing Small- and Medium-Sized Enterprises" *Energies* 2020, 13, 5144; doi:10.3390/en13195144.
4. Zikhali, Whitehead. "Putting the Last First: Using the Chamberian Lenses to Explore Poverty at Sivomo Village, Nkayi District, Zimbabwe." *International Journal of Humanities and Social Sciences (IJHSS)* ISSN(P): 2319-393X; ISSN(E): 2319-3948 55-66
5. Keerthivenkatesh Kumar, A., and E. Baburaj. "Analysis of Energy Efficiency in Sensor Nodes of Wsn Scada Systems Using Cognitive Fuzzy Logic." *International Journal of Electronics and Communication Engineering (IJECE)* ISSN(P): 2278-9901; ISSN(E): 2278-991X, 17-28
6. Sherasiya, Tariqahmad, Hardik Upadhyay, and Hiren B. Patel. "A survey: Intrusion detection system for internet of things." *International Journal of Computer Science and Engineering (IJCSE)* 5.2 (2016): 91-98.
7. Mehta, P. A. L. L. A. V. I., and K. H. U. S. H. B. U. Mehta. "Green HRM practices and organizational culture." *International Journal of Human Resources Management* 6.1 (2017): 1-6.
8. J. Joseph, F. L. Inambao, "Principles for Achieving Energy Efficiency in Developing Countries", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, ISSN (P): 2249-6890; ISSN (E): 2249-8001, Vol. 11, Issue 2, Apr 2021, 265-282.
9. J. Joseph, F.L. Inambao, "Energy Consumption and Energy Efficiency of Airports: A Case Study of Airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* ISSN (P): 2249-6890; ISSN (E): 2249-8001, Vol. 11, Issue 2, Apr 2021, 205-228.

**CHAPTER 9. REDUCING ENERGY CONSUMPTION: INVESTIGATING SOLAR  
THERMAL HEAT DEFLECTION INNOVATIVE TECHNOLOGY TO REDUCE  
AIR CONDITIONING LOAD AT AIRPORTS – A TECHNOECONOMIC  
ASSESSMENT**

This chapter presents an investigation into the adoption of a solar thermal heat deflective innovative technology to reduce air conditioning in airport terminal buildings in South Africa, providing a technical and economic assessment (or technoeconomic assessment).

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# REDUCING ENERGY CONSUMPTION: INVESTIGATING SOLAR THERMAL HEAT DEFLECTION INNOVATIVE TECHNOLOGY TO REDUCE AIR CONDITIONING LOAD AT AIRPORTS – A TECHNOECONOMIC ASSESSMENT

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## Abstract

Air conditioning is a significant energy user in buildings in South Africa. Airports have large, centralized air conditioning systems for their terminal buildings which contributes around 20 % of the airports' energy consumption. Air conditioning systems are sized according to the cooling or heating demand as appropriate. Air conditioning systems not only cost a lot in energy consumption, but also in maintenance which over a 20 to 25-year lifespan can make a significant impact on the environment. Designing air conditioning systems to be as efficient as possible in operations is one way of reducing cost and environmental footprint of air conditioning systems. Another way is to reduce the cooling and heating demand passively. Insulation is effective in resisting heat gain from the environment, but most traditional materials of insulation require maintenance to ensure its effectiveness. Solar heat gain through the roof of buildings is a major contributor to the cooling demand and finding a way to significantly reduce this component will allow for a smaller air conditioning system to be adopted or allow existing air conditioning systems to supply a larger area. This paper presents an investigation into the adoption of a maintenance-free solar thermal heat deflective innovative technology that deflects 85 % to 95 % heat gain to reduce air conditioning energy consumption in airport terminal buildings in South Africa and provides a technical and economic assessment (or technoeconomic assessment).

**Keywords:** Technoeconomic assessments, reducing energy consumption in air conditioning systems, heat deflective coatings that save energy, passive cooling techniques for airport buildings

## Introduction

The sizing of air conditioning systems satisfies cooling demand brought about by heat gains such as solar heat gain, people, equipment, artificial lighting etc. (Fig. 1 and Table 1). There are various passive cooling techniques available which reduce energy consumption of air conditioning systems. These passive cooling techniques include low overhangs to shade large windows and glass facades, use of double glazing or low emissivity glass, the adoption of insulation, etc.

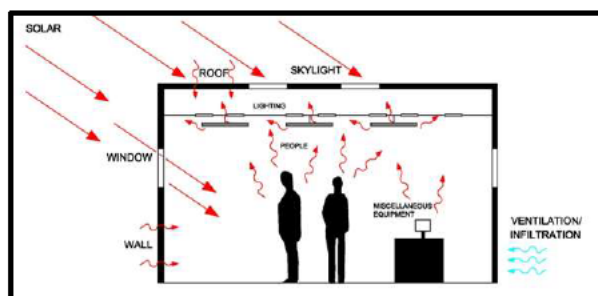


Figure 1: Various heat gains in a building [2]

Table 1: Internal and external heat gains [2]

External heat gains	Internal heat gains
Roofs/walls – conduction	Artificial lighting
Roofs/walls – radiation	Equipment and electronics
Skylights/windows – conduction	People
Skylights/windows – radiation	
Ventilation/infiltration	

Passive cooling techniques are very useful and are the first step of planning before the size of an air conditioning system can be chosen as it serves to reduce the size of an air conditioning system. This saves on capital costs and the cost of energy consumption, and, by implication, can reduce the related carbon footprint. Reducing energy consumption in air conditioning systems is a key focus for airports in South Africa as their contribution to electricity consumption is between 20 % to 30 % [1] of the total electricity consumption.

Even more effective in reducing the size and energy consumption of an air conditioning system is the elimination of components of heat gain such as solar heat gain through the roof of a building. The solar thermal heat deflection innovative technology investigated in this paper can deflect between 85 % to 95 % of the solar heat gain on the surface that it is applied to. Solar heat gain through the roof contributes between 25 % to 35 % of the heat load of an air conditioning system based on the climate of the geographical region, the architecture and material of construction of the roof, and insulation materials if any.

Traditional insulation is cost effective for smaller spaces. However, as the roof area increases, the installation and maintenance cost of insulation versus the overall benefit of reducing the air conditioning load reaches a point where it is not feasible (Fig. 2). Traditional forms of insulation work by typically slowing down the heat ingress into the space by absorbing and retaining the heat within itself over a period of time. Thus, one can argue that the heat eventually reaches the space, however at a much slower rate (Fig. 3).

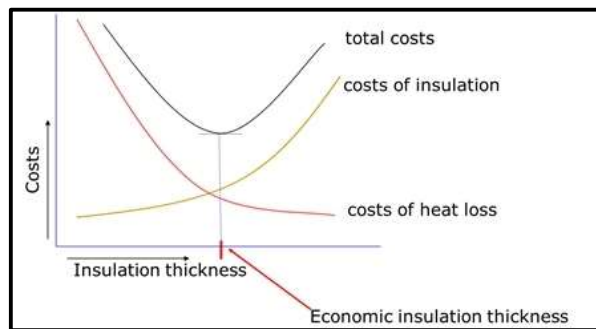


Figure 2: Typical economics curves of traditional insulation materials [3]

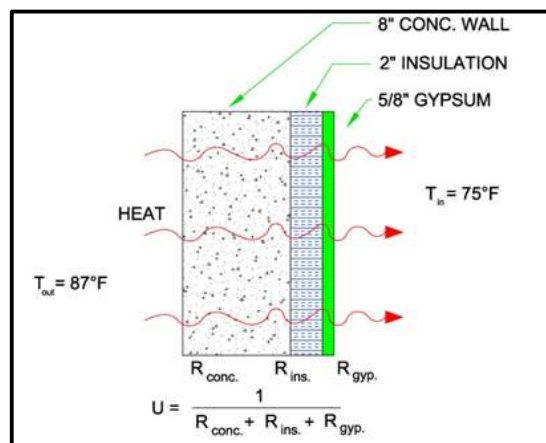


Figure 3: Traditional insulation thermal conductivity and heat resistance relationships [2]

When completing heat load calculations, the time lag factor is key. When the sun shines upon a wall face early in the morning, although the wall does experience a heat load, the amount of heat load experienced in the building at that time is minimal. This is due to the thermal mass of the wall. Thermal mass is also known as heat capacity and is defined as the ability of a material to absorb heat. The radiation from the sun onto the building and the time it takes for the heat to transmit through the

materials must be considered. To calculate the total effect of the difference between the indoor and outdoor temperature, the effect of the solar radiation onto the walls and roofs and the time factor due to the heat storage of the roof/wall material, the engineer usually uses the Cooling Load Temperature Difference or CLTD. [2] The CLTD method uses the following equation to calculate heat ingress into the space:

$$Q = U \times A \times (T_{outdoor} - T_{indoor}) \dots \dots \dots \text{Equation (1)}$$

The solar thermal deflection innovative technology investigated in this paper is a ceramic based insulation with two key innovations, namely, ceramic microspheres which are filled with inert gas. This coating, when applied to the surface exposed to solar radiation, does not allow the surface to heat load but rather deflects all the heat back to the surrounding environment. This means that there is no or negligible heat gain through that surface because it forms a thermal barrier. This innovative coating when applied to the roof surface also reduces the wear and tear on the roof due to expansion and contraction from solar radiation, leading to longer lifespans of the roof material and a better return on investment. This innovative coating was used initially by National Aeronautics and Space Administration (NASA) to protect the front end of booster rockets. It deflected heat gain from wind resistance and engine exhaust.

This ceramic based coating with inert gas filled microspheres has found use in the insulation of furnaces in industry and is commercially available to be used on the roofs of buildings, on walls, and any other surface that needs heat to be deflected. This insulation is investigated in this study for its use in deflecting solar heat gain for terminal building roofs for nine airports in South Africa owned and operated by Airports Company South Africa.

Airports Company South Africa is South Africa’s airport authority, owning and operating nine airports in South Africa, namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport (CTIA) (Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (PEIA) (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (BFIA) (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape).

The key technology features that make ceramic based solar thermal deflection material effective are microscopic, inert gas filled microspheres:

- Ceramic microspheres - the use of spheres increases the durability because a sphere is a very stable shape that can take abuse without cracking. The same cannot be said of irregularly shaped fillers that do not have strong internal structures. Once the ceramic microspheres link together to form a bond with the resin they become even more durable against scratches, cracking, etc. and can withstand regular contact with industrial chemicals without breaking down.
- Inert gas or creation of vacuum – this makes heat transfer via conduction almost impossible.

The key factors and parameters for the ceramic-based solar thermal deflection coating to be adopted at airports are:

- Must be able to reduce the air conditioning load and thus electricity consumption and the airport’s carbon footprint by at least 25 %
- Needs to make financial sense to the business
- There should be no adverse effect on airport operations in respect of glare
- Class A fire rating and “0” flame and smoke
- It should have a manufacturer’s performance guarantee of at least 10 years
- It must be environmentally friendly, non-toxic and not contain any volatile organic compounds (VOCs)

## 1. Description of the technology

The ceramic-based coating referred to as “solar thermal deflective innovation technology” deflects about 95 % of the sun’s thermal energy contained in the infrared and ultraviolet rays. The ability of the ceramic-based coating to achieve this is through two key innovations within the coating which is applied as a paint. The coating contains ceramic microspheres wherein an inert gas or a vacuum exists.

Paint manufacturers blend the inert gas filled ceramic microspheres (usually in a powder form) into the paints so that they form a heat resistant film not allowing heat to pass through, but rather reflecting it back into the atmosphere. Fig. 4 shows a zoomed-in view of the shape and form of the microspheres. Each single ceramic microsphere is small and appears as a single grain of flour (slightly thicker than a human hair).

Fig. 5 shows the shape and form of each ceramic microsphere (left), the paint application and drying process depiction of how the insulating layer is formed (right). In effect they are microscopic hollow vacuum sphere that deflects heat and reduces the transfer of sound.

When mixed into paint, the painted surface dries to a tightly packed layer of the hard, hollow "microspheres", the tightly packed film reflects and dissipates heat by minimizing the path for the transfer of heat. The ceramics are able to reflect, refract and block heat radiation (loss or gain) and dissipate heat rapidly preventing heat transfer through the coating with as much as 90 % of solar infrared rays and 85 % of ultraviolet rays being radiated back into the atmosphere.



Figure 1: Insulating additive form – tiny ceramic inert gas filled microspheres [4]

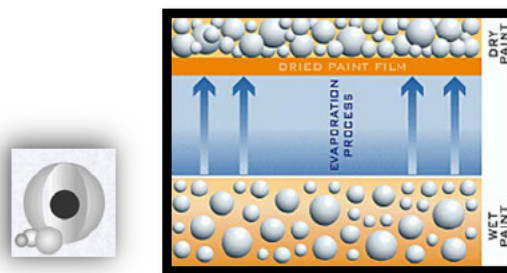


Figure 2: Form of the tiny microsphere (left) Typical paint application and drying process (right) [5]

The technology is available as the white powder additive to be mixed with any type and colour of paint to achieve the insulating effect. The paint itself together with the ceramic inert gas filled (or vacuumed) microspheres can be bought from paint manufacturers.

## 2. Assessment of technology maturity

The ceramic inert gas filled microspheres were invented in the course of searching for an insulating method for solid rocket boosters that experienced immense heat generated by wind resistance and engine exhaust during the launch of a space shuttle. Initial attempts to a solution for this problem were

costly or had very accurate chemical processes, that, if they went out of parameters, became ineffective. To protect the solid rocket boosters, engineers at Marshall Space Flight Center in the 1980s developed a spray-on insulating process that was applied to the boosters' forward assembly, systems tunnel covers, and aft skirt. The materials were costly, and if the application was interrupted or not completed within the five-hour window, the batch was lost. In addition, the strength of the material was difficult to regulate, so it often chipped off during flight and splashdown (when the reusable boosters were dropped into the sea). Another disadvantage was that two of the nine ingredients were harmful to the environment. [5][6]

Through a Space Act Agreement in 1993, Marshall partnered with the United Technologies subsidiary, USBI, of Huntsville, Alabama, to develop an alternative to the old insulating spray. Using Marshall-developed convergent spray technology, they atomized epoxy and different filler materials to create an environmentally friendly ablative insulation material. The material, Marshall Convergent Coating-1 (MCC-1) consisted of 8 % hollow spherical glass, 9 % cork, and 83 % epoxy. The materials were mixed at the time of application, at the point of release from a spray gun, which eliminated the problem of batches being ruined from interruptions and delays. The insulating paint was first flight tested in 1996 on the STS-79 mission, and was successful. It has been employed on all subsequent shuttle flights, with virtually no observed missing or chipped paint on the spent boosters during post-flight inspections. [5][6]

David Page, founder of Tech Traders Inc., of Merritt Island, Florida, sought assistance developing coatings and paints that create a useful thermal reflectance. NASA made available technical assistance to small businesses. After a year of collaboration with NASA as well as additional testing with Dr. Heinz Poppendiek of the San Diego-based Geoscience Ltd., the product was ready for market. The San Diego-based Geoscience Ltd is a research and development firm specializing in heat transfer, fluid flow, mass transfer, micro meteorology, biophysics, engineering design, system fabrication, product evaluation, and the measurement of thermal, mechanical, and fluid properties. [5][6]

The insulating materials reduce heat transfer by reflecting heat away from the painted surface by forming a heat-blocking radiant barrier on the surface. The secret behind the product they called "Insuladd" is the unique propriety process that applies a coating to the microscopic inert gas-filled ceramic microspheres that make up Insuladd. When the paint dries, these form the radiant heat barrier, turning ordinary house paint into heat-reflecting thermal paint. The insulating materials reduce heat transfer by reflecting heat away from the painted surface by forming a heat-blocking radiant barrier on the surface that is painted. [5][6]

The product works with all types of paints and coatings and will not change the coverage rate, application, or adhesion of the paint. It can be used on walls, roofs, ceilings, air-conditioning ducts, steam pipes and fittings, and is particularly well-suited for use on metal buildings, cold storage facilities such as walk-in coolers and freezers, and mobile or modular homes. [5][6]

Following this, many paint manufacturers have created their brands from the two main technology breakthroughs, i.e., ceramic inert gas fill microspheres. According to some paint manufacturers, the microspheres insulating ceramic additive have compressive strengths up to 41 MPa (6 000 psi), a softening point of about 1800 °C, and they are fairly chemical resistant, with low thermal conductivity of 0.1 W/m/°C. The addition of the ceramics to any material provides improved fire resistance, protection of coated surfaces from harmful UV rays, repulsion of chewing insects and increased durability of the coating due to the hard ceramic finish. Ceramic filled paint is easier to clean and lasts far longer than conventional paint pigments. [5][6]

### **3. Cost-benefit analysis**

This section summarizes the rationale for the technology selection and presents the feasibility study should the ceramic based insulation be adopted by the airports.

### 3.1 Rationale for the technology selection

Reducing energy consumption towards carbon neutrality in electricity consumption has two major focuses, i.e., lighting energy consumption and air conditioning energy consumption reduction. [1] To reduce energy consumption from air conditioning systems, many initiatives were considered for implementation. An opportunity of energy conservation through the reduction of solar heat gain through the terminal building roofs was highlighted.

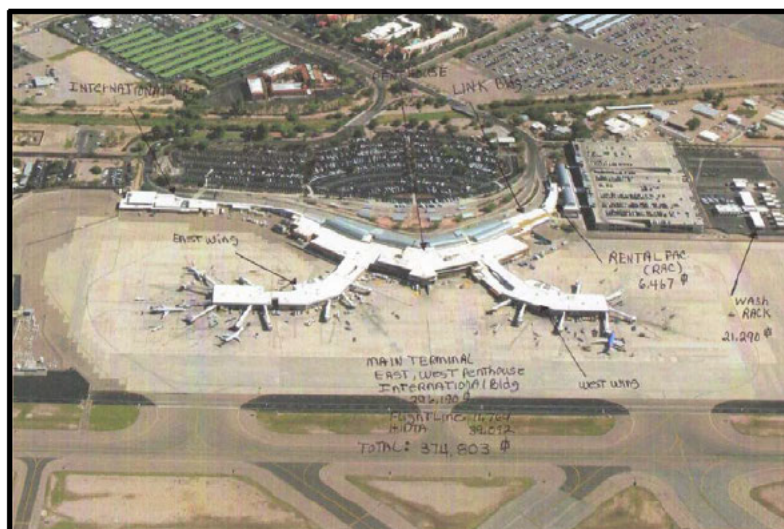
### 3.2 Economic Analysis Results and Benefits

A case study was captured by the Tucson airport that adopted the Smartcoat SUPER THERM<sup>®</sup> brand of ceramic based thermal deflection coating. Table 2 contains the parameters and air conditioning energy savings. Fig. 3 shows the full surface area that constituted the project and the energy savings. Fig. 4 shows a progress snapshot.

**Table 2: Tucson airport summary of the cost of the ceramic based paint and the energy savings**

Tucson airport ceramic based painted roof area (sqft)	Cost of the project per square foot in 2008 (US\$/sqft)	Conversion of sqft to sqm (sqm)	Converted to US\$/sqm	price per square meter in 2018 – using compounded escalation (R/sqm)	Total savings in US\$ per month	% Energy Savings on the HVAC system
374 804	2.1	34 820.41	22.604	584.94	\$22 144 (22 % reduction)	40 % (A/C portion of the total utility being 55 %)

The total roof area of the terminal is 374 804 ft<sup>2</sup> applied at US\$2.10 /ft<sup>2</sup> is US\$787 088. With a cost reduction of US\$22 144 /month, this results in a return withing 35.54 months. With the total utility savings of \$22 144 (22 %) in August for the total facility and the air conditioning portion of the total utility being 55 %, this relates to a 40 % savings in air conditioning operational cost. The savings are beyond the air conditioning running cost; the units cycle more giving longer life, and require less maintenance work and less tonnage to take care of the main terminal and wings. A key point is that the 22 % savings for the airport was on the total energy bill (lighting, elevators, food facilities, etc). This simply means that the SUPER THERM<sup>®</sup> made a 40 % reduction in the air conditioning costs The air conditioning portion of a total energy bill is 55 % which when calculated on the 22 % savings of the total relates to a 40 % savings in pure air conditioning costs. [7]



**Figure 3: Areas painted with ceramic based thermal deflective paint [7]**



Figure 4: Project in progress – Tucson Airport application of the ceramic based thermal deflection paint [7]

For the purposes of the ACSA airports’ economic analysis, a conservative 25 % energy reduction in current HVAC energy consumption was used. Table 3 contains each airport’s HVAC energy consumption estimation (at 25% of their total energy consumption) and the respective roof surface areas to be coated with the ceramic based coating.

Table 3: ACSA airports HVAC Energy consumption and roof surface areas to be covered

Airport	HVAC Annual Energy Consumption (kWhs)	Roof surface area (m <sup>2</sup> )
OR Tambo International Airport	7 255 943.21	100 000
Cape Town International Airport	4 294 822.38	40 000
King Shaka International Airport	2 116 495.00	32 000
Port Elizabeth International Airport	465 320.31	2 000
East London Airport	264 268.75	3 000
Bram Fischer International Airport	202 713.25	3 000
George Airport	123 577.56	4 000
Upington International Airport	48 904.94	2 500
Kimberley Airport	20 227.38	1 800

The economic analysis presented in this study was performed during the period 1 April 2018 to 31 March 2019, by the economic modelling department of Airports Company South Africa.

The economic model yields the net present value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index (PI). The IRR is compared to ACSA’s 11.5 % weighted average cost of capital (WACC) rate (2018) to determine economic feasibility. When the NPV is zero or positive is it an investment that pays itself off during its economic lifespan. The NPV equation used in the economic model is given below (Equation 2). The IRR is the return ( $i$  in below equation) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the

economic lifespan of the investment. The PI (given in Equation 3) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^T \frac{R_t}{(1+i)^t} \dots\dots\dots \text{Equation (2)}$$

Where:  $R_t$  = net cash inflows – outflows during a single period  $t$   
 $i$  = discount rate or return that could be earned  
 $t$  = number of time periods

$$PI = \frac{PV \text{ of future cash flows}}{\text{Initial Investment}} \dots\dots\dots \text{Equation (3)}$$

The summarized economic analysis presented in the next section uses the above figures in economic models.

**(a) Summary**

Table 4 to Table 12 presents the results of economic modelling for each airport considering their adoption of ceramic based thermal deflection paint.

**Table 4: OR Tambo International Airport summarized economic analysis**

Inputs		Output	
Roof surface area (m <sup>2</sup> )	100 000	End of job cost	ZAR 61.48m
Capital cost (2018 basis)	ZAR 58.5m	Net present value	ZAR 17.99m
Electricity kWh saving	7 255 943.21	Internal rate of return	18.1 %
Annual electricity cost saving (ZAR 1.47 /kWh)	ZAR 10.67m	Nominal payback period	4 years
Electricity escalation	5.1 %		
Beneficial operation	2020		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	10 years		
Degradation	0.8 % per annum		
Operations and maintenance cost	ZAR 0		

**Table 5: Cape Town International Airport summarized economic analysis**

Inputs		Output	
Roof surface area (m <sup>2</sup> )	40 000	End of job cost	ZAR 24.59m
Capital cost (2018 basis)	ZAR 23.4m	Net present value	ZAR 19.52m
Electricity kWh saving	4 294 822.38	Internal rate of return	27.8 %
Annual electricity cost saving (ZAR 1.47 /kWh)	ZAR 6.31m	Nominal payback period	3 years
Electricity escalation	5.1 %		
Beneficial operation	2020		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	10 years		
Degradation	0.8 % per annum		
Operations and maintenance cost	ZAR 0		

**Table 6: King Shaka International Airport summarized economic analysis**

Inputs		Output	
Roof surface area (m <sup>2</sup> )	32 000	End of job cost	ZAR 19.67m
Capital cost (2018 basis)	ZAR 18.72m	Net present value	ZAR 1.64m
Electricity kWh saving	2 116 495.00	Internal rate of return	13.5 %
Annual electricity cost saving (ZAR 1.29 /kWh)	ZAR 2.73m	Nominal payback period	5 years
Electricity escalation	5.1 %		
Beneficial operation	2020		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	10 years		
Degradation	0.8 % per annum		
Operations and maintenance cost	ZAR 0		

**Table 7: Port Elizabeth International Airport summarized economic analysis**

Inputs		Output	
Roof Surface area (m <sup>2</sup> )	2 000	End of job cost	ZAR 1.23m
Capital cost (2018 basis)	ZAR 1.17m	Net present value	ZAR 2.69m
Electricity kWh saving	465 320.31	Internal rate of return	50.7 %
Annual electricity cost saving (ZAR 1.29 /kWh)	ZAR 600 263	Nominal payback period	2 years
Electricity escalation	5.1 %		
Beneficial operation	2020		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	10 years		
Degradation	0.8 % per annum		
Operations and maintenance cost	ZAR 0		

**Table 8: East London Airport summarized economic analysis**

Inputs		Output	
Roof surface area (m <sup>2</sup> )	3 000	End of job cost	ZAR 1.84m
Capital cost (2018 basis)	ZAR 1.75m	Net Present Value	-ZAR 0.43m
Electricity kWh saving	264 268.75	Internal rate of return	5.4 %
Annual electricity cost saving (ZAR 0.60 /kWh)	ZAR 158 561	Nominal payback period	7 years
Electricity escalation	5.1 %		
Beneficial operation	2020		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	10 years		
Degradation	0.8 % per annum		
Operations and maintenance cost	ZAR 0		

**Table 9: Bram Fischer International Airport summarized economic analysis**

Inputs		Output	
Roof surface area (m <sup>2</sup> )	3 000	End of job cost	ZAR 1.84m
Capital cost (2018 basis)	ZAR 1.75m	Net present value	ZAR 0.27m
Electricity kWh saving	202 713.25	Internal rate of return	14.9 %
Annual electricity cost saving (ZAR 1.36 /kWh)	ZAR 275 690	Nominal payback period	5 years

Electricity escalation	5.1 %	
Beneficial operation	2020	
Construction period	1 year	
Corporate tax	28 %	
Economic lifespan	10 years	
Degradation	0.8 % per annum	
Operations and maintenance cost	ZAR 0	

**Table 10: George Airport summarized economic analysis**

Inputs		Output	
Roof surface area (m <sup>2</sup> )	4 000	End of job cost	ZAR 2.46m
Capital cost (2018 basis)	ZAR 2.34m	Net present value	-ZAR 1.5m
Electricity kWh saving	123 577.56	Internal rate of return	N/A
Annual electricity cost saving (ZAR 0.68 /kWh)	ZAR 84 032	Nominal payback period	No payback
Electricity escalation	5.1 %		
Beneficial operation	2020		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	10 years		
Degradation	0.8 % per annum		
Operations and maintenance cost	ZAR 0		

**Table 11: Upington International Airport summarized economic analysis**

Inputs		Output	
Roof surface area (m <sup>2</sup> )	2 500	End of job cost	ZAR 1.54m
Capital cost (2018 basis)	ZAR 1.46m	Net present value	-ZAR 0.93m
Electricity kWh saving	48 904.94	Internal rate of return	N/A
Annual electricity cost saving (ZAR 1.10 /kWh)	ZAR 53 795	Nominal payback period	No payback
Electricity escalation	5.1 %		
Beneficial operation	2020		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	10 years		
Degradation	0.8 % per annum		
Operations and maintenance cost	ZAR 0		

**Table 12: Kimberley Airport summarized economic analysis**

Inputs		Output	
Roof surface area (m <sup>2</sup> )	1 800	End of job cost	ZAR 1.11m
Capital cost (2018 basis)	ZAR 1.05m	Net present value	-ZAR 0.46m
Electricity kWh saving	20 227.38	Internal rate of return	N/A
Annual electricity cost saving (ZAR 1.56 /kWh)	ZAR 31 554	Nominal payback period	No payback
Electricity escalation	5.1 %		
Beneficial operation	2020		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	10 years		
Degradation	0.8 % per annum		
Operations and maintenance cost	ZAR 0		

From the economic analyses, one can see that for five airports implementation is currently feasible, i.e., ORTA, CTIA, KSIA, PEIA and BFIA. Implementation at the remaining airports is unfeasible based on the parameters used.

### ***(b) Sensitivity Analysis***

For the sensitivity analysis, the airports that show feasibility need to be looked at for a change in the parameters that made the business case for the airports. The parameters that made the airports implementation feasible is the energy savings (kWh) together with the electricity tariff.

The effect of the electricity tariff in the economic analysis conducted for BFIA and East London Airport can be clearly seen. Their implementation scale is exactly the same, and their energy savings similar, but the significant difference is the electricity tariff (ZAR 1.36 /kWh versus ZAR 0.60 /kWh).

Looking at PEIA and Kimberley Airport, their electricity tariffs are ZAR 1.29 /kWh and ZAR 1.56 /kWh respectively, and their implementation scale almost the same, but the energy savings associated with implementation is what made PEIA's implementation feasible and Kimberley Airport's implementation not. PEIA's energy savings are more than 20 times those of Kimberley Airport's energy savings. PEIA has a central air conditioning system producing chilled water for the airport's cooling needs, whereas Kimberley Airport has a distributed system of split units, wall mounted and cassette units.

Another factor to consider is the climate at each of the sites, their roof material type (concrete or metal based) and their type of air conditioning system meeting the air conditioning need. These factors directly influence the energy consumption for air conditioning. If, by measurement of the air conditioning electricity consumption, the expected energy savings are more for each airport, the economics may be revised accordingly.

## **4. Technology Risk Assessment**

The ceramic based thermal deflective coating is based on two revolutionary technological breakthroughs, namely, ceramic microspheres and the incorporation of an inert gas which together provides structural rigidity, ensuring that the material is able to stand the abuse of impact, temperatures and industrial chemicals and heat deflection by offering almost no medium for heat transfer.

Most of the paint industry is now incorporating these two technologies into their products with some paint industries offering just these two technologies in a powder product to be added to any type of and colour of paint. While using the powder product may seem more convenient and self-applying this could save on costs, however, the risk is that should there arise an issue with the paint mixture once applied, the coating flakes/breaks off, or if the desired insulation effect is not achieved, or the life of the product is not reached within the economic life upon which the project was approved, there will be no way to rectify this in order to ensure that the financial investment is not wasted.

For this reason, it is best that one ensures the following:

- The paint is purchased from a SABS approved manufacturer/supplier.
- The product is applied by the manufacturer or a manufacturer approved contractor that will preserve the warranties and guarantees that come with the product.
- The product should be performance guaranteed (the minimum agreement is that the HVAC system electricity consumption is reduced by at least 25 %) and the guarantee on the lifespan should be at least 10 years (or as per the calculation parameters on feasible economic lifespan).
- As an added convenience to ensure that the investment is protected in terms of guaranteed performance, the paint should contain both the microsphere and inert gas or vacuum technological features.

- The paint should ensure that there is no glare to pilots – a preferable colour is dove-grey rather than white. The microsphere and inert gas technologies are not dependant on colour for their thermal resistance function.
- The ceramic coating must have a Class A fire rating and “0” flame and smoke.
- It must be environmentally friendly, non-toxic and not contain any volatile organic compounds (VOCs).

## 5. Airport’s integration strategy

The airports should adopt this paint as a turnkey solution with guarantees and warranties in place as described in the technology risk assessment section. The current airport’s terminal building roofs should be painted with this paint (exposed metal surfaces are preferable to concrete roofs which already provide enough thermal resistance). All new terminal buildings or terminal building roof refurbishment projects should incorporate this coating within the project. This should also be considered for projects involving refurbishing or resizing a central HVAC or air conditioning system for a facility as a passive cooling technique. A measurement and verification exercise must be undertaken to ensure that the performance guarantee given by the manufacturer is tested and tracked.

## 6. Strategic fit of the solar thermal deflection innovative technology

The solar thermal deflective innovation coating gives an annual cost saving of ZAR 20.6m and results in 6.25 % saving in electricity consumption across five airports in South Africa (Table 13).

**Table 13: Cost savings and impact of solar thermal deflection innovation on the carbon neutrality journey**

Airport	Annual cost savings in ZAR million (expressed in 2018 terms)	Impact of the solar thermal deflection innovative technology project to the airport’s carbon neutrality goal
OR Tambo International	10.67	6.25 %
Cape Town International	6.31	6.25 %
King Shaka International	2.73	6.25 %
Port Elizabeth International	0.600	6.25 %
Bram Fischer International	0.275	6.25 %
<b>Total savings (ZAR in 2018 terms)</b>	<b>20.6</b>	

## Conclusion

The solar thermal heat deflection innovative technology investigated in this paper uses ceramic-based, inert gas fill microspheres to form a heat barrier that deflects heat which does not allow the surface that it is applied to, to heat load. The five airports that showed the solar thermal heat deflective innovation technology feasible for implementation are ORTIA, CTIA, KSIA, PEIA and BFIA. The technology could be implemented for ORTIA, CTIA and KSIA by the airports’ building maintenance departments and for PEIA and BFIA, this implementation could be executed by an external service provider. Should this option be implemented, appropriate measurement and verification exercise should be conducted to ensure that performance guarantees obtained from the manufacturer are tracked. Such a technology would contribute to an average of 6.25 % reduction in electricity consumption and carbon emissions across the selected airports, with a potential annual electricity consumption saving of ZAR 20.6m.

## References

- [1] Joseph, J., Inambao, F.L., “Energy consumption and energy efficiency of airports: A case study of airports in South Africa”, *International Journal of Mechanical and Production Engineering Research and Development*, Volume 11, Issue 2, April 2021.
- [2] Engineering Pro Guides, “Heating/cooling loads for the mechanical HVAC & refrigeration PE exam”, <https://www.engproguides.com/hvac-heating-cooling-loads.html>, accessed 27/06/2021.

- [3] Committee Industrial Insulation Standards, “Minimum total cost method”, <https://www.cini.nl/en/knowledge-center/cinicalc-tool/insulation-thickness/>, 2014, accessed 27/06/2021.
- [4] Alibaba.com [https://www.alibaba.com/product-detail/refractory-material-insulation-cenospheres-hollow-ceramic\\_60721479525.html?spm=a2700.pc\\_countrysearch.main07.1.3e176a31T5Ca0q](https://www.alibaba.com/product-detail/refractory-material-insulation-cenospheres-hollow-ceramic_60721479525.html?spm=a2700.pc_countrysearch.main07.1.3e176a31T5Ca0q), accessed 16/03/2019
- [5] Hy-Tech Thermal Solutions, “ThermaCels™ ceramic paint additive makes any paint insulate”, <http://www.hytechsales.com/ceramics/>, accessed 17/03/2019.
- [6] National Aeronautics and Space Administration, “Insulating paint powder turns every color 'green'”, [https://www.nasa.gov/topics/nasalife/green\\_paint.html](https://www.nasa.gov/topics/nasalife/green_paint.html), accessed 17/03/2019.
- [7] Wilt, C., “Energy Audit and Report: Tucson Airport 374804 sq.ft. of roofing coated with the SUPER BASE(HS) / SUPER THERM® SYSTEM”, Tucson Airport facilities manager, 2009.

## **CHAPTER 10. REDUCING ENERGY CONSUMPTION AT AIRPORTS IN SOUTH AFRICA: INVESTIGATING TECHNOLOGIES THAT REDUCE ELECTRICITY CONSUMPTION**

This chapter presents an investigation into the technologies that will reduce energy consumption at airports in South Africa, estimating the energy reduction impact, investment and return on investment.

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## REDUCING ENERGY CONSUMPTION AT AIRPORTS IN SOUTH AFRICA: INVESTIGATING TECHNOLOGIES THAT REDUCE ELECTRICITY CONSUMPTION

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### ABSTRACT

*Reducing energy consumption through energy efficiency and energy conservation is key as a first step to reducing carbon emissions. It is also essential on the journey to adopting alternative low carbon energy sources such as renewable energy. This paper presents an investigation into technologies that will reduce energy consumption at airports in South Africa, through estimating their energy reduction impact and the required investment and return on investment.*

**KEYWORDS:** *Electricity Reduction Technologies, Energy Reduction for Airports, LED Lighting, Lighting Control, Geyser Sleeve Technology, Low Emissivity Glass, Double Glazing, Energy Savings with Air Conditioning*

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### INTRODUCTION

In the journey towards reducing electricity consumption, it is necessary to ascertain the energy consumption and corresponding carbon footprint and identify the drivers of energy consumption related to a particular site [1]. This exercise will highlight energy wastage. Airports' most significant energy users are lighting and air conditioning [1]. It is thus important that all efforts to reduce carbon emissions through energy efficiency and energy conservation focus on lighting and air conditioning and the systems that contribute or affect the demand for them. Technologies for lighting and air conditioning at the airports must be kept up to date. Factors that contribute to increased energy consumption must be addressed to ensure reduced energy consumption.

Building and interior refurbishments are opportunities to alter designs to complement the lighting and space thermal requirements to promote efficiency and reduce demand. Replacement cycles of infrastructure such as chillers, motors, fans, cooling towers, chilled water pipe runs, lighting, buildings management systems, buildings insulation, building facades and envelope, interior designs, etc. should be regarded as an opportunity to incorporate the best available technology and designs that promote reduction in energy consumption, monitoring, measuring and control of energy consumption for continued improvement in performance.

This paper presents the interventions identified for reduction in electricity consumption for nine airports in South Africa owned and operated by Airports Company South Africa (ACSA), namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport (CTIA) (Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (PEIA) (Eastern Cape), East London Airport (EL) (Eastern Cape), Bram Fischer International Airport (BFIA) (Bloemfontein, Free State), George Airport (GG) (Eastern Cape), Upington International Airport (UPIA) (Northern Cape) and Kimberley Airport (KIM) (Northern Cape).

The focus of this study is on the reduction in carbon emissions in lighting and air conditioning systems at ACS airports and those factors that affect it. Lighting projects focus on changing lighting systems to LED (light emitting diode) technology, and on controlling the lighting according to lighting demand. The adoption of geyser sleeve technology is to control the supply of hot water according to demand. Air conditioning projects focus on reducing the demand by investigating the adoption of low emissivity glass or double glazing for terminal building glass facades, and of solar thermal-deflecting coating on terminal building roof surfaces [2]. Air conditioning projects also investigate the implementation of air conditioning system additions that will control the supply of air conditioning accurately and efficiently to suit the need. Solar thermal energy to power air conditioning chillers is also investigated.

For each of the feasibility studies, an economic model was used, drafted by ACSA's economic modelling department. The economic model yields the net present value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index (PI). The IRR is compared to ACSA's 11.5 % weighted average cost of capital (WACC) rate (2018) to determine economic feasibility. When the NPV is zero or positive is it an investment that pays itself off during its economic lifespan. The NPV equation used in the economic model is given below (Equation 1). The IRR is the return ( $i$  in the below equation) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business [2].

$$NPV = \sum_{t=0}^T \frac{R_t}{(1+i)^t} \quad \text{Equation (1)}$$

Where:

$R_t$  = net cash inflows – outflows during a single period  $t$

$i$  = discount rate or return that could be earned

$t$  = number of time periods

Due to the number of economic models run for all the projects presented here, a summarized economic result is presented giving the NPV and IRR for each investment.

The work presented here was undertaken in FY2018/19, i.e., from 1 April 2018 to 31 March 2019 using the energy consumption of FY2017/18, i.e., from 1 April 2017 to 31 March 2018 as a baseline for comparison. Table 1 gives the energy consumption of the airports for the period 1 April 2017 to 31 March 2018 and was used to determine the impact of the projects in percentage reduction of electricity consumption from the national electricity grid (which is also the % reduction in carbon footprint).

**Table 1: Airports' Energy Consumption for the Period 1 April 2017 to 31 March 2018**

	<b>Airport</b>	<b>Electricity Consumption in kWh (FY2017/18)</b>	<b>Corresponding Carbon Footprint in kgs using 1 kWh = 1.03 kgs CO<sub>2</sub></b>	<b>Electricity Tariff (ZAR/kWh) 2018 Basis</b>
1	O R Tambo International Airport	116 095 091.39	119 577 944.13	ZAR 1.47 /kWh
2	Cape Town International Airport	68 717 158.26	70 778 673.01	ZAR 1.47 /kWh
3	King Shaka International Airport	33 863 920.76	34 879 838.38	ZAR 1.29 /kWh
4	Port Elizabeth International Airport	7 445 125.50	7 668 479.27	ZAR 1.29 /kWh
5	East London Airport	4 228 300.00	4 355 149.00	ZAR 0.60 /kWh

**Impact Factor (JCC): 9.6246**

**NAAS Rating: 3.11**

6	Bram Fischer International Airport	3 243 412.98	3 340 715.37	ZAR 1.36 /kWh
7	George Airport	1 977 241.50	2 036 558.75	ZAR 0.68 /kWh
8	Upington International Airport	782 479.00	805 953.37	ZAR 1.10 /kWh
9	Kimberley Airport	647 276.00	666 694.28	ZAR 1.56 /kWh

The electricity reduction projects given in the following sections provide a guide for airports to investigate the onsite specific conditions and make adjustments as necessary to individual projects per airport. Most adjustments will come from their light fitting count and corresponding energy savings. The results given here confirm the feasibility of the intervention, providing guidance to the airports on their focus areas to reduce electricity consumption.

### 1. Lighting

Lighting contributes at least 50 % of an airports’ electricity consumption [1].LED light is a mature technology and the best available technology when it comes to reduced energy consumption. The fundamental component of LED technology (Figure. 1) is the use of a semiconductor material that is engineered to glow when energy that induces a current passes through it.

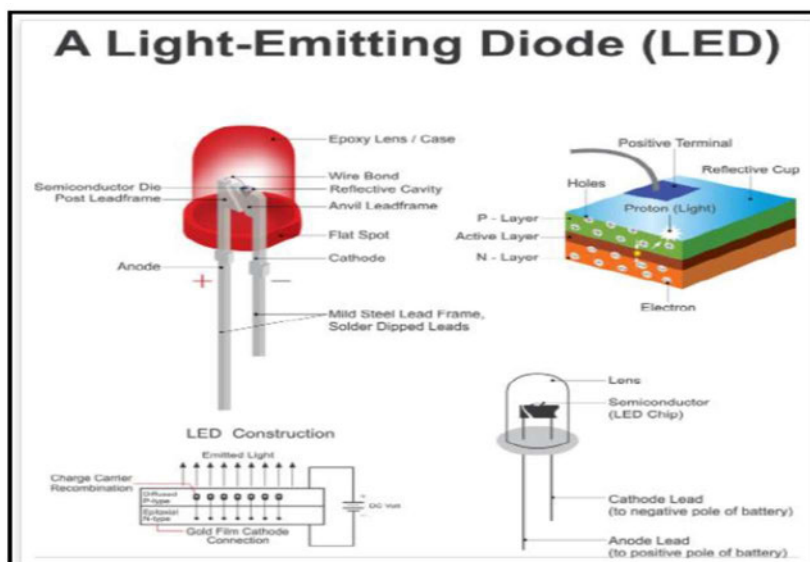


Figure 1: Components of an LED Light [3].

Due to most of the airports’ lighting not being LED technology, there is a significant opportunity to reduce energy consumption of lighting. Some of the smaller airports in the group have implemented LED lighting and the opportunity to reduce energy consumption is relatively smaller there. Due to the airports having thousands of light fittings and the lack of accurate as-built drawings, the estimate of the number of light fittings to be replaced and the estimated energy savings and other criteria were assumed. Assumptions for each airport are provided in Table 2.

Table 2: Assumptions For Each Airport

	Airport	Assumptions	Number of Light Fittings to be Changed
1	ORTIA	Assuming: lighting burns 24 hours a day, 7 days a week; 50% of total electricity consumption is due to lighting; that 40% of the lighting has been changed to LED (20% of total electricity load is efficient). Therefore: 60% of the lighting needs to be changed to LED, i.e., 30% of total electricity load can be reduced by half, i.e., a saving of 15% on total electricity consumption, assuming an average of 50W per fitting.	79 517
2	CTIA		47 067
3	KSIA	Assuming: lighting burns 24 hours a day, 7 days a week; 50% of total electricity consumption is due to lighting; 20% of the lighting has been changed to LED (10% of total electricity load is efficient). Therefore: 80% of the lighting needs to be changed to LED, i.e., 40% of total electricity load can be reduced by half, i.e., a saving of 20% on total electricity consumption, assuming an average of 50W per fitting	30 926
4	PEIA	Assuming: lighting burns 24 hours a day, 7 days a week; 50% of total electricity consumption is due to lighting; that 40% of the lighting has been changed to LED (20% of total electricity load is efficient). Therefore: 60% of the lighting needs to be changed to LED, i.e., 30% of total electricity load can be reduced by half, i.e. a saving of 15% on total electricity consumption, assuming an average of 50W per fitting.	5 099
5	EL		2 896
6	BFIA		2 222
7	GG		1 354
8	UPIA		536
9	KIM		443

Based on the assumptions provided in Table 2 and using an average cost of ZAR 1200 per average 50W supplied and installed, the feasibility indicators and savings are given per airport in Table 3. The lifespan of the light fittings are five years with zero maintenance cost. The annual maintenance cost savings were not included in the economic modelling. The execution of the lighting retrofit for the purposes of the feasibility study is taken to be complete by September 2021.

Table 3: Feasibility of LED retrofitting nine airports in South Africa

	Airport	Cost (ZAR Million)	NPV (ZAR Million)	IRR (%)	Annual kWh Reduction	Annual Cost Savings of kWhs Saved (ZAR Million) 2018 basis	Result
1	ORTIA	95.42	12.740	16.80	17 414 263.71	25.60	Feasible
2	CTIA	56.48	7.51	16.70	10 307 573.70	15.15	Feasible
3	KSIA	37.11	0.94	12.50	6 772 784.00	8.74	Feasible
4	PEIA	6.12	0.14	12.40	1 116 768.75	1.44	Feasible
5	EL	3.48	-1.42	-7.00	634 245.00	0.41	Unfeasible
6	BFIA	2.67	0.18	14.20	486 511.80	0.66	Feasible
7	GG	1.63	-0.61	-5.20	296 586.15	0.20	Unfeasible
8	UPIA	0.64	-0.06	7.80	117 371.85	0.13	Unfeasible
9	KIM	0.53	0.10	18.80	97 091.40	0.15	Feasible

LED retrofits are feasible for ORTIA, CTIA, KSIA, PEIA, BFIA and KIM, however, these are not feasible for EL, GG and UPIA. Further reduction in electricity consumption for lighting can be achieved by controlling the supply of lighting according to the need for lighting.

## 2. Lighting Control

Lighting control to meet lighting demand involves the installation of smart electronics in occupancy sensors, building management system programmes to control lighting supply according to operations, and varying light intensity (dimming functions) to provide the lux levels needed for the space.

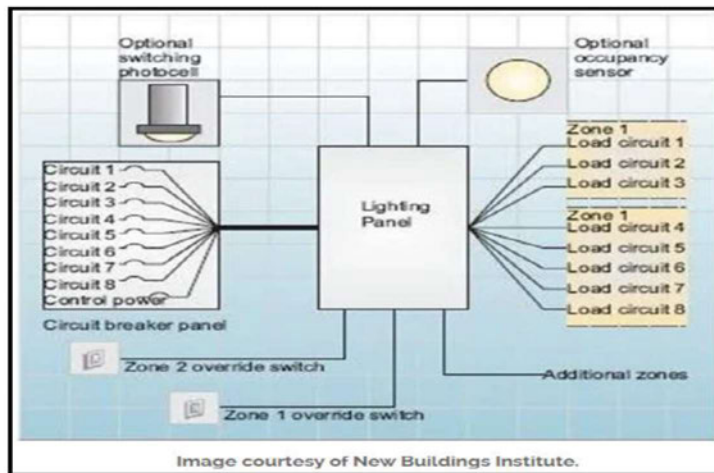


Figure 2: Typical Lighting Control [4].

Figure 2 shows typical lighting control. Figure 3 shows that lighting control technologies can also be extended to other building services such as air conditioning. Wireless means of building services control can also reduce cost and inconvenience as opposed to physical wiring.

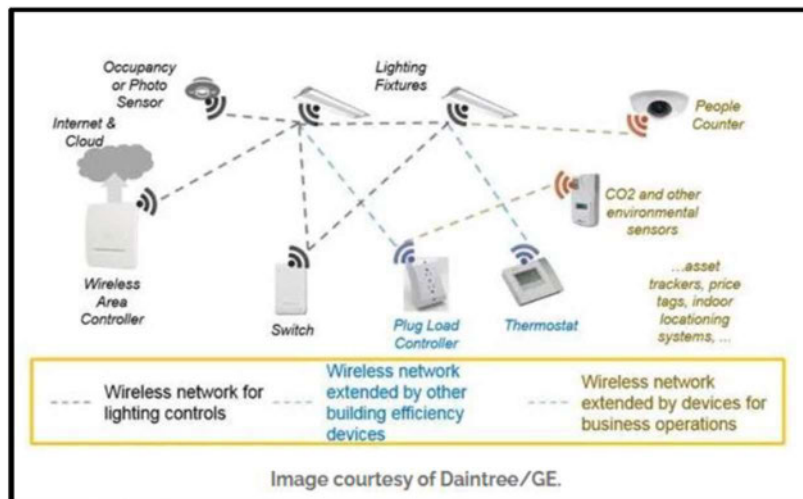


Figure 3: Lighting Control [4].

To get an indication of the feasibility of installing lighting control, an approximation of total electricity savings from lighting control is assumed to be 10 % of the total electricity consumption of the site. It is also assumed that the average cost per 10 light fittings for lighting control is ZAR 1 800 with a lifespan of 15 years and zero maintenance cost. The execution of the lighting control for the airports for the purposes of the feasibility study are to be completed by September 2021. The feasibility results are given in Table 4.

Table 4: Feasibility of Lighting Control for nine Airports in South Africa

	Airport	Estimated Number of Light Fittings	Cost (ZAR Million)	NPV (ZAR Million)	IRR (%)	Annual kWh Reduction	Annual Cost Savings of kWhs Saved (ZAR Million) 2018 Basis	Result
1	ORTIA	132 529	23.86	131.57	68.80	11 609 509.14	17.07	Feasible
2	CTIA	78 444	14.12	77.88	68.80	6 871 715.80	10.10	Feasible
3	KSIA	38 657	6.96	32.98	61.60	3 386 392.08	4.37	Feasible
4	PEIA	8 499	1.53	7.25	61.60	744 512.50	0.96	Feasible
5	EL	4 827	0.87	1.68	34.80	422 830.00	0.27	Feasible
6	BFIA	3 703	0.67	3.36	64.40	324 341.20	0.44	Feasible
7	GG	2 257	0.41	0.86	36.40	197 724.10	0.13	Feasible
8	UPIA	893	0.16	0.63	53.90	78 247.90	0.01	Feasible
9	KIM	739	0.13	0.52	53.90	64 727.60	0.10	Feasible

Lighting control technologies for all airports are feasible and a very attractive investment as the IRR for all airports exceeds 30 %.

### 3. Geyser Sleeve

Another electricity user where electricity consumption is often used inefficiently resulting in wastage, is water heating at airports. Some airports in ACSA use large geysers that heat in excess of 150 litres of water for a simple hand-wash at ablution facilities (needing less than a litre per hand wash) and staff shower facilities which are not used often, but they can heat in excess of 200 litres all day, every day. The geyser sleeve technology which is a technology that allows a smaller amount of water to be heated and only when that amount is used up, more water is heated. It resembles a bladder or silicone sleeve called the Hot Spot (Figure. 4) that is able to hold 50 litres or less that can be retrofitted into a geyser effectively heating up a smaller amount of water each time which is more effective and suits the peak and off-peak demands for hot water.



Figure 4: Sindiswa Qayi and her Invention, the HotSpot Geyser Sleeve [5].

The geyser sleeve technology is a South African invention by a woman in the Eastern Cape (Sandiswa Qayi – Figure. 4) and was tested and endorsed by the CSIR (Council for Scientific and Industrial Research), and is partnered with the Department of Science and Innovation (DSI). The CSIR is South Africa's central and premier scientific research and development organisation. It was established by an act of parliament in 1945 and is situated on its own campus in the city of Pretoria in the province of Gauteng, South Africa.

It is assumed that the energy consumption of an average 200 litre geyser is 10 kWhs per day and that the geysers run for 365 days a year. The energy saving per retrofit is advertised to be proven to be 27% per geyser with a lifespan of 10 years and zero maintenance cost. The execution of the retrofitting of the airports' geysers with the HotSpot for the purposes of the feasibility study is to be completed by September 2019. Table 5 gives the feasibility results.

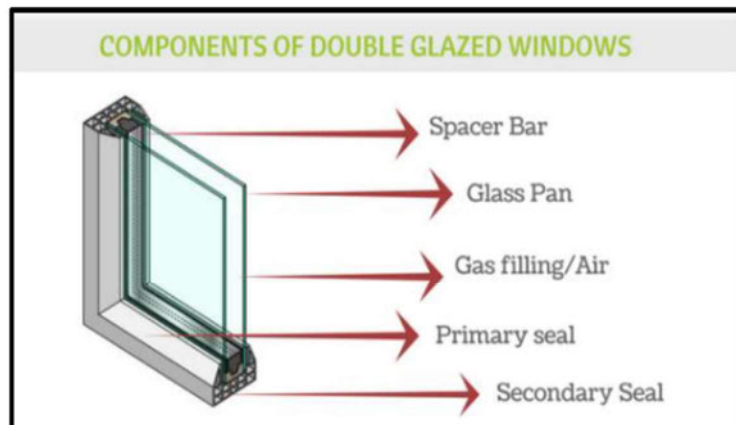
**Table 5: Feasibility of Retrofitting the Geyser sleeve (HotSpot) at Airports in South Africa**

	Airport	Number of Geysers to be Retrofitted	Cost (ZAR Million)	NPV (ZAR Million)	IRR (%)	Annual kWh Reduction	Annual Cost Savings of kWhs Saved (ZAR Million) 2018 basis	Result
1	ORTIA	100	0.11	0.820	129.60	98 550.00	0.14	Feasible
2	CTIA	20	0.02	0.25	184.90	19 710.00	0.03	Feasible
3	KSIA	20	0.02	0.14	115.10	19 710.00	0.03	Feasible
4	PEIA	15	0.02	0.11	115.20	14 782.50	0.02	Feasible
5	EL	15	0.02	0.04	58.50	14 782.50	0.01	Feasible
6	BFIA	10	0.01	0.08	121.20	9 855.00	0.01	Feasible
7	GG	10	0.01	0.03	65.40	9 855.00	0.01	Feasible
8	UPIA	10	0.01	0.06	100.10	9 855.00	0.01	Feasible
9	KIM	10	0.01	0.09	137.40	9 855.00	0.02	Feasible

The geyser sleeve technology retrofit for all airports are feasible and very attractive investment as the IRR for all airports exceeds 50 %.

**3. Double Glazing or low Emissivity Glazing**

The difference between indoor and outdoor temperature drives heat transfer. Introducing a thermal barrier prevents or reduces the rate of heat ingress into a building in summer and insulates the building in winter. Traditional single glazing without treatments to limit solar thermal energy make for poor temperature barriers. Introducing double glazing sandwiching a space either filled with air (Fig. 5) or an inert gas or even a vacuum drastically reduces heat transfer by at least 50 %.



**Figure 5: Components of Double Glazed Windows [6].**

Terminal buildings have at least one exposed side that is a glass facade facing either the rising or the setting sun. The heat transfer coefficient (U-value) of traditional single glazing is 5.7 W/m<sup>2</sup>K and double glazing (air filled) or low emissivity glass has a U-value of 2.8 W/m<sup>2</sup>K. This shows an estimated 50% more heat transference with single glazing terminal building facades. The feasibility study shows the financial viability of replacing all sun-exposed glass facades at terminal buildings with glazing of a U-value of 2.8 W/m<sup>2</sup>K versus a traditional single glazing of U-value 5.7 W/m<sup>2</sup>K during replacement cycles in January 2029.

The CLTD(cooling load temperature difference) [7] method uses Equation (2) to calculate heat ingress into the space:

$$Q = U \times A \times (T_{outdoor} - T_{indoor}) \quad \text{Equation (2)}$$

Equation (2) is used to calculate the energy savings. A lifespan of 20 years is used for the investment. Table 6 gives the data used for the calculations of the feasibility results contained in Table 7.

**Table 6: Data used for the Feasibility Study of the Retrofitting of Single Glazing with 2.8 W/M<sup>2</sup>KGLAZING for Sun-Exposed Glass Facades at Airports in South Africa**

	Airport	Total Area of Glazing Considered for 2.8 W/m <sup>2</sup> K Glazing	Area Assumptions	CDD (22.5 °C base)	HDD (18.0 °C base)	Total DD	Energy Savings (kWh)
1	ORTIA	2400	Exposed glass facade has a length of 800 m on the eastern side (airside), drop of 3 m is assumed	148	1132	1280	259 413.12
2	CTIA	1950	Exposed glass facade has a length of 650 m on the eastern side (airside), drop of 3 m is assumed	143	0	143	56 459.52
3	KSIA	1000	Exposed glass facade has a length of 500 m on the eastern side (airside), drop of 2 m is assumed	232	0	232	35 148.00
4	PEIA	240	Exposed glass facade has a length of 120 m on the eastern side (airside), drop of 2 m is assumed	95	702	797	17 873.28
5	EL	577	Used exact figures from actual measurements	135	516	651	37 107.10
6	BFIA	400	Exposed glass facade has a length of 200 m on the eastern and western sides which are exposed areas, drop of 2 m is assumed	405	1528	1933	61 415.04
7	GG	340	Exposed glass facade has a length of 170 m on the eastern and western side that are exposed, drop of 2 m is assumed	100	1019	1119	32 940.29
8	UPIA	450	Exposed glass facade has a length of 150 m on the eastern and western sides that are exposed areas, drop of 3 m is assumed	1081	867	1948	69 561.72
9	KIM	520	Exposed glass facade has a length of 260 m on the eastern side (airside), drop of 2 m is assumed	629	1120	1749	73 180.22

**Table 7: Feasibility of Replacing Single Glazing at Airports in South Africa with a 2.8 W/m<sup>2</sup>K Glazing**

	Airport	Cost in ZAR Millions at Year of Implementation	Year of Implementation	NPV (ZAR Million)	IRR (%)	Annual Cost Savings of kWhs saved (ZAR Million) 2018 basis	Result
1	ORTIA	14.80	January 2029	-0.58	9.90	0.38	Unfeasible
2	CTIA	11.44	January 2029	-2.70	0.30	0.08	Unfeasible
3	KSIA	6.17	January 2029	-1.30	0.30	0.05	Unfeasible
4	PEIA	1.48	January 2029	-0.19	5.50	0.02	Unfeasible
5	EL	3.56	January 2029	-0.80	-0.80	0.02	Unfeasible
6	BFIA	2.35	January 2029	0.07	12.50	0.08	Feasible
7	GG	2.10	January 2029	-0.37	2.70	0.02	Unfeasible
8	UPIA	2.78	January 2029	-0.06	10.60	0.08	Unfeasible
9	KIM	3.21	January 2029	0.15	13.30	0.11	Feasible

It can be seen from Table 7 that replacing single glazing with low emissivity glass is generally not feasible for the airports, except for BFIA and KIM. The extreme nature of temperatures there relative to the airports in the other geographical locations, combined with their electricity tariffs, make their installations feasible. For the other airports, the cost of low emissivity glazing needs to be reduced and or the electricity tariffs must be significantly higher in order to make such a project feasible.

#### 4. Electricity Savings with Air Conditioning

Air conditioning contributes between 20 % and 30 % of an airports' total electricity consumption, depending on whether the air conditioning system also provides space heating [1]. Centralized air conditioning systems consists of many components and parts whose functions are controlled electronically. One of the challenges of air conditioning control is to ensure that the chiller produces enough chilled water at the correct temperature and that this is distributed at the right time to air handling units that will adequately cool the air circulated from the space, mixing it with just the right amount of fresh air as needed.

Centralized air conditioning systems usually have a fixed setpoint at which chilled water is produced in the chiller, and air handling units usually introduce fresh air through a process that is not necessarily controlled. This fixed setpoint of chilled water production most-times has the capacity to cool much more than is needed and this wastes energy. The chilled water quantity and air flow rates need to be actively controlled to ensure that the correct amount of cooling is achieved. By actively controlling the chilled water setpoint to meet the cooling demand, energy is saved. When the fresh air rate is not controlled or restricted to ensure that the air properties are kept within specific limits, the air handling units must work harder, increasing cooling demand. Controlling fresh air demand according to the needs of the conditioned space saves energy. This presents two energy saving interventions for air conditioning systems:

- Chilled water setpoint control; and
- Fresh air demand control.

Producing chilled water is one of the most energy intensive processes in air conditioning, consuming significant amounts of electricity. To offset this electricity consumption, solar thermal energy can be harvested to power the absorption chillers, which will reduce electricity consumption and the carbon footprint. The feasibility of adopting solar thermal powered absorption chillers for PEIA, EL, BFIA and GG, based on these being smaller airports with centralized HVAC systems, is presented. UPIA and KIM airports have decentralized HVAC systems. The feasibility of adopting active chilled water setpoint control and fresh air demand controls for the centralized air conditioning systems at ORTIA and CTIA are considered, based on the implementation of such systems at KSIA.

#### 4.1 Solar Thermal Powered Absorption Cooling

Using the costs of an absorption chiller system powered by solar thermal energy for the Pretoria Moot Hospital [8] (Fig. 6), the cost per kW of the absorption cooling system is given in Table 8.

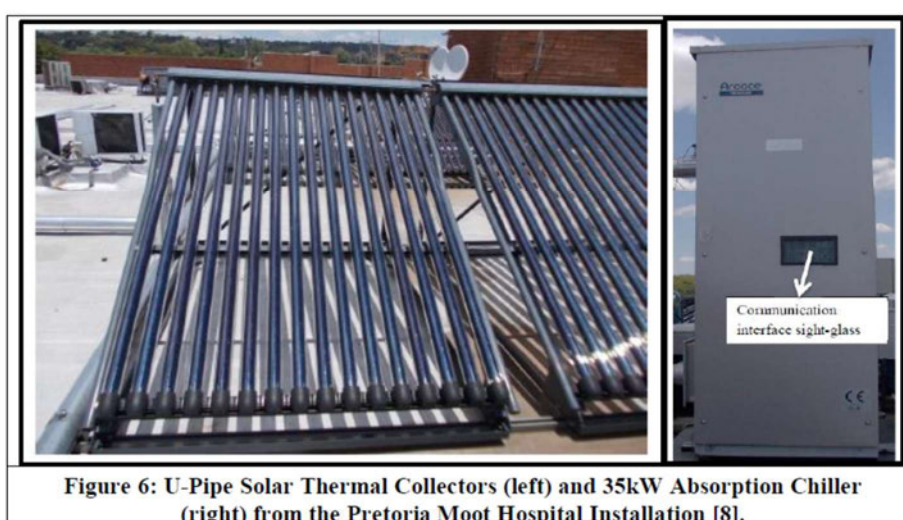


Figure 6: U-Pipe Solar Thermal Collectors (left) and 35kW Absorption Chiller (right) from the Pretoria Moot Hospital Installation [8].

Table 8: Cost of a Solar Thermal Absorption Cooling System Calculated per kW

Item	Quantity	Cost (2018 Basis) in ZAR
35 kW Yazaki absorption chiller	1	314 234.03
Solar collectors (U-pipe evacuated tubes of 1.8 m <sup>2</sup> )	40	441 109.76
Hot water storage tank (6000 litres capacity)	1	187 200.00
controllers/sensors, hardware, software, electronics (PlantVisor Pro)	1	184000.00
Balance of plant (BOP) (piping, pumps, structural support, expansion tank, etc.)	1	288 000.00
<b>Total cost of system in ZAR (2018 basis)</b>		<b>1 414 543.79</b>
<b>Total cost of the system in ZAR per kW</b>		<b>40 415.54</b>

The feasibility study uses 15 years as the economic lifespan of the installation, electricity consumption savings from the grid for 12 hours of the day (where chilled water production is powered by the solar thermal energy plant), annual maintenance cost of the solar thermal absorption HVAC plant estimated at 5 % of the capital cost of the plant, with a 1 year construction period. The feasibility study results are given in Table 9.

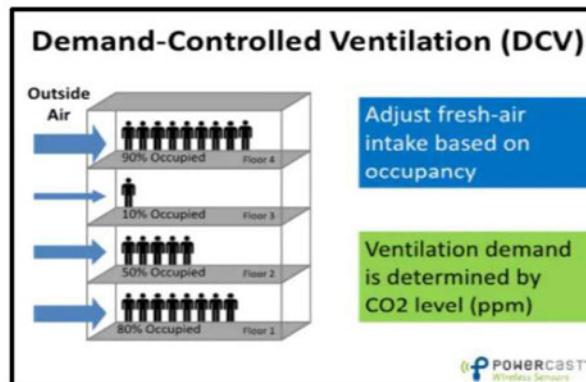
**Table 9: Feasibility of Adoption Solar Thermal Absorption Cooling for Selected Airports**

	Airport	Size of System (kW)	Year of Implementation	Cost (ZAR million)	NPV (ZAR Million)	IRR (%)	Annual kWh Reduction from the Electricity Grid	Annual Cost Savings of kWh Saved (ZAR Million) 2018 basis	Result
1	PEIA	200	2024	10.37	1.22	14.40	876 000.00	1.13	Feasible
2	EL	200	2023	10.37	-3.54	0.80	876 000.00	0.56	Unfeasible
3	BFIA	60	2021	2.82	0.36	14.00	262 800.00	0.36	Feasible
4	GG	60	2023	3.11	-0.88	2.90	262 800.00	0.18	Unfeasible

Table 9 shows that solar thermal powered absorption cooling is feasible for PEIA and BFIA and unfeasible for EL and GG airports. The electricity tariffs for the installations play a critical role in their financial viability.

**4.2 Active Chilled Water Set Point Control and Fresh air Demand Control**

KSIA has already implemented the active chilled water setpoint control and fresh air demand control (Figure. 7), and their energy savings, as well as the cost, was used as a basis for its implementation at ORTIA and CTIA.



**Figure 7: Fresh Air Demand Control [9].**

The energy savings from KSIA’s implementation of the fresh air demand control and active chilled water setpoint control projects are taken from [10] to estimate the energy savings and cost for ORTIA and CTIA which are given in Table 10. For the purposes of the feasibility study, a 20-year lifespan is assumed. The feasibility results are given in Table 11.

Airport	Active Chilled Water Set Point Control		Fresh Air Demand Control		Total	
	Energy Savings (kWh)	Capital Cost 2018 Basis (ZAR)	Energy Savings (kWh)	Capital Cost 2018 Basis (ZAR)	Energy Savings (kWh)	Capital Cost 2018 Basis (ZAR)
1 ORTIA	30 000	134 400.00	2 199 828	3 217 824.00	2 229 828	3 352 224.00
2 CTIA	20 000	89 600.00	1 466 552	2 145 216.00	1 486 552	2 234 816.00

**Table 11: Feasibility of Implementing Active Chilled Water Set Point Control and Fresh Air Demand Control for Selected Airports in South Africa**

	Airport	Year of Implementation	Cost at year of Implementation (ZAR Million)	NPV (ZAR Million)	IRR (%)	Annual kWh Reduction	Annual Cost Savings of kWhs saved (ZAR Million) 2018 basis	Result
1	ORTIA	2020	3.35	31.39	92.20	2 229 828.00	3.28	Feasible
2	CTIA	2022	2.23	20.93	92.20	1 486 552.00	2.19	Feasible

Table 11 shows that implementing an active chilled water setpoint control and fresh air demand control is feasible for ORTIA and CTIA.

#### 4.3 Implementation Notes for Airports

The projects given here were a guide for airports to begin performing onsite verifications, detailing project specification, checking for feasibility and submissions to management for budget approval. Impact and feasibility indicators will be adjusted as the results of the energy consumption of the sites, their electricity tariffs and light fitting count is analysed. Should there be a shortfall in the expected electricity reduction figures, the carbon footprint reduction can be achieved elsewhere through the renewable energy and alternate energy plants planned for the site.

#### CONCLUSIONS

This paper presented the interventions to reduce electricity consumption and their feasibility for nine airports in South Africa. LED lighting retrofits are feasible for ORTIA, CTIA, KSIA, PEIA, BFIA, KIM airports, but are not feasible for EL, GG and KIM. Implementing lighting control technologies are feasible for ORTIA, CTIA, KSIA, PEIA, EL, BFIA, GG, UPIA, KIM. Geyser sleeve technology retrofits in geysers is feasible for ORTIA, CTIA, KSIA, PEIA, EL, BFIA, GG, UPIA, KIM. Replacing terminal building glass facades with double glazing or low emissivity glass is feasible for BFIA and UPIA but is not feasible for ORTIA, CTIA, KSIA, PEIA, EL, GG and KIM. Executing air conditioning interventions to reduce electricity consumption from the grid is feasible for the following airports as follows:

- Solar thermal powered absorption chillers – BFIA and PEIA; and
- Active chilled water setpoint control and fresh air demand control – ORTIA and CTIA.

Ensuring that the interventions presented here are confirmed for each of the airports (including their feasibility) is crucial to reduce electricity consumption in line with the overall plans for renewable and alternative energy for the airports, thereby reducing carbon emissions and ensuring that investment to reduce carbon emissions is efficient.

#### REFERENCES

1. Joseph, J., Inambao, F. L., "Energy consumption and energy efficiency of airports: A case study of airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, Vol. 11, Issue 2, Apr 2021, 205-228.
2. Joseph, J., Inambao, F. L., "Reducing energy consumption: Investigating solar thermal heat deflection innovative technology to reduce air conditioning load at airports – A techno-economic assessment" *International Journal of Mechanical and*

*ProductionEngineering Research and Development, Vol. X, Issue X, Pages X. (In press)*

3. Vector Stock, "Light emitting diode led structure education vector image", retrieved from <https://www.vectorstock.com/royalty-free-vector/light-emitting-diode-led-structure-education-vector-15452093>, accessed 30/07/2021.
4. Dilouie, C., "Introduction to lighting control", Lighting Controls Association, 21/07/2017. Retrieved from <https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/>, accessed 30/07/2021.
5. News24, "Eastern Cape woman's geyser sleeve reduces energy consumption", 23 July 2017. Retrieved from: <https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.news24.com%2Ffin24%2FTech%2FNews%2Feastern-cape-womans-geyser-sleeve-reduces-power-consumption-20170723&psig=AOvVaw3pod0u05zfKvkdvzqfGCO9&ust=1627558298009000&source=images&cd=vfe&ved=0CAsQiRxqFwoTCMj4s7TVhfICFOAAAAAAdAAAAABAD>, accessed 28/07/2021.
6. Vishnubhotla, V., "Double glazed windows" Greenmatch, 9/06/2021. Retrieved from <https://www.greenmatch.co.uk/double-glazing/double-glazed-windows>, accessed 30/07/2021.
7. Engineering Pro Guides, "Heating/cooling loads for the mechanical HVAC & refrigeration PE exam", <https://www.engproguides.com/hvac-heating-cooling-loads.html>, accessed 27/06/2021.
8. Joseph, J., "Study of a solar-assisted air conditioning system for South Africa", Scholars' Press, 2015.
9. Slideshare, "Demand control ventilation and energy savings", 30 April 2012. Retrieved from <https://www.slideshare.net/PowercastSensors/demand-controlled-ventilation-energy-savings>, accessed 30/07/2021.
10. Kasaval, S., Ferreira, J., Spoomaker and Partners Inc. "Preliminary energy audit report for the HVAC installation at King Shaka International Airport", 22/11/2012.
11. Agarwal, Nisha, and Priyanka Yadav. "Reduce Energy Consumption in Wi-Fi Mac Layer Transmitter & Receiver by Using Extended VHDL Modeling." *International Journal of Electrical and Electronics Engineering (IJEEE)* 5.4 (2016): 33-42.
12. Lakshman, R., and A. Ramesh. "A System Dynamic Analysis of Energy Consumption and CO<sub>2</sub> Emission of Indian Iron and Steel Industries." *International Journal of Mechanical Engineering* 3.4 (2014): 49-60.
13. Castrillón, Ferney Giraldo, Miyer Valdés, and Julian Mora Orozco. "Influence of Cutting Parameters on the Energy Consumption of a Leadwell V40 iT Machining Center." *International Journal of Applied Physics* 5 (2020).
14. Alharbi, Emad Ameen, and Rosli Mohamad Zin. "Prediction Model to Reduce Energy Consumption of Mosque Buildings." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 10.3, Jun 2020, 12689-12706

## CHAPTER 11. PRINCIPLES FOR ACHIEVING ENERGY SECURITY IN DEVELOPING COUNTRIES

This chapter presents the principles for achieving energy security in developing countries through an approach to defining a developing country's energy mix that overcomes the financial and technological challenges while being suited to its operating environment.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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## PRINCIPLES FOR ACHIEVING ENERGY SECURITY IN DEVELOPING COUNTRIES

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### ABSTRACT

*Fossil fuel energy sources being carbon intensive have the disadvantage of accelerating climate change as well as being non-renewable and, by implication, limited in supply. This poses a threat to the energy security of a country, especially if carbon intensive energy sources serve as the mainstream energy source of a country. Mitigating climate change is a global imperative and involves a fundamental shift from primarily fossil fuel energy sources to alternative, less carbon intensive, energy sources. For many countries this may mean changing energy sources long before the fossil fuel energy reserves are depleted. Changing energy sources means changing power generation technology and infrastructure to utilize new energy sources which requires finances as well as appropriate changes in legislation, policy and other instruments that influence markets to allow this development to progress, especially where energy generation is a closed market, as found in South Africa. Technology change is usually a complex challenge in developing countries as such countries need to overcome the financial barriers associated with new installations as well as the human capacity barriers in terms of skills in the new technology areas. Added to this is the task of ensuring that the energy sources are suited to the operating environment they serve. This paper presents the principles for achieving energy security in developing countries through exploring the range of energy sources available for a developing country and what energy mix may be suitable, bearing in mind the financial and technological challenges and the nature of the operating environment.*

**KEYWORDS:** *Low Carbon Energy Mix, Energy Security, Renewable Energy, Climate Change Mitigation, Wind Energy, Geothermal Energy, Solar Energy, Tidal Energy & Natural Gas Power Plants*

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### 1. INTRODUCTION

Developing countries face unique challenges regarding the road to achieving energy security in the context of the global warming crisis. Most of these challenges are related to the lack of financial resources and the lack of the necessary skills and expertise to embark on new technologies and strategies to achieve energy security. Typically, developed countries have the skillsets, finance and established markets for technologies that are key in achieving energy security. Developing countries usually have a single primary fuel source and dominating technology for energy production and orientate their efforts and budgets to ensure that this energy production base is increased for greater access to energy. Designs and technologies are targeted to be low-cost and simple so as to produce energy quickly and conveniently in abundance for stimulation of economic growth. Developed countries, however, do not have lack of energy access to the same degree that developing countries have. Typically, energy access has been achieved a while back and with modifications to designs, energy efficiency and other techniques of cost efficiency, developed countries ensure that they have well-developed and competitive energy sector with supporting commercial markets. The oil crisis over the last century has also played a role in their quest for and establishment of

alternative energy sources such as renewable energy [1]. It will be easier for developing countries to transition to energy security from an infrastructure perspective as they do not need to replace or “tear down” existing infrastructure and technologies to shift to less-carbon intensive energy technologies and infrastructure [1].

The task of shifting away from tradition fossil fuel energy sources and power generation infrastructure can be daunting for businesses and organizations in developing countries as they face business risks related to unfamiliar energy sources and associated technologies. In a developing country, this could mean facing risks of businesses not being market competitive, and ineffective in delivering services and producing products, all of which can result in declining profit margins. This paper presents principles and approaches to ensuring that energy security is realized in developing countries.

## 2. PRINCIPLES FOR ENSURING ENERGY SECURITY IN DEVELOPING COUNTRIES

A typical developing country like South Africa is currently facing challenges with energy access in that energy demand has exceeded the capacity of Eskom, the country’s state-owned electricity provider. This has resulted in periodic load shedding since 2008. No plans have been finalized for new energy generation. This approach is not sustainable for the country, and this is evident in the legislation being introduced to allow the market of energy generation via wind and solar PV to be open to the private sector, as well as offering incentives for energy efficient lighting and water heating technologies in the decade following the first rolling blackouts.

South Africa’s aging coal-fired power stations are being operated way beyond their useful lifespans with much needed maintenance being overdue on power generation, transmission and distribution infrastructure, indicating that this is only the beginning of the challenges faced by South Africa when it comes to energy generation. Climate change and the global efforts to move away from coal, which is the primary energy source of the country, paints a foreboding picture of developing countries’ energy security. Any institution or business in South Africa using energy generated by Eskom will face challenges with energy security as all the issues faced by Eskom will be transferred to the institutions it serves. The risk of energy security can be decoupled if a business or site reduces both demand for energy and dependence on Eskom. In [2], [3], [4] and [5] reduction in energy demand through energy efficiency and energy conservation has been systematically addressed. Using these sources as a basis for the energy security solution of decoupling from Eskom, the following three principles are presented to achieving energy security in a developing country like South Africa with characteristic reliance on fossil fuel sources for energy requirements.

### 2.1 Principle 1: Understand the Site’s Available Resources

The four factors of production as outlined in [6] tell us that land, resources, labour and capital are key ingredients for production. It is important that we view all land that is in control of and under ownership of an organization as a commercial resource. The naturally occurring features of the land’s resources and the daily natural endowments must be viewed from the point of its commercial value and its ability to provide for the needs of the site.

**Principle 1: Ascertain the energy generation potential of the site, i.e., what is the:**

- Theoretical energy potential of the site;
- Available energy potential by applying the commercially available technologies; and
- Real energy generation potential considering the spatial and other demands required for energy generation.

Figure 1 shows the flowchart of the process for Principle 1 and the following sections give the definitions of the theoretical energy potential, the available energy potential and the real energy generation potential.

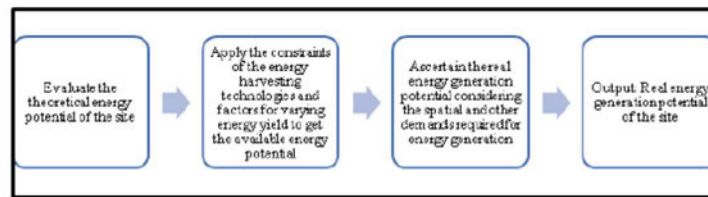


Figure 1: Process Flow for Ascertaining the Energy Generation Potential of a Site.

### A. Theoretical Energy Potential

The energy generation potential of a site includes the renewable energy it experiences such as solar irradiation, wind energy, rainfall for the regeneration of hydro sources and basins, tidal energy for coastal areas, the geothermal energy available due to the site's location and landscape. The energy generation potential should also include the less-carbon intensive energy sources which can be considered as an alternative energy source, such as natural gas networks, hydrogen fuel availability, etc. as per the networks established within the geographical region. The energy generation potential also includes the energy sources that occur from business activities such as sewerage and waste streams. Fig. 2 indicates the typical theoretical energy potential energy sources for South Africa.

Solar irradiation over South Africa is abundant and can be used to generate electricity as well as thermal energy for various processes. Wind energy is abundant in the coastal areas of South Africa and its energy can be used to generate electricity and its motion can also be used directly. Tidal energy can be harvested to generate electricity and the opportunity for tidal energy is abundant as the south, west and east sides of the country are coastal. Geothermal energy can be used for heating and cooling requirements. Hydro energy can be used to generate electricity. The country has natural gas networks in certain regions which could serve as an alternate fuel source (to the predominant coal resource) for energy. As a product of most human activity, solid waste and sewerage that would usually cause a challenge could be used as a fuel source. Thus total theoretical energy potential can be given as represented in Equation (1).

$$\begin{aligned}
 \text{Total Theoretical Energy Potential} &= \sum \text{Renewable energy potential} + \\
 \sum \text{Energy potential from human and industrial activity} &+ \\
 \sum \text{Energy potential from alternative less carbon intensive energy sources} &\text{Equation (1)}
 \end{aligned}$$

Where: energy potential is given in kWh/m<sup>2</sup> and in the case of waste to energy, it is given in kWh/m<sup>3</sup>.

Solar energy potential measured across South Africa is classified into two main types according to how it is harvested and used, i.e., global horizontal irradiation (GHI) and direct normal irradiation (DNI). When intending to produce electricity from solar energy the GHI is considered, and when thermal energy is the intention, the DNI is considered. Figure 3 and figure. 4 show the GHI and DNI potential of South Africa.

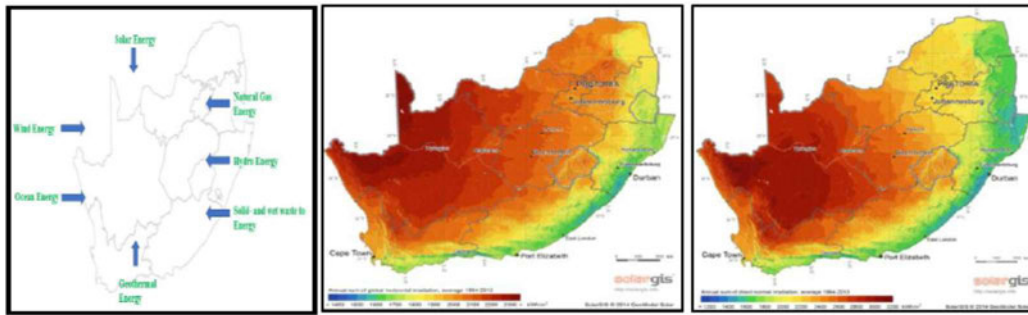


Figure 2: Energy sources Figure 3: Global Horizontal Irradiation [7]. Figure 4: Direct Normal Irradiation [9]. available for South Africa [7]. Irradiation [8]

Figure 3 and figure 4 show that the country of South Africa is generally abundant in solar energy and more abundant in its north westerly parts. The wind energy potential of South Africa can be seen in figure 5.

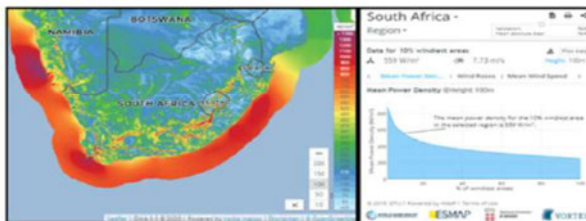


Figure 5: Wind energy potential for South Africa [10].

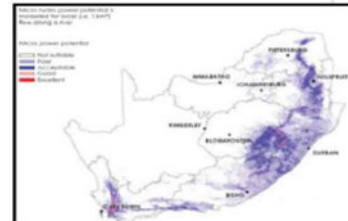


Figure 6: Micro-hydro power potential [11].

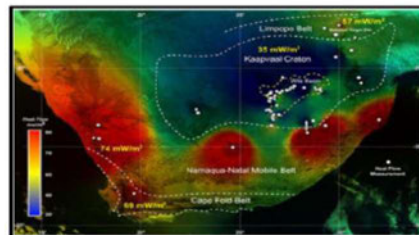


Figure 7: Geothermal energy potential zones around South Africa [13].

South Africa has a strong wind energy potential in the coastal region of the country and a generally wind-rich band between the coast and midland of the country which is about 7.7 m/s at 100 m above ground level with potential mean energy generation of about 560 W/m<sup>2</sup>. The micro-hydro power potential for South Africa seen in Fig. 6 shows that the country has a strong potential on its east coast (from the north to the south) and on the south-west coast. Detailed assessment of the spatial distribution of wave power off the southwest coast has been recently conducted. It was found that the average deep-sea resource range from 33 kW/m to 41 kW/m [12]. Geothermal energy potential in South Africa can be seen in figure 7.

The inland area of South Africa shows an extremely low geothermal energy potential and the coastal areas indicate a much higher geothermal energy potential. One of the well-known geothermal installations in South Africa is the Western Cape’s Hotel Verde geothermal heat sink serving the hotel’s HVAC system, saving on water and energy. This installation does not utilize geothermal resources for heat, but rather, the opposite: it uses the ground as a heat exchange medium to decrease the temperature of the condenser water of the HVAC systems. Traditionally, cooling towers using

significant amounts of water and electricity are used to achieve this decrease in temperature.

A cleaner and greener alternative to coal-generated electricity and heat is the use of natural gas. Globally, this source of energy has been adopted as a solution to reducing carbon emissions [14]. Figure 8 shows that gas is now going head-to-head with coal in power and in industry. South Africa has an established natural gas supply and infrastructure, as illustrated in figure 9. South Africa’s gas supply is primarily from Mozambique, through the ROMPCO pipeline (figure 9).

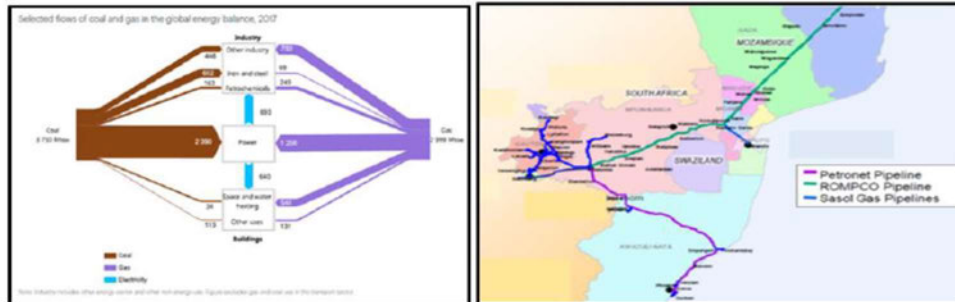


Figure 8: Coal Versus Natural Gas as per the Global Energy Balance in 2017 [14]. Figure 9: Main gas Pipelines within South Africa [15].

The major pipelines are the ROMPCO pipeline, Lilly pipeline and Sasol pipelines. The ROMPCO pipeline is 865 km long originating from Temane in Mozambique to Secunda in South Africa and is jointly owned by Sasol, the Mozambique government and the South African government. The Lilly pipeline is owned by Transnet and is 600 km long from Secunda to KwaZulu-Natal. Sasol owns several gas pipelines originating in Secunda and reaching destinations such as Gauteng, Ekurhuleni, Pretoria, Sasolburg and Emalahleni [15].

The energy potential of renewable energy, waste to energy and alternative fuel for energy must be harvested and converted to usable energy, whether this is heat, electricity, kinetic energy or any other type of energy that can be used to satisfy energy need.

**B. Available Energy Potential**

The available energy potential in this context is the amount of energy available to be used when one considers the capability of the commercial energy conversion technologies. Solar energy, wind energy, tidal energy, geothermal energy, hydro energy, natural gas and other sources of energy must be harnessed or converted into useful energy. Figure 10 shows various energy sources and how we utilize them. The available energy potential is thus represented by Equation (2).

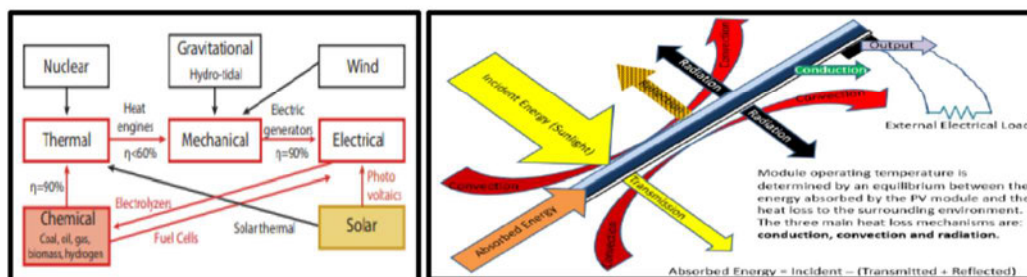


Figure 10: The Different Energy Carriers and how we Utilize them [16]. Figure 11: Solar PV Energy Harvested from Solar PV Module Technology and Inevitable Losses [17].

$$\text{Total Available Energy Potential} = \sum(\text{Theoretical Energy Potential} \times \eta_{\text{energy harvesting technology}})$$

..... Equation(2)

Thus, the “Total Available Energy Potential” considering Equation 2 in the context of the Equation (1) can be found in Equation (3).

$$\begin{aligned} \text{Total Available Energy Potential} = & \sum(\text{Renewable energy potential} \times \eta_{\text{technology}}) + \\ & \sum(\text{Energy potential from human and industrial activity} \times \eta_{\text{technology}}) + \\ & \sum(\text{Energy potential from alternative less carbon intensive energy sources} \times \\ & \eta_{\text{technology}}) \dots\dots\dots \end{aligned}$$

Equation (3)

Where: available energy potential is given in kWh/m<sup>2</sup> and in the case of waste to energy, it is given in kWh/m<sup>3</sup>.

The chemical energy stored in fossil fuels is converted to usable forms of energy via heat by burning, with an efficiency of about 90 %. Using heat engines, thermal energy can be converted into mechanical energy. Heat engines have a conversion efficiency of up to 60 %. Their efficiency is ultimately limited by the Carnot efficiency limit. Mechanical energy can be converted into electricity using electric generators with an efficiency of up to 99 %. Most of the world’s electricity is generated with a turbo generator that is connected to a steam turbine, where coal is the major energy source. In the process of making electricity out of fossil fuels at least 50 % of the initial available chemical energy is lost in the various conversion steps. In nuclear power plants, energy is released as heat during nuclear fission reactions. With the heat steam is generated that drives a steam turbine and subsequently an electric generator, just as in most fossil fuel power plants [16].

Although solar energy falling on South Africa may be abundant, the energy that is able to be converted to electricity and heat is limited to the capacity that can be harvested with available commercial technologies. Energy losses, although they can be minimized through innovative design and smart materials, are inevitable, as illustrated in Fig. 11. Fig. 11 shows a full solar PV module where the solar PV cells are contained within a housing and installed with the electrical circuit that will carry away the electricity generated by the solar PV cells to the end user. Added to the losses represented in Fig. 11 is the capability of solar PV material to convert solar irradiation into electricity. The absorbed energy is the remainder of the incident energy after the transmitted and reflected energies are subtracted. The efficiency of the solar PV cell varies, depending on the photovoltaic material and the electrical design. The most commonly adopted and best trade-off for efficiency and cost solar PV technology is the multi-crystalline cell which is about 23 % efficient [18]. This efficiency is quite low relative to traditional fossil fuel power generation which is upwards of 70 %. This 23 % is further reduced when the cell is used in a power generation module which includes electrical cells. Solar PV technology is also susceptible to high temperatures and soiling which further decreases its efficiency, and this may result in a final efficiency of around 15 % to 17 %, on top of which which age plays a role with an annual decrease of about 0.5 % to 0.8 % over the 20-year useful lifespan of the solar PV technology. There is a theoretical limit for p-n single junction cell called the “Shockley-Queiser” limit (Equation (4)) for maximum solar cell conversion efficiency, and this is 33.7 % [17].

$$\eta(t) = \eta_L \left[ 1 - \exp \left[ \frac{a_0 - a}{c} \right] \right]$$

Equation (4)

Where:  $\eta(t)$  is the time dependant efficiency;  $\eta_L$  is efficiency limit;  $a_0$  is start year;  $a$  is calendar year;  $c$  is the development time

Using solar thermal energy to produce hot water also comes with many losses and unavoidable efficiencies, regardless of which solar thermal collector technology is adopted. Figure 12 shows the energy losses from a flat plate solar thermal collector which is a series of pipes contained in a rectangular containment insulated on all sides and optimized to attract and retain heat except for the top which is typically covered with glass to allow sunlight in. From figure 12 above one can see that there are reflective, convection, and radiation losses, through the top glass cover, but the back and sides are insulated to prevent significant heat losses from there. Various configurations of solar thermal collectors exist. Another popular and more efficient solar thermal collector is the evacuated tube solar collector that consists of a heat pipe contained within a vacuum to reduce the thermal losses that occur with flat plate collectors. Figure 13 shows the configuration of an evacuated tube solar thermal collector with emphasis on the containment of much of the thermal losses compared to the flat plate solar thermal collector.

