DESIGNING A PHOTOVOLTAIC-MICROBIAL FUEL CELL (PV-MFC) RENEWABLE HYBRID SYSTEM BASED ON PUBLIC-PRIVATE PARTNERSHIP AND OTHER SOUTH AFRICA'S POLICIES: A CASE STUDY UMHLATHUZE MUNICIPALITY

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

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

DoHET Accredited Journals

1. Melusi Nhleko and Freddie L. Inambao, Energy efficiency at municipal wastewater treatment plants using microbial fuel cell technology. *International Journal of Mechanical Engineering and Technology (IJMET), 10(12), 2019, pp. 612-624.* https://iaeme.com/Home/article_id/IJMET_10_12_055
2. Melusi Nhleko and Freddie L. Inambao, Energy audit on primary municipal facilities: reflection of municipality's energy consumption as a direct consumer of the energy utility (Eskom). *International Journal of Engineering Research and Technology (IJERT) 13(12), 2020, pp. 4033-4047.*
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3. Melusi Nhleko and Freddie L. Inambao, Impact of municipal infrastructure conditions and maintenance programs in determining municipal service delivery effectiveness, cost effectiveness and energy efficiency. *International Journal of Mechanical Engineering and Technology (IJMET), 11(1), 2020, pp. 163-180.* https://iaeme.com/Home/article_id/IJMET_10_12_057.
4. Melusi Nhleko and Freddie L. Inambao, Energy crises in South Africa and new ways of Fast-tracking remedial actions through diversified and decentralised generation. *International Journal of Engineering Research and Technology (IJERT), 13 (10), 2020, pp. 2814-2823.* http://www.irphouse.com/ijert20/ijertv13n10_37.pdf
5. Melusi Nhleko and Freddie L. Inambao, Modelling and factoring critical system components of PV-MFC systems for improved and efficient energy generation and treatment of municipal effluent at the east coastal regions(s) of South Africa: Case study uMhlathuze municipality. *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 11(3), 2021, pp17-36.*
   http://www.tjprc.org/publishpapers/2-67-1616842614-2IJMPERDJUN20212.pdf
6. Melusi Nhleko and Freddie L. Inambao, Financing and payback of renewable hybrid energy project (technology) such as PV-MFC systems: Case study uMhlathuze municipality. *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 11(3), 2021, pp. 1-16.*
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For all the publications the candidate is the main author while Professor Freddie L. Inambao is the supervisor.

Dedication

This work is dedicated to the living Most High God, the essence of my very life. And to my family for their love, belief and support through this journey of life.

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To the living Most High God in His trinity as God the Father for His unfailing love, God the Son for His genuine mercy and God the Holy Spirit for His undivided and continuous fellowship. And to my mum Mrs N.P. Nhleko for anchoring my life with unremitting love, encouragement and support, and for standing with me in pray through all the phases of life "God is at the throne, and He is in Control." To my siblings, thank you for being with me all the way. To my children, thank you for being a never dying part of me, we in this for the rest of my life, and I love you so much from the deepest and sacred parts of my heart and soul. To all my friends that have supported me to do this work, I am humbled and from the bottom of my heart, "thank you."

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Abstract

South Africa is a developing country with one of the most diverse and energy intense trading activities, but frequently experiences near catastrophic electricity shortage as a result of ill-maintained power generating plants and increased demand. Such shortages negatively affect industrial and other small-to-medium enterprise activities that all happen within municipal jurisdictions. The country's economic health and quality of life of citizens depend on municipal services. Despite government's effort, disruptions still persist and a call has been issued by theSouth African government to both the public and private sector to secure capacity, and to improve the security of supply, reliability and sustainability of generation through a radical shift of generation from conventional (coal) power plant generation to renewable energy generation that is environmentally friendly. The Constitution of the Republic of South Africa together with other legislation calls on municipalities todo all in their affordability (power) to secure and deliver reliable services to the citizens within their jurisdiction. This study aimed to encourage the South African government to use municipalities as a hub for the generation of energy from renewable sources. Since the uMhlathuze municipal area is subject to arecorded average of 283 sun hours for the past 10 years and the municipality treats and discharges on average 25 000 m^3 of effluent a day, the viability of PV-MFC renewable energy hybrid technology (system) has been proposed and examined. Critical components of the PV-MFC hybrid technology are examined using literature for improved performances and for cheaper alternativematerials with similar or improved efficiencies. The study expresses that the profitability of PV-MFC technology will enable themunicipality to power the wastewater treatment plant so as to deliver services effectively while at the same time reduce energy bills and reduce dependency on the national grid in order to provide a sustainable supply ofenergy to the wastewater and discharge of effluent complying with SANS 241. The effects of aged and poorly maintained water and wastewater infrastructure (infrastructure condition) are considered in the study and an energy audit exercise conducted on site using the A-EBERLE PQ BOX 100 to take measurements of energy consumed. Corresponding bills and electricity usage index reflected the performance of the plants. The size and design specifications of the PV-MFC hybrid systemwere based on energy demand and anticipated performance in terms of energy efficiency. Pre-treatment processes are described in the study to ensure that the feedstock achieve required specification for enhanced conversion performances in the PV-MFC system. Project financing tools are described and prescribed to determine the viability offinancing the renewable energy project (HRES) for the municipality to implement including payback. Public- private partnership (PPP) agreement and funding is thus proposed in this study for the municipality to implement the PV-MFC hybrid system project. The suggested design specifications indicate legislative parameters within which detailed feasibility and project implementation can be conducted. This study highlights the contribution of pre-treatment process that uMhlathuze municipality can use to improve PV-MFC performances and the influence that the surrounding available renewable resources and legislation have in designing a high performing hybrid system. Thus, the objective and aim of the study is assisting the municipality to make informed decision in solving energy challenges by using PV-MFC hybrid technology (system).

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Acronyms/Abbreviations

ABBREVIATIONS	MEANING
A	Cross-sectional area
AC	Alternating current
AFC	Alkaline fuel cells
AG	Auditor-General
ATR	Auto thermal reforming
BCA	Benefit-cost analysis
BCR	Benefit-cost ratio
CO	Carbon monoxide
CO_2	Carbon dioxide
COGTA	Cooperative Governance and Traditional Affairs
CoU	City of uMhlathuze
CSIR	Council for Science and Industrial Research
CSTR	Stirring anaerobic tank reactors
DC	Direct current
DEFRA	Department for Environment, Food and Rural Affairs
DoE	Department of Energy
DHO	Direct hydrocarbon oxidation
DR	Dry reforming
EC	Equilibrium constant
e.e	Energy efficiency
EIA	Environmental Impact Assessment
EMS	Energy management strategy
EPB	Energy payback
ESKOM	Electricity Supply Kommissie (commission)
ESR	Equivalent series resistance
F	Faraday’s constant
FA	Fixed assets
FAD	Foskor Acid Division
GDP	Gross domestic product
GWh	Giga-Watt hour
H_2	Hydrogen
H_2O	Water
IC	Invested capital
IEA	International Energy Agency

IMF	International Monetary Fund
INEP	Integrated National Electrification Programme
IRR	Internal rate of return
kW	Kilowatt
kWh	Kilowatt-hour
LC	Levelized cost
LCOE	Levelized cost of energy
l.f	Load-factor
MCC	Motor control centres
MCFC	Molten carbonate fuel cells
MFC	Microbial fuel cell
MFMA	Municipal Finance Management Act
MISA	Municipal Infrastructure Support Agency
MPP	Maximum power point
MPPT	Maximum power point tracker
Ml	Mega-litre
MVA	Megavolt ampere
MWh	Mega-Watt hour
NaCl	Sodium chloride (seawater)
NDP	National Development Plan
NEMA	National Environmental Management Act
NER	Net energy ratio
NMD	Notified maximum demand
NPV	Net Present Value
NT	National Treasury
NTTE	National technical team of experts
P	Power
PAFC	Phosphoric acid fuel cell
PCU	Power conditioning unit
PEM	Proton exchange membrane
PEM	Polymer electrolyte membrane
PEMFC	Polymer electrolyte membrane fuel cell
POS	Point of supply
POX	Partial oxidation
PPP	Public-private partnership
PR	Performance ratio

PrV	Present value
PSP	Professional services providers
PV-MFC	Photovoltaic-microbial fuel cell
R	Universal gas constant
R&D	Research and development
ROI	Return on investment
RSA	Republic of South Africa
SANEDI	South African National Development Institute
SANS	South African National Standards
SA/V	Surface area/volume
SALGA	South African Local Government Association
SCM	Supply chain management
SOFC	Solid oxide fuel cells
SME	Small-to-medium enterprise
SPB	Simple payback
SR	Steam reforming
SRTP	Social rate of time preference
SSA	Specific surface area
T	Temperature
TA	Transactional Advisor
V	Volume
WC	Working capital
WRC	Water Research Commission
WSA	Water Services Act
WWTP	Wastewater treatment plant

Nomenclature

α	solar altitude angle
δ	solar declination angle
ω_s	sunrise hour angle
γ_s	solar azimuth angle
ω_o	sunset and sunrise
ϕ	latitude of the related location (in degrees).
T_j	Cell temperature
E_s	solar radiation
V_{oc}	open circuit voltage
I_{sc}	short circuit current
η	ideal efficiency
F_{in}	input fuel to the cell
ΔG	change in Gibbs energy
ΔH	Change in reaction enthalpy
ΔH_o	hydrogen/oxygen reaction
$\eta_{fc,stack}$	efficiency of the actual fuel stack
m	flow rate of organic matter in the fuel
η_F	Faraday's efficiency
ζ_i	Faraday's parameters
A_c	surface area of the electrode.
P_{out}	power output
P_{in}	input power
$P_{standby}$	standby power consumption
η_{rated}	efficiency at rated power
P_{rated},	rated power
K_0	load independent losses (self-power consumption losses)
K_1	linear load proportional losses (voltage drops in semiconductors)
K_2	load Ohmic losses
$\eta 10$	efficiency of the PCU at 10% of the rated power
$\eta 100$	efficiency of the PCU at 100% of the rated power
V_S	terminal voltage at the supercapacitor
I_S	current that flows into the supercapacitor

I_d	self-discharge current
ESR	equivalent series resistance
K_o	Mass transfer coefficient of oxygen
C_o	oxygen concentration at the cathodic chamber
C	oxygen concentration at the anodic chamber
D_o	oxygen diffusion coefficient
L_t	material's thickness of the membrane
ΔV	Ohmic over potential
δW	distance between the anode and the cathode
σ	solution conductivity
i^+	raw input (variables)
f^-	feedback signal or improvement variables
e_i	efficiency equipment variables
i	input into the internal system (components and the various sub-systems)
d_i	internal disturbance(s)
d_o	external disturbances or factors

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CHAPTER 1: INTRODUCTION

1.0 Background to the Study

Eskom's high tariff increases (higher than CPI) and South Africa's electricity supply crisis has caused many institutions to consider affordable alternative strategies that offer relief in curbing energy consumption and reduce energy bills. However, attempts by these institutions without government participation can only provide partial relief and marginal gains. Modise and Mahota (2009) from the Department of Energy (DoE) in South Africa indicated that the State requires an additional 40 000 MW capacity by 2025. The study indicates that 92.6 % of the country's energy production is from coal-fired power stations, consuming approximately 5.5 billion tonnes of coal per year at the time of the study,and was projected to consume approximately 15 billion tonnes of coal per year by 2025. Satisfying energy demands using coal-fired power stations is not sustainable for the South African economy in the near future. This calls for the South African government to intensively search for sustainable alternatives that are both affordable and that will have a positive impact on the socio-economic well-being of the country.

Municipal infrastructure influences energy efficacy and is one of the most important socio-economic drivers in the country enabling industries and small-to-medium enterprises (SMEs) to produce and enabling the government to deliver services. Therefore, effective management and maintenance of infrastructure is essential to the municipality's core business. Keeping infrastructure in reliable and functional condition is of paramount importance, since a majority of municipal functions are energy dependent. Electricity supply shortages in South Africa is an on-going concern, causing insecurity of supply. This negatively affects economic growth and increases electricity prices for energy consumers, making energy unaffordable for the effective execution of day-to-day activities. Ending energy poverty and achieving access to sustainable energy for all by 2030 is a challenge that government must proactively and effectively plan for and mitigate related risks and consequences.

Poor leadership often results in misguided solutions which, when combined with poor planning for the energy needs of the country, results in worsening energy status and reactive generation of solutions for current and projected energy needs. The country is facing an energy crisis, so well planned initiatives such as conducting energy audits on equipment and feasibility studies centred around renewable energy generation as required by municipal government to restrain the growing energy demand from SA's national supply grid, is important and must be conducted with great commitment.

Developing a hybrid system that assists municipalities with provision of clean sustainable energy and clean water discharge to the environment has been an on-going goal in recent years as stringent legislative precepts have been mandated for both public and private sector institutions. Hybrid systems are cost effective and initially cost less compared to the installation of photovoltaic (PV) systems alone (Pazmino, 2007, as cited in Fiedler, 2014), and can assist the municipality with its multi-functions. Renewable energy based hybridised systems are considered by various authors and researchers to be the future of electricity generation and the most cost-effective means of addressing energy shortages, reducing energy bills and satisfying energy generation targets and development goals in the immediate and near future. The renewable energy sources identified and discussed in this thesis for the development of the PV-MFC hybrid system for the city of uMhlathuze are solar energy and biomass energy from municipal sewage.

The first law of thermodynamics regarding a closed system expresses that energy must remain constant and that energy can neither be created nor destroyed, but can only be converted from one energy form to another (Moskowitz, 2014). Cain (2015) states that the sun is the principal source of energy for all biological and chemical processes on earth and that all forms of energy come from the sun's rays and that different electromagnetic forms of radiation are produced by the sun. Pipe (2014) describes solar power as the energy obtained from the sun's rays that reaches the earth as a mixture of energy carrying with itself both heat and light in the form of electromagnetic waves and ray particles. Thus, in terms of quantum physics, solar power contains pockets of energy atoms that can be directly converted by photovoltaic effect to electricity (Pipe, 2014; Young and Freedman, 1996). Hinrichs and Kleinbach (2002) highlight that solar radiation is a renewable energy source with immense potential that needs no storage in its raw form. When solar energy is converted to electricity, the electrical energy must be stored using capacitors or super-capacitors, also known as batteries.

Balcioglu et al. (2017) state that energy is the most important need in daily human lives and can be converted from a natural form to another form through either natural means such as chemical reactions or a combination of natural and man-made energy technologies such as PV-MFC hybrid technology. Further, the authors indicate that as technology advances, the need for energy increases in importance. Shinn (2018) describes renewable energy as clean energy that comes from natural energy sources or processes that are easily accessible to all humans. The author goes on to say that, ideally, renewable (natural) energy storages get "refilled or replenished" at rates comparable or constant to that at which they are extracted, a view echoed by Pimentel et al. (2002). Bolyssov et al. (2019) point out one of the sustainable development goals adopted in 2015 by the United Nations relating to the importance of energy generation and supply from renewable resources as a key driving factor to sustainable development. Further the authors state that the inexhaustibility and ecological purity of renewable energy sources are a stimulus for rapid developments in the energy sector optimistic forecasts of energy supply, and new investments in renewable energy.

When solar radiation passes through the earth's atmosphere it is attenuated by reflection into space, absorption in the atmosphere and refraction (Stine & Geyer, 2001). The ozone layer filters the sun's rays (that carries with itself energy) as described by Stine and Geyer (2001) resulting in adequate energy being absorbedby the earth's air and crust and by organisms living therein, for heating and for biological and chemical processes (Cain, 2015). Due to the scattering of the sun's rays, lenses or mirrors are required by PV systemsto concentrate solar radiation before being converted by solar cells to electricity. Wenham et al. (2007) describe silicon solar cell (PV cells) as a diode formed by joining p-type (boron doped) silicon and n-type (phosphorus doped) silicon, designed in a manner that maximises the power rating of the solar cell. Figure 1illustrates the behaviour of light on a solar cell, indicating that the power rating of the solar cell is maximised by maximising the desired light absorption (3) and absorption after reflection (5), so thatthe electric field Ē atthe p-n junction sweeps the electron flow so that a finite current is generated.

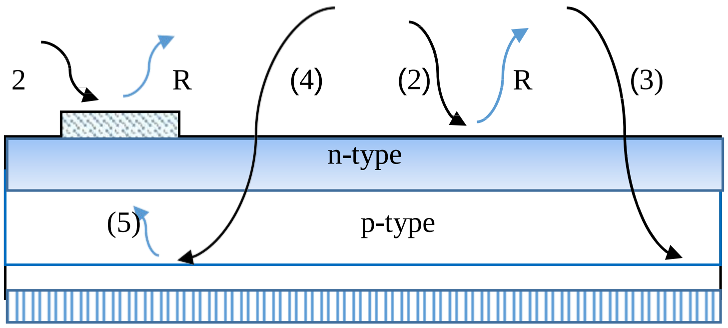

Figure 1-1.1: Behaviour of light shining on a solar cell [source: Wenham et al. (2007)].

Biomass from municipal sewage is also a feasible renewable energy source. Smolinski et al. (2019) state that quality sewage sludge biomass has great potential in the energy generating sector as the volume of sewage sludge increases with population growth and increased processing of industrial and municipal wastewater. Biomass (e.g. municipal sewage) is rich with organic matter that can be used as a fuel throughthe use of appropriate technologies at wastewater treatment plants to harvest energy and generateelectricity (White and Plaskett, 1981; Hong, et al., 2016; Rasmeni & Madyira, 2019; Smolinski et al., 2019). Sewage sludge is a multi-substance mixture that is generated from both municipal and industrial activities and can be characterized based on various physical, chemical and micro-biological parameters which consequently influence the treatment process of the collected raw biomass. Volume index and digestion time characterize the quality of the sewage received (Wiechmann et al. 2013).

Developing countries (such as South Africa) should seriously consider employing sustainable biomass strategies and facilitation for successful power generation (Battacharya et al., 2016; Bernades et al., 2003). Biomass strategies allow for modular increment in energy supply, avoiding stranded investments and minimizing risks at the time of restructuring in the electricity sector (Miah & Shin, 2006). Utilizing renewable energy is reliable and cost-effective (Spilsbury & Spilsbury, 2008), but requires correctly designed and feasible technology (Pipe, 2014).

In order to establish value-for-money when implementing a hybrid renewable energy system (HRES)/technology project, the affordability, technological change or advancement, and relevance of the system to operations and targeted expectations or projections are of essence. For implementation to be effective, the recommended HRES must be customised to available renewable energy resources and performances improved through modelling factors or components or aspects or legislation requirements that contribute to the make-up of a high performing hybrid system. Promethium Carbon and South African National Energy Development Institute (2017) state that the feasibility of hybridised systems seems certainin the energy sector, but the sourcing of funds to finance the implementation of HRES such as photovoltaic microbial fuel cells (PV-MFC) technology is difficult. Access to and financing of renewable energy projects are major challenges for many developing countries such as South Africa, but PPP agreements supported by government using well-structured financing models that account for discounted future valueof renewable energy projects in terms of money and socio-economic impact, are a step in the right direction.

There is no doubt that the South African economy is experiencing a massive blow from the current chronic energy crisis that has caused many small-to-medium businesses to close shop and a rise in job losses. The government needs robust 'out-of-the-box / business unusual' strategies and partnerships to tackle the country's energy crisis, such as decentralizing some of the energy generation and distribution burden to municipal institutions operating at ground level, thereby mandating and entrusting them with providing services to communities and businesses operating within their jurisdiction. This study explored the feasibility of using municipalities as renewable energy hubs for generating their own required energy. The uMhlathuze municipality, also referred to as City of uMhlathuze in this thesis, is used as a case study together with the viability of the PV-MFC hybrid system for its generation use. The format used for this study is qualitative and the thesis layout is outlined as follows.

2.0 Thesis Layout

Chapter 1 is an introduction that provides a brief outline of the subject matter, indicating the potential impact that government would have if it played a leadership role in solving the country's energy crisis by venturing into a more sustainable and affordable renewable energy endeavour that would provide a secure supply of electricity to municipalities without burdening citizenry with additional charges. The city of uMhlathuze is used as a case study for this research study.

Chapter 2 provides a synoptic view of using a PV-MFC renewable hybrid system. The motivation and the purpose and objectives of the research study are outlined. The chapter highlights the research questions, describes the problem statement and spell-out clearly defined aim and objectives that reflect the significance and role of the study. The main contributions to the field of study is highlighted. This thesis is a compilation of research publications that are in alignment with the research topic and the requirements by the University of KwaZulu-Natal for the awarding of a doctoral degree. The total number of produced publications is ten (10).

Chapter 3 provides background related to the research study by consulting literatures on the subject matter, highlighting features that negatively affect or influence the cost effectiveness, energy efficiency and subsequently the effective delivery of services by the municipality to its citizenry. With the challengesfaced by the country highlighted, the chapter reviews existing literatures on the South African energy crises and ways of remedying the security of energy supply, shifting from fossil-fuel based generation to using renewable energy resources at municipal level. This chapter suggests a meaningful leadership role that government must pursue in minimising the effects of electricity shortage by decentralising generation for municipalities to generate their own electricity.

Although the main focus of this study is in pursuit of a hybrid renewable energy system (HRES) by government to solve the country's energy challenges, chapter 4 focusses in highlighting municipal facilities and components in wastewater treatment plants that significantly contribute to the high consumption of electricity. The chapter further ascertain how microbial fuel technology can be used to generate electricity to cater for the high energy consuming components. Discussed is the importance of selecting the best treatment process for collected municipal sewage, a potential source for renewable energy generation, and the benefits of how the implementation of such treatment processes improve the energy conversion efficiency of the microbial fuel cell technology. The prominence of the treatment processes is the cleaning of biomass from toxic substances and foreign unsolicited objects. Focus on wastewater treatment plant is due to the fact that wastewater discharge from communities is among the most important essential service by the municipality, yet contain the very ingredient, biomass, required to generate electricity.

Chapter 5 provides a background literature of why the photovoltaic-microbial fuel cell (PV-MFC) hybrid system has been identified for the City of uMhlathuze, with the main focus being on the available natural renewable resources and legislation that protects the environment from exploitation and pollution. This background according to this study lays a foundation for the make-up of the hybrid system while attempts are to generate electricity. Further, the chapter pursues the principle that hybrid systems are better equipped for the effective execution of multiple municipal functions and that they are also less costly when compared to the installation of mono-systems and other additional mono-systems to address the same municipal functions that would otherwise be addressed by the hybrid system.

Chapter 6 reports the previous findings by researchers on the status of municipal infrastructure and how maintenance practices and programmes are inadequately implemented, resulting in excessive energy consumption, reduced efficiencies and infrastructure performance and the detrimental costs these has on citizens and trading enterprises that are actively contributing to the socio-economic growth or wellbeing of the municipal area and the country. Importance of maintaining good infrastructure conditions are highlighted and recommendations proposed.

Further to maintaining good infrastructure conditions for energy efficacy to be achieved, chapter 7 evaluates how high performances and energy efficiencies can be achieved with a properly designed PV- MFC hybrid system by reviewing the system through modelling and factoring critical components with changing operation and latest technological development. Factors identified are based on the need for efficient generation and the type of renewable energy resource abundantly available for municipalities located at the east coastal regions of the country, with focus being at uMhlathuze municipality. Thus criticalfactors of the hybrid system are identified as to how they can be improved and modelled to secure high and reliable performance for the municipality to have enhanced confidence in servicing mandated obligations. This chapter highlights how energy generation and efficiency can be achieved at the city of uMhlathuze with a customised PV-MFC hybrid system.

Although the development of the for the PV-MFC hybrid system is based on the fundamental principles and functions of mono-technologies of MFC and PV technologies, chapter 8 provides an overall review of the applicable literature, in particular legislation that supports the designing of specifications and the implementation of the PV-MFC hybrid system to improve energy capacity and reliability. Examined is the ease of using government supported tools by the municipality to secure funding or financing of the PV-MFC project and procurement of needed professional services and products (goods). The PPP in the custody of the National Treasury (Department of Finance) is described and discussed. Municipal SCM policies of procuring goodsand services in accordance with the municipal finance management act are highlighted. The specification of procuring services of a transactional advisor (TA) and implementation of PV-MFC renewable hybrid system project is outlined. The TA is the main and important professional services provider that is responsible for ensuring successful execution of key functions and implementation of the HRES (PV-MFC).

Chapter 9 highlights some of the tools that evaluate the financing and payback forecast for implementing a HRES (PV-MFC) project that does not disadvantage communities that are likely to benefit from having such a project implemented. The tools can be used by municipal officials and the transactional advisor in determining the feasibility of the PV-MFC technology for municipality's buy-in. These tools together with government approved modes of securing finances or funding for complex projects, can aid government in improving services to communities. The project financing and payback tools are described and introduced in this study as modes that establishes the viability of implementing a renewable energy project and of addressing anticipated financial concerns with respect to compliance with supply chain management (SCM), funding modes of HRES projects, payback and the benefit (including non-monetary benefits) of undertaking and implementing HRES projects, especially for the uMhlathuze community.