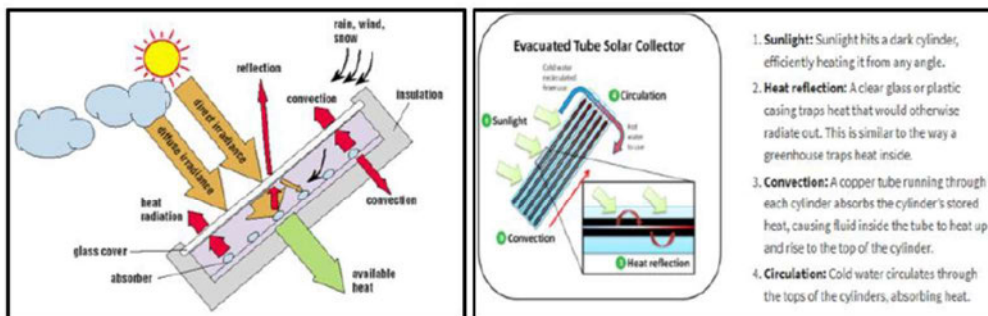


Figure 12: Depiction of Energy Flows for a Solar Thermal Flat Plate Collector [19]. Figure 13: Evacuated Tube Solar Thermal Collectors [20].

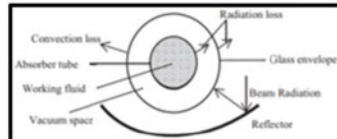


Figure 14: Configuration and energy losses of the parabolic trough collector system [21].

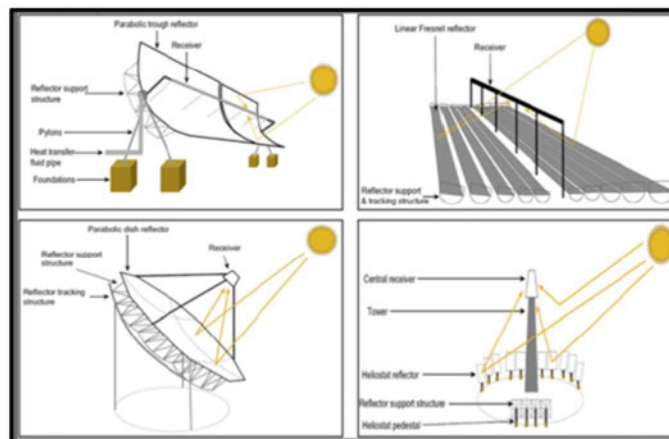


Figure 15: Current concentrated solar power technologies (CSP) [22].

Although much of the heat is trapped inside the heat pipe contained in the vacuum, there are optical losses such as reflection and convective and radiative losses which are relatively negligible when compared to flat plate collectors. Most of these collectors produce hot water and can be used for water heating purposes, as well as input for industrial and engineering processes. Equation (5) expresses the energy harvested by the collector with losses.

$$q_{coll} = F_R(\tau\alpha)G - F_R U_L \Delta T \tag{Equation (5)}$$

Where:  $q_{coll}$  = the energy collected per unit area per unit time ( $W/m^2$ )

- $F_R$  = collector's heat removal factor
- $\tau$  = the transmittance of the cover
- $\alpha$  = shortwave absorptivity of the absorber
- $G$  = global incident solar radiation on the collector ( $W/m^2$ )
- $U_L$  = overall heat loss coefficient for the collector ( $W/m^2K$ )
- $\Delta T$  = temperature differential between the working fluid entering the collectors and outside (K)

Another way of using solar thermal energy is to produce steam via concentrated solar thermal collectors. The intention is to use the DNI (shown in Figure 4) to concentrate solar irradiation, resulting in the very high temperatures needed for the production of steam. Figure 14 shows the typical losses associated with the receiver of a parabolic trough collector. Figure 15 shows the various concentrating power technologies. Soiling plays a significant role in the efficiency of the CSP technologies.

The steam produced using concentrated solar power is usually coupled with a turbine and generator to produce electricity. Solar energy can also be used for drying agricultural produce. In this technology, heated air is used directly to dry agricultural produce.

In solar drying, solar energy is used as either the sole or a supplemental source of heat; air flow can be generated by either forced or natural convection. The heating procedure could involve the passage of preheated air through the product, by directly exposing the product to solar radiation or a combination of both. Figure 16 shows generic solar dryers. Figure 17 shows energy losses (reflective and conductive) associated with indirect solar dryers.

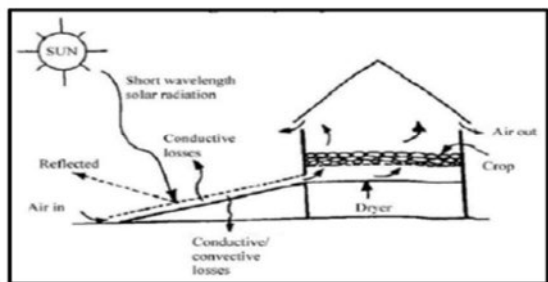
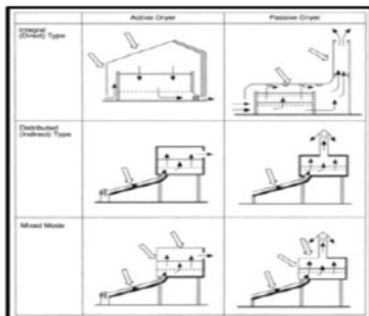


Figure 16: Configurations of Solar Dryers [23]. Figure 17: Energy Losses - Typical Indirect Solar Dryer [23].

Wind turbines have limitations on the amount of wind that can be harvested for energy production. The wind energy potential equation shows the maximum conversion efficiency of wind turbines. This maximum conversion efficiency is called the Betz Limit. This is expressed in Equation (6).

$$\text{Wind Energy Potential: } P = \frac{1}{2} \rho A V^3 C_p \quad \text{Equation (6)}$$

- P = Power available
- $\rho$  = air density = 1.23 kg/m<sup>3</sup>
- V = wind speed
- A =  $\pi r^2$  (r = length of blade)
- $C_p = 0.59$  (Betz Limit) which is the maximum conversion efficiency of a wind turbine

The Betz limit is not static,  $C_p$  changes with wind speed and blade tip speed, given by Equation (7).

$$C_p = \frac{\text{blade tip speed}}{\text{wind speed}} \quad \text{Equation (7)}$$

( $C_p$  needs to be looked at based on wind speeds)

Turbines need to be designed for optimal performance and reliability in whatever weather conditions they may face throughout their lifetimes, be it a gentle breeze on a low-lying plain or a raging offshore storm. Before deciding to build a wind turbine at a particular site, there are a few critical questions a developer needs to answer, such as the average annual wind speed in the intended location, what are the extreme gusts that can occur within a 50-year period, and how turbulent is the wind at the intended site. The three dimensions of wind speed, extreme gusts, and turbulence encompass the wind class of a wind turbine. The International Electrotechnical Commission (IEC) sets international standards for the wind speeds each wind class must withstand, as seen in the Table 1 [24].

**Table 1: IEC Wind Classes [24]**

	I (High Wind)	II (Medium Wind)	III (Low Wind)	IV (Very Low Wind)
Reference Wind Speed	50 m/s	42.5 m/s	37.5 m/s	30 m/s
Annual Average Wind Speed (Max)	10 m/s	8.5 m/s	7.5 m/s	6 m/s
50-year Return Gust	70 m/s	59.5 m/s	52.5 m/s	42 m/s
1-year Return Gust	52.5 m/s	44.6 m/s	39.4 m/s	31.5 m/s

These wind speeds occur at different heights above ground level and sea level. Wind potential changes and generally increases for all areas across South Africa with height above the ground.

Geothermal energy, whether used as a heat sink or for heat extraction, depends on the temperature of the ground and is governed by heat exchange principles and laws, as per Equation (8).

$$Q = m C_p \Delta T \quad \text{Equation (8)}$$

For geothermal heat sinks or heat extraction, Equation (8) can be rewritten to show that the temperature of the ground and the heat exchange working fluid is the efficiency at which the energy source operates, as per Equation (9). A

positive result shows that there is heat extraction and a negative result shows a heat sink.

$$Q_{geothermal} = mC_p(T_{ground} - T_{working\ fluid}) \tag{Equation 9}$$

This implies that ground temperature is key to the geothermal loop's heat extraction and this is reflected in geothermal commercial market technologies (Fig. 18). Ground soil conditions are thus a key component that must be investigated and characterized when designing geothermal heat sinks or heat extraction. Ground temperature also varies with the weather up to 8 m to 9 m below the ground surface [25]. Another factor when designing geothermal heat exchange loops is to take into account that the ground temperature profile will change during the operation of the geothermal energy system, both in the long term and the short term. The short-term temperature profile will change in accordance with the daily heat exchange loads. This will be reflected in the coefficient of performance (COP) as per Equation (10). The COP equation for the heat pump graph in Fig. 19 is as follows:

$$COP_{geothermal\ heat\ pump} = \frac{Q_{geothermal}}{P_{electric\ of\ compressor}} \tag{Equation 10}$$

As  $Q_{geothermal}$  decreases, the COP of the geothermal heat pump decreases. In figure 19,  $t_u$  is the working fluid temperature and  $t_s$  is the temperature of the source which is the ground temperature in this case.

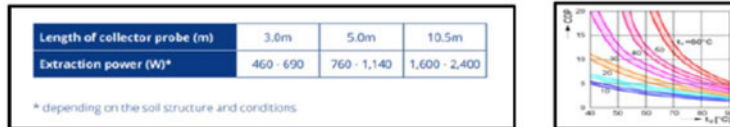


Figure 18: Limitations of Geothermal Heat Extraction [25].

Figure 19: Efficiency Variation - Geothermal Heat Pumps [26].

Similarly, with other power generation technologies, the same can be established. Table 2 shows the efficiency of gas turbine and spark ignition engine technologies. Performance is reduced at different altitudes above sea level and ambient temperatures.

Table 2: Efficiency of Gas Spark Ignition Engine - Typical Performance Characteristics [27].

Cost & Performance Characteristics	System				
	1	2	3	4	5
Baseload electric capacity (kW)	100	633	1121	3326	9341
Total installed cost in 2013 (\$/kW)	2900	2837	2366	1801	1433
Form of recovered heat	H <sub>2</sub> O	H <sub>2</sub> O	H <sub>2</sub> O	H <sub>2</sub> O	H <sub>2</sub> O, steam
Total efficiency (%)	80.0	78.9	78.4	78.3	76.5
Thermal output/Fuel input (%)	53.0	44.4	41.6	37.9	35.0
Power/Heat Ratio	0.51	0.78	0.89	1.06	1.19

Hydroelectric power generation, whether via rivers or the ocean, rely on potential energy and kinetic energy to generate electrical energy. Equation (11) and Equation (12) give the potential energy and kinetic energy equations, respectively.

$$P_{hydroelectric\ (potential)} = \rho ghQ\eta \tag{Equation 11}$$

Where:  $P_{hydroelectric\ (potential)}$  = generated power (W)

- $\rho$  = density of the water ( $\text{kg/m}^3$ )
- $g$  = acceleration due to gravity ( $\text{m/s}^2$ )
- $h$  = head of water (m)
- $Q$  = volume of water flowing per second ( $\text{m}^3/\text{s}$ )
- $\eta$  = efficiency of the turbine

Kinetic energy in hydroelectric generators:  $P_{hydroelectric (kinetic)} = \frac{1}{2} \eta \rho A v^3$  Equation (12)

Where:  $P_{hydroelectric (kinetic)}$  = generated power (W)

- $\eta$  = efficiency of the turbine
- $\rho$  = density of the water ( $\text{kg/m}^3$ )
- $A$  = swept area of the turbine blades ( $\text{m}^2$ )
- $v$  = velocity of the water flow ( $\text{m/s}$ )

If we use Bernoulli's equation:  $v = \sqrt{2gh}$  Equation (13)

Making "h" the subject,  $h = \frac{v^2}{2g}$  Equation (14)

Substituting in Equation (11), we will get Equation (12). If the head or pressure drop is known but not the velocity, use Equation (11). If the velocity is known neglect the head and use Equation (12).

There are three types of hydropower schemes, namely storage scheme, pumped storage hydropower (PSH) or scheme, and run-of-the-river scheme. These can be seen in figure 20. A typical PSH facility layout is shown in figure 21.

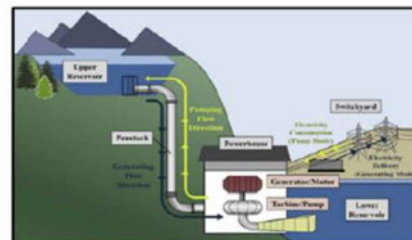
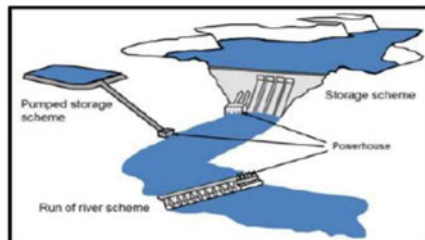


Figure 20: Illustration of the Main Types of Hydropower

Figure 21: Typical Pumped Storage Hydropower Facility Schemes [28]. Layout [29].

The majority of technologies harnessing ocean energy work on the same principles. Harnessing the energy from open-ocean currents requires the use of turbine-driven generators anchored in place in the current stream. Large turbine blades are driven by the moving water, just as windmill blades are moved by the wind. These blades can be used to turn the generators and to harness the energy of the water flow.

Tidal barrages, undersea tidal turbines – like wind turbines but driven by the sea – and a variety of machines harnessing undersea currents are under development. Unlike wind and waves, tidal currents are entirely predictable. Tidal

energy can be exploited in two ways:

- By building semi-permeable barrages across estuaries with a high tidal range, similar to run-of-the-river scheme and storage schemes (Figure. 20)
- By harnessing offshore tidal streams (Figure. 22)

Barrages allow tidal waters to fill an estuary via sluices and to empty through turbines. Tidal streams can be harnessed using offshore underwater devices similar to wind turbines.

Ocean thermal energy conversion (OTEC) uses temperature differences within the ocean to operate similar to the evaporator and condenser of an air conditioning system. There are three potential types of OTEC power plants: closed cycle (Figure. 23), open cycle (Figure. 24) and hybrid systems. Open-cycle OTEC systems exploit the fact that water boils at temperatures below its normal boiling point when it is under lower than normal pressures. Open cycle systems convert warm surface waters into steam in a partial vacuum, and then use this steam to drive a turbine connected to an electrical generator. Cold water piped up from deep below the ocean’s surface condenses the steam. Unlike the initial ocean water, the condensed steam is desalinated which may be used for drinking or irrigation. Closed cycle OTEC systems use warm surface waters passed through a heat exchanger to boil a working fluid, such as ammonia or a chlorofluorocarbon, which has a low boiling point. The vapour given off is passed through a turbine producing electricity. Cold deep ocean water is then used to condense the working fluid and it is returned to the heat exchanger to repeat the cycle. [31]



Figure 22: Harnessing offshore tidal streams [30].

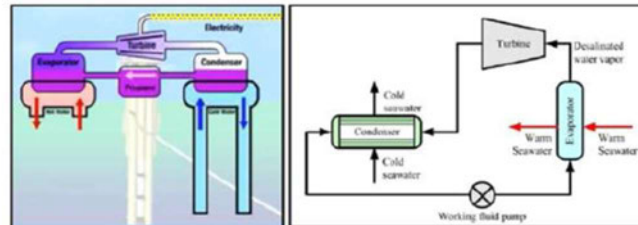


Figure 23: Closed cycle OTEC system [32]. Figure 24: Simplified open-cycle OTEC system [33].

The OTEC system relies on basic relationships between pressure (P), temperature (T) and volume (V) of an ideal fluid, as per Equation (15) [33]

$$\frac{pV}{T} = nR = \text{constant} \tag{Equation (15)}$$

Where: R = the ideal gas constant

- n = the amount of substance

In OTEC systems, the difference in liquid temperature can be used to make an increase in inlet pressure. A pump

is used to move liquids from one place to another through a piping media. The work done by the pump ( $W$ ) can be formulated as per Equation (16) [33]

$$W = V(P_2 - P_1) \quad \text{Equation (16)}$$

Fluid enthalpy before pumping ( $h_1$ ) and after pumping ( $h_2$ ), where the pump efficiency ( $\eta$ ) is 80 %, can be expressed as per Equation (17) [33]

$$h_2 = h_1 - \frac{w}{\eta} \quad \text{Equation (17)}$$

The temperature before entering the evaporator is given by Equation (18) [33]

$$T_w = T_c + W(1 - \frac{1}{\eta})/C_h \quad \text{Equation (18)}$$

Where:  $T_c$  = the temperature of the cold deep seawater (K)

- $T_w$  = the temperature of the warm surface (K)
- $C_h$  = the specific heat of seawater, as 4.186 kJ/kgK

Calculation of the total power of cold and warm seawater pumps ( $P_{tot}$ ) can be formulated as seen in Equation (19) [33]

$$P_{tot} = 2(9.8Qf \frac{L v^2}{D 2g}) \quad \text{Equation (19)}$$

Where:  $Q$  = the water flow rate ( $m^3$ )

- $f$  = the friction factor
- $L$  = the pipe length (m)
- $D$  = the pipe diameter (m)
- $v$  = the water velocity in a pipe (m/s)
- $g$  = the earth's gravitational acceleration ( $m/s^2$ )

A standard temperature ladder is very important to get the values of  $T_w$  and  $T_c$ , respectively. Figure 25 shows the model of temperature ladder for calculation of electrical power.

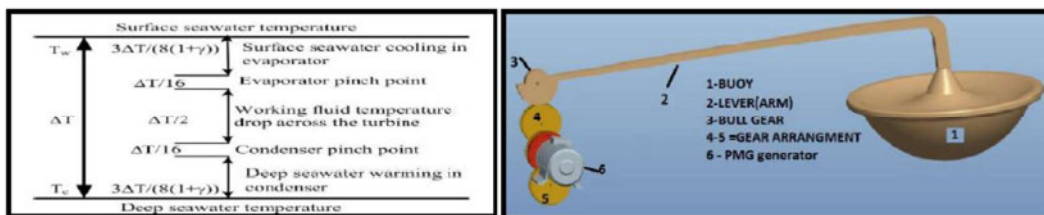


Figure 25: Temperature Ladder Model During OTEC. Figure 26: Components of the Simple and Nonstop Process as Proposed by Nihous (2007) [33]. Buoyant Arm Wave Energy Converter (SAN-BAWEC) [3].

From figure. 25, the gross electrical power ( $P_g$ ) in OTEC process can be written as seen in Equation (20) [33]

$$P_g = \frac{3\rho C_h Q_{cw} \lambda \varepsilon_{tb} (\Delta T)^2}{16(1+\gamma)T_w} \quad \text{Equation (20)}$$

Where:  $\rho$  is the density of seawater in  $\text{kg/m}^3$

- $Q_{cw}$  = the flow rate of the cold water in  $\text{m}^3/\text{s}$
- $\gamma$  = the ratio between warm water and cold water
- $\varepsilon_{tb}$  = the turbine generator efficiency
- $C_h$  = the specific heat of seawater (4.186 kJ/kgK)
- $\Delta T$  = the temperature difference between warm water and cold water (K)

The efficiency of the process is the Carnot efficiency as per Equation (21) [33]

$$\eta = 1 - \frac{T_c}{T_w} \quad \text{Equation (21)}$$

Harnessing wave energy uses Archimedes principle, the physical principle of buoyancy, as per Equation (22)

$$F_b = -\rho g V \quad \text{Equation (22)}$$

Where:  $F_b$  = the buoyant force

- $\rho$  = the density of the fluid
- $g$  = acceleration due to gravity ( $\text{m/s}^2$ )
- $V$  = the fluid volume

Figure. 26 shows one of many patented designs for harnessing wave energy. In simple terms, the buoyancy principle states that the buoyant force on a body floating in a liquid or gas is equivalent in magnitude to the weight of the floating object and is opposite in direction; the object neither rises nor sinks. From Fig. 26, the buoy converts the wave energy of ocean into mechanical energy, connected to a lever. The lever converts the mechanical energy into electrical energy. [34] The efficiency of the technology will be governed by the efficiency of the individual components.

All the technologies presented here have efficiency limitations, experience downtime when they need to be maintained and with renewable energy have varying output and availabilities. In short, a 1 MW peak solar photovoltaic plant will not give the full output at which it is rated, taking into account the efficiency of the solar cells, the downtime experienced during the year, the cloudy days and nights when solar energy is unavailable. These factors are summed up in the technology capacity factor. The capacity factor equation can be seen in Equation (23).

$$\text{Average Capacity Factor (CF)} = \frac{\sum_{t=1}^n E_t}{\sum_{t=1}^n P_t} \quad \text{Equation (23)}$$

Where  $P$  = energy production at full rated capacity in kWh

- $E$  = energy production in kWh
- $t$  = time period

- $n$  = number of time periods

From Equation (23), using the time period of a year which is most commonly used for comparisons of plant performance and reliability, we get the following Equation (24):

$$CF = \frac{\text{kWh produced in a year by the plant}}{\text{kWh in a year at maximum plant capacity}} \quad \text{Equation (24)}$$

In some energy generation sources, especially renewable energy that is affected by the weather conditions (solar energy, wind energy) the capacity factors vary from country to country than do the capacity factors from other energy generation technologies such as nuclear, natural gas, etc. This means that for example solar PV in Europe will have a lower capacity factor than solar PV in South Africa's northern regions. The technology efficiency of the solar PV plant will also affect the capacity factor e.g. mono-crystalline cell material has a greater output than multi-crystalline cells. Thus, the capacity factor varies for different energy generation technologies based on the following factors:

- Geographical location
- Site conditions
- Technology efficiency and efficiency limitations
- Plant efficiency and plant control philosophies
- Operational efficiency and cleaning of materials
- Maintenance downtime

The capacity factor for various energy generation technologies in the United States (US) and South Africa (SA) can be seen in Table 3. The average capacity factors for solar is lowest.

**Table 3: Capacity Factors of Various Energy Sources for the US [35] and SA [36]**

Energy Source	US (2019) [35]	SA (2013) [36]	SA (2014) [36]	SA (2015) [36]	SA (2016) [36]	SA (2017) [36]	SA (2018) [36]
Nuclear	93.5%						
Natural Gas	56.8%						
Coal	47.5%						
Hydropower	39.1%						
Wind	34.8%	19%	32%	32%	35%	36%	36%
Solar PV	24.5%	19%	26%	26%	26%	25%	25%
Concentrated Solar Power					31%	32%	38%

Using the equation of the capacity factor of the energy harvesting technologies, which takes into account all the factors affecting the installed technology, Equation (3) can be rewritten per Equation (25)

$$\begin{aligned} \text{Total Available Energy Potential} = & \sum(\text{Renewable energy potential} \times CF) + \\ & \sum(\text{Energy potential from human and industrial activity} \times CF) + \\ & \sum(\text{Energy potential from alternative less carbon intensive energy sources} \times CF). \end{aligned} \quad \text{Equation (25)}$$

Where: available energy potential is given in kWh/m<sup>2</sup> and for the case of waste to energy, it is given in kWh/m<sup>3</sup>.

### C. Real Energy Generation Potential

The real energy generation potential of a site is the actual energy generation potential that considers the spatial constraints of the site to accommodate the technologies that generate the energy. Table 4 shows the land use intensity of various energy sources. Renewable energy has a notably significant land use intensity compared to fossil fuel energy.

**Table 4: Land use Intensity from Various Energy Sources [Redrawn from [37]]**

Product	Primary Energy Source	Land Use Intensity (m <sup>2</sup> /MWh)					
		US data <sup>a</sup>	US data <sup>b</sup>	EU data <sup>c</sup>	UNEP <sup>d</sup>	Typical <sup>e</sup>	
Electricity	Nuclear	0.1	0.1	1.0		0.1	
	Natural gas	1.0	0.3	0.1	0.2	0.2	
	Coal	Underground	0.6	0.2	0.2		0.2
		Surface ("open-cast")	8.2	0.2	0.4	15.0	5.0
	Renewables	Wind	1.3	1.0	0.7	0.3	1.0
		Geothermal	5.1		2.5	0.3	2.5
		Hydropower (large dams)	16.9	4.1	3.5	3.3	10
		Solar PV	15.0	0.3	8.7	13.0	10
		Solar CSP	19.3		7.8	14.0	15
Biomass (from crops)		810	13	450		500	
Liquid fuel	Fossil oil	0.6		0.1		0.4	
	Biofuels	Corn (maize)	237		220		230
		Sugarcane (from juice)	274		239		250
		Sugarcane (residue)					0.1
		Soybean	296		479		400
		Cellulose, short rotation coppice	565		410		500
		Cellulose, residue			0.1		0.1

[37] Note that data include land use for spacing and from upstream life cycles (e.g. mining). <sup>a</sup>Trainor et al. (2016); <sup>b</sup>Fthenakis and Kim (2009); <sup>c</sup>IINAS (2017); <sup>d</sup>UNEP (2016); <sup>e</sup>Estimate for unspecified region (i.e. generic)

Equation (26) gives the total real energy generation potential of a site including renewable energy, energy sources derived from onsite operational activities and alternative energy sources (less carbon intensive).

$$\text{Total Real Energy Generation Potential} = \sum(\text{Available Energy Potential} \times \text{total area available for energy generation}) \quad \text{Equation (26)}$$

Thus, the total real energy generation potential can be written as seen in Equation (27).

$$\begin{aligned} \text{Total Real Energy Generation Potential} = & \sum(\text{Total real renewable energy generation potential} \times \\ & \text{area available}) + \sum(\text{Total real energy generation potential from human and industrial activity} \times \\ & \text{area available}) + \\ & \sum(\text{Total real energy generation potential from alternative less carbon intensive energy sources} \times \\ & \text{area available}) \end{aligned} \quad \text{Equation (27)}$$

Where: available energy potential is given in kWh.

Note that waste to energy requires the volume (m<sup>3</sup>) and not the area (m<sup>2</sup>).

It may be worth noting that all the land on a site cannot be used for all sources. For example, if 100 m<sup>2</sup> is the total area available for solar photovoltaic and solar photovoltaics is adopted, the same 100 m<sup>2</sup> will not be able to be adopted for wind energy by installing wind turbines in this area. Deciding on what energy sources to adopt require further investigation

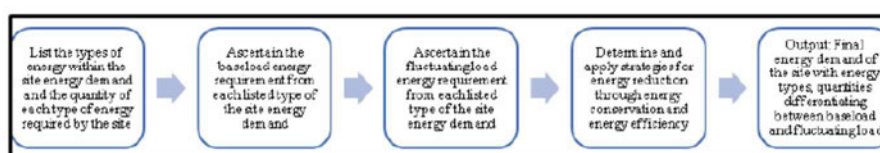
to provide a comprehensive understanding of the present and future (short, medium and long term views) energy demands of the site, as will be discussed in Principle 2.

## 2.2 Principle 2: Ascertain the Business' Onsite Energy Needs

A crucial step that is often skipped when a site is planning to incorporate alternative energy sources is to comprehensively understand the site's energy needs. Principle 2 is given as follows; the process flow of Principle 2 can be seen in Figure 27.

**Principle 2: Ascertain the site's energy needs, both present and future in the short, medium and long term, consider the following:**

- **Type of energy required and their quantities;**
- **Baseload energy requirements;**
- **Fluctuating load energy requirements and its timing; and**
- **Strategies for energy reduction, conservation, load levelling and load shifting techniques and their timing.**



**Figure 27: Process Flow for Ascertaining a Site's Energy Needs.**

To be able to undertake the process flow in Fig. 27, it is necessary to ask crucial questions about the site's present energy demands such as:

- How much energy does the site use on an hourly or half-hourly basis?
- What drives the energy demand of the site?
- Considering the drivers of the energy demand, can the energy demand be reduced?
- How much of the site's energy use is always required? (baseload)
- How much is the maximum energy demand and what drives the fluctuating energy demand?
- What type of energy demand contributes the baseload energy demand and what technologies drive this demand?
- What type of energy demand contributes the fluctuating energy demand and what technologies drive this demand?
- Can the technologies driving the site's energy demand be more efficient? Determine and apply strategies for energy efficiency and quantify the impact of these strategies in relation to the total energy demand.
- Can the technologies driving the site's energy demand be controlled to serve the need accurately, i.e., no idle time or over-supply? Determine and apply strategies for energy conservation and quantify the impact of these strategies in relation to the total energy demand.

Now that the site's energy demand is optimized, understand the site's future development plans and ascertain the site's future energy demand, if possible, to the stage of full development. Even though the energy demand may not be

accurately quantifiable, if at all, one understands:

- The energy types of the future energy demand, and the
- Typical technologies that will be installed.

This is crucial in the next step of satisfying the energy demand with a low-carbon energy mix.

**2.3 Principle 3: Satisfying Business needs Via the Site’s Available Resources**

With the view of the site’s total real energy generation potential and the site’s optimized energy demand for both the present and future, the site’s energy resources can be matched to satisfy its energy demand using Principle 3. The process flow of Principle 3 can be seen in Fig. 28.

**Principle 3: Match the energy sources available to the energy needs of the site considering:**

- Energy efficiency and load dynamics;
- Commercial technologies available and their impact, risks and implications for the business; and
- Feasibility to install, operate and maintain.
- Business imperatives and strategies (less carbon emissions, insource/outsourced strategies, capacity building, corporate social responsibility).

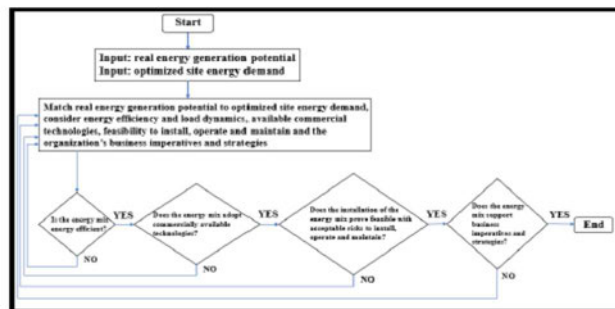


Figure 28: Process Flowchart of Determining a Site’s Low-Carbon Energy Mix.

**Energy Efficiency and Load Dynamics**

Using the principle in [2] for energy efficiency to determine the most energy efficient energy sources to match the energy need, Table 5 lists some common energy needs in commercial and industrial sites energy efficient energy sources.

**Table 5: Energy Efficient Sources for Energy need**

Site Energy Need	Energy Efficient Low Carbon Energy Source
Electricity	<ul style="list-style-type: none"> <li>• From combustion of fuel such as natural gas (from nearby sources or anaerobic digestion)</li> <li>• Solar photovoltaics</li> <li>• Wind turbines</li> </ul>
Heat	<ul style="list-style-type: none"> <li>• Solar thermal,</li> <li>• Waste heat from other process (such as natural gas, co-generation)</li> </ul>
Cooling	<ul style="list-style-type: none"> <li>• Solar thermal (chillers)</li> <li>• Geothermal (heat sinks)</li> </ul>

Motion	• Wind turbines
--------	-----------------

The energy source(s) supplying the baseload energy demand of the site should be available all the time and the availability of the energy source(s) supplying the fluctuating energy demand should be on demand. Should there be a mismatch between the availability of the energy sources to timeously supply the energy demand, there are two ways to get around this:

- Choose another energy source that fulfils the energy requirement or
- Apply load levelling and load shifting techniques that adopt various energy storage media

It is advisable that another energy source be selected if the load shifting and/or load levelling techniques are unfeasible or if their adoption goes against the strategy of reduced carbon emissions. Load shifting techniques act to store energy for use during another time when energy is not available or is advised not to be used, usually due to cost of peak-time energy. Load levelling techniques act to keep energy consumption constant and use methods such as energy storage to cope with any peak energy demands. This technique is commonly used to maximize the use of the site’s notified maximum demand (NMD) with an energy provider. Various energy storage technologies that make load shifting and load levelling possible can be seen in Figure 29.

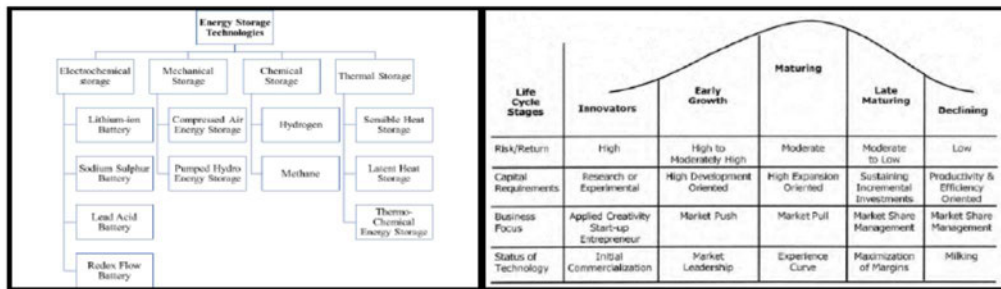


Figure 29: Energy Storage Options (Redrawn from [38]). Figure 30: Life Cycle Analysis of a Technology [39].

Energy storage technologies are adopted to save surplus energy generated by renewable energy technologies and to give a constant power supply of acceptable quality to the site due to the intermittency of renewable energy.

The deciding factors such as the commercial technologies available, their impact, risks and implications on the business will serve to point to the energy sources to be considered for adoption to serve the site’s energy demands.

**Commercial Technologies Available and their Impact, Risks and Implications for the Business**

It is key for developing countries to investigate the energy generation technologies available to their region, more specifically:

- Technology maturity;
- Local footprint of the technology;
- Availability of local markets to supply the technology and spare parts; and
- Availability of skills locally to support the operations and maintenance of the power generation plants.

The aspects above are largely determined from the maturity of the technology in the world. Fig. 30 shows the typical life cycle analysis of a technology. The 'maturing' and 'late maturing' stages indicate a moderate risk because in these stages, technologies are already well established in the market which will have allowed the skills for their operation and maintenance to penetrate the developing world geographical regions. Established technologies also have much better service offerings in terms of manufacturer guarantees and warranties.

There will also be many market competitors which increases the possibility of securing the energy generation technology at a competitive price.

### Feasibility to Install, Operate and Maintain

It is key to establish the financial feasibility of any energy generation technology investment as well as the compatibility of adoption onsite. The financial feasibility will include the cost to install, operate and maintain the energy generation technology. Most trade-offs between the real energy generation potential of each energy generation technology established in Principle 1 matching the site's optimized energy demand, established in Principle 2 will take place at the feasibility stage. An economic model is key in determining indicators of financial feasibility. A good economic model will typically give the net present value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index (PI). Equation (28) gives the NPV calculation. Equation (29) gives the PI. The IRR is the return ( $i$  in Equation 28) when the NPV is zero. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow.

$$NPV = \sum_{t=0}^T \frac{R_t}{(1+i)^t} \quad \text{Equation (28)}$$

Where:  $R_t$  = net cash inflows minus outflows during a single period  $t$

- $i$  = discount rate or return that could be earned
- $t$  = number of time periods

$$PI = \frac{PV \text{ of future cash flows}}{\text{Initial Investment}} \quad \text{Equation (29)}$$

The IRR is compared to an organization's weighted average cost of capital (WACC) rate to determine economic feasibility. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. When the NPV is zero or positive, the investment will pay itself off during its economic lifespan. The payback should be reasonably within the economic lifespan of the investment. The profitability index or PI (given in Equation 3) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects. Economic models will differ for each country based on the taxes, penalties, levies, cost of acquiring capital (if not self-funded), incentives offered by the government (if any), etc. The economic model must take into account all applicable factors for the energy generation investment. At this point most energy sources show their financial competitiveness to be adopted by the site and evaluation of the technical compatibility and integration into the site operations must be conducted. It may be that one technology is more financially feasible than another, however, its adoption at the site may have hurdles and limitations.

### **Business Imperatives and Strategies**

It may be that the financial feasibility and technical compatibility to adopt a certain technology may not appear to be as attractive as other energy generation technologies considered by the site, but the organization has a specific interest, imperative, objective or strategy that requires the technology's adoption. At this stage, the organization's overall vision, strategy and the individual departmental strategies must be considered before a final investment decision is made. Noting that certain energy generation technologies will be phased in over a period of 5 to 10 years, the organization's long terms goals may be to adopt certain technologies that may not seem financially feasible or technically compatible for the present but will be in the future with technology maturity and the execution of an organization's long term strategy. At this point the exercise to select a suite of energy generation technologies called a low carbon energy mix, in relation to the impact they will have in serving the site's energy demand, is concluded.

The application of these three principles for achieving energy security has significant implications on business outlook in that:

- Commercial opportunities may be highlighted from looking at a site's ability to generate and sell energy, maximizing company assets, especially land use.
- Commercial opportunities may be highlighted to establish new markets for operations and maintenance of renewable and alternate energy sources.
- Commercialization of knowledge on the establishment of energy generation technologies and a sustainable energy mix especially in developing countries which can be a service offering.

The applications of these principles have the potential to contribute to the profitability of a business as well as increase the human technical capacity and institutional knowledge within a country, creating employment and demand for renewable energy that will ultimately drive the decrease in cost of adopting renewable energy.

### **3. CONCLUSIONS**

This paper has presented three principles for achieving energy security in developing countries. The three principles for achieving energy security provide direction to achieving a low-carbon energy mix by:

- Establishing the 'theoretical energy potential', 'available energy potential' and the 'real energy generation potential' of a site.
- Establishing the optimized site energy demand to be satisfied.
- Efficiently matching the site's energy generation potential to the site's energy demand, considering energy efficiency, load dynamics, available commercial technologies, feasibility and business imperatives.

These principles as the basis for a site to achieve energy security have the potential of making a significant impact on the outlook of a business and brings to light commercial and business opportunities that may contribute to its profitability and efficiency while achieving energy security and environmental sustainability.

## REFERENCES

1. Joseph, J., Inambao, F. L. "Trends: Energy efficiency and energy security", *International Journal of Engineering Research and Technology*, Volume 13, Number 12, 2020, pp. 4084-4117.
2. Joseph, J., Inambao, F. L. "Principles for achieving energy efficiency in developing countries", *International Journal of Mechanical and Production Engineering Research and Development*, Vol. 11, Issue 2, 2021, 265-282.
3. Joseph, J., Inambao, F. L. "Energy consumption and energy efficiency of airports: A case study of airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*. Vol. 11, Issue 2, 2021, 205-228.
4. Joseph, J., Inambao, F. L. "Energy efficiency for airport infrastructure: A case study of the implementation of energy efficiency for airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, Volume 11, Issue 2, 2021, 383-406.
5. Joseph, J., Inambao, F. L. "Entrenching energy efficiency as a culture at airports: A case study of the implementation of energy efficiency for airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, Volume 11, Issue 3, 2021, 545-560.
6. Joseph, J., Inambao, F. L. "Sustainability: The big challenge", *International Journal of Engineering Research and Technology*, Volume 13, Number 11, 2020, pp. 3080-3098.
7. <https://www.vectorstock.com/royalty-free-vector/outline-south-africa-map-vector-1602127>, accessed 25/03/2021 – map outline used to create the picture.
8. [http://www.crses.sun.ac.za/files/research/publications/SolarGIS\\_GHI\\_South\\_Africa\\_width15cm\\_300dpi.png](http://www.crses.sun.ac.za/files/research/publications/SolarGIS_GHI_South_Africa_width15cm_300dpi.png), accessed 25/03/2021
9. [http://www.crses.sun.ac.za/files/research/publications/SolarGIS\\_DNI\\_South\\_Africa\\_width15cm\\_300dpi.png](http://www.crses.sun.ac.za/files/research/publications/SolarGIS_DNI_South_Africa_width15cm_300dpi.png), accessed 25/03/2021
10. <https://globalwindatlas.info/en/area/South%20Africa?print=true>, accessed 25/03/2021
11. <https://www.get-invest.eu/market-information/south-africa/renewable-electricity-potential/>, accessed 19/03/2021
12. <https://www.get-invest.eu/market-information/south-africa/renewable-electricity-potential/>, accessed 19/03/2021
13. <https://techcentral.co.za/should-sa-tap-geothermal-energy/59737/>, accessed 30/03/2021
14. Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S. von Stechow C. (eds), *Special Report of the Intergovernmental Panel on Climate Change, "Renewable Energy Sources and Climate Change Mitigation"*. Cambridge: Cambridge University Press, 2011
15. <https://www.ownerteamconsult.com/natural-gas-in-southern-africa-part-1-current-supply-and-demand/>, accessed 30/03/2021
16. Jäger, K., Isabella, O., Smets, A. H. M., van Swaaij, R. A. C. M. M. Zeman, M. "Solar energy fundamentals, technology, and systems" Delft University of Technology, 2014.
17. Vorster F., van Dyk, E. *Photovoltaic Module Technology Course*, Nelson Mandela Metropolitan University, October 2016.
18. [https://upload.wikimedia.org/wikipedia/commons/3/35/Best\\_Research-Cell\\_Efficiencies.png](https://upload.wikimedia.org/wikipedia/commons/3/35/Best_Research-Cell_Efficiencies.png), accessed 19/03/2021
19. <https://www.volker-quaschning.de/articles/fundamentals4/index.php>, accessed 29/03/2021
20. <https://www.epa.gov/rhc/solar-heating-and-cooling-technologies>, accessed 29/03/2021

21. Tijani, A. "Simulation analysis of thermal losses of parabolic trough solar collector in Malaysia using computational fluid dynamics", Researchgate, September 2014.
22. Abed, N., Afgan, I. "An extensive review of various technologies for enhancing the thermal and optical performances of parabolic trough collectors", *International Journal of Energy Research*, Volume 44, 5117-5164, 2020.
23. <https://www.thermopedia.com/content/1136/>, accessed 01/04/2021
24. <https://www.lmwindpower.com/en/stories-and-press/stories/learn-about-wind/what-is-a-wind-class>, accessed 25/03/2021
25. Pipelife.com, "Geothermal Energy" n.d. Retrieved from [https://www.pipelife.com/content/dam/pipelife/international/marketing/general/brochures/Geothermal\\_Energy\\_2020.pdf](https://www.pipelife.com/content/dam/pipelife/international/marketing/general/brochures/Geothermal_Energy_2020.pdf), accessed 28/05/2021
26. Sarbu, I., Sebarchievici, C., "Using ground-source heat pump systems for heating/cooling of buildings", *InTechOpen*, 20/01/2016. Retrieved from <https://www.intechopen.com/books/advances-in-geothermal-energy/using-ground-source-heat-pump-systems-for-heating-cooling-of-buildings>, accessed 07/06/2021.
27. U.S. Environmental Protection Agency Combined Heat and Power Partnership, "Catalog of CHP technologies", March 2015.
28. Lumbroso, D., Hurford, A. P., Wimpenny, J., "Synthesis report: Harnessing hydropower technical report", Researchgate, October 2014, DOI: 10.12774/eod\_cr.september2014.lumbrosoetal2.
29. <https://www.paloaltoonline.com/blogs/p/2020/07/19/will-two-lined-swimming-pools-connected-by-a-pipe-help-us-get-rid-of-natural-gas>, accessed 29/06/2021.
30. <https://www.oceanenergycouncil.com/ocean-energy/tidal-energy/>, accessed 17/06/2021
31. <https://www.oceanenergycouncil.com/ocean-energy/otec-energy/devices-used-otec-energy/>, accessed 30/06/2021.
32. <https://www.oceanenergycouncil.com/ocean-energy/otec-energy/>, accessed 30/06/2021.
33. Suparta, W., "Marine heat as a renewable energy source", *Widyakala Journal* Volume 7, Issue 1, March 2020.
34. Kumar, A. S., "Energy harvesting from ocean waves by SAN-BAWEC (Simple and Nonstop-Buoyant arm Wave Energy Converter)", *International Journal of Innovative Research & Development*, Volume 3, Issue 10, October 2014.
35. Office of Nuclear Energy, "What is generation capacity", 01/05/2020. Retrieved from <https://www.energy.gov/ne/articles/what-generation-capacity>, accessed 17/06/2021.
36. Calitz, J., Wright, J., "Statistics of utility scale solar PV, wind and CSP in South Africa in 2018" CSIR Pretoria, January 2019.
37. Fritsche, U. R., Berndes, G., Cowie, A. L., Dale, V. H., Kline, K. L., Langeveld, H., Sharma, N., Watson, H., Woods, J., "Energy and land use" *International Renewable Energy Agency*, 2017.
38. Gustavsson, J., "Energy storage technology comparison", *KTH School of Industrial Engineering and Management*, 2016.
39. Gross, C., Lyons, C., Booras, G., Nguyen, B., "Power generation technology data for integrated resource plan of South Africa", *Electric Power Research Institute*, August 2015.
40. Senthilkumar, P. "Environmental Effect of Using Diesel On Waste Plastic Oil Fueled In Diesel Engine." *International Journal of Mechanical Engineering (IJME)* 7. 3, Apr-May 2018 18.
41. I Al-Samarrai, Khalil, Saleh A Sadeg, and Abdullah Sassi. "Policies of Conventional and Non-Conventional Energy for Sustainability in Libya." *International Journal of General Engineering and Technology (IJGET)* 6.6 (2017): 1-12.

42. Frizziero, L. E. O. N. A. R. D. O., et al. "New recovery energy turnstile achieved through research and innovation eco-design method (EQFD)." *Int. J. Mech. Prod. Eng. Res. Dev* 9 (2019): 277-286.
43. Joshi, Krishna. "Application of Energy Concepts for Green Buildings." *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) ISSN (P) (2016): 2249-6866.*

## CHAPTER 12. ENERGY SECURITY: CONCEPTUALISING A LOW-CARBON ENERGY MIX FOR AIRPORTS IN SOUTH AFRICA

This chapter presents the journey related to conceptualising of a low-carbon energy mix for the nine ACSA airports.

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<http://www.tjprc.org/view-archives.php>

## ENERGY SECURITY: CONCEPTUALISING A LOW-CARBON ENERGY MIX FOR AIRPORTS IN SOUTH AFRICA

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**Abstract**

*Energy security is found in diversification of energy sources drawing power from an energy mix while moving away from carbon intensive energy sources causing climate change. This is a unique challenge for developing countries. This paper presents the journey of conceptualising a low-carbon energy mix for nine airports in South Africa.*

*Keywords: Airports in South Africa low carbon energy mix, baseload energy, fluctuating energy loads, airports natural resources, theoretical energy potential, available energy potential, real energy generation potential.*

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### INTRODUCTION

Airports are a key infrastructure in the economy of a country. At the heart of their proper functioning and security is the availability of reliable sources of energy. The current energy supply challenges facing Eskom threaten the present and future of airports and their proper functioning and security. Relying on Eskom alone for electricity to run airports is not a sustainable solution. Coupled with this is the climate change mitigation imperative that is part of the business’s environmental objective. Airports Company South Africa (ACSA) is South Africa’s airport authority and owns and operates nine airports, namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport (CTIA) (Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape) (PEIA), East London Airport (Eastern Cape) (EL), Bram Fischer International Airport (Bloemfontein, Free State) (BFIA), George Airport (Eastern Cape) (GG), Upington International Airport (Northern Cape) (UPIA) and Kimberley Airport (Northern Cape) (KIM). From [1], the three principles for achieving energy security in developing countries are given as follows:

Principle 1: Ascertain the energy generation potential of the site, i.e., what is the:

- (a) Theoretical energy potential of the site as found in Equation (1):

$$\begin{aligned}
 \text{Total Theoretical Energy Potential} &= \Sigma \text{Renewable energy potential} && + \\
 &\Sigma \text{Energy potential from human and industrial activity} && + \\
 &\Sigma \text{Energy potential from alternative less carbon intensive energy sources} && \dots\dots\dots
 \end{aligned}$$

Equation (1)

- (b) Available energy potential by applying the commercially available technologies as found in Equation (2):

$$\begin{aligned}
 \text{Total Available Energy Potential} &= \Sigma(\text{Renewable energy potential} \times CF) + \\
 &\Sigma(\text{Energy potential from human and industrial activity} \times CF) + \\
 &\Sigma(\text{Energy potential from alternative less carbon intensive energy sources} \times CF) && \text{Eq}
 \end{aligned}$$

(2)

- (c) Real energy generation potential considering the spatial and other demands required for energy generation, as found in Equation (3):

$$\begin{aligned} \text{Total Real Energy Generation Potential} = & \sum(\text{Total real renewable energy generation potential} \times \\ & \text{area available}) + \sum(\text{Total real energy generation potential from human and industrial activity} \times \\ & \text{area available}) + \\ & \sum(\text{Total real energy generation potential from alternative less carbon intensive energy sources} \times \\ & \text{area available}) \end{aligned} \quad \dots\dots\dots \text{Eq(3)}$$

Principle 2: Ascertain the site's energy needs in the present and the future (short, medium and long term) considering the following:

- (a) Type of energy required and their quantities,
- (b) Baseload energy requirements,
- (c) Fluctuating load energy requirements and their timing; and
- (d) Strategies for energy reduction, conservation, load levelling and load shifting and their timing.

Principle 3: Match the energy sources available to the energy needs of the site considering:

- (a) Energy efficiency and load dynamics,
- (b) Commercial technologies available and their impact, risks and implications for the business,
- (c) Feasibility to install, operate and maintain and
- (d) Business imperatives and strategies (less carbon emissions, insource/outsource strategies, capacity building, corporate social responsibility).

The principles for energy security enable one to be aware of the full energy generation potential of the site. This approach is ideal for a strategy that wants to not only generate energy for own use, but for generating commercial revenue. It is also the approach advised to sustainably reach and maintain energy security in developing countries. The strategy that the energy mix for the airports sought to fulfil when it was formulated in FY 2018/2019 (1 April 2018 to 31 March 2019) using data for the period 1 April 2017 to 31 March 2018 was to reach carbon neutrality in electricity consumption. This paper uses these three principles to conceptualise the energy mix for nine airports in South Africa owned and operated by ACSA.

#### **Energy generation potential of airports in South Africa**

The application of Principle 1 gives the theoretical energy potential considering the natural resources available in the geographical region, the available energy potential considering the efficiency of the conversion technologies, and the real energy generation potential considering the spatial and other constraints of the site. Table 1 gives the approximate land footprint of the airports, their occupied land footprint and their occupied land footprint at full development which is at around the year 2050.

Table 1: Estimated land footprint of airports in South Africa

Airport	Onsite facilities as at 2018	Total land footprint	Current occupied land footprint	Final occupied land footprint at full capacity
O R Tambo International Airport	Passenger terminal buildings and passenger boarding bridges including commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, three hotels, car rental facilities and wash bays, car parking lots, office buildings, warehouses, cold storage rooms, maintenance storage and stock rooms, bus staging areas, vehicle fuelling stations.	19.84 km <sup>2</sup> (Estimated using Google Maps, including runways, taxiways and vacant land)	8.31 km <sup>2</sup> (Estimated using Google Maps, including runways and taxiways)	19.84 km <sup>2</sup> (Assumed full development of current land footprint; future land acquisitions not accounted for)
Cape Town International Airport	Passenger terminal buildings and passenger boarding bridges including commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, three hotels, car rental facilities and wash bays, car parking lots, office buildings, warehouses, cold storage rooms, maintenance storage and stock rooms, bus staging areas, vehicle fuelling stations.	9.76 km <sup>2</sup> (Estimated using Google Maps, including runways, taxiways and vacant land)	5.90 km <sup>2</sup> (Estimated using Google Maps, including runways and taxiways)	9.76 km <sup>2</sup> (Assumed full development of current land footprint; future land acquisitions not accounted for)
King Shaka International Airport	Passenger terminal buildings and passenger boarding bridges including commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, three hotels, car rental facilities and wash bays, car parking lots, office buildings, warehouses, cold storage rooms, maintenance storage and stock rooms, bus staging areas, vehicle fuelling stations.	7.11 km <sup>2</sup> (Estimated using Google Maps, including runways, taxiways and vacant land)	3.26 km <sup>2</sup> (Estimated using Google Maps, including runways and taxiways)	7.11 km <sup>2</sup> (Assumed full development of current land footprint; future land acquisitions not accounted for)
Port Elizabeth International Airport	Passenger terminal buildings, retail stores, restaurants, luggage conveyor belts, waste sortation area, water storage tanks, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, car rental facilities and wash bays, car parking lots, office buildings.	3.79 km <sup>2</sup> (Estimated using Google Maps, including runways, taxiways and vacant land)	1.26 km <sup>2</sup> (Estimated using Google Maps, including runways and taxiways)	2.90 km <sup>2</sup> (Assumed development of current land footprint; future land acquisitions not accounted for)
East London Airport	Passenger terminal buildings including restaurants, baggage conveyor belts, waste	1.69 km <sup>2</sup> (Estimated)	0.84 km <sup>2</sup> (Estimated)	1.16 km <sup>2</sup> (Assumed)

	sortation area, office areas, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage tank, runways, taxiways, car rental facilities and wash bays, car parking lots, office building	using Google Maps, including runways, taxiways and vacant land)	using Google Maps, including runways and taxiways)	development of current land footprint; future land acquisitions not accounted for)
Bram Fischer International Airport	Passenger terminal buildings including restaurants, baggage conveyor belts, waste sortation areas, water storage tanks, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, hospital, car rental facilities and wash bays, car parking lot, office building	7.71 km <sup>2</sup> (Estimated using Google Maps, including runways, taxiways and vacant land)	1.87 km <sup>2</sup> (Estimated using Google Maps, including runways and taxiways)	2.97 km <sup>2</sup> (Assumed development of current land footprint; future land acquisitions not accounted for)
George Airport	Passenger terminal buildings including restaurants, baggage conveyor belts, waste sortation area, HVAC plant. Aprons (parking bays for aircraft), Air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage tank, runways, taxiways, car rental facilities and wash bays, car parking lots, office buildings.	2.64 km <sup>2</sup> (Estimated using Google Maps, including runways, taxiways and vacant land)	1.02 km <sup>2</sup> (Estimated using Google Maps, including runways and taxiways)	2.18 km <sup>2</sup> (Assumed development of current land footprint; future land acquisitions not accounted for)
Upington International Airport	Passenger terminal buildings including restaurants, baggage conveyor belt and carousel, water storage tank, HVAC packaged plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage tank, runways, taxiways, car rental facilities and wash bays, car parking lot, office buildings.	8.07 km <sup>2</sup> (Estimated using Google Maps, including runways, taxiways and vacant land)	3.75 km <sup>2</sup> (Estimated using Google Maps, including runways and taxiways)	6.14 km <sup>2</sup> (Assumed development of current land footprint; future land acquisitions not accounted for)
Kimberley Airport	Passenger terminal buildings including a cafe, baggage conveyor belt and carousel, HVAC decentralised units. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage tank, runways, taxiways, car rental facilities and wash bays, car parking lot, office buildings.	5.17 km <sup>2</sup> (Estimated using Google Maps, including runways, taxiways and vacant land)	1.98 km <sup>2</sup> (Estimated using Google Maps, including runways and taxiways)	2.06 km <sup>2</sup> (Assumed development of current land footprint; future land acquisitions not accounted for)

Table 2 contains some of the indicators of the theoretical energy generation potential, the available energy generation potential, and the real energy generation potential of the airport sites. Some energy sources will require further investigation such as natural gas, waste to energy and geothermal heat sinks as the quantity of natural gas that is available to be secured has to be confirmed, the quality of the waste and energy value must be tested in a lab, and the soil conditions must be tested. Wind energy uses vertical axis wind turbines (VAWT) at a height of 12 m.

**Table 2: Theoretical energy generation potential, available energy generation potential and real energy generation potential of the airport sites**

Airport	Type of energy	Annual theoretical energy generation potential	Annual available energy generation potential	Annual real energy generation potential	Notes
ORTIA	Solar to electricity	2000 kWh/m <sup>2</sup> [2]	528 kWh/m <sup>2</sup> (Capacity factor of 26.4 %)	<b>Full site (FS):</b> 10 475.52 GWh <b>Unoccupied land (UL):</b> 6 598.725 GWh <b>Unoccupied land at full development (UL@FD):</b> 0	ORTIA natural gas availability requires investigation; waste to energy will require specific lab tests to determine the calorific value.
	Solar to thermal energy	2250 kWh/m <sup>2</sup> [3]	832.5 kWh/m <sup>2</sup> (Capacity factor of 37 %)	<b>FS:</b> 16 516.80 GWh <b>UL:</b> 9 598.725 GWh <b>UL@FD:</b> 0	
CTIA	Solar to electricity	1900 kWh/m <sup>2</sup> [2]	501.6 kWh/m <sup>2</sup> (Capacity factor 26.4 %)	<b>FS:</b> 4 895.616 GWh <b>UL:</b> 1 936.176 GWh <b>UL@FD:</b> 0	CTIA natural gas availability requires investigation; geothermal resources require in depth investigation into soil conditions for heat exchange, and waste to energy requires specific lab tests to determine calorific value.
	Solar to thermal energy	2100 kWh/m <sup>2</sup> [3]	777 kWh/m <sup>2</sup> (Capacity factor 37 %)	<b>FS:</b> 7 583.52 GWh <b>UL:</b> 2 999.22 GWh <b>UL@FD:</b> 0	
	Wind energy to electricity	112 kWh/m <sup>2</sup> (12 m height)	39.4 kWh/m <sup>2</sup> (Capacity factor 35.2 %)	<b>FS:</b> 384.778 GWh <b>UL:</b> 152.177 GWh <b>UL@FD:</b> 0	
KSIA	Solar to electricity	1500 kWh/m <sup>2</sup> [2]	396 kWh/m <sup>2</sup> (Capacity factor 26.4 %)	<b>FS:</b> 2 815.56 GWh <b>UL:</b> 1 524.6 GWh <b>UL@FD:</b> 0	KSIA natural gas availability requires investigation, and waste to energy requires specific lab tests to determine calorific value.
	Solar to thermal energy	1500 kWh/m <sup>2</sup> [3]	555 kWh/m <sup>2</sup> (Capacity factor 37 %)	<b>FS:</b> 3 946.05 GWh <b>UL:</b> 2 136.75 GWh <b>UL@FD:</b> 0	
PEIA	Solar to electricity	1750 kWh/m <sup>2</sup> [2]	462 kWh/m <sup>2</sup> (Capacity factor 26.4 %)	<b>FS:</b> 1 750.98 GWh <b>UL:</b> 1 168.86 GWh <b>UL@FD:</b> 411.18 GWh	Wind energy using vertical axis wind turbines takes into account the spacing and allows for a maximum height of 12 m. The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	1700 kWh/m <sup>2</sup> [3]	629 kWh/m <sup>2</sup> (Capacity factor 37 %)	<b>FS:</b> 2 383.91 GWh <b>UL:</b> 1 591.37 GWh <b>UL@FD:</b> 559.81 GWh	
	Wind energy	112 kWh/m <sup>2</sup>	39.4 kWh/m <sup>2</sup> (Capacity factor 35.2 %)	<b>FS:</b> 149.42 GWh <b>UL:</b> 99.74 GWh <b>UL@FD:</b> 35.09 GWh	
EL	Solar to electricity	1650 kWh/m <sup>2</sup> [2]	435.6 kWh/m <sup>2</sup> (Capacity factor 26.4 %)	<b>FS:</b> 736.164 GWh <b>UL:</b> 370.26 GWh <b>UL@FD:</b> 230.87 GWh	Wind energy using vertical axis wind turbines takes into account the spacing and allows for a maximum height of 12 m. The waste volumes
	Solar to thermal energy	1600 kWh/m <sup>2</sup> [3]	592 kWh/m <sup>2</sup> (Capacity factor 37 %)	<b>FS:</b> 1 000.48 GWh <b>UL:</b> 503.2 GWh <b>UL@FD:</b> 313.76 GWh	
	Wind energy	112 kWh/m <sup>2</sup>	39.4 kWh/m <sup>2</sup> (Capacity factor 35.2 %)	<b>FS:</b> 66.627 GWh <b>UL:</b> 33.51 GWh	

				UL@FD: 20.89 GWh	are not sufficient to generate energy from.
BFIA	Solar to electricity	2100 kWh/m <sup>2</sup> [2]	554.4 kWh/m <sup>2</sup> (Capacity factor 26.4 %)	FS: 4 274.42 GWh UL: 3 237.7 GWh UL@FD: 2 627.856 GWh	The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	2600 kWh/m <sup>2</sup> [3]	962 kWh/m <sup>2</sup> (Capacity factor 37 %)	FS: 7 417.02 GWh UL: 5 618.08 GWh UL@FD: 4 559.88 GWh	
GG	Solar to electricity	1550 kWh/m <sup>2</sup> [2]	409.2 kWh/m <sup>2</sup> (Capacity factor 26.4 %)	FS: 1 080.288 GWh UL: 662.904 GWh UL@FD: 188.23 GWh	Wind energy using vertical axis wind turbines takes into account the spacing and allows for a maximum height of 12 m. The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	1700 kWh/m <sup>2</sup> [3]	629 kWh/m <sup>2</sup> (Capacity factor 37 %)	FS: 1 660.56 GWh UL: 1 018.98 GWh UL@FD: 289.34 GWh	
	Wind energy	112 kWh/m <sup>2</sup>	39.4 kWh/m <sup>2</sup> (Capacity factor 35.2 %)	FS: 104.079 GWh UL: 63.867 GWh UL@FD: 18.135 GWh	
UPIA	Solar to electricity	2300 kWh/m <sup>2</sup> [2]	607.2 kWh/m <sup>2</sup> (Capacity factor 26.4 %)	FS: 4 900.104 GWh UL: 2 623.104 GWh UL@FD: 1 171.896 GWh	The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	3200 kWh/m <sup>2</sup> [3]	1184 kWh/m <sup>2</sup> (Capacity factor 37 %)	FS: 9 554.88 GWh UL: 5 114.88 GWh UL@FD: 2 285.12 GWh	
KIM	Solar to electricity	2100 kWh/m <sup>2</sup> [2]	554.4 kWh/m <sup>2</sup> (Capacity factor 26.4 %)	FS: 2 866.25 GWh UL: 1 768.536 GWh UL@FD: 1 724.184 GWh	The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	2900 kWh/m <sup>2</sup> [3]	1073 kWh/m <sup>2</sup> (Capacity factor 37 %)	FS: 5 547.41 GWh UL: 3 422.87 GWh UL@FD: 3 337.03 GWh	

The information contained in Table 2 is key in assessing the available resources whenever there is an energy demand to satisfy, or if an organisation wants to commercialise the site's energy resources. ACSA's strategy when undertaking an energy mix for its airports is to reach carbon neutrality in electricity consumption while ensuring that the energy mix implemented is financially feasible and suitable to the airports' operating environment.

#### Airports' Energy Demand

The energy consumption of ACSA's nine airports vary significantly relative to each other. The energy consumption of ACSA's nine airports together with the resulting carbon footprint are given in Figure 1. Each airports' contribution to the total carbon footprint resulting from energy consumption of all nine airports are given in Figure 2.

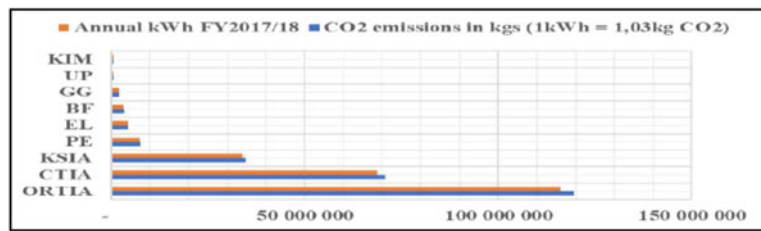


Figure 1: Electrical energy consumption and resulting carbon emissions of ACSA’s airports for the period 1 April 2017 to 31 March 2018

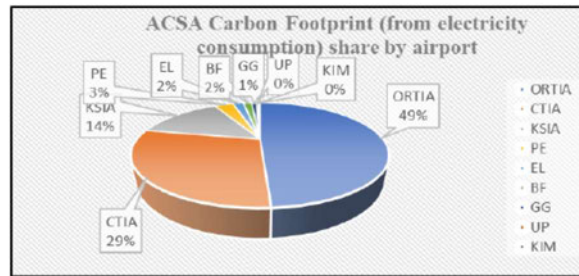
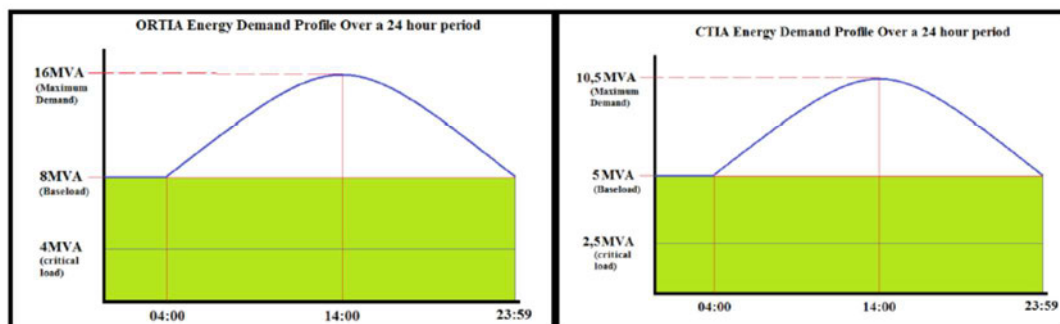


Figure 2: ACSA airports’ carbon footprints share from electricity consumption

ORTIA accounts for about half of the electricity consumption and carbon footprint of the group of nine airports, followed by CTIA at 29 % and KSIA at 14 %, together, these three airports account for 93 % of the energy consumption of the group. The electricity consumption of the airports also varies according to their operational hours and size of the development. Fig. 3 gives the estimated electricity consumption profile of the nine airports, showing their baseload, fluctuating load and critical load portions forming part of the baseload. GG, UPIA and KIM airports existing solar PV plants are shown in their electricity consumption profile as the dotted portion of their peak loads.

An airport’s significant energy users are lighting and air conditioning [4], so these are the main contributors to the shaping of an airport’s electricity demand profile. The lighting load of an airport constitutes much of the baseload, including the critical load as runways and taxiways which have to be lit according to legislation almost all the time. Air conditioning is needed for the comfort of the buildings and for keeping electronic equipment at a specific operating temperature. This causes the peak electricity load of airports. Lighting and air conditioning loads are supplied from the national electricity grid. Peak loads at GG, UPIA and KIM airports are supplied with electricity from their solar PV plants, as indicated in Fig. 3.



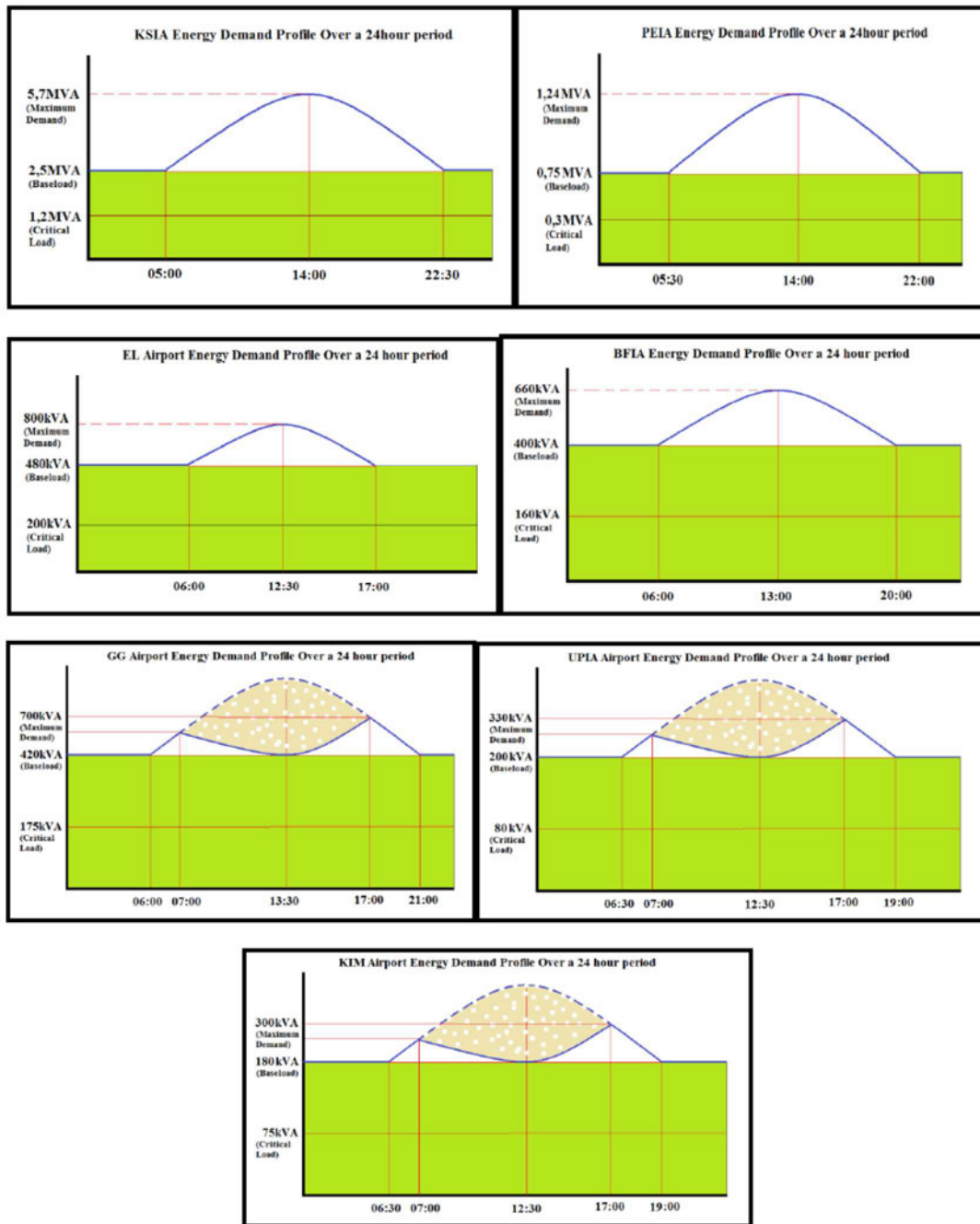


Figure 3: Load dynamics for ACSA's airports in South Africa

**Conceptual roadmaps for achieving a low carbon energy mix**

Reducing and where possible eliminating energy wastage is crucial to cost effectiveness in the journey of reducing carbon emissions. The energy reduction projects to reduce electricity demand through energy efficiency, energy conservation and through supplying an energy demand from a different source are given in Table 3.

Table 3: Planning for Grid Electricity Reduction at Airports

Significant energy user	Description and notes	Projects to be considered for investigation	Notes
Lighting	Lighting share being around 50 % to 60 % of each airport's total energy consumption	This can be reduced by at least 15 % (up to 30 %) through adoption of LED lighting	Investigate the adoption of LED lighting for each airport including feasibility
		Lighting control can give a further 10 % through the adoption of occupancy sensors, timers, photocells and dimming functions installed and programmed.	Investigate the adoption of lighting control for each area where lighting demand varies throughout the day.
Heating, ventilation and air-conditioning	This share varies from 20 % to 30 % of airport's total energy consumption	Air conditioning systems to be re-designed with time by additions and refurbishments to ensure a smooth notified maximum demand curve through the application of energy reduction, load levelling techniques and load shifting techniques. Projects include: - Heat pipe dehumidification - Re-use of condensate as make-up water and as an aid in achieving the temperature required to cool chillers - Re-use of condenser water in a heat exchanger as a pre-heater to the geysers or any other process requiring a heated fluid - Active chilled water set-point control, variable speed drives, air economising, fresh air demand control - Ice storage or chilled water storage	Investigations into the feasibility and technical suitability of implementing these projects at ORTIA, CTIA, KSIA confirming financial viability and technical suitability.
		Reduction of cooling/heating demand projects include: - Heat resistant coating on roof/solar thermal roof/green roof - Solar thermal walls OR heat deflection facades - Building envelope and fenestration projects	Investigations to be done for all airports confirming financial feasibility and application.
		Greenest air conditioning system with existing technology made up of: -Absorption chillers providing space heating and cooling -Powered by solar thermal energy -Using water as refrigerant, lithium bromide as absorbent -Cooling towers to be replaced by geothermal heat sinks	Investigations to be done for PEIA, EL, BFIA and GG, confirming technical suitability and financial viability. Geothermal heat sinks instead of evaporative cooling towers should also be investigated for ORTIA, CTIA and KSIA.

In the journey of investigating the above projects for implementation at the airports, some airports may not be technically suited for certain projects, or a project may not apply to the airport, and thus financial feasibility will not need to follow. Once energy reduction projects have been planned for, reducing carbon emissions further will require the adoption of less carbon intensive energy sources for electricity generation. The adoption of a low carbon energy mix is not common practice in South Africa and alternative energy sources such as renewable energy technologies and their methods of operation are unfamiliar, even though they are proven to work in other countries.

To ensure that the airport sites and business operations adjust, become familiar and confident with alternative energy technologies, a phased approach to achieve carbon neutrality in electricity consumption is proposed. Table 4 gives the phased approach to carbon neutrality in electricity consumption at the nine airports in South Africa.

**Table 4: Phases to Carbon Neutrality in electricity Consumption at the nine airports in South Africa**

Phase	Description of phase
Preliminary and ongoing during the implementation of the energy mix	<ol style="list-style-type: none"> <li>1. Changing of lighting technology to LED.</li> <li>2. Lighting control to be achieved for all areas.</li> <li>3. Implementation of initiatives to reduce HVAC chiller load such as convective boundaries, thermal resistant coatings on walls and roof, heat pipe dehumidification in air handling units and other passive cooling techniques.</li> <li>4. Refurbishment programmes to ensure adoption of energy efficient pumps, motors, controls and processes.</li> </ol>
One (From year 2018 to year 2024)	<ol style="list-style-type: none"> <li>1. The low carbon energy mix will be designed to supply the airports' maximum electricity demands (kVA or MVA) as of the year 2018.</li> <li>2. For ORTIA, CTIA and KSIA, the airport's critical load will be supplied (or backed up) through the national electricity grid to ensure minimal interruptions to airport operations during the initial stages of the operation of the natural gas trigeneration plants (electricity, thermal energy and cooling) which will be designed to have the capacity to support the airports' 2018 electricity demand.</li> <li>3. The existing solar PV plants at GG, UPIA and KIM airports will be provided with solar energy storage to ensure that all the electricity generated by the plant is being utilised by the airports. This is also the approach with the planned solar PV plants for PEIA, EL and BFIA.</li> <li>4. Increase in electricity consumption (kWh) during this period in phase one will either be offset by a decrease in 2018 electricity consumption (baseline) through energy reduction projects or absorbed by the current energy mix as this is designed to supply the airports maximum demand (kVA or MVA).</li> </ol>
Two (From year 2024 to 2027)	<ol style="list-style-type: none"> <li>1. Focus of investigation for implementation will be the business risk to airport operations of supplying the airports' critical electrical load and other new loads from the natural gas trigeneration plants for ORTIA, CTIA and KSIA by either expanding these plants, expanding the energy mix for these airports, or considering forms of energy storage to run the natural gas trigeneration plant in phase one at full capacity.</li> <li>2. For additional loads from this point to ensure that the airports' energy consumption is energy efficient and as low in carbon emissions as possible, the adoption of green star rated buildings will be required for new infrastructure with the emphasis being on designing buildings to be carbon neutral in terms of energy consumption.</li> <li>3. A smart electrical grid will be implemented to coordinate various energy supply sources for uninterrupted service to airport operations and to ensure a constant energy demand profile.</li> </ol>
Three (From year 2027 and beyond)	<ol style="list-style-type: none"> <li>1. Focus of implementation will be on further reduction in carbon emissions from the natural gas engines towards carbon neutrality by considering the following options and combinations thereof: <ul style="list-style-type: none"> <li>- Change of fuel type of the operating natural gas trigeneration plants</li> <li>- Process innovation to capture and sequester the carbon emissions</li> <li>- Technology change of combustion engines to ensure zero carbon emissions</li> </ul> </li> <li>2. Unavoidable carbon emissions for the purposes of ensuring reliable service to airport operations within financial feasibility will be offset by initiatives that allow for ACSA to either purchase carbon credits or implement carbon offsetting solar PV and wind generation plants either on their vacant land or for a community or school as a social development project towards corporate social investment to reach carbon neutrality in electricity consumption.</li> </ol>

Figure 4 to Figure 12 with an accompanying table (Table 5 to Table 13) give the conceptual journey of each airport to carbon neutrality in electricity consumption.

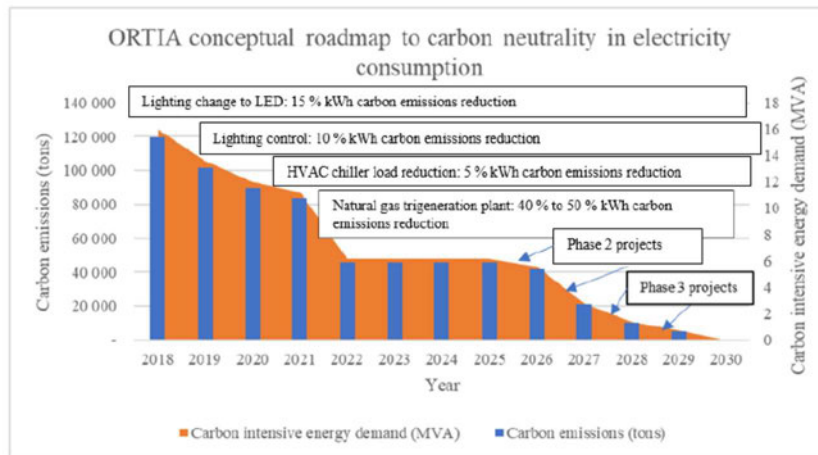


Figure 4: OR Tambo International Airport’s Conceptual Roadmap to Carbon Neutrality in Electricity Consumption

Table 5: Projects for ORTIA’s energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	<ol style="list-style-type: none"> <li>Lighting change to LED.</li> <li>Lighting control: occupancy sensors, BMS (building management system) control, dimming functions.</li> <li>HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (Heat deflective paint on roof/insulation), wind lobbies, etc.</li> <li>Geyser sleeve technology [Too small to count as a step change on graph]</li> </ol>	Financial feasibility and technical assessment (technoeconomic studies)	Wind lobbies were not ideal for ORTIA’s terminal building layout, so this was not taken to the financial feasibility stage.
One	<ol style="list-style-type: none"> <li>Natural gas trigeneration plants producing electricity through the combustion of natural gas and recovering the waste heat for thermal energy uses such as hot water and powering absorption chillers.</li> <li>Waste to energy via anaerobic digestion producing a biogas that can be combusted for electricity generation.</li> </ol>	<ol style="list-style-type: none"> <li>Technoeconomic assessment is required as well as a confirmed feasibility based on the engineering design before a financial investment decision is made and security of fuel gas supply.</li> <li>Waste streams are to be tested for their calorific value and a full technoeconomic assessment should follow</li> </ol>	<ul style="list-style-type: none"> <li>Due to ORTIA’s commercial expansion plans, using solar energy for electricity consumption is spatially not advisable and the high baseload will make energy storage a very costly endeavour.</li> <li>Incinerating dry waste may not be feasible as a fuel source due to its variability in calorific value and carbon emissions.</li> <li>Using geothermal</li> </ul>

			energy as a heat sink involves costly preliminary groundwork such as soil testing. It would be better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.
Two	<ol style="list-style-type: none"> <li>1. Using the natural gas trigeneration plant or using the anaerobic digestion plant from phase one to supply the critical load of the airport and for additional electrical loads.</li> <li>2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption.</li> <li>3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.</li> </ol>	<ol style="list-style-type: none"> <li>1. Confirmation of availability of additional natural gas to supply the airport's critical electrical load, space constraints for plant operation, suitability to support airport critical electrical load, integration requirements, economic feasibility.</li> <li>2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure.</li> <li>3. An in-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment to ensure a feasible electrical integration and smart grid design.</li> </ol>	<ul style="list-style-type: none"> <li>- Adoption of other energy sources such as decentralised packaged waste to energy plants, or rooftop solar PV plants, serving a specific new infrastructure must take into account the operational and maintenance cost of these plants, including the environmental impact.</li> </ul>
Three	<ol style="list-style-type: none"> <li>1. Fuel change from natural gas to a fuel with lower carbon footprint such as LPG or biogas.</li> <li>2. Process innovation to sequester carbon emissions.</li> <li>3. Technology change towards no carbon emissions.</li> <li>4. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.</li> </ol>	<ol style="list-style-type: none"> <li>1. Investigation into possible alternative fuels that are less carbon intense than natural gas and selecting the combustion engine technology that allows multiple fuel type intake is key for this to work cost effectively.</li> <li>2. Sequestering carbon will require in-depth environmental and</li> </ol>	<ul style="list-style-type: none"> <li>- Technology change might not be possible if there are no technology improvements commercially available.</li> <li>- Carbon sequestration might rely on a range of factors, both environmental, site and business related.</li> <li>- The better choice to invest effort in</li> </ul>

		<p>financial investigation.</p> <p>3. Technology change will be dependent on the commercial market evolution, and this must be actively monitored.</p> <p>4. A feasibility study must be undertaken on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.</p>	<p>investigation is a dual fuel combustion engine and carbon offsetting plants on vacant land at regional airports as a commercial venture (independent power producer) or undertake a corporate social investment project installing a solar PV or wind plant at a facility and claim the carbon credits.</p>
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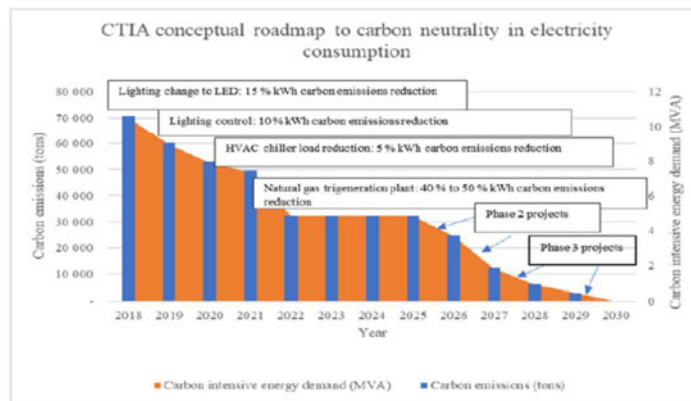


Figure 5: Cape Town International Airport’s conceptual roadmap to carbon neutrality in electricity consumption

Table 6: Projects for CTIA’s energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	<ol style="list-style-type: none"> <li>Lighting change to LED.</li> <li>Lighting control: occupancy sensors, BMS (building management system) control, dimming functions.</li> <li>HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc.</li> <li>Geyser sleeve technology [Too small to count as a step change on graph].</li> </ol>	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for CTIA’s terminal building layout, so was not taken to the financial feasibility stage.

One	<ol style="list-style-type: none"> <li>1. Natural gas trigeneration plants producing electricity through combustion of natural gas and recovering the waste heat for thermal energy uses such as hot water and powering absorption chillers.</li> <li>2. Waste to energy via anaerobic digestion producing a biogas that can be combusted for electricity generation.</li> <li>3. Wind energy generating electricity via vertical axis wind turbines.</li> <li>4. Geothermal heat sinks to replace evaporative cooling towers.</li> </ol>	<ol style="list-style-type: none"> <li>1. Technoeconomic assessment is required as well as a confirmed feasibility study based on the engineering design before a financial investment decision is made and security of fuel gas supply.</li> <li>2. Waste streams are to be tested for their calorific value and a full technoeconomic assessment should follow.</li> <li>3. Securing of a suitable installation site with the necessary approvals from Air Traffic Navigational Services (ATNS) and South African Civil Aviation Authority (SACAA), followed by a full technoeconomic assessment.</li> <li>4. Perform technoeconomic assessment and install a test geothermal heat sink loop similar to the one installed at Hotel Verde, just 2 km from the CTIA terminal building to become familiar with the operational cycles for mass roll out.</li> </ol>	<ul style="list-style-type: none"> <li>- Due to CTIA's commercial expansion plans, using solar energy for electricity consumption is spatially not advisable and the high baseload will make energy storage a very costly endeavour.</li> <li>- Incinerating dry waste may not be as feasible as a fuel source due to its variability in calorific value and carbon emissions.</li> </ul>
Two	<ol style="list-style-type: none"> <li>1. Using the natural gas trigeneration plant or using the anaerobic digestion plant from phase one to supply the critical load of the airport and for additional electrical loads.</li> <li>2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption.</li> <li>3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.</li> </ol>	<ol style="list-style-type: none"> <li>1. Confirmation of availability of additional natural gas to supply the airport's critical electrical load, space constraints for plant operation, suitability to support airport critical electrical load, integration requirements, economic feasibility.</li> <li>2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure.</li> <li>3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation as well as load curtailment to ensure a feasible electrical integration and smart grid design.</li> </ol>	<ul style="list-style-type: none"> <li>- Adoption of other energy sources such as decentralised packaged waste to energy plants or rooftop solar PV plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.</li> </ul>
Three	<ol style="list-style-type: none"> <li>1. Fuel change from natural gas to a fuel with a lower carbon footprint such as LPG or biogas.</li> </ol>	<ol style="list-style-type: none"> <li>1. Investigation into possible alternative fuels that are less carbon intense than natural gas and selecting the</li> </ol>	<ul style="list-style-type: none"> <li>- Technology change might not be possible if there is no technology improvements commercially available.</li> </ul>

	<ol style="list-style-type: none"> <li>2. Process innovation to sequester carbon emissions.</li> <li>3. Technology change towards no carbon emissions.</li> <li>4. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.</li> </ol>	<p>combustion engine technology that allows multiple fuel type intake, is key for this to work cost effectively.</p> <ol style="list-style-type: none"> <li>2. Sequestering carbon will require in-depth environmental and financial investigation.</li> <li>3. Technology change will be dependent on the commercial market evolution, and this must be actively monitored.</li> <li>4. A feasibility study must be undertaken on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.</li> </ol>	<ul style="list-style-type: none"> <li>- Carbon sequestration might rely on a range of factors, both environmental, site and business related.</li> <li>- The better choice to invest effort in investigation is a dual fuel combustion engine and carbon offsetting plants on vacant land at regional airports as a commercial venture (independent power producer) or undertake a corporate social investment project installing a solar PV or wind plant at a facility and claim the carbon credits.</li> </ul>
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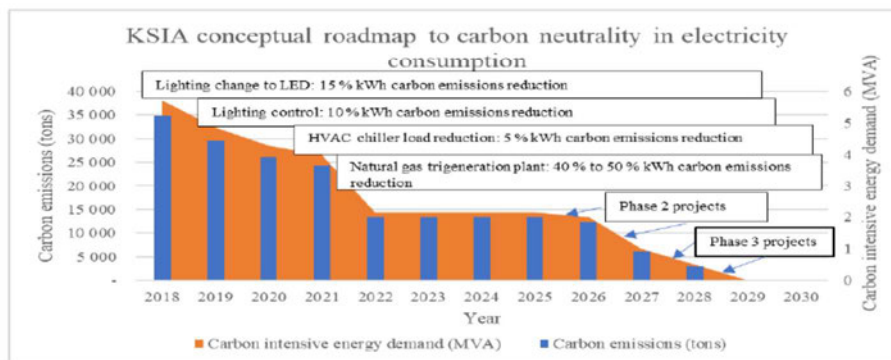


Figure 6: King Shaka International Airport’s conceptual roadmap to carbon neutrality in electricity consumption

Table 7: Projects for KSIA’s energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	<ol style="list-style-type: none"> <li>1. Lighting change to LED.</li> <li>2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions.</li> <li>3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc.</li> <li>4. Geyser sleeve technology [Too small to count as a step change on graph].</li> </ol>	Financial feasibility and technical assessment (technoeconomic studies)	Wind lobbies were not ideal for KSIA’s terminal building layout, so this was not taken to the financial feasibility stage.
One	<ol style="list-style-type: none"> <li>1. Natural gas trigeneration plants producing electricity</li> </ol>	<ol style="list-style-type: none"> <li>1. Technoeconomic assessment is required as well as a</li> </ol>	Due to KSIA’s commercial expansion plans, using solar

	<p>through combustion of natural gas and recovering the waste heat for thermal energy uses such as hot water and powering absorption chillers.</p> <p>2. Waste to energy via anaerobic digestion producing a biogas that can be combusted for electricity generation</p>	<p>confirmed feasibility based on the engineering design before a financial investment decision is made and security of fuel gas supply.</p> <p>2. Waste streams are to be tested for their calorific value and a full technoeconomic assessment should follow.</p>	<p>energy for electricity consumption is spatially not advisable and the high baseload will make energy storage a very costly endeavour.</p> <ul style="list-style-type: none"> <li>- Incinerating dry waste may not be as feasible for a fuel source due to its variability in calorific value and carbon emissions.</li> <li>- Using geothermal energy as a heat sink has costly preliminary groundwork such as soil testing. It is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.</li> </ul>
Two	<p>1. Using the natural gas trigeneration plant or using the anaerobic digestion plant from phase one to supply the critical load of the airport and for additional electrical loads.</p> <p>2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption.</p> <p>3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply</p>	<p>1. Confirmation of availability of additional natural gas to supply the airport's critical electrical load, space constraints for plant operation, suitability to support airport critical electrical load, integration requirements, economic feasibility.</p> <p>2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure.</p> <p>3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation as well as load curtailment to ensure a feasible electrical integration and smart grid design.</p>	<ul style="list-style-type: none"> <li>- Adoption of other energy sources such as decentralised packaged waste to energy plants or rooftop solar PV plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.</li> </ul>
Three	<p>1. Fuel change from natural gas to a fuel with lower carbon footprint such as LPG or biogas.</p> <p>2. Process innovation to sequester carbon emissions.</p> <p>3. Technology change towards no carbon emissions.</p> <p>4. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.</p>	<p>1. Investigation into possible alternative fuels that are less carbon intense than natural gas and selecting the combustion engine technology that allows multiple fuel type intake is key for this to work cost effectively.</p> <p>2. Sequestering carbon will require in-depth environmental and financial investigation.</p> <p>3. Technology change will be dependent on the commercial market</p>	<ul style="list-style-type: none"> <li>- Technology change might not be possible if there are no technology improvements commercially available.</li> <li>- Carbon sequestration might rely on a range of factors, both environmental, site and business related.</li> <li>- The better choice to invest effort in investigation are dual fuel combustion engine and carbon offsetting plants on vacant land at regional airports as a commercial venture (independent power producer) or undertake a corporate social</li> </ul>

		<p>evolution, and this must be actively monitored.</p> <p>4. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.</p>	<p>investment project installing a solar PV or wind plant at a facility and claim the carbon credits.</p>
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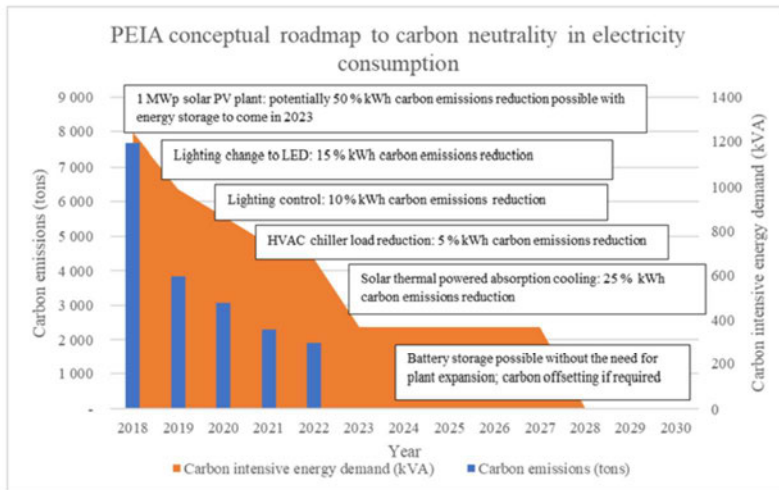


Figure 7: Port Elizabeth International Airport’s conceptual roadmap to carbon neutrality in electricity consumption

Table 8: Projects for PEIA’s energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	<ol style="list-style-type: none"> <li>Lighting change to LED.</li> <li>Lighting control: occupancy sensors, BMS (building management system) control, dimming functions.</li> <li>HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc.</li> <li>Geyser sleeve technology [Too small to count as a step change on graph].</li> </ol>	<p>Financial feasibility and technical assessment (technoeconomic studies).</p>	<p>Wind lobbies were not ideal for PEIA’s terminal building layout so this was not taken to the financial feasibility stage.</p>
One	<ol style="list-style-type: none"> <li>Solar PV plant for electricity generation.</li> <li>Solar thermal plant for powering absorption chillers to satisfy air conditioning requirements.</li> <li>Wind energy generating</li> </ol>	<ol style="list-style-type: none"> <li>1 MWp solar PV plant is being installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection.</li> <li>A financial viability study must be undertaken for a solar thermal</li> </ol>	<ul style="list-style-type: none"> <li>There are insufficient volumes of waste for energy generation.</li> <li>Using geothermal energy as a heat</li> </ul>

	electricity via vertical axis wind turbines.	3. Securing of a suitable installation site with the necessary approvals from Air Traffic Navigational Services (ATNS) and South African Civil Aviation Authority (SACAA), followed by a full technoeconomic assessment.	sink has costly preliminary groundwork such as soil testing. It is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.
Two	<ol style="list-style-type: none"> <li>1. Adequate battery storage for the airport's use after sunset.</li> <li>2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption.</li> <li>3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.</li> </ol>	<ol style="list-style-type: none"> <li>1. Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation.</li> <li>2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure.</li> <li>3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment, to ensure a feasible electrical integration and smart grid design.</li> </ol>	- Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.	1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.	- It could be best to increase capacity on existing solar PV or wind plants and sell excess kWhs produced.