Chapter 10 shows the results obtained from the energy audit exercise conducted on-site to obtain data and the findings on energy consumption. Highlighted are the data trends and analysis of energy consumption, infrastructure conditions (including finding out of any energy efficiency initiative implemented or device installed) and the corresponding monthly energy bills. Audits were conducted of the municipality's critical plants. The chapter explores techniques that exhibit the correlation between various variables in an attempt to provide links and answers to some of the study questions and make recommendations for the use of the PV-MFC hybrid system or technology. For holistic views to be achieved on the feasibility of PV-MFC system application in municipal environment, identified challenges facing the municipality are analyzed and recommendations to alleviate the effects of experienced challenges are compiled. Energy demand by the municipality from the utility (ESKOM) and the municipality's energy consumption are highlighted and discussed, illustrating energy efficiencies and the burden of charges carried by energy consumers supplied by the municipality.

Chapter 11 emphasizes the importance of conducting feasibility studies as a central part of planning in order to see the implementation of an HRES project, in this case the PV-MFC hybrid system for uMhlathuze municipality. The impact and consequences of having inadequate planning are highlighted as factors that have brought the country to the situation of ailing generation capacity and shortage of energy supply.

Chapter 12 provides the conclusion to the study, highlighting the collection of key conclusions arising from the study and related proposals. Also presented in this chapter are recommendations for further research focusing on aspects of conducting comprehensive feasibility studies in order to plan in detail the financing, legal and technical specifications and activities for the procurement and implementation of HRES projectsat municipal level.

Conclusion

This chapter provided an overview to the study of using renewable energy sources and PV-MFC technology to generate power at the city of uMhlathuze to enable energy efficacy and reliable energy efficient municipal operations (use). A brief synopsis of the introduction and background to the study, the importance of the study and format undertaken were presented in terms of the study aims and objectives and to answer the research questions. The next chapter provides a synoptic view of using the PV-MFC HRES and the background and comprehensive literature review to evaluate the various theories and subsequently analyse gathered data.

Scope

This thesis covers work related to identifying and modelling of critical factors that influence the make-u and performance of PV-MFC hybrid system together with tools that enable the implementation thereof successful.

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Chapter 2: The synoptic view of using Photovoltaic- Microbial Fuel Cell (PV-MFC) renewable hybrid system to address municipal electricity needs: Case study City of uMhlathuze

The synoptic view of using the PV-MFC hybrid system is entirely based on identifying the need for the implementation of a PV-MFC renewable hybrid system to address challenges reflected by the problem statement and ways through which the problem has motivated for the study to be conducted. The aim and objectives of the study together with research questions provide a guide or consideration of what must be address in order for the study to be of significance in tackling this national pandemic of energyshortage. The city of uMhlathuze is used to motivate how planning using feasibility studies enables the implementation of customised hybrid technology and demonstrate how renewable resources can be identified and used to secure reliable security of supply for the municipality's needs. This article was accepted for publication in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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THE SYNOPTIC VIEW OFUSING PHOTOVOLTAIC-MICROBIAL FUELCELL(PV-MFC) RENEWABLEHYBRIDSYSTEMTOADDRESSMUNICIPALELECTRICITYNEEDS: CASE STUDYCITYOFUMHLATHUZE

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ABSTRACT

Municipalities are often faced with the challenge of balancing their demand for electricity from the utility and the cost of securing adequate electricity from the same. This, together with poor planning, has led to municipalities ordering more electricity from the utility than the actual energy required and consumed on a month-to-month basis, at the expense of its citizenry because of the additional charges incurred by the municipality in this process. This paper proposes a lasting solution which involves renewable sources that the municipality can easily attain to address challenges highlighted by the problem statement and the research questions. The paper highlights the approach of acquiring electricity from renewable energy sources and the impact that feasibility studies as part of planning and the implementation of photovoltaic-microbial fuel cell (PV-MFC) hybrid system can have on municipal electricity statusand the municipality's ability to provide effective services that support economic growth and improved quality of life within its jurisdiction.

KEYWORDS: Municipality, Electricity Status, Renewable Energy & PV-MFC Hybrid System

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Original Article

1. INTRODUCTION

This paper provides an overview of the importance of innovative thinking in the exploration of renewable energy as a long lasting solution to the present day challenges faced by the country with regards to energy status at a municipal level. Energy sustainability can be implemented and achieved to improve reliability of municipal treatment facilities at the city of uMhlathuze through the use of a hybrid system consisting of microbial fuel cell (MFC) and photovoltaic cell (PVC) technology. An approach of implementing the feasibility of this technology as ameans of generating power at the city of uMhlathuze is discussed by highlighting the problem statement and research questions that must be addressed during planning. This paper highlights the gaps caused by poor municipalinfrastructure, lack of leadership and committed pursuit by government of renewable energy generation, and decreasing security of energy supply at municipal level. These factors negatively affect the economic activities taking place within the municipal jurisdiction and reduces the quality of life of the general citizens. Furthermore, the paper highlights the benefits of local municipalities generating their own power from readily available and easy to process renewable sources using hybrid renewable energy systems such as a PV-MFC hybrid system in order to be able to deliver suitable services to the people and the trading enterprises operating within the care of the municipality.

uMhlathuze municipality is, according to the Constitution of the land, responsible for implementing government mandates of providing meaningful service to the citizens of Richards Bay. The City of uMhlathuze is used as a case study in this paper. In so doing, this paper offers a brief background to the subject matter, including the problem statement and the why and how of the study in order to exhibit the significance of the research. Outlined is the aim of conducting a feasibility study as an integral part of planning that when the corresponding purposes are pursued with great strides, the problem statement will be addressed, the aims and objectives of the research satisfied and the research questions answered.

2. BACKGROUND

South Africa's chronic energy crisis is having dire consequences for the economy and quality of life of its citizens. Industrial and commercial trading enterprises can see that the government integrated energy resource plan (IERP) is useless in forecasting energy requirements and possible strategies of addressing energy shortages (security of supply) and supply challenges. Supply challenges emanate from population growth and exponential demand for energy. Countries should attempt to be energy self-sufficient (Hinrichs and Kleinbach, 2002), which they can do through harvesting energy from renewable sources by using modern technologies that are aimed at optimising the harvesting of energy efficiently from renewable sources (Sørensen, 1979). Kohler (2013) states that the newly developed integrated energy resource plan (IERP) sets out South Africa's plan for energy (electricity) generation and supply over a 20-year period to secure improvedsecurity of supply and energy efficiency. However, the challenges faced by considering potential generation modes in the country is that technical specifications of identified energy systems or projects are evaluated and recommended without always reviewing whether they are affordable.

Joffe (2008) states that the challenges facing South Africa's electricity supply industry are a result of policy and regulatory uncertainty over the previous decades due to the lack of open competition. In this context, Eskom (the government's biggest and only trusted energy utility or enterprise) decided to build two new gigantic coal-fired power plants that are unsustainable in the near future due to depleting coal (unsustainable resource) and the forever increasing costs of using coal to generate electricity. Joffe (2008) further states that South Africa requires massive new financial investments to enhance the country's generating capacity to satisfy growing energy demand, but a lack of planning has resulted in government re-iterating its existing energy strategy of coal-fired power stations as baseload power stations.

Joffe (2008) states that it is essential that the economy facilitates and sustains investment and economic growth in order to provide access to electricity for all. Del Mar Martinez Diaz (2017) states that implementation of innovative means in the renewable energy sector can eradicate energy shortages and undesired related consequences. Joffe (2008) encouraged the government and Eskom to make an urgent transition towards more diverse sources of supply because diversifying the energy mix is important in building confidence in electricity supply, securing energy capacity, addressing challenges of climate change, and attracting new funding and partnerships that secure technology and skills. In addition to diversification, Joffe (2008) points out that energy efficiency is a major driver that shapes the environment in which the existing and new infrastructure delivers electricity. According to Khanal (2008), 722 quadrillion BTUs of energy will be required by year 2030. Sinha (2008) states that the global primary energy consumption of about 1200 EJ/year that is forecast for 2050 can be reduced to 800 EJ/year to 1000 EJ/year by 2050 by means of the incorporation of energy efficiency devices. Sinha (2008) further states that, although 80% of present primary energy requirements globally are met through fossil-based fuel (coal), fossil-based energy consumption must be reduced and limited to 300 EJ/year by 2050.

Modise and Mahota (2009) from the Department of Energy (DoE) of South Africa stated that the procurement target for energy from renewable sources by 2030 is 18.2 GW. According to Ferry and Giljova (2015), South Africa has a high potential for producing lucrative and affordable energy from renewable energy exploration to satisfy the required energy target by 2030 through the installation of modern renewable energy technology. Unfortunately, the target stated by Modise and Mahota (2009) (18.2 GW) is additional required energy and does not account for the replacement of the electricity produced from coal-fired stations by generation from renewable sources. The long-term energy status of the country will continue to be uncertain unless there is a commitment from government to explore renewable energy using modern renewable energy technology which involves conducting comprehensive feasibility studies.

Hasley and Schubert (2017) state that South Africa is a developing country faced with fast depleting fossil-fuel reserves and rising costs, so the South African government should encourage public-private partnership and local municipalities to generate renewable based energy and support municipalities by investing on reconditioning their infrastructure to acceptable conditions to support renewable energy generation and economic growth at municipal level.

The 2008 March issue of the South African Energy Statistics report states that the South African economy is dependent on energy resources because almost all economic activities of the country are one way or the other directly or indirectly linked to energy consumption. Barker (2008) concurs and states that currently the South African economy is heavily reliant on security of supply from the national grid, however the South African economy suffers from lack of power and lack of reliable infrastructure capacity to cater for current and future projected economic investments and activities. Barker (2008) states that lack of power capacity reduces the ability to drive energy dependent economic activity demands. This then affects the ability of South Africa to trade with the rest of the world as investors to South Africa are apprehensive and are starting to lose confidence in the country's energy health and recovery programme. The 2017 report by Deloitte takes a synoptic view of electricity consumption and pricing in South Africa, confirming that economic activities in South Africa are energy intensive, as they have been historically, with only small improvements over the years.

The 2015 Financial Mail publication on South Africa's energy crisis, expresses that the South African government is lagging behind in resolving its energy related problems regarding generation and security of supply, and that the government is currently playing catch-up in order to build sufficient energy capacity to meet the current and future demands so as to support the economic well-being of the country. The Creamer Media Water Report (2012) states that South Africa is increasingly at risk of becoming a high infrastructure and energy failure rate country, due to the lack of government spending (intervention) on infrastructure, lack of support for renewable-energy based initiatives, lack of infrastructure capacity to cater for increased demand, and lack of effective implementation of maintenance programs that seek to restore existing infrastructure to acceptable condition and good levels of performance.

Carter-Jenkins (2008) points out that wastewater treatment plants at municipal level are energy intensive processes that require significant implementation of energy efficient treatment processes to promote and improve sustainability, reduced energy consumption and reduce the costs of operating wastewater treatment facilities. The authors propose that municipalities must be empowered to use resources that are readily available at their disposal, such as biomassfrom municipal sewage and other types of renewable energy sources to generate electricity to power their wastewater treatment plants.

Municipalities in South Africa are the major custodians of the majority of state infrastructure assets. Constitutionally municipalities are mandated to provide delivery of services to communities within their jurisdiction in a sustainable and affordable manner, within the allocated budgets. However, the findings of the 2007 audit study conducted by the Council for Science and Industrial Research (CSIR) on the condition of infrastructure at municipalities indicates that the infrastructure at municipal level is in a poor condition and that there is lack of asset and maintenance information on this infrastructure. For this reason, infrastructure failure related to municipal operations is common, often resulting in community unrest (protests), environmental pollution, accumulation of exorbitant energy and financial bills, and heightened demand for capital 'financial investment' injection.

Xia and Zhang (2015) state that when there is an unbalanced electricity grid, two options exist in attempting to restore stability; the first is to increase the supply by building new infrastructure or electricity generating plants, and the second is to decrease energy demand by improving energy efficiency through encouraging consumers to switch off appliances, or to switch to renewable energy sources. Xia and Zhang (2015) states that whatever option is opted for, it is important to consider time frames, initial capital investment, maintenance and operations costs, as well as potential energy savings. Load-shedding is the least popular method of encouraging a decrease in demand for electricity, as load-shedding dampens investor confidence and has a negative effect on economic growth activities.

Considering the above, and that the uncertainty of coal-based generation has been highlighted time and time again by various authors, the South African government mandated Eskom to construct two new fossil fuel (coal) giant power stations that at the time of reporting by Chris Yelland (2016) had already cost South Africans over R300 billion but were still uncompleted.

Baker and Philips (2019) state that South Africa's electricity sector faces significant government-leadership based and economic challenges, whereby energy politics remains unresponsive to technological change, economic stress and to the transformation of conventional electricity utility models based on centralised system of transmission, generation and distribution to decentralised deployment of renewable energy based generation.