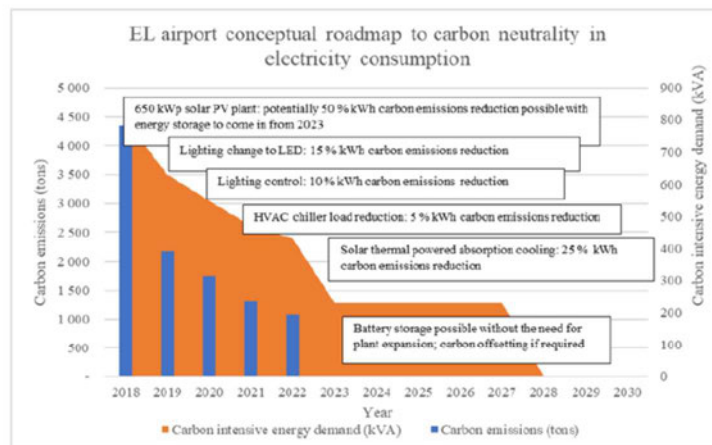


Figure 8: East London Airport's conceptual roadmap to carbon neutrality in electricity consumption

**Table 9: Projects for EL airport's energy mix conceptual roadmap towards carbon neutrality in electricity consumption**

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	<ol style="list-style-type: none"> <li>1. Lighting change to LED.</li> <li>2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions.</li> <li>3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc.</li> <li>4. Geyser sleeve technology [Too small to count as a step change on graph].</li> </ol>	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for EL airport's terminal building layout, so this was not taken to the financial feasibility stage.
One	<ol style="list-style-type: none"> <li>1. Solar PV plant for electricity generation.</li> <li>2. Solar thermal plant for powering absorption chillers to satisfy air conditioning requirements.</li> <li>3. Wind energy generating electricity via vertical axis wind turbines.</li> </ol>	<ol style="list-style-type: none"> <li>1. 650 kWp solar PV plant is being installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection.</li> <li>2. A financial viability study must be undertaken for a solar thermal powered absorption chilling plant.</li> <li>3. Securing of a suitable installation site with the necessary approvals from Air Traffic Navigational Services (ATNS) and South African Civil Aviation Authority (SACAA), followed by a full technoeconomic assessment.</li> </ol>	<ul style="list-style-type: none"> <li>- There are insufficient volumes of waste for energy generation.</li> <li>- Using geothermal energy as a heat sink has costly preliminary groundwork such as soil testing must be undertaken, it is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.</li> </ul>
Two	<ol style="list-style-type: none"> <li>1. Adequate battery storage for the airport's use after sunset.</li> <li>2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption.</li> <li>3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.</li> </ol>	<ol style="list-style-type: none"> <li>1. Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation.</li> <li>2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure.</li> <li>3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation as well as load curtailment to ensure a feasible electrical integration and smart grid design.</li> </ol>	<ul style="list-style-type: none"> <li>- Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.</li> </ul>
Three	<ol style="list-style-type: none"> <li>1. Carbon offsetting plants or purchasing of carbon credits to</li> </ol>	<ol style="list-style-type: none"> <li>1. A feasibility study must be conducted on carbon offsetting</li> </ol>	<ul style="list-style-type: none"> <li>- It could be best to increase capacity on</li> </ul>

	reach carbon neutrality in electricity consumption.	plants versus purchasing carbon credits. An integrated view must be considered.	existing solar PV or wind plants and sell excess kWhs produced.
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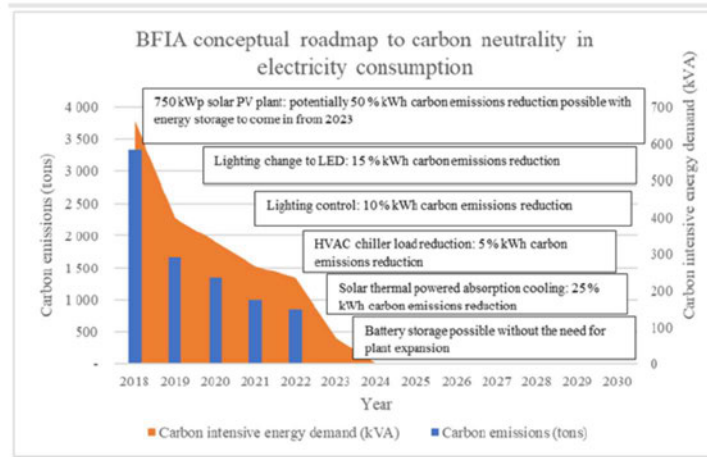


Figure 9: Bram Fischer International Airport’s Conceptual roadmap to carbon neutrality in electricity consumption

Table 10: Projects for BFIA’s energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	<ol style="list-style-type: none"> <li>Lighting change to LED.</li> <li>Lighting control: occupancy sensors, BMS (building management system) control, dimming functions</li> <li>HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc.</li> <li>Geyser sleeve technology [Too small to count as a step change on the graph].</li> </ol>	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for BFIA’s terminal building layout, so this was not taken to the financial feasibility stage.
One	<ol style="list-style-type: none"> <li>Solar PV plant for electricity generation.</li> <li>Solar thermal plant for powering absorption chillers to satisfy air conditioning requirements.</li> </ol>	<ol style="list-style-type: none"> <li>750 kWp solar PV plant is being installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection.</li> <li>A financial viability study must be undertaken for a solar thermal powered absorption chilling plant.</li> </ol>	<ul style="list-style-type: none"> <li>There are insufficient volumes of waste for energy generation.</li> <li>Using geothermal energy as a heat sink has costly preliminary groundwork such as soil testing. It is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.</li> </ul>

Two	<ol style="list-style-type: none"> <li>1. Adequate battery storage for the airport’s use after sunset.</li> <li>2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption.</li> <li>3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.</li> </ol>	<ol style="list-style-type: none"> <li>1. Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation.</li> <li>2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure.</li> <li>3. In-depth investigation into the airport’s real time energy consumption to determine energy storage requirements, load-leveling and load shifting techniques for implementation as well as load curtailment to ensure a feasible electrical integration and smart grid design.</li> </ol>	<ul style="list-style-type: none"> <li>- Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.</li> </ul>
Three	<ol style="list-style-type: none"> <li>1. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.</li> </ol>	<ol style="list-style-type: none"> <li>1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.</li> </ol>	<ul style="list-style-type: none"> <li>- It could be best to increase capacity on existing solar PV or wind plants and sell excess kWhs produced.</li> </ul>

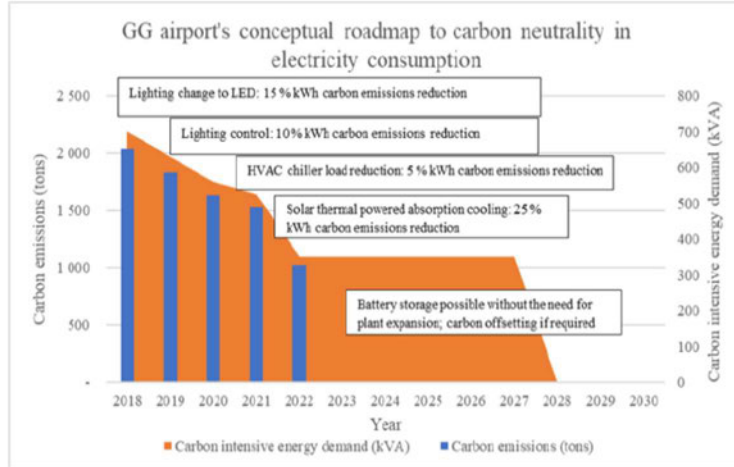


Figure 10: George Airport’s conceptual roadmap to carbon neutrality in electricity consumption

neutrality in electricity consumption.	integrated view must be considered.	PV or wind plants and sell excess kWhs produced.
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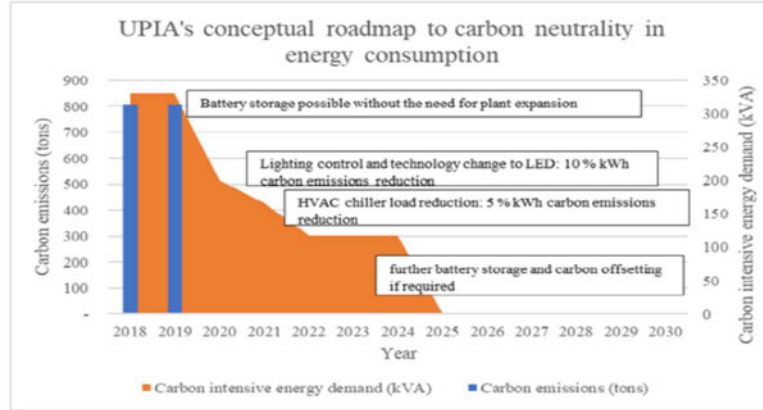


Figure 11: Uppington Airport’s conceptual roadmap to carbon neutrality in electricity consumption

Table 12: Projects for UPIA’s energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	<ol style="list-style-type: none"> <li>Lighting change to LED.</li> <li>Lighting control: occupancy sensors, BMS (building management system) control, dimming functions.</li> <li>HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc.</li> <li>Geyser sleeve technology [Too small to count as a step change on graph].</li> </ol>	Financial feasibility and technical assessment (technoeconomic studies)	Wind lobbies were not ideal for UPIA’s terminal building layout, so this was not taken to the financial feasibility stage.
One	<ol style="list-style-type: none"> <li>Solar PV plant for electricity generation.</li> </ol>	<ol style="list-style-type: none"> <li>500 kWp solar PV plant has been installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection.</li> </ol>	<ul style="list-style-type: none"> <li>It is possible that the solar PV plant installed can provide for the airport’s full energy requirements.</li> </ul>
Two	<ol style="list-style-type: none"> <li>Adequate battery storage for the airport’s use after sunset.</li> <li>New infrastructure to adopt a green star rating targeting carbon neutrality in electricity</li> </ol>	<ol style="list-style-type: none"> <li>Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation.</li> <li>Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new</li> </ol>	<ul style="list-style-type: none"> <li>Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure</li> </ul>

	<p>consumption.</p> <p>3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.</p>	<p>infrastructure.</p> <p>3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment, to ensure a feasible electrical integration and smart grid design.</p>	<p>must take into account the operational and maintenance cost of these plants including the environmental impact.</p>
Three	<p>1. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.</p>	<p>1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.</p>	<p>- It could be best to increase capacity on existing solar PV plant and sell excess kWhs produced.</p>

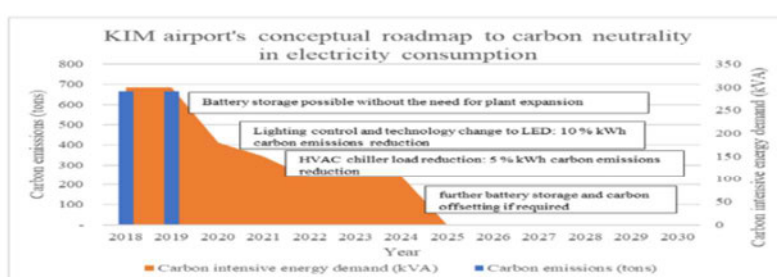


Figure 12: Kimberley Airport's conceptual roadmap to carbon neutrality in electricity consumption

Table 13: Projects for UPIA's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	<p>1. Lighting change to LED.</p> <p>2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions.</p> <p>3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc.</p> <p>4. Geyser sleeve technology [Too small to count as a step change on the graph].</p>	<p>Financial feasibility and technical assessment (technoeconomic studies).</p>	<p>Wind lobbies were not ideal for UPIA's terminal building layout; hence it was not taken to the financial feasibility stage.</p>
One	<p>1. Solar PV plant for electricity generation.</p>	<p>1. 500 kWp solar PV plant has been installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection.</p>	<p>- It is possible that the solar PV plant installed can provide for the airport's full energy requirements.</p>
Two	<p>1. Adequate battery storage for the airport's use after</p>	<p>1. Battery storage must be investigated and a technoeconomic assessment</p>	<p>- Adoption of other energy sources</p>

	<p>sunset.</p> <ol style="list-style-type: none"> <li>2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption.</li> <li>3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.</li> </ol>	<p>undertaken to select the best technology suited for the installation.</p> <ol style="list-style-type: none"> <li>2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure.</li> <li>3. In-depth investigation into the airport’s real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment, to ensure a feasible electrical integration and smart grid design</li> </ol>	<p>such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.</p>
Three	<ol style="list-style-type: none"> <li>1. Carbon offsetting plants or purchasing of carbon credits to reach to carbon neutrality in electricity consumption</li> </ol>	<ol style="list-style-type: none"> <li>1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.</li> </ol>	<p>- It could be best to increase capacity on existing solar PV plant and sell excess kWhs produced.</p>

The conceptual roadmaps to carbon neutrality are the fulfilment of the FEL 1 or front end loading Stage 1 that follows an approved strategy. It can be seen that the conceptual plans to carbon neutrality by 2030 give approximations of carbon emissions reduction for each intervention, however, this has to be confirmed through further investigation. Where the specific intervention does not apply at an airport, or is not technically suitable upon initial enquiry, it will not follow into the technoeconomic assessment route. Some technologies such as LED lighting and lighting control do not need a full technical assessment as they are widely used and familiar technologies. However, where a certain technology is not very well known or proven in South Africa, a full technoeconomic assessment must follow and, in some cases, a preliminary design is required especially where there is high risk and high investment.

The following technologies will be investigated at FEL 2 level which is pre-feasibility for the confirmation of the roadmaps to carbon neutrality:

- LED lighting
- Lighting control
- HVAC energy reduction techniques
- Geysers sleeve technology
- Solar thermal deflection innovation (or heat deflective coating)
- Convective boundaries (double glazing or low emissivity glass)
- Green buildings for new and existing infrastructure
- Solar PV plants
- Solar thermal absorption cooling
- Geothermal heat sinks

- Wind energy with vertical axis wind turbines
- Natural gas trigeneration plants
- Anaerobic digestion

Their applicability to the airports has been highlighted to satisfy the energy demand of the airports. The next step will be to perform the technical and economic assessments. Feasible projects will be used in the confirmed roadmap to carbon neutrality; however, the airports have a business prerogative to certify existing terminal buildings with a 4-, 5- or 6-star green rating, regardless of feasibility as the related operational and public relations benefits far outweigh the capital outlay.

## CONCLUSIONS

This paper presented the conceptual roadmaps to carbon neutrality in electricity consumption for all nine airports in South Africa according to the strategic environmental objective of the organisation to reduce its carbon footprint. It also followed the principles of energy security while on the journey to conceptualisation of the roadmaps to carbon neutrality by 2030. The work that follows to confirm these roadmaps to carbon neutrality by 2030 will be technical and economic assessments with confirmed carbon footprint reduction impact for each of the identified technologies, namely LED lighting, LED lighting control, HVAC energy reduction techniques, geyser sleeve technology, solar thermal deflection innovation (or heat deflective coating), convective boundaries (or double glazing/low emissivity glass), green buildings, solar PV plants, solar thermal absorption cooling, geothermal heat sinks, wind energy with vertical axis wind turbines, natural gas trigeneration plants and anaerobic digestion.

## REFERENCES

1. Joseph, J., Inambao, F.L., "Principles for achieving energy security in developing countries", to be published, 2021.
2. [http://www.crses.sun.ac.za/files/research/publications/SolarGIS\\_GHI\\_South\\_Africa\\_width15cm\\_300dpi.png](http://www.crses.sun.ac.za/files/research/publications/SolarGIS_GHI_South_Africa_width15cm_300dpi.png), accessed 25/03/2021.
3. [http://www.crses.sun.ac.za/files/research/publications/SolarGIS\\_DNI\\_South\\_Africa\\_width15cm\\_300dpi.png](http://www.crses.sun.ac.za/files/research/publications/SolarGIS_DNI_South_Africa_width15cm_300dpi.png), accessed 25/03/2021.
4. Joseph, J., Inambao, F.L., "Energy consumption and energy efficiency of airports: A case study of airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, vol. 11, no. 2, 2021, 205-228.
5. Surekha, B., M. N. Hegde, and K. S. Jagadish. "Energy and building materials." *International Journal of Civil Engineering* 5 (2016): 13-24.
6. Bakhom, E. S., G. L. Garas, and M. E. Allam. "Sustainability Perspective of Saw-Gang Granite Waste in Concrete Mixes." *International Journal of Civil Engineering (IJCE)* 4.5: 1-10.
7. Ilamparithi, A., S. Ponnusamy, and A. Selvaraj. "Investigation on N-Formyl Piperidin-4-Ones as Corrosion Inhibitors for Carbon Steel in Acid Medium." *Int. J. Appl. Nat. Sci.*, 3 (2), 63-80 (2014).
8. Kandavel, T. K., K. Palaksha Reddy, and P. Karthikeyan. "Experimental Investigation on Corrosion Behaviour of Hot Upset P/M Plain Carbon Steel." *International Journal of Mechanical and Production Engineering Research and Development* 8: 207-212.

9. Dinesh, S., et al. "Comprehensive analysis of wire electric discharge machining process in machining high chromium high carbon steel." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 8.1 (2018): 65-74.
10. Xu, C. H. A. N. G. C. H. U. N., H. A. E. N. G. M. U. K. Cho, and D. H. Park. "Effect of different fuels on combustion and emission components of ci engines." *International Journal of Mechanical and Production Engineering Research and Development* 9.6 (2019): 821-34.

## **CHAPTER 13. ENERGY SECURITY: INVESTIGATING WIND ENERGY FOR AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT**

This chapter presents the investigation of establishing a suitable wind energy technology including its technical and economic assessment (technoeconomic assessment) to ensure a reliable and feasible transition for nine ACSA airports.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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**Link:** <http://www.tjprc.org/publishpapers/2-67-1625050719-IJMPERDAUG202117.pdf>  
<http://www.tjprc.org/view-archives.php>

## ENERGY SECURITY: INVESTIGATING WIND ENERGY FOR AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT

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### ABSTRACT

*Establishing a low carbon energy mix to reduce the acceleration of climate change is key for countries, organizations and industries providing services and producing goods for public consumption. Establishing a new energy source for the purposes of satisfying energy needs is a challenge that has many dimensions. Most endeavours to establish alternative energy sources in developing countries face unique challenges that may render their establishment as a reliable energy source unsuccessful. Wind energy is particularly difficult to harness for airports due to wind turbine technology operations being incompatible with the radar operations of airports. This paper presents the investigation of establishing a suitable wind energy technology including its technical and economic assessment (technoeconomic assessment) to ensure a reliable and feasible transition for airports in South Africa.*

**KEYWORDS:** *Technoeconomic assessments, renewable energy, alternative energy, feasibility of renewable energy, wind energy, airports and wind turbines, vertical axis wind turbines*

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### INTRODUCTION

Wind energy is a very old form of harvesting energy and has been around for centuries in the form of windmills. The progress of science and engineering has led to more efficient, durable and reliable designs for various wind speeds. Due to airport operations relying heavily on radar communications for the successful landing and take-off of aircraft, it is not suitable to have horizontal axis wind turbines made of metal, generating energy through spinning of their turbine blades, because this will deflect and corrupt radar communicate signals. It is for this reason that the selection of the type of wind turbine, design, height, maximum speed and positioning at an airport is critical. Wind technologies allow for output to be scalable at the design stage, however, its output varies throughout the day because wind is variable, and this requires the integration of its output to be carefully designed and intermittencies catered for to ensure that there is continuous energy supply for airport operations as intended. Although wind energy is a renewable resource, the wind speeds vary across the planet, making some areas more eligible than others to install wind turbines for wind energy harvesting. To maximise investment, it is logical to construct wind farms where wind speeds are favourable.

Airports Company South Africa is committed to significantly reduce its carbon emissions in the next 10 to 15 years across the nine airports it owns and operates in South Africa so has embarked on investigating alternative energy sources. Wind power is one of the energy sources being investigated to serve their airports' varying energy load, as an accompaniment to the airports' main energy sources and as a carbon offsetting plant. This pre-feasibility and technology assessment study, which is in second stage of the Front-End Loading or FEL 2 Technoeconomic assessment, is typically done after a strategy is complete and a conceptual study (FEL 1) has been conducted to

identify the technologies that will realize the strategy.

This study covers the technology description, identification of the technology type, typical components constituting the technology, the dynamics around their co-existence with the airport environment, the assessment of technology maturity, the cost-benefit analysis that looks at the investment required, the energy derived and the feasibility indicators of the investment, together with a sensitivity analysis. The technoeconomic study also investigates the technology risk assessment and presents design mitigations. The airport integration strategy is presented as well as the proposed operational philosophy.

Airports Company South Africa is South Africa's airport authority, owning and operating nine airports in South Africa, namely, O R Tambo International Airport (Kempton Park, Gauteng), Cape Town International Airport (Western Cape), King Shaka International Airport (Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape).

The key parameters for vertical axis wind turbines (VAWT) to produce electricity at an airport for airports owned and operated by Airports Company South Africa are as follows [1]:

- A minimum operational speed of about 2 m/s (cut-in speed) most of the year (80 % of the hours in a year).
- A wind speed of 45 m/s for at least 30 % of the year for wind turbines to reach their maximum rated capacity, however, wind speeds should not exceed 50 m/s for more than 50 % of the year.
- Available space for a wind turbine installation that experiences the wind speeds described above unhindered by structures, yet not in the flight path and preferably not within 500 metres of buildings or structures that have a daily foot count of people or communications equipment.

The key parameters for the VAWT Technology to be adopted at airports owned and operated by Airports Company South Africa are:

- Must have the potential to reduce the airport's carbon footprint.
- Must make financial sense to the business.
- Must meet all South African Civil Aviation requirements.
- Operational and Technical risks should be acceptable.

#### 1. Description of the Technology

Wind is created from the difference in temperatures of atmospheric air caused by uneven heating of the earth's atmosphere and surface. This imbalance of warm and cool air creates wind (Figure 1).

Harnessing wind energy is through the conversion of the force of moving air molecules against, for example, an object that can rotate (kinetic energy) which is typically then converted to shaft speed within an electrical generator via a gearbox and this creates electricity for use on site.

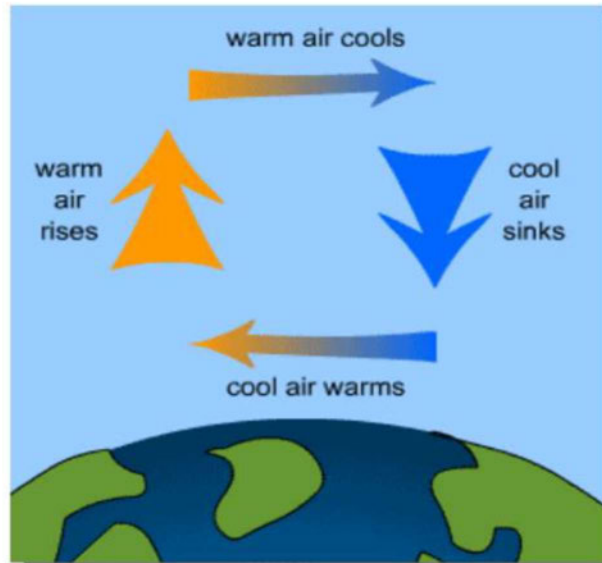


Figure 1: How Global Winds are formed [2]

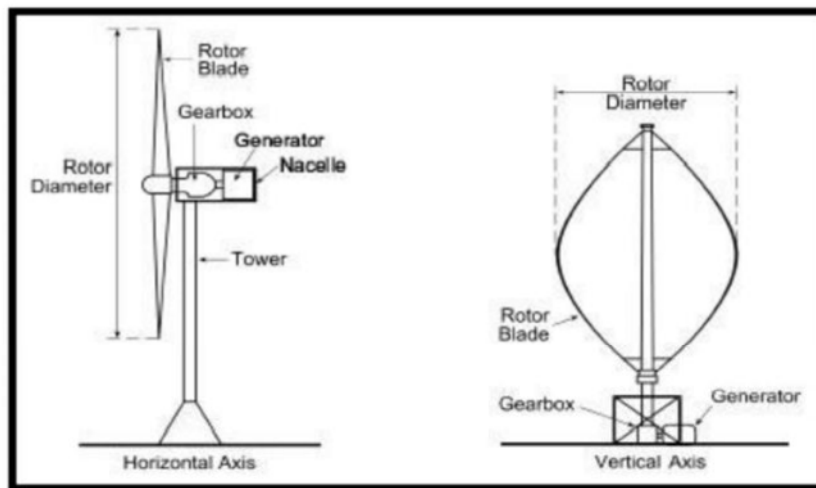


Figure 2: Horizontal and Vertical Axis Wind Turbines Configuration [3]

The preferred technology for harnessing wind energy at airports is VAWT due to their rotational axis not being on the same plane as the aircraft propeller or jet engine turbines and therefore interruptions and confused radar signals are minimized and can be mitigated. Figure 2 shows the differences in configuration of vertical axis and horizontal axis wind turbines (HAWT). This configuration is also preferable for safety reasons. When the generator of wind turbines catch fire, due to the accessibility, it is quite difficult to address. The VAWT has its generator at the base of the wind turbine, located on the ground.

Wind Turbines will typically be connected in series and their direct current (DC) output will be converted using an inverter and this will be sent to a point of connection point where, depending on the design, the grid integration requirements such as voltage step up may be achieved prior to connection to the grid (for grid-tied) systems. Where a site

has multiple systems, the current may feed into a point of common coupling for take-off to multiple users. Figure 3 shows a typical connection.

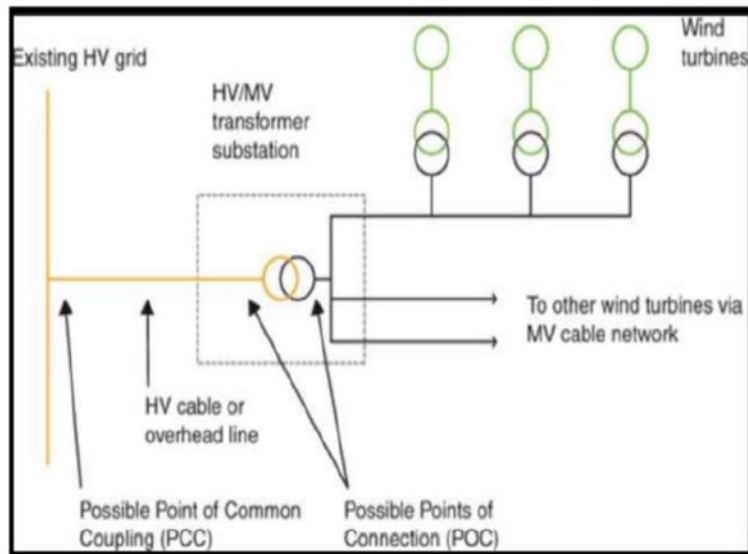


Figure 3: Wind Energy typical Single Line Diagram[4]

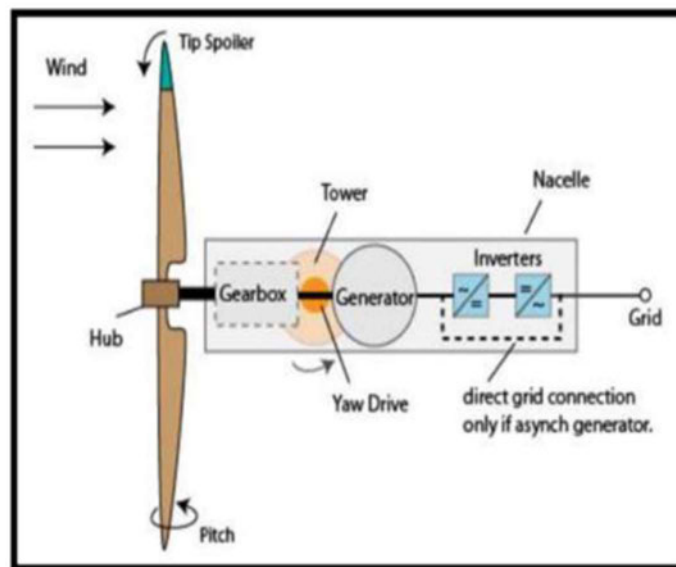


Figure 4: Typical components of a Wind Turbine [5]

The components of a typical wind turbine are seen in Fig 4. In principle, the turbine blades turn the shaft that it is mounted on and this shaft rotation is gear ratioed in the gearbox to deliver a consistent shaft rotation in a generator. The generator output is in direct current (DC) and then needs to be converted using inverters to alternating current (AC).

Typically, in a wind farm arrangement, many wind turbine generators are connected in strings (series or parallel

depending on the electrical design of the voltages and currents). The output of each string will then be connected to a point of connection (POC) where, typically, voltage will be stepped up to match that of the grid in a grid-tied connection. This will then be joined to a point of common coupling (PCC). The gearbox is the maintenance intensive part of this set up and thus an alternative which is less maintenance intensive, with fewer moving parts should be considered to lower operational costs. Flywheel storage together with power electronics is ideal for “ironing out” shaft rotation intermittencies.

The use of an induction motor should be considered; this system should work like an electric car in regenerative braking mode. This arrangement uses kinetic energy to drive the stator of the induction motor which in turn induces a current on a rotor which uses power electronics to control the rotor and RMF (rotating magnetic field) speed such that the rotor speed is greater than the RMF speed, making the induction motor a generator.

The proposed set up is depicted in Figure 5. The fly wheel storage irons out intermittencies in the kinetic energy of the wind turbine and sends the rotation to the stator of an induction motor, inducing a current in the rotor with the power electronics ensuring the rotor speed is greater than the RMF speed. The current produced is DC, which can be converted to AC using an inverter for use by the facility.

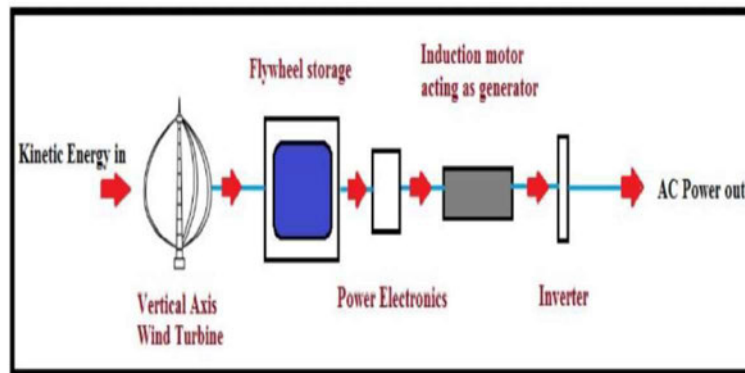


Figure 5: Proposed Electricity Generation by Harnessing Wind Energy

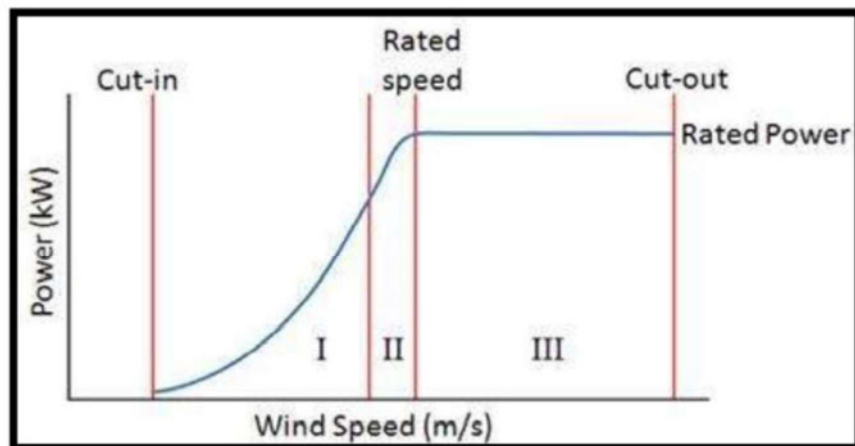


Figure 6: Ideal Wind Turbine Power Curve [6]

Wind speed varies throughout the day based on the fluctuations experienced as depicted in Figure 1. The output power of the wind turbine is limited to the motor capacity as per the rated power of the generator. The minimum wind speed required to overcome friction and turn the turbine blades and generate power is the “cut-in speed”, and the “cut out speed” is the speed at which the turbine blades are brought to rest to avoid damage from high winds. The rated speed is the wind speed at which the turbine can generate electricity at its maximum, or rated capacity. These various parameters are depicted in Figure 6.

The equation governing the power harnessed from wind energy using wind turbines can be seen in Equation 1.

$$\text{Maximum Wind Power} = \frac{1}{2} C_p \rho A V^3 \dots \dots \dots \text{Equation 1}$$

Where:

$C_p$  is the coefficient of performance and is governed by the Betz limit which is 0,59

$\rho$  is the density of the air

$A$  is the swept area

$V$  is the wind velocity

Factors such as the generator efficiency and the efficiency of the power converter and other devices (flywheel or gearbox) depending on the configuration need to be taken into consideration when looking for the actual power production.

Wind turbines can be designed to use aeronautical lift or drag. The key differences can be seen in Figure 7.

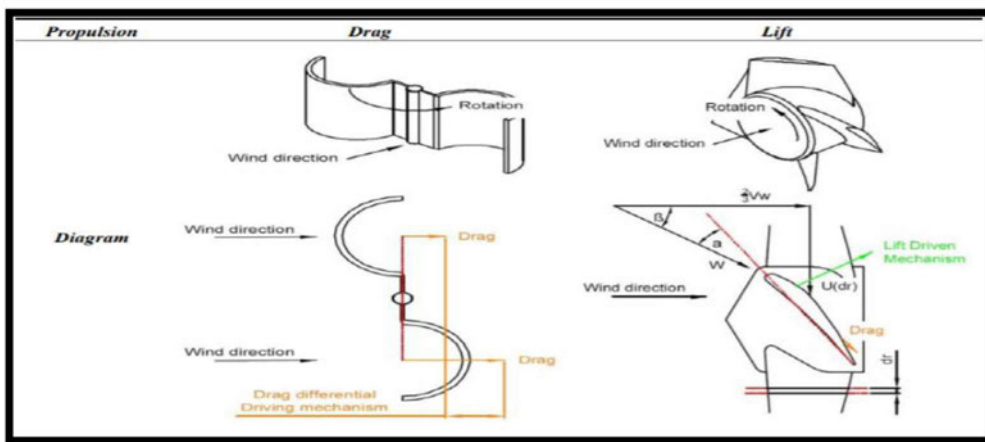


Figure 7: Two Mechanisms of Propulsion Compared [7]

The various efficiencies of the drag and lift designs can be seen in Fig 8. The reason for the choice of VAWT over the HAWT in an airport environment is due to the design of the VAWT being less intrusive on the communication (radar) signals. Moving metal can distort radar signals, thus moving turbine blades are not ideal in an airport environment. Radar may misinterpret signals due to the possible confusion of the moving clutter caused by turbine blades which they are unable to filter out (Figure 9). The signals from fixed clutter (“noise”) can be filtered out to detect the position of an aircraft (which is in motion and is the purpose of radar at an airport); however, when the radar signals deflected off turbine







blades are received, they can be seen as and mistaken for “moving aircraft” causing “noise”. The “noise” generated by the wind turbine blades also have the capacity to impede the “listening ability” of radar receiving stations for approaching aircraft. This is also true for the audible noise generated by the wind turbines turning that is disruptive to human biological systems. It is therefore recommended that these installations are at least 300metres away from human settlements (Figure 10).

Choosing VAWT over HAWT wind turbines for an airport environment does not necessarily eliminate this risk of signal distortion but plays a role in reducing the significance and even the possibility of this happening depending on the material choice for the turbine blades.

The design considered for implementation at airports can be seen in number 6 on Figure 8. The Darrieus Rotor with a 40% efficiency, which when compared to the traditional efficient three blade HAWT in number 7, is 10% less efficient.

There is a four-storey high (about 8m height) installation of three VAWT of the Darrieus type installed at Hotel Verde within a kilometre radius from the Cape Town International Airport central terminal building. The installation is owned and operated by the hotel. Taking learnings from that installation, the installation of the turbines should preferably not be within the communications path of aircraft movements, landings or take-offs and the control tower or their communications systems.

The height of the VAWT is usually based on the desired wind speed most of the time, however, for airport installations there is an added restraint of the “obstacle avoidance” requirement within the aerodrome from the International Civil Aviation Authority (ICAO) which limits the height of any structure. In the case that the VAWT is outside of the aerodrome, the height regulations will be governed by CAA (Civil Aviation Authority) requirements.

Ref No.	Design	Orientation	Use	Propulsion	* Peak Efficiency	Diagram								
1	Savonius rotor	VAWT	Historic Persian windmill to modern day ventilation	Drag	16%									
2	Cup	VAWT	Modern day cup anemometer	Drag	8%									
3	American farm windmill	HAWT	18th century to present day, farm use for Pumping water, grinding wheat, generating electricity	Lift	31%									
4	Dutch Windmill	HAWT	16th Century, used for grinding wheat.	Lift	27%									
5	Darrieus Rotor (egg beater)	VAWT	20th century, electricity generation	Lift	40%									
6	Modern Wind Turbine	HAWT	20th century, electricity generation	Lift	<table border="1"> <thead> <tr> <th>Blade Qty</th> <th>efficiency</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>43%</td> </tr> <tr> <td>2</td> <td>47%</td> </tr> <tr> <td>3</td> <td>50%</td> </tr> </tbody> </table>	Blade Qty	efficiency	1	43%	2	47%	3	50%	
Blade Qty	efficiency													
1	43%													
2	47%													
3	50%													

\* Peak efficiency is dependent upon design, values quoted are maximum efficiencies of designs in operation to date [1].

Figure 8: Modern and historical rotor designs [7]

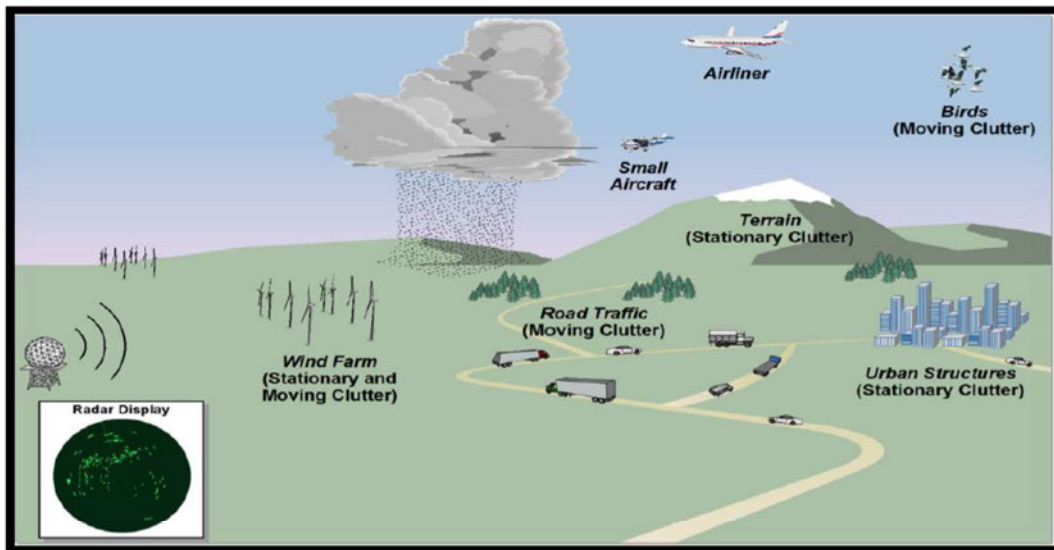


Figure 9: Radar and Wind Turbines [8]

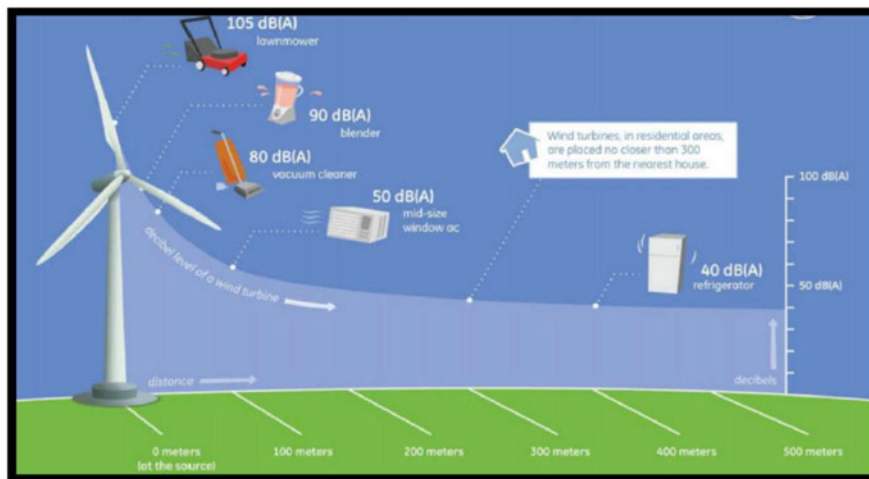


Figure 10: Audible Noise and Human Settlements [9]

## 2. Assessment of Technology Maturity

Wind turbines have been in existence since the first century AD, with their evolution captured in Figure 11. The installed capacities of wind farms around the world by country can be seen in Figure 12. The USA and Germany are leading in the capacity of wind power generation installations with installed capacities increasing by 5 times over the last two decades. Figure 13 shows that harnessing wind energy is among the second most popular choices when it comes to the uptake of renewable energy globally, even more popular than solar energy installations.

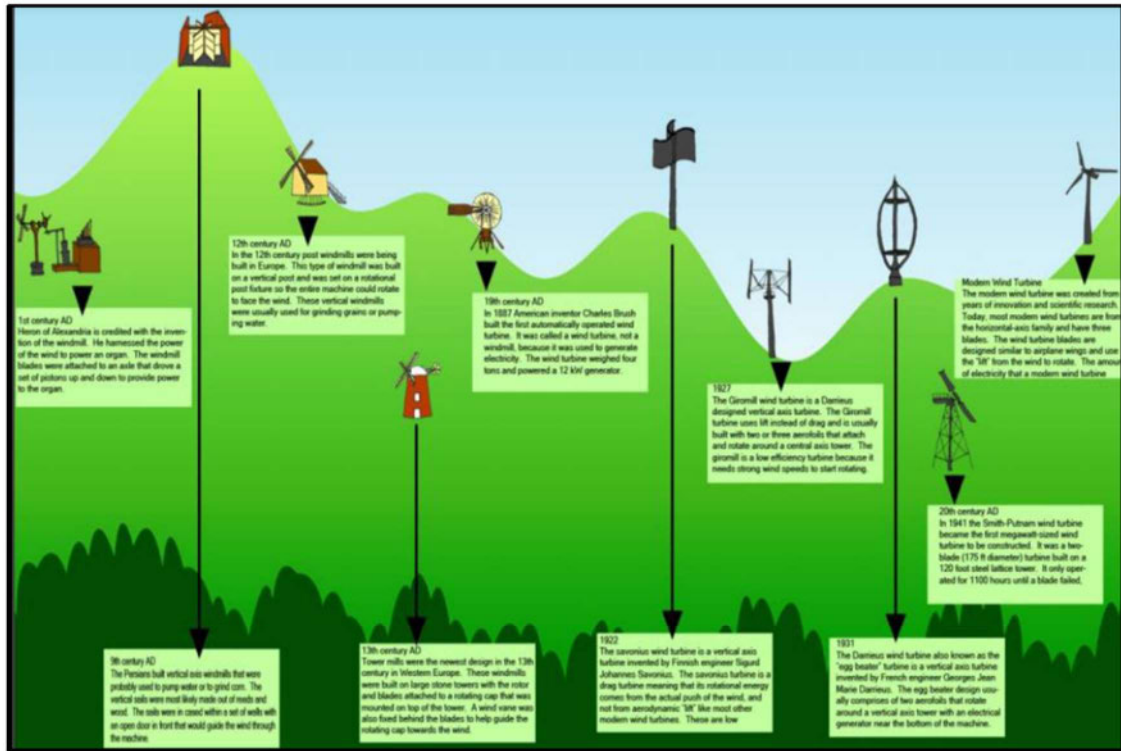


Figure 11: Evolution of Wind Turbines [2]

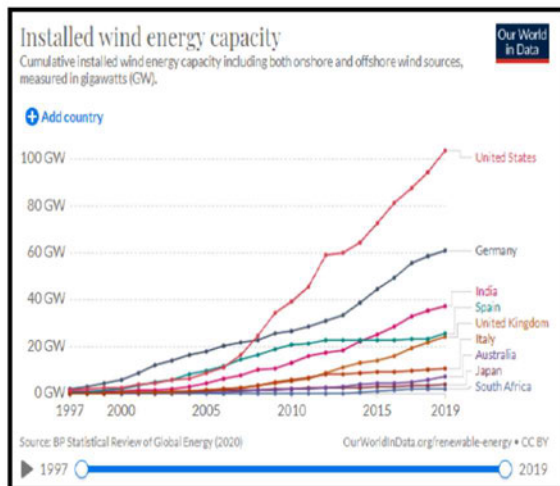


Figure 12: Installed Wind Energy Capacities around the world [10]

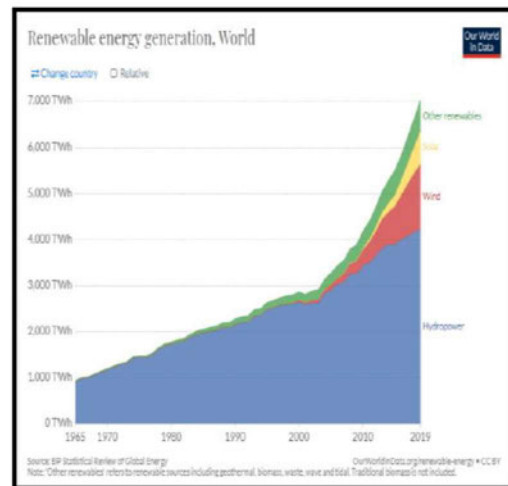


Figure 13: Wind Energy use in relation to other renewables in the energy space [11]

“The origins and use of flywheel technology for mechanical energy storage began several 100 years ago and was developed throughout the Industrial Revolution. One of the first ‘modern’ dissertations on the theoretical stress limitations of rotational disks (isotropic only) is the seminal work by Dr. A. Stodola whose first translation to English was made in 1917. The next big milestones were during the 1960s and 1970s when NASA sponsored programs proposed energy storage

flywheels as possible primary sources for space missions. However, it was not until the 1980s when microelectronics, magnetic bearing systems and high-power density motor-generators became enabling technologies. The next decade proved that a mechanical battery could surpass chemical batteries for many applications.” [12]

South Africa has several wind farm installations. From Figure 12 it can be seen that the installations began showing increase in capacity from 2015. A wind farm using the Darrieus turbine in South Africa is located at Hotel Verde on Cape Town International Airport’s site (Figure 14 and Figure 15).

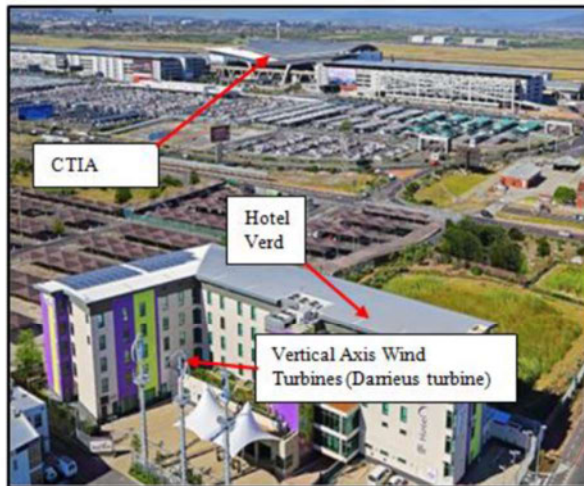


Figure 14: Darrieus VAWT installed at Hotel Verde, 1 km away from CTIA in South Africa [13]



Figure 15: Hotel Verde Vertical Axis Wind Turbines [14]

Harvesting wind energy using wind turbines is not a new concept, and neither is the technology, but the suggested configuration (VAWT) presented in Figure 5 is novel. The probability that the configuration will work is highly likely from a technology perspective as the technology works well independently and is available on the commercial market. It is recommended that this configuration be trialled in relation to airport integration.

### 3. Cost-benefit analysis

Due to this techno economic assessment being a desktop exercise meant to provide an indication of the economics and suitability of wind energy for airports at pre-feasibility (FEL2 or Front-End Loading Stage 2); the airports targeted for harvesting wind energy have been determined from the trend of wind farms installed by other organizations and government driven projects in South Africa. From Figure 16 it is evident that there is a clustering of wind farm installations located on South Africa’s west and south coasts. The establishment of wind farms in these areas prove that the technology will harvest wind energy in these regions.

#### (a) Feasibility Study

The targeted airports for implementation are based on where wind farm installations are currently located in South Africa. The installations of wind power are concentrated in the Eastern Cape and Western Cape of South Africa, which makes four of ACSA’s airports eligible for successfully harnessing of wind power, namely East London, George, Port Elizabeth and Cape Town airports.

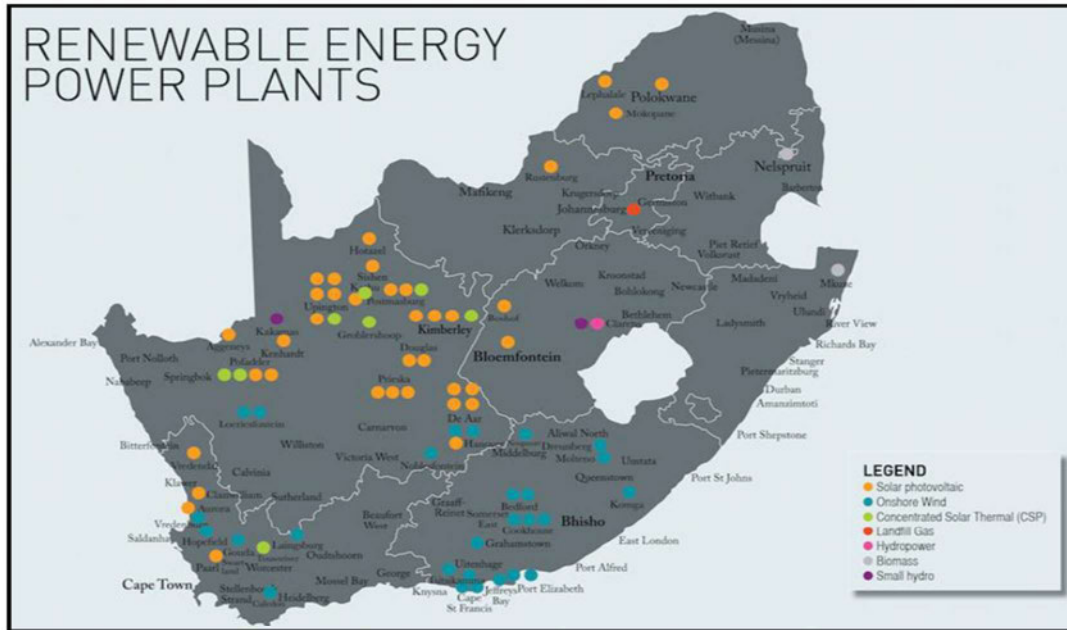


Figure 16: Renewable Energy Power Plants in South Africa showing concentration of Wind Power Plant Installations [15]

Due to wind turbine technology being generally unsuitable for an airport environment, it was decided that large wind power farm installations would not be the intention for airports, whether to serve as an electrical base load or to serve the varying electrical load requirements as performed in the energy mix exercise completed for Airports Company South Africa.

Wind farms could, however, be adopted in small numbers as a supplement to the airport's low carbon energy mix to make up for the shortfall in carbon footprint offset required towards carbon neutrality for the airport site. Land availability co-incidentally is an issue with airports in that open land areas are usually reserved for future airport development. The scale of the wind power plants in each of the four regions were based on the available land area that met the following criteria:

- Outside of a 1km radius from radar and communications
- Outside the aerodrome
- Not reserved for commercial or future airport development
- Outside of the flight path of landing and taking off aircraft and their communications with radar stations

The areas identified at each of the four airports were as follows:

- Cape Town International Airport (CTIA) – 20 000 m<sup>2</sup>
- Port Elizabeth International Airport (PEIA) – 22 000 m<sup>2</sup>
- East London Airport (EL) – 10 000 m<sup>2</sup>

- George Airport (GG) – 94 681 m<sup>2</sup>

Due to George Airport having a solar photovoltaic farm that generates electricity onsite for use at the airport, the full wind power generation capacity of the 94 681 m<sup>2</sup> of land will not be required, with only 30% required to make the shortfall of electricity requirements not met by the existing solar photovoltaic farm.

In order to proceed with the pre-feasibility calculations to get an indication of a business case, it was necessary to choose a suitable commercially available VAWT to get pricing data for the economic models. Table 1 shows the specifications of the VAWT that was chosen. The costing data and economic model presented here was performed in 2018 and the report was submitted in March 2019.

Ft-Q4 VAWT [1] is designed with maglev and Darrieus technology. It is made of lightweight aluminium alloy. Owing to the advanced maglev technology and the power of super magnets, VAWT starts with low wind speed and works stably. It is not affected by the direction of the wind, which is useful in areas where the wind changes direction frequently and quickly. VAWT out performs HAWT in areas where a tall tower is not feasible, like in airport installations where the height is restricted by ICAO regulations. The recommended spacing for wind farms and that which is used in this business case is 4 rotor diameters, rotor diameter taken to be 2.5m as per the specifications in Table 1. The height of the VAWT is taken to be restricted at 10 m which is the height of a typical street light pole.

The cost of the VAWT is US\$1300 each, using a conversion factor of US\$1 is ZAR14.33 (2018), the capital required per VAWT of 1kW rated capacity was estimated using two components, i.e.:

- Cost of VAWT: US\$ 1300 x ZAR 14.33 = ZAR 18 629
- Cost of installation: 0.2 x cost of VAWT = ZAR 3 725.8
- Cost per kW = ZAR22 355

The cost of annual maintenance is assumed to be 5% of the total capital expenditure required for the installation. Table 2 shows the cost and installation capacities of the wind power generation, based on the above costs.

**Table 1: Specifications of VAWT used in the Economic calculations[16]**

Rated Power	1kW
Max Power	1.2kW
Start Wind Speed	2m/s
Rated Wind speed	13m/s
Working Wind Speed	3 m/s to 45m/s
Safety Wind speed	50m/s
Blades Length	2.3m
Blades Rotor Diameter	2.5m
Blades Material	Casting aluminium alloy
Turbine Weight	180kg
Generator Type	maglev
Rated speed	300rpm
Option Voltage	24V/48V/96V
Protection Method	Electromagnetic
Protection Grade	IP54
Working Temperature	From -40°C to 80°C
Lifetime	20 years

**Table 2: Summary of Wind Power Generation Capacities and costs for the Selected Airports**

	land available (m <sup>2</sup> )	wind turbines installation (1kW turbines)	power generated (kWhs)
<b>CTIA</b>	20000	255	781 146
<b>CAPEX</b>		ZAR 5 700 474	
<b>Annual maintenance cost</b>		ZAR 285 024	
	land available (m <sup>2</sup> )	wind turbines installation (1kW turbines)	power generated (kWhs)
<b>PELA</b>	22000	280	858 480
<b>CAPEX</b>		ZAR 6 265 039,49	
<b>Annual maintenance cost</b>		ZAR 313 251,97	
	land available (m <sup>2</sup> )	wind turbines installation (1kW turbines)	power generated (kWhs)
<b>EL</b>	10000	127	390 573
<b>CAPEX</b>		ZAR 2 847 745,22	
<b>Annual maintenance cost</b>		ZAR 142 387,26	
	land available (m <sup>2</sup> )	wind turbines installation (1kW turbines)	power generated (kWhs)
<b>GG</b>	94681	362	1 109 396
<b>CAPEX</b>		ZAR 8 088 821,0	
<b>Annual maintenance cost</b>		ZAR 808 882,10	

Airports Company South Africa has an economic modelling department that creates economic models in Excel spreadsheets. The inputs used in the economic model and the financial outputs for the Cape Town, Port Elizabeth, East London and George airports can be seen in Table 3, Table 4, Table 5 and Table 6. A capacity factor of 35% is used for the kWh production from the wind farm installation.

The economic model yields the net present value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index. The IRR is compared to ACSA’s 11.5% weighted average cost of capital (WACC) rate(2018) to determine economic feasibility. When the NPV is zero or positive it is an investment that pays itself off during its economic lifespan. The NPV equation used in the economic model is given below (Equation 2), the IRR is the return (*i* in below equation) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the economic lifespan of the investment. The profitability index or PI (given in Equation 3) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^T \frac{R_t}{(1+i)^t} \dots \dots \dots \text{Equation 2}$$

Where:

$R_t$  = net cash inflows – outflows during a single period *t*

*i*= discount rate or return that could be earned

$t$  = number of time periods

$$PI = \frac{PV \text{ of future cash flows}}{\text{Initial Investment}} \dots\dots\dots \text{Equation 3}$$

**In summary:**

- Cape Town International Airport – For a 255kW VAWT plant, the NPV is ZAR3.74m (positive) and the IRR is 22.6% which exceeds the ACSA WACC rate of 11.5%. This shows that the installation is feasible.
- Port Elizabeth International Airport – For a 280kW VAWT plant, the NPV is ZAR3.15m (positive) and the IRR is 21.3% which exceeds the ACSA WACC rate of 11.5%. This shows that the installation is feasible.
- East London Airport – For a 127kW VAWT plant, the NPV is -ZAR0.58m (negative) and the IRR is 6.4% which is below the ACSA WACC rate of 11.5%. This shows that the installation is not feasible.
- George Airport – For a 362kW VAWT plant, the NPV is -ZAR1m (negative) and IRR is 8.6 % which is below the ACSA WACC rate of 11.5%. This shows that the installation is not feasible.

**Table 3: Summarized Economic Analysis – Cape Town International Airport**

Inputs		Output	
kW wind rated capacity	255	End of Job cost	ZAR 7.31m
Capital cost @ 2018	ZAR5 700 474	Net Present Value	ZAR 3.74m
Electricity saving at beneficial operation	783 972kWh/annum	Internal Rate of Return	22.6%
Electricity cost (2018)	ZAR1.47/kWh	Nominal payback period	5 years
Beneficial operation	2024	Profitability index	1.88
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	15 years		
Degradation	0.5% per annum		
Operational and maintenance cost	ZAR 285 024/annum (2018 terms)		
Eskom tariff escalation factor	5.1% per annum		
CAPEX escalation factor	1.23		

**Table 4: Summarized Economic Analysis – Port Elizabeth International Airport**

Inputs		Output	
kW wind rated capacity	280	End of job cost	ZAR 8.87m
Capital cost @ 2018	ZAR 6 259 344	Net present value	ZAR 3.15m
Electricity saving at beneficial operation	858 480kWh/annum	Internal rate of return	21.3%
Electricity cost (2018)	ZAR 1.29/kWh	Nominal payback period	5 years
Beneficial operation	2026	Profitability index	1.76
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	15 years		
Degradation	0.5% per annum		
Operational and maintenance cost	ZAR 312 967/annum (2018 terms)		
Eskom tariff escalation factor	5.1% per annum		
CAPEX escalation factor	1.42		

**Table 5: Summarized Economic Analysis – East London Airport**

Inputs		Output	
kW wind rated capacity	127	End of job cost	ZAR 4.02m
Capital cost @ 2018	ZAR 2 839 060	Net present value	-ZAR 0.58m
Electricity saving at beneficial operation	389 382kWh/annum	Internal rate of return	6.4%
Electricity cost (2018)	ZAR 0.60/kWh	Nominal payback period	10 years
Beneficial operation	2026	Profitability index	0.69
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	15 years		
Degradation	0.5% per annum		
Operational and maintenance cost	ZAR 141 953/annum (2018 terms)		
Eskom tariff escalation factor	5.1% per annum		
CAPEX escalation factor	1.42		

**Table 6: Summarized economic analysis – George Airport**

Inputs		Output	
kW wind rated capacity	362	End of job cost	ZAR 11.46m
Capital cost @ 2018	ZAR 8 092 438	Net present value	-ZAR 1m
Electricity saving at beneficial operation	1 109 892 kWh/annum	Internal rate of return	8.6%
Electricity cost (2018)	ZAR 0.60/kWh	Nominal payback period	9 years
Beneficial operation	2026	Profitability index	0.81
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	15 years		
Degradation	0.5% per annum		
Operational and maintenance cost	ZAR 404 622/annum (2018 terms)		
Eskom tariff escalation factor	5.1% per annum		
CAPEX escalation factor	1.42		

This pre-feasibility study (FEL2) conducted for the four selected airports show that two wind farm installations are feasible (Cape Town International Airport and Port Elizabeth International Airport) and two wind farm installation are not feasible (East London Airport and George Airport). To determine the factors that this pre-feasibility study is most sensitive to, a sensitivity analysis was conducted.

#### *(b) Sensitivity Analysis*

For the sensitivity analysis, the three factors that play a role in the determination of the profitability of the investment were varied equally to see the significance of the impact each parameter had on profitability relative to each other. The base cases used for the airports that had feasible economic results are described in Table 3 and Table 4.

The profitability of the investment relies on the capital cost of the installation, the cost of electricity from Eskom and the operational cost of the VAWT plants. The effect that these three factors have on the NPV of the installations can be seen in Figure 17 and Figure 18.

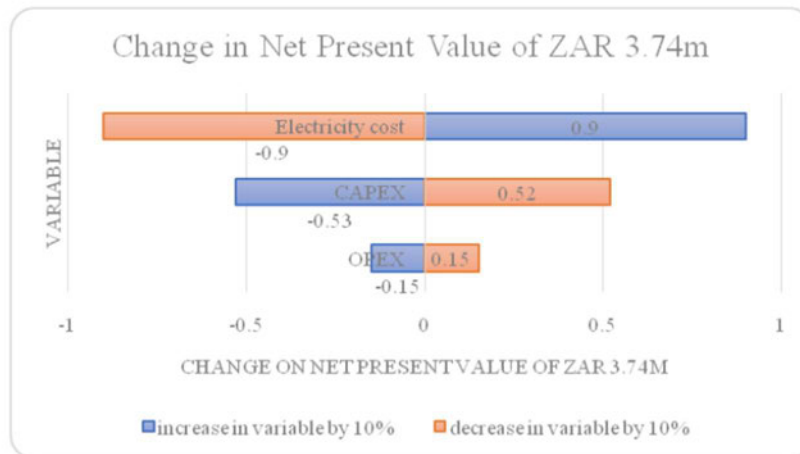


Figure 17: Sensitivity analysis of the CTIA Wind Farm Installation

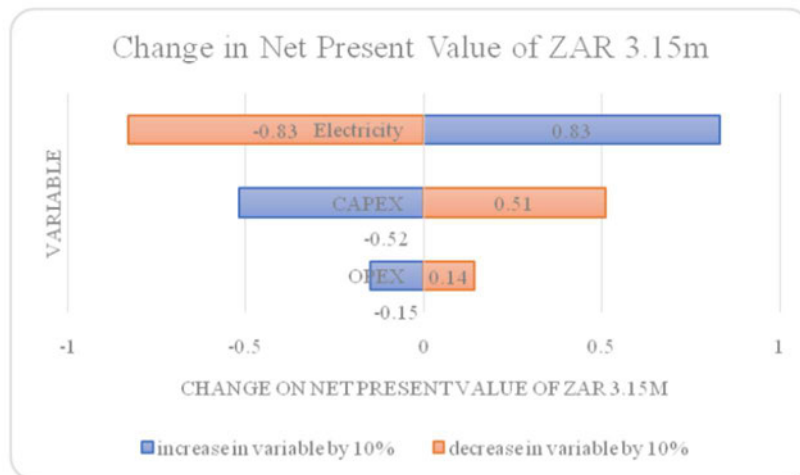


Figure 18: Sensitivity analysis of the PEIA Wind Farm Installation

A 10% increase or a 10 % decrease in the CAPEX, OPEX, electricity cost and water cost show that the electricity cost is the most significant factor and the operational cost the least significant factor in the feasibility of the wind farm investments for CTIA and PEIA. A 10% increase in the electricity cost results in an increase in the NPV of ZAR 0.9m for CTIA and ZAR 0.83m for PEIA, however a 10% decrease in the electricity cost shows a decrease in NPV of ZAR 0.9m for CTIA and ZAR 0.83m for PEIA. The effect of a 10% change in CAPEX has just over half of the effect that the 10 % change in electricity cost has on the NPV of ZAR 3.15m. The effect that a 10 % change in OPEX has on the NPV of ZAR 3.15m is the least significant in comparison to the effect of the changes in CAPEX and electricity cost of same magnitude on the NPV of ZAR 3.15m. These results tell us that we should monitor the electricity tariffs of the airports closely as a change will affect the feasibility of the investment. The results also show that the feasibility is sound in that even a 10 % change in the electricity, capital expenditure required, or operational expenditure required will not make the investment into the wind farms unfeasible.

#### 4. Technology Risk Assessment

The technologies that make up the wind farm installation can be seen in Figure 5. The Darrieus VAWT has been around for about eight decades and the related systems such as the flywheel and induction motor have evolved over a much longer period. The technology risk assessment in this context is provided in Table 7.

**Table 7: Technology Risk Assessment**

Risk	Description	Possible Mitigation
<b>Insufficient wind for upkeep of flywheel output</b>	Wind is intermittent throughout the day and night; however, a smooth power output is required for use at airports.	<ol style="list-style-type: none"> <li>1. Using flywheel storage instead of a gearbox to ensure a smoothing out of generation intermittencies will require an intelligent control system (power electronics) coupled with an induction generator.</li> <li>2. An intelligent control system should be employed to ensure that the flywheel is able to respond to the intermittencies of the wind turbine and still give a smooth output without frequent shutdowns within the day.</li> <li>3. The flywheel's charge and discharge periods should also be variable to enable optimum control for a smooth output to the generator.</li> </ol>
<b>Single point of failure</b>	This is failure at a single point at which without it the entire plant will not be able to operate. This will include failure at the point of connection.	<ol style="list-style-type: none"> <li>1. Design flexibility should be introduced so that should a failure occur at the point of connection, it can be isolated, bypassed and another point of connection with spare capacity is able to carry the load while the failed point of connection is being restored.</li> <li>2. Back-up energy storage or generation systems connected in parallel with the point of connection designed to carry the full load should be part of the wind farm design and smart electricity grid configuration.</li> <li>3. Active monitoring and early detection of failure should be incorporated. A fail-safe mode or default mode should be programmed/hard-wired into the system in case of loss of the control system or smart grid.</li> </ol>
<b>Agility</b>	This is the ability of the plant's operational output to respond to varying demand timeously without causing operational impacts or damage to infrastructure.	The wind plant's output is dependent on the wind speed of the prevailing winds experienced on site and is, thus, by nature, intermittent. The wind plant will then never be a stand-alone power generation source but will be coupled with another generation source/s which will make up for its intermittency. Grid-tied design is suitable for a site that just has Eskom power as well as a site that has a smart system including power control for a site that has multiple power generation sources. The smart electrical grid design should ideally coordinate all power sources.
<b>Turn-down ratio</b>	This is the ability of the plant design capacity to be increased and decreased in capacity to suit operations, site demand and maintenance regimes to maintain cost effectiveness.	The ability to ground and release certain turbines and strings to "bring in loads" and "turn down loads" should be part of control system designs.

#### 5. Airports' Integration Strategy

Due to wind farms being novel to the ACSA airport environment and field of experience, collaboration and investigations as well as a pilot installation is required to ensure that the technology's installation will not have adverse effects on airport

operations, specifically, radar communications. It is therefore required that the Air Traffic Navigational Services (ATNS) and the South African Civil Aviation Authority (SACAA) be consulted and their respective requirements be adhered to in the course of wind farm installation.

ACSA needs to be assured that their investment will not result in undesirable, unavoidable, costly impacts on the business. For this reason, the roll-out of the installation of wind farms need to take place in phases to prove that the site selected and the wind turbines’ height and ‘sight’ in respect of the radar communications are acceptable to airport operations. Figure 19 shows the proposed roll-out plan to ensure that wind farm installations are successful in their coexistence with airport environments. The four phases of the proposed rollout identify eligible sites for the wind farm installation; the installation of about 10 wind turbines each at both Port Elizabeth International Airport and Cape Town International Airport, not connected to the airport grid allowing for flexibility so that they can be moved about should the site selected not be suitable to airport radar communications. The observation and recording of radar communication interactions in all operational conditions in the presence of the wind farm will be undertaken.

The roll-out will provide information related to:

- Site selection of the wind farm installation,
- Height of the wind turbines,
- The unimpacted radar communications “sight” of the wind turbines, and
- Effect of the multiplication of the number of wind turbines that is required for the full wind farm installation.

The next phase of the installation is the full wind farm which should be established based on the assurance received from the previous phase. However, should the first phase of installation not provide assurance on any of the points given, alternative sites should be considered. If the alternative eligible sites identified at the respective airport fail to provide the assurance, the wind turbines purchased should be transferred to another airport in the group where the roll-out plan was successfully completed, to constitute the wind farm there. Should transferring to another airport not be an option, an offsite plant used for “carbon footprint offsetting” should be considered.

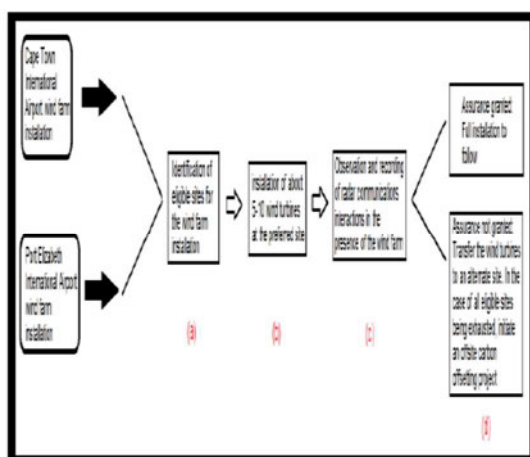


Figure 19: Phases of integration of Wind Energy at ACSA

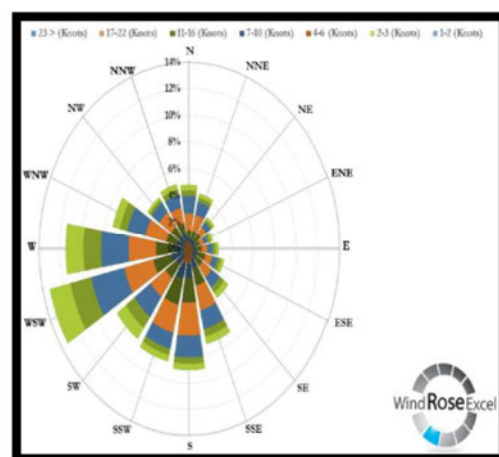


Figure 20: Wind Rose Diagram [17]

The following sections contain information for the execution of the phases which will follow the FEL2 techno economic study, as laid out in Figure 19.

**(a) Identification of eligible sites for wind farm installation**

The study should consider the requirements of the SACAA, ICAO and ATNS as well as OEM requirements of radar equipment to identify eligible sites, taking care to select those sites that are favourable to higher wind speeds for the majority of the time as seen in the wind rose diagram in Figure 20. Outputs of the study for the eligible sites must provide wind rose diagrams, and the height and maximum number of wind turbines that can be accommodated within the site. The measuring station should consider the following:

- The height allowable by the SACAA, ICAO and ATNS.
- The distance away from the radar equipment such that the radar is not affected by wind turbines.

Figure 21 and Figure 22 show the eligible sites identified for CTIA and PEIA respectively. These eligible sites identified by ACSA were then discussed with the CAA and ATNS. Table 8 and Table 9 show the longitude and latitude of the eligible points for each airport. From each eligible point, a 20 000 m<sup>2</sup>land area radiating around it (about 80 m radius)is the land area demarcated for the wind farm. Only one land plot of 20 000 m<sup>2</sup> is required per airport for the wind farm.



Figure 21: Eligible sites identified for wind farm installations at CTIA



Figure 22: Eligible sites identified for wind farm installations at PEIA

Table 8: Longitudes and latitudes of the eligible sites for CTIA Wind Farm Installation

Eligible sites		Degrees	Minutes	Seconds	Latitude/ Longitude
POINT 1	18,6226116	18	37	21	E
	33,9543497	33	57	16	S
POINT 2	18,5936476	18	36	37	E
	33,9638453	33	58	50	S
POINT 3	18,5939816	18	36	38	E
	33,9677581	33	58	4	S
POINT 4	18,5943156	18	36	40	E

	33,9700008	33	58	12	S
POINT 5	18,5912618	18	35	29	E
	33,9710983	33	58	16	S
POINT 6	18,5925024	18	36	33	E
	33,9724343	33	58	21	S
POINT 7	18,5951268	18	36	42	E
	33,9716709	33	58	18	S
POINT 8	18,5990197	18	36	56	E
	33,9806927	33	59	50	S

Table 9: Longitudes and latitudes of the eligible sites for PEIA wind Farm Installation

Eligible sites		Degrees	Minutes	Seconds	Latitude/ Longitude
POINT 1	25,6095421	25	37	34	E
	33,9933188	33	60	36	S
POINT 2	25,5804351	25	35	50	E
	34,0026072	34	0	9	S
POINT 3	25,5818867	25	35	55	E
	34,0042892	34	0	15	S
POINT 4	25,5838222	25	35	2	E
	34,0009942	34	0	4	S
POINT 5	25,5855734	25	35	8	E
	34,0031832	34	0	11	S
POINT 6	25,6112159	25	37	40	E
	33,982935	33	59	59	S
POINT 7	25,6112159	25	37	40	E
	33,9827382	33	59	58	S
POINT 8	25,61489	25	37	54	E
	33,982104	33	59	56	S
POINT 9	25,6102761	25	37	37	E
	33,9834833	33	59	1	S
POINT 10	25,6068549	25	36	25	E
	33,9836215	33	59	1	S
POINT 11	25,6066937	25	36	24	E
	33,9849232	33	59	6	S

Any wind farm installation has to be granted permission by the SACAA who collaborates with the ATNS for the approval of the wind farm installation based on the height of the installation, and the line of sight of the wind farm to radar communication towers and equipment. To determine the harmonious coexistence of the wind farm with the airport, the ATNS runs a computer simulation that highlights points of concern given input of certain parameters of the wind farm such as the maximum rated speed of the wind turbines blades, axis of rotation, material of construction, height of turbine, number of turbines and their location spacing and spread. This is a costly exercise, so in an effort to reduce the cost of the preliminary work, a meeting was held with ATNS and SACAA to reduce the number of eligible sites to save on cost. The

meeting with SACAA and ATNS in March 2020 yielded 4 points per airport as the most likely to be approved to co-exist with the airports' radar systems. These points are POINTS3, 4, 7 and 8 for CTIA and POINTS 1, 6, 7 and 9 for PEIA. The next step is to choose one most likely location to be run by the simulation based on the available land, i.e. land not reserved for future development.

**(b) Pilot installation**

The eligible sites investigated in phase (a) should be characterized in order of preference for the wind farm installation. The installation should not necessarily be feeding into the grid, but the wind turbines should be allowed to turn and have the capability of being "grounded" so that they do not turn for wind speeds that are unsafe or disruptive to airport operations.

**(c) Observation and recording of radar communications in the presence of mini/pilot wind farm**

In this phase, an observation programme should be carried out on the radar operations with the existence of the pilot sized wind farm. Ideally, the recording of radar operations alone should be done first to establish a baseline against which recording of radar communications with the mini/pilot wind farm installation can be compared. The programme should be agreed upon with technical experts at SACAA and ATNS and all interested and affected parties, requiring sign off for procedures and implementation timeline. Risks should also be identified and managed. It is advisable that a full week of observations occur, with particular care exercised in the first few hours when the radar operations must be very carefully monitored to ensure that no undue risks are present. The results of the observations will lead to a decision regarding whether the full installation follows or whether the pilot installation is relocated at the next preferable eligible site until the requirements for full installation have been satisfied or until the eligible sites have been exhausted.

**(d) Full installation**

If the results from the pilot phase show that there are no interruptions on the radar operations nor unacceptable risks to airport operations, the pilot/mini installation may proceed to a full installation. In the case that all eligible sites have been exhausted and there is no suitable onsite location for the wind farm, alternative options such as investigating the feasibility of an off-site installation that will either benefit a local community or earn commercial revenue ensuring that carbon credits are claimed to offset the airports' carbon footprint. The wind turbines could also be transferred between airports.

It is advisable that PEIA installation be trialled first and the CTIA installation thereafter, due to the flexibility of PEIA over CTIA in terms of unreserved space, fewer aircraft movements and thus fewer risks.

**6. Proposed Operational Philosophy**

**(a) Technical**

The wind farm installations at both Port Elizabeth and Cape Town airports will be an energy source installed within a mix of other energy sources. There will be at least one electricity source already installed when the wind farm installations are realized. The intention will be to install a smart grid to coordinate the energy sources for the purposes of continuous electricity supply according to the airport's demand and to ensure that the cost at which this comes is optimized. This smart grid will come in with the installation of the first alternative energy source that is incorporated for the airport's use.

Based on the nature of renewable energy being intermittent, the alternative energy source is meant to support a variable load energy requirement (as opposed to the base load energy requirements). Algorithms in the smart electrical grid

will coordinate the energy sources. The electrical output from the wind farm will feed into an energy storage/buffer medium to be drawn upon by the airport's energy demand at the required frequency.

The technical set-up in Figure 5 should be adopted based on the plant design and the success of the flywheel storage pilot being run in the next phase (FEL 3).

#### **(b) Plant operation for business continuity and cost effectiveness**

For the purposes of cost effectiveness, it is recommended that wind turbines with the greatest possible output capacity per unit be adopted to constitute the targeted total wind farm capacity, as this will decrease the number of moving parts and maintenance required as well as spatial demands.

A smart grid is essential to deliver the wind farm electrical output to the airport's electrical network in a cost-effective way. The smart grid principles should prioritize the renewable energy sources not containing battery storage as the energy generated needs to be used by the site as it is generated before other energy generation sources such as Eskom's grid power or fuel generators thus maximizing asset utilization on renewable energy sources not containing battery storage.

Wind power should not be considered or invested in as a primary energy source feeding airport base loads or critical loads, but rather as an augmentation or supplement to the main energy sources or to offset airport carbon emissions. Due to the uncertainty around wind turbines and radar communications interactions, wind farms total generation capacity should be limited to ensure that their existence does not interrupt airport operations.

#### **(c) Operations and Maintenance activities**

Operation of the wind farms and their integration into the airport electrical grids should be as per electronic algorithm via a smart grid. Operation anomalies and maintenance of the wind farms together with their related control systems will be contracted out as this is not a skill found within ACSA. Breakdown maintenance will be on a call-out basis. Preventative maintenance should be conducted as per the contract value to maintain operability and warranties. There should be a long-term plan in place that transfers skills in-house and develops local talent for operations and maintenance activities.

### **CONCLUSIONS**

The harvesting of wind energy is feasible for Cape Town International Airport and Port Elizabeth International Airport but is not feasible for East London Airport and George Airport. Due to the uncertainty around wind turbines and airport radar operations working together, harvesting wind energy has been limited to serve the airports' varying load as opposed to serving the airports' base load. A 1kW Darrieus VAWT made by FT New Energy Company Ltd in China was used for the feasibility study at a height of an airport's typical street light, i.e. 10 metres. The height of the wind turbines is restricted and the location of the wind farm is critical in ensuring that radar communications are not interrupted or affected. Four eligible locations for CTIA and PEIA each have been selected by Air Traffic Navigational Services to narrow down the number of sites identified by ACSA for the wind farm installation.

As a next step to realizing wind energy in two of ACSA's airports, it is important that the four selected sites per airport be narrowed down further to preferably two for each airport based upon which ATNS can perform a computer simulation of the proposed wind farm to gauge the impact on radar and airport operations. Based on the outcomes of this computer simulation, the pilot phase of a mini-installation containing 10 1 kW VAWT should be installed (at PEIA and CTIA each) to monitor and confirm no impact on airport operations.

## REFERENCES

1. Specifications of 1kW Darrieus Vertical Axis Wind Turbine made by FT New Energy Company Ltd in China retrieved from [https://www.alibaba.com/product-detail/High-efficiency-home-use-maglev-wind\\_60745315605.html?spm=a2700.7724857.normalList.29.6e54264bJAYPvK](https://www.alibaba.com/product-detail/High-efficiency-home-use-maglev-wind_60745315605.html?spm=a2700.7724857.normalList.29.6e54264bJAYPvK), accessed 25/03/2019
2. Kvamsdal, T., "Harvesting the wind energy," Dept. of Mathematical Sciences, Norwegian University of Science & Technology, n.d. Retrieved from <http://www.norcowe.no/doc/Documents%20for%20web/SS2015-presentasonar/Harvesting%20Wind%20Energy%20T.%20Kvamsdal.pdf>, accessed 25/03/2019
3. Spence, J., "Renewable energy in the Australian red meat processing industry & the viability of paunch as a biofuel." Master's thesis, University of Southern Queensland, Toowoomba, Australia, 2012. Retrieved from [https://www.researchgate.net/figure/The-diagram-shows-horizontal-and-vertical-axis-wind-turbine-design-Scottish-government\\_fig5\\_306316439](https://www.researchgate.net/figure/The-diagram-shows-horizontal-and-vertical-axis-wind-turbine-design-Scottish-government_fig5_306316439), accessed 25/03/2019.
4. European Wind Energy Association. "Electrical system," n.d. Retrieved from <https://www.wind-energy-the-facts.org/electrical-system.html>, accessed 25/03/2019.
5. Green Rhino Energy. "Wind Energy Systems and Wind Farms," n.d. Retrieved from [http://www.greenrhinoenergy.com/renewable/wind/wind\\_systems.php](http://www.greenrhinoenergy.com/renewable/wind/wind_systems.php), accessed 25/03/2019.
6. Manrique, R., and Sofrony R. "Data driven fault detection and isolation: a wind turbine scenario." *Tecnura*, 19(44), p. 71, 2015. Retrieved from [https://www.researchgate.net/figure/Ideal-Wind-Turbine-Power-Curve-Operating-Zones\\_fig5\\_275334051](https://www.researchgate.net/figure/Ideal-Wind-Turbine-Power-Curve-Operating-Zones_fig5_275334051), accessed 25/03/2019.
7. Schubel, P. J., and Crossley, R. J. "Wind Turbine blade design." *Energies*, 5(9), 3425-3449, 2012.
8. Retrieved from [https://www.windpowerengineering.com/wp-content/uploads/2014/12/Turbine\\_radar\\_SAND\\_20140951P.png](https://www.windpowerengineering.com/wp-content/uploads/2014/12/Turbine_radar_SAND_20140951P.png), accessed 28/05/2021.
9. Engineering.com "Can IceWind's Six-Bladed Microturbines Power Off-Grid Homes?" n.d. Retrieved from <https://www.engineering.com/story/can-icewinds-six-bladed-microturbines-power-off-grid-homes>, accessed 28/05/2021.
10. Our World in Data. "Installed wind energy," n.d. Retrieved from <https://ourworldindata.org/grapher/cumulative-installed-wind-energy-capacity-gigawatts?country=ESP~IND~AUS~DEU~JPN~ITA~ZAF~GBR~USA>, accessed 10/05/2021
11. 25/03/2019.
12. Our World in Data. "Renewable energy," n.d. <https://ourworldindata.org/renewable-energy>, accessed 10/05/2021.
13. Bitterly, J. G., "Flywheel technology past, present, and 21st Century projections," *IECEC-97 Proceedings of the Thirty-Second Intersociety Energy Conversion Engineering Conference*, 1997. Retrieved from <https://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=5277>, accessed 28/05/2021.
14. Morling, L. "Hotel Verde: the greenest hotel in Africa!" 2014. Retrieved from <https://www.travelground.com/blog/hotel-verde-greenest-hotel-africa>, accessed 5/10/2021.
15. Ecolution Consulting. "Hotel Verde," n.d. Retrieved from <https://ecolution.co.za/hotel-verde-cape-town/>, accessed 5/10/2021
16. Worthington, R. "Renewable energy is the answer," 2015. Retrieved from <https://aidc.org.za/renewable-energy-answer/>, accessed 5/10/2021
17. Alibaba. "High efficiency home use maglev wind turbine," n.d. Retrieved from [https://www.alibaba.com/product-detail/High-efficiency-home-use-maglev-wind\\_60745315605.html?spm=a2700.7724857.normalList.29.6e54264bJAYPvK](https://www.alibaba.com/product-detail/High-efficiency-home-use-maglev-wind_60745315605.html?spm=a2700.7724857.normalList.29.6e54264bJAYPvK), accessed

18/03/2019

18. Wind Rose Excel. "How to: Interpret a wind rose diagram," n.d. Retrieved from <https://windroseexcel.com/guides/how-to-interpret-a-wind-rose-diagram/>, accessed 25/03/2019

## **CHAPTER 14. ENERGY SECURITY: INVESTIGATING ANAEROBIC DIGESTION FOR AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT**

This chapter presents the technical and financial evaluation (pre-feasibility) or technoeconomic assessment of using waste from the ACSA airports in an anaerobic digestion process producing methane gas to be used as fuel for energy.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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<http://www.tjprc.org/view-archives.php>

## ENERGY SECURITY: INVESTIGATING ANAEROBIC DIGESTION FOR AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT

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### ABSTRACT

*The environmental impact of waste is a growing global concern. Its contribution to global warming via methane emissions being released into the atmosphere is relatively more intense than coal-fired power stations through carbon-dioxide emissions on a unit for unit basis. Sites that have daily high human occupancy rates such as airports produce significant volumes of ablution waste, kitchen sink run-off, storm water and wastewater from other commercial and operational activities including car washes, aircraft ablutions wash off, etc. It can become costly to install, operate and maintain wastewater treatment plants in the instance when the local municipal waste water treatment works are not able to accommodate sewage capacity produced by the site as in the case of King Shaka International Airport in South Africa. The more common practice for airport sewage design is to construct holding tanks and release to municipal works when these tanks reach a certain level. This infrastructure is costly to install and maintain. Failure in any of the mechanisms of timeously releasing sewage is very inconvenient to airport operations. Processing this waste for the purposes of producing methane rich fuel gas for power production and using the digestate as fertilizer while making available second-class water to reduce potable water demand as the potential to solve the multiple challenge of greenhouse gas emissions and conserve potable water. This paper presents the technical and financial evaluation (pre-feasibility) or techno economic assessment of using waste from airports in South Africa in an anaerobic digestion process producing methane gas to be used as fuel for energy.*

**KEYWORDS:** *Techno-Economic Assessments, Renewable Energy, Alternative Energy, Feasibility of Renewable Energy, Anaerobic Digestion, Biogas Generation & Reuse of Treated Effluent*

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### 1. INTRODUCTION

Many countries are awaking to the reality that waste is a serious threat not just due to global warming, but also because of the resulting contaminated water sources. Due to this, many countries are imposing restrictions and legislations that drive waste re-use and repurposing. Many countries have strict rules in place for organizations producing toxic waste, such as chemical and solid by-products of industrial processes that protect water quality and preserve natural habitats. Where wastewater spillage occurs or industrial chemical spills occur, the clean-up and rehabilitation of contaminated land is costly and there is never a guaranteed zero impact from the clean up or rehabilitation.

With population growth in the age of consumerism and urbanization, there is a growing need for landfills and there is the challenge of protecting water quality as more people have access to indoor plumbing, and every product sold has packaging and short use. There is a need for innovative thinking around sustainably solving these problems. Airports are like mini-cities in that they provide retail, food and beverage services, accommodation,

travel networks and transport services, fuelling stations, postal and cargo services. They are centres where high waste volumes are produced, both wet waste or sewage and dry or solid waste. Operational cost and maintenance costs are high.

Negating the need for costs associated with disposing of sewage, including the cost of infrastructure associated with conveying the sewage to the municipal works, by using the waste to generate energy, is a possibility that can be considered for OR Tambo International Airport, Cape Town International Airport and King Shaka International Airport. King Shaka International Airport has a Wastewater Treatment Plant (WWTP) onsite built for the airport's sewage processing which is maintained and operated by the airport. Monthly disposal costs of sludge and wastewater when they do not meet specific criteria to be released into natural streams are high. Cape Town International Airport and OR Tambo International Airport have holding tanks for the sewage generated by the airport after which, having reached a certain level, it is transferred to the municipal water treatment works via a bulk sewer pipeline.

In the course of looking at waste as a potential revenue stream as opposed to an operational cost, anaerobic digestion was considered and evaluated for the three larger international airports within the Airports Company South Africa group of nine airports. The waste volumes at the other airports within the group was not large enough or consistently enough replenished to be considered for anaerobic digestion. Solid waste was initially considered, however, since the generation of carbon-dioxide on-site from incinerating the waste material will go against the goal of decreased carbon footprint, it was decided that an increase in recycling be the focus rather than energy generation.

Airports Company South Africa is South Africa's airport authority in South Africa owning and operating nine airports, namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport (CTIA) (Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape).

This techno economic assessment focuses largely on the economics of utilizing sewage (and food waste) for the generation of biogas through anaerobic digestion (AD) based on sewage waste volumes and characterization of the food waste at KSIA, and the sewage streams at CTIA. The economics presented here provides direction on whether anaerobic digestion is worth further investigation. The study also presents the dynamics surrounding the needs and benefits of anaerobic digestion which are in addition to biogas production for energy generation. The study covers the technology description, technology types and typical plant equipment, the assessment of technology maturity, the cost-benefit analysis with financial indicators, technology risk assessment, airport integration strategy, proposed operational philosophy and concludes by proposing future steps.

The key parameters for the waste stream to be suitable for anaerobic digestion are:

- Chemical oxygen demand (COD) limits. COD is used to quantify the amount of organic matter in waste streams and predict the potential for biogas production. The oxygen equivalent of organic matter that can be oxidised, is measured using a strong chemical oxidising agent in an acidic medium. During anaerobic digestion, the biodegradable COD present in organic material is preserved in the end products, namely methane and the newly formed bacterial mass. For domestic sewage, typical COD is between 550 mg/L to 700 mg/L.
- Carbon-nitrogen ratio of the input material, optimum ratio of C:N is 20-30:1; excess nitrogen will lead to the

production of ammonia which will inhibit the digestion process.

- Optimum pH level of 6.8 to 7.2 (6.5 to 8.0 is tolerable).
- The degree of contamination with plastic, glass and metals will require more mechanical processing and thus increase capital costs. For domestic sewage, the degree of contamination is between 250 mg/L to 400mg/L.

The key parameters for the success of the AD process are:

- Feedstock characterization.
- Operational conditions.
- Temperature – Optimum temperature of a mesophilic digester is 35°C An acceptable range, although with decreased production, is 10°C to 37°C. The optimum temperature range for athermophilic digester is 55°C to 60 °C.
- pH and alkalinity – 6.5 to 8.0 is an acceptable range.
- Toxicity is undesirable, although not entirely avoidable.

The key parameters for anaerobic digestion to be adopted are:

- It should have the potential to reduce the airport's carbon footprint.
- Must make financial sense to the business.
- Risks should be acceptable.
- It should have a local footprint for technical support with operationally acceptable response times.

## **2. DESCRIPTION OF THE TECHNOLOGY**

AD is the natural process in which complex organic materials are broken down into simpler compounds in the absence of oxygen by the action of several micro-organism communities. AD consists of four biochemical steps: hydrolysis where hydrolytic bacteria remove polymers to monomers; acidogenesis where acidogenic bacteria remove monomers to short carboxylic acid, carbon dioxide, hydrogen and alcohol; acetogenesis where the products of the previous phase are removed to acetic acid and methanogenesis where methane is built of the acetic acid [1]. figure 1 and figure 2 present the process chematically.