Taking into consideration the effects of poor planning and management of the construction of the new power plants, the opportunity costs of not embarking on full pursuit of the exploration of renewable projects, and the impact of the prevalence of corruption in South Africa, energy costs are estimated to increase, making energy unaffordable for industries, businesses and the general citizenry. In response to the views of Xia and Zhang (2015), and taking into consideration prices to process coal to electricity and the uncertainties of the future of coal reserves, this paper highlights that conducting detailed feasibility studies on the use of renewable energy sources together with identified hybrid technologies in order to establish customised models for the energy sector of the country to establish reliable, sustainable and affordable electricity supply for the country based at municipal levels that is without harmful effects to the environment is of paramount importance and must be conducted with great commitment.

In an attempt to focus on the impact that an PV-MFC hybrid system would have in the uMhlathuze municipality, planning the implementation of a PV-MFC hybrid renewable system through the use of the feasibility study must comprehensively take into account the history of the climate in Richards Bay, the type of effluent discharged, capacity of the wastewater treatment plant (which in this study is the water treatment plant and water pump station), energy bills, condition of infrastructure of the treatment plant, the pre-treatment processes required for the system, and performances of each plant especially in terms of energy efficiency and the effectiveness of policy reviews.

The task that this paper firstly submits is that the municipality's monthly energy consumptions must be established, the challenges encountered by the municipality in honouring obligations in terms of energy conservation and management and reduction of energy bills, and in maintaining acceptable good infrastructure conditions. A number of studies by various researchers regarding the various technologies focussing on renewable energy have been conducted, but the feasibility of developing technologies in terms of available natural resources (location or site characteristic properties of natural renewable resources) at the disposal of municipalities has not been adequately covered in South African research. Thus, considering the gaps and challenges identified, this study recommends implementation of an PV-MFC hybrid system with the objective of encouraging customized energy generation and enhancement of energy sustainability atuMhlathuze local municipality.

Therefore, the study must focus on assessment and evaluation of the efficiency of wastewater infrastructure under the responsibility of the Infrastructure Services Department of the municipality because this department is responsible for keeping the water and wastewater infrastructure operational and for identifying and proposing ventures into new innovation around infrastructure development (they are the custodians of infrastructure related initiatives and sustainability), and the Electricity Services Department because this department is responsible for energy management, energy audits, distribution of electricity from the national grid and collecting corresponding revenue, and could conduct other energy related initiatives such as electricity generation using natural resources.

In a nutshell, this paper has been motivated by the shortage of electricity supply that has resulted in load-shedding and a call by government for partnership agreements related to alternative affordable sources of energy. This paper highlights a method or approach that the South African government can pursue to achieve affordable and sustainable 'renewable energy based' means of generation. The use of municipalities to generate their own electricity and reduce bills accordingly that is aimed at powering the treatment plant so that citizens within the jurisdiction can have access to reliable energy and efficient delivery of services.

2.1 Problem Statement

Karekezi et al. (2004) state that the problem faced by most African countries is not the increase in energy consumption per se, but the confident access to clean energy supply preferably through energy efficient methods. The African continent has abundant renewable energy sources that can support the exponential growth in energy demand. Karekezi et al. (2004) (citing Zhou, 2003) state that generation using renewable energy research has not received enough attention from governments on the African continent, in terms of committing funds and conducting feasibility investigations and pilot implementations of renewable-based generation at an up-scaled size. This has consequently resulted in renewable technology remaining unproven for municipal buy-in. This has perpetuated the unaffordable energy supply paradigms that have led to current serious challenges. In support of the above view, Onyekwelu and Akindeke (2006) state that the economies of various developing countries are dominated by a few multinational corporations that are often profit oriented and that African governments tend to be loyal to them at the expense of the poor citizens.

The Delloite (2017) report indicates that the energy consumption at treatment plants is highly dependent on the modernisation of households to conserve water and electricity, the condition and performance of the municipal water and wastewater infrastructure system, the ingress of unsolicited substances that resultantly dictate the type of treatment required and any additional processes required in separating and/or treating unwelcomed substances, and the degree to which the technology used at the treatment plant is energy efficient and conservation orientated. Due to the changing operational conditions based on various factors such as infrastructure degradation, and new economic activities from new industries and commercial institutions, frequent review of treatment processes and programs directed towards the implementation of rehabilitation of infrastructure must be pursued in order to improve energy consumption, improve the quality of municipal biomass (sewerage) and effective performance and efficiency of the municipal infrastructure i.e. the treatment plants.

Winkler and Marquard (2009) state that the South African industrial electricity efficiency is an ongoing concern as it contributes far less to the South African GDP and is considerably lower than the global average. In order to address this challenge, Kohler (2013 citing Inglesi-Lotz and Blignanat, 2011), suggests that South Africa's electricity supply shortages require a nation-wide demand-side management programme that will see energy efficiency improve.

Maistry and McKay (2016) state that research institutions are faced with increasing pressure to come up with effective management technologies that manage electricity demand and costs reduction caused by energy inefficiencies and resource uncertainty. Historically, a lot of facilities and equipment in South Africa were built when energy optimisationwas unimportant, the challenges of managing electricity consumption from the national grid were insignificant, and the difficulties of sorting and engaging sustainable practices that seek to create energy-efficient technologies were not considered important. Thus, there was no urgency for financial investments in technologies that tapped into multi- renewable energy sources. For this reason, the CSIR report (Wall, 2010) reflects that energy-efficient devices are not common in conventional treatment plants in South Africa. Based on views by Saini (2007), well-motivated personnel are best at developing and implementing energy efficiency policies that are pragmatic and benefit cost reduction, enable savings on utility bills, improve ways at which facilities and equipment are operated and maintained, and play a major role to having energy efficient systems.

Municipal institutions around the country owe Eskom tens of billions of rands, leading to heavy national deficits in terms of energy and South African rands, lack of power capacity and inability of the country to provide reliable energy supply and proper service delivery at municipal levels (Barker, 2008). High national debt leads to downgrading of the country's credit rating which has a negative impact on South Africa's ability to acquire funds (borrowing power) to implement hybrid renewable energy system (HRES) projects (Smith and Lunsche, 2008). The danger is that investors will then take their monies and skills elsewhere (Mthombeni, 2008).

Lunsche (2008) states that government cannot afford to repeatedly find itself consistently underestimating energy demands as it is currently doing. Government must invest in other forms of energy sources to fast-track security of energy supply and also counteract the increasing effects (costs) of generating electricity from the fast-depleting and now more expensive fossil based fuels (coal), as lower grade coal is increasingly being encountered.

Cherp and Jewell (2011) state that the three distinct perspectives of energy security are: sovereignty, robustness and resilience. Trollip et al. (2014) add that energy security is complex, requiring a multi-disciplinary approach that analyses resilience and addresses integrity challenges.

Trollip et al. (2014) state that the myopic focus in solving energy resource challenges facing South Africa's energy system has created a monumental backlog in infrastructure development and investment paralysis, shortages in bulk electricity supply, a growing backlog and ongoing deterioration of electricity redistribution infrastructure, poor household energy security, discontinuities in coal supply, absence of a credible liquid fuels policy and comparatively low crude oil stocks.

Trollip et al. (2014) advocate for a broad conceptualisation of energy security based on the World Energy Council's (WEC's) tenets of accessibility, availability and acceptability, supplementing the Department of Energy's (DoE's) focus of ensuring diverse energy resources in sustainable quantities and at affordable prices being made available.

Ketelhodt and Wocke (2008) state that, though small and medium enterprises (SMEs) in South Africa are regarded as the future engines of growth for the South African economy, SMEs are one of the most vulnerable sectors to unstable energy environment and policy shifts. Since SMEs are generally incapable or lack the resources necessary to invest in alternative sources of energy themselves, and are generally operated, located, and served by municipalities, a reliable, abundant, low priced source of electricity at this level is critical. The lack of availability of low priced primary energy sources hinders or constrain the future growth of the South African economy as SMEs are left with bleak future prospects.

The efficient use of energy, especially at municipal level, is an important concept that needs to be embraced to support economic growth activities. Pakenas (1995) states that though wastewater treatment plants consume large amounts of energy, the same plants have the capacity to produce large amounts of biogas (a combination of methane and carbon dioxide) from sewage sludge. In support, Hampton (2017) states that the process using harvested natural reserves such as from human waste for the purpose of generating electricity, together with the use of appropriate technologies that produce and use a mixture of methane, carbon dioxide and traces of other gases, must be pursued to power the pumping equipment in treatment plants. Onyekwelu and Akindele (2006) state that the use of animal or human residue is a cheap and viable alternative to national grid power.

Wong (2011) states that wastewater treatment plants present untapped sources of renewable energy, and the use of bio-solids can generate biogas that contains up to 70 % methane which can be used to generate electricity. Pirnie (2005) states that over and above having local sources of energy, municipalities must undertake continuous sub-metering of major pieces of equipment in wastewater treatment facilities in order to identify energy-saving opportunities by capturing diurnal variations in electric energy demand so that reviews of equipment replacement or modification and methods of operations are made.

Soltes et al. (1982) state that technology and technology improvement is vital for economies of scale in terms of process efficiencies and investment. Energy output, according to Soltes et al. (1982) is the amount of electricity generated, and that before generation, the fixed power requirements must be determined and viable technological options of producing electricity from municipal waste and other readily available resources must be identified and be aligned with the purpose of powering some of the identified municipal equipment.

The most crucial step that municipalities must undertake before implementation of renewable energy projects, is an energy audit of the treatment plant (Hallet et al., 2012). This involves the comprehensive collection of data in order to:

- Evaluate energy consumption and efficiency through an on-site survey to identify maintenance and/or operational needs and deficient equipment;
- Analyse energy consumption information in order to understand energy usage patterns and develop an energy baseline; and

- Estimate energy and cost savings with emphasis on incorporating low or no-cost measures such as energy saving devices, or the redesign and reconfiguration of the plant equipment and/or processes (Hallet et al., 2012).

King (2004) states that energy comes in many forms, and can be converted from one form to another. Gikas and Tsoutsos (2013) state that the most common process of harvesting energy in municipal wastewater is to use activated sludge treatment. The aeration process is by far the greatest energy consuming process in a conventional activated sludge wastewater treatment plant, with the aeration tank consuming up to 55% of the energy (Gikas and Tsoutsos, 2013; Badruzzaman et al., 2015). For energy usage to reduce, consideration and introduction of energy efficient devices must be used together with replacing or improving core equipment with energy efficient (advanced) automated devices and technologies (Badruzzaman et al., 2015).

The location of the city of uMhlathuze and the need to address energy consumption challenges of adequately operating pumping installations at the treatment plant, and energy from available biomass and abundance of sunlight (solar energy) must be investigated to examine the prospects of implementing a PV-MFC hybrid system to power the municipal treatment plant at affordable rates that subsequently benefit SMEs and the citizenry. The benefits of employing a hybrid system rather than individual mono-systems such as MFC systems or PV cells systems have been highlighted and examined by various researchers, endorsing the feasibility of a hybrid system at a municipality's best aid with its functions of effectively delivering services to customers and citizens within its jurisdiction.

In order to propose the best-suited hybrid system, the quantity and quality of sludge required to achieve optimum efficiencies using microbial fuel cell technique must be examined together with the abundance of sunlight based on the topographical location of uMhlathuze municipality. Establishing these factors together with needed electricity, the type and size of the hybrid system can easily be identified and formulated from the different MFC system types and PV system types in the market that best suit the South African market. In satisfying the objectives of this research of using solar energy source and biomass to co-generate, this paper aims at assisting the municipality to decide on which renewable energy configuration and procurement route to undertake. Financial models for financing this renewable energy project must be evaluated and outlined for purposes of evaluating the viability of the HRES and its payback under clearly defined, well-understood and government supported legal rules.

The City of uMhlathuze municipality has been procuring services of a service provider to operate and maintain the water and wastewater treatment facilities in order to ensure effective performance in the delivery of services and acceptable infrastructure conditions. One of the measures that should be a reliable indicator of the effectiveness of the maintenance program in place and the infrastructure condition at the wastewater treatment plants is the availability, accuracy and reliability of performance data of each treatment plant and the records of the frequencies of inspections and maintenance work conducted on the infrastructure. Thus, the impact of infrastructure conditions and assesses the corresponding energy bills is crucial. Strategies or known initiatives employed by the municipality in alleviating energy demands at treatment plants such as incorporation of energy saving devices or components and sourcing alternative energy supplies to power treatment plants (if any) were noted. The purpose of the above examination is to capture the true reflection of the impact of incorporating renewable energy supply technologies in these plants through conducting a detailed feasibility study. Liff (2011) highlights that the biggest challenges that managers in government institutions face isthe lack of support from their superiors because they are not given the autonomy to devise new ways to solve problems, and encounter red-tape in trying to get approval for spending of funds for initiatives deem fit by the manager. In addition, the government's budget cycle inhibits the manager from acting immediately, and inter-departmental or inter-disciplinary challenges tend to limit the formation of an integrated high performing team. Therefore, some managers take the path of least resistance.