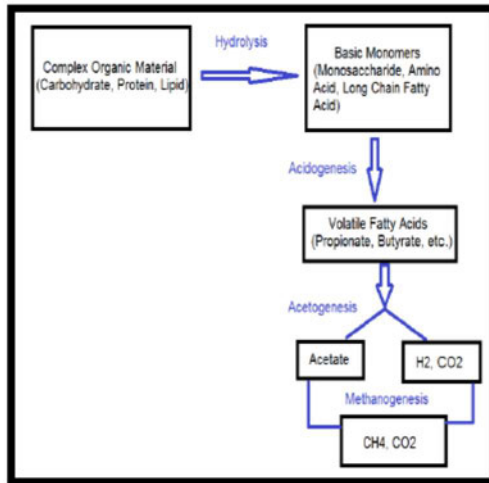
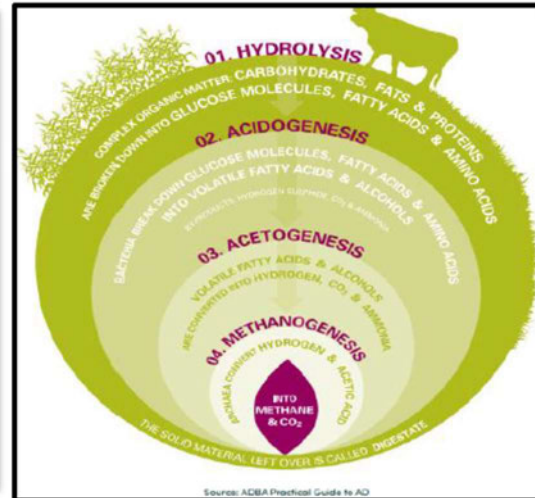


Figure 1: Anaerobic Digestion Process Producing

Figure 2: Anaerobic Digestion [2] Methane (CH<sub>4</sub>).

The key benefit of the AD process is the production of biogas, a renewable energy source, which can be used as fuel for the internal combustion engines, for direct heating and, in cogeneration, for electricity production as well.

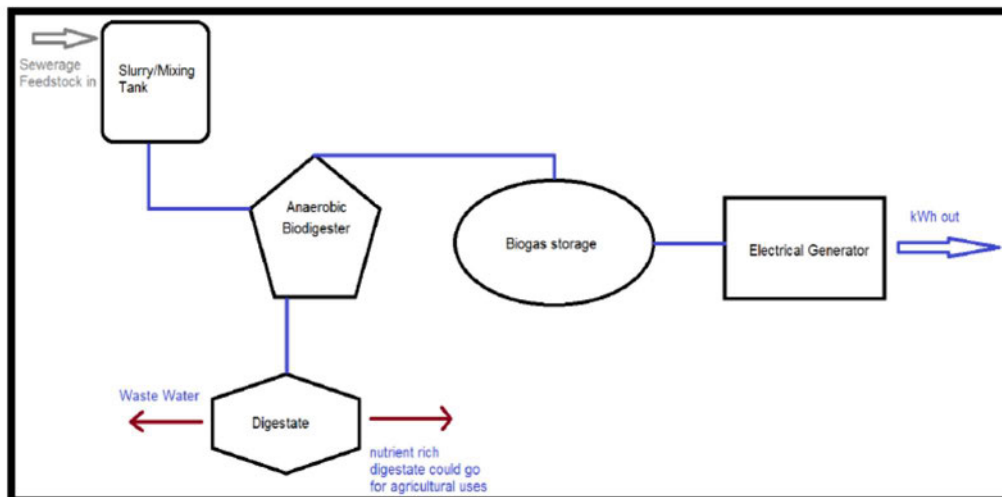


Figure 3: Simplified Plant Schematic for the Anaerobic Digestion Process.

The feedstock is anaerobically digested in a biodigester where the methane gas product is captured and stored until it is combusted in a combustion engine, turning the shaft of an electrical generator and thus producing electricity. Figure 3 shows the process schematically. Other products produced in the AD process are the digestate containing mineralized remains of dead bacteria, and lignin and cellulose suspended in water. This could be used for agricultural purposes.

The purpose of the slurry or mixing tank shown in Fig. 3 is to break down the organic matter prior to it entering the biodigester/reactor. This is called a continuous process. In the alternative, which is a batch process, the biodigester is

fed with feedstock at the start of the process and then sealed for the duration of the AD process.

AD takes place at two optimum temperature ranges, 35°C to 40°C (mesophilic) and 55°C to 60°C (thermophilic). Most AD plants around the world operate in the mesophilic range as less heat is required to maintain that temperature and the digestion process is more stable under these conditions. Thermophilic reactors, although requiring greater attention to operate, are sometimes installed as they accelerate degradation rates and create higher yields of biogas and reduce pathogens in the digestate produced. Based on the constituents and consistency of the food waste treated, an AD can be designed as a ‘wet’, ‘dry’, ‘liquid’ or ‘co-digestion’ system [2]. Fig.4 provides information about the configurations.

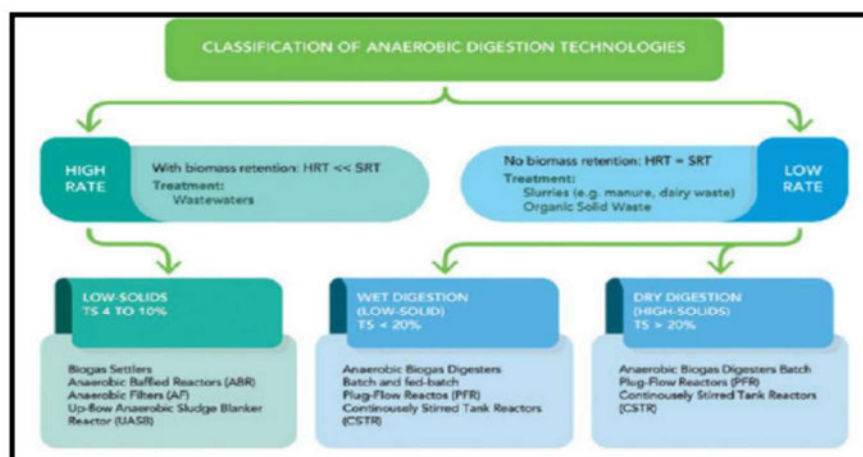


Figure 4: Anaerobic Digestion Technologies [2]

The classification of anaerobic digestion technologies is divided into high rate and low rate. The high rate has low solids (4 % to 10 %) with biomass retention where the solids retention time (SRT) is much higher than the hydraulic retention time (HRT). This is characteristic of wastewater treatment. The low rate has no biomass retention, i.e., the HRT and SRT are equal. This is characteristic in slurry treatment (such as manure and dairy waste) and organic solid waste. The low-rate AD technologies are further classified into wet digestion where the solid content is less than 20%, and dry digestion where the solid content exceeds 20%. [2]

The HRT is the amount of time in hours for wastewater to pass through a tank, such as an aeration tank. Changes in the HRT of an activated sludge process (slurry or mixing tank as in Fig. 3 which introduces air into the sewage feedstock) can affect biological activity. For example, decreasing HRT adversely affects nitrification, while increasing HRT favours nitrification and the solubilization of colloidal biochemical oxygen demand (BOD) and particulate BOD. BOD is the amount of oxygen required to chemically breakdown the pollutants biologically through micro-organisms. The mean cell residence time (MCRT) is the amount of time, in days, that solids or bacteria are maintained in the activated sludge system. The MCRT is known also as the solids retention time (SRT). To calculate the MCRT of an activated sludge process, it is necessary to know the amount (in kilograms) of solids or suspended solids in the activated sludge system and the amount (in kilograms) of suspended solids leaving the activated sludge system [3].

A biogas plant has a reception area where the feedstock from various sources is received. The waste sides in the reception area for some hours whilst it is loaded into the next stage: pre-treatment. This next stage generally involves washing, maceration of the feedstock, screening and pressing depending on the feedstock. Packaging, such as plastic bags,

is stripped out, while any metallic items such as cutlery may be removed using magnetic devices to prevent damage to moving parts. In addition, grit (such as glass, eggshells, ceramics, bones and sand) may need to be removed at the pre-treatment stage if the digester does not have the internal capability of extracting these. If not removed, grit may build up at the bottom of the tank over a period of time leading to loss of volume and failure of the system [2].

After the pre-treatment process, the feedstock is fed to the digester where it undergoes decomposition in the absence of oxygen. This process can take place at different operating temperatures and system setups. During this process, biogas is released and collected in biogas storage tanks or in an inflatable dome. To reduce the sulphur content in biogas, it is piped to a desulphurisation unit. The biogas, which is rich in methane, may be processed further depending upon the desired end use such as electricity, heating, cooling or vehicle fuel. Within the digester, the organic material that is left over after digestion, or digestate, is extracted and may then undergo pasteurisation, followed by composting or separation of wet and dry solids for application to agricultural land, depending on the use and regulations of the jurisdiction. [2]

Drier, stackable substrates, such as food and yard waste, are suitable for digestion in tunnel-like chambers. Tunnel-style systems typically have near-zero wastewater discharge as well, so this style of system has advantages where the discharge of digester liquids is a liability. The wetter the material, the more suitable it will be for handling with standard pumps instead of energy-intensive concrete pumps and physical means of movement. Also, the wetter the material, the more volume and area it takes up relative to the levels of gas produced. A typical plant layout that treats urban sewage can be seen in figure. 5 showing the digesters and gas storage tank as indicated in the plant layout in figure 3.



Figure 5: An on-Farm Anaerobic Digester Plant Showing the Gas Storage Tank and Digesters [2].

The biodigester/reactor design is based on the intended operational need for electricity/heating, the feedstock constituents and flow rate and the climatic or environmental conditions. The control of temperature, pH, toxicity and other parameters in the process depends on the feedstock characterization and climatic conditions. The chemical equation for anaerobic digestion can be seen in Equation 1 and the corresponding biogas composition can be seen in Table 1.



Table 1: Typical Composition of Biogas [4]

Compound	Formula	%
Methane	CH <sub>4</sub>	55 to 65
Carbon dioxide	CO <sub>2</sub>	35 to 45
Carbon monoxide	CO	0 to 3
Nitrogen	N <sub>2</sub>	0 to 1
Hydrogen	H <sub>2</sub>	0 to 1
Hydrogen sulphide	H <sub>2</sub> S	0 to 1
Oxygen	O <sub>2</sub>	0 to 2

Figure 6 shows the anaerobic bioprocess performance in the anaerobic membrane bioreactor (AnMBR). The AnMBR is a wastewater treatment technology that combines anaerobic suspended-growth biological treatment with membrane filtration. AnMBRs will likely play a significant role in wastewater treatment in the future as the anaerobic process has low energy and nutrient requirements, low sludge production and can generate biogas that can be directly employed as an energy source. The use of membranes for biomass separation can provide long solid retention times (SRTs) which are required to offset the low growth rates of anaerobic organisms while also producing a solids-free effluent [5].

Type of Municipal WW	Scale/ Membrane module	Type of Reactor <sup>a</sup>	Volume (L)	Operation Time (day)	Temp (°C)	SRT (d)	HRT (d)	Digester TSS (g/L)	Effluent COD (mg/L)	Biogas Production	Reference
Municipal WW COD 280-340mg/L	Beach Hollow Fiber	(IAF)MBR	5.8	160	35	-	8, 6, 4	-	13, 22, 50	0.14-0.19L CH <sub>4</sub> /g COD	Geo et al., 2014
Municipal WW COD 365-486mg/L	Beach Hollow Fiber	CSTR	6	40	25-30	30, 60, 90	10	8.0, 12.6, 12.7	47-73 (No impact by SRT)	0.04, 0.06, 0.10L CH <sub>4</sub> /g COD	Huang et al., 2013
Synthetic (COD 513mg/L)	Beach Hollow Fiber	Upstream anaerobic bioreactor+AFMBR	10.64	120	35	-	42-5	11.6(TSS)	3-11	0.17LCH <sub>4</sub> /g COD	Kim et al., 2011
Synthetic (COD 550 mg/L)	Beach plate and frame	CSTR	6	150	25-30	30, 60, infinite <sup>b</sup>	8, 10, 12	5.5-10.5	5.5-16.5	0.12-0.25 L CH <sub>4</sub> /g COD	Huang et al., 2011
Pre-treated Sewage (COD 36-131)	Beach -	CSTR	10	440	-	15-217	12-48	1-7	sCOD 14-51	No gas production	Bank et al., 2010
Synthetic (OLR: 2kg/m <sup>3</sup> .d)	Beach Tubular	CSTR	4	270	25	60-360	6-12	6-11	18-40	0.21L CH <sub>4</sub> /gCOD	Ho and Sung, 2009
Municipal WW (0.5mm screened COD: 350-540mg/L)	Full Hollow Fiber	CSTR	2100	340	35	70	6-21	8-22	44-100	0.069L CH <sub>4</sub> /gCOD	Günawan et al., 2011
Pre-treated Sewage (COD 540mg/L)	Beach/Hollow fiber	CSTR	180	365	25	-	4.5, 6, 12	14-80 (TSS)	45	-	Lee et al., 2000
Synthetic (COD 440-480 mg/L)	Beach/Hollow fiber and flat sheet	CSTR	3	100	35	-	48, 24, 12, 6, 3	Around 4 (TSS)	<50 (COD increasing with HRT decreasing)	0.22-0.33L CH <sub>4</sub> /gCOD	Ho and Suckey, 2006
Municipal WW (COD: 337-459mg/L)+ glucose+total COD (548-712)	Pilot flat sheet	CSTR	350	100	35	-	~16.5	15	COD=80 BOD=25	0.2-0.25L CH <sub>4</sub> /gCOD	Martins-Sousa et al., 2011
Synthetic (COD340-290 mg/L)	Beach tubular	UASB	12.5	-	-	-	4, 8, 12	-	40-65, (COD increasing with HRT decreasing)	-	Sabatini-Peliter, et al., 2011

a: IAFMBR: integrated anaerobic fluidized-bed membrane bioreactor AFMBR indicates anaerobic fluidized bed bioreactor; UASB: upflow anaerobic sludge blanket reactor; CSTR: completely stirred tank reactor  
b: infinite indicates no sludge wasting  
-: not indicated

Figure 6: Typical Anaerobic Bioprocess Performance in Anaerobic Membrane Bioreactor with Municipal Wastewater (Sewage) as Feedstock [5].

In figure. 6, note the typical COD levels and the biogas yield together with the corresponding SRTs, HRTs and total suspended solids (TSS) parameters. The techno economic assessment uses the sewage from ORTIA, CTIA and KSIA and the food waste from KSIA to determine the suitability for the anaerobic digestion when examining the COD levels and other parameters established in the previous section. A municipal Excel based model is used to simulate the biogas production for this techno economic assessment.

### 3. ASSESSMENT OF TECHNOLOGY MATURITY

Although there is already a wide application of biogas technologies around the world, the industry is still in its initial stages of development. Micro digesters have been used for at least several centuries. Indeed, if we go back in ancient history, we will find elementary biogas production during the Assyrian Empire 3000 years ago whilst more recognisably modern applications began to develop during the 17th century. Micro digesters play a very important role in rural areas of developing countries, where they are an integral part of farming, waste management and energy security. There is a total of close to 50 million micro-scaledigesters operating around the globe with 42 million [6] operating in China [7]and another 4.9 million in India [8].700000 biogas plants are estimated to have been installed in the rest of Asia, Africa and South America [9][2].

Generation of electricity from biogas is an established technology which has been widely implemented around the globe. This is most commonly done with a combined heat and power (CHP) engine with some form of heat recovery and use. A CHP engine can be linked to any operating anaerobic digester. For it to be economic, a CHP engine requires a minimum size. Operators of biogas plants are trying to maximise efficiency and income streams by increasing the utilisation of heat. There is also a growing interest in trigeneration which generates electricity, heat and cooling when needed. The biogas industry is growing globally. IRENA statistics on global electricity generation from biogas show that it has grown from 46108 GWh in 2010 to 87500 GWh in 2016 [10], a 90% growth in six years [2].

Upgrading of biogas to biomethane is relatively new but is by now a proven technology. While some plants upgrade biogas to be used as vehicle fuel, others inject it into local or national grids. Plants are also beginning to capture carbon dioxide to be used in greenhouses and the food and drinks industry. There are over 540 upgrading plants operating in Europe with 195 in Germany, 92 in the UK, 70 in Sweden, 44 in France, and 13 in the Netherlands [11]. Outside of Europe, there are about 50 in the USA [12], 25 in China [13], 20 in Canada [14] and a few in Japan, South Korea, Brazil and India. Based on the data available, it is estimated that 700 plants globally upgrade biogas to biomethane.

In comparison to other renewable energy technologies installed capacity, global biogas installed capacity as of year 2020is still behind hydropower, solar photovoltaic installations, wind power (onshore and offshore) and solid biofuel technologies. However, its adoption is more popular than geothermal energy, solar thermal energy, liquid biofuels and marine energy technologies. This is shown in Figure. 7. When looking at biogas energy related to 'renewable municipal waste' (Figure. 8), China is leading in installed technology capacity, and when looking at biogas technologies (Fig. 9),Germany has the most installed technology capacity followed by the USA and UK.

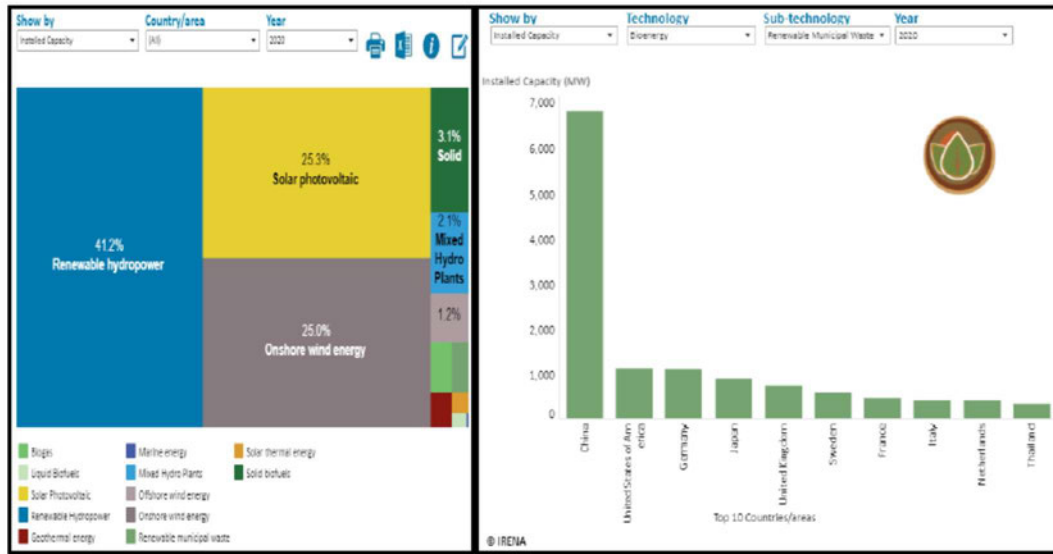


Figure 7: Global Renewable Energy Installed Capacity, 2020 [15]

Figure 8: Top Ten Countries Renewable Municipal Waste Energy Technologies Installed Capacity [16].

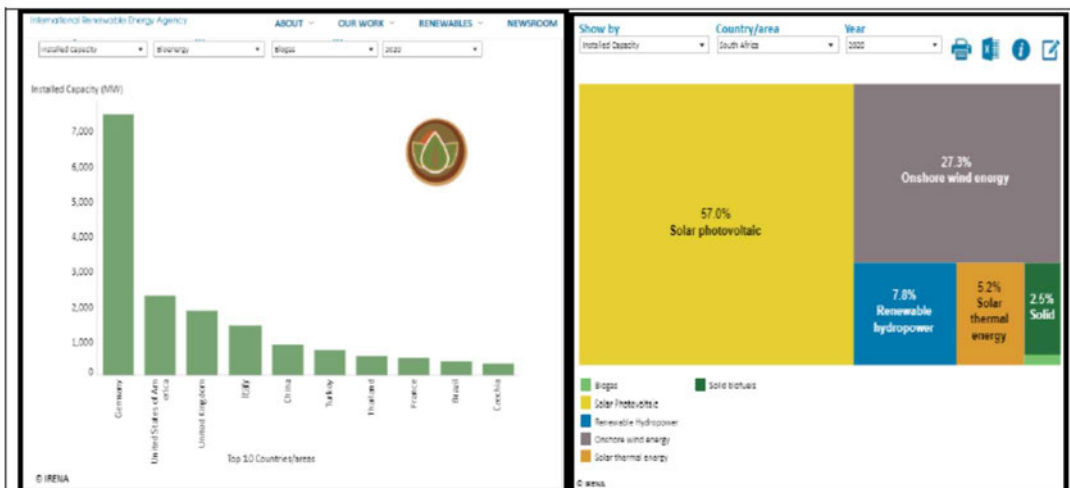


Figure 9: Top Ten Countries Biogas Energy Technologies Installed Capacity [16]

Figure 10: Renewable Energy Technologies Installed Capacities in South Africa, 2020 [15].



When looking at South Africa, biogas has the smallest share of installed technology capacity among South Africa’s solar photovoltaic, onshore wind, renewable hydropower, solar thermal and solid biofuel energy installed technologies, figure. 10. 9 Figure. 11 shows a biogas demonstration plant installed in Wellington in the Western Cape province of South Africa. Renewable energy and waste disposal solutions provider Global Energy constructed this fully operational biogas demonstration plant using technology that has been designed to be more cost effective, manufactured locally and simpler to operate and maintain [17].



Figure 11: Biogas Demo Plant Installed in the Western Cape, South Africa (2018) [17].

Biogas technologies are established globally and in South Africa. It may not be as widely adopted as other renewable energy sources such as wind, solar, hydro, marine, liquid and solid biofuel. This means that there are established commercial markets and technical support for anaerobic digestion technologies. It may not be as plentiful as other renewable energy technologies, but it is present.

#### 4. COST BENEFIT ANALYSIS

This section summarizes the cost benefit analysis at pre-feasibility and is meant to provide direction as to the financial gains of using anaerobic digestion to generate energy. A pre-feasibility study conducted at the Front-End Loading Stage 2 (FEL 2) is typically performed after a strategy is approved and the necessary technologies and other instruments have been identified for the realization of the strategy. Due to the AD and associated technologies not having been investigated before for ACSA or its airports, it is important to get an indication of the waste quantities and quality of waste streams (waste characterization) with as little investment as possible so as to determine whether AD is suitable for further investment. A feasibility study follows after the pre-feasibility and technology assessment has been completed.

AD of sewage and food waste (referred to as feedstock) for the purposes of airport energy consumption requires a steady production of biogas, which means a steady flow of feedstock. This is characteristic of the three larger airports, namely, ORTIA, CTIA and KSIA. The other airports owned and operated by ACSA do not have steady volumes of feedstock. The volume of sewage output of the three airports can be seen in table 2.

Table 2: Raw Sewage Volumes of ACSA's International Airports

Airport	m <sup>3</sup> of Raw Sewage per Year	m <sup>3</sup> /Day of Raw Sewage
OR Tambo International Airport	1 200 000,00	3 287,67
Cape Town International Airport	600 000,00	1 643,84
King Shaka International Airport	400 000,00	1 095,89

At FEL2, it is important to confirm if the airports' sewage streams are suitable for anaerobic digestion process. Confirming key parameters for ORTIA's sewage was costly and it was decided that the waste characterization of the other two airports would be sufficient. At KSIA and CTIA the sewage waste was tested for suitability as feedstock in the AD process. KSIA's feed waste was also characterized to determine the possibility of AD. The sampling results of KSIA's onsite North and South Waste-Water Treatment Plant's (WWTP's) raw sewage is included in Table 3. Table 4 shows the sampling results from CTIA's raw sewage which is usually pumped to municipal works. KSIA treats the raw sewage of both North and South WWTP at the South WWTP. The sewage sampling was performed by KSIA's waste service

provider for KSIA’s sewage and by an independent lab for KSIA’s food waste. The sampling for CTIA’s sewage was performed by another independent lab. Table 3: KSIA South and North Waste-Water Treatment Plant results, testing for suitability as feedstock in anaerobic digestion

Table 3

Sample Number	Date of Sample	Chemical Oxygen Demand (mg/l)	Suspended Solids @ 105°C (mg/l)	Oil and Grease (mg/l)	Electrical Conductivity at 25°C (mS/m)	pH at 25°C	Ammonia (NH <sub>3</sub> ) (mg/l)	Nitrate (NO <sub>3</sub> ) (mg/l)
1	12/10/2018	1 300,0	734,0	112,0	190,5	7,9	87,9	0,1
2	20/10/2018	549,0	218,0	64,0	148,8	7,9	56,6	0,9
3	23/10/2018	952,0	526,0	84,0	204,0	8,6	99,3	0,8
4	13/11/2018	657,0	-	-	116,3	7,5	48,2	1,1
5	21/11/2018	896,0	750,0	43,0	171,1	8,2	91,0	1,1
6	27/11/2018	762,0	348,0	72,0	164,1	7,4	75,3	0,9
7	04/12/2018	325,0	206,0	-	112,4	7,0	68,0	<0,1
8	13/12/2018	608,0	420,0	38,0	132,4	8,0	54,0	62,0
9	19/12/2018	602,0	202,0	-	162,5	7,3	148,0	<0,1
10	22/01/2019	575,0	512,0	62,0	112,3	7,1	41,8	0,6
11	31/01/2019	546,0	240,0	44,0	110,2	7,9	41,3	0,4
12	04/02/2019	672,0	484,0	75,0	113,3	7,4	41,9	0,3
13	11/02/2019	1 147,0	560,0	110,0	115,8	6,9	31,9	0,4
14	08/03/2019	855,0	838,0	-	182,1	8,8	17,4	0,7
15	14/03/2019	676,0	456,0	66,0	143,9	7,6	42,6	0,4
16	20/03/2019	255,0	112,0	8,0	64,6	8,0	0,5	17,6
17	25/03/2019	-	-	-	143,8	7,7	53,8	0,7
18	08/04/2019	751,0	406,0	103,0	125,0	8,4	48,3	0,6
19	15/04/2019	553,0	286,0	51,0	107,6	7,7	32,1	1,1
20	25/04/2019	-	-	-	62,9	6,8	10,0	1,0
<i>Table 3 continued</i>								
Sample Number	Date of Sample	Chemical Oxygen Demand (mg/l)	Suspended Solids @ 105 °C (mg/l)	Oil and Grease (mg/l)	Electrical Conductivity at 25 °C (mS/m)	pH at 25°C	Ammonia (NH <sub>3</sub> ) (mg/l)	Nitrate (NO <sub>3</sub> ) (mg/l)
21	12/10/2018	704,0	270,0	86,0	111,4	8,8	25,9	0,8
22	20/10/2018	516,0	248,0	12,0	52,8	7,0	9,8	0,9
23	23/10/2018	194,0	112,0	3,0	64,3	7,8	17,6	0,0
24	13/11/2018	279,0	-	-	124,1	7,7	39,7	1,0
25	21/11/2018	448,0	252,0	17,0	112,9	7,2	23,9	0,0
26	27/11/2018	132,0	80,0	7,0	62,0	7,2	16,7	0,9
27	04/12/2018	171,0	104,0	4,0	51,4	7,2	6,7	5,1
28	13/12/2018	185,0	120,0	<1	87,3	7,1	53,0	<0,1
29	19/12/2018	185,0	114,0	<1	78,9	7,0	50,0	<0,1
30	22/01/2019	387,0	206,0	48,0	92,4	7,4	16,2	0,5
31	31/01/2019	150,0	52,0	10,0	67,3	8,3	22,1	0,4
32	04/02/2019	850,0	422,0	161,0	61,2	6,7	13,2	0,4
33	11/02/2019	358,0	203,0	26,0	70,7	6,5	9,2	0,4
34	08/03/2019	177,0	98,0	-	91,4	8,5	41,2	0,7
35	14/03/2019	153,0	112,0	11,0	66,6	7,4	19,5	0,4
36	20/03/2019	470,0	104,0	24,0	70,9	7,0	23,7	0,4
37	08/04/2019	1 344,0	967,0	191,0	123,0	7,7	28,4	0,6
38	15/04/2019	2 042,0	1 440,0	197,0	106,2	7,3	27,6	0,8
39	25/04/2019	-	-	-	69,7	8,2	19,1	0,6
	<b>Average values</b>	<b>595</b>	<b>359</b>	<b>62</b>	<b>109</b>	<b>8</b>	<b>40</b>	<b>3</b>

**Table 4: CTIA Raw Sewage Sample Results, Testing for Suitability as Feedstock in Anaerobic Digestion**

Sample Number	Sample Date	Nitrate as N (mg/l)	Ammonia (mg/l)	COD (mg/l)	Electrical Conductivity (uS/cm)	Oil and Grease (mg/l)	pH Level	Total Suspended solids (mg/l)
1	02/09/2019	0.38	107.2	620	1680	813	7.34	309
2	16/09/2019	<0.05	201.88	818	1883	93	7.61	382
3	30/09/2019	<0.05	203.79	1040	1992	65	7.72	708
4	15/10/2019	<0.05	179.89	910	1724	<50	7.25	705
5	30/10/2019	<0.05	140.62	963	1454	<50	7.1	716
	<b>Average values</b>	<b>0,38</b>	<b>166,68</b>	<b>870,20</b>	<b>1 746,60</b>	<b>323,67</b>	<b>7,40</b>	<b>564,00</b>

When reviewing the sampling results in Tables 3 and 4, the parameters for AD highlighted in the introduction are largely met with a few deviations that can be controlled. The food waste at KSIA was also sampled for its suitability as feedstock in the AD process (Tables 5 and 6). The food waste, rich in carbon content, can also be fed into the anaerobic digestion of the raw sewage to neutralize certain parameters that are outliers in the raw sewage such as pH Level. Due to lack of results for ORTIA and CTIA food waste and the ORTIA sewage, for the purposes of this pre-feasibility study, we are going to make the reasonable assumption that the parameters of the waste streams are within suitability as feedstock for anaerobic digestion.

**Table 5: KSIA Food Waste Types and Area Generation for Analysis as Presented in Table 6**

	Waste Category	Waste Type	Waste Generation Geographic Areas
Included	Wet waste (Organic)	Left-over food	Terminal: retail premises, offices, food outlets Airsides: waste from aircraft cleaning and apron activities and other general areas around the apron Landside: public parking, multi-storey parking, staff parking
		Bones from meat	
		Coffee grounds	
Dry waste	Solid waste from terminal and offices		
Excluded	Hazardous waste	Galley waste (aircraft kitchens)	
		Office paper	
	Recyclables	Cardboard	
		Plastic – PET bottles, HD bottles and LD plastic	
		Cans	
		Glass bottles	

**Table 6: KSIA Food Waste Lab Results, Testing for Suitability as Feedstock in Anaerobic Digestion Process**

Sample Number	Date of Sample	Total Mass of Waste Generated on the Day (kg)	COD (mg Oxygen/kg)	Total Organic Carbon (%g/g)	Total Nitrogen (%m/m)	Total Ammonia (mg N/kg)	pH Level @ 25 °C	Wetness (%Water)
1	12/07/2019	332	89779	77	0.87	76	5	56
2	31/07/2019	663,5	41256	97	0.7924	8903	5,6	53
3	02/08/2019	460,5	33267	96	0.6888	8400	3,6	70
4	14/08/2019	682	45000	98	0.26	28	3,3	51
5	16/08/2019	560	50766	88	0.19	72	3,3	91
6	28/08/2019	740	64400	97	1.1	2.8	2,7	74
7	30/08/2019	508	83990	90	1.8	4,5	3,3	65
8	11/09/2019	503	41584	95	1.8	145	3,8	44
9	13/09/2019	512,5	62366	92	2.1	68	3,1	61
10	25/09/2019	358,5	141589	86	1.7	44	3,8	56
11	27/09/2019	505	19107	94	1.8	71	6,5	64
		<b>Average Values</b>	<b>61191</b>	<b>92</b>	<b>1,2</b>	<b>1619</b>	<b>4</b>	<b>62</b>

It can be seen that the food waste material largely meets the minimum conditions for AD. Due to the airports being like mini cities in terms of their activities, it can be assumed that their food waste and sewage will be like that of municipal sewage and food waste. The AD model used for KwaZulu Natal’s eThekweni Municipality was run for the airports’ works using the input data shown in Table 7. The AD model’s expected output of biogas is shown in Table 7.

**Table 7: Input parameters and potential quantity of output of biogas**

Airport	CoD – Chemical Oxygen Demand (mg/L)	Suspended Solids (mg/L)	PST COD Removal Efficiency (%)	PST Suspended Solids Removal Efficiency (%)	Output of Biogas (m <sup>3</sup> /Day)
ORTIA	650	400	30	50	263
CTIA	870	564			188
KSIA	595	359			80
Comment	Domestic sewage is assumed for ORTIA	Domestic sewage is assumed for ORTIA	Process specific	Process specific	Output of anaerobic digestion model done for Durban eThekweni municipal works

If this sewage is put through an AD plant made up of 100m<sup>3</sup> reactors (biodigesters), ORTIA will need approximately 33, CTIA will need 17 and KSIA 11 to process the daily flow as depicted in Table 2. The cost for a 100m<sup>3</sup> reactor can be seen in Table 8.

**Table 8: Cost of a 100m<sup>3</sup> Anaerobic Reactor and Plant**

Bill of Quantities (100m <sup>3</sup> )	Size Specifications	Material	Quantity	Capital Cost (Rands) for a 100m <sup>3</sup> per day System
Steel neck for tank inner	Digester inner (166cm); Digester outer (196cm); height 130cm	Steel mould boards	3	50 220,00 [18]
Steel mould with outer	Digester inner (600cm); outer (640 cm); height, 380cm)	Type 316 steel (stainless steel) mould	3	502 200,00 [19]
Glass Fibre Plastic Gas Collector	Diameter (164cm); height 70cm	Glass Fibre Plastic	3	15 066,00 [20]
Glass Fibre Reinforced Plastic Cover	640cm; (32,17m <sup>2</sup> )	Glass Fibre Reinforced Plastic	3	80 778,87 [21]
Steel parts for reinforcement	For between the inner and outer parts of the tank	reinforcement	3	502 200,00 [22]
Biogas purification system	Less than 400m <sup>3</sup> /day interface caliber (diameter 50cm) PVC flange; Desulfurizing filler: 200kgs; suitable to install indoor and outdoor		3	251 100,00 [23]
Sewage pump	5,5kW; 60m <sup>3</sup> /hr; head 10m		3	15 066,00 [24]
Water pump	3kW; 40m <sup>3</sup> /hr; head 13metres		3	3 515,40 [25]
Biogas generator	10kVA		3	50 220,00 [26]
Installation and commissioning	Estimate		10% of cost of plant	147 036,63
Piping and storage	Estimate		5% of cost of plant	73 518,31
<b>TOTAL (ZAR)</b>				<b>1 690 921,21</b>

The capital cost estimate for the systems can then be estimated to be as captured in Table 9 and the expected electricity output is given in Table 10.

**Table 9: Capital Cost of the Anaerobic Digestion Plants for each Airport**

Airport	Number of 100m <sup>3</sup> Anaerobic Digestion Reactors	Plant Supply and Installation (ZAR)
OR Tambo International Airport	33	55 800 399,95
Cape Town International Airport	17	28 745 660,58
King Shaka International Airport	11	18 600 133,32

**Table 10: Electricity Produced from Anaerobic Digestion**

Airport	Daily Output Biogas (m <sup>3</sup> )	Methane Content	Electrical Generator Efficiency	Methane Heating Value (MJ/m <sup>3</sup> )	Conversion Factor (1 kWh=3,6MJ)	Daily kWhs
ORTIA	263	0,65	0,38	37,78	3,6	681,73
CTIA	188	0,65	0,38	37,78	3,6	487,32
KSIA	80	0,65	0,38	37,78	3,6	207,37

**5. ECONOMIC ANALYSIS**

**(a) Summary**

Airports Company South Africa has an economic modelling department that creates economic models in Excel spreadsheets. The inputs used in the economic model and the financial outputs for the ORTAL, CTIA and KSIA can be seen in Table 11, Table 12, Table 13 and Table 6.

The economic model yields the net present value (NPV), internal rate of return (IRR), nominal payback period and profitability index. The IRR is compared to ACSA’s 11,5% weighted average cost of capital (WACC) rate (2020) to determine economic feasibility. When the NPV is zero or positive it is an investment that pays itself off during its economic lifespan. The NPV equation used in the economic model is given below (Equation 2).The IRR is the return (*i* in Equation 2) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the economic lifespan of the investment. The profitability index or PI (given in Equation 3) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^T \frac{R_t}{(1+i)^t} \dots\dots\dots \text{Equation 2}$$

Where:

*R<sub>t</sub>* = net cash inflows and outflows during a single period *t*

*i* = discount rate or return that could be earned

*t* = number of time periods

$$PI = \frac{PV \text{ of future cash flows}}{\text{Initial Investment}} \dots\dots\dots \text{Equation 3}$$

In summary:

- OR Tambo International Airport – For a 3.3MLAD plant, NPV is ZAR -38.52m (negative) which shows that the installation is not feasible. There will be no internal rate of return nor payback during the economic lifespan of the plant.
- Cape Town International Airport – For a 1.7ML AD plant, the NPV is ZAR -16.29m (negative) which shows that the installation is not feasible. There will be no internal rate of return nor payback during the economic lifespan of the plant.
- King Shaka International Airport – For a 1.1 ML anaerobic digestion plant, the NPV is ZAR -13.13m (negative) which shows that the installation is not feasible. There will be no internal rate of return nor payback during the economic lifespan of the plant.

**Table 11: ORTIA Summarized Economic Analysis**

Inputs		Output	
Capacity of reactors for anaerobic digestion (m <sup>3</sup> )	3300	End of job cost	ZAR71.56m
Capital cost @ 2020	ZAR55 800 400	Net present value	-ZAR38.52m
Electricity production	248 831.31 kWh/annum	Internal rate of return	N/A
Electricity cost	ZAR1.40/kWh	Nominal payback period	No payback
Beneficial operation	2026	Exclusions: Cost of labour and final sludge waste removal (transportation –inbound and outbound), utilities (water and electricity), savings from municipal waste costs	
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	20 years		
Degradation	0.8% per annum		
Operational and maintenance cost	ZAR1 227 609/annum (2020 terms)		

**Table 12: CTIA Summarized Economic Analysis**

Inputs		Output	
Capacity of reactors for anaerobic digestion (m <sup>3</sup> )	1700	End of job cost	ZAR42.8m
Capital cost @ 2020	ZAR28 745 661	Net present value	-ZAR16.29m
Electricity production	177 871.81 kWh/annum	Internal rate of return	N/A
Electricity cost	ZAR1.07/kWh	Nominal payback period	No payback
Beneficial operation	2029	Exclusions: Cost of labour and final sludge waste removal (transportation –inbound and outbound), utilities (water and electricity), savings from municipal waste costs	
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	20 years		
Degradation	0.8% per annum		
Operational and maintenance cost	ZAR632 405/annum (2020 terms)		

Table 13: KSIA Summarized Economic Analysis

Inputs		Output	
Capacity of reactors for anaerobic digestion (m <sup>3</sup> )	1100	End of job cost	ZAR23.85m
Capital cost @ 2020	ZAR18 600 133	Net present value	-ZAR13.13m
Electricity production	75 690.13 kWh/annum	Internal rate of return	N/A
Electricity cost	ZAR1.23/kWh	Nominal payback period	No payback
Beneficial operation	2026	Exclusions: Cost of labour and final sludge waste removal (transportation –inbound and outbound), utilities (water and electricity), savings from municipal waste costs, avoidance cost of north and south WWTP disposal and logistics	
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	20 years		
Degradation	0.8% per annum		
Operational and maintenance cost	ZAR409 203/annum (2020 terms)		

The avoidance cost for the operations of KSIA's WWTP have not been considered due to the current plans of the municipality to convert the plant to a pump station that will transfer the sewage to the nearby extended municipal water treatment works. If this condition changes, the model must consider the avoidance cost. The cost of logistics around disposal of sludge etc. have not been considered for the prefeasibility stage. It is important to note that if these costs were taken into consideration, it would not change the result of the business case, but rather provide a stronger "unfeasible" result.

The resulting economic analysis shown in Tables 11, 12 and 13 prove that AD from the sewage produced by the airports is currently not feasible based on electricity generation alone.

#### (b) Additional Factors to be Considered in the Adoption of Anaerobic Digestion

Upon discussion with the eThekweni Municipality Wastewater department, the volumes of sewage that the airport produces will not make for substantial energy generation. With the lack of environmental penalties and personal responsibility for treating the sewage, it will be cheaper to allow the wastewater to be handled by the relevant municipalities.

If KSIA intended to manage the WWTP permanently, this would make a business case as the logistics for treated effluent release is significantly more than the maintenance and operations of an AD plant. Discussions with Sasol, a giant petrochemicals company, experienced in many types of waste to energy technologies, including AD, revealed that for the waste volumes and the nature of waste produced at the airports, getting one's benefits solely from the energy produced will not make for a viable business case. However, if ACSA had to be held liable for the waste streams, as is the case with Sasol who are not allowed to release their petrochemical waste into natural rivers and streams, using AD and other methods of treating the waste are crucial. It also proves feasible not in terms of energy generation, but in terms of cost avoidance of environmental penalties.

A factor that may cause a difference in the business case is the legislation of the Western Cape government that requires a 50% reduction in food waste to landfill and zero food waste to landfill by 2027 which will attract special disposal costs or penalties. This avoidance cost may make for a feasible business case for Cape Town International Airport.

## 6. TECHNOLOGY RISK ASSESSMENT

This section looks at the various risks associated with the operations of an onsite AD plant. Table 14 shows the various

technology risks and the possible risk mitigations. The focus is an overview of feedstock level (influent) fluctuations, single point of failure, agility and turn-down ratio.

Table 14

Risk	Description	Possible Mitigation
Insufficient feedstock for upkeep of biogas output or too much feedstock due to water leaks or from a firefighting event	If sewage is limited due to decreased operations of the airport, continuous output of biogas will be interrupted. This will affect the airports' energy mix in that the shortfall must be made up from another energy source. Excess feedstock may result in spillage that will require environmental clean-up.	<ol style="list-style-type: none"> <li>To make up for the shortfall in sewage feedstock, sewage from neighbouring sites or the municipal line could be drawn in. An overflow of sewage could be contained in a designed overflow tank in the case of KSIA and a release into the municipal line in the case of CTIA and ORTIA. An intelligent control system will need to be adopted and prior arrangements secured for the system to mitigate shortfalls and overflows.</li> <li>Alternately a smart electricity grid could be designed to make up for the shortfall and fluctuations in biogas output by load curtailment programmes or prioritization of the use of biogas in the case of above average biogas output.</li> </ol>
Single Point of Failure	This is failure at a single point such that without it the entire plant will not be able to operate. For the AD plant, the single point of failure focuses on the case that the AD process is unsuccessful.	<ol style="list-style-type: none"> <li>Electronic monitoring of all critical parameters that are paramount to the success of the AD process and putting in place a record-keeping and early warning systems are key to the process control of the system.</li> <li>It is advisable that process control be put in place to ensure that parameters are optimal for AD.</li> <li>Care should be taken to monitor the VFA (volatile Fatty Acids) level as this can raise the pH level and cause digester failure. [27] Appropriate chemical treatments such as lime, soda ash, muriatic acid, etc. should be electronically controlled to avoid failure [28].</li> <li>A fail-safe mode or default mode should be programmed/hard-wired into the system in case of loss of the control system.</li> </ol>
Agility	This is the ability of the plant's operational output to respond to varying demand timeously without causing operational impacts or damage to infrastructure.	<ol style="list-style-type: none"> <li>Working with the influent to ensure the correct organic loading, i.e., within desired parameters as described in the key parameters for AD forms a critical basis for the control of the AD process to respond to increase or decrease in biogas output.</li> </ol>
Turn-down ratio	This is the ability of the plant design capacity to be increased and decreased in capacity to suit operations, site demand and maintenance regimes towards cost effectiveness	<ol style="list-style-type: none"> <li>Increase in enzymes can quicken the digestive process in the first stage, hydrolysis. [27]</li> <li>Increase in temperature can increase the rate of digestion, however, this will have to be designed for: thermophilic digesters operate at temperatures higher than ambient (mesophilic digesters). [28]</li> </ol>

## 7. AIRPORTS INTEGRATION STRATEGY

Due to this pre-feasibility study showing that all three installations would be unfeasible, proceeding further with the AD technology must have other motivations. It is advised that for KSIA and CTIA this pre-feasibility study be revised to include all costs and savings that have been excluded:

- KSIA – in the instance that the municipality fails to put in place the additional sewage plant capacity to handle the

airport's sewage volumes, the handling and processing costs of the airport's treated sludge will provide a strong economic case due to the cost savings.

- CTIA – in preparation for the legislation of the Western Cape Government of 50% food waste to landfill by 2025 and zero food waste to landfill by 2027.

The adoption of KSIA's anaerobic digestion plant should focus on upgrading technology and plant equipment of the airport's current South WWTP and include a capture for biogas production and transfer to the CHP plant onsite or if another use is identified, this could be used in a smaller CHP plant.

The adoption of AD at CTIA will need an in-depth investigation into waste to energy plants planned or established within a reasonable distance from the airport. The most reasonable economic decision must be made considering the cost to process waste food onsite versus paying for another business to process waste food safely and legally, i.e., in accordance with the Western Cape Government's legislation. Based on the work done for CTIA's and KSIA's AD plants, learnings can be applied when approaching the furthering of the AD pre-feasibility study.

## 8. PROPOSED OPERATIONAL PHILOSOPHY

This section describes the proposed operational philosophy that should be considered for an airport environment covering technical, business, operations, and maintenance activities. It would be advisable that the costs for each operational philosophy be firmed up for the next revision of the airports' pre-feasibility studies.

### (a) Technical

The proposed technical operating philosophy is described in the context of the inflows and outputs as depicted in figure. 12. The influent is the wastewater at the airports, added to which is the food waste that will enrich the influent and help with organic loading. The influent enters the anaerobic digester. The anaerobic digester set up is shown in figure. 13. Once digested, there are three products as seen in figure. 12 that need to be used, i.e. biogas, effluent and compost. The biogas is a useful fuel that can be used as a supplement to the planned natural gas CHP cycle to support the airports' base load energy requirements. The proposed plan is to establish off-takers for the compost such as neighbouring farms. KSIA has many prospective off-takers considering that the area has many sugar-cane farming establishments and other farming activities within a 15km radius. For the other airports, the market for off-takers is yet to be established. The effluent is proposed to be filtered and used for second class water purposes, especially flushing of toilets.

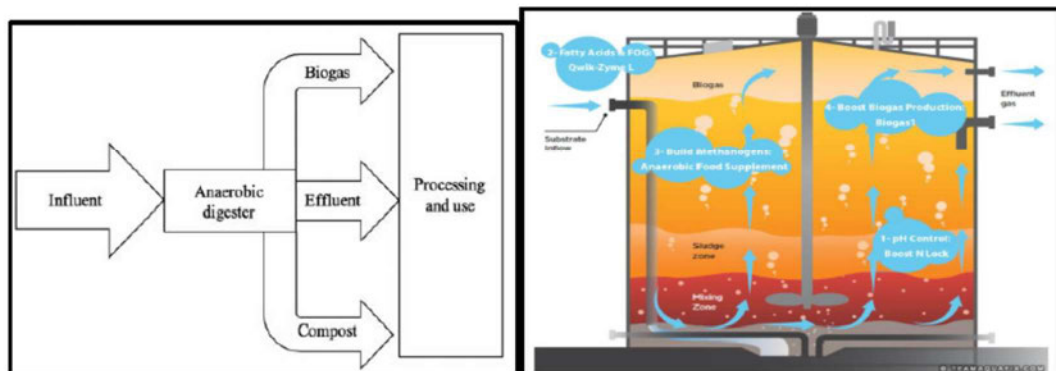


Figure 12: The Anaerobic Influent and output Systems [27] Figure 13: Anaerobic Digester [28].

The reuse of the treated effluent for flushing toilets, which is about the biggest single user of water at airports, could be the game changer that saves costs on potable water and makes the investment feasible.

**(b) Plant Operation for Business Continuity and Cost Effectiveness**

Due to the international airports (ORTIA, CTIA and KSIA) being investigated for the use of natural gas in a combined heat and power (CHP) cycle to satisfy baseload energy demands and at certain times even the fluctuating energy demand, it is proposed that the biogas produced in the AD process be used as supplemental fuel to the natural gas fuelled CHP cycle. It is not advisable for biogas output to be used as a mainstream fuel or as a stand-alone fuel source for any energy demand, as fluctuations in biogas output and biodigester failure may cost downtime that interrupts airport operations. It is proposed that the treated effluent be used in a closed loop for the flushing of ablution facilities which will be the game changer that makes the AD plants cost effective for the airports. Proper investigation into the risks of using treated effluent for flushing of ablutions including risk mitigation and control measures to ensure that it is safe, must be undertaken. A separate second-class water reticulation line should be established for the flushing of ablution facilities. Should there be an interruption in service from the second-class water reticulation line, the potable water line could provide service.

Off-takers for compost should be established and secured via agreements to ensure that there is a proper income as well as guaranteed removal of compost off-site.

**(C) Operations and Maintenance Activities**

Maintenance and operations will need to be contracted out as the specialized fields of AD together with associated process controls are not found within ACSA's expertise, unless ACSA seeks to employ these skills in house. It is also critical that the entire AD process is continuously monitored electronically, the process controlled electronically, and alarms be recorded and transmitted for specific events occurring during operations of the plant. Preventative and condition-based maintenance is proposed to be electronically triggered and monitored.

If the electronic control system is well designed and implemented, it is possible that 24/7 onsite presence may not be needed – it could be remotely controlled and operated, and call-outs be made when special procedures or attention is required.

**CONCLUSIONS**

Even though all three international airports' economic models for the AD produce unfeasible results for the FEL2 stage, it is recommended that it be taken to the FEL3 stage for CTIA and KSIA based on the following reasons:

- The impending Western Cape legislation for a 50% reduction in food waste to landfill by 2025 progressing to zero food waste to landfill by 2027.
- The cost of operations of KSIA's North and South WWTPs are significant and the urgent need to reduce operational cost due to the financial impact of COVID-19 on the airport business.

To prepare for the FEL3 stage, it is recommended that an investigation be undertaken to ascertain the possibility and feasibility of supplementing the South WWTP at KSIA to undertake anaerobic digestion on a full scale.

The FEL3 stage should include in its scope of work the investigation into the relationship between the temperature in the biodigester, retention time of the feedstock and biogas production, as well as organic loading rates. The biogas

production models must be programmed for specific conditions prevailing for the airport waste streams. The quantification of effluent and compost should also be included in the model. The investigation into the use of treated effluent for second class water purposes such as flushing of toilets should be included in the study. The investigating of the market for compost off-takers should be undertaken.

In terms of pilot implementation, it is recommended that KSIA be fitted and operated with a packaged biodigester (on a small scale) to understand the challenges and process controls required for anaerobic digestion of the airport's waste streams (sewage and food waste). A small generator should be installed along with the packaged biodigester to produce electricity from the biogas production to run the pumps at the waste-water treatment plant, and thermal harvesting be done to satisfy the thermal energy requirement for AD.

As a result of this pilot implementation, the necessary operational and process flow regimes will be available for further roll-out as needed across the group of airports.

#### REFERENCES

1. Cioabla, A.E., Ionel, I., Dumitral, G.A., Poescu, F., "Comparative study on factors affecting anaerobic digestion of agricultural vegetal residues", *Biotechnology for Biofuels*, 5(39), 2012. Retrieved from <http://www.biotechnologyforbiofuels.com/content/5/1/39>, accessed 17/05/2021.
2. S. Jain, D. Newman, A. Nizhou, H. Dekker, et al., "Global Potential of Biogas", *World Biogas Association*, June 2019. Retrieved from [https://www.worldbiogasassociation.org/wp-content/uploads/2019/07/WBA-globalreport-56ppa4\\_digital.pdf](https://www.worldbiogasassociation.org/wp-content/uploads/2019/07/WBA-globalreport-56ppa4_digital.pdf), accessed 17/05/2021.
3. Gerardi, M.H., "Nitrification and Denitrification in the Activated Sludge Process", 2002. John Wiley & Sons.
4. Adebayo, A.O., Jekayinfa, S.O., "Effects of Organic Loading Rate on Biogas Yield in a Continuously Stirred Tank Reactor Experiment at Mesophilic Temperature", *British Journal of Applied Science & Technology* 11(4): 1-9, 2015, Article no. BJAST.18040. Retrieved from [https://www.researchgate.net/publication/316846366\\_Effects\\_of\\_Organic\\_Loading\\_Rate\\_on\\_Biogas\\_Yield\\_in\\_a\\_Continuously\\_Stirred\\_Tank\\_Reactor\\_Experiment\\_at\\_Mesophilic\\_Temperature](https://www.researchgate.net/publication/316846366_Effects_of_Organic_Loading_Rate_on_Biogas_Yield_in_a_Continuously_Stirred_Tank_Reactor_Experiment_at_Mesophilic_Temperature), accessed 03/06/2021
5. Dong, Q., "Characterization of anaerobic membrane bioreactors (AnMBR) treating municipal wastewater", PhD Civil Engineering thesis, University of Waterloo, Ontario Canada, 2015.
6. International Renewable Energy Agency, "Biogas for domestic cooking: Technology brief", Abu Dhabi, 2017. Retrieved from [http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Dec/IRENA\\_Biogas\\_for\\_domestic\\_cooking\\_2017.pdf](http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Dec/IRENA_Biogas_for_domestic_cooking_2017.pdf), accessed 15/05/2021.
7. Y. Yang, J.-Q. Ni, W. Zhu, and G. Xie, "Life cycle assessment of large-scale compressed bio-natural gas production in China: A case study on manure co-digestion with corn stover", *Energies*, 12(3), 429, 2019. Retrieved from <http://www.mdpi.com/1996-1073/12/3/429/html>, accessed 15/05/2021.
8. Renewable Energy Policy Network for the 21<sup>st</sup> Century, "Renewables 2018
9. Global Status Report" REN21, 2018. Retrieved from <https://www.ren21.net/wp-content/uploads/2019/08/Full-Report-2018.pdf>, accessed 06/06/2021.
10. SNV, "Energy: Biogas", Retrieved from <http://www.snv.org/sector/energy/topic/biogas>, accessed 15/05/2021.
11. International Renewable Energy Agency, "Bioenergy", Retrieved from <http://www.irena.org/bioenergy>, accessed 15/05/2021.

12. European Biogas Association, "EBA Statistical Report 2018", 2018. Retrieved from [https://www.europeanbiogas.eu/wp-content/uploads/2019/05/EBA\\_Statistical-Report-2018\\_AbridedPublic\\_web.pdf](https://www.europeanbiogas.eu/wp-content/uploads/2019/05/EBA_Statistical-Report-2018_AbridedPublic_web.pdf), accessed 06/06/2021
13. IEA Bioenergy, "Plant Lists". Retrieved from <http://task37.ieabioenergy.com/plant-list.html>, accessed 15/05/2021
14. Bundesministerium für Wirtschaft und Energie, "Opportunity and challenge of biogas market in China". Retrieved from [http://www.oav.de/fileadmin/user\\_upload/2\\_Termine/Allgemein/biogas\\_development\\_in\\_China.pdf](http://www.oav.de/fileadmin/user_upload/2_Termine/Allgemein/biogas_development_in_China.pdf), accessed 15/05/2021
15. Canadian Biogas Association, "Biogas projects in Canada". Retrieved from [https://biogasassociation.ca/index.php/about\\_biogas/projects\\_canada](https://biogasassociation.ca/index.php/about_biogas/projects_canada), accessed 15/05/2021
16. International Renewable Energy Agency, "Technologies". Retrieved from <https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies>, accessed 14/05/2021.
17. International Renewable Energy Agency, "Country rankings". Retrieved from <https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Country-Rankings>, accessed 14/05/2021.
18. P. Müller, "Biogas plant demonstrates potential using new tech". Engineering News, 17<sup>th</sup> August 2018. Retrieved from [https://www.engineeringnews.co.za/article/biogas-plant-demonstrates-potential-using-new-tech-2018-08-01/rep\\_id:4136](https://www.engineeringnews.co.za/article/biogas-plant-demonstrates-potential-using-new-tech-2018-08-01/rep_id:4136), accessed 15/05/2021.
19. 100m<sup>3</sup> digesting tank; 16,74 dollar rand exchange rate (7/9/2020); [https://www.alibaba.com/product-detail/biomass-septic-tank\\_60300987507.html?spm=a2700.7724857.normalList.129.169d29aa6jSRMo](https://www.alibaba.com/product-detail/biomass-septic-tank_60300987507.html?spm=a2700.7724857.normalList.129.169d29aa6jSRMo)
20. 100m<sup>3</sup> steel tank; 16,74 dollar rand exchange rate (7/09/2020); [https://www.alibaba.com/product-detail/2015-CE-and-ISO-Approved-Biomass\\_60364930438.html?spm=a2700.7724857.normalList.49.4af061bbWVkOgt](https://www.alibaba.com/product-detail/2015-CE-and-ISO-Approved-Biomass_60364930438.html?spm=a2700.7724857.normalList.49.4af061bbWVkOgt)
21. 6m<sup>3</sup> biodigester; 16,74 dollar rand exchange rate (7/09/2020); [https://www.alibaba.com/product-detail/Fiberglass-Biogas-Digester-Biogas-Plant\\_60014995838.html?spm=a2700.7724857.normalList.1.527e4cbcaD5ZBJ](https://www.alibaba.com/product-detail/Fiberglass-Biogas-Digester-Biogas-Plant_60014995838.html?spm=a2700.7724857.normalList.1.527e4cbcaD5ZBJ)
22. \$50 per sqm; 32,17sqm; 16,74 dollar rand exchange rate (7/09/2020)
23. Estimated the price for the steel parts for between the inner and outer parts of the tank
24. Rand dollar exchange rate 16,74 (7/09/2020); 20-30Nm<sup>3</sup>/hour <https://alongnewenergy.en.made-in-china.com/product/HNKxvTUbkZ/China-Biogas-Scrubber-Biogas-Pre-Treatment-System.html>
25. Rand dollar exchange rate 16,74 (7/09/2020); submersible sewage pump of 5kW on alibaba [https://www.alibaba.com/product-detail/5kw-sewage-pump-submersible-sewage-wq\\_60664584562.html?spm=a2700.7724857.normalList.1.2e7b172dYqLiB&s=p](https://www.alibaba.com/product-detail/5kw-sewage-pump-submersible-sewage-wq_60664584562.html?spm=a2700.7724857.normalList.1.2e7b172dYqLiB&s=p)
26. Rand dollar exchange rate 16,74 (7/09/2020); 3kW on alibaba <https://www.alibaba.com/showroom/3kw-water-pump.html>
27. Rand dollar exchange rate 16,74 (7/09/2020); 10kVA on alibaba <https://www.alibaba.com/showroom/biogas-generator-10kva.html>
28. J.N. Meegoda, B. Li, K. Patel, L. B. Wang, "A review of the processes, parameters, and optimization of anaerobic digestion", *International Journal of Environmental Research and Public Health*, 15, 2224, 2018.. doi:10.3390/ijerph15102224.
29. Aquafix, "Anaerobic digester upset & troubleshooting". Retrieved from <https://teamaquafix.com/anaerobic-digester-upset-troubleshooting/>, accessed 17/05/2021.
30. Parmar, Jigar K., Sunny K. Darji, and Gajendra R. Patel. "Fuzzy Based MPPT Controller of Wind Energy Conversion System using PMSG." *International Journal of Electrical and Electronics Engineering (IJEEE)* 7.3: 17-30.

31. Darji, Sunny K., Jigar K. Parmar, and Gajendra R. Patel. "Energy Storage System with Multilevel Inverter for Distributed Grid Application." *International Journal of Electrical and Electronics Engineering (IJEET)* 7. 3, pp, 1-16.
32. Bhaskar, K., et al. "Effect of dimethoxy-methane (C<sub>3</sub>H<sub>8</sub>O<sub>2</sub>) additive on emission characteristics of a diesel engine fueled with biodiesel." *International Journal of Mechanical and Production Engineering Research and Development* 8.1 : 399-406.
33. Koul, Bharti, Kamwardeep Singh, and Yadwinder Singh Brar. "An Integration of Smart Grids with Demand Side Management and Renewable Energy: A Review." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Vol. 9, Issue 4, pp, 839-848

## **CHAPTER 15. ENERGY SECURITY: INVESTIGATING NATURAL GAS FOR ENERGY GENERATION AT AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT**

This chapter presents the investigation into natural gas as an energy source for the ACSA, providing the technical and financial evaluation (or technoeconomic assessment) of its adoption at airports.

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## ENERGY SECURITY: INVESTIGATING NATURAL GAS FOR ENERGY GENERATION AT AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT

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### ABSTRACT

*Reducing carbon-dioxide emissions that come from coal-fired power stations is a major challenge especially for developing countries. Renewable energy has reached and surpassed grid parity in many countries, however, due to the intermittent nature of solar and wind energy which are popular choices of renewable energy, energy storage becomes necessary to serve baseload energy requirements. The need for energy storage increases the cost of adopting renewable energy and in most cases makes the investment unfeasible. Furthermore, the spatial demands of renewable energy make it an unsuitable choice for many sites that have high baseload energy requirements such as airports. Emissions from natural gas-powered stations are half those of coal-fired power stations, therefore it is an attractive alternative in the quest for reducing carbon emissions in developing countries. This paper presents an investigation into natural gas as an energy source for airports in South Africa, providing a technical and financial evaluation (or technoeconomic assessment) of its adoption at airports.*

**KEYWORDS:** *Techno-Economic Assessments, Alternative Energy, Feasibility of Natural Gas for Airports, Natural Gas Installations, Combined Heat and Power, Natural Gas Trigenation for Airports, Natural Gas Turbine & Natural Gas Internal Combustion Engines*

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### INTRODUCTION

Natural gas is the cleanest of all fossil fuels and the main products of combustion of natural gas are carbon dioxide and water vapour. The combustion of natural gas releases small amounts of nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>), carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), other reactive hydrocarbons and virtually no particulate matter [1]. For this reason, natural gas is a popular choice in replacing coal as a fuel source especially where space and cost is a limitation when considering renewable energy and its energy storage requirements.

Some airports in South Africa face the challenge of high baseload energy demand with limited space for renewable energy and the added cost of energy storage makes renewable energy unfeasible. Airports Company South Africa (ACSA) is South Africa's airport authority owning and operating nine airports in South Africa namely OR Tambo International Airport (ORTIA) (in Kempton Park, Gauteng), Cape Town International Airport (CTIA) (in the Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (PEIA) (in the Eastern Cape), East London Airport (EL) (in the Eastern Cape), Bram Fischer International Airport (BFIA) (in Bloemfontein, Free State), George Airport (GG) (in the Eastern Cape), Upington International Airport (UPIA) (in the Northern Cape) and Kimberley Airport (KIM) (in the Northern Cape). Renewable energy can easily be incorporated into ACSA's six regional airports as their operational hours and

energy demands are low compared to its three busiest international airports, OR Tambo International Airport (ORTIA), (CTIA) and (KSIA).

ACSA's quest for reducing carbon emissions resulting from their electricity consumption has led to the installation of solar photovoltaic (PV) plants at PEIA, BFIA, GG, UPIA and KIM with a sixth solar PV plant at installation stage for EL. The same approach could not be adopted for ORTIA, CTIA and KSIA as the operating hours and extent of operations result in high baseload energy demand coupled with the fact that most of the available land has been reserved for commercial development and the addition of future capacity. Renewable energy also becomes unfeasible when considered in larger scales, especially with the energy storage required to smooth out intermittencies. Renewable energy technologies have low capacity factors.

The availability of natural gas close to ORTIA and KSIA as well as the establishment of virtual gas networks covering their geographical areas, including CTIA, makes natural gas an attractive alternative in the quest for reduction in carbon emissions resulting from the airports' grid electricity consumption. The Eskom load shedding and ageing power generation fleet coupled with increasing electricity tariffs make the search for alternative energy a business risk and an economic push for ACSA's international airports. Using natural gas to produce both electricity and recovery of heat for heating demands and to provide air conditioning (trigeneration or combined heat and power) is beneficial and energy efficient.

This study covers technology description, identification of technology type, typical components constituting the technology, assessment of technology maturity, cost benefit analysis that looks at the investment required, energy derived, feasibility indicators of the investment sensitivity analysis of using natural gas as an energy source for ORTIA, CTIA and KSIA. The study also presents the technology risk assessment, airports integration strategy and the proposed operational philosophy covering the technical aspects, plant operation for business continuity and for cost effectiveness as well as the operations and maintenance philosophies.

The key parameters for the natural gas-to-power technology to work successfully for airports are:

- Availability of natural gas supply in the region
- Effective integration of the technology into the airport environment

The key parameters for natural gas power plants to be adopted at airports owned and operated by ACSA are:

- It must prove to be economically feasible for the airports
- The technical and business risks of plant operations and plant related activity must be acceptable, this includes cost impact and implications
- The natural gas fuel supply must be guaranteed for the economic lifespan of the plant, and the supply capacity must be security backed with the ability to be increased

### **Description of the Technology**

Natural gas is formed in the earth's crust as a result of transformation of organic matter due to heat and pressure of overlying rock. The gas hydrocarbons can also be produced as a result of microbial decomposition of organic substances and due to reduction of mineral salts. Some of these gases are released into the atmosphere or hydrosphere while the rest

accumulates in the upper layers of the earth’s crust. The composition of natural gas varies depending on a number of factors such as origin, location of deposit and geological structure. Natural gas mainly consists of saturated aliphatic hydrocarbons like methane. Components such as carbon dioxide, hydrogen sulphide, nitrogen and helium constitute an insignificant proportion of natural gas composition [1].

The natural gas extracted is available in different forms for commercial and industrial use. While liquefied natural gas (LNG) and compressed natural gas (CNG) are similar, their delivery and storage methods are different. LNG is frozen in order to turn it into liquid form, whereas CNG is pressurised to the point where it is very compact. LNG takes up less storage space on a vehicle than CNG, and it also offers an energy density that can be compared to diesel fuel. This makes it a common choice among many long-haul trucking companies. Using proper procedures, LNG can be converted to CNG. On the other hand, CNG is easier to refuel than LNG, which requires special handling and equipment. CNG is also very light, so if there is a leak, it will dissipate. It has an unlimited hold time, so even if it goes unused, there is no fuel loss. This makes CNG a safer choice over LNG. CNG also has lower production costs than LNG [2].

“CNG can be transported through pipelines. Some components need to be removed from the natural gas before CNG can be safely delivered. Also, while being processed, producers typically add an unpleasant smell (mostly ethanethiol), thus making natural gas easily recognisable in case of leaking. Like CNG, liquefied natural gas also occupies less space than it did in its gaseous state. Liquid gas can be 600 times denser than it was after extraction. Liquefied natural gas can be transported in barrels. The process of creating LNG is more expensive, so the price of LNG is higher than CNG, but it is a great opportunity to transport natural gas over long distances effectively. Without pipelines, LNG is a great alternative as a power source.” [3]

This technoeconomic assessment focuses on the use of natural gas for power generation and excludes its use for energy storage (such as natural gas powering fuel cells, etc) and vehicle fleets (cars, light delivery vehicles, etc., running on natural gas). Power can be generated by natural gas through its combustion in gas turbines (GT) or internal combustion engines (ICE) to produce electricity, and heat may also be recovered.

Natural gas turbines have various plant configurations as can be seen in Fig.1. A GT unit includes an air compressor, a combustor, and an expansion turbine. A typical gas turbine can be seen in Fig. 2. Gaseous or liquid fuels (in this case natural gas) are burned under pressure in the combustor, producing hot gases that pass through the expansion turbine, driving the air compressor. Fig. 3 shows the schematic of a closed cycle gas turbine (CCGT) [4].

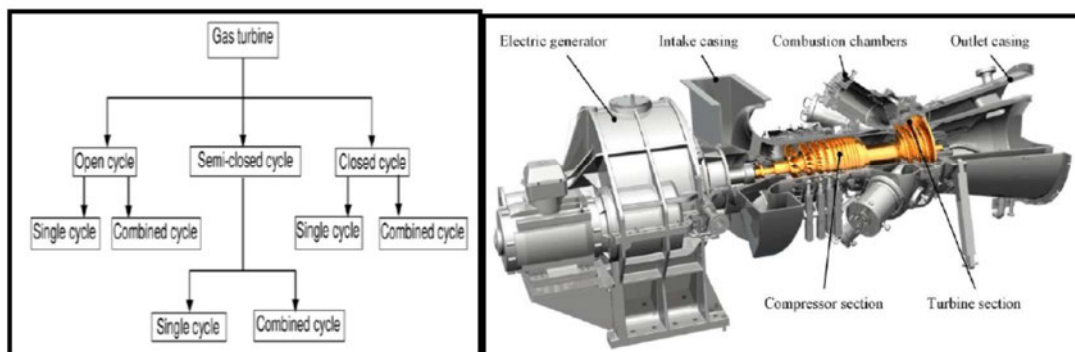


Figure 1: Classification of Gas Turbines. Figure 2: Typical Gas Turbine Construction [6] based on Thermodynamic Cycles [5].

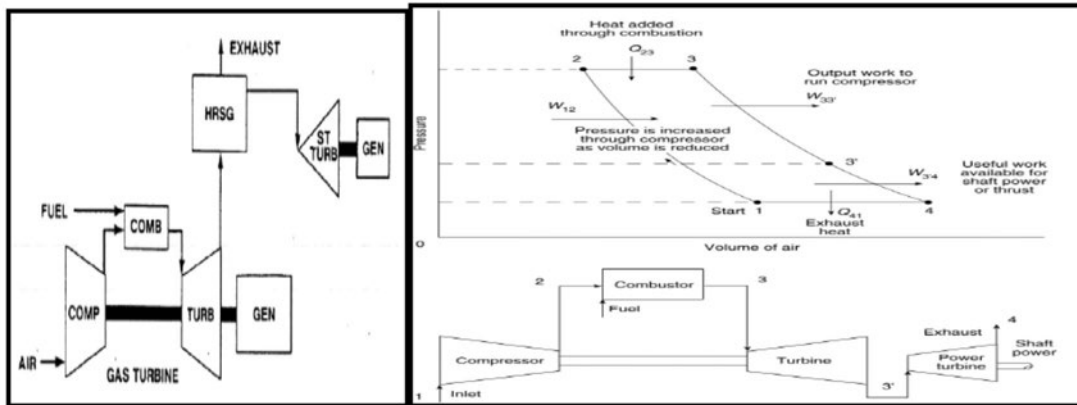


Figure 3: Simple Schematic of a Figure 4: Gas Turbines Thermodynamic Brayton Cycle Closed Cycle Gas Turbine (CCGT) [4] for Open Cycle Gas Turbine (OCGT) [7].

The shaft of the GT is coupled to an electric generator which is driven by the mechanical energy produced by the GT. The hot exhaust gas exits the GT at temperatures of between 538 °C and 593 °C and passes through a heat recovery steam generator (HRSG) where it exchanges heat with water producing steam at two or three pressures and may incorporate a reheat loop. The exhaust gas is cooled to between 80 °C and 135 °C before exiting through the HRSG stack. Depending on the selected GT and its associated exhaust temperatures, the high-pressure steam conditions from the HRSG range anywhere between 4.32 MPa(g) and 17.23 MPa(g) with temperatures of 482 °C to 565 °C [4].

The steam produced in the HRSG is used to drive a steam turbine generator. In larger plants, it is common to have two or three GT/HRSG trains providing steam for a single large steam turbine. Usually about two-thirds of the total power is produced from the GTs and one-third from the steam turbine. The steam from the steam turbine is condensed using an air-cooled condenser or a closed-loop cooling tower, and the condensate is returned to the HRSG by condensate pumps. [4] The thermodynamic cycle in the gas turbine is the Brayton cycle (Fig. 4 shows the Brayton Cycle for an open cycle gas turbine) and in the steam turbine is the Rankine cycle (Fig. 5). “An OCGT is one in which the working fluid remains gaseous throughout the thermodynamic cycle. The main advantages of open cycle GTs include flexibility in siting, low emission levels with natural gas fuel, low capital cost, and short construction time. These advantages make them attractive for peaking duty applications. Peaking duty open cycle site arrangements can be designed to allow for later conversion to combined cycle through staged development.” [4]

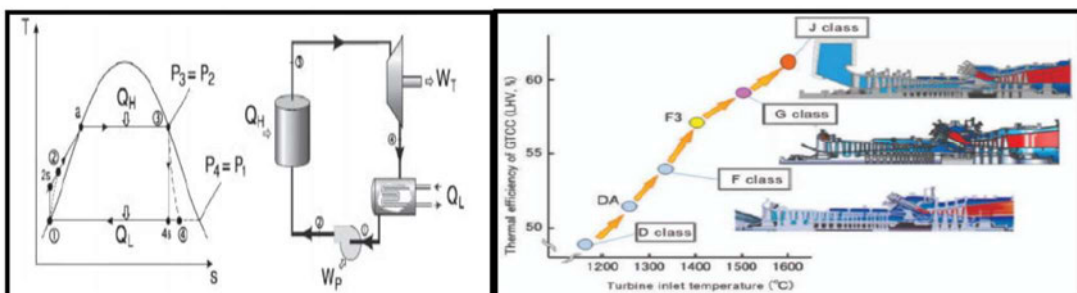


Figure 5: Steam Turbines Thermodynamic Simple Rankine Cycle [8]. Figure 6: Development History of Mitsubishi Gas Engines [9]

There are various types and categories of GTs available in the market today. These include the earlier designed E- or lower-class turbine models, the state-of-the-art heavy-duty F-, G- and H-class turbine models, and the aeroderivative GTs that are generally used in power, combined heat and power (CHP), and industrial applications. These GTs are available in given sizes or ratings. Their efficiencies are strongly influenced by several factors such as inlet mass flow, compression ratio, and expansion turbine inlet temperature. The earlier design of heavy-duty GTs had maximum turbine inlet temperatures ranging anywhere between 815 °C and 1093 °C. More recent state-of-the-art heavy-duty GT designs have turbine inlet temperatures that reach 1315 °C to 1371 °C. These turbines are designed with innovative hot gas path materials and coatings, advanced secondary air cooling systems, and enhanced sealing techniques that enable higher compression ratios and turbine inlet temperatures. The advancements made in the newer GTs by the manufacturers are generally adopted into the earlier models for efficiency and power output improvements. Fig. 6 shows the development history of Mitsubishi gas engines. Combined cycle plants can operate with both conventional and advanced GTs. With GTs running at higher turbine inlet temperatures that result in higher exhaust temperatures, it is possible to include a reheat stage in the steam turbine. This further increases the efficiency in the bottoming cycle [4].

Natural gas power plants can also produce electricity through an internal combustion engine (ICE) which is popular with smaller power plants serving specific commercial businesses or small industrial sites. They are usually used in a combined heat and power (CHP) plant that primarily produces electricity with the heat of the ICE being recovered to be used either for plant heating or site heating processes. For commercial sites, natural gas trigeneration plants are popular in that the natural gas powered ICE engine is adopted to produce electricity, the heat is recovered to produce hot water or steam that powers an absorption chiller which provides space air conditioning (heating and cooling), and remaining heat is used to satisfy water heating demands or used for process heating purposes. The Otto cycle is the thermodynamic cycle that takes place in a four-stroke spark ignition internal combustion engine. Fig. 7 and Fig. 8 show the four stroke and Otto cycles respectively.

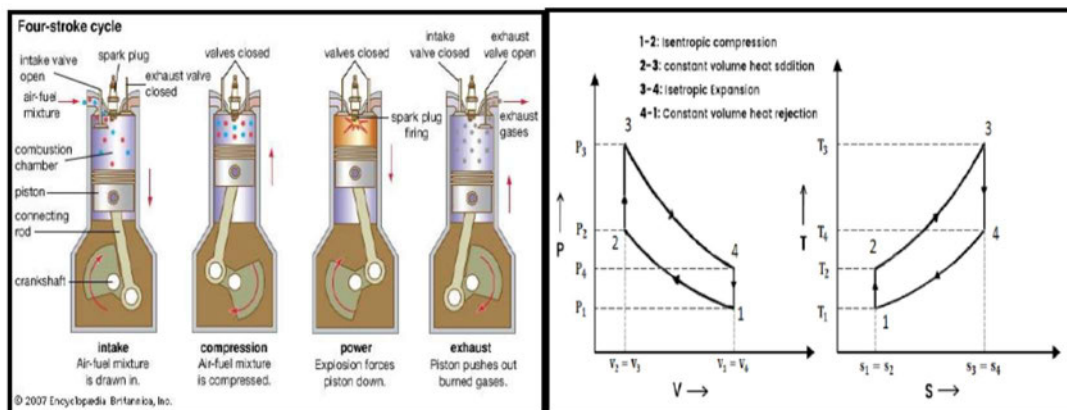


Figure 7: Spark Ignition Internal Combustion Engine. Figure 8: P-V and T-S Diagram of the Otto Cycle [11] (ICE) Working [10].

Internal combustion engines in large, stationary power generation applications are 4-stroke, spark-ignited (SI) engines. Natural gas is supplied to the engine through a gas-regulating unit that filters the gas and regulates the pressure. The maximum pressure needed by large engines is approximately 4.5 bar (absolute). Many gas supply networks have a natural gas pressure sufficient to supply engine-generators without the need for natural gas compressors. The four strokes

in a power cycle are intake, compression, expansion, and exhaust stroke. Small natural gas engines typically use natural aspiration for their air-intake. Large natural gas engines have a turbocharger to boost air flow. The turbocharger utilises exhaust gas energy in the expansion turbine to drive the air compressor. With more air flow comes more fuel, resulting in higher output. Compression ratios in the large bore engine class are in the range of 11:1 to 12:1. The compression ratio is limited since a higher compression ratio could lead to auto-ignition of the fuel which can damage the engine (knock) [4].

One of the key decisions that ACSA has to take is the technology choice for the adoption of natural gas power generation at the airports. Many factors must be considered that take into account the costs (operational, capital expenditure, maintenance, risks, insurance and the cost of doing business), and fuel availability and security for the duration of the economic lifespan of the natural gas power plants. Table 1 provides the technical comparison of gas turbines and internal combustion engines.

**Table 1: Technical Comparison of the Operation of Gas Turbines and Internal Combustion Engines [12]**

	Dimension of Comparison	Gas Turbines (GT)	Internal Combustion Engines (ICE)	Advantage to GT or ICE
1	Start-up time	Combined cycle gas turbines can take over 30 minutes to start.	Combustion engine power plants can start and reach full load in less than 10 minutes, providing flexible, quick-start capability.	ICE
2	Advantages of modularity	Modularity in architecture provides limited operational modularity for gas turbines due to the size of units, limited number of units, and efficiency trade-offs for simple cycle versus combined cycle.	Combustion engine power plants comprised of multiple generating units complement renewable energy without sacrificing efficiency.	ICE
3	Part load efficiency and flexibility	Gas turbine manufacturers boast efficiencies of 55 % or greater, at full load, dropping to below 50 % between 55 % to 65 % of full load and less than 30 % efficiency at half load. Operation at partial load and turndown limitations can restrict the flexibility of CCGT plants.	Combustion engine power plants do not have minimum load limitations and can maintain high efficiency at partial load due to modularity of design s load is decreased, individual engines within the generating set are shut down to reduce output. The engines that remain operating can generate at full load, retaining high efficiency of the generating set.	ICE
4	Pulse load efficiency and profitability	For short duration pulse load needed to balance solar and wind output, gas turbines are not profitable.	Combustion engine power plants offer significant advantages over gas turbines, with higher pulse load efficiency and the capability to provide ultra-flexible and cost-efficient output.	ICE
5	Derating due to ambient temperature	Gas turbines in particular can experience significant performance derating in hot, humid conditions.	Combustion engines are less sensitive to temperature and humidity, outperforming gas turbines in hot conditions.	ICE
6	Ramp rate	Ramp rates of most industrial frame gas turbine models are advertised as 10 MW/min up to 100 MW/min, with an average of about 25 MW/min.	Combustion engines can ramp at over 250 MW/minute, much faster than gas turbines, providing ultra-responsive power that is needed to integrate renewable energy.	ICE

7	Fuel flexibility	While gas turbines are often advertised as having fuel flexibility, about 90 % of gas turbines worldwide operate on natural gas or liquefied natural gas (LNG) because of its purity and ease of combustion. Gas turbines require about 10 minutes to switchover from baseload gas to fuel oil.	Combustion engine maintenance is not affected by fuel type as the engines are not sensitive to metals or salts in fuel oils. They are able to switch from natural gas to fuel oil instantaneously. They are also able to operate in fuel sharing mode burning varying percentages of gaseous and liquid fuels simultaneously.	ICE
8	Water consumption	A combined cycle gas turbine power plant (CCGT) with a recirculating system will consume approximately 780 litres/MWh.	Combustion engine power plant operating in simple cycle on natural gas will consume a mere 3 litres/MWh. This is due to the high efficiency and low cooling needs.	ICE

The technology to be adopted will be decided upon in the next stage of the project cycle, i.e., the feasibility and front-end engineering design (FEED) study (FEL 3), considering the technical dimension given in Table 1.

#### Assessment of Technology Maturity

“John Barber was granted the world’s first gas turbine patent, in 1791 in England, for his design that used the thermodynamic cycle of the modern gas turbine but obviously not the similar components. In 1903, Norwegian engineer Aegidius Elling successfully designed and built the first simple cycle gas turbine with a net power output of 8.1 kW and turbine inlet temperature of 400 °C. During the same time when Elling’s work was in progress, Franz Stolze, a German engineer who got patent in 1899 for his gas turbine that was designed in 1873, was installing world’s first complete axial design GT at Berlin-Weissensee Power Station in Germany and tested it in 1905. Another gas turbine of historical importance, developed by Charles Lamale and Rene Armengaud and designed by French engineer August Rateau in 1905-1906. In 1920s and 1930s considerable amount of efforts were made at BBC (later ABB and now Alstom Power) in developing efficient axial compressors. The world’s first successful electric power generating gas turbine consisting of a single shaft design with a 23 stage axial compressor, one single can combustor and a seven stage axial turbine, developed by BBC went into commercial operation in Neuchatel, Switzerland in 1939.” [13]

The use of natural gas for electricity generation is not a new concept, but a tried and tested, mature technology in use around the world. There are more than 130 major natural gas to power plants installed in the world ranging from 55 MW in Australia (Barcaldine Power Station) to 5.6 GW in Russia (Surgat-2 Power Station) [14].

Natural gas has gained popularity over the last two and a half decades as a choice for electricity production with oil and coal sources being somewhat at a lower growth rate in terms of use for electricity. This could be owing to price fluctuations of oil and the carbon footprint associated with coal. In the light of climate change natural gas is the preferred fuel for efficiency and reduction in carbon dioxide emissions associated with electricity generation (figure 9). South Africa has been growing their uptake of natural gas over the last decade and a half (figure 10). The gas turbine market is dominated by North America and the Asia Pacific (figure 11).

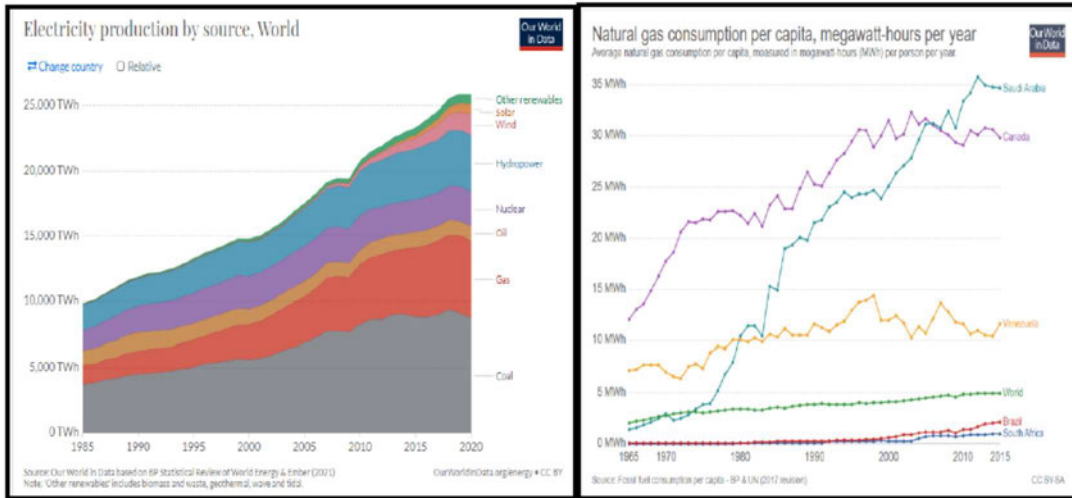


Figure 9: Growing Trend of use of Natural Gas. Figure 10: South Africa Appearing on the Trend of to Produce Electricity [15] Natural Gas Consumption [16].



Figure 11: Gas Turbine Market Share [17]. Figure 12: Sasol Natural Gas Power Plant [19].

Reciprocating internal combustion engines are a well-established and widely used technology. Worldwide production for reciprocating internal combustion engines is over 200 million units per year. Reciprocating engines include both diesel and spark-ignition configurations. The long history of technical development and high production levels have contributed to making reciprocating engines a rugged, reliable, and economic choice as a prime mover for CHP applications. Reciprocating engine technology has improved dramatically over the past three decades, driven by economic and environmental pressures for power density improvements (more output per unit of engine displacement), increased fuel efficiency, and reduced emissions. There are over 2 000 active reciprocating engine combined heat and power (CHP) installations in the U.S. providing nearly 2.3 GW of power capacity. These systems are predominantly spark ignition engines fuelled by natural gas and other gaseous fuels (biogas, landfill gas). Natural gas is lower in cost than petroleum based fuels and emissions control is generally more effective using gaseous fuels. Reciprocating engine CHP systems are common in universities, hospitals, water treatment facilities, industrial facilities, and commercial and residential buildings. Facility capacities range from 30 kW to 30 MW, with many larger facilities comprised of multiple units. Spark ignited engines fuelled by natural gas or other gaseous fuels represent 84 % of the installed reciprocating engine CHP capacity.

Current natural gas engines for power generation offer low first cost, fast start-up, proven reliability when properly maintained, excellent load-following characteristics, and significant heat recovery potential. Natural gas is the predominant spark ignition engine fuel used in electric generation and CHP applications. Dual fuel engines are predominantly fuelled by natural gas with a small percentage of diesel oil added. There are two main configurations for introducing the gaseous fuel in a dual fuel engine. These engines can be purpose built or conversions of diesel engines. Such engines can be switched to 100 % diesel operation. Dual fuel engines provide a multi-use functionality. Operation on predominantly cheaper and cleaner burning natural gas allows the engine to be used in CHP and peak shaving applications, while operation on 100 % diesel allows the engine to also meet the onsite fuel requirements of emergency generators. The dual function adds benefit in applications that have specific emergency generator requirements such as in hospitals or in public buildings [18].

In South Africa, the largest natural gas powerplant is owned by Sasol. The 140 MW plant is located at Sasolburg, South Africa. It was commissioned in December 2012 and has been fully operational from July 2013. [19] Newcastle Energy own an existing 18.5 MW capacity gas fired co-generation plant within the Karbochem Industrial Complex in Newcastle, KwaZulu-Natal. Through the Newcastle Gas Engine Power Plant (NGEPP) Independent Power Producer (IPP) project, Newcastle Energy proposes to increase its electricity generation capacity, within the same site, to approximately 100 MW [20].

Avon Peaking Power (Avon) is an energy generating facility that is located in Shakaskraal, in the province of KwaZulu-Natal, owned by Avon Peaking Power (RF) Pty Ltd. Avon is a 670 MW greenfield OCGT facility that is privately owned. It was built and funded by the owner, and then endorsed by the Department of Energy (DoE). It solely supplies power to Eskom under a 15 year power purchase agreement (PPA). The facility supplies electricity to the national grid during peak demand hours as well as during emergency situations. In addition to its generating capabilities the facility can also be used to regulate network voltage fluctuations, that is, to stabilise the grid. Avon is located adjacent to an existing high-voltage Eskom substation with the electricity being fed into the transmission system at 275 kV. [21] There are other power plants in South Africa using gas turbine generators, fuelled by diesel oil and other fuels.

Dedisa Peaking Power (Dedisa) plant is a facility owned by Dedisa Peaking Power (RF) Pty Ltd. It performs the same function as the Avon peaking plant but is 335 MW, located in the Coega Industrial Development Zone (IDZ) in Port Elizabeth [22]. East London in South Africa is home to Eskom's Port Rex Power Station, a 171 MW power plant consisting of three 57 MW gas turbine generators, which is critical for system voltage stability in the Eastern Cape. The station can be operated by remote control from Eskom's National Control Centre at Simmerpan to provide back-up and black-start. [23]

The Western Cape in South Africa has three power stations running with gas turbine generators. Acacia Power Station consists of three 57 MW gas turbine engines at an installed capacity of 171 MW and provides back-up electrical supply to Koeberg Nuclear Power Station as per National Nuclear Regulator licensing requirement [24]. Ankerlig Power Station is a 1 327 MW gas turbine plant consisting of nine OCGT generating units running on fuel oil (diesel) [25], the Gourikwa Power Station is 740 MW and consists of five units [26].

There is a 2 MW natural gas trigeneration plant operating in Fairland, Gauteng owned by mobile telecommunications operator MTN which powers a building housing a data centre and a test switch centre at its head office campus. The trigeneration plant is powered by methane gas, which is piped over 800 km from Sasol's Mozambique gas fields to Egoli Gas in Johannesburg, and then to the company's office, MTN South Africa. The 400 °C exhaust gas is sent

through lithium bromide absorption chillers to cool water, which MTN uses for the cooling needs in the building. The plant consisted of two 1 MW General Electric Jenbacher gas engines, and the absorption chillers were supplied by Carrier [27].

The MTN trigeneration plant was visited by the ACSA technical team in an effort to understand how the plant operates and serves the energy needs of the buildings at the MTN head office in Fairways. This plant setup, fuel supply and energy distribution (electricity, chilled water and heat) is what ACSA is considering in the investigation of the adoption of natural gas as a fuel supply for the three airports, ORTIA, CTIA and KSIA.

**Cost Benefit Analysis**

Due to this technoeconomic assessment being a desktop exercise meant to provide an indication of the economics of the adoption of natural gas fuel trigeneration plants for airports at pre-feasibility (FEL 2 or Front-End Loading Stage 2), factors such as the cost of fuel gas supply logistics, the savings and benefits of using air conditioning and heat are excluded. The capital cost of the plant was based on the MTN trigeneration plant cost.

*(a) Rationale for the Scale of Natural Gas to Power*

The rationale for the selection of the size of electrical generators using natural gas power lies in the conceptualisation of the energy mix for the airports towards zero carbon emissions. Figures 17, 18 and 19 show the electrical demand approximated for ORTIA, CTIA and KSIA respectively in 2018. The total electrical demand for ORTIA is 16 MVA, for CTIA is 10.5 MVA and for KSIA is 5.7 MVA. Conceptualising the energy mix for the airports, shows that the plan is that when full electrical demand occurs (16 MVA for ORTIA, 10.5 MVA for CTIA and 5.7 MVA for KSIA), the critical load will be supplied by the national electricity grid. For ORTIA and CTIA, this critical load forms about 50 % of the baseload which is about 25 % of the total electrical demand. KSIA’s baseload is about 45 % of the total energy demand, with the critical load being 20 %.

The remainder of the baseload at the airports were considered to be supplied from a lower carbon energy source other than the national electricity grid (alternative energy source). HVAC chiller loads forming part of the fluctuating load currently consuming electricity were considered to be changed to heat demand (renewable or waste heat) through the use of absorption chillers. The remainder of the fluctuating electrical load was considered to be supplied by renewable energy such as solar energy and wind energy.