This research paper thus highlights that the extent to which exploring alternative renewable sources encourages sustainability of treatment plants and credible delivery of services, determine the feasibility of PV-MFC hybrid technology at the municipal level and how the hybrid system positively impacts the energy demand, reduction of energy bills and reduce negative impact on the environment.

3. Methodology

3.1 Motivation for the Study

This paper examined the leadership challenges faced by the country with regards to energy shortages that disrupt municipal functions as mandated by chapter 2 of the Constitution, resulting in undesired consequences that negatively affect the socio-economic portfolio of the country. Municipalities at the time of writing this paper secure energy mainly from fossil- fuel (coal) power plants, and studies by various authors indicate that the vulnerability of the country's national grid emanates from the dynamic behaviour of coal reserves, poor planning and leadership in forecasting and implementing strategies that resolve energy challenges and poor infrastructure conditions.

In order to salvage the country from the irreversible catastrophic consequences of unsustainable and unreliable security of supply, this paper proposes the implementation of a hybrid renewable energy (HRES) project using municipal resources such human resources, finances and other government developed tools like public-private partnerships (PPP) to fast-track and enable the implementation of renewable energy generation. The view expressed in this paper is that decentralisation of generation and the use of municipalities as energy hubs to pursue renewable energy generation projects need to be pursued. The city of uMhlathuze is used as a case study for government to pursue this initiative.

The call by the South African government for public-private partnership is a step in the right direction, however the guidelines as to how such partnerships can be managed without disadvantaging citizens is of paramount importance. For successful coherent partnership of government with services providers (research institutions, professional private companies and person(s), experts in the energy sector) through fair use of procurement tools and processes stipulated in the public-private partnership (PPP) guidelines and other supply chain management (SCM) policies must be put in place to enable municipal procurement to be conducted and handled with care, with zero objections or perceptions of corrupt practices.

3.2 Aim of the Study

The aim of the study is to establish a means for determining the feasibility of PV-MFC hybrid system at uMhlathuze municipality to power the municipal wastewater treatment plant and how energy management and reduction of energy bills can be achieved in powering wastewater treatment plants. Gaps with regards to energy supply policies (legislation and governance) and initiatives (funding and implementation of energy efficacy strategies) must be identified and defined together with shortfalls of strategies in place of reducing energy wastage and infrastructure challenges that have negative effects on energy demand. A relationship is reflected by various authors of how infrastructure condition impacts energy demand, and how employing alternative renewable energy sources using HRES such as PV-MFC hybrid system reduces energy bills from the national grid (energy conservation), resulting in savings in the short-to-medium term that can be used elsewhere and improve the sustainability of energy supply. Thus, this paper reflects the strengths of implementing PV- MFC hybrid systems in powering wastewater treatment plant.

3.3 Objectives of the Study

- To evaluate the current infrastructure conditions at the treatment plant and how energy consumption is influenced by this.
- Identify gaps that worsen energy demand or increase energy bills (include energy wastage).
- Identify gaps of governance on energy management and energy supply by municipality to treatment plants. Consider national stipulation encouraging municipalities and other institutions in implementing technologies that aid harvesting renewable energy to power their own facilities.
- Establish the link or relationship of the country's energy status to economic activities, quality of life of citizens, effective delivery of services to the benefit of immediately implementing HRES projects that improve energy affordability, energy reliability and sustainable management and forecasting of energy efficacy.
- Establish the link between energy demand and accrued costs.
- Establish the feasibility of how the implementation of renewable sources can offset demand from the national grid, looking at treatment facilities at uMhlathuze municipality only.
- Recommend PV-MFC hybrid system as a viable technology that can produce a long lasting positive impact on energy demand, energy savings (conservation), and have a safe environmental impact.

The methodology in this paper thus outlines how adequately addressing the research questions in a manner that reflects the significance of the study that satisfies the aims and objectives of the paper can be achieved. The research questions are indicated.

3.4 Research Questions

- What impact does the country's economic and energy status have on municipal functions and its citizenry?
- What impact has the national grid and fossil-fuel (coal) based generation and supply have on municipalities, economic health of businesses in municipal jurisdictions, citizens and the environment?
- What impact does a poorly maintained municipal infrastructure such as a treatment plant have on energy consumption?
- What impact does having unrevised treatment processes with non-energy efficiency sensitive technologies and unreviewed policies have on energy consumption in conventional treatment plants (especially regarding energy conservation and efficiency)?
- What is the correlation or relationship between energy bills incurred and the costs of generating energy from fossil-fuel based sources?
- What are the gaps of implementing renewable energy systems or projects that enable generation of power from renewable energy sources as an alternative compared to fossil fuel generation for the municipality?

- What is the cost-benefit of using an PV-MFC hybrid system to generate electricity to power the wastewater treatment plant? In other words, what is the feasibility of employing the hybrid system to power treatment plants?
- What continuous improvement strategies can the municipality employ to enhance energy savings from the national grid and promote energy sustainability supply to the treatment plant?
- What modification can be conducted to improve performance and efficiency of a PV-MFC hybrid system using available self-replenishing renewable sources? And can such a self-sustaining system or technology be economically viable for local municipalities such as uMhlathuze local municipality?
- How would the system be feasible or be of positive impact for uMhlathuze municipality and for municipalities to invest in? Is decentralised renewable energy generation using municipalities as power generating hubs feasible for the South African energy market?
- What impact does legislation have in the energy sector, environment and design of a modified PV-MFC hybrid system?
- Can energy bills be reduced as a result of the implementation of the PV-MFC hybrid system and proposed incorporation of energy saving devices to the wastewater treatment plant in the medium-to-long term?
- How effective will the developed hybrid system be in replacing the conventional source of power from the national grid to power the wastewater treatment plant?
- What financing tools and/or agreements are in place, even if they are not effectively used? Can these be used by municipalities in effectively implementing renewable projects that ensure reliable and sustainable generation and supply that is all inclusive? Can both public and private sector partnerships be used to address energy related challenges (shortages, disruptions, etc.)?
- Can such a renewable system or project (i.e. the municipality generating energy and powering treatment plants) be self-sustaining, offering the municipality good revenue and the citizenry (including small-to-medium businesses and industries) affordable energy?

3.5 Significance of the Study

The significance of this study lies in its ability to address the above research questions and provide insight into how municipal institutions such as the City of uMhlathuze can use renewable energy as a feasible alternative source of generating electricity from available abundant resources to power heavy duty facilities such as municipal wastewater treatment plants. Although energy requirements vary from municipality to municipality depending on affordability or borrowing power of the municipality to willingly pursue energy generation from available renewable energy resources, an improved and reliable supply of energy can enhance the quality of life of citizens, promote reliable economic activities and delivery of services, and provide comfort or confidence of having a good security of supply. For uMhlathuze local municipality in the Richards Bay area, PV-MFC hybrid technology is recommended as a system that will aid the municipality in harvesting energy from reliable renewable sources, as the municipal area is imbued with abundant sunlight and can collect adequate quantities of biomass.

The feasibility of renewable energy supply for each municipality depends on the location of the municipality and abundance of readily available renewable resources at the location under investigation or considered location. The municipality under study is situated in the industrialised town of Richards Bay, situated on the north-east coast of the KZN province, with a land coverage area of 123 325 hectares, and is estimated to have 110 503 households (using 2016 statistics), discharges an average of 25 000 m^3 of sewage to the effluent pipeline, accounting also for waste discharge from industrial and commercial activities. This means that biomass and sunlight are readily available abundant renewable sources that the city of uMhlathuze should explore for the generation of electricity.

Another significance that the paper highlights is that the benefit of using a hybrid system rather than a mono- system to harness renewable energy, is because then more than one readily available renewable energy source can be explored. That is, rather than municipalities investing in mono-systems or technologies, municipalities can invest in hybrid systems to circumvent the limiting factors of relying on one renewable energy source. The paper is of the view that the savings and added reliability in generating electricity from employing hybrid technology compared to mono based technology surpasses any cost consideration and anticipated risks.

Further significance is the importance of keeping infrastructure in acceptable operating conditions in order to aid efficiency and energy conservation, thus reducing energy wastage and high energy consumption resulting from poorly maintained infrastructure, and providing credible information and data regarding the impact of the hybrid technology on energy preservation and sustainability of supply.

4. RECOMMENDATION

4.1 Main Contributions to the Field of Study

According to Abd El-Aal (2005), a hybrid system is an economical alternative to large conventional power generating stand-alone mono-systems. The author states that PV-diesel generator hybrid systems are popularly used to power wastewater and water treatment plants, while diesel remains highly influenced by coal reserves and unpredictable markets. With this paper, the PV-Battery-MFC hybrid system has the diesel generator replaced by an MFC, and the fuel cell system is normally used as a back-up when the batteries reach a minimum allowable charging level and/or when the load (peak loads) exceeds the power produced by the PV system. Although Abd El-Aal (2005) reflects that MFCs have a slow response to the above mentioned conditions, a blended approach of generation is proposed, whereby PV and MFC based generation are continuous, with the PV system generating a larger proportion of the required energy. Thus, this paper reflects that all factors that seek to contribute to high and efficient generation of sustainable and reliable energy that enhance municipal confidence in securing security of supply, reduced energy bills in the medium-long term period, ensure rapid MFC response to electricity disruptions and delivery of multiple services to the community must be considered and modelled to ensure that high performance is achieved. The possibility of producing energy to meet demand, legislative requirements and objectives, reliable generation and supply standards and forecast based on population growth and industrial activities are some of the envisaged factors that must be observed and modelled.

5. CONCLUSIONS

This paper highlights the view that if questions and problem statements are adequately addressed, and kept at the core of finding lasting solutions, the feasibility studies are a crucial element to the successful planning for a HRES project, and adequate resources made available will see the implementation of HRES project an achievable reality. If feasibility studies are viewed as a time consuming exercise that require exorbitant funds that yield meaningless results, this will lead to misdiagnosis of the problem at hand. Thus, outlining the problem statement and clearly indicating the above questions is necessary in the initial stage of a renewable energy project. Embarking on a comprehensive feasibility study on the use of PV-MFC hybrid system will enable the uMhlathuze municipality to conduct its business or provide for its current obligations with confidence and look forward to reliable future energy supply in a sustainable manner.

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Chapter 3: Energy Crises in South Africa and New Ways of Fast-tracking remedial actions through diversified and decentralised generation

The author is reviewing views expressed by other authors and researchers with regards to the energy challenges facing the country and also provide a meaningful view that the South African government can pursue to solve the persisting energy challenges. The article was published in the International Journal of Engineering Researchand Technology (IJERT).

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Energy Crises in South Africa and New Ways of Fast-Tracking Remedial Actions Through Diversified and Decentralised Generation

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Abstract

There no doubt that the South African economy is experiencing a massive blow from the current chronic energy crisis. As a consequence, small businesses are closing, municipalities and other industries and institutions are significantly affected in their operations and ability to provide services. Though global markets call for diversified economies with a mix in the provision of goods and services, South Africa is troubled by inadequacy of energy to support such additional trading in addition to the already existing heavy energy dependent trade activities. The South African government must fast-track its efforts to provide credible and reliable electricity supply through diversified generation and decentralized generation strategies. Thus, this paper highlights the critical nature of the current energy situation and the means of curbing the ripple effect of energy shortages on the ground in municipal jurisdictions.

Keywords: Energy utility, security of energy supply, energy crises, decentralisation

I. INTRODUCTION

The energy crises in South Africa has reached near catastrophic levels with far reaching consequences that have caused many small-to-medium businesses to close shop and a rise in job losses in the labor market. Government needs to engage in robust 'out-of-the-box / business unusual' approaches and partnership in order to decentralize some of the energy generation and distribution burden to institutions operating at ground level and entrust them with providing services to communities and businesses within jurisdiction. The aim of this paper is to highlight the severity of the energy crises thatpersists and the means that government could embark on to fast-track the implementation of new forms of energy generation using renewable energy sources.

II. METHODOLOGY

A. Background

The Oxford South African School Dictionary [1] defines 'energy' as the ability or power from electricity that makes machines work. According to [2], energy is one of the major building blocks in modern society and is used to create goods and provide services that contribute to economic development and improved standards of living.

[3] states that the large appetite for electricity/ electrical energy by many societies has stimulated the relative ease with which electricity can be generated, distributed, and utilised. The authors question is whether the consumption of electricity should continue to grow unmonitored or unchecked. Whatever the case, it is evident that there is an ever-increasing demand for this form of energy, thus, in order to meet the world's demand, radical expansion of generating capacity must be a principal focus [3].