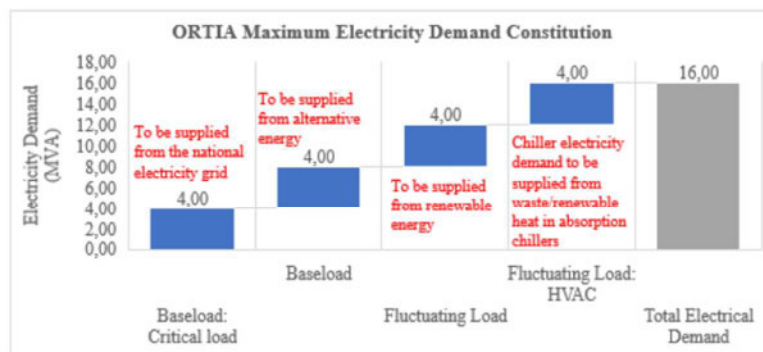


Figure 13: ORTIA Maximum Electrical Demand and Concept Plan for Energy Security.

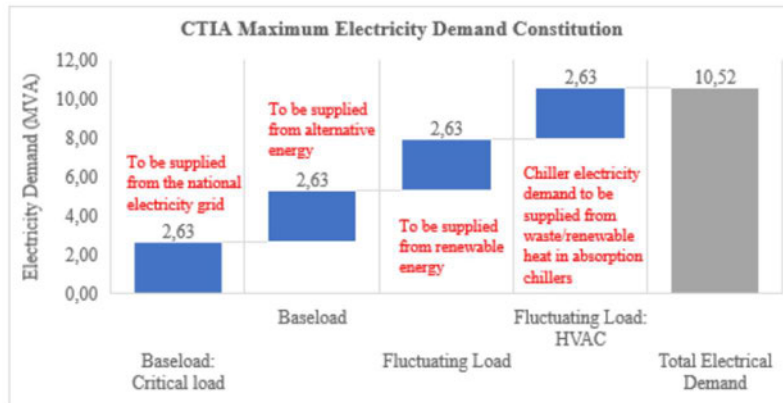


Figure 14: CTIA Maximum Electrical Demand and Concept Plan for Energy Security.

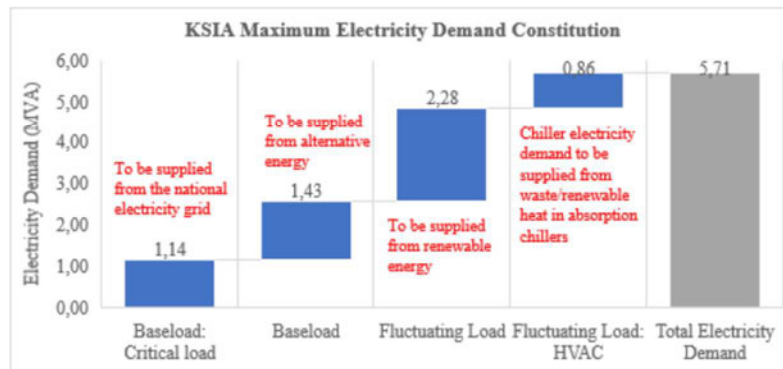


Figure 15: KSIA Maximum Electrical Demand and Concept Plan for Energy Security.

The focus in this paper is using natural gas as an alternative energy source to power the airports' baseload energy supply. For the fluctuating load, the renewable energy considered for the airports were solar photovoltaic (PV) plants. Solar PV was considered for investigation as the renewable energy option due to its ease of incorporation, familiarity to ACSA airports' operating environment and the availability of sufficient solar irradiation at all three locations. Natural gas was selected due to its availability in the three geographical regions, its maturity in the market and its high capacity factor.

Following the conceptual energy mix summarised in Fig. 13, 14 and 15, a FEL 2 (prefeasibility study) was performed on the energy sources proposed. Space availability for the solar PV plants was taken into consideration due to the land limitations that ORTIA, CTIA and KSIA face as growing airports where land is reserved for commercial and operational development. The capacity of solar PV plants needed to satisfy the fluctuating load was quite demanding in terms of spatial constraints. When compared to the option of increasing the capacity of the natural gas generator to rather serve the fluctuating load, such an investment seems like a better option. Refer to Tables 2, 3 and 4 for ORTIA, CTIA and KSIA respectively.

Table 2: Rationale for ORTIA's Gas-to-Power Plant Sizing

	Energy Mix Concept	Energy Mix Concept with Spatial Constraints Applied	Optimised Energy Mix Concept
Energy generating plant sizes and Capital Expenditure (2018 basis)	<p><b>Fluctuating load:</b> Solar PV 4 MW nominal power output which is 21 MW installed capacity at 19 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), the project capital = ZAR 510m (2018 basis)</li> </ul> <p><b>Baseload:</b> Gas-to-power 4 MW nominal power output which is 5.25 MW installed capacity at 76 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 115m (2018 basis)</li> </ul>	<p><b>Fluctuating load:</b> Solar PV 750 kW nominal power output which is 4 MW installed capacity at 19 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 97m (2018 basis)</li> </ul> <p><b>Baseload</b> Gas-to-power 7.25 MW nominal power output which is 10.5 MW installed capacity at 69 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 230m (2018 basis)</li> </ul>	<p><b>Baseload and fluctuating load:</b> Natural gas generator 8 MW nominal power output which is 10.5 MW installed capacity at 76 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 230m (2018 basis)</li> </ul>
Operational expenditure parameters used (2018 basis)	<ul style="list-style-type: none"> <li><b>Solar PV:</b> Fixed operations and maintenance cost – ZAR 331 /kW-year;</li> <li><b>G2P:</b> Fixed operations and maintenance cost – ZAR 175 /kW-year; Variable operations and maintenance cost – ZAR 23.2 /MWh; Fuel – ZAR 135 /GJ (based on Sasol rates)</li> </ul>		
Macro-economic parameters used (2018 basis)	<ul style="list-style-type: none"> <li>Discount rate: 11.5 %, Corporate tax rate: 28 %, Economic life: 20 years</li> </ul>		

Table 3: Rationale for CTIA's Gas-to-Power Plant Sizing

	Energy Mix Concept	Energy Mix Concept with Spatial Constraints Applied	Optimised Energy Mix Concept
Energy generating plant sizes and capital expenditure (2018 basis)	<p><b>Fluctuating load:</b> Solar PV 2.63 MW nominal power output which is 13.8 MW installed capacity at 19 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 335m (2018 basis)</li> </ul> <p><b>Baseload:</b> Gas-to-power 2.63 MW nominal power output which is 3.5 MW installed capacity at 75 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 18k /kW (2015 end of job cost</li> </ul>	<p><b>Fluctuating load:</b> Solar PV 1.9 MW nominal power output which is 10 MW installed capacity at 19 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 243m (2018 basis)</li> </ul> <p><b>Baseload</b> Gas-to-power 3.36 MW nominal power output which is 5.25 MW installed capacity at 64 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW</li> </ul>	<p><b>Baseload and fluctuating load:</b> Natural gas generator 5.26 MW nominal power output which is 7 MW installed capacity at 75 % CF</p> <ul style="list-style-type: none"> <li>At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 153m (2018 basis)</li> </ul>

	of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 77m (2018 basis)	natural gas trigeneration plant), project capital = ZAR 115m (2018 basis)	
Operational expenditure parameters used (2018 basis)	<ul style="list-style-type: none"> <li>• <b>Solar PV:</b> Fixed operations and maintenance cost – ZAR 331 /kW-year;</li> <li>• <b>G2P:</b> Fixed operations and maintenance cost – ZAR 175 /kW-year; Variable operations and maintenance cost – ZAR 23.2 /MWh; Fuel – ZAR 135 /GJ (based on Sasol rates)</li> </ul>		
Macro-economic parameters used (2018 basis)	<ul style="list-style-type: none"> <li>• Discount rate: 11.5 %, Corporate tax rate: 28 %, Economic life: 20 years</li> </ul>		

Table 4: Rationale for KSIA’s Gas-to-Power Plant Sizing

	Energy Mix Concept	Energy Mix Concept with Spatial Constraints Applied	Optimised Energy Mix Concept
Energy generating plant sizes and Capital Expenditure (2018 basis)	<p><b>Fluctuating load:</b> Solar PV 1.43 MW nominal power output which is 7.25 MW installed capacity at 19 % CF</p> <ul style="list-style-type: none"> <li>• At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 182m (2018 basis)</li> </ul> <p><b>Baseload:</b> Gas to Power 2.28 MW nominal power output which is 3.5 MW installed capacity at 65 % CF</p> <ul style="list-style-type: none"> <li>• At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 77m (2018 basis)</li> </ul>	<p><b>Fluctuating load:</b> Solar PV 1.9 MW nominal power output which is 10 MW installed capacity at 19 % CF</p> <ul style="list-style-type: none"> <li>• At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 243m (2018 basis)</li> </ul> <p><b>Baseload:</b> Gas to Power 1.81 MW nominal power output which is 3.5 MW installed capacity at 52 % CF</p> <ul style="list-style-type: none"> <li>• At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 77m (2018 basis)</li> </ul>	<p><b>Baseload and fluctuating load:</b> Natural gas generator 3.71 MW nominal power output which is 5.25 MW installed capacity at 71 % CF</p> <ul style="list-style-type: none"> <li>• At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 115m (2018 basis)</li> </ul>
Operational expenditure parameters used (2018 basis)	<ul style="list-style-type: none"> <li>• <b>Solar PV:</b> Fixed operations and maintenance cost – ZAR 331 /kW-year;</li> <li>• <b>G2P:</b> Fixed operations and maintenance cost – ZAR 175 /kW-year; Variable operations and maintenance cost – ZAR 23.2 /MWh; Fuel – ZAR 135 /GJ (based on Sasol rates)</li> </ul>		
Macro-economic parameters used (2018 basis)	<ul style="list-style-type: none"> <li>• Discount rate: 11.5 %, Corporate tax rate: 28 %, Economic life: 20 years</li> </ul>		

The nominal capacities of the natural gas-to-power technologies thus take on the fluctuating demand at smaller engine sizes for each of the international airports. The resulting installation capacity for each installation investigated for feasibility is 10.5 MW, 7 MW and 5.25 MW for ORIA, CTIA and KSIA respectively. Full details are provided below.

**(b) Feasibility Study Results**

Airports Company South Africa has an economic modelling department that creates economic models in excel spreadsheets. The economic model yields the net present value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index. The IRR is compared to ACSA's 11.5% weighted average cost of capital (WACC) rate (2018) to determine economic feasibility. When the NPV is zero or positive it is an investment that pays itself off during its economic lifespan. The net present value (NPV) equation used in the economic model is given below, Equation (1), where the internal rate of return (IRR) is the return ( $i$  in below equation) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the economic lifespan of the investment. The profitability index (PI) provided in Equation (2) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^T \frac{R_t}{(1+i)^t} \quad \text{Equation (1)}$$

Where:  $R_t$  = net cash inflows – outflows during a single period  $t$

- $i$  = discount rate or return that could be earned
- $t$  = number of time periods

$$PI = \frac{PV \text{ of future cash flows}}{\text{Initial Investment}} \quad \text{Equation (2)}$$

Tables 5, 6 and 7 show the economic model inputs and outputs. In summary:

- OR Tambo International Airport – For a 10.5 MW natural gas-powered plant, the NPV is ZAR 347.75m (positive) and IRR of 22.8 % (exceeding the ACSA WACC rate of 11.5 %) which shows that the installation is feasible.
- Cape Town International Airport – For a 7 MW natural gas-powered plant, the NPV is ZAR 226m (positive) and IRR of 22.6 % (exceeding the ACSA WACC rate of 11.5 %) which shows that the installation is feasible.
- King Shaka International Airport – For a 5.25 MW natural gas-powered plant, the NPV is ZAR 87.29m (positive) and IRR of 17.7 % (exceeding the ACSA WACC rate of 11.5 %) which shows that the installation is feasible.

**Table 5: O R Tambo International Airport Economic Inputs and Outputs**

Inputs		Output	
MW natural gas powerplant rated capacity	10.5	End of job cost	ZAR 230m
Capital cost (2018 basis)	ZAR 230m	Net present value	ZAR 347.75m
Electricity saving at beneficial operation	70 080 000 kWh/annum	Internal rate of return	22.8 %
Electricity cost (2018)	ZAR 1.47 /kWh	Nominal payback period	6 years
Beneficial operation	2020	Profitability index	2.6
Construction period	2 years		

Corporate tax	28 %	
Economic lifespan	20 years	
Operational and maintenance cost (2018 terms)	Fixed: ZAR 175 /kW-year; Variable: ZAR 23.2 /MWh; Fuel: ZAR 135 /GJ	
Eskom tariff escalation	5.1 % per annum	
CAPEX escalation factor	1.05	

**Table 6: Cape Town International Airport Economic Inputs and Outputs**

Inputs		Output	
MW natural gas powerplant rated capacity	7	End of job cost	ZAR 153m
Capital cost @ 2018	ZAR 153m	Net present value	ZAR 226m
Electricity saving at beneficial operation	46 077 600 kWh/annum	Internal rate of return	22.6 %
Electricity cost (2018)	ZAR 1.47 /kWh	Nominal payback period	6 years
Beneficial operation	2020	Profitability index	2.56
Construction period	2 years		
Corporate tax	28 %		
Economic lifespan	20 years		
Operational and Maintenance cost (2018 terms)	Fixed: ZAR 175 /kW-year; Variable: ZAR 23.2 /MWh; Fuel: ZAR 135 /GJ		
Eskom tariff escalation factor	5.1 % per annum		
CAPEX escalation factor	1.05		

**Table 7: King Shaka International Airport Economic Inputs and Outputs**

Inputs		Output	
MW natural gas powerplant rated capacity	5.25	End of job cost	ZAR 115m
Capital cost @ 2018	ZAR 115m	Net present value	ZAR 87.29m
Electricity saving at beneficial operation	32 499 600 kWh/annum	Internal rate of return	17.7 %
Electricity cost (2018)	ZAR 1.29 /kWh	Nominal payback period	8 years
Beneficial operation	2020	Profitability index	1.81
Construction period	2 years		
Corporate tax	28 %		
Economic lifespan	20 years		
Operational and maintenance cost (2018 terms)	Fixed: ZAR 175 /kW-year; Variable: ZAR 23.2 /MWh; Fuel: ZAR 135 /GJ		
Eskom tariff escalation factor	5.1 % per annum		
CAPEX escalation factor	1.05		

This prefeasibility study (FEL 2) conducted for the three selected airports show that all three natural gas trigeneration plant installations are feasible, i.e., ORTIA, CTIA and KSIA. To determine the factors that the prefeasibility would be most susceptible to, a sensitivity analysis was done.

**(c) Sensitivity Analysis**

For the sensitivity analysis, the four factors that play a role in the determination of the profitability of the investment were varied equally to see the significance of the impact that each parameter had on the profitability relative to each other. The base cases used are described in table 5, Table 6 and table 7 for ORTIA, CTIA and KSIA respectively.

The profitability of the investment relies on the capital cost of the installation, the cost of electricity from Eskom, the operations and maintenance cost, and the fuel (feedstock) cost of the natural gas trigeneration plants. The effect that these four factors have on the NPV of the installations can be seen in Fig. 16, figure 17 and figure 18.

A 10 % increase or a 10 % decrease in the capital expenditure, electricity tariff, feedstock and operations and maintenance (O&M) cost shows that the electricity tariff is the most significant factor and the O&M cost the least significant factor in the feasibility of the natural gas trigeneration plant installation investments for ORTIA, CTIA and KSIA. A 10 % increase in the electricity tariff results in an increase in the NPV of ZAR 115.4m for ORTIA; ZAR 75.9m for CTIA and ZAR 47m for KSIA, however a 10% decrease in the electricity cost shows a decrease in NPV of ZAR 115.4m for ORTIA; ZAR 75.9m for CTIA and ZAR 47m for KSIA. A 10 % change in the feedstock cost has just over 50 % of the effect that the electricity tariff has the NPV. These results tell us that we should monitor the electricity tariffs of the airports closely as a change will affect the feasibility of the investment.

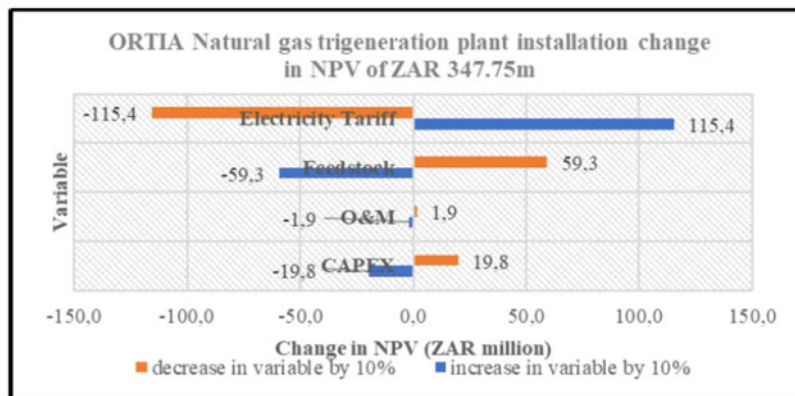


Figure 16: Sensitivity Analysis of the ORTIA Natural Gas Trigeneration Plant Installation.

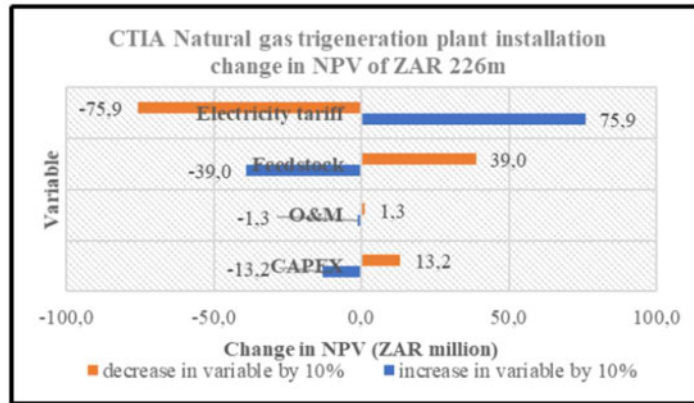


Figure 17: Sensitivity Analysis of the CTIA Natural Gas Trigeneration Plant Installation.

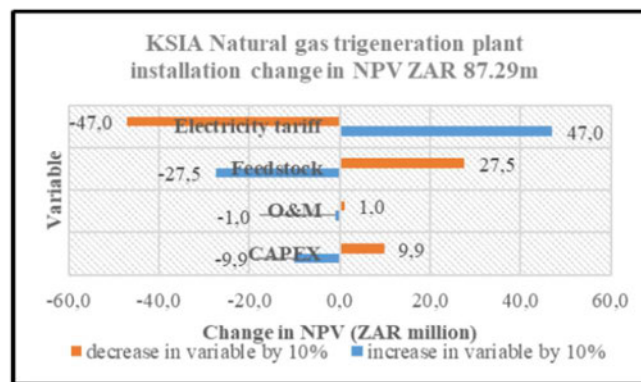


Figure 18: Sensitivity Analysis of the KSIA Natural Gas Trigeneration Plant Installation.

The results also show that the feasibility is sound in that even a 10 % change in the electricity, capital expenditure required, or operational expenditure required will not make the investment into natural gas trigeneration powerplants for ORTIA, CTIA and KSIA unfeasible.

#### Technology Risk Assessment

The natural gas powerplant technology being used as a baseload SOURCE of energy for ORTIA, CTIA and KSIA must be always available. The fluctuating load portion that the natural gas powerplant is meant to serve requires that the plant be able to respond to the varying energy demands efficiently and effectively. Table 8 performs a technology risk assessment and provides the possible mitigations.

Table 8: Technology Risk Assessment for the Natural Gas Power Plant for ORTIA, CTIA, KSIA

Risk	Description	Possible Mitigation
Feedstock supply	Natural gas supply is primarily from Sasol. Should their contract with Mozambique be terminated in 2028, alternative suppliers of natural gas will need to be acquired.	<ul style="list-style-type: none"> <li>Alternative suppliers of natural gas should be identified.</li> <li>Adopt combustion engines that can use more than one type of feedstock.</li> </ul>
Single point of failure	This is failure at a single point which, without, the entire plant will not generate electricity or heat for air conditioning or hot water. The failure of the natural gas engine is the single point of failure.	<ul style="list-style-type: none"> <li>Modularity must be introduced such that should a failure occur in one engine, the rest of the engines will be able to supply the energy demand.</li> <li>Control systems must be employed to ensure that this transition is smooth and there is no impact on airport operations.</li> </ul>
Agility	This is the ability of the plant's operational output to respond to varying demand timeously without causing operational impacts or damage to infrastructure.	<ul style="list-style-type: none"> <li>Adopt natural gas engines that have a high ramp rate and are able to respond to varying energy demand effectively.</li> <li>Ensure that controls are tested during commissioning to guarantee the system's ability to respond to varying demand without causing damage to infrastructure or negatively impacting airport operations.</li> </ul>
Turn-down ratio	This is the ability of the plant design capacity to be increased and decreased to suit operational demand and work effectively for the purposes of maintenance towards cost effectiveness.	<ul style="list-style-type: none"> <li>Understand the demand profile of the airport's electricity, air conditioning and water heating requirements and apply the appropriate scale for the airport based on plant utilisation of the electricity and hot water generated.</li> <li>Consider economies of scale for total plant design capacity and modular operations for the various demand requirements at every hour in the 24-hour day</li> </ul>

### 5. Airports Integration Strategy

The natural gas power plant primarily produces electricity that will be used to satisfy the airports' electricity need. The natural gas powerplant generates a significant amount of heat which can then be harvested and used to satisfy air conditioning demand through the adoption of hot water driven absorption chillers and water heating demands (Fig. 19). Table 9 shows the airport integration strategies for ORTIA, CTIA and KSIA.

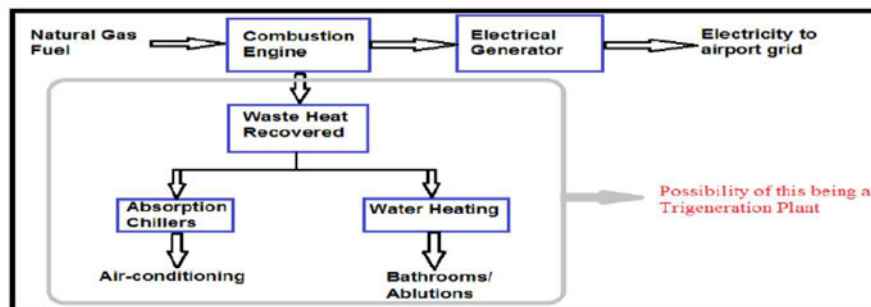


Figure 19: Natural Gas Power Plant Configuration with the Possibility of Waste Heat Recovery for Trigenation.

**Table 9: Suggested Integration Strategy of Natural gas Trigeneration for ORTIA, CTIA, KSIA**

Generation Component of the Natural Gas Trigeneration Plant	Suggested Integration Strategy	Required Investigation
<b>Electricity</b>	Provide electricity to the airport’s electrical reticulation system as a primary supply with Eskom supply as back up for the rest of the airport’s electrical requirement. A smart grid to be employed to coordinate power supply such that the airport receives smooth output of electricity while maximising the cost.	Investigate electricity consumption profile of the airport at various times of the day and during various seasons to secure new notified maximum demand (NMD) from Eskom.
<b>Air conditioning</b>	Absorption chillers to be employed that utilise waste heat from the natural gas engines to produce chilled water for distribution to the air handling units. Prior to distribution of chilled water to air handling units, there should be a buffer chilled water storage tank. Chilled water should be utilised from the absorption chillers primarily. The chillers in the original HVAC plantrooms should be used and cycled as per their cost effectiveness to produce chilled water to make up for any shortfall in production of chilled water. In terms of heating, this should be provided by the absorption chillers primarily. Heaters in air handling units at ORTIA should be disconnected.	Investigate air conditioning demand and how much of this can be satisfied through the absorption chillers; investigate and ascertain piping and instrumentation required for chiller integration.
<b>Hot Water</b>	Hot water to be stored in a hot water tank/s and distributed to the various areas for rest room showers and basins. Should pipe runs result in significant heat loss, this heat loss should be “made up” as per the design with reheat (using, for example, spot heaters for basins and geysers for showers).	Investigate the hot water requirements of the airport and that which can be satisfied from the plant; investigate and ascertain piping and instrumentation required for hot water integration.

**Proposed Operational Philosophy**

**(a) Technical**

When the natural gas power plant is running and providing electricity to the airport, the production of chilled water and hot water will be possible. Electricity will be provided as per demand of the airport and running of the generators will be such that it is at optimum capacity for the production of electricity, chilled water and hot water requirements with make-up of electricity requirements being provided by Eskom, with existing chillers and hot water making up shortfalls for air conditioning and water heating requirements.

**(b) Plant Operation for Business Continuity and Cost Effectiveness**

Plant operation should be designed to run in modular fashion considering the maintenance downtime required. In case of total plant failure either due to technical issues or lack of fuel supply, this should be addressed by business continuity plans that must be put into place before beneficial operation of the plant. This will include memoranda of understanding with various suppliers for alternative fuel supply and capacity required from Eskom in the event of total failure. Guarantees from the plant operators and insurance should also be in place to protect the cost effectiveness of providing electricity to the airport via the natural gas power plants.

**(c) Operations and Maintenance**

It is proposed that the plant be constructed by ACSA, however, the operations and maintenance should be contracted out as

this is not ACSA's core function nor does the company have the internal skills to operate and maintain this type of plant. With time, the operations and maintenance skills should be transferred to the inhouse team.

## CONCLUSIONS

Using natural gas powerplants to serve the baseload and fluctuating energy demands of ORTIA, CTIA and KSIA are feasible. The waste heat harvested from the natural gas engines can be used to serve the airport's space conditioning needs as well as provide for their water heating needs. Natural gas engine technology is a mature technology world-wide, however, not as common in South Africa. Natural gas as a source of fuel has about 50 % of the carbon footprint of the traditional coal-fired power stations. The natural gas power plants will be instrumental in transitioning the three international airports toward a lower carbon footprint, enabling strides toward the airports' agenda of its green star rating through the Green Building Council South Africa (GBCSA) and the Airports Council International (ACI) carbon accreditation. The impact that the natural gas power plants potentially have on the reduction of the carbon footprint of the airports are around 30 % for the ACSA airports. Individually, ORTIA's carbon footprint in electricity consumption will be reduced by about 30 %, CTIA by about 34 % and KSIA by about 48 % by implementing and using natural gas powerplants. To adopt these natural gas powerplants, a final feasibility study (FEL 3) drawn from individual preliminary designs (Front End Engineering Designs or FEED studies) for the airports, together with a detailed risk analysis and legislative requirements including the cost of all requirements must be evaluated against the benefits, so that a financial investment decision can be made.

## REFERENCES

1. F. Y. Liang, M. Ryvak, S. Sayeed, N. Zhao, "The role of natural gas as a primary fuel in the near future, including comparisons of acquisition, transmission and waste handling costs of as with competitive alternatives", *Chemistry Central Journal* 2012, 6(Suppl 1):S4, <http://journal.chemistrycentral.com/content/6/S1/S4>.
2. Universal Technical Institute, "CNG vs. LPG vs. LNG fuel: Understanding the differences", 30 January 2020, <https://www.uti.edu/blog/diesel/cng-lpg-lng-fuel#:~:text=While%20liquefied%20natural%20gas%20and,where%20it%20is%20very%20compact.&text=CNG%20also%20has%20lower%20production%20costs%20than%20LNG,> accessed 25/05/2021
3. The MET group, "CNG vs LNG: what are the differences?", 20 November 2020, <https://group.met.com/energy-insight/cng-vs-lng/15>, accessed 25/05/2021
4. Lyon, C., "power generation technology data for integrated resource plan of South Africa", *Technical Update by Electric Power Research Institute (EPRI) prepared for Department of Energy South Africa*, April 2017.
5. Okoroigwe, E. C., "Solar gas turbine systems", *Encyclopedia of Sustainable Technologies*, 2017, 377–388.
6. Mevissen, F., Meo, M., "A review of NDT/Structural health monitoring techniques for hot gas components in gas turbines", *Sensors* 2019, 19, 711; doi:10.3390/s19030711
7. Langston, L.S., "Turbines, Gas", *Encyclopedia of Energy*, 2004, ISBN 978-0-12-176480-7, <https://www.sciencedirect.com/topics/engineering/gas-brayton-cycle>, accessed 25/05/2021
8. Khalil, E., "Steam power plants", *WIT Transactions on State of the Art in Science and Engineering*, Vol 42, <http://www.witpress.com/>
9. <https://www.ee.co.za/article/development-high-efficiency-flexible-gas-turbine.html>, accessed 25/05/2021

10. <https://www.britannica.com/technology/four-stroke-cycle>, accessed 25/05/2021
11. <https://theunboxfactory.com/otto-cycle/>, accessed 25/05/2021
12. <https://www.wartsila.com/energy/learn-more/technical-comparisons/gas-turbine-for-power-generation-introduction>, accessed 31/05/2021
13. Bhargava, R., Bianchi, M., De Pascale, A., Montenegro, A., Peretto, A., "Gas turbine-based power cycles – a state-of-the-art review", *International Conference on Power Engineering-2007*, October 23-27, 2007, Hangzhou, China
14. List of natural gas power generation stations, [https://en.wikipedia.org/wiki/List\\_of\\_natural\\_gas\\_power\\_stations](https://en.wikipedia.org/wiki/List_of_natural_gas_power_stations), accessed 06/03/2021
15. Our World in Data, <https://ourworldindata.org/grapher/electricity-prod-source-stacked>, accessed 06/06/2021.
16. Our World in Data, <https://ourworldindata.org/grapher/gas-consumption-per-capita>, accessed 06/06/2021.
17. <https://www.transparencymarketresearch.com/gas-turbines-market.html>, accessed 25/05/2021.
18. U.S. Environmental Protection Agency Combined Heat and Power Partnership, "Catalog of CHP technologies", March 2015.
19. Power Technology, "Sasol gas engine power plant". Retrieved from <https://www.power-technology.com/projects/sasol-gas-engine-power-plant/>, accessed 09/06/2021.
20. <https://docs.srk.co.za/en/za-newcastle-gas-engine-power-plant-100-mw-ipp-project-scoping-eia>, accessed 09/06/2021.
21. <https://www.peakers.com/avon.html>, accessed 10/06/2021
22. <https://www.peakers.com/dedisa.html>, accessed 11/06/2021
23. [https://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Peaking/Pages/Port\\_Rex\\_Power\\_Station.aspx](https://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Peaking/Pages/Port_Rex_Power_Station.aspx), accessed 11/06/2021
24. [https://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Peaking/Pages/Acacia\\_Power\\_Station.aspx](https://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Peaking/Pages/Acacia_Power_Station.aspx), accessed 11/06/2021
25. <https://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Peaking/Pages/Ankerlig.aspx>, accessed 11/06/2021
26. <https://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Pages/Gourikwa.aspx>, accessed 11/06/2021
27. <https://www.engineeringnews.co.za/article/mtm-unveils-r22m-trigeneration-power-plant-2010-08-02>, accessed 12/06/2021
28. Okyere, Stephen, Jiaqi Yang, and Monde Aminatou. "Influence of Multimodal Transport System Dynamics on Logistics Responsiveness: An Ordinal Logistic Regression Approach." *International Journal of Civil Engineering (IJCE)* 6.6 (2017): 9-24.
29. Emeara, Mohamed S., Ahmed Farouk Abdelgawad, and Ahmed H. EL Abagy. "A Case Study of Cairo International Airport "Cia": Proposed Installation of Photovoltaic "PV" For High Energy-Production." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 10.5, Oct 2020, 399–410
30. Okokpujie, I. P., et al. "Optimal Design and Stress/Strain Analysis of Wind Turbine Blade for Optimum Performance in Energy Generation Via Simulation Approach." *International Journal of Mechanical and Production Engineering Research and Development* 10.1 (2020): 95-104.
31. Sharma, Gangaraju Srinivasa, MVS Murali Krishna, and D. N. Reddy. "CFD analysis for adaptability of producer gas for power generation in gas turbines." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 5.2 (2015): 21-32 (2015).

## **CHAPTER 16. ENERGY SECURITY: INVESTIGATING GEOTHERMAL HEAT SINKS FOR AIR CONDITIONING SYSTEMS AT AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT**

This chapter presents an investigation into the adoption of geothermal heat sinks to serve as a replacements of cooling towers in an airport environment in South Africa, providing a technical and economic assessment (technoeconomic assessment) based on the geothermal heat sink installation at Hotel Verde in the Western Cape of South Africa.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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<http://www.tjprc.org/view-archives.php>

## ENERGY SECURITY: INVESTIGATING GEOTHERMAL HEAT SINKS FOR AIR CONDITIONING SYSTEMS AT AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT

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### ABSTRACT

*The use of renewable energy instead of carbon intensive fossil fuels for energy to reduce our ever-increasing global carbon emissions that is accelerating climate change is now a common trend. The uptake of renewable energy, however, needs to increase exponentially if the countries of the world are to follow the reduction by 1.5 or 2 pathways as per the Paris Agreement to arrest climate change. Air conditioning is a significant energy user in buildings especially in warmer countries like South Africa and accounts for a significant amount of electricity being consumed within a year. Air conditioning systems that adopt water cooled chillers also consume significant amounts of water to make up in losses due to evaporation. In their 20 to 25-year lifespan air conditioning systems place a great burden on the environment. This cost to the environment also costs the owners of the air conditioning systems. Finding a way to save on the amount of water and electricity used for cooling towers of air conditioning systems so that the natural environment cools the chillers without huge costs for electricity to drive fans and water to make up for evaporative losses, is a financial win for owners of air conditioning systems as well as a contribution to the environment by way of reduction in carbon emissions. This paper investigates the adoption of geothermal heat sinks to serve as a replacement to cooling towers at an airport environment in South Africa, showing the technical and economic assessment (technoeconomic assessment) based on the geothermal heat sink installation at Hotel Verde in the Western Cape of South Africa.*

**KEYWORDS:** *Renewable Energy, Geothermal Heat Sink, Green Air Conditioning, Energy Conservation for Air Conditioning Systems & Water Saving for Air Conditioning Systems*

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### 1. INTRODUCTION

Reducing the need for large amounts of electricity to meet the requirements of air conditioning and saving on potable water by the adoption of geothermal heat sinks is a major operational cost saving and carbon footprint offset. Using geothermal energy to serve as a heat sink saves on the cost of maintenance and reduces the carbon footprint of a site.

In geothermal heat sink systems, electricity is required to run circulation pumps, but this is minimal due to the hydraulic design of the system. Water is used in a closed loop system so water consumption is negligible. With a lifespan of about 50 years, such a system is an ideal investment due to its low cost of maintenance. The use of geothermal heat sinks is favourable with a ground temperature of 20 °C at a depth below the seasonal layer of the ground which is about 8 m.

This study performed over the financial year 2018/2019 (April 2018 – March 2019) covers technology description, identification of technology type, typical components constituting the technology, dynamics around

their coexistence within the operating environment, assessment of technology maturity, cost benefit analysis that looks at the investment required, energy and water saved, feasibility indicators of the investment and a sensitivity analysis.

This technology is targeted at this stage for the Cape Town International Airport (CTIA) which is owned and operated by Airports Company South Africa (ACSA), however, with time and familiarity with the technology, the intention is to adopt it across more airports in South Africa. The geothermal heat sink technology being scalable and modular in design makes an attractive replacement for air conditioning cooling towers across the airport group. In terms of reduction of the airports' carbon footprint, air conditioning can contribute 10 % to 30 % of the airports' energy consumption and cooling towers can contribute 3 % to 10 % of the total energy consumption of an airport. Historically, cooling towers have proven to be a challenge for ACSA in certain airports due to the cost of maintenance and water (especially in water scarce regions).

Airports Company South Africa is South Africa's airport authority, owning and operating nine airports in South Africa, namely, O R Tambo International Airport (Kempton Park, Gauteng), Cape Town International Airport (Western Cape), King Shaka International Airport (Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape).

The key parameters for the geothermal heat sink technology to work are:

- A ground temperature profile of 20 °C below the seasonal layer (about 8 m to 10 m) of the soil surface.
- Available and accessible ground (soil) space for a geothermal heat exchanger loop installation; a horizontal or vertical loop can be employed based on the flexibility and availability of the space.

The key criteria for geothermal heat sink technology to be adopted at airports in South Africa are:

- Must have the potential to reduce the airport's carbon footprint.
- Must make financial sense to the business.
- Must be a reliable and effective heat sink with a high-capacity factor that is able to sustain the airport's HVAC heat sink requirements.
- Risks should be acceptable.
- Should have a local footprint for technical support with acceptable response times to support operations.

## 2. DESCRIPTION OF THE TECHNOLOGY

Conventional geothermal energy technologies extract ground heat occurring as a result of seismic activity for steam generation that either turns the shaft of an electrical generator, producing electricity, or that is used directly for space heating in winter (Figure. 1). This sort of geothermal energy generation is popular in the United States of America and in countries where it often snows during the winter months. South Africa has geothermal energy potential as well, but this has not been tapped into (Figure. 2).

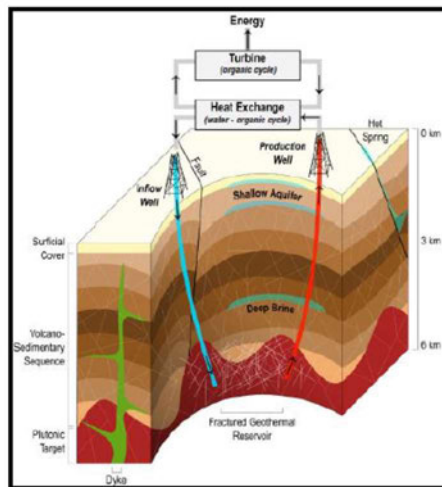


Figure 1: Conventional Geothermal Energy Extraction Generating Electricity [1].

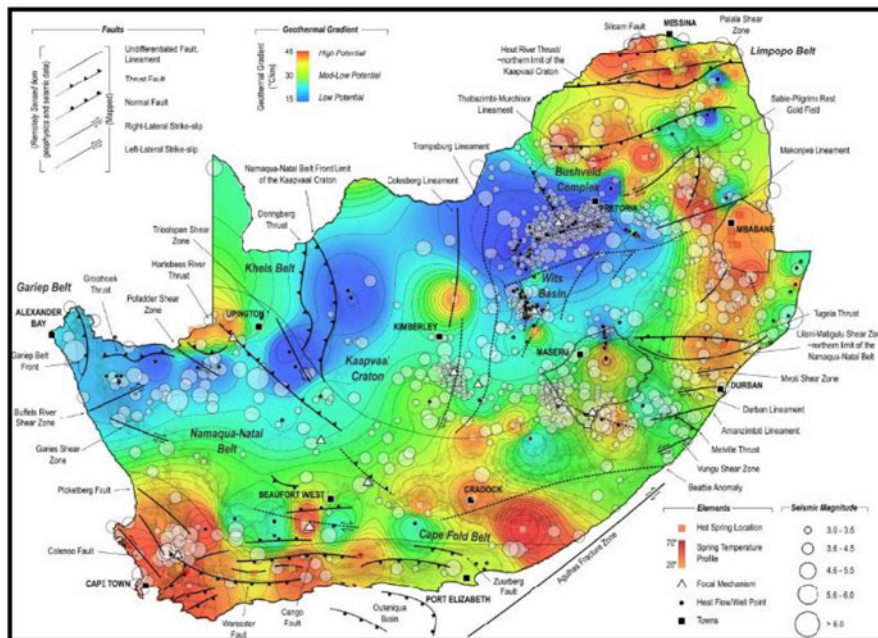


Figure 2: Graphical Overview of the Calculated Geothermal Gradients Across South Africa. (Map Includes Major Tectonic Contacts and Structures, Seismic Activity and Earthquake Focal Mechanisms and Hot Spring Locations) [1].

“Low-enthalpy geothermal energy is becoming increasingly popular around the world. This popularity is largely because it requires geothermal gradients as low as ca 40 °C/km, which may be found in many global settings. South Africa does not have any active or recent volcanism and is situated far from any active continental and/or oceanic plate boundaries but does have anomalously high heat flow regions that could meet the requirements for low-enthalpy geothermal energy development. Low-enthalpy resources are usually associated with ancient tectonic activity and are often defined by plutonic rocks with high concentrations of heat-producing radiogenic elements (e.g., uranium and potassium)

which are overlain by a thick and insulating volcano/sedimentary sequence.” [1]

Conventional geothermal energy generation where the heat source must be accessed a few kilometres below ground is costly compared to geothermal heat sink requirements. Using the ground as a heat sink relies on the fact that the ground temperature beyond the seasonal layer (8 m) is at a stable temperature.

Geothermal heat sink technology uses the stable ground temperature as a heat exchange medium to cool the hot water exiting the condenser of a chiller. The heat sink technology consists of high-density polyethylene (HDPE) piping installed below ground in loops, arranged either horizontally or vertically in order for heat exchange from the fluid flowing through the HDPE piping to be transferred to the surrounding soil below the seasonal layer at 8 m – 10 m below the surface of the ground. The flow rate of the fluid within the HDPE piping is achieved via the hydraulic design of the heat sink loops and a mechanical pump with control system to vary the flow rate based on the heat rejection requirement. Fig. 3 shows the geothermal heat sink loop set-up with an existing chiller which is the typical arrangement anticipated with the adoption of geothermal heat sink loops at CTIA.

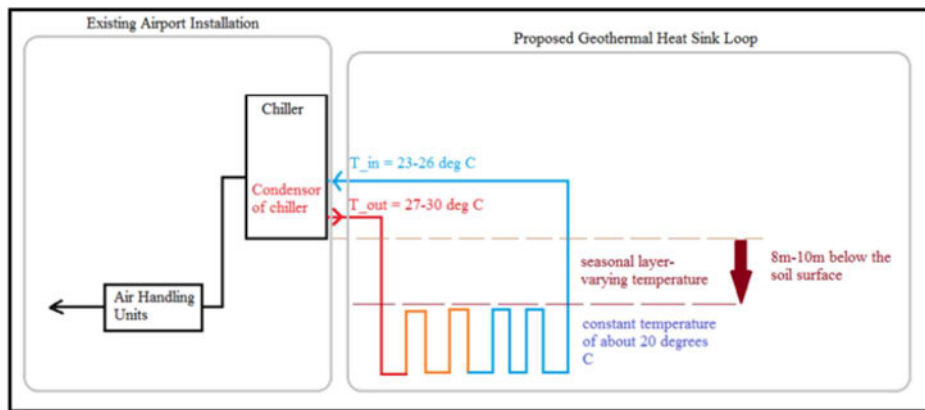


Figure 3: Geothermal Heat Sink Loop with Existing Chiller Set-up.

A difference in temperature of about 4 °C is required, as can be seen in Figure. 3. This  $\Delta T$  of 4 °C is possible due to the ground temperature being at a stable temperature of 20 °C which is below the desired output temperature of a chiller’s condenser at about 23°C. The ground heat exchanger loop arrangement depends on the space available, the space constraints (such as structural integrity), and convenience from a practical and cost perspective. Figure. 4 shows typical vertical and horizontal loop arrangements.

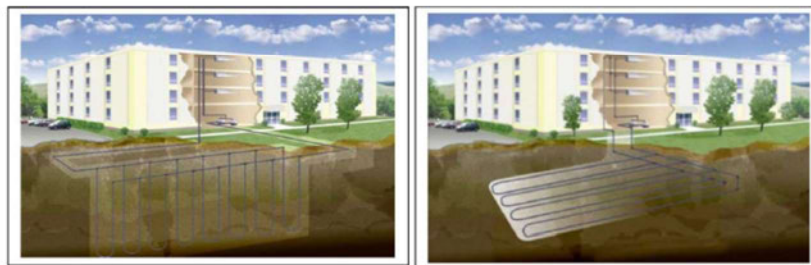


Figure 4: Vertical Loop (Left) and Horizontal Loop (Right) [2].

Vertical loops run perpendicular to the surface and can be buried several hundred feet deep. At these depths, the undisturbed ground temperature does not change throughout the year. Vertical loops require approximately 6.5 m<sup>2</sup>/kW to 8 m<sup>2</sup>/kW (250 to 300 ft<sup>2</sup>/ton) of refrigeration [2]. A horizontal loop runs piping parallel and close to the surface. The undisturbed ground temperature often changes seasonally depending upon where the loops are installed. Horizontal loops are easier to install but require significantly more area than other loop types, approximately 65 m<sup>2</sup>/kW (2500 ft<sup>2</sup>/ton refrigeration) [2]. The geothermal heat exchanger loops are covered in grout which is a mixture of bentonite [2] and other elements such as quartzite, iron ore, cement mortar, and fly ash intended to protect the ground water in case of leaks but has minimal effects on thermal conductivity.

The installed technology involves designing a heat exchanger using HDPE piping with the ground functioning as the heat exchange medium. Each design will have a specific control programme as this is crucial for achieving the desired temperature change across the heat exchanger pipes. Therefore, it is important to study the ground temperature profiles carefully and design a programme that can respond dynamically.

### 3. ASSESSMENT OF TECHNOLOGY MATURITY

Geothermal energy use is not a new concept, and neither is its technology. The installed geothermal from 1990 to 2019 can be seen in Figure. 5. It is evident from the figure that this technology is particularly popular in the northern hemisphere, due to the cold winters in those regions. Geothermal energy can be used to heat homes in winter as well as provide for other energy needs.

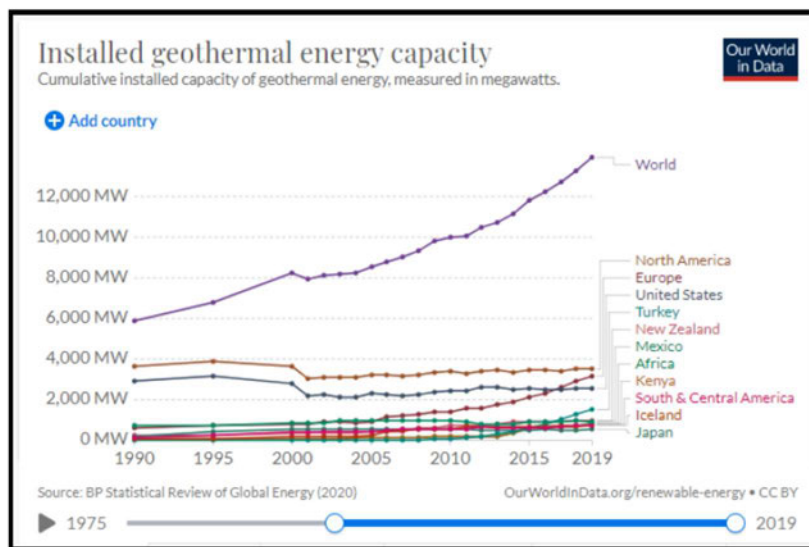


Figure 5: Installed Geothermal Energy Capacity from 1990 to 2019 [3].

According to the United States Department of Energy’s website, about 50 000 geothermal heat pumps are installed in the United States of America each year [4]. Geothermal usage is low in the ranking of renewable energy technologies, but the uptake in the world is increasing at a fast rate (Figure.6) [5].

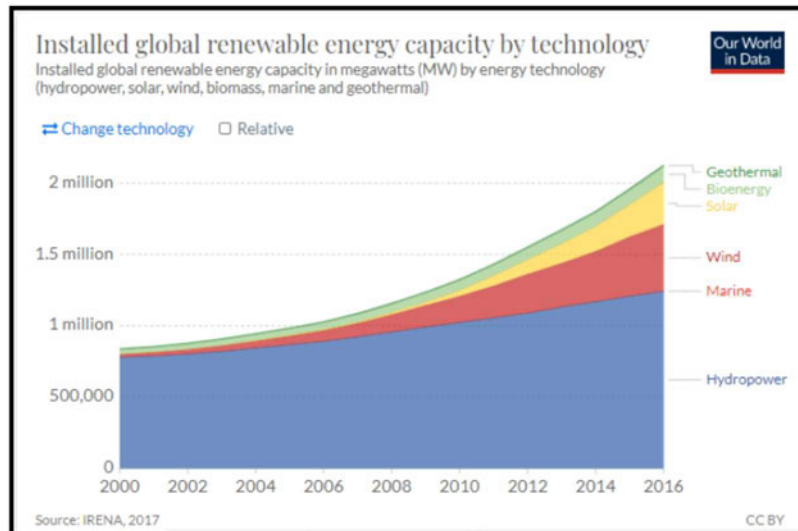


Figure 6: Geothermal Energy use in Relation to other Renewables in the Energy Space [5].

In South Africa, aside from Hotel Verde's installation, there is only one other geothermal system installed, an 18 borehole closed-loop geothermal heat pump system at the private residence of South African billionaire Douw Steyn. This is located in Steyn City, Johannesburg, and was installed by local environmental contracting company Environmental Drilling & Remediation Services (EDRS) [5].

#### 4. COST-BENEFIT ANALYSIS

This technoeconomic assessment is a desktop exercise meant to provide an indication of the economics and suitability of geothermal heat sinks for an airport at pre-feasibility (FEL 2 or Front-End Loading Stage 2). The airport targeted for utilising a heat sink has been limited to CTIA due to the Hotel Verde installation about 2 km from the airport's terminal building. This section summarises the rationale for the scale of the geothermal heat sink technology at CTIA and presents the cost benefit analysis at pre-feasibility.

##### (a) Rationale for the Scale of Geothermal Heat Sink

Geothermal heat sinks are possible at all the nine geographical locations where the airports owned and operated by ACSA. However, to establish the depth at which the non-seasonal layer begins as well as develop a temperature profile of the ground at various depths, soil conditions, etc., a study must be conducted at each of the site locations. Hotel Verde is located in about 2km from CTIA and has successfully implemented geothermal heat sinks at 8 m depth. This indicates that there is a high likelihood of this technology working for CTIA provided that there is space available for the installation.

Due to the rarity of geothermal heat sink installations in South Africa, it was decided that the scale and cost of the Hotel Verde geothermal installation should be adopted for investigation at CTIA. A geothermal loop is intended to serve as a heat sink for the cooling towers, and the initial installation will have additional control and measurement devices to determine heat transfer coefficients, temperature difference, flow regimes and cyclic nature of the heat sink. This will serve as information for future ACSA installations across other airports.

Table 1 shows the various cooling towers at CTIA with the aim of selecting one that is closest to the heat rejection of Hotel Verde’s installation for the purposes of replacement. The flow rate and fan capacities were taken from the data sheets of the cooling towers. The pump capacity was assumed to be 1 % of the cooling duty which is the case with most cooling towers, and the kW cooling required was calculated using the equation (1):

$$Q_{heat\ rejection} = mC_p\Delta T \tag{Equation (1)}$$

Where:  $m$  is the mass flow rate in kg/s which is the flow rate in table 2 multiplied by 1000

$C_p$  is the specific heat capacity of water at constant pressure = 4.19 J/kgK

$\Delta T$  is the change in temperature in Kelvin (K) and is taken at 2.5 K

The cooling tower heat rejection that best matched the Hotel Verde scale at CTIA was cooling tower 1 in terminal 5, as highlighted in Table 1. Hotel Verde’s full HVAC system consists of an integrated heat pump system providing the hot water needs of the hotel as well as the HVAC requirements, and cost ZAR 26 600 000 [4]. The heat rejection which is accomplished via the geothermal loop is around 305 kW, consisting of 100 boreholes drilled to a depth of 65 m each and 13 km of HDPE piping. The 2018 cost of the system is shown in Table 2.

**Table 1: Cape Town International Airport Cooling Towers Specifications**

CTIA Cooling Towers	Flow Rate (m <sup>3</sup> /s)	Total Cooling Required (kW)	Fan Capacity (kW)	Pump Capacity (kW) – Approximated to be about 1 % of the Total kW Cooling
Terminal 5: Cooling Tower 1	0.039	408.525	22	4.1
Terminal 5: Cooling Tower 2	0.039	408.525	22	4.1
Terminal 1: Cooling Tower 1	0.042	439.95	30	4.4
Terminal 1: Cooling Tower 2	0.042	439.95	44	4.4
CTB: Cooling Tower 1	0.083	869.425	11	8.7
CTB: Cooling Tower 2	0.083	869.425	11	8.7
CTB: Cooling Tower 3	0.083	869.425	11	8.7
CTB: Cooling Tower 4	0.083	869.425	11	8.7
CTB: Cooling Tower 5	0.083	869.425	11	8.7
Total Cooling (kW)		6044.075	173	47.87075

Table 2: Approximate Cost of Hotel Verde's Geothermal Heat Sink System in 2018

Item	Cost in South African Rands ZAR (2018 basis)	Cost Detail and Notes
Boreholes, piping	4 104 810.00	<ul style="list-style-type: none"> <li>100 boreholes at ZAR 41 000 per borehole of 65 m deep (estimated 2018 price from a previous project done at KSIA on the feasibility study of borehole water use).</li> <li>13 km of HDPE Piping at ZAR 370 per km (estimated 2018 price from online sales).</li> </ul>
Instrumentation	205 240.50	<ul style="list-style-type: none"> <li>Estimated at 5 % of the cost of total cost of drilling the boreholes (include cost of control and instrumentation to monitor the operations of the installation).</li> </ul>
Design and labour; balance of plant (BoP)	820 962.00	<ul style="list-style-type: none"> <li>Estimated at 20 % of the total cost of drilling the boreholes (typical figures used for design and labour and extra allowance is made for BoP).</li> </ul>
<b>Total</b>	<b>5 131 012.50</b>	<ul style="list-style-type: none"> <li>This total cost agrees with the cost as per the United States (US) geothermal installations.</li> </ul>

The above total cost of ZAR 5 131 012.50 was used as the 2018 cost basis upon which it was benchmarked according to the US geothermal installed systems.

#### (b) Feasibility Study Results

Airports Company South Africa has an economic modelling department that creates economic models in excel spreadsheets. The economic model yields the Net Present Value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index. The IRR is compared to ACSA's 11.5 % weighted average cost of capital (WACC) rate (2018) to determine economic feasibility. When the NPV is zero or positive is it an investment that pays itself off during its economic lifespan. The NPV equation used in the economic model is given below (Equation 2), the IRR is the return ( $i$  in below equation) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the economic lifespan of the investment. The profitability index (PI) (given in Equation 3) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^T \frac{R_t}{(1+i)^t} \quad \text{Equation (2)}$$

Where:  $R_t$  = net cash inflows – outflows during a single period  $t$

- $i$  = discount rate or return that could be earned
- $t$  = number of time periods

$$PI = \frac{PV \text{ of future cash flows}}{\text{Initial Investment}} \quad \text{Equation (3)}$$

The resulting replication of the Hotel Verde geothermal heat sink loop gives an end of job (EoJ) cost of ZAR 5.67m and a NPV of ZAR 2.51m at an IRR of 18.1%. The inputs used in the economic modelling and the financial outputs can be seen in Table 3. Further description of the data used in the economic models and the source of the information is

provided in Table 4.

**Table 3: Summarised economic analysis**

Inputs		Output	
kW heat rejection	305 kW	End of job cost	ZAR 5.67m
Capital cost (2018 basis)	ZAR 5 131 012.50	Net present value	ZAR 2.51m
Water saving	9.12 kL/day	Internal rate of return	18.1 %
Water cost	ZAR 88.75 /kL	Annual operational cost saving	ZAR 463 382.91
Electricity saving	114 253 kWh/annum	Nominal payback period	6 years
Electricity cost (2018 basis)	ZAR 1.47 /kWh	Profitability index	1.55
Beneficial operation	2021		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	20 years		
Degradation	0.5 % per annum		
Operational and maintenance cost	ZAR 12 000 /annum (2018 terms)		

**Table 4: Base Case Description**

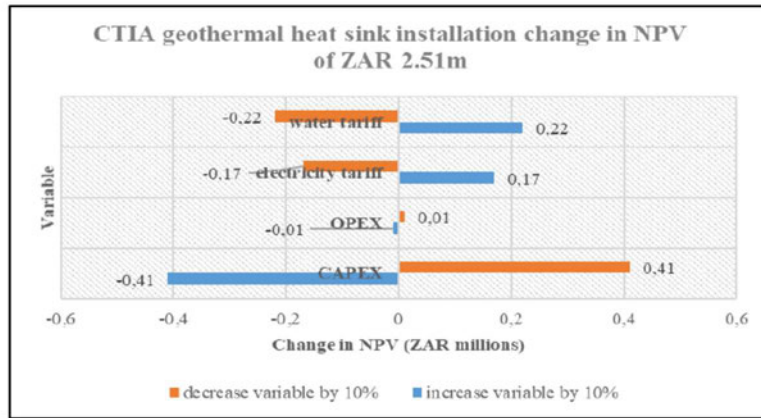
Base case Descriptor	Base case Parameter/Result	Base Case Sources and Assumptions
Airport for implementation	Cape Town International Airport	Due to the Hotel Verde’s proven implementation within a 1 km radius from CTIA
Size of plant	305 kW heat rejection	Duplication of Hotel Verde’s geothermal heat sink loop
Annual electricity saving	114 253 kWh	Based on the fan and pump electricity savings running for 12 hours a day, 365 days a year; Hotel Verde’s system achieves fluid circulation through a carefully designed hydraulic configuration where the water flows naturally
Annual water saving	9.12 kL/day	Based on actual cooling tower water consumption; blowdown losses accounted for using actual data
Capacity factor	N/A	The geothermal loop will be available all the time
Depth of boreholes	65 m	As per Hotel Verde’s boreholes depth
Potential annual cost saving at full capacity	ZAR 463 383	Based on savings from electricity and water consumption
Annual maintenance cost	ZAR 12 000	Based on Hotel Verde’s maintenance cost of R60 000 spend to repair a leak that developed after 5 years

This pre-feasibility study (FEL 2) conducted for CTIA by replicating the geothermal loop at Hotel Verde proves to be feasible. To determine the factors that this feasibility is most sensitive to, a sensitivity analysis was performed.

**(c) Sensitivity Analysis**

For the sensitivity analysis, the four factors that play a role in the determination of the profitability of the investment were varied equally to see the significance of impact each parameter had on the profitability of the project relative to each other.

The profitability of the investment relies on the capital cost of the installation (CAPEX), the cost of potable water, the cost of electricity from Eskom and the operational cost (OPEX) of the geothermal heat sink loop field. The effect that these four factors have on the NPV of the project can be seen in Figure 8.



**Figure 8: Sensitivity Analysis of the Replication of the Hotel Verde's Geothermal Loop at CTIA.**

A 10 % increase and decrease in CAPEX, OPEX, electricity cost and water cost show that the capital cost is the most significant factor and the operational cost the least significant factor. The variation in water tariff has about 50 % of the impact that the variation in capital cost has on the NPV. Following closely on the impact of the water tariff is the impact of the electricity tariff. This sensitivity analysis implies that water consumption savings are key to the business case for geothermal heat sinks.

If it is known that any of the other airports are experiencing a drought condition and the cost of water is approaching or exceeded ZAR 88,75 /kL, this technology should be considered for implementation instead of using cooling towers.

**5. TECHNOLOGY RISK ASSESSMENT**

The technology (piping, pumps, etc.) that use the ground as a heat sink have all been in existence for longer than the concept of utilising it for geothermal energy. The HDPE pipework in geothermal ground heat exchange is used in plumbing applications, and pumps and controls have been in existence for longer than 50 years. Heat exchanger designs in air conditioning, engines and other applications were being used before the advent of geothermal applications as well. The unique factor to be considered in ground heat exchanger design need are ground temperature and its fluctuations, hence the control system real time response is crucial. The technology risk assessment in this context is provided in Table 5.

**Table 5: Technology Risk Assessment**

Risk	Description	Possible Mitigation
Ground temperature and fluid temperature to be cooled being equal	As in any heat exchanger design, heat naturally flows from a hot reservoir to a cold reservoir; it is this difference in temperature that causes heat exchange. Should the temperature difference cease, there will be no further heat exchange until a temperature difference exists.	<ol style="list-style-type: none"> <li>1. Designing of the loop field must model scenarios of possible ground temperature change due to the added heat load of the building and ensure that the system is designed to minimise/eliminate the possibility of a temperature equalisation.</li> <li>2. The design should incorporate an alternative method of achieving the heat sink such as bypassing the geothermal loop for another cooling tower or using another chiller to carry the heat load especially for the first installation until a temperature gradient is restored.</li> </ol>

Single point of failure	This is failure at a single point which without, the entire plant will not be able to operate. This includes loss of pressure (mechanically) or loss of control system (software, hardware or communications).	<ol style="list-style-type: none"> <li>3. Modularity should be introduced so that should a failure occur in one loop, it can be isolated and the rest of the loops can carry the load while the failed loop is being repaired.</li> <li>4. Control systems must be employed to ensure that this transition is smooth and there is no impact on HVAC operations.</li> <li>5. Active monitoring and early detection of failure should be incorporated. A fail-safe mode or default mode should be programmed/hard-wired into the system in case of operational loss of the control system.</li> </ol>
Agility	This is the ability of the plant's operational output to respond to varying demand timeously without causing operational impacts or damage to infrastructure.	<ol style="list-style-type: none"> <li>6. During design, dynamic varying of fluid flow rates should be programmed based on the ground temperature, fluid temperature, required heat rejection and alternative heat sink/s or back up plans should be incorporated in case of reduced heat exchange.</li> </ol>
Turn-down ratio	This is the ability of the plant design capacity to be increased and decreased in capacity to suit operational need and maintenance regimes towards cost effectiveness.	<ol style="list-style-type: none"> <li>7. Understand the demand profile of the airport's air conditioning load, the corresponding heat sink requirements, ground temperature profiles and adjusted temperature profiles of the ground during operation of the geothermal loop to build in modularity towards cost effectiveness for operations and maintenance.</li> </ol>

## 6. AIRPORT'S INTEGRATION STRATEGY

The consideration of geothermal heat sinks for CTIA must be in relation to the airports HVAC refurbishment and replacement programmes should be adopted for a cost-effective integration strategy. CTIA's integration strategy should be such that the first installation is completed as a replication of Hotel Verde's installation. Monitoring and analysis of flow regimes should then follow to generate accurate design data for further installations. Roll out of the geothermal heat sink loop should then follow. Refer to the schematic in Figure. 9. The three phases as per the airport's integration is described following Figure. 9.

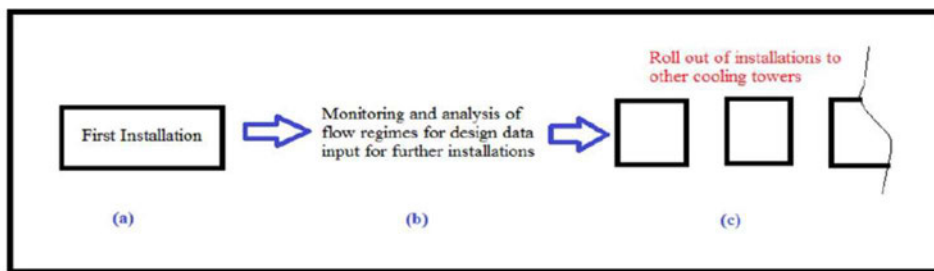


Figure 9: Phases of Integration of the Geothermal Heat Sink Technology Replacing Evaporative Cooling Towers at CTIA.

The following sections describe the phases of integration of the geothermal heat sink installation at CTIA in time replacing all the evaporative cooling towers at the airport.

### (a) Replication of Hotel Verde's Geothermal Loop

The integration of the geothermal heat sink loop into CTIA's HVAC system should be such that the first geothermal heat

sink loop installation is done to replace the evaporative cooling tower that meets the following criteria:

- Due or soon due for replacement/refurbishment and a low book value
- Has adequate land area for either a vertical or horizontal geothermal heat sink loop
- Can be easily integrated without inconvenience that will either pose unacceptable operational risks or result in capital integration costs that will result in a negative IRR.

The FEL 3 (final feasibility) stage should include further investigation that may require funding for services to perform detailed investigations that will confirm the financial viability of the installation based on the prevailing soil and spatial conditions at CTIA. Table 6 gives the scope and indicative cost of the professional services required to confirm feasibility at FEL 3 of a geothermal heat sink installation at CTIA.

**Table 6: Cost to Confirm Feasibility for an Investment Decision (FEL 3 Stage)**

	Task	Duration (hours)	Estimated cost (ZAR) (2019 basis)
	<b>Integration parameters of geothermal at CTIA</b>	<b>32</b>	<b>67 584</b>
1	• Capital cost of integration, pipework, controls and instrumentation, modifications and other integration requirements	24	50 688
	• Confirmation of scale and design parameters of geothermal heat sink loop as per Hotel Verde's design and qualify suitability for implementation at CTIA	4	8 448
	• Operational cost of the geothermal field	4	8 448
	<b>Plant scale and operational parameters to mitigate risk. Requirements are:</b>	<b>128</b>	<b>270 336</b>
2	• Investigation into the ground temperature profiles and proposal of the possible geothermal heat sink loop sites for full roll out	16	33 792
	• Investigation into airport's heat sink load profiles in totality and specific to each cooling tower in conjunction with ground temperature profiles to establish flow regimes, control methodology and integration into airport's current HVAC system	24	50 688
	• Investigate environmental obligations and provide scope, timeline and costing	8	16 896
	• Identify risks, mitigations and investigate the cost of risk	8	16 896
	• Provide condition assessment of cooling towers and advise on cost effective roll-out strategy	24	50 688
	• Plant footprint, identification of plant location, spatial and legal requirements and associated costs	36	76 032
	• Single point of failure analysis, cost to restore, mitigations and cost of mitigation	12	25 344
	<b>Feasibility and implementation</b>	<b>48</b>	<b>101 376</b>
3	• Total cost of installation	8	16 896
	• Owner's cost	8	16 896
	• Feasibility of the investment and sensitivities	8	16 896
	• Project timelines, milestones	4	8 448
	• Procurement strategy for installation, operations and maintenance	8	16 896
	• Basic design that will inform detailed design	12	25 344
	<b>Other costs</b>		<b>65 894</b>
4	Travel, preliminaries and general		21 965
	Monitoring, data collection, simulation		43 930
	<b>Contingency</b>	<b>10 %</b>	<b>50 519</b>
	<b>TOTAL</b>	<b>208</b>	<b>555 709</b>

#### (b) Monitoring, Collection of Data and Analysis

Once the first installation is complete, continuous monitoring and analysis of the various heat flow cycles, flow rates and response of the systems should be done to enable the next design to easily determine the following parameters as contained

in Equation (4): [2]

$$Q_c = \frac{L(T_g - T_w)}{R} \quad \text{Equation (4)}$$

Where:  $Q_c$  is the heat load (Btu/hr)

$L$  is the pipe length (feet)

$T_g$  is the ground temperature

$T_w$  is the fluid temperature

$R$  is the thermal resistance to heat transfer.

The challenge in loop design is that the ground temperature does not stay constant, the loop itself affects the ground temperature. For loop design, it is common to break the effects into three parts: [2]

- **Long Term Effect** - This is the change in the ground temperature over many years. If the building has a net heat gain or a net heat loss, the ground temperature will change. The more densely placed the boreholes are, the larger this effect will be. Ground water moving through the bore hole field can help remove energy and limit the long-term temperature change. For commercial applications, ground temperature generally climbs. An example of a long-term effect would be a 6 °C average ground temperature increases over 10 years due to the heat added to the borehole field. The penalty will not be present during the first year, but this type of heat build-up will change the system performance over time [2].
- **Annual Effect** - Over the course of a year, the heat load on a bore field will change and this will affect the ground temperature on a monthly basis. It is this “flywheel” effect that can cause the warmest ground loop temperature to occur after the peak load has occurred [2].
- **Short Term Effect** - The actual load on the loop will affect the fluid supply temperature. For example, if the building was shut down, the fluid temperature would quickly become the ground temperature. However, the loop temperature would be the ground temperature plus the design approach at design load. The actual hourly load also affects the borehole field’s ability to dissipate heat. Therefore, the ground temperature will change with the hourly load. Most loop sizing software group the design day loads into four-hour intervals rather than using all 24 hours [2].

These three effects must be known to find the required pipe length. The length suitable for CTIA may be established by the summer heat sink load requirement. The summer peaking load establishes the length, and the designer should go back and evaluate the cooling performance with the longer length. This will improve the summer performance and minimise the need for back-up cooling towers. Understanding the ground temperature profile, the airport’s heat sink requirements and the loop temperature response for the geothermal heat sink zone is key for effective design.

#### (c) CTIA’s Full Roll out of Geothermal Heat Sink Loops

The establishment of a better understanding of the designing of heat sink loops based on the first installation will be the basis for further roll-out at CTIA. The roll-out should be timed with the replacement cycles of the existing evaporative

cooling towers, however, back-up cooling towers should be available to serve the fluctuating heat rejection load (i.e., excluding the baseload) limited to 25 % of maximum heat rejection load or as per the most economical ratio for back-up cooling towers. The potential of the full roll-out of the geothermal heat sink loops is provided in Table 7.

**Table 7: Summary of Benefits of the Geothermal Heat Sink Technology for CTIA**

CTIA Cooling Towers Replacement with Replication of Hotel Verde's Geothermal Heat Sink Loop	Potential Annual Energy Saving (kWh)	Potential Annual Water Saving (kL)	Potential Annual Operational Cost Saving (ZAR) (Excluding Maintenance Cost Savings)	Potential Annual Carbon Footprint offset (%) from Electricity Savings only
Terminal 5: Cooling Tower 1 replaced with 1 x Hotel Verde's geothermal loop	114 253 kWh	3 328 kL	ZAR 463 383	0.17 %
Terminal 5: Cooling Tower 2 replaced with 1 x Hotel Verde's geothermal loop	114 253 kWh	3 328 kL	ZAR 463 383	0.17 %
Terminal 1: Cooling Tower 1 replaced with 1 x Hotel Verde's geothermal loop	114 253 kWh	3 328 kL	ZAR 463 383	0.17 %
CTB: Cooling Tower 1 replaced with 2 x Hotel Verde's geothermal loop	228 506 kWh	6 656 kL	ZAR 926 766	0.33 %
CTB: Cooling Tower 2 replaced with 2 x Hotel Verde's geothermal loop	228 506 kWh	6 656 kL	ZAR 926 766	0.33 %
CTB: Cooling Tower 3 replaced with 2 x Hotel Verde's geothermal loop	228 506 kWh	6 656 kL	ZAR 926 766	0.33 %
<b>Total</b>	<b>1 028 277 kWh</b>	<b>29 952 kL</b>	<b>ZAR 4 170 447</b>	<b>1.5 %</b>

## 7. PROPOSED OPERATIONAL PHILOSOPHY

### (a) Technical

The phase of integration that involves the replication of Hotel Verde's geothermal heat sink loop will be from terminal 5 as seen in Figure. 10 below.

- The geothermal heat sink loop will take most of the operational load with peak loads being shared with a cooling tower. It is advisable to keep the cooling tower that is in a better condition and replace the second cooling tower with the geothermal heat sink loop the size of Hotel Verde's installation.
- The geothermal heat sink loop itself should be divided into two ground heat exchange zones such that when the ground temperature and the fluid temperature are equalised and further heat exchange is required, the second zone should be able to carry the load.
- The geothermal loops should be designed for ease of isolation and maintenance purposes without compromising the functionality of the rest of the geothermal heat sink loop field.
- As far as possible, pumping head and flow rate should be minimised making use of hydraulic design, Bernoulli's equation and Pascal's Law.

The monitoring, collection of data and analysis thereof should carefully consider the outputs required for efficient

designs that could be used for further roll-out. Monitoring for establishment of suitable flow regimes, length and depth of geothermal loops, grout types and pumping capacities will be key inputs into further designs. The heat sink load profile during the summer period, ground temperature profile effects and flow regimes are crucial for this phase to fine tune the replicated geothermal loop and as input into further designs. It is advised that this phase be timed such that it considers the summer heat sink loads.

The final rollout phase should seek to achieve the set-up described in Figure. 10. The geothermal heat sink loop fields should be sized to serve the operational baseload and peak loads should load share with standby cooling towers as well to ensure that the heat sink loop has sufficient time to recover in order to maintain a temperature gradient.

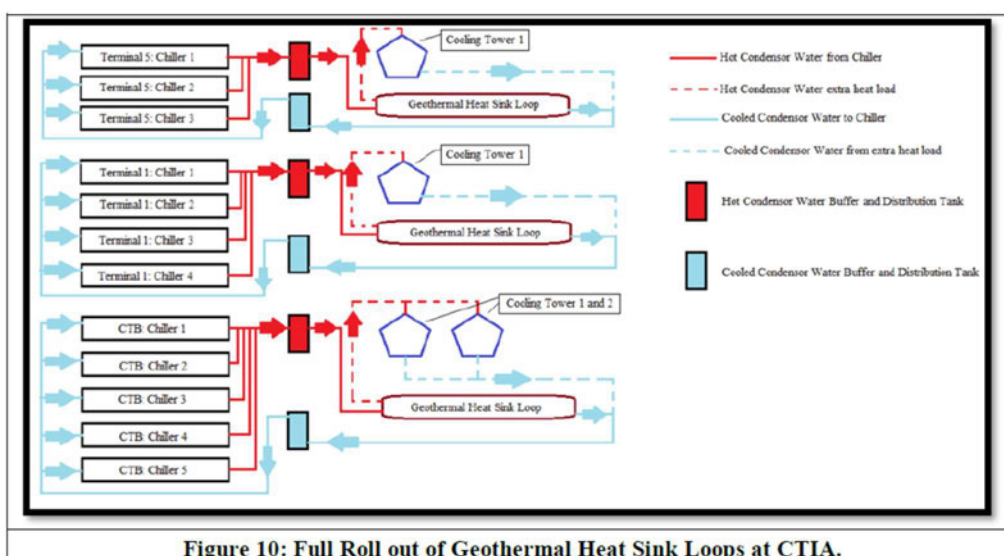


Figure 10: Full Roll out of Geothermal Heat Sink Loops at CTIA.

**(b) Plant Operation for Business Continuity and Cost Effectiveness**

The geothermal loop heat sink cooling duty and the cooling towers heat sink cooling duties should consider the following:

- Baseload and fluctuating load in the heat sink load profile
- Time for the geothermal heat sink zone’s temperature to equalise to the temperature flowing within the loop
- Economies of scale

Using the above information, the geothermal heat sink zones should be spaced accordingly such that the heat load profile can be met. The capacity of heat sink loads placed on cooling towers should consider the minimum cooling requirement in the case of a total loss of the geothermal loop field.

**(c) Operations and Maintenance Activities**

Operations of the geothermal loop field is to be electronically programmed and run independently of human input. There should be a default mode should the system parameters received from the control system that are used in real time feedback control not be within pre-defined parameter bounds. Pressure loss or any other failure should be linked to a maintenance alert system which will switch the system to a fail-safe mode of operation.

Maintenance will need to be contracted out for the first installation as this is not a skill found within ACSA. Breakdown maintenance should be on a call-out basis and is likely to be mainly due to heat sink loop leaks. Preventative maintenance should be based on the condition of the geothermal loop. The system usually runs as per the electronic control programme and requires no human intervention, except for maintenance.

## 8. CONCLUSIONS

The use of geothermal energy is not a new concept and is frequently used in the northern hemisphere for heating and cooling purposes. The technology is also well known, however, its use in South Africa is not as common as solar photovoltaic technology. Geothermal energy technology works for Hotel Verde in the Western Cape of South Africa, located within a kilometre of the CTIA. It is for this reason that the technology will work for CTIA. The feasibility study (FEL 2) conducted for the installation at CTIA proves that it is financially feasible. At FEL 2 (pre-feasibility stage), geothermal energy has the potential to save ZAR 4.1m per annum and the potential to reduce carbon footprint by 1.5 %. This will be instrumental in transitioning CTIA toward a lower carbon footprint, enabling progress towards the airport's green star rating with the Green Building Council of South Africa as well as the Airports Council International (ACI) carbon accreditation.

## REFERENCES

1. Dhansay, T., Musekiwa, C., Ntholi, T., Chevallier, L., Cole, D., De Wit, M.J., "South Africa's geothermal energy hotspots inferred from subsurface temperature and geology", *South African Journal of Science*, Volume 113, December 2017. Retrieved from <http://www.scielo.org.za/pdf/sajs/v113n11-12/18.pdf>, accessed 22/06/2021.
2. McQuay Air Conditioning International, "Geothermal Heat Pump Design Manual", 2002.
3. Our World in Data, [https://ourworldindata.org/grapher/installed-geothermal-capacity?tab=chart&country=USA-ISL-TUR-Africa-OWID\\_WRL-Europe-JPN-KEN-MEX-North+America-NZL-South+%26+Central+America](https://ourworldindata.org/grapher/installed-geothermal-capacity?tab=chart&country=USA-ISL-TUR-Africa-OWID_WRL-Europe-JPN-KEN-MEX-North+America-NZL-South+%26+Central+America), accessed 22/06/2021
4. Derek Whitfield, owner of local environmental contracting company Environmental Drilling & Remediation Services (EDRS) in *Engineering News*: "Geothermal Systems installed at Steyn City Development; 20<sup>th</sup> September 2013 [http://m.engineeringnews.co.za/article/geothermal-systems-installed-at-steyn-city-development-2013-09-20/rep\\_id:4433](http://m.engineeringnews.co.za/article/geothermal-systems-installed-at-steyn-city-development-2013-09-20/rep_id:4433)
5. Our World in Data, <https://ourworldindata.org/grapher/installed-global-renewable-energy-capacity-by-technology>, accessed 22/06/2021.
6. Patel, G., Dilip B. Patel, and KINJAL M. Paghda. "Analysis of P&O MPPT algorithm for PV system." *International Journal of Electrical and Electronics Engineering (IJECE)* 5.6 (2016): 1-10.
7. Kamanzi, Janvier, and Mohamed Tariq Kahn. "Closed-Structure Multisided PV Systems for Evenly Distributed Irradiance Collection." *International Journal of Electronics and Communication Engineering (IJECE)* 5.6: 29-36.
8. Darji, Sunny K., Jigar K. Parmar, and Gajendra R. Patel. "Energy Storage System with Multilevel Inverter for Distributed Grid Application." *International Journal of Electrical and Electronics Engineering (IJECE)* 7. 3, Apr-May 2018, 1 16.
9. Mundhe, Raju G. "Renewable Energy Source Algae Biodiesel as Alternative Fuel." (2017).
10. Koul, Bharti, Kanwardeep Singh, and Yadwinder Singh Brar. "An Integration of Smart Grids with Demand Side Management and Renewable Energy: A Review." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* ISSN (P): 2249-6890.

**CHAPTER 17. ENERGY SECURITY: STANDARDS AND GUIDELINES FOR  
SOLAR PHOTOVOLTAIC INSTALLATIONS INCLUDING TECHNICAL PLAN TO  
TRANSITION SOLAR PHOTOVOLTAIC PLANT MAINTENANCE TO BE  
PERFORMED IN-HOUSE FOR AIRPORTS IN SOUTH AFRICA**

This chapter presents the standards and guidelines relating to technical aspects of the current solar photovoltaic installations at the ACSA airports, and the proposed and supported plan for transitioning the maintenance of all plants to be performed inhouse.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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## ENERGY SECURITY: STANDARDS AND GUIDELINES FOR SOLAR PHOTOVOLTAIC INSTALLATIONS INCLUDING TECHNICAL PLAN TO TRANSITION SOLAR PHOTOVOLTAIC PLANT MAINTENANCE TO BE PERFORMED IN-HOUSE FOR AIRPORTS IN SOUTH AFRICA

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### ABSTRACT

*Establishing renewable energy technologies as a viable long-term strategy for developing countries calls for the documentation of learnings from previous installations and the establishment of an in-house maintenance team for conducting regular maintenance and operations. Documentation of learnings from past installations is necessary to ensure profitable transactions in relation to the logistics of the plant equipment and spares, labour for installation, and design of plant and associated systems. The documentation of learnings should extend to the operations of the plant to mitigate certain undesirable effects at design stage that could not otherwise be foreseen. These undesirable effects include site conditions, testing, operational disruptions, and security. Gradual but certain establishment of an in-house maintenance team is key to better plant performance, plant longevity and ensuring the validity of original equipment manufacturer's guarantees and warranties. This paper presents the standards and guidelines relating to technical aspects of the solar photovoltaic installations at airports in South Africa and the proposed and supported plan for transitioning the maintenance of all plants to be performed in-house.*

**KEYWORDS:** *Solar PV Plants, Solar PV Modules, Solar PV Maintenance for Airports, Solar PV Installations at Airports, Solar PV Plant Design for Airports & Cost of Maintenance for Solar PV Plants at Airports in South Africa*

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### 1. INTRODUCTION

According to the South African Photovoltaic Industry Association, "The sun provides almost all the energy we use for our daily life. Also, all fossil energy like coal and oil are based on energy that came from the sun – albeit billions of years ago. Even wind energy is driven by the power of the sun. Only nuclear power and geothermal power are driven by nuclear reactions. The solar energy reaching the Earth's surface would, in theory, be sufficient to solve all the energy problems on Earth. Outside the Earth's atmosphere solar energy has an almost constant value of 1367 W/m<sup>2</sup>. While passing through the atmosphere, the energy and the spectral behaviour of the sunlight changes. Due to reflections on particles in the air, clouds, as well as ground reflection, the direct irradiation is reduced and a diffuse irradiation is added. The sum of both irradiation types is usually below the value found outside the atmosphere. For a sunny day and optimised orientation towards the sun, the global irradiation is about 1000 W/m<sup>2</sup>. On cloudy days there is almost no direct irradiation left, the diffuse irradiation depends on the cloud type, and can be less than 100 W/m<sup>2</sup>." [1]

Although solar PV power generation plants currently represent a small percentage of global power generation, installations are growing rapidly for both utility-scale and distributed power generation applications.

Reductions in costs driven by technological advances, economies of scale in manufacturing, and innovations in financing have brought solar power within reach of grid parity in an increasing number of markets. Continued advancements and further cost reductions will expand these opportunities, including in developing countries where favourable solar conditions exist, as in South Africa. Policy environments for renewable energy in the developing world are being refined, drawing on the lessons learned from the successes and failures of policies adopted in first-mover markets. Several regulatory models are being successfully deployed in the developing world with consequent increase in investment and installations. This rapid market growth has been accompanied by an observed uneven expertise and know-how demonstrated by new market entrants. Building capacity and knowledge on the practical aspects of solar power project development, particularly for smaller developers, will help ensure that new PV projects are well-designed, well-executed, and built to last [2].

The curve of standardisation for technological innovation can be seen in Fig. 1. With time, the development of technologies calls for the need for certain levels of quality, such as standards guaranteeing safety, functionality and compliance with various legislative requirements concerning materials and environmental sustainability. Standardisation is useful in the reduction of variety and also makes for cost effective mass manufacturing and after-market services such as maintenance, upgrading, refurbishments, etc. Standardising in solar PV plant installations allows for cost effective installations, making use of economies of scale for solar PV panels, electrical and control systems and software platforms as well as familiarity in operations and maintenance.

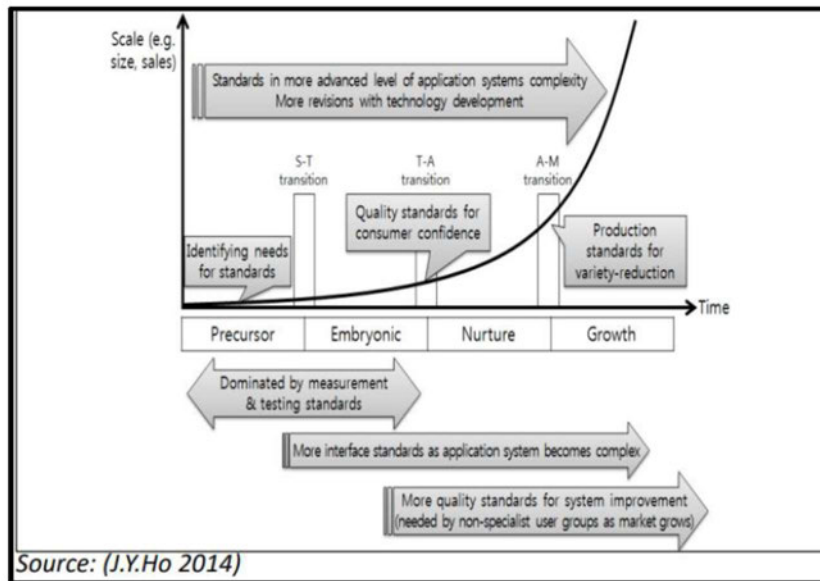


Figure 1: Standardisation in Technological Innovation [3].

Table 1 shows the various organisations that are involved in solar PV standards development. There are six major organisations identified in this study as seen in Table 1.

**Table 1: Organisations involved in solar photovoltaic standards development**

	Standards Development Organisation		Membership	Focus of Activities
1	International Electrotechnical Commission	IEC	National committees	Performance and safety of products, systems and services
2	ASTM International (formerly American Society for Testing and Materials)	ASTM	Individual experts	Measurement principles and specialty tests
3	Semiconductor Equipment Manufacturers' Institute	SEMI	Member companies	Primarily manufacturing related (materials and equipment)
4	Underwriter Laboratories	UL	Invited experts	Product safety
5	International Code Council	ICC	Invited experts	Building and fire codes
6	Institute of Electrical and Electronics Engineers	IEEE	Individual experts	Grid connection codes

The first solar photovoltaic (PV) plant to be established at an airport in South Africa was at the George Airport in the Eastern Cape province. It was under construction mid-2015 and was operational in 2016. Soon after this installation was commissioned, two other solar PV plants were installed and became operational in the second half of 2016. Airports Company South Africa (ACSA), South Africa's airport authority, planned three more solar PV plants that were in the design and build stage, passing the prefeasibility stage at the time (financial year 2017/18). It was then decided that the designs of the upcoming plants must capture learnings established from the previous three installations and include them in their designs and installations. The technical learnings from the solar PV plants installed at George Airport, Kimberley Airport and Upington International Airport (UPIA) were captured and are contained in this paper and were included in the design and construction specifications of the solar PV installations at Port Elizabeth International Airport (PEIA), Bram Fischer International Airport (BFIA) and East London Airport.

Outsourcing the maintenance of these plants can become costly with many routine tasks being done by different service providers at different geographical locations, secured at different rates. With this arrangement, similar problems are sometimes re-investigated multiple times with maintenance taking place in isolated forms. With a large investment in solar PV already across the airport group and future aspirations of adopting solar PV for offsetting carbon footprint of airports, it is in the best interests of the company to transition maintenance so that it is performed in-house. ACSA has five solar PV plants at the following airports and a sixth planned for East London Airport (650 kWp).

- George Airport (750 kWp)
- Upington International Airport (500 kWp)
- Kimberley Airport (500 kWp)
- Port Elizabeth Airport (1000 kWp)
- Bram Fischer International Airport (750 kWp)

This paper presents the standards and guidelines that were implemented at PEIA, BFIA and are planned East London Airport based on the installations done at George Airport, UPIA and Kimberley Airport. This paper also presents the plan to transition the maintenance and operations of the plants in-house.

## 2. STANDARDS AND GUIDELINES FOR SOLAR PV INSTALLATIONS AT AIRPORTS

Figure. 2 shows the approach used to draft the standards and guidelines for solar PV installations. The clauses included in the standards and guidelines for solar PV installation were workshopped with the technical staff and technical management at the airports prior to their adoption at airports.

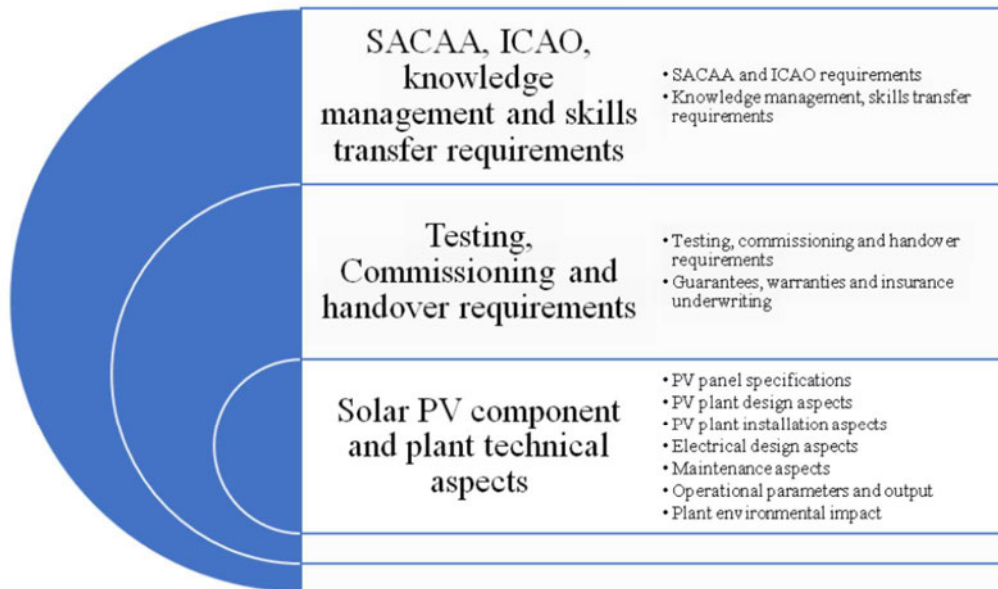


Figure 2: Approach to Drafting Standards and Guidelines for Solar PV Installations.

The clauses address the solar technical aspects of the plant, the project aspects of testing, commissioning and handover, as well as business imperatives and operating environment requirements, such as legislative requirements of the business and operating environment, and the skills transfer requirements.

### 2.1 Solar PV Plant Design Aspects

- Performance ratio of the solar PV plant must be optimised to a minimum of 0.8.
- The control and integration software in the PV plant shall be open source.
- The design of the PV plant must consider future expansion.
- The design of the PV plant shall be of a modular type allowing easy maintenance and repair.
- The design of the PV plant shall allow for additions of power storage and integration of back-up power supply.
- The design of the PV plant shall make provision for the installation of monitoring equipment for importing/exporting of power in compliance with National Regulatory Standards, NRS 048/9.
- The solar PV design stringing shall consider down-time and risks with respect to the loads being fed.
- Design must allow for ease of maintenance such as washing of PV panels; rainwater harvesting should be considered at design stage for the purposes of washing of panels.

- Design must consider maintenance of the performance ratio during times of corrective maintenance.
- A prioritising controller shall be included and integrated to ensure that the solar PV plant can generate electricity for the site in the absence of electricity from the national electricity grid.
- A monitoring system to improve the reliability and productivity of the plant shall be installed in accordance with IEC 61724 Ed 1.0 Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis. The monitoring system shall include the monitoring of plant performance to optimise the energy output, detect abnormal losses and be used for planning preventative maintenance actions.
- The installation shall ensure that solar PV yield is being used first before electricity from the national electricity grid is used for the site.

## **2.2 Solar PV Panel Specifications**

- The semiconductor material to be selected for PV plants shall have a minimum cell efficiency of 20.3 % with a minimum lifespan of 25 years.
- Solar PV panels that do not incorporate integrated bypass diodes that cause adverse effects when it comes to shading (particularly thin film technology) shall not be used.
- Factory acceptance electroluminescence tests must be submitted with all panels purchased. Variations of  $\pm 5W$  are allowed in PV panel output wattage and must be clearly stated.
- The PV panels chosen shall be compliant and certified to the following IEC standards: [4]
  - IEC 61215-2:2016 Terrestrial photovoltaic modules – Design qualification and type approval
  - IEC 60068 -1: 2017 Environmental testing
  - IEC 61730-1:2016 Photovoltaic module safety qualification – Requirements for construction
  - IEC 61730 -2:2016 Requirements for testing
  - IEC 61701-2:2011 Salt mist corrosion testing of photovoltaic modules
  - IEC 60891:2009 Procedures for temperature and irradiance corrections to measured I-V characteristics
  - IEC 60904-1:2006 Measurement of photovoltaic current-voltage characteristics
  - IEC 60904-3:2016 Measurement and principles
  - IEC 60904-5:2011 Determination of equivalent cell temperature (ECT)
  - IEC 60904-8: Measurement of spectral responsivity of multi-junction photovoltaic (PV) devices (where applicable)
  - IEC 61853: Performance testing and energy rating.
- The equipment should be able to operate at nominal operating cell temperature or NOCT of  $45\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$  and operating temperature of between  $-10\text{ }^{\circ}\text{C}$  and  $80\text{ }^{\circ}\text{C}$  at maximum operating system voltage of 1000 V DC [4].

- The following information should be made available in writing from the solar PV module manufacturer: [4]
  - Confirmation of surface texturing applied to the panel to reduce reflection and surface reflection parameters of the panel
  - Confirmation of the application of silicon nitride or other treatments to optimise optical properties
  - Confirmation of edge isolation done and the series and shunt resistances
  - Confirmation of the treatment of lightly diffused phosphorous emitters to reduce recombination losses and avoid the existence of a dead layer at the cell surface
  - Confirmation that design minimises metal contact areas to reduce resistance and heavy doping beneath the contact areas to reduce recombination
  - Confirmation of rear and front surface passivation
  - Confirm recyclability of the panel.
- A glare study confirming no glare to aircraft pilots from the solar PV installation shall be completed.
- The junction boxes must be at least IP67 rated.

### 2.3 Solar PV Plant Installation Aspects

- Transportation and handling shall be as per manufacturer's recommendation and in absence of this, the panels shall be transported in a vertical arrangement. Freight forwarding documentation shall be included in the handover documentation and shall be checked prior to installation of the solar PV plant.
- The installation of PV panels shall consider the ground or installation surface conditions, shading, and direction of solar irradiation, for optimum capture of solar energy.
- All ground installations shall be preceded by an environmental impact study.
- Soil resistivity tests should be undertaken for ground mounted installations.
- Fixed or tracking arrays shall be decided based on feasibility.
- A lightning risk assessment shall be done.
- Evaluation including execution of a study of shadows falling from aircraft landing and taking off and from fixed structures to ensure that performance ratio of plant is not affected.
- Mounting structure must comply with the following standards:
  - SANS 10160 Part 2 – Self weight and imposed loads
  - SANS 10160 Part 3 – Wind actions.

### 2.4 Electrical Design Aspects

- The following must be complied with for the PV plant installation:
  - IEC 60364-4-41: 2017 Protection for safety, protection against electric shock

- IEC 60364-4-43:2008 Protection against overcurrent
- IEC 60364-4-44:2007 Voltage disturbances
- The minimum insulation resistance shall be 20 MΩ when measured at 500 V DC
- IEC 60364-7-712:2017 Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems
- IEC 61730-2:2016 Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing
- IEC 61439-1:2011 Low-voltage switchgear and control-gear assemblies
- IEC 60529 Ingress protection code
- IEC 60099-6:2002 Protection against transients and overvoltage
- All solar PV systems shall utilise 400 V to 11 KV step up transformers, star-delta vector configuration.
- For security of supply all installations shall be grid tied with priority given to the solar PV plant supply.
- The inverter system voltage shall be designed for 1000 V DC and input voltage shall be 400 V to 800 V and output voltage 400 V.
- The inverters shall be of string inverter type.
- The operating voltage ( $V_m \times$  number of modules in series at all temperatures at the installation location) shall fall within the inverters maximum power point tracker (MPPT) voltage range.
- The total  $I_{sc}$  current for strings in parallel shall be lower than the maximum input current for the inverter.
- Panel stringing must consider the panel output wattage from factory acceptance electroluminescence (EL) tests.
- Inverter shall include a protection for anti-islanding (in accordance with NRS 097-2-1 “Inverter type test certificate and test report”).
- Inverters must include the following protection functions:
  - DC reverse polarity protection
  - Reverse current protection
  - ESS switch disconnecter
  - AC short circuit protection
  - Ground fault monitoring
  - Galvanically isolated
  - All-pole sensitive fault
  - Current monitoring unit
  - DC overvoltage protector type II

- String failure detection
- Protection class 1
- Overvoltage category III.
- All inverters must carry an ingress protection rating of 66 (IP66).
- All inverters shall be programmed such that solar PV energy is used first before grid power is used.
- The PV plant may be designed to accommodate battery storage.
- Orientation of the module strings and array strings will be based on the anticipation of shading to ensure optimum output.
- The cabling shall be such that it avoids enveloping the panel with transient currents.
- Remotely controlled breakers should be employed at substations.
- A meter that is AMR (automatic meter reading) compatible shall be installed to accurately determine output of plant being used for the site.
- Verification and documentation of fault current must be done.
- Verify electrical ring network protection settings, the final protection settings are to be included in handover documentation, out of sync settings must be corrected.
- The inverter shall comply with the following standards:
  - IEC 60364-7-712 (requirements for DC switch)
  - IEC 62109 Safety requirements
  - IEC 62116 performance of islanding prevention.
- Inverters must be protected from weather conditions.
- The combined cable losses should not exceed 3 %, i.e. the AC and DC cable losses combined.
- Cables used in outdoor environment shall be UV (ultraviolet) resistant.
- Cables should have a class II rating for insulation.
- Cables must be rated for temperatures from -40 °C to +90 °C.
- Cables shall comply with SANS 1507.
- Cables must be installed in conduits and hooded cable trays. The cable return path should ensure that induction loops are avoided.
- Cables shall be terminated with MC4 connectors.
- All connectors shall be UV resistant, ozone protected, being temperature rated equal to or better than -40 °C to +90 °C, having an IP class of at least 65. They must be equipped with a locking system to avoid disconnection of

the parts. Male and female connectors will be of the same make.

- The lightning protection must be designed in compliance with SAN 10313 and IEC 62305.
- Earthing shall comply with 10142 Parts 1 (LV) and 2 (MV), SANS 10292 and SANS 10199.
- Surge protection devices must be installed at string box, combiner box, inverter (AC and DC side) and at transformer level.

## **2.5 Solar PV Maintenance Aspects**

- Only competent personnel trained in the maintenance and operation of the photovoltaic system shall be allowed to perform maintenance on the plant. This includes working near or on live equipment and in a live chamber. At least two people shall work on maintenance at any point in time. All isolation procedures shall be in accordance with the high-voltage regulations, i.e. ORHVS - operating regulations of high voltage system.
- No cleaning shall occur before sunset and after sunrise.
- For all installations, critical spares (up to 10 %) shall be procured and stored on site.
- Connectivity shall be in accordance with ORLVS – operating regulations of low voltage systems.
- All maintenance shall be in accordance with original equipment manufacturer (OEM) recommendations.
- Where feasible, alternative water sources should be implemented for the washing of the PV panels.
- The project shall purchase a portable I-V tracer, infrared camera and signal transmission device for verification of availability and reliability of the PV plant.
- Maintenance shall be done to maintain the warranty and guarantee of all plant equipment and the performance ratio to above 0.8.
- All spares and replaced components shall be of equal quality or exceed the original quality subject to its compatibility with the solar PV plant.
- Full report shall be done in the event of the failure of a PV panel or other system component before the guarantee and or warranty period, to establish the root cause and put in place preventative maintenance measures.
- Should the performance ratio of the plant fall below 0.8, a full investigation and report shall be produced to the plant owner by the installation contractor during the defects liability period and the maintenance contractor during the respective maintenance period and any warranty or guarantee claim shall be handled respectively by these contractors.
- The contractor shall carry out all operations and maintenance in the defects liability period to achieve the energy production and the following services are a minimum:
  - Regular operation
  - Scheduled maintenance
  - Preventative maintenance as per manufacturer manuals and best practice

- Daily plant performance and functional monitoring
- Administrative and financial services
- Management of alarms and events
- Predictive maintenance as per manufacturer manuals and best practice
- Corrective maintenance
- Quarterly performance and operations and maintenance (O&M) reporting, including keeping an O&M logbook
- Spare parts management
- Management of the insurance policies.
- Calibration of all equipment must be done upon handover of plant from the maintenance period, defects liability period, intermediate acceptance period or whenever, there is a handover from one party to another for whatever reason.

## 2.6 Solar PV Operational Parameters and Plant Output

- For electrical energy contributed to the grid, a memorandum of understanding shall be drawn up with the respective municipalities based on the local utility bylaws.
- The quality of electrical supply from the PV plant shall comply with the NRS 048 part 2 and part 4.
- Power quality monitoring equipment shall be installed on the PV plant before connection to the grid.
- Power quality incident logging shall be stored and backed up on the server. Critical alarms shall be relayed immediately to the plant's responsible person. Other alarms shall be relayed to the infrastructure monitoring and control (IMC) team.
- Monitoring of PV module and PV plant performance shall be in line with IEC 61724-2:2016.
- The expected linear or stepped power output warranty period of the solar modules shall be at least over 25 years.
- Any performance ratio deviation outside 0.8 shall be investigated in the context of the warranty.
- Any deviation in the performance of the plant from the linear performance warranty shall be investigated by the manufacturer.
- Should the PV plant be generating electricity into the national electricity grid, this must be granted approval from the relevant regulatory bodies, such as the National Energy Regulator of South Africa (NERSA) prior to plant installation.
- The plant shall have separate metering for import and export and must be compliant with SANS 474/NRS057.
- A weather monitoring station shall be installed on the plant that allows for plant performance ratio calculations according to IEC 61724 Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis.

- A monitoring system must be installed to monitor data that must be used for optimising energy output, detecting abnormal losses and planning preventative maintenance actions.
- The monitoring system must be able to record meteorological data, electrical parameters and status of the PV plant components.
- Continuous monitoring is required.
- The minimum data to be monitored are as follows:
  - DC current and voltage at combiner box level
  - Inverter behaviour
  - DC current and voltage input
  - Output active and reactive power
  - Phase voltage and current
  - Energy output
  - Alarms and faults
  - Meteorological data – Module temperature on 1 % of the plants' modules, ambient temperature, irradiation, wind speed
  - Energy output at the meters (import and export, plant yield)
  - Status of the equipment (protection devices, inverters)
  - Any other information which will be required by the laws and norms in respect of this installation.

## **2.7 Guarantees, Warranties and Insurance Underwriting**

- Performance warranty of the solar PV panels shall be a minimum of 25 years and a total of 20 % linear degradation as a maximum over 25 years. Solar panel warranty of 25 years must be insurance backed, with full details of claim procedure and insurance backing submitted. Plant registration with the supplier is the responsibility of the installation party appointed.
- Upon installation, registration documentation of the photovoltaic plant installed must be submitted.
- Verification certificate that certifies that commissioning was conducted per the standards and requirements of the warranty.
- The monitoring system must be designed and implemented in such a way to have a lifetime of 25 years.
- The mounting structure shall have at least 10 years warranty and shall be designed for a minimum lifetime of 25 years. Corrosion prevention must start at the design stage considering site and soil specific parameters.
- Inverters must have at least a 5-year warranty, with a clearly defined claiming procedure.
- The conditions which void warranties for all equipment and installations must be clearly stated, preserved and

communicated to the plant owner and all handling parties.

## 2.8 Environmental Impact

- Disposal method of the plant and its equipment at end of lifespan shall be decided based on the outcomes of a feasibility study, environmental impact study and the objectives of the business.
- The installation contractor shall be liable for any environmental impacts arising from the plant installation during the defects liability period.
- The maintenance contractor shall be liable for any environmental impacts arising from the plant maintenance activities during the maintenance period.

## 2.9 Testing, Commissioning and Handover

- Commissioning shall be done per the following standards:
  - IEC 62446: Grid connected photovoltaic system
  - IEC 60364-6: IEC 60364-6: Low voltage electrical installations – Part 6: Verification
  - IEC 62337: Commissioning of electrical, instrumentation and control systems in the process industry – Specific phases and milestones.
- The following shall be submitted upon handover:
  - Approved as-built drawings and design report signed by a professional engineer, registered with the Engineering Council of South Africa (ECSA)
  - Operating and maintenance documentation
  - Equipment datasheets
  - Calibration certificates of all equipment
  - Verification certificate that certifies commissioning was conducted per the standard IEC 62446 Grid connected photovoltaic systems
  - I-V curves
  - PV panel electroluminescence (EL) tests
  - Signal transmission device data
  - Testing and commissioning data including but not limited to details of PV array, results of polarity, insulation, grounding, voltage and current tests
  - Test certificates that certify compliance with relevant codes and standards listed for the photovoltaic plant components and systems
  - Factory acceptance tests (FAT)
  - Open circuit voltage

- Short circuit current
  - Continuity of grounding system
  - Integrity of electrical insulation on power circuits
  - Operating voltage
  - Operating current
  - Verification of fault current and electrical ring network protection settings
  - Whole system performance (performance ratio which is actual output to predicted output).
- Competent representatives from both the client and the contractor shall be present for FAT.
  - Performance ratio must be calculated according to the standard CEI EN 61724 (CEI 82-15) standard. Inverter availability must be established and exceed 0.85 as calculated below. The following equations will be used to calculate the inverter availability and the plant annual availability:

$$\text{Inverter Availability}(\%) = \frac{\sum OT + \sum TnAC}{TOT} \times 100$$

Where:

TOT Total theoretical operating time [minutes]. (This accounts for the total amount of time in which an inverter (i) exceeds the minimum irradiation threshold of 30 W/m<sup>2</sup>.)

OT Operating time [minutes]

TnAC Time of non-availability [minutes] with causes not attributable to the contractor. During these periods, all inverters are considered as available. In this case, the operator must provide satisfactory evidence.

The operating time is calculated as the time when each inverter was considered as available. The requirement is that there is voltage in the output terminals of the connection box and the ratio of the actual production (Pi,ind) divided by the average production (PAV) of all inverters exceeds 0.85. This requirement is applied with the granularity of 15 minute periods. For such period of computation:

if  $P_{i,ind}/PAV > 0.85$ , the inverter i is considered as available,

if  $P_{i,ind}/PAV < 0.85$ , the inverter i is considered as not available,

Where:

Pi, ind actual production of the inverter i in fifteen minute periods

PAV average production of all inverters in fifteen minute periods.

- The following tests must be performed as a minimum (not limited to):
  - Mechanical completion test to ensure that all parts of the facility has been physically checked completed and installed correctly and according to the as-built documents. Once the mechanical completion of the installation is achieved, the contractor will proceed to energise the facility and carry out the tests for

completion to ensure each component of the plant is working properly and in accordance with the national and local electricity grid codes. It is the responsibility of the contractor to deliver a grid code compliant plant.

- Provisional acceptance tests (Phase 1 of IEC 62446) shall be performed to confirm the performance ratio of the entire facility and quality of design, construction and correct operation and must be supervised by an independent technical adviser.
- Intermediate acceptance tests (Phase 2 of IEC 62446) shall be performed where the performance and availability verification are executed for a period of 1 year. A visual inspection and thermal analysis (using thermal camera) is made on the plant to check for possible defects.
- Final acceptance tests (Phase 3 of IEC 62446) shall be performed for two years after the provisional acceptance tests. All remarks made during the provisional acceptance tests are verified as complete and a final performance and availability verification in this two-year period.
- Minimum requirements for taking over are as follows:
  - All works as per the contract are complete
  - Tests on completion have been passed and approved by the plant owner
  - Final O&M manuals for the works have been issued to the plant owner
  - List of open points has been agreed and signed by the plant owner and contractor
  - Provisional and final acceptance tests have been successful in meeting the minimum guaranteed performance and availability over the periods of analysis.

#### **2.10 South African Civil Aviation Authority (SACAA) and International Civil Aviation Organisation (ICAO) requirements**

- Any PV installation within the aerodrome vicinity shall be of an anti-glare nature and simulation with the “Solar Glare Hazard Analysis Tool” must be done in partnership and agreement with SACAA requirements.
- In cases where the height exceeds the maximum height in a roof mounted installation, obstruction lights shall be installed according to civil aviation regulations, CAR 139.01.30.
- Prior approval and consultation with all relevant stakeholders shall be acquired for solar PV installations within the airport environment.
- The solar PV installation shall not infringe any airports operations, safety, security or operational licence requirements as dictated by ICAO and SACAA regulations.

#### **2.11 Knowledge Management, Skills Transfer and Learnings**

- The consultant shall ensure that the site agent maintains a daily log of all events, occurrences and progress for the duration of the installation until commissioning of the solar PV installation.

- The consultant shall ensure that the project manager and design engineer compile a list of learnings from the design and installation of the facility which is to be attached to the close out report to be included in the handover documentation.
- The maintenance contractor shall compile a list of learnings from the maintenance of the solar PV plant which can be viewed from time to time and must be submitted annually to the ACSA person managing the maintenance contract.
- The installation contractor shall submit to the plant owner a comprehensive report on the supply market for solar PV panels, solar cells, inverters, transformers, software and sensors, mounting structures, and all other equipment and tools utilised for the installation.
- The consultant shall ensure that knowledge on all aspects of the plant design, supply process, installation and commissioning and project management is transferred to at least two of the plant owner's personnel.
- The maintenance site manager shall ensure that knowledge transfer is done through regular technical updates and, if need be, practical demonstration sessions as chosen by the plant owner's managing personnel.
- During the twelve-month defects liability period, performance ratio must be maintained at above 0.8 and all activities and steps taken to ensure this performance ratio must be documented and submitted as a report to the plant owner.
- The maintenance contractor shall be key in facilitating any research done by a research student from a university or other tertiary institution.
- The following shall be communicated as a minimum as per the learning and skills transfer:
  - Basic concepts on solar PV panel technology
  - Theoretical introduction to commissioning and test programmes
  - Practical introduction to correct use of maintenance manuals
  - Basic trouble shooting and fault finding
  - Safety procedures for operating and maintaining the plant
  - Theory and practice of electrical power system. Operational activity that is permissible by the plant owner for their personnel during the warranty period
  - Safety methods for equipment isolation during maintenance
  - Description of the electrical system including details of LV and data cable routes
  - Identification of protection relays and equipment
  - Review of protection relay settings
  - Description interface with any existing substation equipment and with the utility grid
  - Replacement of minor parts (e.g. fuses)

- Safety access, operations and maintenance procedures where special procedures are required which would not be familiar to experienced, qualified/registered personnel
- Monitoring and interpret a performance report.

### **3. PLANS TO ESTABLISH MAINTENANCE AND OPERATIONS OF SOLAR PV INSTALLATIONS AT AIRPORTS IN SOUTH AFRICA**

The plan presents a solar PV maintenance schedule for the next 3-year period of the solar PV maintenance term including the cost saving analysis performed that has a mix of insourced and outsourced tasks, including knowledge requirements for full insourcing to be adopted based on:

- Operational cost savings to the business
- Benefit of standardisation of maintenance across airports for solar PV installations
- Utilisation of in-house skills for tasks that can be executed by internal personnel
- Maximisation of existing maintenance contracts such as electrical reticulation
- Cultivating in-house skills for the full insourcing of solar PV maintenance over a 3-year period, potential commercialisation opportunities

ACSA's five solar PV plants produce yield whose value is around ZAR 6.4m per annum. These solar PV plants require maintenance to ensure their optimal output, execution of preventative maintenance and maintaining the plant's equipment guarantees and warranties. Maintenance can cost around ZAR 980k per plant. Refer to Table 2. It will cost between ZAR5m and ZAR6m to renew 3-year maintenance contracts for all six solar PV plants within the group.

The range of skills required to perform the work as can be seen in Table 2 are varied between labourers, semi-skilled and skilled workers mainly within the electricians and electrical engineering fields. All these skills are entirely possible to cultivate in-house. Due to the financial impact of the COVID-19 pandemic on the business, coupled with the business imperatives to build technical capacity in-house, a solar PV maintenance schedule that takes a hybrid approach as follows is proposed:

- Do certain maintenance tasks in-house
- Include medium voltage (MV) maintenance under the airports' general MV maintenance contracts
- Outsource the remaining tasks under the usual 3-year solar PV maintenance contracts

An analysis was conducted of the potential cost savings with this approach and it was found that 30 % (ZAR 1.7m) cost savings could be realised over the next three years (Table 3).

**Table 2: Estimated Cost of Solar PV Maintenance**

Solar PV Maintenance Cost (2017)			Solar PV Maintenance Cost (2020)	
	ZAR per Annum	CPI Escalation	Estimated cost per Annum (ZAR)	CPI escalation
Year 1 maintenance charge	258 297.34		307 636.26	
Year 2 maintenance charge	273 795.18	6.00 %	326 094.44	6.00 %
Year 3 maintenance charge	290 222.89	6.00 %	345 660.11	6.00 %
Total	822 315.41	12.00 %	979 390.81	12.00 %
Cost of Labour				
	ZAR per Hour 2017	ZAR per Hour 2020		
Labourer	62	73.16		
Semi-skilled	134	158.12		
Skilled	226	266.68		
Site manager	438	516.84		
Engineer/ Technologist	1307	1 542.26		

**Table 3: Cost Savings for Hybrid Approach (Insource/Outsource) of Solar PV Maintenance**

Maintenance Task	Frequency	Cost Saving (ZAR)	Notes
Array and Grid Junction box maintenance	Annually, with two follow up checks	21 334 <sup>1</sup>	<sup>1</sup> Skilled labourer rate calculated for 4 days for annual check-up, 3 days each for the two follow ups. Includes analysis of thermographic scans, including 1 day for corrective maintenance (in the 4-day annual check-up). Excludes cost of connectors for corrective maintenance
Earthing integrity check, maintenance and corrective action	Annually	6 400 <sup>2</sup>	<sup>2</sup> Skilled labourer rate calculated for 3 x 8 hour days. Includes corrective action. Excludes corrective action material
LV and MV cabling integrity checks and corrective action	Annually	21 334 <sup>3</sup>	<sup>3</sup> Skilled labourer rate calculated for 10 x 8 hour days. Excludes corrective maintenance. LV- in-house, MV to be done by a separate service provider
Structural integrity check and corrective action	Annually	6 400 <sup>4</sup>	<sup>4</sup> Skilled labourer rate calculated for 3 x 8 hour days. Excludes corrective maintenance
Vegetation management	At least twice a year - maintain vegetation height	37 949 <sup>5</sup>	<sup>5</sup> Semi-skilled labourer rate calculated for 3 people, 5 days x 2 times a year for 8 hours per day. Excludes cost of equipment, materials and fuel
<b>Total Savings (Zar)</b>	Per plant per annum	<b>93 418 (30%)</b>	The cost saving represented here assumes that the value of the contract awarded will exclude costings as per itemised costing of a typical contract. It does not take into account the market dynamics at the regional airports or the associated cost of doing business in these regions
	Per plant for a three-year contract	<b>297 070 (30%)</b>	

The solar PV plant maintenance schedule (Table 4) with insource/outsource model for cost reduction including knowledge management requirements (Table 5) for full insourcing model proposed for adoption in ACSA was co-developed with UPIA's Maintenance Manager with input from George Airport's Maintenance Manager. Table 6 explores the typical work involved with the insourced solar PV tasks, the skills and certifications required, as well as any special

equipment needed to perform the work involved.

**Table 4: Proposed Model for Transitioning Solar PV Maintenance in-House for Solar PV Installations at Airports**

	Task	Minimum Frequency	Specific Requirements	In-House/ Outsource
Solar PV Plant Major Components	Array and grid junction box maintenance	Annually, with two follow up checks	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	In-house
	Inverter maintenance	Annually	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	Outsourced
	Substation and transformer maintenance	Annually	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	To be done by the airports' existing medium voltage (MV) service provider
	Photovoltaic panels maintenance	Cleaning at least twice a year, with spot cleaning (for bird droppings and others) every two months	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	Outsourced
	*Maintenance of battery storage system	At least twice a year, following OEM recommendations	Not applicable	
Solar PV Plant Supporting Systems	Solar PV module connection integrity and corrective action	Twice a year	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	Outsourced
	Earthing integrity check, maintenance and corrective action	Annually	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	In-house
	LV and MV cabling integrity checks and corrective action	Annually	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	Low voltage (LV) in-house. MV to be done by a separate service provider
	Structural integrity check and corrective action	Annually	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	In-house
	Solar PV panels thermographic imaging and corrective action	Twice a year		Outsourced
	Vegetation management	At least twice a year and as required to maintain vegetation height	Maintenance of vegetation height at 10 cm	In-house
Solar PV Balance of System	Maintenance and calibration of meteorological equipment	Annually	Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees	Outsourced
	Auxiliary and ancillary systems maintenance	As per OEM requirements – annual integrity checks and	As per OEM requirements	Outsourced

	[Communication systems and balance of plant]	corrective action		
	*Calibration of active I-V curve optimisation system per string, including maintenance (*where installed)	At least twice a year for the full plant and after every repair, replacement/adjustment undertaken on a string	As per OEM requirements	Outsourced
	*Maintenance of active expected yield calculation system that takes into account temperature of modules and incident solar insolation (*where installed)	Twice a year	As per OEM requirements	Outsourced
Contractual Obligations	Corrective maintenance	When required	This must be carried out when it is required and must be done so as to maintain the plant quality, safety and product guarantees and warranties	Outsourced unless otherwise specified in the above line items
	Real-time performance monitoring and reporting	Real time	Showing the total yield of the plant, the kWhs used by the airport and the kWhs exported to the grid	Outsourced
	Monthly service reports detailing all the maintenance and corrective actions with route cause analysis where relevant	Monthly	Service reports including the performance of the plant and comparison against the expected performance of the plant with real time performance monitoring results	Outsourced
	Knowledge transfer for two ACSA employees every quarter on all issues with respect to this contract's scope of works	Shadowing, mentoring, teaching as per knowledge transfer requirements below	This knowledge transfer must cover technical and administrative aspects	Knowledge Transfer for two resources per solar PV plant and must cover the entire maintenance contract on technical issues as well as administrative tasks, competencies required and practical experience which must be acquired during the management of the contract
	Preparation and lodging of claims on equipment warranties/guarantees on behalf of ACSA	When required	This must be carried out as per the requirements of each OEM	Outsourced

**Table 5: Knowledge and Skills Transfer Requirements to be Performed Successfully for fully Insourcing Solar PV Maintenance at Airports**

<b>At Least Three Personnel per Solar PV Plant. The following must be Achieved Annually for the full Scope of the Maintenance Contract:</b>	
<b>A Theoretical Class every Quarter, Explaining Concepts of the Solar PV Plant Maintenance to be done in the following Quarter</b>	
1	(a) This theoretical class must have formal notes
	(b) This class must have a verbal, interactive session where team members can ask questions
	(c) This class must be followed up with an evaluation to test the knowledge transfer
	(d) An evaluation report of the team member's performance must be written up, providing insight on the candidate's learning gaps and readiness to perform the works tasks on site
	(e) Any lack in qualifications of the candidate to legally perform the maintenance tasks must be highlighted and submitted within the report
	(f) Registers and the evaluations must be kept as evidence that this task has been completed and must be submitted to the plant owner
	(g) A soft copy of ALL training material must be provided to the plant owner
<b>Practical onsite work must be undertaken on the solar PV plant every maintenance cycle (quarterly as a minimum and when required for corrective maintenance) ensuring that all maintenance tasks are included in the scope of the practical work</b>	
2	(a) The work tasks (both preventative and corrective maintenance tasks) must be demonstrated by the contractor with the candidate in attention, after which the candidate will safely attempt the task under the guidance of the contractor, until the candidate is confident to do the task on their own
	(b) Once the candidate is confident in doing the task on their own, the contractor writes this up, including evidence of the candidate having been practically trained and undertaking the task confidently on their own (safely and without risk to any warranties or guarantees) and submitted to the plant owner. The write-up must include professional feedback on the candidate's performance including the tools and any competencies that s/he will need to have should s/he undertake the task without the tools and supervision of the contractor. The candidates' signature on the report as being a true reflection of what transpired during the onsite work must be captured.
	(c) Attendance registers and photos must be used as evidence as well as signed off check sheets of who performed each task on the maintenance checklist and report that follows. All of this must be submitted to the plant owner
	(d) The candidate must produce a write-up on the site work performed and comment on his/her confidence to undertake the maintenance un-aided and this must be submitted to the plant owner
<b>Calibration, programming of parameters where required in this contract, measuring of efficiencies and administrative tasks such as putting in claims, report writing on performance of the solar PV plant must be covered</b>	
3	(a) Each candidate must be able to perform calibration, programming and adjusting of solar PV plant parameters where required, measuring and calculating of plant and component efficiencies effectively and confidently, understanding all concepts and underlying principles involved with each of these tasks which must be covered in the quarterly theoretical class outlined above
	(b) One monthly report every year must be undertaken by the candidate on the form that the contractor reports on a monthly basis. The candidate must do the report independently and the contractor must not do any of the work for this report. The contractor must sign in approval of this report as being true and accurate. Learning to write this report must be done in other months where the contractor usually submits this report.
	(c) At least one claim against the guarantee/warranty for the plant must be completed by the candidate. Evidence of this must be presented, such as report write-ups, emails sent, communications and liaisons recorded. This does not need to be done annually but can be done once per candidate for the duration of the contract.

**Table 6: Outlining the Typical Work Involved, Skills and Certification Required, and Equipment needed for the Insourced Solar PV Maintenance Tasks**

	Task	In-House/ Outsource	Typical Work Involved	Notes	Skills	Certification	Equipment Required
Solar PV Plant Major Components	Array and Grid Junction box Maintenance	In-house	Visual check for connection and thermographic scan for hot connections	Quick repair mainly involving replacement of connector- no effect on electrical loads	Qualified electrician with IR scanning training	Trade Test, Thermography certificate (3-day course)	Thermal imaging camera, printer, electrical cable connectors for replacement of defective connectors
Solar PV Plant Supporting Systems	Earthing Integrity Check, Maintenance and Corrective Action	In-house	Tightening of earth connections and checking bonding between steel structures and earth mat, annual resistance check using a device commonly known as the "Megger test" (an earth resistance tester to measure the soil [earth] resistivity)	Requires each airport to have an insulation resistance tester (Megger test); which most airports have onsite	Qualified electrician	Trade Test	Require an insulation resistance tester known as a "Megger test"
	LV and MV Cabling Integrity Checks and Corrective Action	Preventative maintenance to be done in- house. Outsource corrective maintenance	Repairing of damaged or compromised cabling mainly buried underground	Skills for repairing MV cable joints may not be present at each airport; these cables are also buried underground and are labour intensive	Qualified electrician	Trade Test	Visual checks required, so good eyesight and knowledge of how a healthy cable should appear
	Structural integrity Check and Corrective Action	In-house	Checks for corrosion and loose/failed bolts, loose connections	Major structural failure to be handled differently	Qualified electrician	Trade Test	Visual checks required, so good eyesight and knowledge of a joint/structural beams free of corrosion should appear to and be seen going into the ground, properly secured without compromise

Vegetation Management	In-house	Grass cutting with caution of flying debris causing damage to panels	Manage risk of panel damage	Grass cutting/Vegetation management	On the job training - minimum PPE	Requires grass cutting machine(s), fuel and safety gear, taking precaution to first clear the field of stones and objects that can cause damage to panels
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## CONCLUSIONS

This paper presented standards and guidelines for solar PV installations at airports and the proposal for solar PV maintenance to be insourced. The standards and guidelines for solar PV installations addressed the technical aspects of the solar PV plant, including the design aspects, installation aspects, solar PV specifications, operational parameters and output, environmental impact; testing commissioning and handover requirements including insurance underwriting and the SACAA, ICAO and knowledge transfer requirements. The proposed insourced/outsourced solar PV maintenance model is intended to be fully insourced in due course which will save about 30 % on operational cost. A fully insourced solar PV maintenance model ensures that the airports have cost effective maintenance and operations for business sustainability as well as presenting commercial opportunities due to the skills capacity built within the organisation.

## REFERENCES

1. South African Photovoltaic Industry Association, "Solar PV Installation Guidelines", South Africa, May 2017.
2. International Finance Corporation, World Bank Group, "Utility-Scale Solar Photovoltaic Power Plants", Washington DC., 2015.
3. Kelly G., "Forum on Regional Cooperation: Developing Quality Infrastructure for Photovoltaic Energy Generation", Santiago, Chile, 13-14 September 2017. Retrieved from [https://www.irena.org/-/media/Files/IRENA/Agency/Events/2017/Sep/Quality-infrastructure/1125\\_Standards\\_-\\_George-Kelly.pdf?la=en&hash=96BF73824D5AC761D88C026FB7D0AD07E8F6F521](https://www.irena.org/-/media/Files/IRENA/Agency/Events/2017/Sep/Quality-infrastructure/1125_Standards_-_George-Kelly.pdf?la=en&hash=96BF73824D5AC761D88C026FB7D0AD07E8F6F521), accessed 17/06/2021.
4. Dr Vorster, F., Prof van Dyk, E., "Photovoltaics Short Learning Programme", Nelson Mandela Metropolitan University, October 2016.
5. Shantika, Tito, Tri Sigit Purwanto, and Martin Garnida. "Design Rotor Turbine Hybrid of Pv-Picohydro Power Plant As Energy Sources For Rural Area In Indonesia." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 10.3 (2020).
6. Prakhya, Rajesh Kumar, and C. Krishna Reddy. "Comparison of Various Types of Rooftop Grid Connected Solar Plants: A Case Study." *International Journal of Electrical and Electronics Engineering Research (IJEEER)* 7.2 (2017): 11-22.
7. Kanchikere, Jayanna, A. K. Ghosh, and Kalyan Kumar. "Analysis of 80 KW grid connected rooftop solar power plant using SISIFO." *Int. J. Mech. Prod. Eng. Res. Dev* 8 (2018): 33-46.
8. Reddy, P. Surendra, et al. "Wind load analysis of solar farm using computational fluid dynamics." *Int J Mech Prod Eng Res Dev* 9.6 (2019): 485-498.

## **CHAPTER 18. ENERGY SECURITY: ESTABLISHING A LOW CARBON ENERGY MIX FOR AIRPORTS IN SOUTH AFRICA**

This chapter presents the establishment of a range of energy generation technologies forming a low carbon energy mix that is economically feasible and technically suited to the operating environment to ensure a reliable and feasible transition for nine ACSA airports to realise energy security.

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<http://www.tjprc.org/view-archives.php>

## ENERGY SECURITY: ESTABLISHING A LOW CARBON ENERGY MIX AND ROADMAPS TO CARBON NEUTRALITY IN ELECTRICITY CONSUMPTION FOR AIRPORTS IN SOUTH AFRICA

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### ABSTRACT

*Establishing a low carbon energy mix for developing countries is a multidimensional challenge and most organisations that embark on such a challenge are not successful and find themselves either reverting to paying for energy that is not guaranteed, or relying on a developing market of private energy service providers usually in the renewable energy sector involving South Africa's wind and solar energy independent power producers. The challenges associated with establishing power generation that is quite different from the established power generation energy sources stems from unfamiliar power generation technologies, technology markets, skills for operations and maintenance. These challenges have the common ground of increased relative cost and business risk. This paper presents the process for the establishment of energy generation technologies forming a low carbon energy mix that is economically feasible and technically suited to the operating environment to ensure a reliable and feasible transition for nine airports in South Africa to realise energy security.*

**KEYWORDS:** *Techno-Economic Assessments, Renewable energy, Alternative Energy, Feasibility of Renewable Energy, Geothermal Heat Sinks, Solar PV Energy, Energy Reduction Projects, Low Carbon Energy Mix, Solar Thermal Absorption Cooling, Solar Thermal Deflection Innovation, Air Conditioning Energy Reduction, LED Lighting Technology, Lighting Control, Natural Gas Trigeneration, Energy Security, Carbon Neutrality & Green Buildings*

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### 1. INTRODUCTION

Airports Company South Africa (ACSA) owns and operates nine airports in South Africa, namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport (CTIA) (Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape) (PEIA), East London Airport (Eastern Cape) (EL), Bram Fischer International Airport (Bloemfontein, Free State) (BFIA), George Airport (Eastern Cape) (GG), Upington International Airport (Northern Cape) (UPIA) and Kimberley Airport (Northern Cape) (KIM).

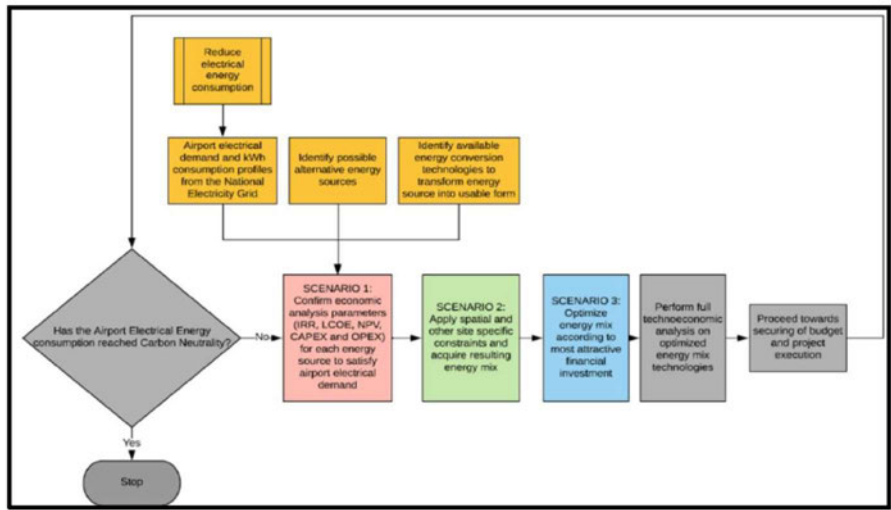
ACSA's objective is to establish an energy mix that is feasible and suitable for the operating environment in their strategic journey to reach carbon neutrality in electricity consumption which is the largest constituent of the airports' carbon footprint. Reducing the airports' electricity consumption is an objective in the journey towards carbon neutrality together with the establishment of certified green star rating of existing terminal buildings and certifying all new office, terminal and commercial buildings with green star ratings to ensure that the investment into energy efficiency, energy conservation and alternative energy mix is sustained, and investments preserved. Green star rating of terminal buildings is included as a goal regardless of the financial viability of this process as the

operational and efficiency benefits far outweigh the direct financial benefit.

This paper presents the confirmed energy mix for all nine airports, including the feasible alternative energy projects, their energy reduction projects, and the green star rating targeted for all airports.

**2. FINALISING THE LOW CARBON ENERGY MIX AND ROADMAPS TO CARBON NEUTRALITY IN ELECTRICITY CONSUMPTION FOR NINE AIRPORTS**

Determining a feasible energy mix for airports starts with the preliminary work of ascertaining and analysing the airports’ energy consumption followed by reducing the airports’ electricity demand [1] [2] [3]. This involves assessment of the energy demand profiles and determination of the alternative low carbon energy sources available to each site, then conducting technoeconomic assessments regarding the adoption of the alternative energy sources identified to supply the energy demand [4] [5] [6] [7]. Following the principles for energy efficiency [8] and the principles for energy security [9], the energy source identified can be matched to the energy demand considering the shortest energy conversion route, considering the site specific constraints, and optimising for cost effectiveness (Figure. 1).



**Figure 1: Flowchart: Energy Mix Determination Towards Carbon Neutrality in Electricity Consumption at Airports.**

Based on the conceptualised low carbon energy mix per airport [10], and the technoeconomic assessments, the final low carbon energy mix reaching carbon neutrality is shown in Figure. 2 to Figure. 10, each figure is followed by a table with the project details, Table 1 to Table 9. The roadmaps to carbon neutrality use the energy consumption of the airports during the period 1 April 2019 to 31 March 2020 or 2019/20 financial year (FY 2019/2020) as a baseline to offset carbon emissions, with the first reduction noticeable in the FY 2021/2022 (1 April 2021 to 31 March 2022).

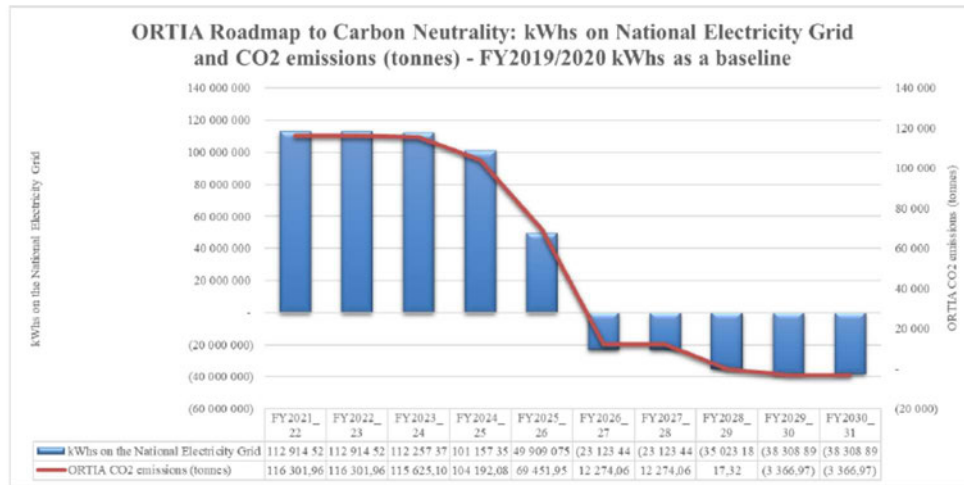


Figure 2: ORTIA Roadmap to Carbon Neutrality in Electricity Consumption.

ORTIA’s roadmap to carbon neutrality (Figure. 2 and Table 1) shows a reduction of electricity consumption from the grid, a reliance on natural gas trigeneration as a main power source, and an excess generation of kWhs as a result of using a carbon offsetting technique for generating green kWhs via a solar PV plant so that carbon credits can be claimed to offset carbon emissions and excess kWhs can be sold commercially.

Table 1: ORTIA Roadmap to Carbon Neutrality in Electricity Consumption

Objective	Project Guidance	#	ORTIA Project	Date of Beneficial Operation	kWh Savings Approximated	kWh Generation Approximated	% impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
Reduction in kWh consumption	Lighting change to LED	1.1	Runway	2026	5 914 278.24		11.52 %	14.99 %
		1.2	Cargo warehouse	2023	657 142.03			
		1.3	Streetlighting	2025	1 642 855.07			
		1.4	High-masts	2024	985 713.04			
		1.5	Phase 1 replacement	2024	4 928 565.20			
		1.6	Phase 2 replacement	2029	3 285 710.13			
	Lighting control	2.1	Lighting control system	2025	11 609 509.14		7.68 %	9.99 %
	Heat deflective coating	3.1	Application on terminal building roof	2028	7 255 943.21		4.80 %	6.25 %
	Geyser sleeve	4.1	Geyser sleeve	2026	98 550.00		0.07 %	0.08 %

	technology		retrofit					
	HVAC energy savings	5.1	Active chilled water setpoint control	2024	2 229 828.00		1.47 %	1.92 %
Energy mix	Natural gas	6.1	10.5 MWp (electrical) natural gas trigeneration	2025 (50 %); 2026 (100 %)	29 023 772.85 (HVAC energy consumption)	70 080 000.00	65.53 %	55.14 %
	Carbon offsetting plant	7.1	Solar PV plant 5.3 MWp	2024 (33 %); 2025 (66 %); 2026 (100 %)		8 867 748.00	5.86 %	7.63 %
	Smart grid	8	Implement a smart grid to coordinate energy sources					
Embedding energy efficiency culture	Existing terminal buildings green star rating	9.1	5-star green rated terminal	2028	4 643 803.66		3.07 %	4.00 %
		10	Maintain terminal building green star rating					
<b>Total kWhs off the national electricity grid</b>						<b>151 223 418.57</b>	<b>100 %</b>	
<b>Total CO<sub>2</sub> emissions offset (tonnes)</b>						<b>119 668.92</b>		<b>100 %</b>

CTIA’s roadmap to carbon neutrality (Fig. 3, Table 2) shows a reduction of electricity consumption from the grid, a reliance on natural gas trigeneration as a main power source, incorporation of a geothermal heat sink to replace a cooling tower, vertical axis wind turbines, and excess generation of kWhs as a result of using a carbon offsetting technique for generating green kWhs through a solar PV plant so that carbon credits can be claimed to offset carbon emissions and kWhs can be sold commercially.

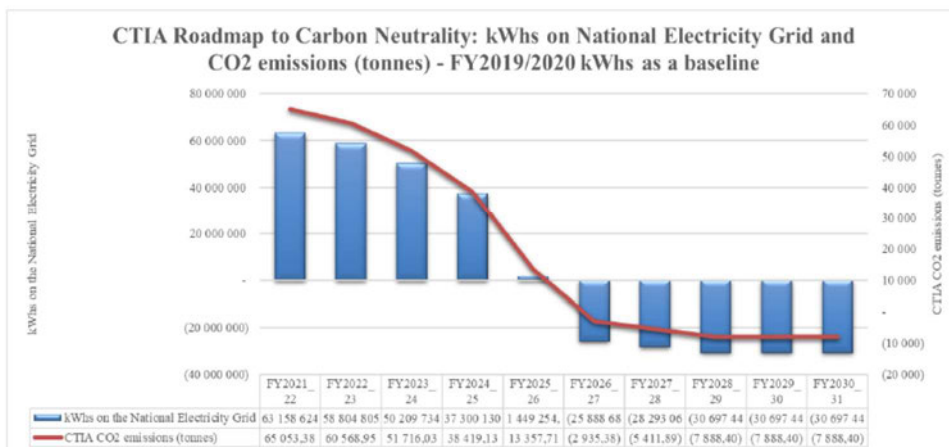


Figure 3: CTIA Roadmap to Carbon Neutrality in Electricity Consumption.

Table 2: CTIA Roadmap to Carbon Neutrality in Electricity Consumption

Objective	Project Guidance	#	CTIA Project	Date of Beneficial Operation	kWh Savings Approximated	kWh Generation Approximated	% Impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
Reduction in kWh consumption	Lighting change to LED	1.1	Parking areas	2026	240 437.92		15.74 %	20.86 %
		1.2	Terminal	2023	1 815 306.31			
		1.3	High-masts	2025	577 051.01			
		1.4	Runway	2024	120 218.96			
		1.5	Mass LED retrofit (4 years)	2025; 2026; 2027; 2028	9 617 516.88			
		1.6	LED retrofit and control	2024	2 404 379.22			
	Lighting control	2.1	Lighting control system	2023	2 404 379.22		2.56 %	3.40 %
	Heat deflective coating	3.1	Application on terminal building roof	2024	4 294 822.38		4.58 %	6.06 %
	Geyser sleeve technology	4.1	Geyser sleeve retrofit	2024	19 710.00		0.02 %	0.03 %
	HVAC energy savings	5.1	Chilled water setpoint and fresh air demand control	2024	1 486 552.00		1.58 %	2.10 %
Energy mix	Natural gas	6.1	7 MWp (electrical) natural gas trigeneration	2025 (50 %); 2026 (100%)	1 894 758.75	46 077 600.00	51.11 %	35.21 %
	Geothermal heat sink	7.1	Cooling Towers at Terminal 1	2022	114 253.40		0.12 %	0.16 %
	Carbon offsetting plant	8.1	Solar PV plant 11 MWp	2023 (33 %); 2024 (66 %); 2025 (100 %)		18 572 076.00	19.79 %	26.23 %
	Vertical Axis Wind Turbines	9.1	255 kWp wind plant	2025		781 146.50	0.83 %	1.10 %
	Smart grid	10	Implement a smart grid to coordinate energy sources					
Embedding energy efficiency	Existing terminal buildings	11.1	6-star green rated terminal	2025	3 435 857.91		3.66 %	4.85 %

<b>culture</b>	green star rating	12	Maintain terminal building green star rating		
<b>Total kWhs off the national electricity grid</b>			<b>93</b>	<b>856 066.44</b>	<b>100 %</b>
<b>Total CO<sub>2</sub> emissions offset (tonnes)</b>			<b>72 941.78</b>		<b>100 %</b>

KSIA’s roadmap to carbon neutrality (Figure. 4 and Table 3) shows a reduction of electricity consumption from the grid, a reliance on natural gas trigeneration as a main power source, and excess generation in kWhs as a result of using a carbon offsetting technique for generating green kWhs via a solar PV plant so that carbon credits can be claimed to offset carbon emissions and kWhs can be sold commercially.

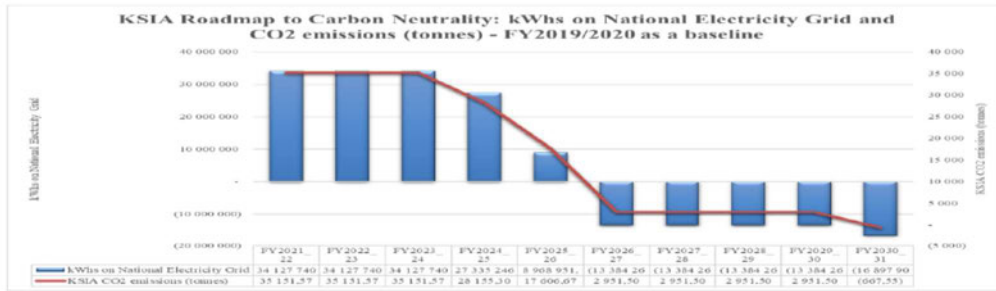


Figure 4: KSIA Roadmap to Carbon Neutrality in Electricity Consumption.

Table 3: KSIA roadmap to carbon neutrality in electricity consumption

Objective	Project Guidance	#	KSIA Project	Date of Beneficial Operation	kWh Savings Approximate	kWh Generation Approximate	% Impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
<b>Reduction in kWh consumption</b>	Lighting change to LED	1.1	Lighting change to LED	2024	6 772 784.00		13.27 %	19.48 %
	Lighting control	2.1	Lighting control system	2026	3 386 392.08		6.64 %	9.74 %
	Heat deflective coating	3.1	Application on terminal building roof	2025	2 116 495.00		4.15 %	6.09 %
	Geyser sleeve technology	4.1	Geyser sleeve retrofit	2024	19 710.00		0.04 %	0.06 %
<b>Energy mix</b>	Natural gas	5.1	5.25 MWp (electrical) natural gas trigeneration	2025 (50%); 2026 (100%)	1 023 832.22	32 499 600.00	65.70 %	49.67 %
	Carbon offsetting plant	6.1	Solar PV plant 2.1 MWp	2030		3 513 636.00	6.89 %	10.10 %

	Smart grid	7	Implement a smart grid to coordinate energy sources					
Embedding energy efficiency culture	Existing terminal buildings green star rating	8.1	6-star green rated terminal	2026	1 693 196.04		3.32 %	4.87 %
		9	Maintain terminal building green star rating					
<b>Total kWhs off the national electricity grid</b>						<b>51 025 645.34</b>	<b>100 %</b>	
<b>Total CO<sub>2</sub> emissions offset (tonnes)</b>						<b>35 819.12</b>		<b>100 %</b>

PEIA’s roadmap to carbon neutrality (Figure. 5, Table 4) shows a reduction of electricity consumption from the grid, a reliance on the existing 1 MWp solar PV powerplant as a main power source, vertical axis wind turbines, incorporation of solar thermal energy for powering absorption chillers, and excess generation in kWhs as a result of extending the existing solar PV plant to cover the airport’s remaining electricity demand. There are a few surplus kWhs which can either be sold off commercially or the carbon credits used by another airport. Geysler sleeve technology, although feasible for PEIA [1], was excluded due to the geysers being replaced with heat pumps.

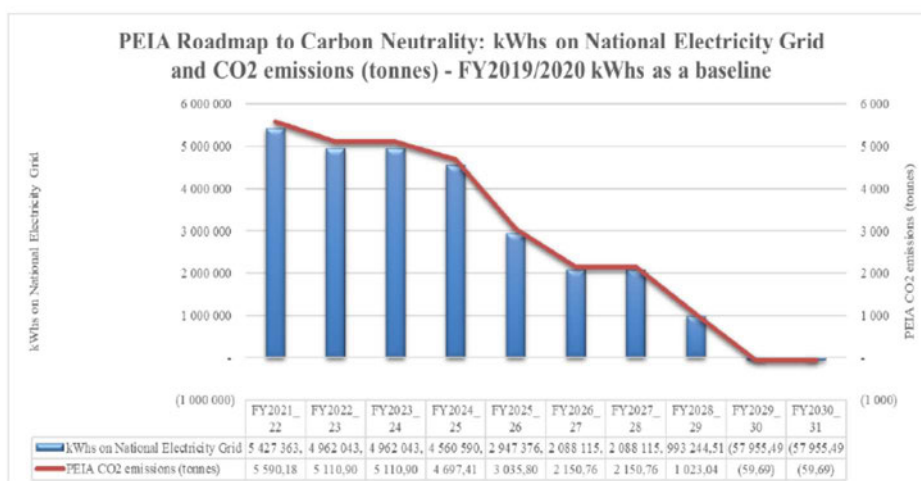


Figure 5: PEIA Roadmap to Carbon Neutrality in Electricity Consumption.

Table 4: PEIA Roadmap to Carbon Neutrality in Electricity Consumption

Objective	Project Guidance	#	PEIA Project	Date of Beneficial Operation	kWh savings Approximate	kWh Generation Approximate	% Impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
Reduction in kWh consumption	Lighting change to LED and lighting control	1.1	Terminal	2024	97 321.90		33.93 %	33.93 %
		1.2	Runway phase 1	2028	425 783.29			
		1.3	Runway phase 2	2028	669 088.03			
		1.4	Mass retrofit	2024	304 130.92			



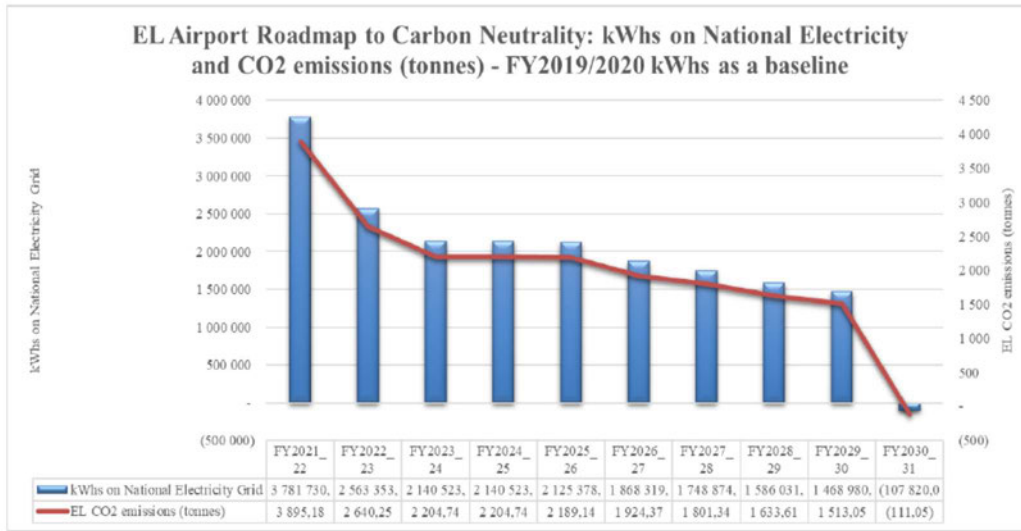


Figure 6: EL Airport Roadmap to Carbon Neutrality in Electricity Consumption.

Table 5: EL Airport Roadmap to Carbon Neutrality in Electricity Consumption

Objective	Project Guidance	#	EL airport Project	Date of Beneficial Operation	kWh Savings Approximated	kWh Generation Approximated	% Impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
Reduction in kWh consumption	Lighting change to LED and lighting control	1.1	Staff parking	2025	15 144.87		25.46 %	25.46 %
		1.2	Terminal and parking areas	2027	119 445.07			
		1.3	Runway phase 1	2028	162 843.06			
		1.4	Runway phase 2	2026	87 926.93			
		1.5	Runway phase 3	2029	117 051.24			
		1.6	Runway phase 4	2022	64 848.33			
	Lighting control	2.1	Lighting control system	2023	422 830.00		0.38 %	0.38 %
Energy mix	Planned solar PV plant	4.1	Solar PV plant 650 kWp	2022		1 138 800.00	29.28 %	29.28 %
	Solar PV plant expansion required	5.1	900 kWp plant with energy storage for night demand	2030		1 576 800.00	40.54 %	40.54 %

			from existing plant and expansion					
	Smart grid	6	Implement a smart grid to coordinate energy sources					
Embedding energy efficiency culture	Existing terminal buildings green star rating	7	5-star green rated terminal	2026	169 132.00		4.35 %	4.35 %
		8	Maintain terminal building green star rating					
<b>Total kWhs off the national electricity grid</b>					<b>3</b>	<b>889 550.00</b>	<b>100 %</b>	
<b>Total CO<sub>2</sub> emissions offset (tonnes)</b>					<b>4 006.24</b>			<b>100 %</b>

BFIA’s roadmap to carbon neutrality (Fig. 7, Table 6) shows a reduction of electricity consumption from the grid, a reliance on the existing 750 kWp solar PV powerplant as a main power source, incorporation of solar thermal energy for powering absorption chillers, and excess generation of kWhs as a result of extending the existing solar PV plant to cover the airport’s remaining electricity demand. There are a few surplus kWhs which can either be sold off commercially or the carbon credits can be used by another airport. The geyser sleeve technology, although feasible for BFIA [1], was excluded due to the geysers being replaced with heat pumps. Low emissivity glass (or double glazing), although feasible for BFIA [1], was reserved for new infrastructure and replacements due to existing infrastructure damage.

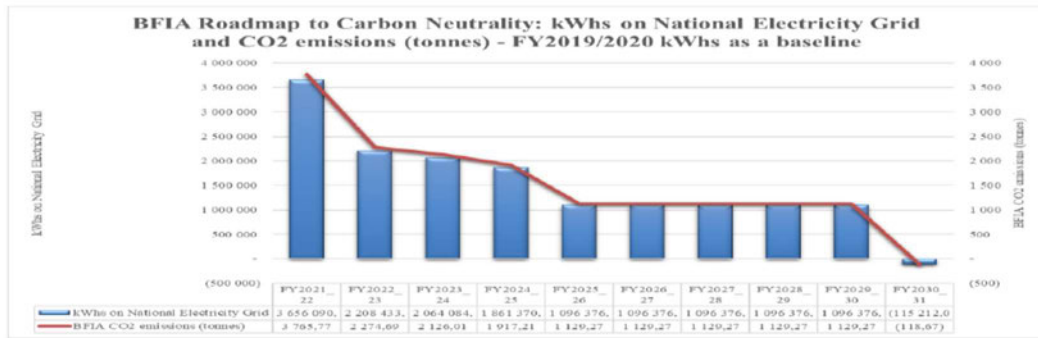


Figure 7: BFIA Roadmap to Carbon Neutrality in Electricity Consumption.

Table 6: BFIA Roadmap to Carbon Neutrality in Electricity Consumption

Objective	Project Guidance	#	BFIA Project	Date of Beneficial Operation	kWh Savings Approximate	kWh Generation Approximate	% Impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
Reduction in kWh consumption	Lighting change to LED	1.	Airfield	2025	48 116.55		12.90 %	12.90 %
		1.	High-masts	2030	160 388.51			
		1.	Terminal and offices	2023	144 349.65			
		1.	LED retrofits	2022	133 657.09			

	Lighting control	2.1	Lighting control system	2025	324 341.20		8.60 %	8.60 %
	Heat defllective coating	3.1	Application on terminal building roof	2024	202 713.25		5.38 %	5.38 %
Energy mix	Solar thermal absorption cooling	4.1	60 kWp solar thermal absorption plant	2025	262 800.00		6.97 %	6.97 %
	Maximising existing solar PV plant	5.1	Solar PV plant 750 kWp	2022		1 314 000.00	34.84 %	34.84 %
	Solar PV plant expansion required	6.1	600 kWp plant with energy storage for night demand from existing plant and expansion	2030		1 051 200.00	27.87 %	27.87 %
	Smart grid	7	Implement a smart grid to coordinate energy sources					
Embedding energy efficiency culture	Existing terminal buildings green star rating	8.1	5-star green rated terminal	2025	129 736.52		3.44 %	3.44 %
		9	Maintain terminal building green star rating					
<b>Total kWhs off the national electricity grid</b>						<b>3 771 302.77</b>	<b>100 %</b>	
<b>Total CO<sub>2</sub> emissions offset (tonnes)</b>						<b>3 884.44</b>		<b>100 %</b>

GG airport's roadmap to carbon neutrality (Figure. 8, Table 7) shows a reduction of electricity consumption from the grid, a reliance on the existing 750 kWp solar PV powerplant as a main power source, and excess generation of kWhs as a result of extending the existing solar PV plant to cover the airport's remaining electricity demand. There are a few surplus kWhs which can either be sold off commercially or the carbon credits used for another airport. The geyser sleeve technology, although feasible for GG airport [1], was excluded due to the geysers being replaced with heat pumps.

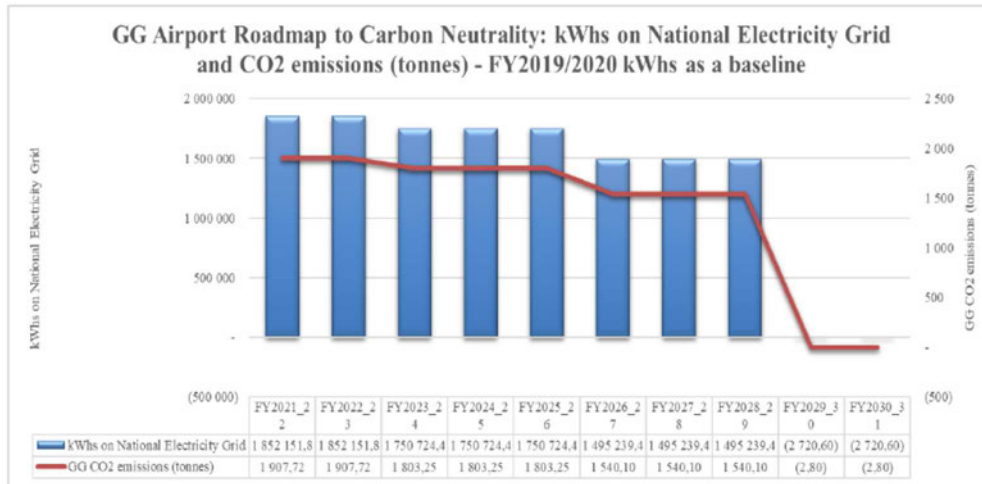


Figure 8: GG Airport Roadmap to Carbon Neutrality in Electricity Consumption.

Table 7: GG Airport Roadmap to Carbon Neutrality in Electricity Consumption

Objective	Project Guidance	#	GG Airport Project	Date of Beneficial Operation	kWh Savings Approximated	kWh Generation Approximated	% Impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
Reduction in kWh consumption	Lighting change to LED	1.1	Airfield	2026	101 427.36		14.98 %	14.98 %
	Lighting control	2.1	Lighting control system	2023	176 395.41			
Energy mix	Solar PV plant expansion required	3.1	900 kWp plant with energy storage for night demand from existing plant and expansion	2029		1 497 960.00	80.76 %	80.76 %
	Smart grid	4	Implement a smart grid to coordinate energy sources					
Embedding energy efficiency culture	Existing terminal buildings green star rating	5.1	5-star green rated terminal	2026	79 089.66		4.26 %	4.26 %
		6	Maintain terminal building green star rating					
<b>Total kWhs off the national electricity grid</b>						<b>1 854 872.43</b>	<b>100 %</b>	
<b>Total CO<sub>2</sub> emissions offset (tonnes)</b>						<b>1 910.52</b>		<b>100 %</b>

UPIA’s roadmap to carbon neutrality (Figure. 9, Table 8) shows a reduction of electricity consumption from the grid, a reliance on the existing 500 kWp solar PV powerplant as a main power source, and excess generation in kWhs as a

result of extending the existing solar PV plant to cover the airport’s remaining electricity demand. There are a few surplus kWhs which can either be sold off commercially or the carbon credits used for another airport. The geyser sleeve technology, although feasible for UPIA [1], was excluded due to the geysers being replaced with heat pumps.

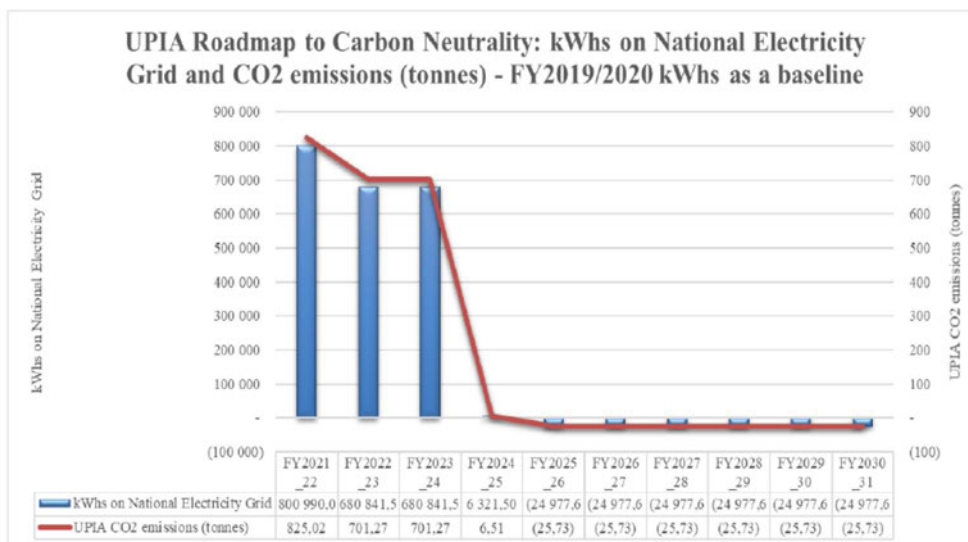


Figure 9: UPIA Roadmap to Carbon Neutrality in Electricity Consumption.

Table 8: UPIA Roadmap to Carbon Neutrality in Electricity Consumption

Objective	Project Guidance	#	ORTIA Project	Date of Beneficial Operation	kWh Savings Approximated	kWh Generation Approximated	% Impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
Reduction in kWh consumption	Lighting change to LED	1.1	Runway	2022	70 086.63		8.49 %	8.49 %
	Lighting control	2.1	Lighting control system	2022	50 061.88		6.06 %	6.06 %
Energy mix	Solar PV plant expansion required	3.1	200 kWp plant with energy storage for night demand from existing plant and expansion	2024		674 520.00	81.66 %	81.66 %
	Smart grid	4	Implement a smart grid to coordinate energy sources					
Embedding Energy Efficiency culture	Existing terminal buildings green star rating	5.1	5-star green rated terminal	2025	31 299.16		3.79 %	3.79 %
		6	Maintain terminal building green star rating					

<b>Total kWhs off the national electricity grid</b>	<b>825 967.66</b>	<b>100 %</b>	
<b>Total CO<sub>2</sub> emissions offset</b>	<b>850.75</b>		<b>100 %</b>

KIM airport’s roadmap to carbon neutrality (Figure. 10, Table 9) shows a reduction of electricity consumption from the grid, a reliance on the existing 500 kWp solar PV powerplant as a main power source and an excess generation in kWhs as a result of extending the existing solar PV plant to cover the airport’s remaining electricity demand. There are a few kWhs surplus which can either be sold off commercially or the carbon credits used for another airport. Low emissivity glass (or double glazing), although feasible for KIM airport [1] was reserved for new infrastructure and replacements due to existing infrastructure damage.

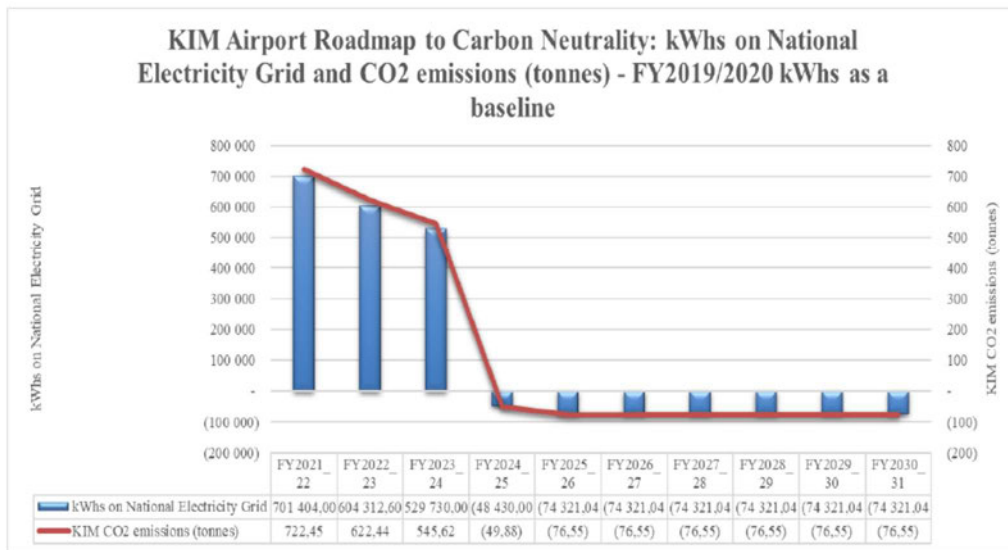


Figure 10: KIM Airport Roadmap to Carbon Neutrality in Electricity Consumption.

Table 9: KIM Airport Roadmap to Carbon Neutrality in Electricity Consumption

Objective	Project Guidance	#	ORTIA Project	Date of Beneficial Operation	kWh Savings Approximated	kWh Generation Approximated	% Impact on kWh Reduction	% Impact on CO <sub>2</sub> Emissions Reduction
Reduction in kWh consumption	Lighting change to LED	1.1	Airfield	2022	97 091.40		12.52 %	12.52 %
	Lighting control	2.1	Lighting control system	2023	64 727.60		8.34 %	8.34 %
	Geyser sleeve technology	3.1	Geyser sleeve retrofit	2023	9 855.00		1.27 %	1.27 %
Energy mix	Solar PV plant expansion required	4.1	150 kWp plant with energy storage for night demand	2024		578 160.00	74.53 %	74.53 %

			from existing plant and expansion					
	Smart grid	5	Implement a smart grid to coordinate energy sources					
<b>Embedding energy efficiency culture</b>	Existing terminal buildings green star rating	6.1	5-star green rated terminal	2025	25 891.04		3.34 %	3.34 %
		7	Maintain terminal building green star rating					
<b>Total kWhs off the national electricity grid</b>						<b>775 725.04</b>	<b>100 %</b>	
<b>Total CO<sub>2</sub> emissions offset (tonnes)</b>						<b>799.00</b>		<b>100 %</b>

Each airport’s roadmap to carbon neutrality is currently live and implementation will be adjusted according to circumstances and the changing energy demands of the airports. Geysers were investigated for all the airports and proved feasible; however, their implementation will not be needed at airports where heat pumps have been installed. It was decided that retrofitting glass facades with low emissivity or double glazing will not be the best approach and should rather be used in new installations as well as in repairs if appropriate. Implementation will be adjusted according to circumstances and the changing energy demands.

The roadmaps to carbon neutrality in electricity consumption for the airports aim to offset the quantity of carbon emissions as of the financial year ending 31 March 2020. Future electrical loads will be subject to the standards and guidelines for energy efficiency [10] and new infrastructure projects will be required to attain a green star certification. This will ensure that new loads are efficient and the roadmaps to carbon neutrality efforts are maximised. The intention is to increase the capacity of existing power plants to either supply new loads and/or offset carbon emissions.

### 3. CONCLUSIONS

This paper presented the confirmed low carbon, economically feasible energy mix and the green star rating targets for the nine airports in South Africa owned and operated by ACSA, and the associated roadmaps to carbon neutrality. The main low carbon energy source for ORTIA, CTIA and KSIA is natural gas trigeneration plants that will provide electrical kWhs and heat for water heating purposes and power absorption chillers for air conditioning. Wind energy and geothermal heat sinks are also in the energy mix for CTIA. To offset the carbon emissions from natural gas engines, solar PV plants are used. Excess generation from the carbon offsetting solar PV plants can be commercialised or can be targeted as an offsite corporate social investment project, claiming carbon credits. Solar PV energy with energy storage is the main energy source for PEIA, EL airport, BFIA, GG airport, UPIA and KIM airport. Solar thermal energy powering absorption chillers at PEIA and BFIA further reduce kWhs from the electricity grid. Wind energy is also in the low carbon-energy mix for PEIA. The roadmaps to carbon neutrality offset the carbon emissions from the airports’ electricity consumption from the grid, and the green star ratings targeted for existing terminal buildings as well as for new infrastructure ensures that investment into carbon neutrality is sustained and optimised.

### REFERENCES

1. Joseph, J., Inambao, F.L., “Reducing energy consumption at airports in South Africa: Investigating technologies that reduce electricity consumption” to be published, 2021.

2. Joseph, J., Inambao, F.L., "Reducing energy consumption: Investigating solar thermal heat deflection innovative technology to reduce air conditioning load at airports – A technoeconomic assessment", accepted for publication, *International Journal of Mechanical and Production Engineering Research and Development*, 2021.
3. Joseph, J., Inambao, F.L., "Energy consumption and energy efficiency of airports: A case study of airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, Vol. 11, Issue 2, Apr 2021, pp 205-228.
4. Joseph, J., Inambao, F.L., "Energy security: Investigating wind energy for airports in South Africa – A technoeconomic assessment", *International Journal of Mechanical and Production Engineering Research and Development*, Vol. 11, Issue 4, Aug 2021, pp 203-228.
5. Joseph, J., Inambao, F.L., "Energy Security: Investigating Anaerobic Digestion for Airports in South Africa – A Technoeconomic Assessment", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Vol. 11, Issue 4, Aug 2021, pp 319-340.
6. Joseph, J., Inambao, F.L., "Energy security: Investigating natural gas for energy generation at airports in South Africa – A technoeconomic assessment", accepted for publication, *International Journal of Mechanical and Production Engineering Research and Development*, 2021.
7. Joseph, J., Inambao, F.L., "Energy security: Investigating geothermal heat sinks for air conditioning systems at airports in South Africa – A technoeconomic assessment", accepted for publication, *International Journal of Mechanical and Production Engineering Research and Development*, 2021.
8. Joseph, J., Inambao, F.L., "Principles for achieving energy efficiency in developing countries", *International Journal of Mechanical and Production Engineering Research and Development*, Vol. 11, Issue 2, Apr 2021, pp 265-282.
9. Joseph, J., Inambao, F.L., "Principles for achieving energy security in developing countries", to be published, 2021.
10. Joseph, J., Inambao, F.L., "Energy efficiency for airport infrastructure: A case study of the implementation of energy efficiency for airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, Vol. 11, Issue 2, Apr 2021, pp 383-406.
11. Sounthari, P., et al. "Inhibition of Acidic Corrosion of Low Carbon Steel by Symmetrical 1, 3, 4-Oxadiazoles." *International Journal of Applied and Natural Sciences (IJANS)* 2.3, July 2013, 25-40
12. Kandavel, T. K., K. Palaksha Reddy, and P. Karthikeyan. "Experimental Investigation on Corrosion Behaviour of Hot Upset P/M Plain Carbon Steel." *International Journal of Mechanical and Production Engineering Research and Development* 8: 207-212.
13. Dinesh, S., et al. "Comprehensive analysis of wire electric discharge machining process in machining high chromium high carbon steel." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 8.1 (2018): 65-74.
14. Xu, C. H. A. N. G. C. H. U. N., H. A. E. N. G. M. U. K. Cho, and D. H. Park. "Effect of different fuels on combustion and emission components of ci engines." *International Journal of Mechanical and Production Engineering Research and Development* 9.6 (2019): 821-34.

## **CHAPTER 19. ENSURING SUSTAINABILITY OF ENERGY EFFICIENCY AND ENERGY SECURITY IN DEVELOPING COUNTRIES: A CASE STUDY OF AIRPORTS IN SOUTH AFRICA**

This chapter presents principles that provide an approach to ensuring that climate change mitigation efforts are sustained through implementing relevant technologies, legislation, personnel and markets and shows the application of these principles in an airport environment.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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<http://www.tjprc.org/view-archives.php>

## ENSURING SUSTAINABILITY OF ENERGY EFFICIENCY AND ENERGY SECURITY IN DEVELOPING COUNTRIES: A CASE STUDY OF AIRPORTS IN SOUTH AFRICA

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### ABSTRACT

*Energy efficiency projects that change inefficient lighting technologies to light emitting diode (LED) technology or employ a solar PV plant to lower carbon emissions to bring a certain level of carbon footprint reduction as well as energy security, bring assurance for as long as the lifespan of these technologies. With the passing of time, technologies change and so does legislation, the market, and business focus. Changes in personnel within organisations, governments and even changes in society, culture and way of life is inevitable. To ensure that energy efficiency and energy security are sustained through time this approach must be embedded in employees' everyday lives, independent of specific persons within governments and organisations who advocate for the mitigation of climate change. With the nature of our knowledge of the planet growing all the time, our use of certain technologies and energy sources may be shifted to be aligned to our understanding of what contributes to climate change and other environmental impacts, working with trade-offs to find the most suitable pathway for all affected entities. Our efforts to mitigate climate change cannot be short lived but must constantly evolve to ensure mitigation of climate change. This paper presents principles that provide an approach to ensure that climate change mitigation efforts are sustained through changing technologies, legislation, personnel and markets, and shows the application of these principles in an airport environment.*

**KEYWORDS:** *Sustaining Efforts for Climate Change Mitigation, Sustained Reduction in Energy Demand, Sustained Reduction in Carbon emissions, Energy and Demand Management Strategy, Energy Technology, Energy Legislation, Feasibility Studies, Climate Change Mitigation*

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### INTRODUCTION

Airports Company South Africa (ACSA) over the past eleven years (2010 to present) has been making an effort to reduce carbon emissions across the nine airports it owns and operates in South Africa. The journey began with energy reduction projects being undertaken by the company's electrical and mechanical engineering departments. The efforts to reduce energy consumption was spurred on by the 2008 rolling black-outs and load shedding due to Eskom's lack of electricity capacity to serve the country and the resulting increase in the cost of electricity. Airports were usually prioritised along with medical facilities such as hospitals, but this was on the condition that energy consumption was reduced. As time went on and Eskom's position did not improve, relying on Eskom supply to the airports 24 hours a day, 7 days a week became unsustainable.

The reduction in energy consumption at OR Tambo International Airport (ORTIA) was driven purely by cost savings primarily through a reduction in maximum electricity demand initiatives in collaboration with onsite hotel owners and retail facilities, and lighting upgrades as fluorescent lighting and later LED (light emitting diode)

technology matured in the commercial market. The regional airports, namely, Port Elizabeth International Airport (PEIA), East London (EL) Airport, Bram Fischer International Airport (BFIA), George (GG) Airport, Upington International Airport (UPIA) and Kimberley (KIM) Airport faced a more serious problem of lack of capacity to supply the airport electricity demand as the geographical areas where these airports are were not as developed or urbanised as Johannesburg, Cape Town or Durban. Efforts to reduce energy consumption through replacement of lighting with more efficient matured technology at that time (fluorescent lighting at the regional airports) and the installation of solar PV plants were investigated to make up for the shortfall in energy supply from Eskom. Cape Town International Airport (CTIA) also undertook lighting changes and installed lighting control. King Shaka International Airport (KSIA) being quite new, having been commissioned in May 2010, including new technologies and efficient technologies from the beginning, together with timers for lighting circuits, daylight sensors for outdoor lighting, efficient fluorescent lighting and state of the art air conditioning system with continuous energy saving initiatives being undertaken for its large, centralised air conditioning system. With the cost of a loan to pay off from building the greenfield airport on its monthly debt, it was imperative to reduce cost and reduce energy consumption through energy conservation and energy efficiency which became a key performance indicator that featured on the monthly maintenance and engineering forum made up of maintenance and engineering managers from all the airports with invited electrical or mechanical engineers from the airports spearheading energy reduction projects.

Setting energy reduction targets of 10 % year on year became an unreasonable and unsustainable task especially without the backing of investment and a strategy including a plan of what needed to be done each year to reduce energy consumption enough to meet the target. Certain inconsistencies were also noted where airports that did not attempt any energy saving interventions nevertheless achieved 10 % energy reduction, and those who executed projects to reduce energy consumption observed an increase in energy consumption. This, together with the fact that depending on how the energy reduction target of 10 % year on year was interpreted, by year 10 the airports should consume no energy, highlighted the need for a clear strategy and reasonable, measurable targets that would be achievable based on the investment that management was willing to make. The mechanical engineer who was the representative from KSIA at the maintenance engineering forum (also involved in the commissioning of most of the mechanical engineering infrastructure during the construction stage of the airport) identified this and presented a strategy that was achievable for KSIA, the airport where replacing any new infrastructure to achieve energy savings was not supported by management, due to the airport's completed construction and commissioning in May 2010. KSIA's management team supported the energy management strategy for implementation at KSIA which involved Eskom incentivised lighting replacement for its multi-storey parkade, promotion of energy awareness through a campaign for all its tenants and onsite stakeholders (over 700 participants), and an energy systems optimisation programme undertaken in collaboration with the Industrial Energy Efficiency Project South Africa for its air conditioning and lighting systems, these having been identified as significant energy users. This strategy was supported by KSIA's Chief Aerodrome Engineer at the time and proposed to be adopted for the group of nine airports at the maintenance and engineering forum in 2014.

KSIA's successful energy reduction from 2010 to 2013 and strategy implementation from 2012 [1] resulted in the adoption of an energy management strategy in 2015 for the rest of the airports which proposed an energy management system which mapped out the path for ACSA operated airports to reduce dependency on the grid for their power requirements (power generation). The short term goal was to reduce energy demand (Demand Side Management or DSM) through the implementation of efficient engineering technology systems and optimising processes requiring power with a

view towards creating an ACSA standard which contains energy specifications for all future buildings and infrastructure. Its objectives were to achieve and maintain energy efficiency at all ACSA operated airports in a structured and collective manner by integrating energy efficiency and management into existing maintenance activities and ACSA departmental influencers' decision making, stakeholders, service providers, tenants, retailers and passengers activities to sustain an energy efficient culture, and drafting policies that specified minimum energy requirements for all future buildings and equipment at ACSA operated airports in their path towards compliance with existing global energy standards.

The key mechanical and electrical engineers from the airports formed an Energy Forum led by KSIA's mechanical engineer who proposed the strategy and spearheaded the formulation of the energy reduction projects, commitment to energy reduction targets, drafting of standards and guidelines for energy efficiency and formulation of roadmaps to energy efficiency for all nine airports. Green buildings were quite new in South Africa at that stage, and were investigated, but ACSA was not yet ready for the bold investment commitments to certify infrastructure with green star ratings. When ACSA restructured and implemented a new governance structure and operating model with a new vision, objectives and key performance indicators, "Energy and Demand Management" became formalised within airport structures appointing energy and demand management engineers at the airports and a Chief Energy and Demand Management Engineer role at its corporate office.

With rising electricity prices and the bold vision of ACSA to be leaders in the airport business, there was a need to align energy and demand management efforts to the global context with local relevance. The appointed Chief Energy and Demand Management Engineer (previously the KSIA's mechanical engineer who was instrumental in formulating KSIA's energy management strategy in 2014) led the formulation of the revised energy and demand management strategy which focussed on reducing carbon emissions towards carbon neutrality in electricity consumption.

During the journey of development, progress and awards [1], [2], [3] for efforts of energy reduction, carbon footprint reduction through changing company strategies, personnel, technologies and legislation, there were three key principles that underpinned its sustained success. This paper presents the principles that were used to ensure that energy efficiency and energy security are sustained at ACSA owned and operated airports, which can be used in any developing country.

#### **Principles for Sustaining Energy Efficiency and Energy Security in Developing Countries**

Energy affects and is involved in everything we do in life, whether we are at home, at work, at leisure or commuting, regardless of geographical location, political or social structure. Trying to achieve a reduction in carbon emissions to mitigate climate change is ineffective without agreement and support from all parties involved, whether voluntarily or bound by contract, law or business strategy. Most times when energy reduction is achieved due to reduction in costs alone, the trend in Figure 1 is observed.

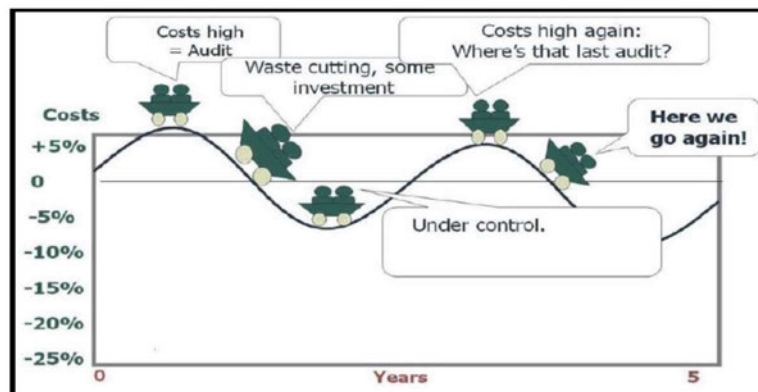


Figure 1: Ad-Hoc Approach to Managing Energy [4].



Figure 2: Isolated Attempts to Reduce Energy Consumption.

Without energy efficiency being embedded into everyday activities, there will be no sustained energy decrease, but rather ad hoc projects to reduce energy consumption while inefficient operational activities continue, negating all project efforts that reduce site energy consumption. This is like exercising to lose unwanted kilograms while not controlling one's diet (Figure 2).

While some projects that upgrade technology may have certain operational advantages, making them desirable, without the proper establishment of energy reduction projects in the business process considering the three dimensions of social, environmental and economic integration, most energy reductions projects will fail to gain management support for investment and effort, with other projects taking preference (Fig. 3). This is one of the main reasons why many energy reduction and carbon reduction projects require advocacy, because just a few people believe in it, and it fails to gain traction, becoming unsustainable within the organisation. It usually dies when those who were 'keeping the wheel turning' leave the organisation.

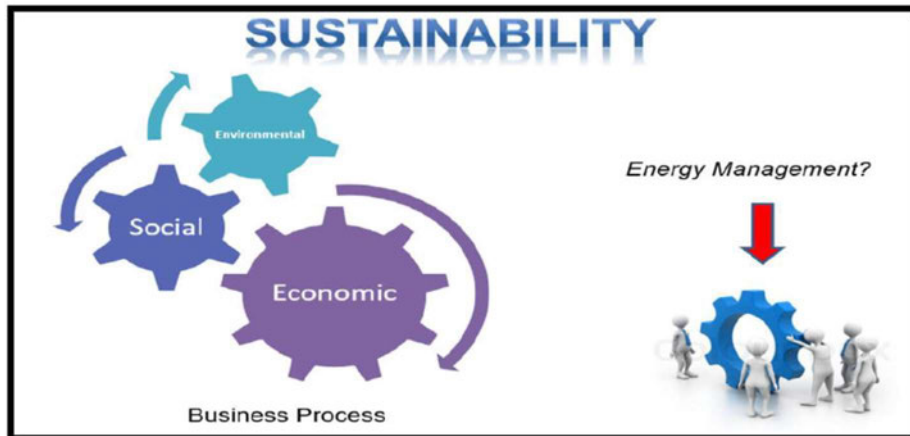


Figure 3: Energy Management Operating outside of the Business Process Poses Sustainability Issues.

Being convinced that climate change is a concern that must be addressed is key to begin the journey of embedding it within the organisations as what people believe filters through to their behaviour, becomes what they practice, and forms part of their culture. When they are convinced about pollution and climate change being a real threat to their way of life, they find ways to ensure that awareness is created and this filters into their way of doing business so as to preserve their way of life (Figure 4).

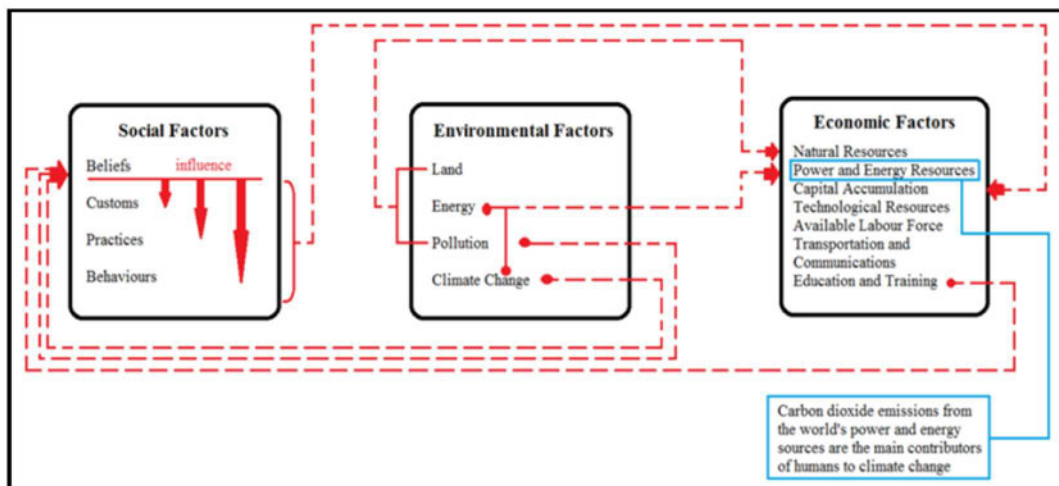


Figure 4: Highlighting the Connectedness of Social Factors to Environmental and Economic Factors.

To ensure the sustainability of efforts to reduce carbon emissions for the continued life of humankind on earth as we know it presently, there are three principles upon which these efforts must be built:

**Principle One**

Energy efficiency and energy security must form part of an organisation’s strategic plan.

**Principle Two**

The energy efficiency and energy security strategy must be underpinned by a functional structure that ensures the strategy

is relevant in the global context.

### Principle Three

The energy efficiency and energy security strategy must be executed according to the three dimensions of business sustainability, i.e., with social, economic and environmental dimensions becoming part of every business activity and transaction.

These principles will be discussed below, presenting the work that underpinned the success story [1] [2] [3] of ACSA and its nine airports operating in South Africa.

#### A. Embedding Energy Efficiency and Energy Security in Strategy

While many organisations and countries, if not all, start off with a few energy efficiency and energy conservation projects due to their advantages in lowering costs and optimising operational performance, there comes a point when further efforts to reduce energy consumption are rejected by management due to their priorities being elsewhere, mostly in profitability, and, for state owned organisations, satisfying objectives and commitments made to its shareholders and stakeholders. Reduction in carbon emissions must find its importance and relevance within an organisation's vision, prerogatives and objectives for it to be sustained and become company culture (Figure 5).

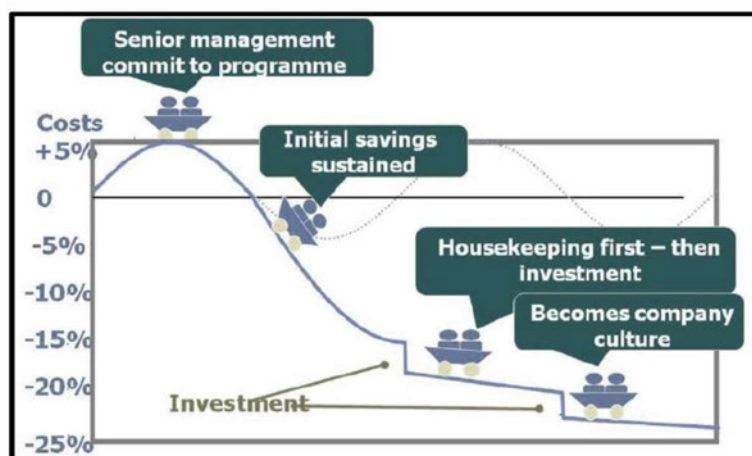


Figure 5: Structured Approach to Managing Energy [4].

The strategy employed must relate to the mitigation of climate change and address the threat faced by the organisation. For a developing country like South Africa, climate change is accelerated through CO<sub>2</sub> emissions by Eskom's coal fired power stations and the threat to the country's off-takers like businesses, organisations, homes, etc. is the risk that energy is not guaranteed for its operations at present and poses great risk into the future. Airport operations thus require a reduction in carbon emissions while securing a reliable source of power that is guaranteed for its future, while remaining profitable. Table 1 shows the energy management strategy proposed and adopted by ACSA for its nine airports in September 2017, after their appointment of a Chief Energy and Demand Management Engineer.