[2] states that energy can be best described by what it can do, and that energy cannot be seen, cannot be created nor destroyed, but can be used and its effects observed. Further, the authors state that the interdependent world through its modern economic activities has forged a common quest for collective access to adequate and reliable energy resources, as energy supplies are central to economic growth. Many countries are now seeking to be energy self-sufficient and produce their own power to cater for the energy demands stemming from modernisation and industrialisation. The availability of adequate, reliable and sustainable sources of energy supply is of paramount importance for developing countries such as South Africa, as well-planned use of energy resources with minimal or no wastage together with efficient energy converting technologies must be established [2].

[4] states that the demand for electricity is growing for both developed and developing countries due to increasingly fast industrialization. Energy security has become a global challenge that stems from rising energy demand and increase of conventional generation costs [5]. Growing industrialization and motorization of the world has led to a steep rise in demand for petroleum-based fuel, but the limited reserves of these irreplaceable sources has accelerated the appetite for alternative energy sources [6]. This global energy crisis and continuous increase in energy produce from fossil fuel-based sources has stimulated an urgent need to develop technologies or modify existing technologies that can efficiently convert renewable energy sources to usable form, rendering renewable energy viable to supply the current growing and future projected energy demand.

Energy makes the world work as most of the world's machines and economic activities are powered by energy which can be from non-renewable energy sources such as fossil fuels or from

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renewable sources such as wind, solar and biomass [7]. However, the ongoing unchecked consumption of fossil fuel based energy sources such as oil, coal and natural gases has contributed tremendously to global warming, environmental pollution and increased prices of energy production [8].

[9] states that South Africa is a country that has for the past decade been experiencing serious energy supply challenges. Challenges included are inadequate facilitation of energy structures to support economic growth and development, poor assurance for quality of energy provision and infrastructure efficacy, ineffective infrastructure management on existing infrastructure that promotes energy efficacy, poor planning and innovative means for the construction of new infrastructure and energy capacity, and poor energy and infrastructure life cycle management planning. This has inhibited economic activities and increased energy related consequences suffered by the South African community [9].

South Africa is highly dependent on fast depleting fossil fuel based sources and the costs of generating electricity from these sources are continually rising; the increase in energy demand and consumption trends tend to suggest that the South African government must urgently seek for cheaper and more sustainable alternative energy sources [10]. The Financial Mail (2015) [11] publication on South Africa’s energy crisis indicates that the South African government has been playing catch-up since the early 2000s in building sufficient energy capacity to meet current and future demand.

[12] states that the South African economy is extremely energy dependent compared to other countries when using international instruments and standards of determining the energy usage index. Energy trends reflect South Africa’s resource endowments, historical underpricing of coal and electricity, and low electricity (energy) efficiency.

Despite the above challenges, the irony is that the South African government has continued in its capital investment endeavors of pursuing fossil (coal)-based sources and commenced in the late 2000s the construction of two giant power stations with the current costs of the unfinished power plants reflecting more than R300 billion; over R145 billion currently spent for Kusilepower station a 4800MW plant and over R161.4 billion for Medupi power station, a 4764MW dry-cooled coal-fired powerplant. Using Eskom’s 2016 financial statements, the total construction costs of building the utility’s power plants by end of construction period (early 2020s) are estimated to be R208.7 billion and R239.4 billion for Medupi and Kusile power plants respectively [13].

The Financial Mail [11] indicated that, in order for the South African government to build up sufficient energy capacity to satisfy the current and forecast future demands for high performance skills and other energy related resource processes for fossil-fuel based energy security of supply, R420 billion is required to address South Africa’s energy infrastructure plan, and the economic growth of the country is negatively impacted by the lack of power capacity to meet economic activity demands. [14] reports that a lack of capacity impacts the economy in two ways: it reduces local economic activities which in turn force a large number of thriving industries to review their operations, energy utilization and costs, which causes loss in investor confidence as investors worry about energy shortages and future energy supplies that negatively impact production and profits, erode investment related benefits towards growth and expansion of economic activities, and subsequently impact the manner in which operations should be and are actually conducted.

According to [15], Eskom’s total carrying value of unaudited debt at the end of March 2019 was R440 billion, of which R273 billion is government guaranteed. Eskom’s investment spending cuts in recent years has seen the energy utility face a huge backlog in repairs to existing plants while they are all operating at almost full capacity, and that due to the investmentspending cuts there has also been a lag in the construction workof the two giant plants (Kusile and Medupi) and modification (rehabilitation or refurbishment) works on existing plants. Worsening the situation according to [15] is that most of Eskom’s ageing coal-based plants are due to reach their allowable working and economic life in the 2020s and some in the early 2030s. This has stimulated a lot of discussions in government, regarding what best can be done to reduce debt and remedy the energy utility, including considering some form of privatization. Options for securing an affordable and sustainable energy supply for the country and its citizens has recently been amongst the top of the agenda, including procuring new sources of energy supply.

In an article titled ‘Understanding America’s Water and Wastewater Challenges’ [16] states that although the general public expects effective delivery of services, the public’s understanding of the complicated and expensive systems required to deliver those services is minimal and theyreflexively oppose new charges and fees so are reluctant or unable to accept a higher price for services rendered. Therefore, the service providers face the challenge of raising mission- critical funding from a skeptical public while maintaining affordability for those services which makes it difficult for government to provide promised energy supply services.

[14] states that the South African economy is suffering from lack of power, and hundreds of billions of rands need to be invested rapidly to address South Africa’s lack of capacity to ensure economic stability. This is because South Africa is currently not in a position to lose both investor confidence (investment) and reduction in production activities. Considering this, and the rising costs of acquiring fossil-fuel (coal) and the rising greenhouse gasses associated with this, the question is: why is the South African government not committing the same amount of money to support the exploration and production of more reliable and sustainable renewable energy sources throughvarious initiatives at different government levels?

Eskom’s audited 2018 annual report [17] highlights that debt for energy accumulated by municipalities over the previous 10 years is a staggering R13.6 billion. Although Eskom has undertaken far-reaching strategies of conserving energy supply through load-shedding and awareness, these strategies have not had a significant impact on investor confidence and the already dampened economic activities. This means that industries located and operating within municipal jurisdiction are faced

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with reduced production and labour resources as the energy supplies from both municipalities and Eskom are limited.

Two unfortunate facts are: government's support for renewable energy is on a small scale and the South African government unfortunately perceives seeking and securing alternative energy supply as an expensive exercise in the current ailing (weak) economy. The question is: why is it taking government such a long time to formulate strategies that attempt to curb or address such energy crises, especially contributed by municipalities to the energy sector?

Recently, in the third quarter of South Africa's government 2018/2019 financial year (September 2019 to December 2019), the South African media [18] reported that the South African government through President Cyril Ramaphosa approached 'giant' first world countries and other international platforms such as BRICS in an endeavour to boost investor confidence towards South Africa, managed to acquire investment funding to the value of over 40 billion United States dollars (approximately R580 billion).

The state of South Africa's energy supply can largely be attributed to infrastructure failure, poor energy and infrastructure based planning (nationally, provincially and at municipality level), growing incompetence of technical personnel in government institutions, corruption, socio-economic ills of poverty which results in activities such as cable theft, inadequate government supported initiatives towards alternative 'out of the box' or 'business unusual' strategies, insufficient allocation of budget towards infrastructure retention and energy conservation, inability of the executive (lack of leadership) in identifying looming challenges and formulating necessary energy supply strategies, and South Africa's lack of strategy aimed at auditing available resources and developing a consolidated energy demand approach that will see the country undertake necessary procurement strategies and time-based implementation plans that address infrastructure backlogs (existing infrastructure conditions) and energy deficits at both national and municipal levels.

According to [9], South Africa is experiencing serious infrastructure challenges from inefficient maintenance of existing infrastructure that had been installed in the late 1960s and early 1970s, and also suffers from unmonitored and unaudited usage or consumption of energy. The government interventions required according to [9] among others, are:

- strong public sector leadership
- government commitment and ownership of existing infrastructure and energy demand through comprehensive policies, infrastructure maintenance and restoration programs and initiatives, and technological advancement
- government commitment and ownership of energy efficacy and sourcing meaningful and sustainable solutions in the energy sector such as exploration of readily available renewable energy sources for the South African market or society
- commitment to comprehensive planning in the energy sector and corresponding infrastructure requirements at all levels of government
- commitment to financial investment and support for security of energy supply at all government levels
- commitment towards time-based implementation of the exploration of identified sustainable energy sources as per agreed upon and gazetted national, provincial and municipal energy supply plan and strategies;
- appropriate institutional arrangements and skills development, and
- establishment of suitable support strategies, systems, tools and technologies that solidify infrastructure efficiency [9].

The recently developed National Development Plan (NDP) according to [19] seeks, amongst other things, to provide a framework for government institutions to promote economic development through provision of reliable infrastructure and affordable energy. Although the NDP requires the development of an additional 10 000 MW electricity capacity to be established by 2019 against a set baseline of 44 000 MW, the NDP fails to outline in detail how each strategy can be accomplished through clearly defined comprehensive time-based implementation plans.

[20] states that urgent investment intervention actions are needed to combat infrastructure stresses and energy vulnerability. The author further indicates that amongst themany challenges facing the efficient use of energy and infrastructure performances are ageing infrastructure, lack of or inadequate maintenance attention to infrastructure, lack of technological improvement or modifications to infrastructure, lack of adequate installation of devices that monitor infrastructure condition and energy performance levels, lack ofinstalled devices that support energy efficiency, lack of modelling and controlling of infrastructure loading and energy consumption, and etcetera. According to [20] the above factors heavily contribute to heightened energy consumption, increasedenergy wastage and the near collapse of the national grid.

A well-functioning system reduces transaction costs. In order to achieve energy efficacy, well-functioning infrastructure systems must be well-maintained, and financial investment to alternative energy sources must be explored as this improves competitiveness by reducing transaction and trade costs [21]. The author further states that financing of public infrastructure must be viewed as a fast-tracking factor for change and must remain as one of the key goals for sustainable development. [22] supports [20]'s view and states that the economic sector is more affected by poor infrastructure conditions, thus infrastructure investment is one of the most important factors related to the growth of economic development than any other factor.

According to [23], South Africa is increasingly becoming a high infrastructure and energy failure rate risk country due to the lack of government spending (intervention) on infrastructure and lack of support for renewable-energy based initiatives which results in amplified energy bills due to

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uncontrolled consumption of energy, lack of infrastructure capacity to cater for increased demand, lack of effective implementation of maintenance programs that seek to restore existing infrastructure to acceptable condition and good levels of performance, and the increasing continued support for coal-based generation.

To settle the persisting energy crises of the country, one of the government initiatives is to identify low hanging fruits that reduce energy demand from the national grid. Emanating from this initiative is a strategy of decentralizing generation to municipalities (public sector institutions) by providing municipalities with the autonomy to generate their own required electricity. In this regard, [24] proposes that municipalities must be empowered to use resources that are readily available at their disposal, such as biomass from municipal sewage and other types of renewable energy sources to generate electricity to power treatment plants and supply communities within jurisdiction.

According to [2], since countries seek to be energy self-sufficient, [25] states that to achieve this countries and governments must be encouraged to support and expand their endeavors to harness renewable sources and develop modified technologies aimed at optimizing the harnessing of energy from renewable sources, and that the development of energy converting technologies must make energy efficacy an achievable reality.

Due to the large amount of energy required to power industries together with their respective treatment requirements, an attempt to reduce energy consumption results in increased efficiency and amount of energy available for use, thus promoting a robust economy [26].

The Department of Energy (DoE) of South Africaacknowledges recommendations by the World Economic Forum (WEF) that:

- energy sources must support economic growth and development
- energy sources must support environmental sustainability, and
- energy sources must support energy access and security [27].

[11] states that the newly developed integrated energy plan (IEP) sets out South Africa's plan for energy (electricity) generation and the crucial role that energy plays in the country's economy and also determines the best way to meet current and future energy service needs in the most efficient, affordable and beneficial manner over a 20-year period with one of the main aims being to improve South Africa's energy supply. [28] suggests that the artificially low electricity tariffs in South Africa should be replaced by a system that better reflects the capital costs of power generation and transmission in order to encourage both local and foreign investment and efficiency improvements in power generating capacity.

Drafting and adopting a differentiated electricity price policy would create effective energy guidelines for South Africa [29]. If differentiated electricity price policies are adopted and implemented in a similar manner to those of the Chinese government, this would encourage electricity savings and improve efficiency [30].

[27] provides the following facts regarding South Africa's electricity market: South Africa's nominal capacity is 44 175 MW, 92.6 % is produced from coal-fired stations. The authors state that the electricity demand projections indicate that an additional target of 40 000 MW capacity is required by 2025. Further, in their reporting, they indicated that, although South Africa's renewable energy sector is relatively young, the growing renewable energy industry in South Africa produces about 1415.52 MW, of which 43.6% (631.53 MW) of the country's renewable energy is produced from solar PV energy system.