**Table 1: ACSA’s Energy Management Strategy**

<b>Vision:</b> To be a recognised leader in the implementation of energy solutions that are economically and environmentally sustainable to airport businesses. <b>Aim:</b> To reach carbon neutrality in electricity consumption by 2030			
Objectives	Measures of success	Initiatives	Measures of success
1. Reduce kWh consumption simultaneously driving carbon neutrality	<ul style="list-style-type: none"> <li>Percentage kWh reduction and resulting carbon footprint reduction.</li> </ul>	<ul style="list-style-type: none"> <li>Develop and implement a carbon neutrality model and track the move towards carbon neutrality</li> <li>Optimise processes that require energy</li> <li>Review and update technology constituting baseload energy consumption</li> <li>Implement energy consumption controls such that energy is consumed only when and where needed</li> </ul>	<ul style="list-style-type: none"> <li>Develop carbon footprint targets and check progress against targets</li> <li>Determine engineering equipment process efficiency targets and check progress against targets</li> <li>Develop baseload energy reduction targets and check progress against targets</li> <li>Determine energy profile driver targets and check progress against targets</li> </ul>
2. Introduce a low carbon energy mix that is responsive to the Airports Company South Africa business and operating environment	<ul style="list-style-type: none"> <li>Percentage internal energy mix to grid supplied energy</li> </ul>	<ul style="list-style-type: none"> <li>Expand solar footprint</li> <li>Develop and implement an Airports Company South Africa specific energy mix that will not compromise core business objectives</li> </ul>	<ul style="list-style-type: none"> <li>Develop solar footprint targets and check progress against targets</li> <li>Develop energy mix targets and compare non-grid supplied energy sources to grid supplied energy sources</li> </ul>
3. Drive an energy efficiency culture within Airports Company South Africa that is structured and standardised	<ul style="list-style-type: none"> <li>Green Star Accreditation and Airport Carbon Accreditation progress</li> </ul>	<ul style="list-style-type: none"> <li>Develop and implement department specific energy efficiency targets</li> <li>Develop and implement a dashboard of energy performance indicators and targets that will assess progress against targets at airport and group level</li> </ul>	<ul style="list-style-type: none"> <li>Compare energy efficiency progress against energy efficiency targets for each department</li> <li>Indicate progress on energy performance indicators at airport and group level</li> </ul>

Gaining management support for a strategy like the one given in Table 1 is the start of a journey of change that must be managed within the company. It is easier to gain traction if the strategy is co-created and open to adjustments when required for it to be successful in reaching its aim. The strategy in Table 1 was co-created with the energy and demand management forum which has representatives from each airport, and comment and adjustment was invited from implementing managers at the airports before it was submitted to executive management for approval, forming part of board KPIs. The strategy needed to consider greater company objectives and support the organisation’s vision. ACSA’s vision to be a leader in the airport business required that they position themselves as leaders in the climate change mitigation challenge. The strategy objectives had to be specific, relevant, achievable, timed and its progress measured. To embed this within an organisation is the start of creating a company culture and it starts with the awareness that the current way of doing business needs to change (conviction) (Figure. 6).

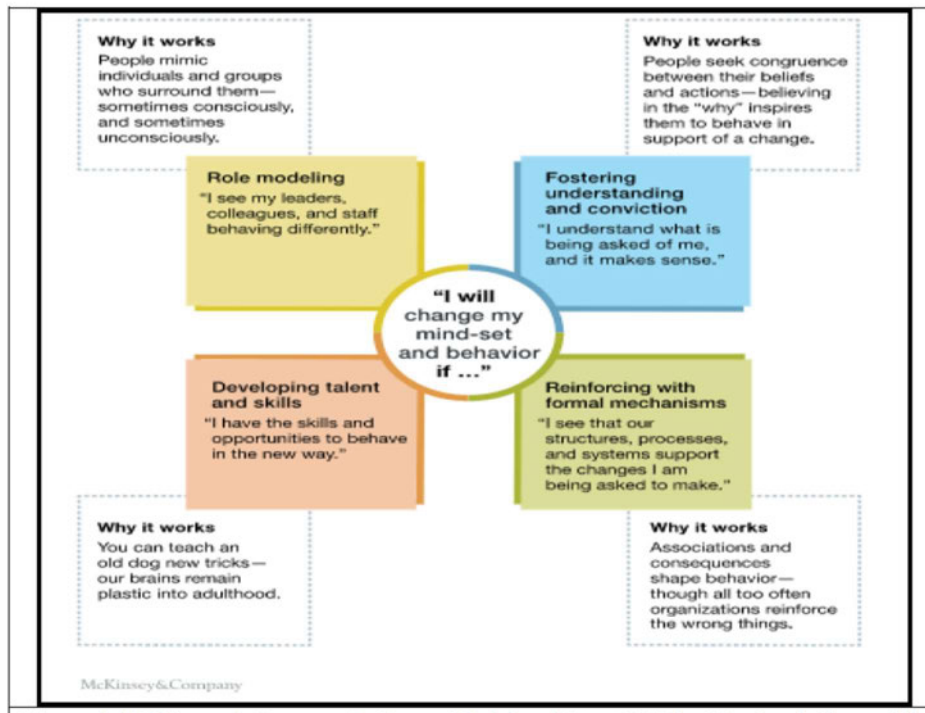


Figure 6: McKinsey & Company Influence Model and Four Building Blocks of Change [5].

Awareness needs to be created in a manner that is relatable to the personnel at various levels within the organisation. When the energy and demand management strategy was approved, the Chief Energy and Demand Management Engineer spent two to three months travelling to the nine airports communicating the strategy to all airport management and maintenance engineering personnel. The method of communication differed. Communication to management took place in boardrooms and follow up was via email with respect to targets and key performance indicators, while communication to maintenance engineering personnel took place in their areas of work, followed by a walk through audit of air conditioning and lighting systems, identification of inefficiencies and need for change in operations and technologies. Energy teams [6] were formed at each airport with roles and responsibilities agreed upon. Formal and informal training followed to ensure that implementation was successful. To achieve carbon neutrality, a suite of technologies was identified for investigation together with the increasing adoption of proven technologies such as LED lighting, lighting control, heat pumps and solar photovoltaic energy. Table 2 gives the identified suite of technologies.

Table 2: List of Technologies to be Investigated for Implementation at Airports to Reach Carbon Neutrality

#	Technology to be Investigated	Notes
1	Natural gas trigeneration [7]	Best suited for ORTIA, CTIA and KSIA due to their large energy baseloads. Utilising waste heat from combustion can be used for water heating requirements and to power absorption chillers.
2	Solar thermal absorption cooling [8]	Could use waste heat or solar thermal energy. When coupled with geothermal heat sinks this is the greenest air conditioning system that possible considering commercially available air conditioning systems. This can be considered for all airports with a centralised air conditioning system.

3	Geothermal energy as a heat sink [9]	Using the ground as a heat sink saves energy and water and can be used as a replacement for any airport with evaporative cooling towers. A trial installation is required.
4	Wind energy using vertical axis wind turbines [10]	Wind turbines and airport communication systems are not always compatible, however, placing vertical axis wind turbines in carefully chosen locations at restricted heights can overcome the barriers to their coexistence. CTIA, PEIA, EL and GG airports are suitable to harvest wind energy.
5	Green star rated facilities [11] [12]	Certifying existing terminal buildings and building all new terminals, offices and retail centres according to 4-, 5- or 6-star green ratings will play a key role in sustaining all efforts to reach and maintain carbon neutrality in electricity.
6	Waste to energy via anaerobic digestion [13]	ORTIA, CTIA and KSIA generate significant volumes of waste that can be used to generate energy.
7	Geyser sleeve technology [8]	Can be adopted for all airports with geysers over 150 litre capacity.
8	Solar thermal deflection innovation [14]	Reduces air conditioning demand.
9	Convective boundaries – low emissivity glazing or double glazing [8]	Reduces air conditioning demand.

As the strategy moved into implementation, targets were included in performance contracts and when company budgets were forecast, the feasible projects were included. This communicated clear expectation and leadership in reducing carbon emissions. Keeping track of progress is key to maintaining traction. Using the plan, do, check, act (PDCA) cycle (Figure. 7) is a good way of ensuring that work is executed, and adjustments made to suit operations.

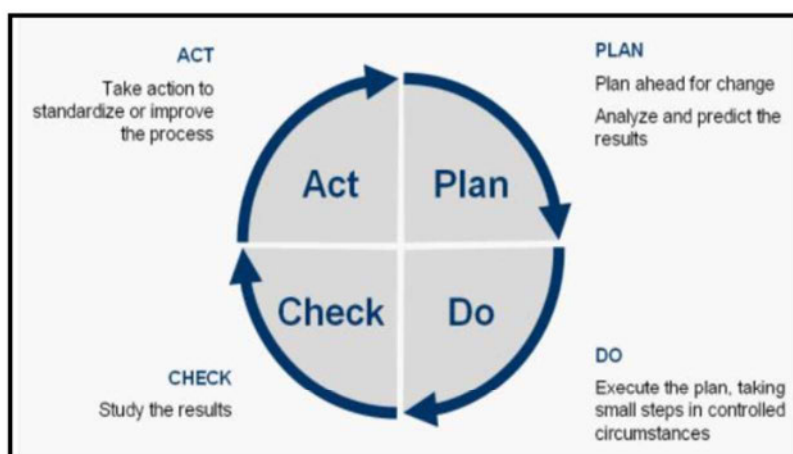


Figure 7: Visualisation of the Plan, do, Check, Act Cycle [15].

Implementation of the projects required to reach carbon neutrality in electricity consumption must be done within a PDCA cycle. The roadmaps to carbon neutrality [16] contain implementable projects that must be executed to reach carbon neutrality, however, there are other activities that must also be considered that do not necessarily involve capital

cost but are equally important in managing energy consumption and influencing decisions that affect the airports' carbon footprint.

#### Plan

- Annual target to reduce energy consumption including:
- Identify lighting and HVAC operations to reduce energy consumption
- Acquire budgets for projects to be implemented that reduce energy consumption
- Identify and agree on tenant energy reduction activities
- Investigate technologies for implementation of a low carbon energy mix to reduce energy consumption
- Identify technologies applicable to the airport's journey to carbon neutrality
- Gather information necessary for the investigation
- Policies, standards, programmes required to create a culture to reach carbon neutrality
- Plan workshops for standards and guidelines for energy efficiency [17]
- Plan an energy efficiency ambassador programme [17]
- Identify requirements for green leases for tenants [6]
- Identify requirements for service providers service level agreements to align to energy and carbon reduction footprint imperatives
- Standardisation
- Plan workshops for standards and guidelines for solar PV plant installations [18]
- Plans to insource maintenance and operations of solar PV plant installations [18]
- Plan for drafting technical manuals for green buildings (new) [11]
- Plan for drafting technical manuals for transitioning existing buildings into green star buildings [12]
- Catalytic initiatives
- Identify energy and efficiency audits to be done
- Identify training requirements for team members to enable them to operate new technologies and execute operational tasks for reaching carbon neutrality
- Identify management interventions required like ISO 50001 energy management system, energy awareness and communication plans
- Create airport energy teams, finalise roles and responsibilities and finalise terms of reference for the energy and demand management forum

**Do**

- Execute projects and operational activities to reach the annual energy reduction and carbon reduction targets
- Perform technical and economic investigations on technologies applicable to each airport for their roadmaps to carbon neutrality
- Draft, finalise, agree on, sign and implement tenant lease extracts and service provider service level agreements
- Draft, gain approval, integrate and implement standards and guidelines for energy efficiency, standards and guidelines for solar PV installations
- Draft, finalise and implement guidelines in technical manuals to certify new infrastructure and transition existing terminal buildings towards compliance for a green star rating
- Create and run energy efficiency ambassador programmes
- Draft and agree on phasing of insourcing maintenance and operations of solar PV plants, gain approval and budgets, implement training, acquire necessary certifications and activate skills transfer plans
- Hold environmental awareness campaigns
- Develop and implement communication plan
- Implement requirements for ISO 50001 aligned energy management system
- Perform energy audits
- Train and familiarise technical team members on operations of targeted technologies and efficiency operations of onsite existing technologies
- Execute roles and responsibilities in the airport energy team and energy forum

**Check**

- Progress on energy reduction and carbon footprint reduction against targets
- Check effectiveness of tenant lease agreement and service level agreement activities in keeping commitments
- Effectiveness of airport energy team and energy forum activities
- Effectiveness of training of team members
- Effectiveness and assess suitability of standards and guidelines
- Effectiveness and applicability of energy ambassador programmes
- Collate learnings of project implementation, ISO 50001 implementation and
- Assess suggestions from awareness campaigns and feedback sessions from the tenants, service providers, energy teams and energy forums

**Act**

- Adjust as required to improve accuracy in target setting
- Improvement in efforts of tenants and service providers to meet agreed commitments
- Adjust communication plan
- Adjust as per suggestions from awareness campaigns
- Revise standards and guidelines where necessary
- Capture and adjust as per learnings in project implementation
- Adjust energy teams roles, responsibilities, team constitution and energy and demand management forum terms of reference

The energy and demand management forum (Figure. 8) made up of the team leaders of each of the airports' energy teams led by the Chief Energy and Demand Management Engineer undertook tasks that required approval, made strategic decisions in consultation with the airport energy teams, drafted standards and guiding documents, negotiated and agreed on energy reduction and carbon footprint reduction targets. Implementation was carried out at the airports facilitated by the airports' energy teams. The energy teams [6] provided feedback on progress as well as learnings and suggestions for improvement on the effectiveness of the various initiatives to realise the strategy (Figure. 9). Every quarterly meeting included feedback on progress, reporting of barriers and difficulties faced during implementation, and identifying gaps in skills or required training for competence. The quarterly meetings ended with a focussed technical talk on a specific technology or engineering system either for familiarity or for knowledge on efficient and effective maintenance and operations.



**Figure 8: Constitution of the Energy and Demand Management Forum.**

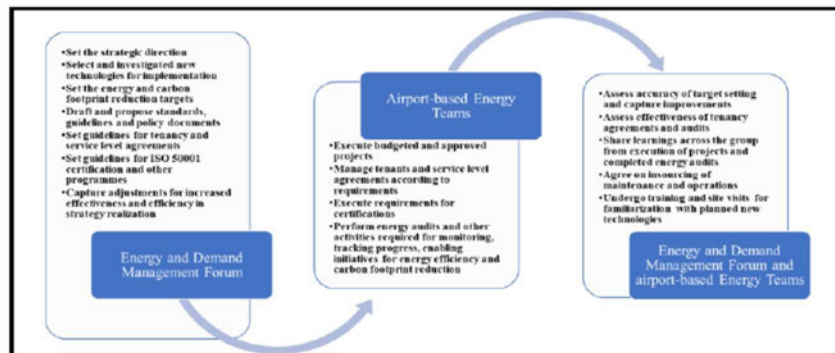


Figure 9: Roles of the Energy and Demand Management Forum and the airport based Energy Teams.

The activities and their details must ensure relevancy to the business and find context within the larger region of South Africa and the rest of the world. The underlying functional structure to ensure that this is done successfully is discussed next.

### B. Energy Security and Energy Efficiency Functional Structure

One of the patterns identified at the airports was a heavy reliance on specific persons who were viewed by management and colleagues as having specific knowledge of airport infrastructure and their actions were almost always approved, while others had to go through these individuals to gain support, and little emphasis was placed on the merits of a proposal. As these individuals either retired or left the organisation, certain programmes were halted and this became unacceptable when pursuing a bold vision like being the most sought-after partner in the world for the provision of sustainable airport management solutions.

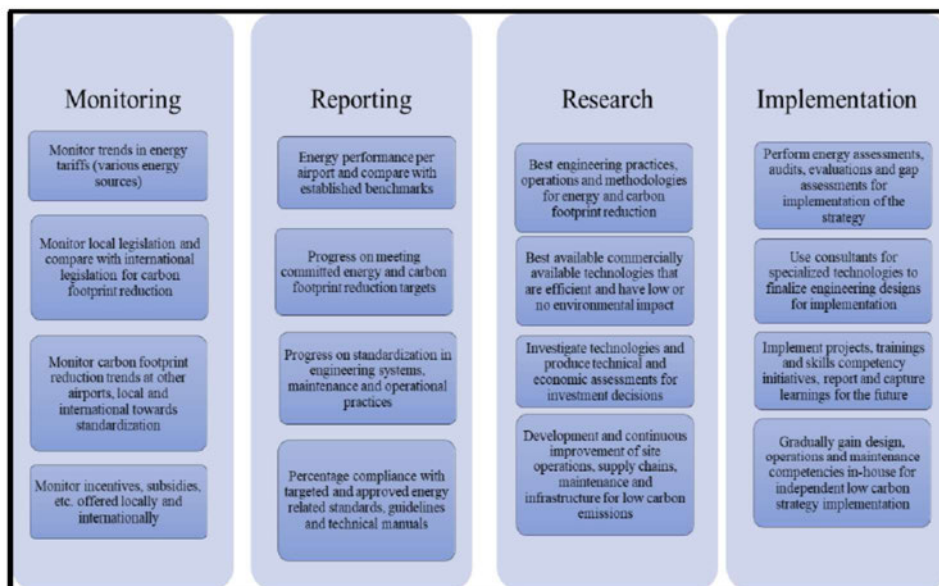


Figure 10: Energy Efficiency and Energy Security Functional Structure.

The activities undertaken to achieve carbon neutrality effectively and sustainably independent of personnel was paramount to the success of realising carbon neutrality. Thus, going back to basic scientific principles that every engineer and technician would be familiar with was the basis to establish robust engineering practices that would be approved and supported by management. These scientific principles formed the basis of engineering policies and became the focus of knowledge sharing in the quarterly technical talks of the energy and demand management forum. Another crucial ingredient for management support is the knowledge of and comparison to international and local benchmarks and assessing where the airports are and where they aim to be based on the approved strategy. Thorough research prior to implementation of alternative energy projects as well as showing the financial value and commercial opportunities of in-sourcing operations and maintenance of specialised group-wide adopted technologies began to change the perception of management and their approval from person-based to merit-based, scientifically proven systems adopted around the world that are proven feasible for the airports. The energy efficiency and energy security functional structure underpinning all activities towards the carbon-neutrality goal is given in Figure 10.

The monitoring function (Figure 10) keeps a “finger on the pulse” of local and international key activities and trends towards reduced carbon emissions. The reporting function shows where the airports are in key aspects of the journey towards energy efficiency and energy security. The research function ensures that all technologies and initiatives towards energy efficiency and energy security are sought out and thoroughly investigated for their benefits, applicability and role in the airports’ journey towards carbon neutrality. The implementation function ensures that whatever has been approved and agreed on is implemented well, learnings captured for continuous improvement with skills and knowledge transfer crucial to daily operations, maintenance and design aspects of technologies and engineering systems.

### **C. Establish Implementation and Investment for Projects in the Business Process**

The business process has social, environmental and economic aspects that, if any initiative is effectively integrated, will be successful. Many times engineering solutions do not go well, however technically brilliant or innovative they are, simply because those who fund and approve such initiatives have not thoroughly bought into it. Technical appreciation is not always the reason that funders and managers support carbon footprint projects. Advantages of alternative energy technologies and technologies that are more efficient must be contextualised through highlighting aspects that are important to funders such as return on investment, and to managers such as increased operational efficiency, the meeting of key performance indicators, decreased operational costs, increasing and building technical capacity, etc.

Many engineers focus on the design of a project, e.g. solar photovoltaic plant, and do not pay attention to how it will be maintained, who will maintain it, where will spare parts be procured from, what happens should the plant fail and downtime exceeds 24 hours, which is often why their projects are not approved.

Another common trap to fall into are ‘greenwashing’ technologies, products, techniques and systems that tend to be prevalent in emerging markets promoted by market players that want to exploit market share. It is important to understand where products come from, how they are made and how certain technological solutions’ implementation will affect the overall site energy consumption, carbon footprint and environmental impact. The environmental impact must be considered more than just from the point of view of reducing energy consumption. Some common trade-offs that are not straight-forward in saving energy is the adoption of skylights in large buildings to reduce the artificial lighting demand as it places additional demand on air conditioning and water heating control which may result in more energy consumed should there be multiple occasions that a water heater is switched off. Another environmental trade-off made is the disposal



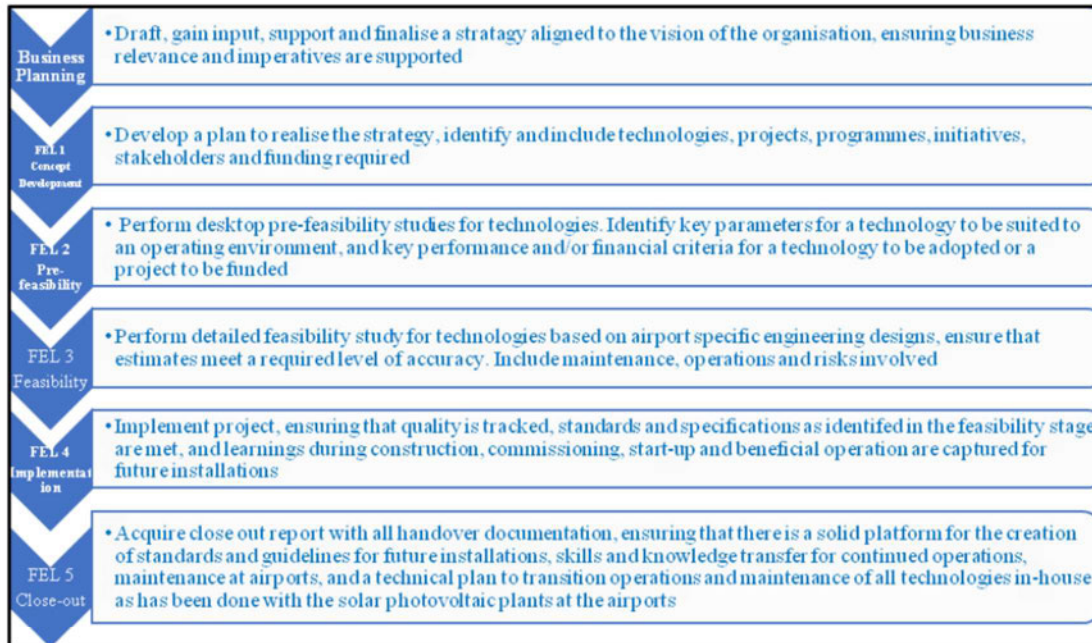


Figure 11: Process for Projects to be Integrated into Business Process.

Financial feasibility follows business planning and concept development stages (Figure. 11). Prior to getting to financial feasibility, projects must be aligned to and be born from the need to realise ACSA’s energy management strategy (Table 1). This must be followed by concept development which is instrumental in achieving the goals set out within the strategy. Implementation and close-out must always consider daily operations and maintenance, risks to the business and future cost cutting opportunities and commercial potential.

Business sustainability of new technologies implemented can be ensured by having a logical process to follow that will make the business self-sufficient (Figure. 12).

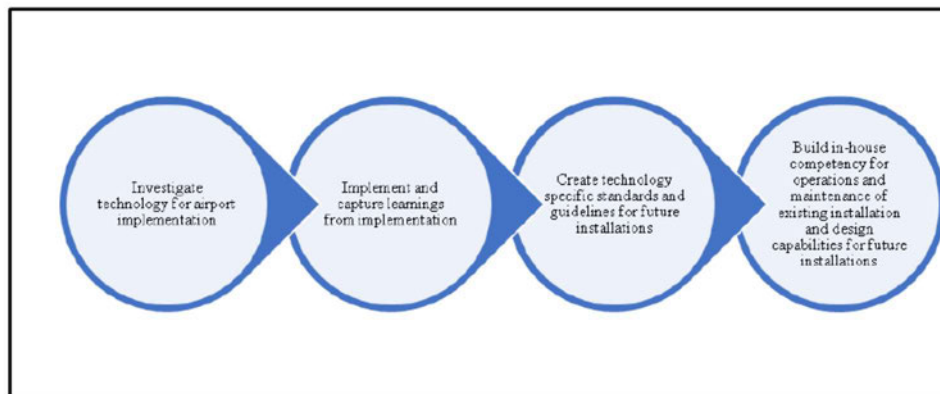


Figure 12: Process for Ensuring Sustainability of New Technologies Introduced into the Business.

Following this process removes the anxiety and ‘fear of the unknown’ that organisations experience when faced with unfamiliar technologies and their operation and maintenance. It also makes organisations re-assess the way they do business currently with established technologies, highlighting opportunities for improvement and commercial gain. This

approach has the potential to revolutionise the way of doing business and can go as far as restructuring and addressing governance and revenue streams.

## CONCLUSIONS

This paper presented three principles to sustain energy efficiency and energy security in a business, presenting the application of the principles in an airport setting. The strategy applicable to ensure energy efficiency and energy security in a business was presented, together with the technologies for realising the strategy, the process for execution of the strategy, the facilitating teams and their coordination for continued progress and improvement. This paper also presented the underpinning functional structure which will ensure that the energy efficiency and energy security activities are relevant to the business and in the global context. The integrating of project activity into the business process encompassing social, environmental and economic aspects, was also given. The application of these three principles reduces the anxiety and removes the unknown involved with adopting new technologies and their operation and maintenance, ensuring that technologies and initiatives are relevant, current and aligned to business imperatives as well as strategy, and that their execution is self-sustaining due to being process dependent.

## REFERENCES

1. Industrial Energy Efficiency Project, "Industrial energy efficiency project in South Africa case study–EnMS", UNIDO, 2014. Retrieved from [https://www.industrialenergyaccelerator.org/wp-content/uploads/King\\_Shaka\\_Int\\_Airport\\_Full\\_Case\\_study\\_April\\_20141-copy.pdf](https://www.industrialenergyaccelerator.org/wp-content/uploads/King_Shaka_Int_Airport_Full_Case_study_April_20141-copy.pdf), accessed 11/08/2021.
2. Mail and Guardian special report, "Cleaner energy for airports — a concept that is spreading rapidly across South Africa", Mail and Guardian, 29 Jul 2016. Retrieved from <https://mg.co.za/article/2016-07-29-00-cleaner-energy-for-airports-a-concept-that-is-spreading-rapidly-across-south-africa/>, accessed 11/08/2021.
3. Green Economy Media, "Profile Airports Company South Africa – Flying high into a green future", Positive Impact Magazine, Issue 8, October 2020. Retrieved from [https://issuu.com/alive2green/docs/0.8\\_20impact\\_20full\\_20mag\\_2028\\_20oct/s/11230755](https://issuu.com/alive2green/docs/0.8_20impact_20full_20mag_2028_20oct/s/11230755), accessed 11/08/2021.
4. Mkhacwa, F., "EnMS methodology and approach towards ISO 50001 certification", National Cleaner Production Centre South Africa, 27 October 2020.
5. Basford, T., Schaninger, B., "The four building blocks of change", McKinsey Quarterly, 11 April 2016. Retrieved from <https://www.mckinsey.com/business-functions/organization/our-insights/the-four-building-blocks--of-change>, accessed 12/08/2021.
6. Joseph, J., Inambao, F.L., "Entrenching energy efficiency as a culture at airports: A case study of the implementation of energy efficiency for airports in South Africa", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Vol. 11, Issue 3, June 2021, pp 545–560.
7. Joseph J., Inambao, F.L., "Energy security: Investigating natural gas for energy generation at airports in South Africa – A technoeconomic assessment", accepted for publication, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 2021.
8. Joseph J., Inambao, F.L., "Reducing energy consumption at airports in South Africa: Investigating technologies that reduce electricity consumption", to be published, 2021.
9. Joseph J., Inambao, F.L., "Energy security: Investigating geothermal heat sinks for air conditioning systems at airports in South Africa – A technoeconomic assessment", to be published 2021.

10. Joseph J., Inambao, F.L., "Energy security: Investigating wind energy for airports in South Africa – A technoeconomic assessment", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Vol. 11, Issue 4, Aug 2021, pp 203-228.
11. Joseph J., Inambao, F.L., "Sustainability of energy efficiency and energy security for airports in South Africa: Guidelines for adopting green building status for new infrastructure", to be published 2021.
12. Joseph J., Inambao, F.L., "Sustainability of energy efficiency and energy security for airports in South Africa: Guidelines for transitioning existing terminal buildings to green building status", to be published, 2021.
13. Joseph J., Inambao, F.L., "Energy security: Investigating anaerobic digestion for airports in South Africa – A technoeconomic assessment", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Vol. 11, Issue 4, Aug 2021, pp 319–340.
14. Joseph J., Inambao, F.L., "Reducing energy consumption: Investigating solar thermal heat deflection innovative technology to reduce air conditioning load at airports – A technoeconomic assessment", accepted for publication, *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, 2021.
15. Tang D., "Continuous improvement 101: The Deming Cycle (PDCA)", Retrieved from <https://flevy.com/blog/continuous-improvement-101-the-deming-cycle-pdca/>, accessed 12/08/2012.
16. Joseph, J., Inambao, F.L., "Energy security: Establishing a low carbon energy mix and roadmaps to carbon neutrality in electricity consumption for airports in South Africa", to be published, 2021.
17. Joseph, J., Inambao, F.L., "Energy efficiency for airport infrastructure: A case study of the implementation of energy efficiency for airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Vol. 11, Issue 2, Apr 2021, pp 383–406.
18. Joseph, J., Inambao, F.L., "Energy security: Standards and guidelines for solar photovoltaic installations including technical plan to transition solar photovoltaic plant maintenance to be performed inhouse for airports in South Africa", to be published, 2021.
19. Godilano-Sarmiento, B. A. N. J. I. E., and C. H. R. I. S. T. I. A. Almario-Guevara. "Students' Conceptual Understanding and Attitude on Climate Change Resilience and Mitigation Practices." *International Journal of Educational Science and Research (IJESR)* 6 (2016): 7-16.
20. Dympep, A. L. E. T. H. E. A., and R. J. Singh. "A test to measure knowledge of farmers on mitigation and adaptation practices of cli
21. Husain, Mohammed A. "An analysis of the Constraints of Policy Framework for Physical Planning in a Changing Climate in Nigeria." *International Journal of Environment, Ecology, Family and Urban Studies (IJEFUS) ISSN (P)* (2014): 2250-0065.
22. Adebayo, A. A., et al. "Awareness of climate change impacts and adaptation in Adamawa state, Nigeria." *Int J Environ Ecol Family Urban Stud* 3.1 (2013): 11-18.

**CHAPTER 20. SUSTAINABILITY OF ENERGY EFFICIENCY AND ENERGY  
SECURITY FOR AIRPORTS IN SOUTH AFRICA: GUIDELINES FOR ADOPTING  
GREEN BUILDING STATUS FOR NEW INFRASTRUCTURE**

This chapter presents the guidelines for development of green star rated infrastructure at airports in South Africa sustaining energy efficiency and energy security for new terminal, office and commercial buildings, in compliance with the green star rating system of the Green Building Council of South Africa.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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## SUSTAINABILITY OF ENERGY EFFICIENCY AND ENERGY SECURITY FOR AIRPORTS IN SOUTH AFRICA: GUIDELINES FOR ADOPTING GREEN BUILDING STATUS FOR NEW INFRASTRUCTURE

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### ABSTRACT

*Executing projects that save energy through efficiency and conservation for a site and adopting alternative energy to reduce its carbon footprint can assist in abating climate change. However, with time, new infrastructure will be adopted either through expansion or refurbishments that could threaten to negate the efforts of previous projects in reducing carbon emissions. The adoption of “green buildings” that are compliant with environmental requirements including reduction in carbon emissions and energy consumption will serve to ensure that previous efforts towards reduced carbon emissions are sustained. In South Africa, the Green Building Council of South Africa has green star rating frameworks and accreditation for new infrastructure. This paper presents the guidelines for adopting green star rated infrastructure at airports in South Africa in order to sustain energy efficiency and energy security for new terminal, office and commercial buildings in compliance with the green star rating system of the Green Building Council of South Africa.*

**KEYWORDS:** *Energy Efficiency, Energy Security, Green Buildings, Environmentally Sustainable Buildings, Environmental Responsibility & Resource Efficiency*

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### 1. INTRODUCTION

Reducing carbon emissions in any organisation requires a lot of effort and involves a change in thinking when satisfying business needs, putting in place strategies and creating a culture of doing business that reduces carbon emissions. Ensuring that this culture of reduced carbon emissions is sustained requires adoption of relevant standards at an early stage so that changes that occur with the passing of time and changes in personnel, strategies, commercial markets and products as well as construction of new infrastructure do not undermine the initial gains. Airports Company South Africa (ACSA) has an ambition to reduce carbon emissions across its airports in South Africa and has put in place an energy and demand management strategy, approved a suite of technologies to reduce carbon emissions, and adopted standards and guidelines for energy efficiency.

ACSA owns and operates nine airports in South Africa, namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport (CTIA) (Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (PEIA) (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (BFIA) (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape). ACSA's energy and demand management strategy aims to make ACSA a recognised leader in the implementation of energy solutions that are economically and environmentally sustainable for airport businesses. This strategy is in line with ACSA's vision of being "... the most sought-after partner in the world for the provision

of sustainable airport management solutions.”

At its core, ACSA’s energy and demand management strategy intends to reach carbon neutrality in electricity consumption by 2030. The three strategic objectives to support the strategy are: (1) reduce energy consumption to drive carbon neutrality, (2) introduce an energy mix that is responsive to the ACSA business and operating environment, and (3) drive an energy efficiency culture within ACSA through accountability, standardisation and a structured approach to managing energy intensive infrastructure. These strategic objectives have been translated into executable projects and initiatives that have been included in each of ACSA’s nine airports’ roadmaps to carbon neutrality. Significant progress has been made to reduce energy consumption and plans are in process to realise a low carbon energy mix at the airports. The low carbon energy mix transitions the airports’ current electricity demand towards carbon neutrality and makes provision for future energy demand. However, to ensure that energy wastage and practices that negate efforts to drive carbon neutrality are mitigated when new infrastructure is introduced, standards must be adopted. To bring about a culture of energy efficiency, standardisation and a structured approach to managing energy intensive infrastructure, there must be adherence to green buildings design for all new infrastructure to ensure that environmentally sustainable decisions are implemented.

Green buildings incorporate design, construction and operational practices that significantly reduce or eliminate the negative impact of development on the environment and people. Green buildings are:

- Energy efficient,
- Resource efficient,
- Environmentally responsible,
- Healthy and productive environments for people.

In short, a green buildings approach will ensure that whatever the development (whether office, terminal building, commercial building, etc.) the aim will be to reduce demand and impact on the environment and health of humans. This approach entails rainwater harvesting, onsite processing of waste into useful products, generation of energy, reducing energy and water consumption, using recycled building materials and materials low in greenhouse gas emissions, better air quality, etc.

The Green Building Council of South Africa (GBCSA) has been set up to certify infrastructure such as office buildings, retail centres, public and education buildings, and precincts, according to a green star rating framework, namely, 4-star, 5-star and 6-star rated. The GBCSA is an independent, non-profit member-based company that was formed in 2007 to lead the greening of South Africa’s commercial property sector. GBCSA provides the tools, training, knowledge, connections and networks, to promote green building practices across the country and build a national movement that aims to change the way the world is built. There are over 98 individual and recognised green building councils worldwide whose mission is to abate climate change through green building. The World Green Building Council is an umbrella organisation that gives guidance to the different green building councils, of which the GBCSA is a member alongside Australia, the United States and the United Kingdom amongst others. The Green Building Council of South Africa has adopted, adapted, and contextualised the Green Star rating system. Originally developed by the Green Building Council of Australia, that rating system was used as a base and has been significantly modified to fit the local market and environmental context [1].

The GBCSA started off with green star rating tools for residential, office, public and education buildings, retail developments and existing buildings, as well as interiors of developments. Their tools have extended to rating sustainable precincts, net zero (carbon, water, waste, ecology), energy and water performance, and more in order to meet the South African market demand. There have been over 400 green star certifications between 2007 and 2018 in South Africa [1].

Certifying new airport buildings will serve to independently verify the airports' achievements and recognition as a leader in environmentally sustainable solutions for airport businesses. This paper describes the green star rating frameworks of the GBCSA, the structure of the technical manuals for the implementation of green star rated buildings for new infrastructure at airports, the rationale applied when selecting credits to make up the green star rating of new airport infrastructure, the key technologies, design features, standards for compliance, construction and project requirements for airports' green star rating, and the process to implement green star rated buildings for new airport infrastructure.

## 2. GREEN STAR RATING FRAMEWORKS DESCRIPTION

Green Star SA has established a number of categories under which specific key criteria are grouped and assessed. This framework is used by the Green Star SA rating tool. The basic Green Star SA structure is shown in Fig. 1 [2]

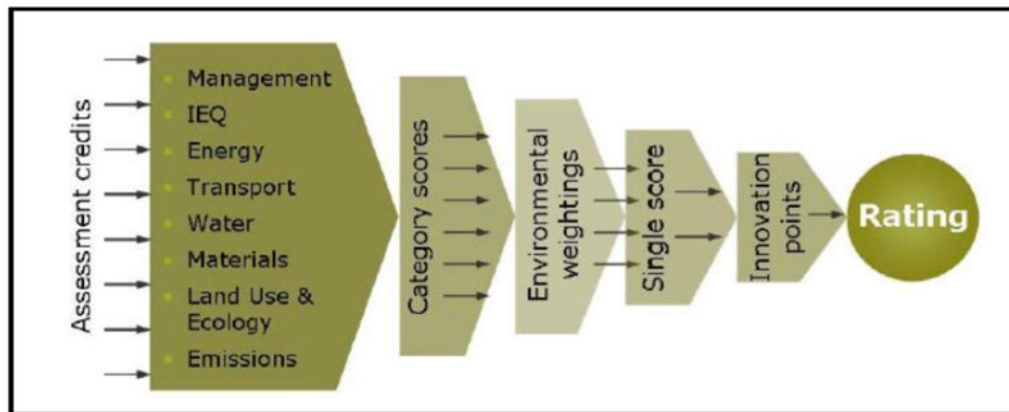


Figure 1: Structure of the Green Star SA Rating System [2].

Green Star SA rating tools include nine separate environmental impact categories:

- **Management** - promote the adoption of environmental principles from project inception, design and construction phases, to commissioning, tuning and operation of the building and its systems;
- **Indoor Environment Quality** - target the wellbeing of the occupants through addressing the heating and cooling systems, lighting, indoor air pollutants and some building attributes which contribute to a healthier indoor environment quality;
- **Energy** - target an overall reduction in energy consumption and a reduction of greenhouse gas (GHG) emissions associated with energy generation from fossil fuels;
- **Transport** - reward the reduction in automotive commuting by simultaneously discouraging it and encouraging use of alternative transportation;
- **Water** - address the reduction of potable water use through design of water efficient systems, rainwater collection

and water re-use;

- **Materials** - target the consumption of resources through selection and reuse of materials, and efficient management practices;
- **Land Use and Ecology** - promote initiatives to improve or reduce impacts on ecological systems and biodiversity;
- **Emissions** - target the environmental impacts of a development's emissions or substances emitted from the site (excluding greenhouse gas emissions which are dealt with in the energy category); and
- **Innovation** - encourage, recognise and reward the spread of innovative technologies, designs and processes for commercial building applications that impact upon environmental performance.

The categories contain credits which addresses specific initiatives that improve or have the potential to improve a design, project or building's environmental performance. Points are awarded in each category for actions that demonstrate that the project has met the overall objectives of Green Star SA and the specific aims of the Green Star SA rating tool. Green Star SA environmental weighting factors vary across rating tools to reflect differing environmental concerns and imperatives for different building types and lifecycle phases. To encourage the development and spread of innovative technologies, designs and processes that can improve buildings' environmental performance, an 'Innovation' category is included in each Green Star SA rating tool. Table 1 [2] contains the overall score and corresponding green star rating according to the green star rating system. [2]

**Table 1: Green Star Rating SA Tool Scores**

Overall Score	Rating	Outcome
10-19	1 Star	Not eligible for formal certification
20-29	2 Stars	Not eligible for formal certification
30-44	3 Stars	Not eligible for formal certification
45-59	4 Stars	Eligible for 4-Star Certified Rating that recognises/rewards 'Best Practice'
60-74	5 Stars	Eligible for 5-Star Certified Rating that recognises/rewards 'South Africa Excellence'
75+	6 Stars	Eligible for 6-Star Certified Rating that recognises/rewards 'World Leadership'

The certification process for a green star rating is extremely specific in terms of timing, documentation to prove criteria for each credit met as well as eligibility for the registration of a project to be certified. The process for certification is as illustrated in figure 2. If the project submission does not receive a rating in the first round, it is given a chance to submit outstanding or supplementary documentation in a second round to achieve a green star rating.

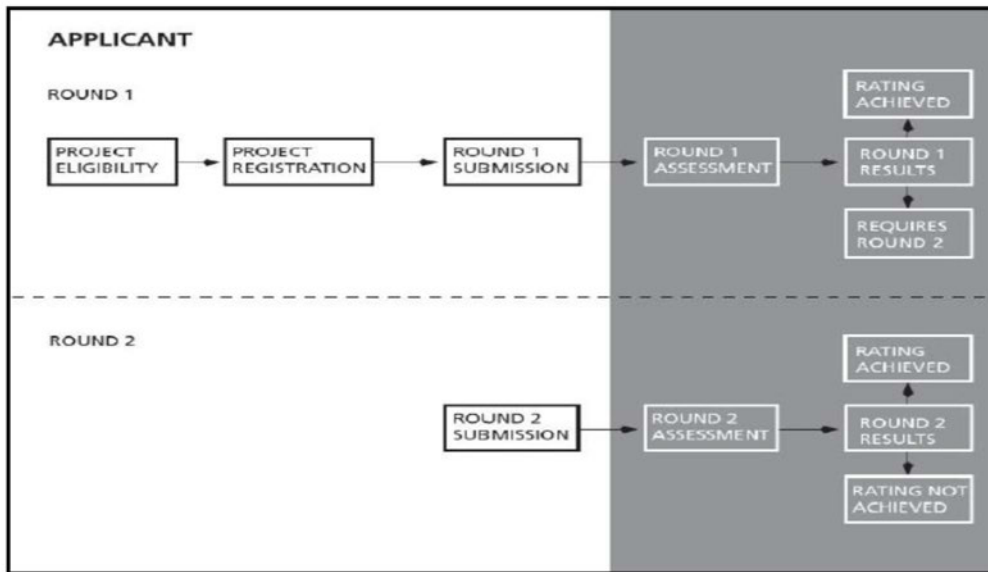


Figure 2: Overview of GBCSA Green Star Certification Process [2].

The following sections contain the structure of the technical manuals drafted for new airport infrastructure in the form of project specifications to be easily included in the design, construction, commissioning, and certification of new airport infrastructure in compliance with the specifications of the frameworks of the green star ratings of the GBCSA.

### 3. STRUCTURE OF THE TECHNICAL MANUALS FOR THE IMPLEMENTATION OF GREEN STAR RATED BUILDINGS FOR NEW INFRASTRUCTURE AT AIRPORTS

The ACSA technical manuals contain project specifications for the design, construction, commissioning and certification of new terminal buildings, retail centres and office buildings in compliance with the requirements set out for green star ratings and the particular credits required. Certain credits are targeted based on what is key to ACSA's business focus, convenience and strategic intention in design and construction of new buildings for the green building credits to achieve 4, 5 and 6-star ratings. These expectations are converted into six categories for ACSA project execution: [3]

- **General Requirements (GR):** This section outlines the principles and requirements that apply to all sustainability requirements for the project regardless of the targeted green star rating chosen.
- **Technologies (T):** This section contains all the technologies that must be implemented in the project to achieve the targeted green star rating.
- **Design Features (DF):** This section includes all the design features that must be included for the project's design and construction to achieve the targeted green star rating.
- **Standards Compliance (SC):** This section lists the standards that the project must comply with during the various project stages to achieve the targeted green star rating.
- **Construction Requirements (CR):** This section provides all the requirements that must be adhered to during the construction stage of the project for the targeted green star rating of which acceptable records must be kept.

- **Project Requirements (PR):** This section has all other requirements that are not covered in the above sections such as professionals that must be appointed together with their duties in the project, modelling, simulations, calculations, reports, strategies, management plans that must be done, surveys, design reviews and other requirements that must be completed to achieve the targeted green star rating.

The information given in all the sections above, except for the GR, are designed to be cumulative, i.e., to achieve a 5-star green rating, the 4-star green rating requirements must be included, and additional requirements listed under the 5-star green rating must be implemented. The specifications given can be used in a project's scope of works. Due to the length and extensive detail given in the technical manuals written in project specification language, there is a quick reference tool provided in the form of a one-pager for executive decision-making enabling executives to view the various requirements for the tiers of green star rating at a summary level to determine which green star rating is to be targeted for a project to be undertaken. This executive decision-making tool can be referred to before Front End Loading (FEL) stages (business planning); namely FEL 01 (conceptual), FEL 02 (pre-feasibility) and also FEL 03 (feasibility) stages of the project [3].

The one-pager executive decision-making tool lists in summarised form the requirements for projects which include base requirements that all projects in ACSA must comply with regardless of green star rating being targeted or not. Additional requirements are given to meet a 4-star rating, 5-star rating and 6-star rating, all requirements being cumulative, i.e. to get to a 4-star rating, one must comply with base requirements and four star rating requirements, to get to a 5-star rating, one must comply with the base requirements, 4-star rating requirements and those requirements listed for the 5-star rating requirements, and so on. The intention is that executive managers consult this tool to review how achievable the green star requirements are in the context of the project's budget constraints, risks, business imperatives and focus areas enabling them to choose the most suitable green star rating. The executive decision-making tool can also be used as a summary in the project briefs and when developed into the project's scope of works, the detailed sections in the technical manual can be used. The credits chosen to be included in each of the various infrastructure types, i.e. terminal, office or retail building, follows [3].

#### **4. RATIONALE FOR THE SELECTION OF CREDITS TO MAKE UP THE GREEN STAR RATINGS FOR THE NEW AIRPORT INFRASTRUCTURE**

The business imperatives that played a role in the selection of the credits to be targeted for the 4-star, 5-star and 6-star rated green buildings are discussed; the rationale used when targeting the number of credits with the range given for a 4-star, 5-star and 6-star rating is given, and the credits that are most targeted, as well as those limited or ignored due to lack of focus of the business in those areas, are listed in the followings sections.

##### **4.1 Business Imperatives**

One of the most important steps in targeting a green star rating is the selection of the combination of credits that will give points needed to meet the requirements for the green star rating intended (Table 1). In most cases the selection of credits that give the points contributes to the financial implications associated with the green star rating in such a way that there can be negligible excess cost if planned carefully. More importantly, these elements can reduce operational and maintenance costs making for an attractive business case. The credits in each of the green star frameworks (4-, 5- and 6-star green ratings) are chosen based on the following ACSA business principles: [3]

- Savings in operational cost with preferably low or no extra capital cost and any extra capital costs are offset within the project, e.g., extra capital cost for using passive cooling techniques such as low emissivity glass and insulation result in a lower cooling and heating load and thus a smaller capacity HVAC system, lower capex cost of HVAC, lower electricity cost for operations and potentially lower maintenance cost for a smaller system.
- Supporting of the organisational strategic goals, especially those that are aligned to ACSA's vision for stand-alone airports, reduction in operational cost (running and maintenance costs), Occupational Health and Safety and Asset Information Management imperatives.
- Focus placed on credits that reduce environmental impact, therefore significant weighting of waste management and water and energy consumption.
- Knowledge transfer and operating conditions that are fine tuned for operational efficiency.
- Focus on credits that support the Airports Council International (ACI) Carbon Accreditation [3]

#### **4.2 Green Building Framework Design**

The combination of credits targeted have been designed to always give points over the minimum threshold for the targeted green star rating due to the nature of project execution in general, where thoroughness in terms of project documentation and timelines in terms of project duration and loss in communication in design and execution results in certain credits targeted not being able to be awarded as per GBCSA strict rules. For this reason, the green star rating target is designed to aim for at least 4 points above the threshold for the targeted green star rating but not within 5 points of the threshold for the next green star rating as this will mean extra cost and effort for the same green star rating.

#### **4.3 Green Building Credits Targeted and Excluded**

In accordance with the business case for green buildings, and in keeping with the ACSA operating environment and business imperatives, the credit categories are prioritised as follows:

- Water and energy credits within these categories have been maximised as they are both high in operational cost and scarce resources in South Africa.
- Waste management credits within the materials category have also been targeted towards social responsibility and looming legislation of reduced waste to landfill by 2025 (Western Cape) with penalties for non-compliance and is the direction that most of the world is most probably headed.
- Credits throughout the categories that embed ease of maintenance, operations and management of infrastructure, health and safety best practices, project management and construction management are maximised for a good foundation and which facilitate ACSA's vision and its strategic objectives.
- Credits that allow for implementation considering the highly regulated environment that ACSA complies with as well as that consider the known market capabilities (local and international, i.e., South African marketplace and environmental context).

The following credits have been intentionally limited due to their lack of support of the business and operating environment of ACSA:

- Credits on boiler and generator emissions in the emissions category have been avoided due to airports never using industrial boilers.
- Credits including transport have been excluded as these are typically not considered per building, but rather as an airport planning exercise and in response to demand and commercial opportunity.
- Credits with respect to using recycled materials for building and furnishing, design for disassembly, dematerialisation, etc. have been avoided due to the risk of lifecycle longevity with respect to structural integrity, maintenance requirements and market capability to deliver design concepts and products which may cause time delays as well as compromise Airport Service Quality Ratings (ASQ).
- Credits pertaining to land use and ecology have been largely avoided due to the applicability of these credits from project to project, and because they require special conditions to be at play such as soil contamination before the start of the project, greenfield development, etc. These credits can be revisited for consideration if the conditions are applicable.
- Innovative strategy credits have been excluded to divorce the dependency on them to make up the credits needed for the targeted green star rating as these innovation points are awarded solely on the discretion of Green Buildings Council South Africa.

## 5. KEY TECHNOLOGIES, DESIGN FEATURES, STANDARDS FOR COMPLIANCE, CONSTRUCTION AND PROJECT REQUIREMENTS FOR AIRPORTS' GREEN STAR RATING

The technical manuals written by the GBCSA provide criteria to be met for each of the nine categories described, however, they do not stipulate the technologies, engineering design features and interventions to be adopted that would allow a project to meet the criteria. The three technical manuals drafted for ACSA give the preferential selection of credits, technologies, design features, standards for compliance, construction requirements and project requirements to be met for each green star rating. To ensure environmental sustainability even when a green star rating is not targeted for a project, certain general requirements and base requirements must be met for adoption of technologies, design features, standards for compliance, construction and project requirements, and must be adhered to for all ACSA projects.

The requirements are contained in three technical manuals for green buildings as follows:

- Technical Manual for Green Star Rated New Terminal Buildings [3]
- Technical Manual for Green Star Rated New Office Buildings [5]
- Technical Manual for Green Star Rated New Retail Centres [6]

Table 2 gives the general requirements for new infrastructure projects in ACSA, regardless of whether a green star rating is targeted or not. Table 3 to Table 17 contain a summary of the key elements of the technologies, design features, standards for compliance, construction requirements and project requirements for new terminal buildings, office buildings and retail centres for 4-star, 5-star and 6-star green buildings certification. Table 3 to Table 7 cover new terminal buildings, Table 8 to Table 12 cover office buildings, and Table 13 to Table 17 cover new retail centres.

**Table 2: General Requirements Ensuring Minimum Considerations for the Environment for all New Infrastructure [3][5][6]**

<b>General Requirements for all New Infrastructure Projects at ACSA Airports</b>
<ul style="list-style-type: none"> <li>• Design for cost effectiveness and convenience</li> <li>• Water, working fluids and electrical reticulation to be designed cost effectively to allow for sub-metering and connection to SCADA and BMS systems.</li> <li>• Water, working fluids and electrical reticulation designs must consider ease of maintainability, modularisation, cost effective disassembly, isolation and alternative supply for reduction of operational disruptions.</li> </ul>
<ul style="list-style-type: none"> <li>• Engineering handover and asset information management (AIM)</li> <li>• Handover documents must be complete, containing original equipment manufacturer (OEM) specifications, as-built drawings, design documents, commissioning results, operations and maintenance (O&amp;M) manuals, user guides, spares supply and inventory.</li> <li>• All maintainable assets to be captured on the AIM database containing asset tags and capturing of all maintenance and technical specifications for each maintainable asset.</li> </ul>
<ul style="list-style-type: none"> <li>• Knowledge management (KM)</li> <li>• Knowledge transfer must be for all disciplines of the project (engineering, operational, maintenance, costing, market research, project management) and for all phases of the project (design, construction, commissioning, start-up and handover) for at least two people at ACSA per project discipline.</li> <li>• Information management system must be created and maintained during the project to be handed over on an electronic platform that contains all project history, revisions of drawings, meeting minutes, cost revisions, engineering sign offs and certifications, records of interactions with all project parties for the purposes of achieving project deliverables.</li> </ul>
<ul style="list-style-type: none"> <li>• Tenant lease agreement extracts to preserve the green star rating standard – where shell and core fitouts are part of the project, the appointed green building accredited professional must ensure that the fitout requirements according to the GBCSA targeted green star rating are documented and submitted for enforcement.</li> </ul>
<ul style="list-style-type: none"> <li>• The appointed green building accredited professional is responsible to ensure that all team members during all phases of the project (design, construction, commissioning and handover – including FEL 03 if appointed at this stage) are aware of the requirements for the green star rating and timeously execute the documentation requirements.</li> </ul>

**Table 3: Requirements for Airport Green star Rated Terminal Buildings: Technology Requirements [7]**

<b>Base technologies</b>	<ul style="list-style-type: none"> <li>Standards and guidelines for energy efficiency [4]</li> <li>Power factor correction</li> <li>Air-cooled chillers</li> <li>Dual flush ablutions (3 L and 6 L per flush)</li> <li>Low flow taps, sensor activated (max 3 L/min)</li> <li>Low flow shower heads (max 6 L/min)</li> </ul>
<b>4-star rating technologies</b>	<ul style="list-style-type: none"> <li>Paints to meet specific volatile organic compound (VOC) limits</li> <li>Reduction in greenhouse gas emissions by 20 % through alternative energy sources</li> <li>Automated smart energy metering for tenants</li> <li>Maximum electrical demand reduction by 10 %, using pre-programmed load curtailment programmes, electronically controlled. Buffer storage tanks for chilled water storage, lighting circuit switching techniques, daylight harvesting, low emissivity glazing and heat deflective paint to be adopted to reduce peak demand for cooling</li> <li>Closed loop geothermal heat sink to be adopted in place of cooling towers</li> <li>Waterless urinals</li> <li>Rainwater harvesting for irrigation, washing motor vehicles and other second-class water purposes.</li> <li>Active leak detection system for potable water reticulation</li> <li>Collection and use of stormwater for irrigation and designing xeriscape gardens</li> <li>Adoption of methods such as trenches, basins, porous pavements, filter strips, grass swales, media filters, detention ponds, grease and litter traps, hydrocarbon detention, etc. for the management of stormwater and the reduction of total suspended solids (TSS) by 80 % for the run-off volume for rainfall events up to a 1-in-2-year storm.</li> <li>Refrigerants and fire suppression gases to have a zero-ozone depletion potential (ODP)</li> </ul>
<b>5-star rating technologies</b>	<ul style="list-style-type: none"> <li>Adhesives and sealants to meet specific VOC limits</li> <li>Total reduction in greenhouse gas emissions by 35 % through alternative energy sources</li> <li>Automated smart metering strategy to include thermal energy meters</li> <li>Reduction in maximum electrical demand through the adoption of ice storage tanks for air conditioning systems</li> <li>Re-use water used for washing of motor vehicles</li> <li>Flush ablutions with grey water or re-used water</li> </ul>
<b>6-star rating technologies</b>	<ul style="list-style-type: none"> <li>Daylight glare control systems eliminating 95 % of all direct sun penetration, with blinds/screens having a visual light transmittance (VLT) of &lt; 10 %</li> <li>Carpets and floor coverings to meet specific VOC limits</li> <li>Total reduction in greenhouse gas emissions by 60 % through alternative energy sources and carbon offsetting plants</li> <li>Total reduction in maximum electrical demand by 20 % through making use of waste heat from alternative energy plants to power absorption chillers</li> <li>Where potable water is used to flush ablutions, adopt solenoid control valves for automatic shut off when area is not in use</li> <li>All refrigerants to have a global warming potential (GWP) of 10 or less</li> </ul>

**Table 4: Requirements For Airport Green Star Rated Terminal Buildings: Design Feature Requirements [7]**

<b>Base design features</b>	<ul style="list-style-type: none"> <li>Building management system (BMS)</li> <li>Standards and guidelines for energy efficiency [4]</li> </ul>
<b>4-star rating design features</b>	<ul style="list-style-type: none"> <li>Display of sustainability features of the building on an electronic screen in waiting areas, entrances, exhibition areas, etc.</li> <li>Design for maintainability and performing design reviews</li> <li>Lighting is zoned appropriately and controlled according to demand</li> <li>Adoption of roofing, paving and building materials (external hardscape) must have a solar reflectance index (SRI) greater than or equal to 29 and for pitched roof areas less than or equal to 10 degrees, the SRI must be greater than or equal to 78</li> </ul>

<b>5-star rating design features</b>	<ul style="list-style-type: none"> <li>• Design of HVAC system must ensure humidity control of the space at 60 % RH and in the supply ducting 80 % RH</li> <li>• Reduce sewer outflow from the development during operations by 30 %</li> </ul>
<b>6-star rating design features</b>	<ul style="list-style-type: none"> <li>• Reduce sewer outflow from the development during operations by 50 % through employing blackwater treatment to recirculate treated water in a closed loop system to ablutions</li> </ul>

**Table 5: Requirements for Airport Green Star Rated Terminal Buildings: Standards for Compliance [7]**

<b>Base standards for compliance</b>	<ul style="list-style-type: none"> <li>• Occupational Health and Safety Act (Act 85 of 1993)</li> <li>• Construction regulations, 2014 – Guidelines GN 489 in Government Gazette 40883, dated 2 June 2017</li> <li>• Regulations for hazardous chemical substances GNR 1179 in Government Gazette 16596, dated 25 August 1995</li> <li>• Environmental regulations for workplaces GNR 2281 in Government Gazette 10988, dated 16 October 1987</li> <li>• SANS 204 Energy efficiency</li> <li>• SANS 10400 as applicable</li> <li>• NEMA Act 107 of 1998: NEMA Regulations Government Notice R385 of 2006, Listing Notice 1 Government Notice R386 and R387 of 2006</li> <li>• ACSA ISO 14001 Environmental Management System: T020 001ASOP – Resources roles and responsibilities of stakeholders</li> <li>• ACSA T030 001-T030 002ASOP – Monitoring and auditing</li> <li>• ACSA T050 002-T050 008ASOP – Environmental management</li> </ul>
<b>4-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>• Commissioning according to CIBSE (Chartered Institution of Building Services Engineers) codes</li> <li>• Maximum lighting illuminance level of no more than 80 % of the illumination levels prescribed in SANS 10114-1: 2005</li> <li>• ASHRAE 55-2004 Acceptability limits (80 % for 98 % of occupied hours) for naturally ventilated spaces</li> <li>• ISO 7730 for mechanically ventilated spaces (PMV levels between -1 and +1)</li> <li>• The acoustic design must ensure that the noise levels are compliant to SANS 10103: 2008</li> <li>• Lighting illuminance simulation to demonstrate compliance with SANS 10114-1: 2005 illuminance levels</li> </ul>
<b>5-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>• Lighting pollution prevention through targeted design and illuminance levels compliance with CIBSE LG6 Lighting Guide: 1992</li> </ul>
<b>6-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>• ASHRAE 55-2004 Acceptability limits (90 % for 98 % of occupied hours) for naturally ventilated spaces</li> <li>• ISO 7730 for mechanically ventilated spaces (PMV levels between -0.5 and +0.5)</li> </ul>

**Table 6: Requirements for Airport Green Star Rated Terminal Buildings: Construction Requirements [7]**

<b>Base construction requirements</b>	<ul style="list-style-type: none"> <li>• Environmental management plan (project specific) in accordance with section 3 South Wales, Australia EMS guidelines 2007 or relevant sections of the Provincial Government of the Western Cape EMP Guidelines 2005</li> </ul>
<b>4-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>• 1. Construction waste management to recycle 30 % of waste from construction</li> <li>• 2. For brownfield development, the execution of a hazardous materials survey and disposal is required</li> </ul>
<b>5-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>• 1. Construction waste management to recycle a total of 50 % of waste from construction</li> </ul>
<b>6-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>• 1. Construction waste management to recycle a total of 70 % of waste from construction</li> </ul>

**Table 7: Requirements for Airport Green Star Rated Terminal Buildings: Project Requirements [7]**

<b>Base project requirements</b>	<ul style="list-style-type: none"> <li>• Design and as-built drawings, short reports and schematics of all technologies and design features</li> <li>• Operations and maintenance manuals of all systems and design features</li> <li>• Commissioning of all systems and features to be given upon handover</li> </ul>
<b>4-star rating project requirements</b>	<ul style="list-style-type: none"> <li>• Life cycle costing according to ISO 15686-5:2008 performed</li> <li>• 12-month building tuning programme</li> <li>• Appointment of a green star accredited professional (AP)</li> <li>• Issue a building users guide</li> <li>• Appointment of an independent commissioning agent</li> <li>• Energy modelling required demonstrating reduced carbon emissions</li> <li>• Adoption of an automated metering strategy</li> <li>• Adoption of an operational waste recycling and management plan</li> <li>• Appointment of a professional natural scientist</li> </ul>
<b>5-star rating project requirements</b>	<ul style="list-style-type: none"> <li>• Contractors and sub-contractors to have ISO 14001 certificate</li> </ul>
<b>6-star rating project requirements</b>	None for the selected credits for 6-star rated terminal buildings

**Table 8: Requirements for Airport Green Star Rated Office Buildings: Technology Requirements [8]**

<b>Base technologies</b>	<ul style="list-style-type: none"> <li>• Standards and guidelines for energy efficiency [4]</li> <li>• Power factor correction</li> <li>• Air-cooled chillers</li> <li>• Dual flush ablutions (3 L and 6 L per flush)</li> <li>• Low flow taps, sensor activated (max 3 L/min)</li> <li>• Low flow shower heads (max 6 L/min)</li> </ul>
<b>4-star rating technologies</b>	<ul style="list-style-type: none"> <li>• Paints to meet specific volatile organic compound (VOC) limits</li> <li>• Reduction in greenhouse gas emissions by 20 % through alternative energy sources</li> <li>• Automated smart energy metering for tenants</li> <li>• Closed loop geothermal heat sink to be adopted in place of cooling towers or if this is not possible with designs, adoption of heat recovery from the chiller's condenser to be used for water heating needs as well as recovery of condensate from air handling units for re-use as make-up water for cooling towers</li> <li>• Waterless urinals</li> <li>• Rainwater harvesting for irrigation, washing motor vehicles and other second-class water purposes</li> <li>• Active leak detection system for potable water reticulation</li> <li>• Collection and use of stormwater for irrigation and designing xeriscape gardens</li> <li>• Adoption of methods such as trenches, basins, porous pavements, filter strips, grass swales, media filters, detention ponds, grease and litter traps, hydrocarbon detention, etc. for the management of stormwater and the reduction of total suspended solids (TSS) by 80 % for the run-off volume for rainfall events up to a 1-in-2-year storm</li> <li>• All refrigerants and fire suppression systems to have a "0" ODP</li> <li>• All insulants to have a "0" ODP</li> </ul>
<b>5-star rating technologies</b>	<ul style="list-style-type: none"> <li>• Adhesives and sealants to meet specific VOC limits</li> <li>• Total reduction in greenhouse gas emissions by 35 % through alternative energy sources</li> <li>• Flush ablutions with grey water/re-used water</li> <li>• Reduction of potable water demand by 50 % through use of closed loop geothermal heat sinks or air-cooled chillers</li> <li>• Daylight glare control is reduced by using fixed shading devices (overhangs, louvres, etc.) and automated blinds/screens to be adjusted that will reduce direct sun at desk-height for 80 % of standard working hours</li> <li>• Composite wood products used in the project (particleboard, plywood, veneer, MDF and decorative overlaid wood panels) must have zero or minimal formaldehyde emissions in compliance with specific values</li> </ul>

<b>6-star rating technologies</b>	<ul style="list-style-type: none"> <li>• Installation of a daylight glare control system that eliminates 95 % of all direct sun penetration, blinds/screens to have a visual light transmittance of &lt; 10 % and can be controlled by occupants</li> <li>• Carpets and floor coverings used in the building and facilities must meet specific VOC limits</li> <li>• Total reduction in greenhouse gas emissions by 60 % through alternative energy sources and carbon offsetting plants</li> <li>• Borehole water use for non-potable water demand</li> <li>• Where potable water is used to flush ablutions, adopt solenoid control valves for automatic shut off when area is not in use</li> <li>• Water based heat rejection systems prohibited</li> <li>• The run-off volume resulting from one day of rainfall that is equaled or exceeded on average three times per year, is either captured and re-used onsite or infiltrated within the site; litter, oil and grease are trapped at source</li> <li>• No water-based evaporative cooling systems</li> <li>• Refrigerant leak detection system and refrigerant recovery system to be installed on HVAC system</li> </ul>
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**Table 9: Requirements for Airport Green Star Rated Office Buildings: Design Feature Requirements [8]**

<b>Base design features</b>	<ul style="list-style-type: none"> <li>• Building management system (BMS)</li> <li>• Standards and guidelines for energy efficiency [4]</li> <li>• Tobacco smoke avoidance in designs such that no indoor spaces be provided for the purposes of smoking</li> </ul>
<b>4-star rating design features</b>	<ul style="list-style-type: none"> <li>• For 95 % of the usable area, lighting power densities of 3.0 W/m<sup>2</sup> per 100 lux at 720 mm above finished floor level (FFL) with default maintenance factor of 0.8</li> <li>• Lighting is zoned appropriately and controlled according to demand</li> <li>• Reduce sewerage outflow by 30 %</li> <li>• 30 % of the usable area must have a measured daylight factor of not less than 2 % at desk height level (720 mm) under a uniform design sky</li> </ul>
<b>5-star rating design features</b>	<ul style="list-style-type: none"> <li>• Design of HVAC system must ensure humidity control of the space at 60 % RH and in the supply ducting 80 % RH</li> <li>• For 95 % of the usable area, lighting power densities of 2 W/m<sup>2</sup> per 100 lux at 720 mm above FFL with default maintenance factor of 0.8</li> <li>• The development does not increase (pre-development) peak stormwater flows for rainfall events of up to a 1-in-2-year storm; litter, oil and grease trapped at source</li> <li>• Dedicated tenant exhaust riser to remove indoor pollutants from print and copy areas</li> <li>• Noise levels to be 40 dB(A) eq for general office space and 45 dB(A) eq for open plan space (&gt; 50 m<sup>2</sup>), acoustic design, report and survey from acoustician</li> </ul>
<b>6-star rating design features</b>	<ul style="list-style-type: none"> <li>• For 95 % of the usable area, lighting power densities of 1.5 W/m<sup>2</sup> per 100 lux at 720 mm above FFL with default maintenance factor of 0.8</li> </ul>

**Table 10: Requirements for Airport Green Star Rated Office Buildings: Standards for Compliance [8]**

<b>Base standards for compliance</b>	<ul style="list-style-type: none"> <li>Occupational Health and Safety Act (Act 85 of 1993)</li> <li>Construction regulations, 2014 – Guidelines GN 489 in Government Gazette 40883, dated 2 June 2017</li> <li>Regulations for hazardous chemical substances GNR 1179 in Government Gazette 16596, dated 25 August 1995</li> <li>Environmental regulations for workplaces GNR 2281 in Government Gazette 10988, dated 16 October 1987</li> <li>SANS 204 Energy efficiency</li> <li>SANS 10400 as applicable</li> <li>NEMA Act 107 of 1998: NEMA Regulations Government Notice R385 of 2006, Listing Notice 1 Government Notice R386 and R387 of 2006</li> <li>ACSA ISO 14001 Environmental Management System: T020 001ASOP – Resources roles and responsibilities of stakeholders</li> <li>ACSA T030 001-T030 002ASOP – Monitoring and auditing</li> <li>ACSA T050 002-T050 008ASOP – Environmental management</li> </ul>
<b>4-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>Maximum lighting illuminance level of no more than 80 % of the illumination levels prescribed in SANS 10114-1: 2005</li> <li>Compliance with ASHRAE 55-2004 Acceptability limits (80 % for 98 % of occupied hours) for naturally ventilated spaces and ISO 7730 for mechanically ventilated spaces (PMV levels between -1.5 and +1.5)</li> <li>The acoustic design must ensure that the noise levels are compliant to SANS 10103:2008</li> <li>Lighting illuminance simulation to demonstrate compliance with SANS 10114-1: 2005 illuminance levels</li> <li>Lighting pollution prevention through targeted design and compliance with illuminance levels in CIBSE LG6 Lighting Guide: 1992</li> </ul>
<b>5-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>Contractors and sub-contractors ISO 14001 certificate</li> </ul>
<b>6-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>Compliance with ASHRAE 55-2004 Acceptability limits (90 % for 98 % of occupied hours) for naturally ventilated spaces and ISO 7730 for mechanically ventilated spaces (PMV levels between -0.5 and +0.5)</li> </ul>

**Table 11: Requirements for Airport Green Star Rated Office Buildings: Construction Requirements [8]**

<b>Base construction requirements</b>	<ul style="list-style-type: none"> <li>Environmental management plan (project specific) in accordance with section 3 South Wales, Australia EMS guidelines 2007 or relevant sections of the Provincial Government of the Western Cape EMP Guidelines 2005</li> </ul>
<b>4-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>Construction waste management to recycle 30 % of waste from construction</li> <li>For brownfield development, the execution of a hazardous materials survey and disposal is required</li> </ul>
<b>5-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>Construction waste management to recycle a total of 50 % of waste from construction</li> </ul>
<b>6-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>Construction waste management to recycle a total of 70 % of waste from construction</li> </ul>

**Table 12: Requirements for Airport Green Star Rated Office Buildings: Project Requirements [8]**

<b>Base project requirements</b>	<ul style="list-style-type: none"> <li>• Design and as-built drawings, short reports and schematics of all technologies and design features</li> <li>• Operations and maintenance manuals of all systems and design features</li> <li>• Commissioning of all systems and features to be given upon handover</li> </ul>
<b>4-star rating project requirements</b>	<ul style="list-style-type: none"> <li>• Energy modelling required demonstrating reduced carbon emissions</li> <li>• Adoption of an automated metering strategy</li> <li>• Adoption of an operational waste recycling and management plan</li> <li>• Appointment of a professional natural scientist</li> </ul>
<b>5-star rating project requirements</b>	None for the selected credits for 5-star rated office buildings
<b>6-star rating project requirements</b>	None for the selected credits for 6-star rated office buildings

**Table 13: Requirements for Airport Green Star Rated Retail Centres: Technology Requirements [9]**

<b>Base technologies</b>	<ul style="list-style-type: none"> <li>• Standards and guidelines for energy efficiency [4]</li> <li>• Power factor correction to be done for establishments of electrical demand 1 MW or 10 % of the airport's load, whichever is the smaller</li> <li>• Air-cooled chillers</li> <li>• Dual flush ablutions (3 L and 6 L per flush)</li> <li>• Low flow taps, sensor activated (max 3 L/min)</li> <li>• Low flow shower heads (max 6 L/min)</li> </ul>
<b>4-star rating technologies</b>	<ul style="list-style-type: none"> <li>• Paints to meet specific VOC limits</li> <li>• Reduction in greenhouse gas emissions by 20 % through alternative energy sources</li> <li>• Automated electrical metering strategy that includes smart meters for all users in the building 100 kVA or more</li> <li>• Maximum electrical demand reduction by 10 %, using pre-programmed load curtailment programmes, electronically controlled. Buffer storage tanks for chilled water storage, lighting circuit switching techniques, daylight harvesting, low emissivity glazing and heat deflective paint to be adopted to reduce peak demand for cooling</li> <li>• Closed loop geothermal heat sink to be adopted in place of cooling towers</li> <li>• Waterless urinals</li> <li>• Rainwater harvesting for irrigation, washing motor vehicles and other second-class water purposes</li> <li>• Active leak detection system for potable water reticulation</li> <li>• Collection and use of stormwater for irrigation and designing xeriscape gardens</li> <li>• Adoption of methods such as trenches, basins, porous pavements, filter strips, grass swales, media filters, detention ponds, grease and litter traps, hydrocarbon detention, etc. for the management of stormwater and the reduction of total suspended solids (TSS) by 80 % for the run-off volume for rainfall events up to a 1-in-2-year storm</li> <li>• All refrigerants and fire suppression systems to have a "0" ODP</li> </ul>
<b>5-star rating technologies</b>	<ul style="list-style-type: none"> <li>• Adhesives and sealants to meet specific VOC limits</li> <li>• Total reduction in greenhouse gas emissions by 35 % through alternative energy sources</li> <li>• Automated smart metering strategy to include thermal energy meters</li> <li>• Reduction of maximum electrical demand by a further 10 % making use of ice storage tanks that will allow for a relatively flat HVAC demand</li> <li>• Flush ablutions with grey water or re-used water</li> <li>• All insulants to have a "0" ODP</li> <li>• Reduction of potable water demand by 50% through use of closed loop geothermal heat sinks or air-cooled chillers</li> <li>• Composite wood products used in the project (particleboard, plywood, veneer, MDF and decorative overlaid wood panels) must have zero or minimal formaldehyde emissions in compliance with specific values</li> <li>• Metering thermal energy users (10 kW or more) with connection to the BMS system</li> </ul>

<b>6-star rating technologies</b>	<ul style="list-style-type: none"> <li>• Total reduction in greenhouse gas emissions by 60 % through alternative energy sources and carbon offsetting plants</li> <li>• Total reduction in maximum electrical demand by 20 % through additionally making use of waste heat from alternative energy plants to power absorption chillers</li> <li>• Borehole water use for non-potable water demand</li> <li>• Where potable water is used to flush ablutions, adopt solenoid control valves for automatic shut off when area is not in use</li> <li>• Water based heat rejection systems prohibited</li> <li>• Refrigerant leak detection system and refrigerant recovery system to be installed on HVAC system</li> <li>• All refrigerants adopted to have a Global Warming Potential (GWP 100) of 10 or less</li> </ul>
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**Table 14: Requirements for Airport Green Star Rated Retail Centres: Design Feature Requirements [9]**

<b>Base design features</b>	<ul style="list-style-type: none"> <li>• Building management system</li> <li>• Standards and guidelines for energy efficiency [4]</li> </ul>
<b>4-star rating design features</b>	<ul style="list-style-type: none"> <li>• Adoption of a waste and recycling management plan that seeks to reduce the operational waste generated and recycle maximum waste from all users (including tenants), setting waste targets and making provision for facilities supporting separation at source</li> <li>• The building owner/manager must ensure that no less than 80 % of the rentable area (as per SAPOA definition) is committed to a tenancy lease agreement that requires the tenants to monitor and report quarterly on electrical energy consumption, water consumption, waste recycling, having submitted a plan for each of these at the beginning of the lease, together with a green procurement policy to procure environmentally friendly consumables</li> <li>• The acoustic design and report must ensure that the noise levels do not exceed 55 dBA in full operation</li> <li>• Provision must be made for respite and connection to nature for staff and visitors, minimum of 50 m<sup>2</sup> and 0.1 % of the retail GFA (gross floor area) must be set aside as a rest area that has direct physical and visual connection to the natural environment</li> <li>• Energy modelling required demonstrating reduced carbon emissions</li> <li>• Adoption of an “automated metering strategy” that meters all major water users and tenants connected to a smart metering system that can be used for billing, historical data analysis and live tracking of water losses through water zonal meters as well as being integrated to the active potable water leak detection system</li> <li>• Adoption of an operational waste recycling and management plan</li> <li>• Appointment of a professional natural scientist</li> <li>• Adoption of roofing, paving and building materials (external hardscape) must have a solar reflectance index (SRI) greater than or equal to 29 and for pitched roof areas less than or equal to 10 degrees, the SRI must be greater than or equal to 78</li> <li>• Reduce sewerage outflow by 30 %</li> </ul>
<b>5-star rating design features</b>	<ul style="list-style-type: none"> <li>• Design of HVAC system must ensure humidity control of the space at 60 % RH and in the supply ducting 80 % RH</li> <li>• Kitchen exhaust points must be located not closer than 1.0m to a neighbouring usable space or walkway, or a fresh air intake of that development or another development</li> </ul>
<b>6-star rating design features</b>	None for the selected credits for 6-star rated retail centres

**Table 15: Requirements for Airport Green Star Rated Retail Centres: Standards for Compliance [9]**

<b>Base standards for compliance</b>	<ul style="list-style-type: none"> <li>Occupational Health and Safety Act (Act 85 of 1993)</li> <li>Construction regulations, 2014 – Guidelines GN 489 in Government Gazette 40883, dated 2 June 2017</li> <li>Regulations for hazardous chemical substances GNR 1179 in Government Gazette 16596, dated 25 August 1995</li> <li>Environmental regulations for workplaces GNR 2281 in Government Gazette 10988, dated 16 October 1987</li> <li>SANS 204 Energy efficiency</li> <li>SANS 10400 as applicable</li> <li>NEMA Act 107 of 1998: NEMA Regulations Government Notice R385 of 2006, Listing Notice 1 Government Notice R386 and R387 of 2006</li> <li>ACSA ISO 14001 Environmental Management System: T020 001ASOP – Resources roles and responsibilities of stakeholders</li> <li>ACSA T030 001-T030 002ASOP – Monitoring and auditing</li> <li>ACSA T050 002-T050 008ASOP – Environmental management</li> </ul>
<b>4-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>ASHRAE 55-2004 Acceptability limits (80% for 98% of occupied hours) for naturally ventilated spaces</li> <li>ISO 7730 for mechanically ventilated spaces (PMV levels between -1.5 and +1.5)</li> <li>Lighting illuminance simulation to demonstrate compliance with SANS 10114-1: 2005 illuminance levels</li> <li>Lighting pollution prevention through targeted design and illuminance levels compliance with CIBSE LG6 Lighting Guide: 1992</li> </ul>
<b>5-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>Contractors and sub-contractors ISO 14001 certificate</li> <li>SANS 1850: 2003 Design and manufacture of commercial kitchen extraction, ASHRAE Handbook 2007: HVAC Application, Chapter 31 Kitchen ventilation</li> </ul>
<b>6-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>ASHRAE 55-2004 Acceptability limits (90% for 98% of occupied hours) for naturally ventilated spaces</li> <li>ISO 7730 for mechanically ventilated spaces (PMV levels between -0.5 and +0.5)</li> </ul>

**Table 16: Requirements for Airport Green Star Rated Retail Centres: Construction Requirements [9]**

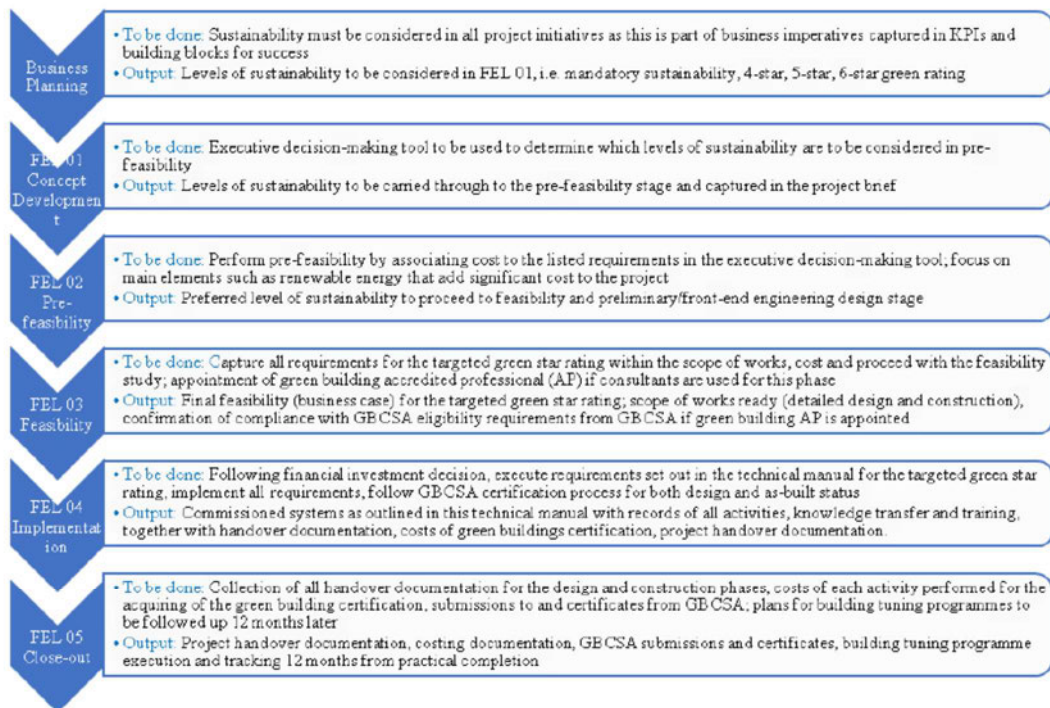
<b>Base construction requirements</b>	<ul style="list-style-type: none"> <li>Environmental management plan (project specific) in accordance with section 3 South Wales, Australia EMS guidelines 2007 or relevant sections of the Provincial Government of the Western Cape EMP Guidelines 2005</li> </ul>
<b>4-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>Construction waste management to recycle 30 % of waste from construction</li> <li>For brownfield development, the execution of a hazardous materials survey and disposal is required</li> </ul>
<b>5-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>Construction waste management to recycle a total of 50 % of waste from construction</li> </ul>
<b>6-star rating construction requirements</b>	<ul style="list-style-type: none"> <li>Construction waste management to recycle a total of 70 % of waste from construction</li> </ul>

Requirement Level	Requirements
<b>Base project requirements</b>	<ul style="list-style-type: none"> <li>• Design and as-built drawings, short reports and schematics of all technologies and design features</li> <li>• Operations and maintenance manuals of all systems and design features</li> <li>• Commissioning of all systems and features to be given upon handover</li> </ul>
<b>4-star rating project requirements</b>	<ul style="list-style-type: none"> <li>• Construction waste management to recycle 30 % of waste from construction</li> <li>• For brownfield development, the execution of a hazardous materials survey and disposal is required</li> </ul>
<b>5-star rating project requirements</b>	None for the selected credits for 5-star rated retail centres
<b>6-star rating project requirements</b>	None for the selected credits for 6-star rated retail centres

The requirements contained in Table 3 to Table 17 is highly summarised and correspond to credits that amount to the number of points for a 4-star, 5-star and 6-star green ratings.

## 6. PROCESS TO IMPLEMENT GREEN BUILDINGS FOR NEW INFRASTRUCTURE AT AIRPORTS

In the process flow of ACSA's project management plan, five levels or stages are identified, i.e., FEL 01 to FEL 05 after business planning takes place to identify all the initiatives that need to take place (Pre-Level FEL01). The execution of sustainability (and green buildings) in each of the stages within the project management process flow can be seen in Fig. 3.



**Figure 3: Project Management Process Flow.**

During **business planning**, the company's business imperatives, which are largely guided by the company's vision, strategic objectives and business KPIs, must be incorporated into the high-level definition of targeted initiatives (soon to become projects). At this level, environmental sustainability must be taken into account due to environmental sustainability being part of the company's vision.

From **FEL 01** stage where **concept development** starts, the level of sustainability targeted must be considered and guided by the strategic objective of attaining carbon neutrality in energy consumption; the availability, cost and risks to the business of energy and water supply; and the legislative requirements around waste management over the project lifecycle. The minimum requirements for energy efficiency in all projects are contained in the Standards and Guidelines for Energy Efficiency which is a company policy document in ACSA

The targeted green star rating decision should be taken at Level **FEL 02 (pre-feasibility)** in order to determine the cost and benefit using high level trade-offs between water, electricity savings (and waste generation where data is available) and capital costs.

For **FEL 03 (feasibility)**, the detailed clauses contained in the technical manual must be used to define the scope of works for the targeted green star rating, from which a project specific capital cost can be drawn up together with operational cost savings, from which a business case can be formed.

The Green Star Rating for ACSA is targeted for both "design" and "as-built" status. Once a financial investment decision (FID) is made to go ahead with the project, registration of the project for the targeted green star rating must commence with Green Building Council of South Africa (GBCSA).

Step 1 in the GBCSA process is checking for eligibility for the targeted green star rating. This can be sought in FEL03. At this point it is advisable to appoint a green building accredited professional (AP), although this can also be done in FEL 04. The project will be checked for compliance with four eligibility requirements, i.e., spatial differentiation, space use, two conditional requirements and timing of certification as follows:

- In the spatial differentiation requirement, the project must be clearly distinct as a free-standing building or an extension of an existing building, i.e., no partial components of projects will qualify.
- The space use requirement determines which GBCSA green star rating tool is applicable.
- The conditional requirements that the project must meet are with respect to the energy category and the land use and ecology category.
- The timing of the certification requirement is that obtaining of the certification (both "design" and "as-built") must be within 24 months of the date of practical completion of the project.

Once the eligibility requirement has been met, the project can then be submitted for the GBCSA certification process (Figure. 2). The relevant documentation must be put together as per the targeted green star rating requirements. Assessment takes about 7 weeks. Should the rating need documentation which could not be found in the first submission, this will activate a second round giving the opportunity to submit the required documentation. Important to note is that there are only two rounds in the green building certification process.

In **FEL 05 (close-out)**, all documentation including O&M manuals, building user guides, training and knowledge transfer records and material, commissioning and technical specifications, manufacturer's data sheets as well as signoffs from each stage gate must be handed over. The costings for the green star rating must be included together with all submissions (and data) to, and received from, GBCSA. The 12-month building tuning programme must be ready (with implementation plan, resourced) and be put into action, tracked and closed out after 12 months with handover documentation submitted. Once this is done, the process is complete.

## 7. CONCLUSIONS

This paper successfully presented the guidelines for implementing green star rated new terminal buildings, office buildings and retail centres. The guidelines included general requirements, technology requirements, design feature requirements, standards for compliance, construction requirements and project requirements for 4-star, 5-star and 6-star rated green new terminal, office and retail infrastructure. The guidelines were a summary taken from the technical manuals for green buildings prepared for ACSA in accordance with the Green Building Council South Africa (GBCSA). A description of the green star rating frameworks and the rationale used to select the credits that give the green star rating for each type of infrastructure is given. The process to implement the green star rated infrastructure at the airports is outlined showing how carbon emissions are being reduced, and environmental consciousness is being observed. This ensures the efforts to transform the airport sites towards energy efficiency and energy security are sustained.

## REFERENCES

1. Joseph, J.S., Inambao, F.L., "Trends: Energy Efficiency and Energy Security", *International Journal of Engineering Research and Technology*, Vol. 13, Issue 12 (2020), pp. 4084-4117.
2. Green Building Council South Africa, "Technical Manual Green Star SA Public & Education Building Design/As Built v1", March 2013.
3. Joseph, J.S., "Technical Manual for Green Buildings In Accordance with the Green Buildings Council of South Africa (Public and Education Building Design and As-Built V1 2013) Specifications for newly constructed Terminal Buildings in Airports Company South Africa", Chief Engineer: Energy and Demand Management for Airports Company South Africa, 25/06/2020.
4. Joseph, J., Inambao, F.L., "Energy Efficiency for Airport Infrastructure: A Case Study of the Implementation of Energy Efficiency for Airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, Vol. 11, Issue 2, Apr 2021, 383-406.
5. Joseph, J.S., "Technical Manual for Green Buildings In Accordance with the Green Buildings Council of South Africa (Office Buildings Design and As-Built V1.1 2014) Specifications for newly constructed Office Buildings in Airports Company South Africa", Chief Engineer: Energy and Demand Management for Airports Company South Africa, 25/06/2020.
6. Joseph, J.S., "Technical Manual for Green Buildings In accordance with the Green Buildings Council of South Africa (Retail Centre Design and As-Built V1 2010) Specifications for newly constructed Retail Buildings in Airports Company South Africa", Chief Engineer: Energy and Demand Management for Airports Company South Africa, 25/06/2020.
7. Joseph, J.S., "New Terminal Buildings – Executive Decision-Making Tool for Green Star Buildings (Green Star Rating Tool according to Green Buildings Council South Africa) Extracted from the Technical Manual for Green Buildings done for Airports Company South Africa", Chief Engineer: Energy and Demand Management, 2020.
8. Joseph, J.S., "New Office Buildings – Executive Decision-Making Tool for Green Star Buildings (Green Star Rating Tool according to Green Buildings Council South Africa) Extracted from the Technical Manual for Green Buildings done for

- Airports Company South Africa*", *Chief Engineer: Energy and Demand Management*, 2020.
9. Joseph, J.S., "New Retail Buildings – Executive Decision-Making Tool (Green Star Rating Tool According to Green Buildings Council South Africa) Extracted from the Technical Manual for Green Buildings done for Airports Company South Africa", *Chief Engineer: Energy and Demand Management*, 2020.
  10. Frizziero, L. E. O. N. A. R. D. O., et al. "New recovery energy turnstile achieved through research and innovation eco-design method (EQFD)." *Int. J. Mech. Prod. Eng. Res. Dev* 9 (2019): 277-286.
  11. Joshi, Krishna. "Application of Energy Concepts for Green Buildings." *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) ISSN (P) (2016): 2249-6866*.
  12. Mohapatra, Hitesh, et al. "A comparative analysis of clustering protocols of wireless sensor network." *International journal of mechanical and production engineering research and development (IJMPERD) ISSN (P) 10.3 (2020): 2249-6890*.
  13. Senthilkumar, P. "Environmental Effect Of Using Diesel On Waste Plastic Oil Fueled In Diesel Engine." *International Journal of Mechanical Engineering (IJME) 7. 3, Apr-May 2018 18*.

**CHAPTER 21. SUSTAINABILITY OF ENERGY EFFICIENCY AND ENERGY  
SECURITY FOR AIRPORTS IN SOUTH AFRICA: GUIDELINES FOR  
TRANSITIONING EXISTING TERMINAL BUILDINGS TO GREEN BUILDING  
STATUS**

This chapter presents the guidelines for transitioning existing airport terminal buildings towards the adoption of a green star rating as per the green star rating system of the Green Building Council of South Africa.

The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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## SUSTAINABILITY OF ENERGY EFFICIENCY AND ENERGY SECURITY FOR AIRPORTS IN SOUTH AFRICA: GUIDELINES FOR TRANSITIONING EXISTING TERMINAL BUILDINGS TO GREEN BUILDING STATUS

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### ABSTRACT

*The execution of projects that achieve energy efficiency and energy conservation for existing infrastructure at a site reduces the site's carbon footprint. Adopting low carbon energy sources to power existing buildings further reduces the carbon footprint allowing carbon neutrality for the site to become achievable. Projects that adopt a low or no carbon emissions approach require investment, which, if operations at the respective sites do not preserve this approach, could negate the return on the investment and increase the carbon emissions of that site. Changes in personnel lead to inevitable loss in energy efficient working regimes thus requiring culture change programmes to restore energy conscious behaviour within daily operations. Working towards, then achieving and maintaining a green star rating for the existing buildings motivates and requires personnel to sustain reduced carbon emissions in all their work. The adoption of "green buildings" ensures compliance with environmental requirements including reduction in carbon emissions and energy consumption which serves to ensure that investments towards reduced carbon emissions realise their returns. This paper presents guidelines for transitioning existing airport terminal buildings towards the adoption of a green star rating as per the green star rating system of the Green Building Council of South Africa.*

**KEYWORDS:** *Energy Efficiency, Energy Security, Green Buildings, Environmentally Sustainable Buildings, Environmental Responsibility, Resource Efficiency & Green Star Rated Airport Terminal Buildings*

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### INTRODUCTION

The challenge that any organisation faces, especially those exceeding ten people, is to ensure that the culture within a company does not work against the strategy, vision, business imperatives, values and desired work ethic of the organisation. Management of organisations work through their human resources (HR) departments to ensure that employees are aware of what the company represents and how it operates through the company strategy, company policies, work procedures, legal and ethical obligations as well as expectations in terms of standards of work output and behaviour. HR teams have internal disciplinary programmes to ensure that misdemeanours are addressed appropriately to preserve all that the company stands for. Arguably, the more difficult human dynamic to address is the aspect of company culture that relies on an employed person for efficient work output and competency that if lacking does not result in immediate harm to the company, but may cause short, medium or long term undesirable effects. These short- and medium-term harms may be financial loss, decrease in profitability, increase in maintenance or operational costs, or decreased efficiency of systems, all of which may be very difficult to prove and account for. The long-term harm is a culture of neglect through personnel influence which goes unaddressed.