The 2018 South African Energy Sector [31] report echoed the above figures and stated that the 40 000 MW capacity is required to address previously disadvantaged communities and affordable access to electricity. Meeting this requirement has increasingly caused a steep demand for electricity and this has further increased the load on Eskom's power plants, resulting in the over commitment of the power generating plants [31].

The [27] report further provides that an additional procurement of 18.2 GW of renewable energy is required by 2030, of which solar PV would be expected to contribute about 46% (8.4 GW), biomass about 2% (0.4 GW) and the remaining to other forms of renewable energy sources. The report indicates that the above figures are a reflection of additional energy required but does not include or account for renewable energy required to gradually replace electricity produced from coal-fired stations that are becoming more and more unstable as they coming to the end of their service life. This in other words states that operating the giant coal-fired power stations is proving to be expensive as well as keeping them functional. Thus procurement of renewable energy must be pursued by South African government with great interest in the view of climate change and health reasons as well.

According to [27], although government has in place policies that encourage the undertaking of green project(s) and has proposed over R20 billion towards such project(s), time-based implementation plans and new energy production policies at decentralized institutions such as municipalities are lacking and consideration of energy efficiency as a major contributing factor to energy usage in municipalities and/or any other institutions on the ground authorized to generate and distribute energy receive inadequate drafting of proposed comprehensive strategies and solutions that attempt to address energy inefficiencies.

[27] further points out that government has in place policies that promote green projects based on rebates for installation of energy efficiency and demand management interventions, tax credits for deployment of energy efficiency interventions and investment in green (renewable) projects. These policies include the following:

- Renewable Energy White Paper, 2003
- Energy Efficiency Strategy, 2005
- Regulations on Energy Savings Allowance, 2011
- Integrated Resource Plan (2010-2030), and

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- New Generation Capacity Regulations, 2009

Unfortunately, the above policies reflect government support for energy generation by private sector institutions and subsidies that benefit the same but lack government commitment of being an active partner in energy generation using renewable energy source(s). This lack of partnership or lack of desire to own diversified energy generation will create problems for the South African government in the near future as center of power in generation will shift from government owned to private owned. The projected effects of privately owned generation will counter or erode government objective of access to affordable electricity, and render the energy economy venerable to multinational manipulation.

In order to promote renewable energy exploration andutilization to the extent required to make it viable on a large scale, government should either invest and support municipalities and select identified small-to-medium enterprises (SMMEs) with the necessary expertise to aid municipalities, and/or institute a public sector institution with similar magnitude and capacity as Eskom that solely focus on green projects and be responsible for the generation and transmission of electricity from renewable energy sources. This will in a manner fast-track remedying the current energy situation and enable the ease of achieving targeted additional energy.

The March 2008 issue of South African Energy Statistics [32] carried a report which stated that the South African economy is dependent on energy resources because almost all economic activities of the country are in one way or the other directly or indirectly linked to energy consumption. The report further reflects that South Africa is a country with less rainfall and abundant sunshine, but still relies on coal as the main source of energy. The report observes that South Africa uses largely fossil based resources, and that guides and regulations have not been fully established to enable supported harnessing of renewable resources on a large enough scale to generate required amount of energy at municipal and subsequently national level.

[33] indicates that the ‘source-supply-process’ costs of harnessing energy from fossil fuels to secure the country’s energy security is a short term solution with severe consequences compared to renewable energy based sources. Thus government must invest in establishing infrastructure that enable and support renewable energy based initiatives.

The 2017 report by Deloitte [34] conveys a synoptic view of electricity consumption and pricing in South Africa and considers the relationship of economic activities of the country to energy demand, and vice versa. The report defines electricity intensity as the amount of electricity consumed to produce a unit of output and states that little transition has been made in shifting from high energy dependent economic activities in thepast 30 years and that electricity consumption resulting from such transition or economic activities with relatively less energy-intense result mainly from commercial institutions and government services institution which contribute about 15 % of the total electricity consumption.

[34] further indicated that the energy consumption of water and wastewater treatment plants is dependent on the sensitivity of the technology used at the treatment plants in terms of energy efficiency and the modernization of households as households are responsible for water consumption and sewer load discharge to wastewater treatment plants, as the sewer type dictate the number and type of process activities that must be conducted at the wastewater treatment plants. A study by CSIR [35] indicated that most, if not all municipal wastewater treatment plants in the country use old poorly maintained technology that has no consideration for energy efficiency.

[36] lists the following factors as influencing demand for electricity:

- price of electricity which mainly depends on the type of source used, process of producing electricity and supply status of electricity to demand at hand
- growth in level of economic production
- population growth
- weather patterns, and
- technological advancement

A report presented under the auspices of Project 90 [63] estimates that by 2030 energy transformation in South Africa will result with 69 % of the country’s energy production being from coal-based sources, a decrease from the current 92.6 % contribution from the same source. Further [63] indicate that the projected energy produce by 2030 would have a 11% and 3% contribution of the total electricity generation from solar and wind sources respectively. Furthermore, the report reflects that biomass energy production will also grow along with solar and wind energy production. The question is: has government established resources and tools to ensure that projected goals are met other than the allocating of funds without any proper detailed plan?

According to the International Energy Agency (IEA) report of 2013 [63] there are two fundamental drivers of demand for electricity at a macroeconomic level; revenue and price. According to the principles of macroeconomics, rising levels of economic activity are normally associated with increased demand for electricity and energy in general, and rising electricity prices tend to reduce energy or electricity consumption. The report states that the other factors that significantly influence the aggregate demand for electricity are energy intensity of economic growth and impact of technological change. The IEA report in essence indicates that the affinity for electricity is greatly influenced by cost associated with electricity generation from type of fuel source used and the type of processing for generation.

Both [63] and [36] indicate that a change in technology has an important impact on electricity demand, though tensions exist between technological factors regarding those that are considered to increase energy demand versus those that decrease energy demand. [63] states that the key drivers or components of electricity demand, based on a decomposition demand approach, are:

- activity effect which is the change in demand due to change in economic activities. The change in economic activities of each sector is known as the gross value-added (GVA).

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- Structural effect which is the change in demand due to change in the mix of economic activities or sectors within the economy, and
- Intensity or efficiency effect which is the change in demand due to change in energy use per unit of sectoral activity.

In support of the above mentioned factors, [38] determines that energy (electricity) demand is influenced by the sector's electricity share effect on total energy demand and the intensity effect. [38] indicates that the share effect is the positive impact of sectors on electricity demand substituting away the dependence on other energy sources towards electricity, whereas the intensity effect is responsible for the dominance in electricity consumption over a period.

Based on the views of [63] and the World Energy Council (WEC) [39] on energy efficiency, [11] states that the reduction in energy consumption associated with technological changes usually focuses on efficiency based electricity intensity, which [40-42] define as the change recorded in electricity intensity in terms of electricity consumption per national production unit in Joules per rand of the GDP. Reduction in energy consumption by this method would result in an improved economic condition that improves electricity consumption of production processes, which is a low cost and effective way of curbing energy demand in the economy [11].

[43] states that the South African industrial electricity efficiency is an ongoing concern as it contributes far less to the South African GDP, and is considerably low than global averages. In order to address this challenge [11] suggests, based on the views of [42], that South Africa's electricity supply shortages require a nation-wide demand-side management programme that will improve energy efficiency.

[44] points out that research institutions are faced with increasing pressure to come up with management technologies that can manage electricity demand and cost reduction caused by energy efficiency. In particular, these technologies are required for many legacy facilities and equipment that were built at a time when energy optimisation was unimportant and the challenges of managing electricity consumption from the national grid were insignificant.

Energy-efficient facilities are not common in South Africa; therefore, technical interventions must be supported in order to achieve energy efficiency [44]. [45] is of the view that well-motivated personnel are best at developing and implementing energy efficiency policies which can produce benefits such as cost reduction, savings on utility bills, improvements in ways in which facilities and equipment are operated and maintained, and creation of energy efficient systems.

When there is an unbalanced grid, two options exist to restore a stable electricity grid: the first is to increase the supply by building new infrastructure or electricity generating plants, and the second is to decrease energy demand by improving energy efficiency through encouraging consumers to switch off appliances, or switch to renewable energy sources [46]. The author further states that, since it is important to consider time frames, initial capital investment, maintenance and operations costs, as well as potential energy savings, load-shedding is the least popular method to bring about a decrease in demand for electricity, as load-shedding also frightens investor confidence and has negative effects on economic growth activities.

Considering that the government endorsed the building of new coal-fuelled power stations (Medupi and Kusile) which were costly to build and are costly to operate, and taking into account the prices of processing coal to electricity, and, finally, considering the uncertainties of unreliable behavioural of the existing coal-fuelled power stations together with actions by consumers, as stated by [46], this paper aims at suggesting decentralised and diversified generation using renewableenergy sources as the future of the energy sector in South Africathat will secure first class economic trade and development with no harmful effects on the environment especially at municipal level.

The energy status of South Africa is at a crisis level because municipal institutions around the country owe Eskom billions of rands leading to heavy national deficits in terms of energy and cash, lack of power capacity, inability of the country to provide reliable energy supply, and reduced ability to drive energy dependent economic activities and service delivery at municipal level. Worsening the situation is that because South Africa cannot claim a reliable energy supply there are threats of a downgrade by rating agencies which affect inward investment and the ability to borrow money, and then there is the issue of corruption which its tremendous impact is difficult to quantify at this stage. This all has a negative impact on South Africa's economic ability and capacity for development [14].

The above analysis is echoed by [47] who states that the critical challenge of addressing power shortages lies with finding money to support renewable energy based initiatives (power supply) and investing in expanding infrastructure that positively supports energy supply and restoration of efficiencies of existing power generating and transmitting infrastructure. [48] echoes concerns expressed by various sources on energy related challenges in South Africa saying that investors are taking their monies and skills elsewhere where their interests will be more safely secured than a country characterised by incapability and incompetence in being able to provide security of energy supply to meet desired operations and rising energy demand projections.

[49] states that government cannot afford to underestimate energy demands as it seems to be doing all the time. Government should invest in comprehensive strategies and capital investments that facilitate and fast-track security of energy supply and counteract the effects (costs) of generating electricity from the fast-depleting coal-based fuels that erode any form of financial savings.

[50] reiterates the challenges of South Africa's electricity supply industry by stating that the power crisis faced by South Africa is as a result of energy generation uncertainty, indicating that the electricity supply industry in South Africa is not open to competition, which is why Eskom (the government's biggestand only trusted energy utility or enterprise) continues to build coal-fired power plants irrespective of being expensive to operate and generate electricity. The author further suggests that the electricity supply industry in South Africa should be openedto competition.

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Although generation did not accommodate full private sector participation in energy generation nor was the private sector allowed to design and influence electricity tariffs in order to give private investors the returns on investment attractive, government is starting to engage private sector institutions through various indaba conferences with the different trade sectors such as mines to achieve far reaching (sustainable) solutions.

[50] writes, diversifying the energy mix with renewable sources addresses long-term energy shortages and WEF recommendations. [50] states that, although additional energy supply from renewable sources is the prime focus, all of the above is fruitless if energy efficiency is not considered, as energy efficiency is one of the major drivers that shapes the environment in which the electricity supply industry is required to deliver electricity now and for decades to come.

[51] states that, although South Africa has a massive target of new energy generation capacity from renewable sources, one of the identified sources for scaling up is the recovery of energy from waste at municipal level.

Based on views expressed by [52], [53] states that the three paramount elements of energy security are sovereignty, robustness and resilience. According to [53], in order for government to speedily achieve adequate energy security, government must work tirelessly, aggressively and have control of processes that address infrastructure backlogs, investment or funding paralysis, inadequate planning and forecasting of resource management, preventions of public- private partnership, lack of resource change management, lack of energy efficiency management concept and implementation, and lack of frequent reviews. Further, [53] states that to address the complexity of energy security in South Africa the authors advocate for conceptualisation of energy security that is in line with the World Energy Council's tenets of accessibility, availability and acceptability, also endorsed by the Department of Minerals and Energy.

[54] states that, though small and medium enterprises (SMEs) in South Africa are regarded as the future engines of growth for the South African economy, they are one of the most vulnerable sectors in the face of an unstable energy environment and policy shifts, since SMEs are generally incapable or lack the resources necessary to invest in alternative sources of energy. Because of this vulnerability, the South African economy faces struggling growth within municipal jurisdictions.

Regulations on new generation capacity under the Electricity Regulations Act have been developed to encourage co-generation which includes current conventional energy sources and renewable sources. The national energy efficiency strategy developed and reviewed in 2017 forms the basis for mandatory biofuel blending regulation [10]. With these policies in place a platform has only been recently created to allow institutions such as municipalities to authentically generate and distribute their own electricity using renewable sources. However, lack of funding or financing of the feasibility of municipalities generating own electricity is lacking. The question is how long will these feasibilities at municipal level be attained during a time when energy solutions are so essential.