Executing energy efficiency relies heavily on the culture of the people working for an organisation [1], [2]. Without a conscious daily effort to change energy inefficient behaviour, energy efficiency at a site will not be achieved. Change management for energy efficiency is challenging compared to performing a technical task like maintaining a chiller on a specific day of the year, as it requires consistency and depends on the majority of personnel undertaking their daily activities at a site. Ensuring energy security requires a different way of thinking to the norm of simply relying on electricity from the national electricity grid. At some point, policies, standards, procedures and expectations must be put in place to ensure that the desired result is achieved. This needs to be suitably captured in the company vision, strategies and business imperatives.

Airports Company South Africa (ACSA) has the ambition to reduce carbon emissions across its airports in South Africa and put in place an energy and demand management strategy, and to this end has approved a suite of technologies to reduce carbon emissions and adopt standards and guidelines for energy efficiency. ACSA owns and operates nine airports in South Africa, namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport (CTIA) (Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (PEIA) (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (BFIA) (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape). ACSA's energy and demand management strategy aims to make ACSA a recognised leader in the implementation of energy solutions that are economically and environmentally sustainable for airport businesses. This strategy is in line with ACSA's vision of being "... the most sought-after partner in the world for the provision of sustainable airport management solutions."

At its core, ACSA's energy and demand management strategy intend to reach carbon neutrality in electricity consumption by 2030. The three strategic objectives to support the strategy are: (1) reduce energy consumption to drive carbon neutrality, (2) introduce an energy mix that is responsive to the ACSA business and operating environment, and (3) drive an energy efficiency culture within ACSA through accountability, standardisation and a structured approach to managing energy intensive infrastructure. These strategic objectives have been translated into executable projects and initiatives that have been included in each of ACSA's nine airports' roadmaps to carbon neutrality. Significant progress has been made to reduce energy consumption and plans are in progress to realise a low carbon energy mix at the airports. The low carbon energy mix transitions the airports' current electricity demand towards carbon neutrality and makes provision for future energy demand. However, to ensure that energy wastage and practices that negate efforts to drive carbon neutrality are mitigated when new personnel join the organisation, certain standards must be adopted. To bring about a culture of energy efficiency and standardisation across existing infrastructure, adherence to green buildings requirements for all existing terminal buildings must be adopted.

Green buildings incorporate design, construction and operational practices that significantly reduce or eliminate the negative impact of development on the environment and people. Green buildings are:

- Energy efficient,
- Resource efficient,
- Environmentally responsible,
- Healthy and productive environments for people.

The Green Building Council of South Africa (GBCSA) is an independent, non-profit member-based company that was formed in 2007 to lead the greening of South Africa’s commercial property sector. GBCSA provides the tools, training, knowledge, connections and networks, to promote green building practices across the country and build a national movement that aims to change the way the world is built. There are over 98 individual and recognised green building councils worldwide whose mission is to abate climate change through green building. The World Green Building Council is an umbrella organisation that provides guidance to the different green building councils, of which the GBCSA is a member alongside Australia, the United States and the United Kingdom amongst others. The GBCSA has adopted, adapted, and contextualised the Green Star rating system. Originally developed by the Green Building Council of Australia, this rating system was used as a base and has been significantly modified to fit the local market and environmental context [3].

The GBCSA started off with the Green Star Rating tools for residential, office, public and education buildings, retail developments, existing buildings, and interiors of developments. Their tools have extended to rating sustainable precincts, custom tools regarding net zero (carbon, water, waste, ecology), energy and water performance tools, and many more that meet the South African market demand. There have been over 400 green star certifications between 2007 and 2018 in South Africa [3].

Certifying existing terminal buildings will serve to hold personnel accountable to deliver a standard of energy, water and resource efficiency as well as environmental responsibility. This will also serve to independently verify the airports’ achievements and recognition as leaders in environmentally sustainable solutions for airport businesses. This paper describes the green star rating frameworks of the GBCSA, and the requirements for transitioning the existing terminal buildings towards a 4-, 5- or 6-star rated terminal buildings through the implementation of certain technologies, certification according to specific standards, projects and management requirements to meet the credit requirements of the GBCSA rating frameworks.

### 1. GBCSA’s Green Star Rated Frameworks

GBCSA has established a number of categories under which specific key criteria are grouped and assessed [4]. This framework is referred to as the Green Star SA rating framework. The basic Green Star SA structure is shown in Figure. 1.

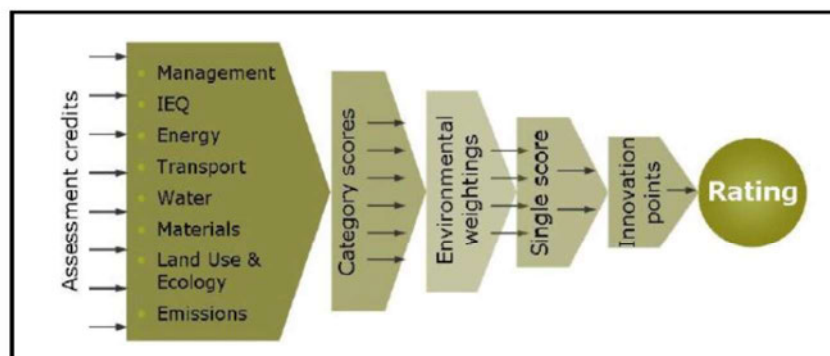


Figure 1: Structure of the Green Star SA Rating System [5].

Green Star SA rating tools include nine separate environmental impact categories:

- **Management** - promotes the adoption of environmental principles from project inception, design and construction phases, to commissioning, tuning and operation of the building and its systems.
- **Indoor Environment Quality** - targets the wellbeing of the occupants, addresses the heating and cooling systems, lighting, indoor air pollutants and building attributes that contribute to a healthier indoor environment quality.
- **Energy** - targets an overall reduction in energy consumption and a reduction of greenhouse gas (GHG) emissions associated with energy generation from fossil fuels.
- **Transport** - rewards reduction in automotive commuting by simultaneously discouraging it and encouraging the use of alternative transportation.
- **Water** - addresses the reduction of potable water use through the design of water efficient systems, rainwater collection and water reuse.
- **Materials** - targets the consumption of resources through selection and reuse of materials and efficient management practices.
- **Land Use and Ecology** - promotes initiatives to improve or reduce impacts on ecological systems and biodiversity.
- **Emissions** - targets the environmental impacts of a development's emissions or substances emitted from the site (excluding greenhouse gas emissions which are dealt with in the Energy category).
- **Innovation** - encourages, recognises and rewards the spread of innovative technologies, designs and processes for commercial building applications that impact upon environmental performance.

The categories contain credits which addresses specific initiatives that improve or have the potential to improve a design, project or building's environmental performance. Points are awarded in each credit for actions that demonstrate that the project has met the overall objectives of Green Star SA and the specific aims of the pertinent Green Star SA rating tool. Green Star SA environmental weighting factors vary across rating tools to reflect differing environmental concerns and imperatives for different building types and lifecycle phases. To encourage the development and spread of innovative technologies, designs and processes that could improve buildings' environmental performance, an 'Innovation' category is included in each Green Star SA rating tool. Table 1 [5] contains the overall score corresponding to a green star rating according to the green star rating system. [4]

**Table 1: GBCSA's Green Star Rating tool Scoring and Rating**

Overall Score	Rating	Represents
10-19	1-star	"On the journey to a better, greener building"
20-29	2-star	"On the journey to a better, greener building"
30-44	3-star	"Good Practice"
45-59	4-star	"Best Practice"
60-74	5-star	"South Africa Excellence"
75+	6-star	"World Leadership"

As indicated in Table 1, the minimum Green Star SA rating is 1-star and the maximum is 6-star. In the Design or As Built ratings, Green Star SA only recognises and rewards market leaders (only certifies 4-star or above), but in the Existing Building Performance tool the GBCSA recognises that the move to becoming a 4-6 star rated building may be a lengthy journey for some, and those who are doing significant work in reaching this point should be acknowledged along this journey [5].

In the process of certification (Figure. 2), the timing of the certification is very specific as are the duration of the requirements for certification which are mostly evaluated over a 12-month period. The following are the general conditions of certification which is valid for a 3-year period by which time re-certification for the next 3-year period must be achieved: [5]

- Must have been operational for a minimum of 12 months after final completion.
- The building’s ‘performance period’ (period under which the building’s performance is measured) is to be 12 consecutive months.
- Energy and Water performance periods must end within 90 days of each other.
- The project must submit for certification within 90 days of the end of the building’s 12-month performance period.
- Certification is valid for 3 years from the end of the certified performance period. Thereafter re-certification will need to be undertaken.
- Re-certification can take place at any time within the 3-year period, but the project’s rating will lapse if not re-certified within 3 years.
- Annual submission during the 3-year period is required for:
  - Energy consumption data
  - Water consumption data

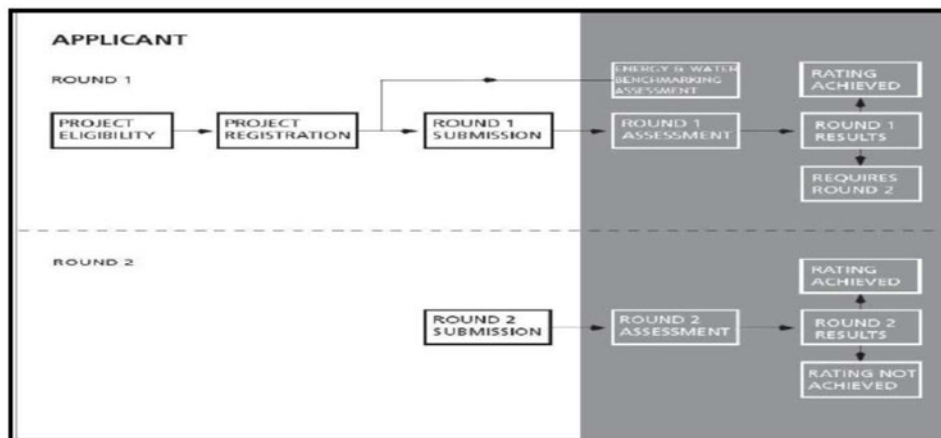


Figure 2: Overview of GBCSA Green Star Certification Process [5].

Energy and Water performance will be assessed and a formal Energy and Water Benchmarking Certificate issued to the project by the GBCSA. From submission of Energy and Water benchmarking information to the GBCSA, results will be provided within five weeks of submission. From the date of receipt of the project's submission of all targeted credits (Round 1), the GBCSA provides the assessment results within seven weeks. Upon receipt of these results, the project may be required to submit documentation for credits to be confirmed. The project will then be required to provide the Round 2 submission within 90 days of the Round 1 assessment results being issued [5]. The following sections contain the structure of the technical manuals drafted for existing airport terminal buildings to transition towards a green star rating (4- to 6-star).

## 2. Requirements to Transition Existing Terminal Buildings Towards a Green Star Rating

The targeting of certain credits is based on what is key to ACSA's business focus as well as convenience and strategic intention for their existing terminal buildings to achieve 4-, 5- and 6-star ratings, and further converts the expectations in these credits into three categories for execution:

- **Standards Compliance (SC):** This section lists the standards that the terminal building specific systems must comply with in order to achieve the targeted green star rating.
- **Project Requirements (PR):** This section has all project requirements that must be initiated so that GBCSA requirements are met to achieve the targeted green star rating.
- **Management Practices (MP):** These are everyday operational management practices that must be put in place to meet GBCSA's requirements for the targeted green star rating.

The information given in all the sections above are designed to be cumulative, i.e., to achieve a 5-star green rating, the 4-star green rating requirements must be achieved and additional requirements listed under the 5-star green rating must be implemented, etc.

## 3. Rationale for the Selection of Credits to Make up the Green Star Ratings for the New Airport Infrastructure

The following sections present the business imperatives that played a role in the selection of the credits to be targeted for the 4-star, 5-star and 6-star rated green buildings. The rationale used when targeting the number of credits with the range given for a 4-star, 5-star and 6-star rating is provided and the credits that are most targeted as well as those less targeted due to lack of focus of the business in those areas are listed.

### 3.1 Business Imperatives

One of the most important steps in targeting a green star rating is the selection of the combination of credits that gives points for meeting the requirements for the green star rating being applied for (Table 1). The selection of credits has financial implications but with careful planning, the overall costs can be negligible and such investments can actually reduce operational and maintenance costs making for an attractive business case. The credits to be targeted in each of the green star frameworks (4-, 5- and 6-star green ratings) have been chosen on the following ACSA business principles: [3]

- Savings in operational cost with preferably low or no extra capital cost, and any extra capital costs to be offset within the project, e.g., extra capital cost for using passive cooling techniques such as low emissivity glass and insulation will result in a lower cooling and heating load and thus a smaller capacity HVAC system, lower capex

cost of HVAC, lower electricity cost for operations and potentially lower maintenance cost for a smaller system.

- Supporting of the organisational strategic goals, especially those that are aligned to ACSA's vision for stand-alone airports, reduction in operational cost (running and maintenance costs), Occupational Health and Safety and Asset Information Management imperatives.
- Focus placed on credits that reduce environmental impact and thus significant weighting of water, waste and energy consumption.
- Knowledge transfer and operating conditions that are fine tuned for operational efficiency.
- Focus on credits that support the Airports Council International (ACI) Carbon Accreditation system [3].

### **3.2 Green Building Framework Design**

The combination of credits targeted by ACSA have been designed to always give points over the minimum threshold for the targeted green star rating due to the nature of project execution in general, bearing in mind that thoroughness in terms of project documentation, timelines in terms of project duration and loss in communication in design and execution, result in certain credits targeted not being able to be awarded as per GBCSA strict rules. For this reason, the green star rating target is designed to aim for at least four points above the threshold for the targeted green star rating but not within five points or less than the threshold for the next green star rating, as this would mean extra cost and effort for the same green star rating.

### **3.3 Green Building Credits Targeted and Excluded**

In following with the business case for green buildings and in keeping with the ACSA operating environment and business imperatives, the credits categories are targeted as follows:

- Water and Energy – credits within these categories have been maximised as they are both high in operational cost and scarce resources in South Africa.
- Waste management – credits within the Materials category have also been targeted towards social responsibility and looming legislation of reduced waste to landfill by 2025 (Western Cape) with penalties for non-compliance and is the direction that most of the world is heading in.
- Credits throughout the categories that embed ease of maintenance, operations and management of infrastructure, health and safety best practices, project management, and construction management, are maximised for a good foundation which can facilitate ACSA's vision and its strategic objectives.
- Credits that allow for implementation considering the highly regulated environment that ACSA complies with and considering the known market capabilities (local and international, i.e., the South African marketplace and environmental context).

The following credits have been intentionally limited due to their lack of support of the business and operating environment of ACSA:

- Credits involving transport have been excluded as these are typically not considered per building, but rather as an airport planning exercise and in response to demand and commercial opportunity.

- Innovative strategy credits have been excluded to divorce dependency on them to make up the credits needed for the targeted green star rating, as these innovation points are awarded solely on the discretion of Green Buildings Council South Africa.

#### 4. Standards for Compliance, Project Requirements and Management Practices for Airports' Existing Terminal Buildings Green Star Ratings

The Technical Manual Existing Building Performance Tool V1, December 2014 by the GBCSA, provides criteria to be met for each of the nine categories described, however, the manual does not always give the interventions to be adopted that would enable a project to meet the criteria. The following tables (Table 2, Table 3, and Table 4) provide the preferential selection of credits by describing the standards for compliance, project requirements and management practice requirements to be met for each green star rating.

**Table 2: Requirements for Airport Green Star Rated Existing Terminal Buildings: Standards for Compliance**

<b>4-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>• Audit, monitor and measure lighting levels of at least 60 % of the occupied areas to comply with maximum maintained illuminance level of no more than 80 % of the levels prescribed in SANS 10114-1:2005. These requirements must be captured for tenants in lease agreements, obtaining their signed commitment. This must be put in place before the 12-month trial period begins.</li> <li>• Put in place a process to manage overall risk presented by Legionnaires' disease during the 12-month trial period. Furthermore, it should be demonstrated that such a risk management process is monitored and reviewed regularly as per SANS 893 Part 1. Put in place an effective programme for treatment and control of Legionnaires' disease in water systems during the 12-month trial period as per SANS 893 Part 2.</li> </ul>
<b>5-star rating standards for compliance</b>	<ul style="list-style-type: none"> <li>• Perform quantitative acoustic testing through an acoustic specialist to ensure that internal noise levels are within 2 dBA of the maximum equivalent continuous rating levels as set out in SANS 10103:2008, with less than 10 % of areas non-compliant. Confirmation that noise from building services plant does not exceed the recommended levels of noise as set out in SANS 10103:2008 at the property boundary, or does not exceed the existing baseline ambient noise level (8h LAeq) by 3 dBC at the property boundary, or demonstrates compliance with provincial noise control regulations where applicable. This must be ready for evaluation at any time within the 12-month trial period.</li> </ul>
<b>6-star rating standards for compliance</b>	None for the selected credits for 6-star rated existing terminal buildings

**Table 3: Requirements for Airport Green Star Rated Existing Terminal Buildings: Project Requirements**

- Appoint a green star accredited professional to consult with and guide the preparation and accreditation process at least 6 months before the trial period and for 5-6 months after the trial period for the preparation of response to the Round 1 submissions.
- Building management system (BMS) to include automated water and electricity monitoring and reporting.
- Put in place an advanced monitoring and metering strategy that covers relevant areas or functions of a building, collecting and processing data, alerting management in case of missing data and when consumption is out of targeted parameters, and producing quarterly reports. This must be put in place before the 12-month trial period begins.
- Put in place physical displays containing real-time information of energy and water performance of the building as well as communication on sustainability features and initiatives. Put in place awareness programmes that include energy efficiency, water efficiency, waste management as a minimum, for all building occupants. This must be put in place and be tested in the 12-month trial period.
- Appoint an indoor air quality (IAQ) manager to supervise and manage the optimisation of practices that prevent and minimise the build-up of indoor pollutants in buildings. System performance audit to be performed to ensure specific air quality criteria are being met, with corrective action plan in place. IAQ testing to maintain CO levels not exceeding 26 ppm and CO<sub>2</sub> levels not exceeding 1000 ppm for at least 70 % of the measured areas. This will be measured for the duration of the 12-month trial period.
- Luminaire magnetic ballasts to be changed to high-frequency electronic ballasts, magnetic ballast replacement policy in place, audit performed to confirm that 95 % of lighting is high frequency. These requirements must be captured for tenants in lease agreements, obtaining their signed commitment. This must be put place before the 12-month trial period begins.
- Occupant survey for thermal comfort and temperature to be measured in occupied spaces at least once in the summer and once in the winter with corrective action plan in place to correct any concerns. For areas that are tenanted, include these requirements in lease agreements. This must be preferably in place and ready to be checked anytime within the 12-month trial period.
- Perform an occupant comfort survey that covers acoustic comfort, thermal comfort, lighting comfort, indoor air quality and ventilation comfort, and building management cleanliness (odours, etc.) requiring more than 80 % of respondents to be satisfied, with a corrective action plan in place to improve performance. This must be ready to be evaluated at any time within the 12-month trial period.
- Perform a high-level acoustic audit considering occupant feedback, impact of plant and equipment noise on occupants, surrounding properties and external noise on occupants including noise transference between tenancies, putting in place a corrective action plan to improve performance. Issue operational guidelines to tenants with recommendations with regards to fit-out for acoustic comfort and space utilization for acoustic comfort. This must be ready to be evaluated at any time within the 12-month trial period.

<p><b>5-star rating project requirements</b></p>	<ul style="list-style-type: none"> <li>• Energy saving projects to be activated and put in place before the 12-month trial period begins, to reduce kWh consumption onsite: <ul style="list-style-type: none"> <li>• Execution of lighting replacement programme to ensure that the existing installations are transformed to LED lighting</li> <li>• Execution of lighting control programmes to ensure that lighting is controlled according to demand</li> <li>• Implementation of HVAC time schedules and chiller loading methodology to ensure that energy consumption is optimised</li> <li>• For coastal airports, employment of heat pipe dehumidification in fresh air units</li> <li>• Adoption of air-economising (free air cooling) in existing HVAC systems</li> <li>• Incorporation of active chilled water setpoint control for chillers</li> <li>• Installation of ducted return air with feedback control sensors for temperature control</li> <li>• Adoption of constant air volume (CAV) to cool the baseload and variable air volume (VAV) for fluctuating load</li> <li>• Incorporate heat recovery from the condenser to satisfy any heating requirements</li> <li>• Reduction in cooling demand using low emissivity glass (not more than 3 W/m<sup>2</sup>K) and heat deflective paint (adopting ceramic microspheres) to deflect solar heat gain</li> </ul> </li> </ul> <p>IAQ testing showing CO<sub>2</sub> levels not exceeding 800 ppm for at least 70 % of the measured areas. This will be measured for the duration of the 12-month trial period.</p> <ul style="list-style-type: none"> <li>• Implement frameworks and programmes to encourage and incentivise (or create a shared incentive) for the top ten energy users to reduce onsite energy consumption and maximum demand.</li> <li>• Additionally, implement the following before the beginning of the 12-month trial period for further potable water savings: <ul style="list-style-type: none"> <li>• Water reuse for washing of motor vehicles.</li> <li>• Flushing of toilets with grey water/reused water.</li> </ul> </li> <li>• 100 % of the refrigerants by mass serving the building has to have ODP and at least 50 % to have a GWP (global warming potential) of less than 10.</li> </ul>
<p><b>6-star rating project requirements</b></p>	<ul style="list-style-type: none"> <li>• Implement a project to adopt solar thermal absorption cooling or make use of waste heat to power absorption chillers.</li> <li>• Additionally, implement the following before the 12-month trial period begins for further water savings: <ul style="list-style-type: none"> <li>• Borehole water use for non-potable water demand.</li> <li>• Where potable water is supplied to an end-use such as a toilet or basin, solenoid control valves for automatic shut off must be installed. Water supply to the toilet area/amenity (as per the internal water zoning) must be controlled according to occupancy through a sensor and or timer.</li> </ul> </li> </ul>

**Table 4: Requirements for Airport Green Star Rated Terminal Buildings: Management Practice Requirements**

<p><b>4-star rating management practice requirements</b></p>	<ul style="list-style-type: none"> <li>• Compile and implement a building operations manual as a guide for operating building systems efficiently and managing resources effectively to be done before the 12-month trial period begins.</li> <li>• Issue a building user's guide issued to users, occupants and tenants that includes the energy and environmental strategy, the monitoring and targets for water and energy consumption, operation of the air conditioning, lighting, electrical and hot water systems, details on transport facilities, materials and waste recycling, community facilities, landscape management and biodiversity features, as well as preferred materials for refurbishing and fitting out a rented space. This must be in place before the 12-month trial period begins.</li> <li>• Compile and implement a maintenance schedule in relation to operational expenditure items only to contain (at least) planned preventative types of maintenance activities for electrical and electronic systems, mechanical systems and fire protection systems. This must be put in place before the 12-month trial period begins.</li> <li>• Put in place a building tuning process that includes an initial audit of the existing system, followed by reporting and an action plan leading to continuous monitoring, system testing, corrective action response, ongoing measurement and appropriate documentation for BMS systems and air conditioning systems. This must be put in place before the 12-month trial period begins.</li> <li>• Issue and implement a green cleaning policy in line with specific sustainability criteria. This should preferably be put in place before the 12-month trial period begins, it is however measured over a 6-month period.</li> <li>• Implement a green lease for new leases and lease renewals that will include cost and benefit sharing mechanisms, specific requirements for tenancy fit out and alterations, management and operations, owner commitment covering at least 20 % of the total tenanted gross lettable area. This should be put in place before the 12-month trial period begins.</li> <li>• Put in place a landscape management plan according to leading practice methods, hard surface and building exterior management plan according to leading practice methods, and an integrated pest management plan. This will be evaluated anytime within the 12-month performance period.</li> <li>• Implement a storm water run-off management plan which ensures that the site and hard surfaces are managed to control storm water runoff and filter litter or pollutants to reduce peak flows, erosion and contamination of ground water, streams and rivers. Include an annual inspection programme of all storm water facilities to confirm continued performance. Peak storm water flows must be calculated and disclosed for the performance period and required maintenance that was assessed must be implemented. This must be ready to be evaluated anytime within the 12-month trial period.</li> </ul>
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<p><b>5-star rating management practice requirements</b></p>	<ul style="list-style-type: none"> <li>• Purchase green cleaning consumables in line with specific sustainability criteria. This should preferably be put in place before the 12-month trial period begins, it is however measured over a 6-month period.</li> <li>• Implement a green lease for new leases and lease renewals that include cost and benefit sharing mechanisms, specific requirements for tenancy fit out and alterations, management and operations, owner commitment covering a total of at least 50% of the total tenanted gross lettable area. This should be put in place before the 12-month trial period begins.</li> <li>• Put in place a specific green procurement policy aligned with the Green Star SA Policy &amp; Programme Model which encourages use of products that are environmentally preferable that will be evaluated within the 12-month trial period.</li> <li>• Put in place a solid waste management policy whose scope includes ongoing consumables, hazardous materials, movable and electronic goods and construction waste from churn and alterations. Execute a waste stream audit; carry out a waste stream audit of the building's entire ongoing consumable waste stream to establish a baseline that identifies the types and amounts of waste making up the waste stream, thereby identifying opportunities for increased waste minimisation, recycling and waste diversion from which an operational waste and materials management plan (OWMMP) must be put in place. Diversion of 75 % of operational waste to landfill, 50 % of construction waste diverted, and hazardous waste being collected in a separate process. Reduce generation of operational waste by 10 %. The policy will be evaluated anytime within the 12-month trial period, whereas the rest of the requirements must be actively executed within the 12-month trial period.</li> </ul>
<p><b>6-star rating management practice requirements</b></p>	<ul style="list-style-type: none"> <li>• Perform a cleaning audit in line with GBCSA's requirements. This should preferably be put in place before the 12-month trial period begins, it is however measured over a 6-month period.</li> <li>• Provides at least one 'Community Facility' for access and benefit to the local community or public and a shared facility within the building that is actively utilised to allow part-time use for community or public benefit activities. This must be put in place before the 12-month trial period begins.</li> </ul>

The requirements contained in Table 2, Table 3 and Table 4 are highly summarised and correspond to credits that amount to the number of points for a 4-star, 5-star and 6-star green rating.

#### 4. Process to Implement Green Buildings for Existing Airport Terminal Buildings

It is advisable to run the implementation of a green star rating for existing terminal buildings as a project every two years to maintain the 3-year renewable cycle of the green star rating certification. Figure. 3 sets out the steps required for the first certification of a green star rating of an existing terminal building.



**Figure 3: Proposed Process to Transition Existing Terminal Buildings to Green Star Certification by GBCSA.**

It is critical to gain top management support and funding and it will be most beneficial to gain the support of all stakeholders, and to establish networks and working groups that include stakeholders both inside and outside the organisation as support and coordination is paramount for the accomplishment of successful green star certification.

## CONCLUSIONS

This paper presented the guidelines for transitioning existing terminal buildings towards and 4-, 5- and 6-star green rating. The guidelines included standards for compliance, project requirements and management practice requirements for a 4-star, 5-star and 6-star green rated terminal building. A description of the green star rating frameworks and the rationale used to select the credits that give the green star rating is given. The process to transition the green star rated infrastructure at the airports is outlined so as to reduce carbon emission and cultivate environmental consciousness. This will ensure that the efforts to transform the airport sites towards energy efficiency and energy security are sustained.

## REFERENCES

1. Joseph, J., Inambao, F. L., "Energy efficiency for airport infrastructure: A case study of the implementation of energy efficiency for airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, Volume 11, Issue 2, Apr 2021, 383–406
2. Joseph, J., Inambao, F. L., "Entrenching energy efficiency as a culture at airports: A case study of the implementation of energy efficiency for airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development*, Volume 11, Issue 3, Jun 2021, 405–420.
3. Joseph, J., Inambao, F. L., "Trends: Energy efficiency and energy security", *International Journal of Engineering Research and Technology*, Volume 13, Issue 12, 2020, 4084-4117.
4. Green Building Council of South Africa, "Technical manual Green Star SA Public & Education Building Design/As Built v1", March 2013.
5. Green Building Council of South Africa, "Technical manual Existing Building Performance Tool V1", December 2014.
6. Joshi, Krishna. "Application of Energy Concepts for Green Buildings." *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) ISSN (P) (2016): 2249-6866.*
7. Bhalla, Rupa, and P. O. O. J. A. Mehta. "Green HR: The essence for sustainability in the 21st century." *International Journal of Human Resource Management and Research (IJHRMR) 6.1 (2016): 1-6.*
8. Pallavi, E. V. P. A. S., and M. Bhamu. "Green HRM: A way for corporate sustainability." *International Journal of Human Resource Management and Research (IJHRMR) 6.2 (2016): 13-20.*
9. Chadalavada, Karthik, and Ramesh Srikonda. "Vernacular Practices: An Appraisal for Sustainability for Housing in Uttarakhand and Himachal Pradesh, India." *International Journal of Humanities and Social Sciences (IJHSS) 10.3, Apr–May 2021; 1–14*

## **CHAPTER 22. LEVERAGING FOURTH INDUSTRIAL REVOLUTION TECHNOLOGIES AND DESIGNS FOR REALISING ENERGY EFFICIENCY AND ENERGY SECURITY IN DEVELOPING COUNTRIES**

This chapter presents an approach to leveraging the instruments of the fourth industrial revolution to overcome the challenges faced by developing countries in adopting energy efficiency and making provision for their energy security.

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## LEVERAGING FOURTH INDUSTRIAL REVOLUTION TECHNOLOGIES AND DESIGNS FOR REALISING ENERGY EFFICIENCY AND ENERGY SECURITY IN DEVELOPING COUNTRIES

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### ABSTRACT

*The human capacity challenges faced by developing countries regarding energy efficiency and energy security projects will take longer in comparison to obtaining financing and unfortunately cannot be developed overnight. Depending on the extent of the implementation of new technologies (within a specific organisation or the national energy generation scheme of a developing country), changing to technologies that are new to the operating environment may pose a hurdle to implementation due to the business, safety or operational risks that the technical unknowns may present. Another challenge with renewable energy is its intermittency and space requirements which call for energy storage and land availability. Energy storage technology, although has made significant progress requires greater efficiency for attractive payback periods. This makes many renewable energy projects unfeasible. Renewable energy is unlikely to be adopted on a large scale due to it not being able to efficiently serve customers' needs. Energy demand naturally has peaks and troughs according to human and economic activities and requiring a baseload energy capacity, which makes energy generation a challenging and costly task, especially with renewable energy. These challenges can be speeded up through innovative thinking and the use of instruments arising from the fourth industrial revolution. This paper presents an approach to leveraging the instruments of the fourth industrial revolution to overcome the challenges faced by developing countries in adopting energy efficiency and making provisions for their energy security.*

**KEYWORDS:** *Fourth Industrial Revolution and Energy Efficiency, Smart Electrical Grid and Renewable Energy, Load Curtailment Programmes & Smart Control Systems*

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### INTRODUCTION

Industrial revolutions change the way we live through technological advancements and innovation (Fig. 1). Each industrial revolution brings benefits and challenges to the countries that have engaged in such transformation [1]. Great Britain led the first industrial revolution with the invention of the steam engine, which revolutionised communication and transportation and led to many other industrial developments [1]. In the second industrial revolution, the United States led with the telephone which revolutionised communication. In the third industrial revolution, the internet was the key factor and succeeded because it was conceived of as a public infrastructure technology rather than a proprietary technology [1]. The internet transformed the world economic landscape, and this is being carried forward with the internet of things (IoT) [1]. Industry 4.0 is not an exception to the previous eras of industries; it is expected to bring immense benefits and many challenges, the main one being the cybersecurity risk [1]. Industry 4.0 is characterised by what is called the "smart factory" [1]. In a smart factory, a virtual copy of the physical world and decentralised decision making can be developed, physical systems can

communicate with each other and with humans in real time, all enabled by the IoT and related services [1].

Industry 4.0, which started in Germany, is being adopted by countries around the world including the USA, France and Japan which have already taken the first step in this direction by launching nation-wide programmes [2]. With the increased use of digital technologies, the boundary between the real and the virtual world is increasingly blurred, giving rise to what is known as cyber-physical production systems (figure 2) [2].

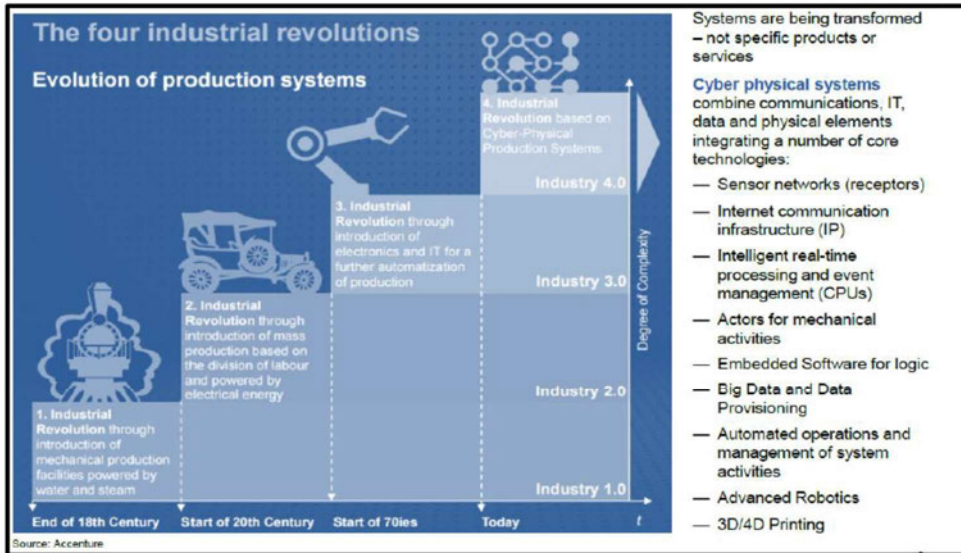


Figure 1: The Four Industrial Revolutions [3].

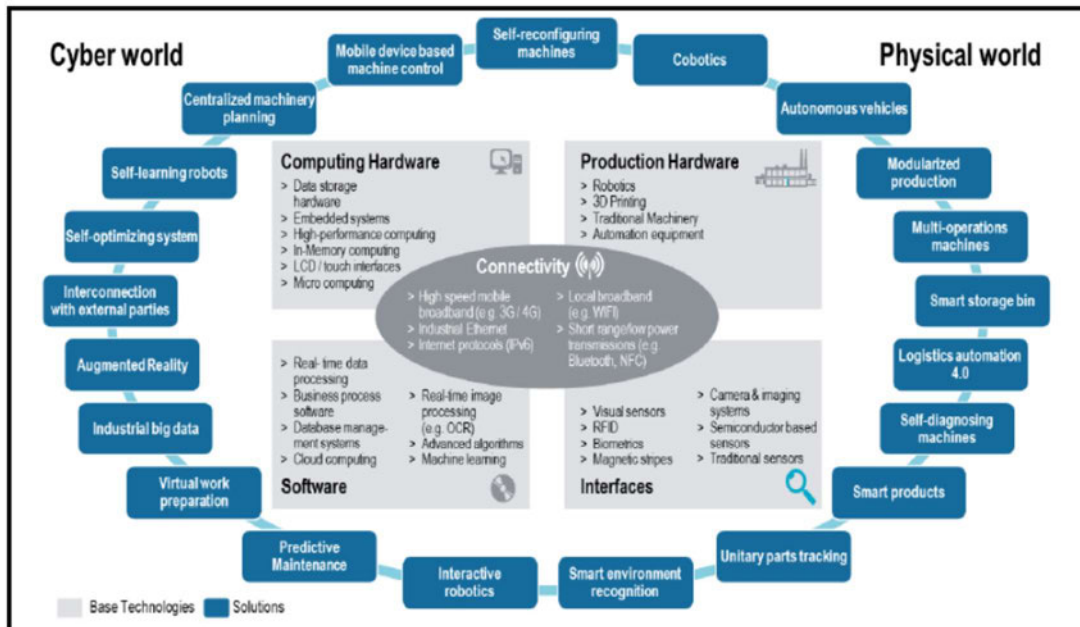
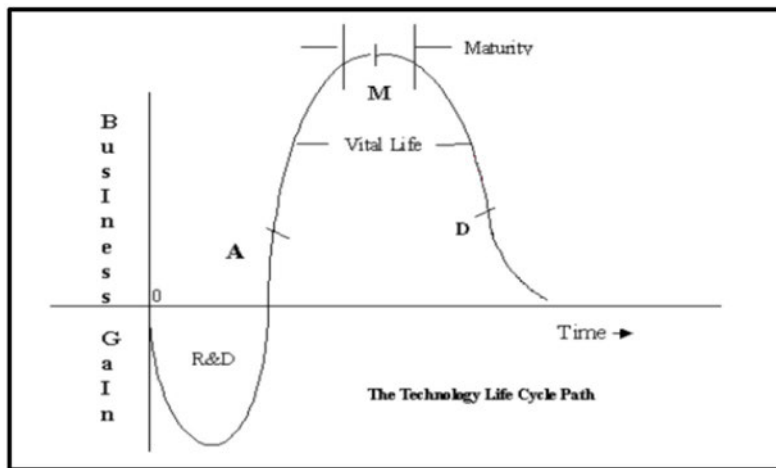


Figure 2: Potential Industry 4.0 Solutions [2].

The capacity to store, process and provide real time control of engineering systems based on artificial intelligence (AI) algorithms has been an industry-changing moment for the world. The full potential of AI and its applications has not yet been fully exploited and its applications are limitless. However, AI in the context of employment and socioeconomic challenges are regarded in some quarters as being a disadvantage because it makes certain careers obsolete and requires that the workforce be trained to use the technology. This paper discusses specific opportunities that the technologies of the fourth industrial revolution provide for energy efficiency and energy security in developing countries.

Most of the barriers faced by developing countries stem from the nature of the life cycle of technology (Figure. 3). Current fossil fuel generation technology such as coal-fired power plants have been around for at least 100 years and therefore this is a mature technology. There is a lot of business gain with such technology as indicated in the graph in Figure 3. Figure 4 shows the market saturation curve in relation to the technology life cycle development. Competition is great towards the latter part of the technology generation curve and the prime time for developing countries to adopt the technology at a low price, meeting their affordability, and over time building technical capability.



Note: A = Ascent phase, M = Maturity stage, D = Decline (or Decay) Stage  
 Figure 3: The Technology Life Cycle Path (Adapted from [4]).

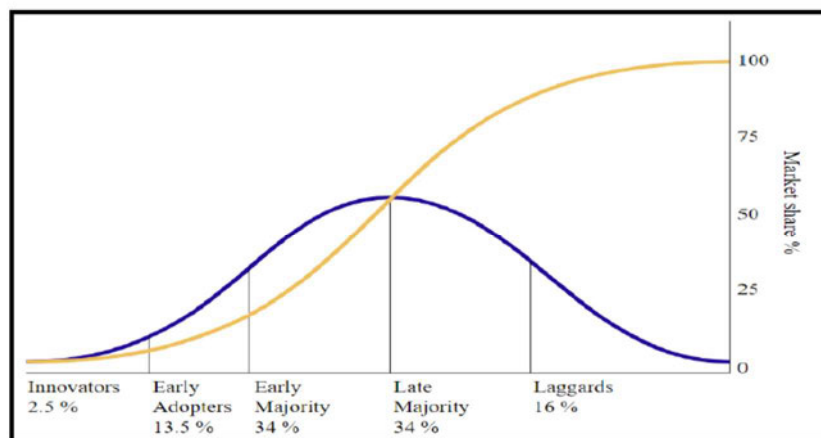


Figure 4: Technology Life Cycle Bell Curve (Blue) and Market Saturation Curve (Yellow) [4].

Developing countries are on a budget in that they look for goods and services at the lowest possible first cost especially regarding access to energy that is key for economic development and the betterment of the lives of its citizens. Thinking long term in the context of sustainability and adoption of new technologies that come with the research and development costs (R&D), as indicated in figure 3, is not a priority when competing concerns of access to clean water, housing, medical care, food and jobs are immediate needs.

This is not necessarily a negative characteristic of developing countries, but what this type of behaviour does in the long term is that it leads to the developing countries always playing “catch up” when it comes to technology adoption and inevitably, therefore, lag in economic growth in relation to developed countries. There is a need to take a different view that does not ignore developing countries’ immediate needs and dynamics but looks at the potential of the move to sustainability as a market opportunity to generate the change needed to swing economic favour in the direction of developing countries at the same time as providing the much needed revenue for the immediate needs of the country.

Innovation is key to economic development. The fourth industrial revolution with cyber-physical systems and AI presents major opportunities for developing countries to leapfrog the barriers faced in transitioning towards energy efficiency and energy security. The following sections present solutions that leverage off the fourth industrial revolution to establish and sustain the move of developing countries towards energy efficiency and energy security.

One of the barriers faced by developing countries to achieve energy efficiency and energy security lies in the capacity of the workforce that is required to operate and maintain the technologies for an alternative low carbon energy mix. The capacitating of the local workforce is part of the journey that developing countries must make and this could be the limiting factor preventing them from realising a low carbon energy mix. Many times, those developing countries that progress well with climate change mitigation make use of a significant portion of foreign labour. While this is good in the context of climate change, it is not sustainable from a socio-economic perspective. It takes a certain amount of time for the local workforce to be trained and competent in operating and maintaining new technologies. Technologies that are emerging in this fourth industrial revolution phase that utilise AI can be designed to transition developing countries utilizing low carbon energy generation technologies by intelligently operating itself and providing detailed information that will assist trouble shooting and maintenance.

At some point in time, however, developing countries must have a local workforce that understands the engineering technologies in detail so that design and manufacturing can be done locally which will involve knowledge and skills transfer of technologies designed by other countries. Computer simulations can assist with knowledge transfer and training for competence and the virtual work environment can effectively lower the cost of foreign consulting and expertise.

An energy mix on its own is not sufficient – there must also be coordination of renewable and alternative energy sources according to availability, cost and other business imperatives to ensure that the site’s energy demand is satisfied efficiently and without interruptions. Computer algorithms and programmable logic controllers (PLCs) can coordinate energy sources in a smart electrical grid as well as engineer the energy demand for the most efficient energy supply and demand matching.

### **1. Artificial Intelligence for Maintenance, Operations and Trouble Shooting**

AI involves a computer system performing as a substitute for intelligent functions of human beings [5]. In this case, a

computer system performing troubleshooting for maintenance, providing key indicators that inform predictive maintenance and operations of the plant. AI computer systems mimic the methods of learning and solving problems by human beings through knowledge gathering [5]. AI includes the following areas of activities [5]:

- Processing of human language
- Image processing
- Intelligent robots
- Expert systems
- Neural networks

These systems have the knowledge of experts and can make a diagnosis of any abnormality of a given piece of equipment [5]. Time-based preventive maintenance has been used as a basic method; increasingly condition-based maintenance is being introduced in many working environments [5]. Diagnostic techniques based on machine condition are used to detect degradation of plant equipment [5]. In Japan, these techniques have been known since the 1960s in the steel manufacturing industry [5]. The following are some examples [5]:

#### **Machinery and Equipment [5]**

- Fluid machines
- Electric rotation machines
- Mills
- Stationary electric machines
- Motors
- Blowers
- Pumps
- Towers
- Drums

#### **Sensing Place [5]**

- Bearing portions
- Tanks
- Shafts
- Pipes

Many expert systems for diagnosis were developed by maintenance engineers, and software tools have been introduced in the United States and reconstructed in Japan [5]. An expert system contains a knowledge base and an inference engine [5]. The knowledge required for the diagnosis is expressed by production rules or frame representations

[5]. The basic structure of an expert system is given in figure 5 [5].

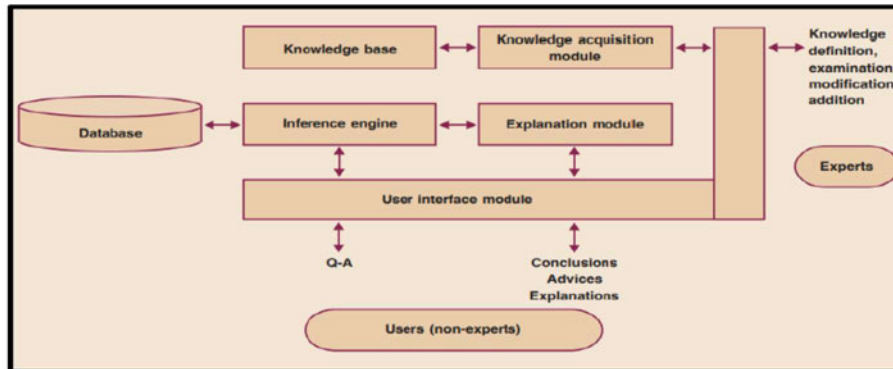


Figure 5: Overview of an Expert System [5].

“Based on given information of the apparatus, the inference engine works to obtain conclusions and give advice” [5]. The application of AI for the operations, maintenance and troubleshooting for renewable energy and alternative energy technologies are already available commercially. Solar photovoltaic (PV) plants can be designed with an intelligent control system having a SCADA (supervisory control and data acquisition) interface for real-time operational control. Further programming and neural networking are also possible on solar PV plants to provide alerts for maintenance and in some cases also perform maintenance such as washing of panels via robots. Troubleshooting for effective corrective action to be executed is also achievable with neural networking, sensors and databases providing the platforms for artificial intelligence.

Alternative energy such as natural gas trigeneration plants, anaerobic digestion plants, renewable energy such as solar thermal, solar PV, wind energy, geothermal energy, are novel sources of energy being adopted by sites like airports in South Africa [6], [7], [8], [9], [10], [11]. In these settings, AI can reduce the cost of operations and maintenance as well as downtime through troubleshooting. Furthermore, AI provides a means for closing the immediate skills gap by allowing the local workforce to learn about the operations and maintenance of the system through the record keeping database of the system.

Regarding the adoption of renewable and alternative energy technologies at airports in South Africa [6], [7], [8], [9], [10], [11], it is advised that AI be used in relation to:

- Solar photovoltaic power plants
- Solar thermal absorption cooling plants
- Natural gas trigeneration power plants
- Geothermal heat sink plants
- Anaerobic digestion power plants
- Vertical axis turbine wind powerplants

AI should be used to provide a real-time “heartbeat” of each powerplant and store data in a cloud-based system.

This data should be accessible by the plant designers for the first 18-24 months via a web-link so that plant operational glitches and AI bugs can be resolved remotely as well operational parameters be refined to suit the operating environment. It is crucial that during this period a selected number of suitably qualified engineering personnel from the plant owner become familiar with, and if necessary be trained on the technologies and their operations, so that they can become familiar with troubleshooting and undertaking maintenance tasks. A computer programmer selected by the plant owner should be included in the project for the first 18-24 months which will position the plant owner to be able to insource all operations and maintenance in due course.

It is advised that sensors and neural networks be arranged around the:

- Maintainable components
- Components and plant aspects that can fail which can then cause plant failure
- Parameters that must be monitored for optimal operations
- Parameters that must be controlled for daily plant operations
- Components and plant that will be used daily for quality checks
- Records of daily activity on plant, SCADA and web-based systems

After this period, it may be that the need for an onsite operations and maintenance team and the need for outsourcing these services be assessed against the cost of renewal of software licences, sensors and hardware of neural networks and auxiliary systems. Based on cost, efficiency, market availability and maturity and other business imperatives, the plant owner may decide to reduce the neural network coverage and outsource the operations and maintenance or retain the AI component and perform inhouse maintenance and operations or even reduce the AI component depending on the business risk and technology complexity versus the demand for personnel.

This AI approach to close the skills gap for organisations will reduce the anxiety and address many business risks related to operations, maintenance, troubleshooting for efficient, reliable and uninterrupted energy supply from a low carbon energy mix.

## **2. The Value of Computer Simulation as a Tool for Learning about New Engineering Technologies**

In order for developing countries to transition to a low carbon energy supply, capacity needs to be built to understand and design low carbon and renewable energy power generation technologies and develop competence from manufacturing to operation and maintenance. Before the fourth industrial revolution, design of the technologies relied on universities, methods of learning the operation of new technologies relied on person-to-person knowledge transfer, and maintenance relied solely on technical training. Although quite thorough, these methods required costly investments and usually, proprietary information was a barrier to plant owners becoming independent of original equipment manufacturers (OEM) and plant designers. This arrangement still exists in South Africa with many technologies, especially those that have specialised SCADA interfaces. This has major disadvantages to plant owners starting with exorbitant costs and extensive business risks due to consultants being overseas and mostly person-dependant.

Computer simulation that details the working of various renewable and alternative power generation technologies can bring easy access to technology familiarisation. A computer simulation is a programme that contains a model of a

system, natural or artificial, of equipment or a process [12]. A computer simulation accepts inputs, incorporates those inputs into calculations or modelling, and presents functional outputs [13]. By actively involving learners in exploring and discovering, computer simulations are powerful learning tools, as learning that involves doing is retained for longer than learning via listening, reading, or seeing [12]. Computer simulation of engineering work focuses on the design of products and processes to meet social needs. Virtual laboratories that focus on engineering practice can centre on design [14]. The design process is built around iteration, where a design idea is improved based on the identified shortcomings of previous attempts [14]. Identified shortcomings allow a feedback cycle where the designers can identify gaps in their knowledge and understanding, providing impetus for further learning [14]. For engineering professionals, this practice of knowledge building through iterative design cycles is critical [14]. Figure. 6 shows the process of building a computer model and the interplay between experiment, simulation and theory.

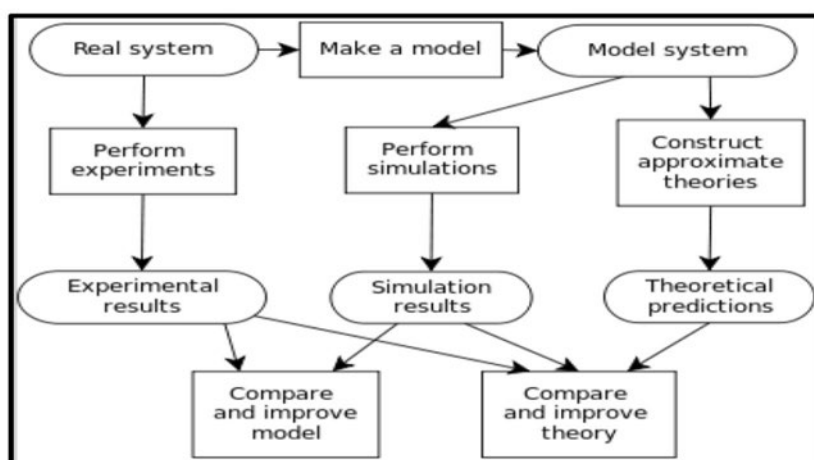


Figure 6: Process of Building a Computer Model and the Interplay between Experiment, Simulation and Theory [15].

It is advised that computer simulation for the purposes of technology familiarisation include:

- Scientific principles that make the technology work
- Technology design
- Important design making for plant design
- Daily operations
- Preventive and breakdown maintenance
- Selected maintenance procedures

During the 18-24 months of fine-tuning operations and debugging the AI systems controlling the power generation technologies, computer simulation of the operations of the powerplants be made for the purpose of knowledge and skills transfer. This will also be relevant with changes in the plant owner's personnel because computer simulation can be used to familiarise new personnel with the operations.

### 3. Using International Resources through a Virtual Work Environment

When energy generation technologies are being adopted in a country for the first time and their design and manufacture is being done in another country, foreign consultancy is inevitable, whether for plant design and the establishment and even operations and maintenance. It can be costly to transport, accommodate and pay for foreign consultants to be present at the plant. However, nowadays due to fourth industrial revolution software, international resources can be accessed through a virtual work environment that can be used to establish a platform to investigate unfamiliar technologies that are essential to climate change mitigation in terms of energy efficiency and energy security. A virtual workplace is a workplace that is not located in any one physical space and not limited to any geographic boundaries [16]. Employees and management are connected via a private network or the internet and interact with each other via phone, Skype, cloud computing programmes and a whole host of other virtual options [16].

Unified Communications (UC), refers to the way different forms of communication tools in the digital workforce interact and collaborate (Fig. 7) [17]. By unifying phone calls, web conferencing, SMS, and email and other channels, users are able to share and access data and collaborate in real-time [17]. The right unified communications solution can take business processes to the next level, improving on collaboration, boost productivity, increase mobility and enhance the user experience [17].

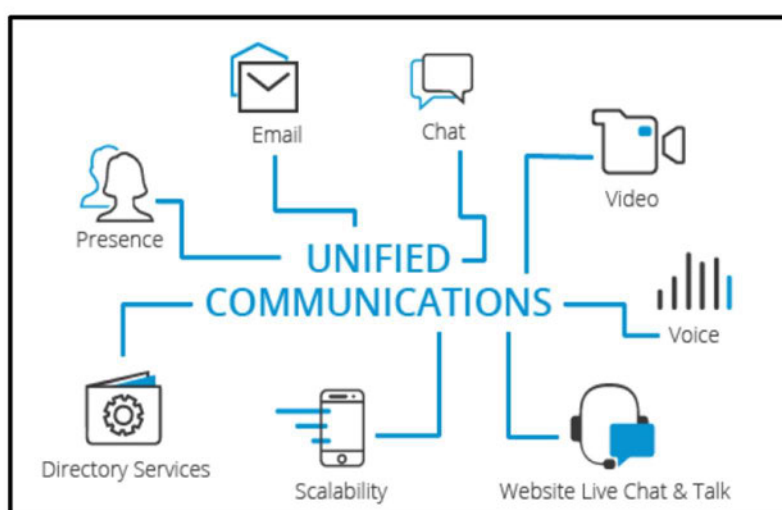


Figure 7: Virtual Work Environment [17].

Not only do the instruments of the fourth industrial revolution allow us to communicate with each other, but they also allow remote control of plant, equipment and processes. Internet technology allows companies to overcome many of the physical constraints that often prevent them from doing business in distant markets [18]. The issue of process control has been central in raising the productivity in industrial automation for years [18]. Remote control of processes is a new era which is presently supported by only a few companies, who are the giants of the automation industry [18]. Remote processing has a bright future, especially in the companies with many branches where electronically controlled machines are deployed as a part of the workforce [18]. While a computer connected to the automation devices can control and take data from processes at a production unit, the operator is able to process the data according to the rules and regulations and then issue commands necessary to control the system [18]. A schematic of a web-based monitoring system can be seen in

figure 8.

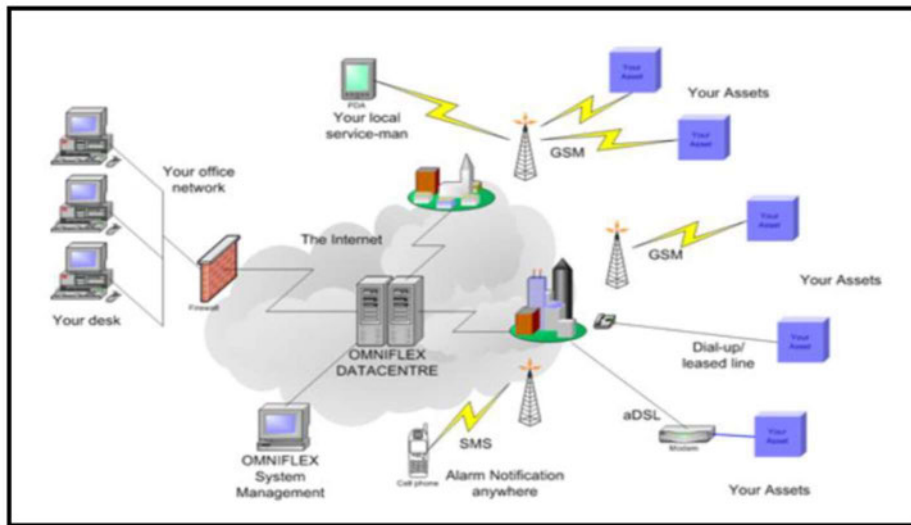


Figure 8: An Example of a Web-based Monitoring and Control System [19].

A computer connected to automation devices can control and store data from processes at a production unit. In the remote process control environment (REPCO) this process is done using a PLC connected to a server, which can be controlled via the internet by a user who is far away from unit, as shown in Figure 9 [18].

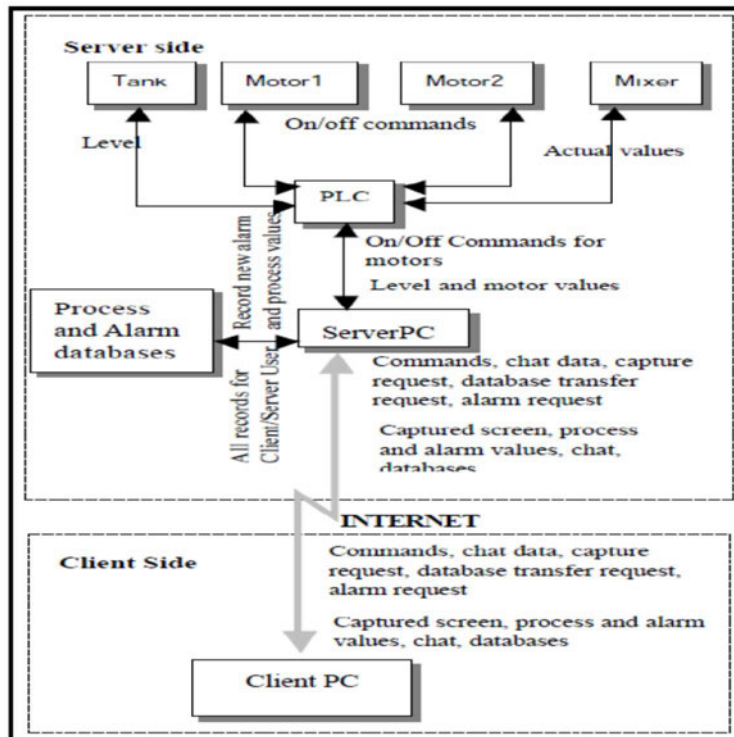


Figure 9: The Architecture of a Web-based System [18].

It is advised that web-based monitoring and control include:

- Plant control
- Troubleshooting and plant diagnosis capabilities
- Real time monitoring with SCADA
- Downloadable reports and records

This means that an organisation's workforce can be geographically anywhere and still perform their duties, especially where specific expertise is required and only available abroad. It will be cost effective to establish certain international consultancy relationships regarding specialised skills that can be operated remotely, except where physical work needs to take place and skills to perform the physical work are not locally available, in which case international personnel will have to be brought in.

#### 4. Smart Electricity Grid

Having to coordinate multiple energy sources for a site is crucial in ensuring business continuity and reducing risks associated with business operations. In the fourth industrial revolution context, a smart grid uses advanced information and communication systems to connect power generators, distribution stations, and consumers [20]. Advanced data processing allows the processes of electricity distribution to be efficient, decentralised, flexible, reliable, and secure [20]. A smart grid also integrates the use of renewable energy sources into the existing power grid and creates microgrids to supply electricity demand [20]. A smart grid is an electricity grid which integrates the behaviour and actions of all entities connected (Fig. 10) [20]. There are three types of entities: generators, which generate electricity; consumers, which consume electricity; and those which can do both. These entities create a peer-to-peer network to ensure efficient distribution of the electricity, maintain low losses and a high level of quality, which maintains the security of electricity supply [20].

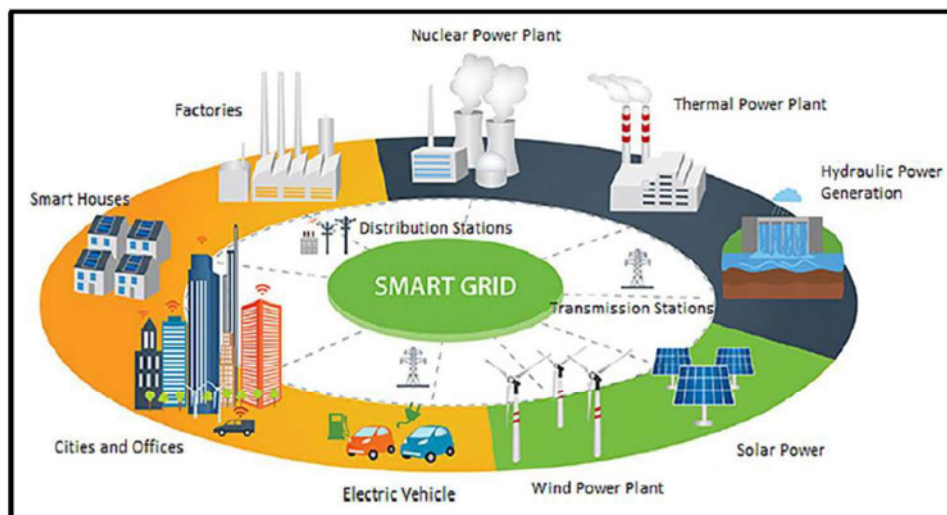


Figure 10: Smart Electrical Grid [20]. Smart Grids are Characterised by [21].

- Cutting edge applications, automation, efficient architecture, better management and standardised protocols

- Bi-directional communications
- Integrated with renewable energy sources and have wireless sensor networks

They have [21]:

- Demand-side energy management
- Intelligent fault detection
- Volt-var optimisation
- Wide-area early warning systems
- Integration of renewable energy sources into smart grids
- Microgrids as a normal feature in the overall grid system
- Integration of renewables in radial distribution networks via smart links
- Voltage based control of distribution generation units (DGUs)
- Active loads in smart microgrids
- Electric vehicles in a smart grid environment
- Low voltage, DC grid-powered LED lighting system with smart ambient sensor control in green buildings
- Multiple distributed smart microgrids with a self-autonomous, energy harvesting wireless sensor network
- Wireless sensor networks for consumer applications in the smart grid
- Wireless monitoring and control system for smart grids

Smart meters and sensors provide rapid two-way flow of data which allow both energy user and the generator to know exactly how much energy is being used at any given time. With a smart device, monitoring energy use is possible. The smart grid is a more reliable and responsive grid compared to our current one-way electricity grid between the electricity utility and customer. Power failures can be managed, and electricity restored at the push of a button. It is a more flexible grid that will be able to integrate renewable energy and electric vehicles into the network. This is part of a major transformation in the energy industry. The power is moving from the centre to the periphery of the grid. Previously passive consumers can become active participants in the network. Customers can become producers of power, feeding surplus energy back into the grid.

The potential support that the smart electrical grid can provide to coordinate and provide a smooth, uninterrupted and reliable energy supply in the process of transitioning to low carbon or carbon neutral energy supply, is attractive. Considering the airports in South Africa and their adoption of renewable and alternative energy [6], [7], [8], [9], [10], [11] in the journey towards carbon neutrality in electricity consumption, there is a need to coordinate the various energy sources for energy supply to the airport facilities. In terms of the principles of energy efficiency [22], principle one relates to the appropriate energy sources supplying the various energy needs (figure 11). In the transition, there will be a period of time where the energy demand for a facility or infrastructure will exceed the energy efficient energy source which means that

energy from another source will need to be brought online to satisfy the demand. For example, the ground heat sink may be exhausted and the chillers still require further heat rejection, or the solar heat or waste heat harvested from natural gas engines may not be enough to power absorption chillers for satisfying the cooling demand. At airports where wind energy and solar to electricity are adopted, cloudy days will decrease the solar photovoltaic plant electricity yield and wind energy will need to be used by the site. During these times the smart grid will need to work off an algorithm that will decide how to address the energy demand. The smart grid algorithm could (figure. 12 and figure. 13):

- use a load curtailment programme,
- employ another available power source to satisfy the demand or
- draw from stored power reserves.

The smart grid will be key to the success of energy supply from the airports' onsite energy mix. It will also enable selling energy to others and purchasing energy from others in the future.

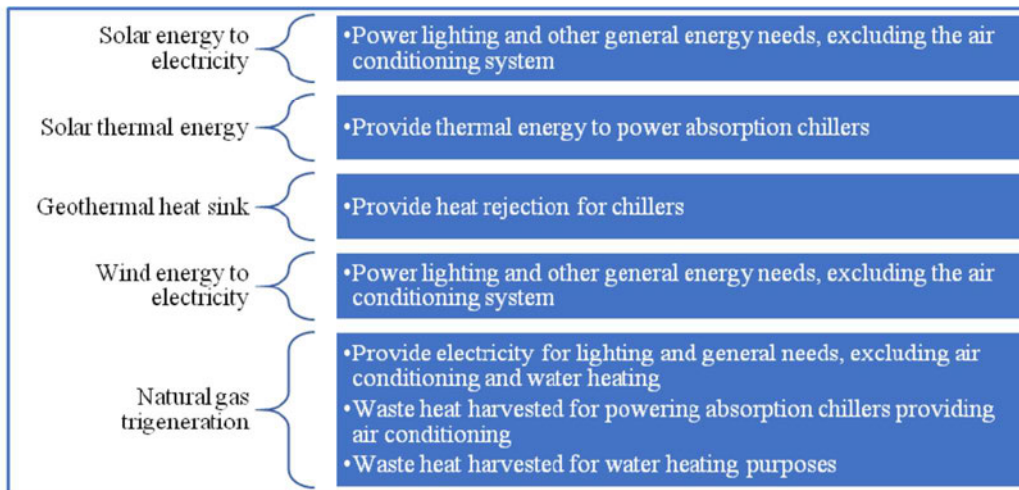


Figure 11: Efficiently Matching Energy Source to Energy need at Airports in South Africa.

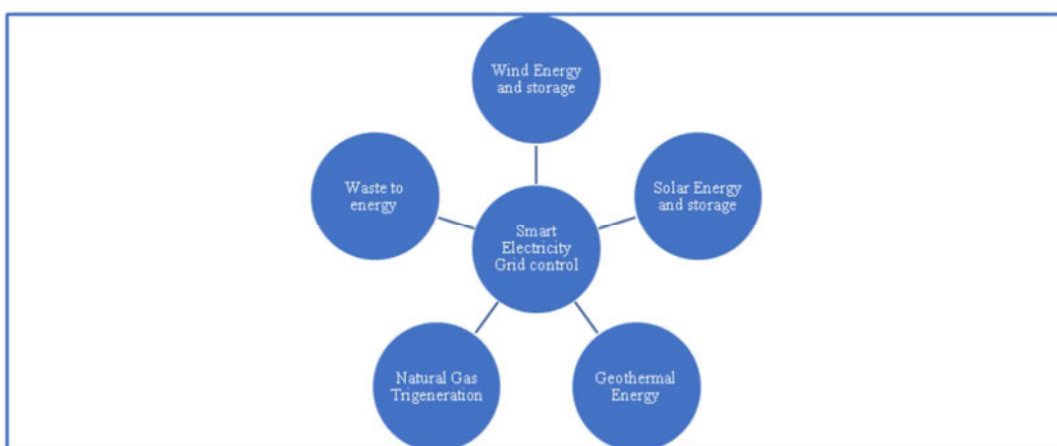


Figure 12: Smart Grid Concept for Cape Town International Airport.

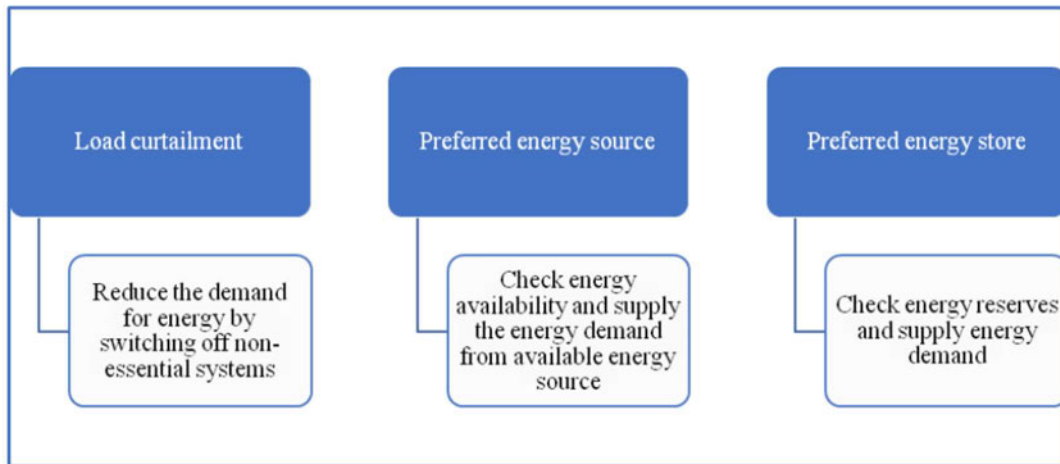


Figure 13: Typical Smart Grid Decisions for Supplying the Site Energy Demand.

### 5. Overcoming Energy Demand and Supply Mismatches

When energy supply exceeds energy demand there are usually no issues with respect to a smooth, uninterrupted power service, however, when there are instances or periods of time where energy demand exceeds energy supply, a short circuit will occur resulting in power interruption. Understanding the site's energy demand as well as the site's daily energy supply from the site's planned energy mix is crucial to identifying energy demand and energy supply mismatches. The energy generation plants can be capacitated accordingly, including energy storage where needed. The energy demand can also be engineered to coincide with the energy supply availability. Demand-side management (DSM) (figure 14) is a way to reduce peak load demand so that adequacy of electricity will be maintained without interruption [23].

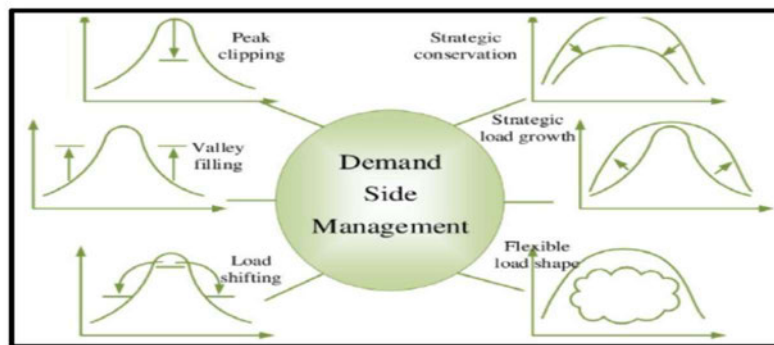


Figure 14: Demand side Management Techniques [23].

Some load levelling and load shifting techniques include:

- Thermal storage (ice storage) for air conditioning systems to reduce and or shift peak energy demand,
- Daylight harvesting to reduce daytime energy demand
- Controlling artificial lighting to specific lux levels
- Use of technologies that decrease demand for space conditioning

Most of the load levelling and load shifting techniques work through electronic control. Smart lighting systems can modulate lighting according to lighting demand and employing skylights and appropriate colours and materials of interior furnishing which will also reduce the lighting demand. Similarly, reducing solar heat gain by employing convective boundaries such as low emissivity glazing, an air-tight building envelope and insulation or heat deflective coatings on building roof will reduce space conditioning demand. Energy storage can be adopted for the storing of additional energy generation from renewable energy plants for use when needed. Other design interventions for chillers such as employing a standby vapour compression chiller when the thermal yield is insufficient to meet cooling demand, and employing electricity run evaporative cooling towers to satisfy additional heat rejection requirement, can be built in.

The energy supply can also be engineered to ensure efficiency through:

- Adequate plant sizing
- Plant modularisation for controlling energy yield
- Adequate and efficient energy storage media
- Matching energy type and energy demand efficiently and proportionally

Controlling the loading of natural gas engines so that yield meets energy demand efficiently through adequate modularisation is key to preserving fuel efficiency as well. Using the smart grid, selling off surplus energy could work well in terms of cost effectiveness and efficiency. Choosing the right energy storage medium and electronically controlling charge and discharge will preserve the plant against energy efficiency losses as well as ensuring that energy is available when needed.

## CONCLUSIONS

This paper identified the four industrial revolutions and their key characteristics. Five areas where fourth industrial revolution instruments will be effective in overcoming barriers and challenges experienced by developing countries in achieving energy security and energy efficiency were explored. The use of AI to jumpstart the skills and competency shortfalls that will be experienced in maintenance, troubleshooting and operations of renewable and alternative energy plants was described. Another opportunity identified and explored was the value of computer simulation of renewable and alternative energy technologies to be used as a learning tool so that skills and competency can be transferred to the developing country's local workforce. To reduce costs as well as have access to skills and competency available abroad to establish renewable and alternative energy plants in developing countries, the potential of the virtual work environment including communication applications and web-based monitoring and control was presented. The smart electricity grid and its application in establishing an energy mix to serve a specific site was discussed followed by ways of overcoming energy supply and demand mismatches. This paper has established the usefulness and applications of the instruments of the fourth industrial revolution to enable and overcome challenges that developing countries may face when adopting renewable and alternative low-carbon energy sources.

## REFERENCES

1. Morrar, R., Arman, H., Mousa, S., "The fourth industrial revolution (Industry 4.0): A social innovation perspective", *Technology Innovation Management Review*, Volume 7, Issue 11, November 2017.

2. Aulbur, W., Arvind, C.J., Bigghe, R., "Skill development for industry 4.0", Whitepaper, BRICS Skill Development Working Group, 2016.
3. Moavenzadeh, J., "The 4th industrial revolution: Reshaping the future of production", World Economic Forum, October 2015. Retrieved from [https://na.eventscloud.com/file\\_uploads/fe238270f05e2dbf187e2a60cbcdd68e\\_2\\_Keynote\\_John\\_Moavenzadeh\\_World\\_Economic\\_Forum.pdf](https://na.eventscloud.com/file_uploads/fe238270f05e2dbf187e2a60cbcdd68e_2_Keynote_John_Moavenzadeh_World_Economic_Forum.pdf), accessed 26/08/2021.
4. <https://courses.lumenlearning.com/boundless-management/chapter/technology-and-innovation/>, accessed 04/06/2021.
5. Reis, D., Pati, N., "Applications of artificial intelligence to condition-based maintenance", RAE - Revista de Administração de Empresas, Sao Paulo, Vol 40, no. 2, June 2000, pp 102-107.
6. Joseph, J., Inambao, F.L., "Reducing energy consumption at airports in South Africa: Investigating technologies that reduce electricity consumption", to be published 2021.
7. Joseph, J., Inambao, F.L., "Energy security: Investigating wind energy for airports in South Africa – A technoeconomic assessment", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Vol. 11, Issue 4, Aug 2021, pp 203-228.
8. Joseph, J., Inambao, F.L., "Energy security: Investigating anaerobic digestion for airports in South Africa – A technoeconomic assessment", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Vol. 11, Issue 4, Aug 2021, pp 319-340.
9. Joseph, J., Inambao, F.L., "Energy security: Investigating geothermal heat sinks for air conditioning systems at airports in South Africa – A technoeconomic assessment", accepted for publication, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 2021.
10. Joseph, J., Inambao, F.L., "Energy security: Investigating natural gas for energy generation at airports in South Africa – A technoeconomic assessment", accepted for publication, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 2021.
11. Joseph, J., Inambao, F.L., "Energy security: Standards and guidelines for solar photovoltaic installations including technical plan to transition solar photovoltaic plant maintenance to be performed inhouse for airports in South Africa", accepted for publication, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 2021.
12. Rutten, N., van Joolingen, W.R., van der Veen, J.T., "The learning effects of computer simulations in science education", ScienceDirect Computers & Education, Vol. 58, 2012, pp 136-153.
13. Tajvidi, M., Fang, N., "Application of computer simulation and animation (CSA) in teaching and learning engineering mechanics", 122<sup>nd</sup> ASEE Annual Conference & Exposition, Seattle, June 2015.
14. Koretsky, M.D., Magana, A.J., "Using technology to enhance learning and engagement in engineering", Advances in Engineering Education, Spring 2019.
15. [https://en.wikipedia.org/wiki/Computer\\_simulation](https://en.wikipedia.org/wiki/Computer_simulation), accessed 30/08/2021.
16. <https://theleegroup.com/understanding-virtual-workplace/>, accessed 30/08/2021.
17. <https://www.3cx.com/pbx/unified-communications/>, accessed 31/08/2021.
18. Altun, Z.G., Topaloglu, U., Saygin, A.V., Bayrak, C., "Web-based system monitoring and control", ResearchGate publication, January 2002. Retrieved from [https://www.researchgate.net/publication/272093240\\_Web-Based\\_System\\_Monitoring\\_and\\_Control](https://www.researchgate.net/publication/272093240_Web-Based_System_Monitoring_and_Control) accessed 30/08/2021.

19. [https://www.omniflex.com/solutions\\_web\\_based\\_monitoring.php](https://www.omniflex.com/solutions_web_based_monitoring.php), accessed 31/08/2021.
20. Agung, A. A. G., Handayani, R., "Blockchain for smart grid", *Journal of King Saud University – Computer and Information Sciences*, Elsevier, January 2020.
21. Schilling, D. R., "Smart grid design & new methods of energy generation", *Industry Tap into news*, May 2017. Retrieved from <https://www.industrytap.com/smart-grid-design-new-methods-energy-generation/42198>, accessed 31/08/2021.
22. Joseph, J., Inambao, F. L., "Energy efficiency for airport infrastructure: A case study of the implementation of energy efficiency for airports in South Africa", *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Vol. 11, Issue 2, Apr 2021, 383–406.
23. Energy Central, "How important is load shifting in MicroGrids", April 2021. Retrieved from <https://energycentral.com/c/gn/how-important-load-shifting-microgrids>, accessed 01/09/2021.
24. Deshmukh, S., and G. T. Thampi. "Transformative effect of e-commerce and m-commerce on national productivity in India." *International Journal of Applied Engineering Research and Development (IJAERD)* 4.2 (2014): 65-80.
25. Khan, Nabila. "The Role of Hr Professional in Technologically Advanced Hr Function." *International Journal of Human Resource Management and Research (IJHRMR)* 7.5, Oct 2017, 1-8
26. Khatoon, Nuzhath. "Quality of work-life of professional knowledge workers (challenges and satisfactory factors)." *International Journal of Human Resource Management and Research* 4.1 (2014): 1-8.
27. Sinha, Neeta, and Neelam Kshatriya. "The Expectations Of Gen Y In The Changing Workplace Dynamics-An Indication To The Hr Managers." *International Journal of Business and General Management (IJBGM)* 5. 6, Oct-Nov 2016; 41 50 (2016).

## CHAPTER 23. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

### Conclusion

The aim of this study was to present a solution that ensures sustainability of energy efficiency and energy security in developing countries thereby contributing to a reduction of carbon emissions causing global warming. This study presented an engineering solution entrenched in business sustainability ensuring that efforts of energy efficiency and energy security in developing countries are effectively sustained.

This study has successfully derived principles for energy efficiency in developing countries and demonstrated their implementation in a corporate environment by implementing them for nine airports in South Africa. The principles are summarized below:

- Principle One: Match energy source and energy need using the shortest route from the energy source to the energy end use, and ensure that the energy source is the best choice for cost effectiveness and is as close to zero carbon emissions as possible.
- Principle Two: Take a systems approach when it comes to energy efficiency. This means considering the energy consuming device or technology, the system that the device or technology is a part of, as well as factors affecting the system and factors affected by the system.
- Principle Three: Ensure that the approach to implementation of energy efficiency meets business imperatives and supports operations based on “Standards and Guidelines for Energy Efficiency”. These standards and guidelines must include device types, system types and preferred designs that will apply when new buildings and facilities are constructed, and replacement cycles for existing buildings and facilities. Energy efficiency obligations must be included in tenant lease agreements. An energy efficient culture must be embedded in operations and business functions. All these initiatives must be incorporated in the site’s roadmap to energy efficiency.

Standards and guidelines for energy efficiency were derived and implemented for nine airports in South Africa. Energy efficiency was integrated into tenant lease agreements, airport operations and maintenance. Technoeconomic assessments were performed for innovative technologies that can reduce energy consumption at the nine ACSA airports in South Africa:

- Heat deflective paint to reduce solar heat gain on roofs of airport buildings that will reduce solar heat gain.
- Double glazing to reduce solar thermal heat gain into airport buildings.

- Geysler sleeves to reduce energy consumption required for geysers heating water at airport buildings.

This study successfully derived principles for energy security in developing countries and demonstrated their implementation at nine ACSA airports:

- Principle One: Ascertain the energy generation potential of the site, i.e., what is the:
  - theoretical energy potential,
  - available energy potential,
  - real energy generation potential considering the spatial and other demands required for energy generation.
- Principle Two: Understand the site's energy needs, both present and future in the short, medium and long term, considering the following:
  - Type of energy required and their quantities,
  - Baseload energy requirements,
  - Fluctuating load energy requirements and their timing,
  - Strategies for energy reduction, conservation, load levelling and load shifting techniques and their timing.
- Principle Three: Match the energy sources available to the energy needs of the site considering:
  - Energy efficiency and load dynamics,
  - Commercial technologies available and their impact, risks and implications for the business,
  - Feasibility to install, operate and maintain,
  - Business imperatives and strategies.

These principles for energy security were applied at the nine ACSA airports, conceptualising a low-carbon energy mix to satisfy energy requirements. Technoeconomic assessments were performed on the technologies identified:

- Wind energy harnessed by vertical axis wind turbines,
- Waste to energy for sewage and food waste streams via anaerobic digestion,
- Electricity generators powered by natural gas,
- Geothermal heat sinks as a replacement for cooling towers of water-cooled air-conditioning systems.

Standards and guidelines for solar photovoltaic installations were derived and a technical plan to transition operations and maintenance of solar photovoltaic plants inhouse were presented. A low carbon energy mix was confirmed for the nine ACSA airports.

Principles for sustaining energy efficiency and energy security in developing countries were successfully derived with application of the principles for the nine ACSA airports in South Africa:

- Principle One: Energy efficiency and energy security must form part of an organisation's strategic plan.
- Principle Two: The energy efficiency and energy security strategy must be underpinned by a functional structure that ensures the strategy is relevant in the global context.
- Principle Three: The energy efficiency and energy security strategy must be executed according to the three dimensions of business sustainability, i.e. social, economic and environmental dimensions becoming part of every business activity and transaction.

Guidelines were derived for adoption of green buildings for new airport infrastructure (commercial, terminal and office buildings) to satisfy the green star rating framework by the Green Building Council of South Africa. Guidelines were derived for transitioning existing terminal buildings to green star rated terminal buildings in compliance with the green star rating system by the Green Building Council South Africa.

The results of the study and its implementation show that the solutions presented for energy efficiency and a low carbon energy mix are realistic and successful, while being grounded in sound scientific and engineering principles and sustained through inevitable changes. Since the COVID-19 pandemic, the capital projects that support energy efficiency and energy security have been promoted and attracted interested from external investors. The true test of its sustainability shows in its validity and the increased urgency in execution as a business priority even in the financial crisis faced by the aviation industry since the COVID-19 pandemic. The principles derived, technologies investigated, standards and guidelines presented that address energy efficiency and energy security, as well as its sustainability in developing countries has application in commercial, industrial, domestic and country-wide settings and will be effective through changes in technologies, legislation, personnel and markets that inevitably take place over time.

### **Recommendations for future work**

The energy efficiency- and energy security-based strategy to reduce carbon emissions presented in this study was supported and approved for implementation at nine ACSA airports in South Africa in September 2017 at the completion of the business planning stage (Fig. 1). Over the period from September 2017 to October 2020, the technoeconomic assessments (at Front End Loading Stage 2 or FEL 2) for the various energy saving technologies, the renewable energy generating plants and the

alternative energy generation plants were completed and approved to be taken to final feasibility (FEL 3). The projects included in the energy mix were supported by airport management across the nine airports in South Africa for adoption. However, the technologies will be required to complete the FEL 3 stage before being implemented (Fig. 1)

The FEL 3 study is currently being undertaken for natural gas trigeneration plants at ORTIA, CTIA and KSIA. The rest of the renewable and alternative energy plants are seeking external funding for further development (FEL 3) due to the financial crisis brought on by the COVID-19 pandemic.

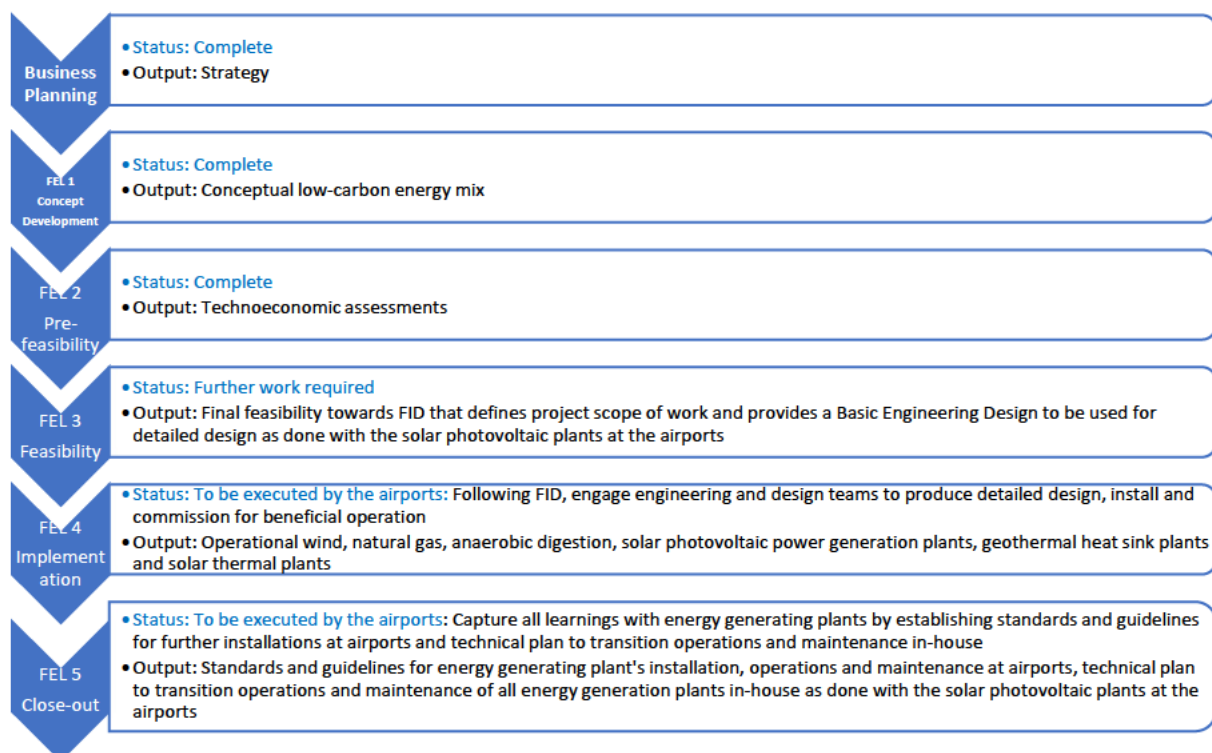


Figure 1: Work completed and further work to be done for the beneficial operation of the energy generating plants contained in the low carbon energy mix at ACSA airports in South Africa

It is recommended that the FEL 3 scope of works be undertaken for all the approved energy generation technologies so that the funding required for the FEL 3 development be sought. The scope of works should include project development which includes the scope of works and specifications for Basic Engineering Design (BED) or Front End Engineering Design (FEED) as well as the project cost at a class II capital expenditure estimate for the full plant. At the end of a successful FEL 3 study when a financial investment decision (FID) is taken, the implementation (detailed design, purchasing, installation and commissioning) of the plants follow. Capturing of all learnings experienced with the establishment of the energy generating plants at the airports to produce standards and guidelines for further installations with a technical plan to transition the plants' maintenance and operations inhouse,

is key to maximizing the investment into low carbon energy sources. This has been done for the solar photovoltaic plants established for the airports.

Using the guidelines developed to transition existing terminal buildings towards green star rated terminal buildings, as well as ensuring that new office, commercial and terminal buildings are green star rated will ensure that energy efficiency and energy security are sustained within operations and business activities.

Following the full development as advised of the work started in this study will ensure that energy efficiency and energy security is sustained through implementing relevant personnel, technologies, legislation and markets.

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---

## **EDITING CERTIFICATE**

**Re: Jerusha Joseph**

**Journal article: Entrenching Energy Efficiency as a Culture at Airports: A Case Study of the Implementation of Energy Efficiency for Airports in South Africa**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**20 March 2021**

*per email*

## **DR RICHARD STEELE**

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---

## **EDITING CERTIFICATE**

Re: Jerusha Joseph

Journal article: **Reducing Energy Consumption: Investigating Solar Thermal Heat Deflection Innovative Technology to Reduce Air Conditioning Load at Airports – A Technoeconomic Assessment**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**13 July 2021**

*per email*

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---

### **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

For editing journal article: **Reducing Energy Consumption at Airports in South Africa: Investigating Technologies that Reduce Electricity Consumption**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**29 August 2021**

*per email*

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---

## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

Journal article: **Principles for achieving energy security in developing countries**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**24 July 2021**

*per email*

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---

## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

For editing journal article: **Energy Security: Conceptualising a Low-Carbon  
Energy Mix for Airports in South Africa**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**02 September 2021**

*per email*

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---

## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

Journal article: **Energy Security: Investigating Wind Energy for Airports in South Africa – A Technoeconomic Assessment**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**27 May 2021**

*per email*

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---

## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

Journal article: **Energy Security: Investigating Anaerobic Digestion for Airports in South Africa – A Technoeconomic Assessment**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**02 June 2021**

*per email*

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## **EDITING CERTIFICATE**

**Re: Jerusha Joseph**

**Journal article: Energy Security: Investigating Natural Gas for Energy Generation at Airports in South Africa – A Technoeconomic Assessment**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**02 August 2021**

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## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

Journal article: **Energy Security: Investigating Geothermal Heat Sinks for Air Conditioning Systems at Airports in South Africa – A Technoeconomic Assessment**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**01 August 2021**

*per email*

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## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

Journal article: **Energy Security Reviewing and Establishing Standards and Guidelines for Solar PV Installations for Airports in South Africa**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**15 August 2021**

*per email*

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### **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

For editing journal article: **Energy security: Establishing a low carbon energy mix and roadmaps to carbon neutrality in electricity consumption for airports in South Africa**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**04 September 2021**

*per email*

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## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

For editing journal article: **Ensuring Sustainability of Energy Efficiency and Energy Security in Developing Countries: A Case Study of Airports in South Africa**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**08 September 2021**

*per email*

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---

### **EDITING CERTIFICATE**

**Re: Jerusha Joseph**

**Journal article: Sustainability of Energy Efficiency and Energy Security for Airports in South Africa: Guidelines for Adopting Green Building Status for New Infrastructure**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**13 August 2021**

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## **DR RICHARD STEELE**

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## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

For editing journal article: **Sustainability of Energy Efficiency and Energy Security for Airports in South Africa: Guidelines for Transitioning Existing Terminal Buildings to Green Building Status**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**23 August 2021**

*per email*

## **DR RICHARD STEELE**

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## **EDITING CERTIFICATE**

Re: **Jerusha Joseph**

For editing journal article: **Leveraging fourth industrial revolution technologies and designs for realising energy efficiency and energy security in developing countries**

I confirm that I have edited this article and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele

**12 September 2021**

*per email*

## Appendix II: Documentation showing journal paper acceptance



Jul 16, 2021

To

Professor Freddie Inambao  
University of Kwazulu Natal  
Private Bag X54001  
Durban  
4000  
South Africa  
Vat Number – 4860209305

Dear Scholar. Professor Freddie Inambao,

**Subject:** Acceptance of research paper for publication in our International Journal

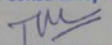
Greetings.

It's our pleasure to inform you that, after the peer review of your paper, Titled: "REDUCING ENERGY CONSUMPTION: INVESTIGATING SOLAR THERMAL HEAT DEFLECTION INNOVATIVE TECHNOLOGY TO REDUCE AIR CONDITIONING LOAD AT AIRPORTS – A TECHNOECONOMIC ASSESSMENT" authored by "JERUSHA JOSEPH & FREDDIE INAMBAO " submitted to us for an evaluation by you on Jul 15, 2021 has been provisionally accepted by the Review Board for publishing in "International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) journal with ISSN (Print): 2249-6890; ISSN (Online): 2249-8001; Impact Factor (JCC): 9.6246; NAAS Rating: 3.11; IBI Factor: 3.2; ICV 2015:60.6.

Again, thank you for working with TRANSSTELLAR. We believe that our collaboration will help to accelerate the global knowledge creation and sharing one step further. TRANSSTELLAR looks forward to your final publication package. Please do not hesitate to contact us if you have any further questions.

Thanking you,

Yours sincerely,

For Transstellar Journal Publications  
& Research Consultancy Pvt. Ltd.  
  
Authorized Signatory

Associate Editor

TJPRC Pvt Ltd.