III. RECOMMENDATIONS

Studies conducted by the United States Environmental Protection Agency in 2013 [55] on energy efficiency in water and wastewater facilities indicated that local municipalities are among the largest consumers of energy in the community, and significant amounts of municipal energy consumption occurs at water and wastewater treatment facilities. The report states that local governments can save energy through employing energy efficiency improvement strategies on both water and wastewater treatment plants within their jurisdiction in order to reduce operating costs, energy consumption and also free resources to embark in additional investments that promote energy conservation. In agreement with the views expressed by the United States Environmental Protection Agency [55], [51] point out that the Constitution of the Republic of South Africa mandates municipalities to responsible for the role of harnessing waste for energy purposes.

Although wastewater treatment plants consume large amounts of energy, the same plants have the capacity to produce large amounts of biogas (a combination of methane and carbon dioxide) from sewage sludge [56]. In support of this [8] states that the process of using harvested natural gas (methane) from natural reserves such as from human waste for the purpose of generating electricity, together with the use of improved appropriate technologies that produce and use the mixture of methane, carbon dioxide and traces of other gases, deserves investment in order to enhance energy generation.

Municipal wastewater treatment plants present untapped sources of renewable energy, and the use of bio-solids can generate biogas that contains up to 70 % methane which can be used to generate electricity [58]. [58] states that over and above having raw sources of energy, municipalities must undertake continuous sub-metering measures of industries and major pieces of equipment in their facilities in order to identify energy-saving opportunities by capturing diurnal variations in electric energy demand so that reviews of equipment replacement or modification and methods of operations can be made.

[59] states that the time has come to challenge the conventional electricity utility business model which is based on a centralised system of generation, transmission and distribution, through the use of disruptive technologies (innovations that when scaled up causes disruption to the basic architecture of the electricity generation system) and 'prosumer' (producer- consumer) electrification. When a disruption occurs in a centralised system the whole grid (nation) gets affected whereas when disruption occurs in a decentralised system, the problem is localised in that area. The benefits among others are reduced repair time, reduced transaction costs and impact to the general economy, and etcetera.

The Mercury newspaper of 4th February 2020 [60] reports that the current Minister of Mineral Resources and Energy at a mining indaba held in Cape Town said that the government was going to focus on two main initiatives: partnering with investors regarding generation of new forms of energy, (with a blueprint setting out the rate and schedule of decommissioning Eskom's ageing coal-fired power plants by 2050), and providing municipalities with autonomy to generate their own

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electricity. The minister claimed that government is currently in the process of gazetting a revised Schedule 2 of the Electricity Regulation Act that will facilitate municipal generation options under 'distributed generation'.

Based on the 2008 Statistician General's report on South Africa's Energy [61] that South Africa has abundant sunshine, partnering with expert investors in solar energy production is a step in the right direction for securing stable and adequate energy supply. Onyekwelu and Akindeke (2006) [62] warn that the most common mistake made by African governments is their tendency of owing allegiance to multinational corporations that are often profit oriented, to the detriment of their citizens.

If each province had their own tailor made renewable energy plants at municipal level, each municipality would have their very own business attraction and model, and each respective province would be an economic hub influenced by the type of and dominant energy generating scheme found in that province. [63] proposes decentralised generation and distribution on the primary grid component with smaller macro-grids being supported by mini-grids.

IV. CONCLUSION

Based on the above views of the energy supply status in South Africa, the country stands a chance of recovering from its near catastrophic energy crises by finding meaningful strategies that fast-track dealing with the core energy issues in a well-thought out manner. This involves identifying that the energy supply basket must to be opened to diverse forms of energy generation from different sources, that more role players must be introduced in the energy supply sector through partnership agreements with both local (public and private) institutions and multi-national companies, and that energy generation be decentralised to municipalities where mines, industries, and other business activities are located.

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Chapter 4: Energy Efficiency at municipal wastewater treatment plants using Microbial Fuel Cell technology

The author examine the views expressed by researchers and other scholars in the field on what treatment processes are available and can be used to ensure that the conversion process of biomass from municipal waste (sewage) is efficient when using the microbial fuel cell (MFC) technology for the generation of electricity. The article was published in the International Journal of Mechanical Engineering and Technology (IJMET).

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ENERGY EFFICIENCY AT MUNICIPAL WASTEWATER TREATMENT PLANTS USING MICROBIAL FUEL CELL TECHNOLOGY

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ABSTRACT

Microbial fuel cells (MFCs) are bio-electrochemical devices that convert organic substrates found in biomass to electrical energy. For efficient conversion of organic substrates by MFCs, and consideration of energy efficient treatment processes, the collected raw biomass (sludge from municipal sewage) must be treated before being ready for MFC or bio-fuel production. For this study, the treatment of raw biomass before use is considered as pre-treatment, and the details of the importance of pre-treatment is highlighted together with the need for municipalities in South Africa to conduct technical feasibility studies for pre-treatment processes before selecting which technology to use. This paper highlights the contribution of pre-treatment process technologies that are available for municipalities to utilise when exploring energy generation using MFC technology.

Keywords: Microbial fuel cells, bio-electrochemical devices, energy efficiency.

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1. INTRODUCTION

South Africa has three spheres of government; the national sphere, the provincial sphere and the municipal sphere. Since the country is currently facing an energy crisis, well planned initiatives centred around renewable energy are required by all spheres of government to restrainthe growing energy demand from SA's national supply grid. This paper focuses on theimportance of pre-treatment of municipal wastewater for the purposes of electricity generation by means of microbial fuel cells (MFC). Lieu [1] states that untreated municipal wastewater is a leading source of pollution, and that municipal wastewater must be treated before being discharged to the environment or used as the basis for power generation. In order to generate electricity from collected municipal wastewater, feasibility studies of pre- treatment processes must be undertaken in order to assess the benefits of energy efficient processes. The parameters of this research work do not include the effect of the condition of the infrastructure and the performance of the technology used, namely, MFC.

2. METHODOLOGY

2.1. Background

Sørensen [2] defines energy as the power from electricity that is used to make machines work. Lindo [3] states that since we live in a power- (energy-) hungry world where power is key to industry, and that different forms of energy exist, what is important is the transformation of energy from one stable energy state to another. Lindo [3] further states that electrical energy is a stable energy form that is produced by converting (among other material) biomass to produce electric current. Basically, bioenergy is energy stored in biomass [4].

The demand for electricity is growing in both developed and developing countries due to increasingly fast industrialisation [5] therefore energy security has become a global challenge regarding rising energy demand and increasing generation costs [6]. Wastewater treatment plants in the municipal environment or sphere are energy intensive processes that require significant implementation of efficient treatment processes or systems to improve sustainability, reduce energy consumption and reduce the costs of generating electricity and operating wastewater treatment facilities [7].

The increasing industrialisation and motorization of the world has led to a steep rise in demand for the dominant replaceable petroleum based fuels at the same time as reserves are fast depleting, thus accelerating the appetite for alternative renewable sources of energy [8]. This global energy crisis and continuous increase in energy produced from fossils-based sourceshas stimulated an urgent need to develop or improve existing developed technologies that will grow renewable energy as a viable source of energy to cater for the current growing and future projected energy demand.

The Financial Mail [9] edition on South Africa's energy crisis together with the views of Barker [10] show that the South African government is far from resolving its energy related matters regarding security of supply. Government is currently playing catch-up in order to build sufficient energy capacity to meet the current and forecast demand. One of the methods implemented to accumulate capacity, apart from the construction of the coal-fuel based power stations Kusile and Medupi power stations which started in 2010 and is still ongoing, is the implementation of load-shedding. Load-shedding has frequently been used by Eskom (South Africa's only government owned energy utility) to accumulate capacity, however the downside of this method is that it damages investor confidence.

The South African economy suffers from lack of power but at the same time hundreds of billions of rands are owed by municipal institutions around the country to Eskom [10], thus leading to heavy national deficits in terms of energy due to lack of maintenance. Coupled to the above is the competency of energy planning personnel at both national level and institutional (Eskom) level, and high levels of corruption in the energy sector. The lack of power capacity reduces the ability to drive energy dependent economic activity growth [10].

South Africa is a developing country with fast depleting fossil fuel based energy resources, with rising costs; the energy demand and usage trends suggest that cheaper sustainable energy resources must be explored, and one of the resources is biomass conversion at municipal level [11]. The government must seek new strategies of supporting municipalities in developing the capacity for energy generation in order to reduce grid demand and enhance energy sustenance at municipal level in relation to its plants and facilities that currently contribute to high energy bills.

While countries seek to be energy self-sufficient and produce their own power, the interdependent world through its modern economic activities has forged a common requirement for access to adequate and reliable energy resources, as energy supplies are central for economic growth [12]. Countries, governments, industries and individuals must be urged and encouraged to support and expand existing technologies aimed at utilising renewable energy, and make such energy converting technologies more viable [13].

The Water Research Commission (WRC) [14] of South Africa published a basic guide for municipalities and government institutions at municipal levels regarding the various wastewater treatment technologies available for the South African market, focusing mainly on sewer and industrial discharge systems. The WRC report suggests that in order to ensure that there is sustainable development in the biomass industry, suitable technology types must be selected in a manner that suits specific purposes, developments and applications. Efforts to improve and modernise biomass processing should be an important component of national energy strategies, so African countries such as South Africa and institutions at a municipal level must significantly increase their appetite for adopting more modern, efficient and sustainable bioenergy production, conversion and end-use technologies to secure and enhance their renewable energy base [4]. Government must encourage municipal officials to utilize energy efficient technology that not only addresses biomass resources, but also enables the production of electricity from biomass as a viable alternative for clean and sustainable sources of energy that improve the quality of life [1].

The pre-treatment process itself requires some form of energy consumption, but one can no longer simply rely on the ability of the technology employed to treat raw biomass for generating electricity without consideration of energy efficiency. At this stage of the energy crises across South Africa, the feasibility of pre-treatment must be investigated and the best- suited technology be selected, bearing in mind energy efficiency in the type of processes that are required for electricity generation. Due to the large amount of energy required to drive power generating industries together with advanced treatment requirements, energy consumption must be reduced through efficiency in order to promote a more robust economy [15].

Biomass is a viable energy resource at municipal level, but the benefit of biomass is determined by the type of processing technique used to pre-treat and main-treat the raw biomass. Biofuel production or electrical energy generation relies heavily on new bio-refining technologies, pre-treatment, treatment and saving of biomass for electricity production in the energy sector [16].

The pre-treatment process is important and crucial to the whole electricity generating process from biomass, however, the following aspects must be determined to ensure efficient processing:

- Condition or specification of the fuel to be produced for the generation of electricity.
- The process efficiency of generating electricity and energy conservation.
- The suitability of the technology used to produce the necessary biofuel, although this item or aspect is partly influenced by the type of raw biomass being collected at the wastewater treatment plant.

The above is indicated in view of current practises in South Africa where there is an increasing tendency for procuring well-marketed technology without adequate feasibility examination of the technology in relation to the prevailing environmental conditions within which the technology must operate. This paper attempts to demonstrate the importance of implementing the correct selection of processes and technologies as a means of enhancing energy efficiency, thus reducing the energy required to convert the appropriate biomass to electricity. This work places an emphasis on efficiency of treatment based on having a detailed understanding of biomass content and energy considerations rather than basing treatment processes on the available technology at a particular time to conduct the treatment process.

The purpose of conducting a feasibility study is to critically examine the following items so that the effects of the pre-treatment technique can be determined with accuracy in terms of energy conservation and efficiency:

- Determine the elements present in the raw biomass collected at the treatment plant.
- Determine the environmental conditions in which technology must operate.
- Determine the type of operations of the equipment (application).
- Determine the maintenance conditions of equipment.

Sinha [17] further states that, in view of the above, the following factors must be incorporated in motivating for the use of MFCs for electricity production:

- The bacteria and bacteria type that are adapted to feed on virtually all available carbon sources (complex organic matter in sewage, sludge, and etcetera), making bacteria potential catalysts for electricity generation from organic waste.
- The characteristics exhibited by each bacteria type in terms of being omnipresent and self-producing, self-renewing catalysts, thus can be cultured continuous in an MFC for long term operation.
- The catalytic core of fuel cells – considering and comparing conventional fuel cells that use very expensive metals, and bacteria used in MFCs that significantly reduce the cost, as a viable alternative.

Research suggests that that the pre-treatment of biomass substantially improves anaerobic digestibility and biogas production as a basis for electricity generation [18]. Raw biomass must be treated before use in such a way as to produce specific and suitable energy fuel for use [17]. Sinha [17] lists three classes of treatment in the municipal environment:

- Biomass cleaning, a process that involves cleaning and removing harmful species and elements such as sulphur, halides, ammonia, and nitrogen.
- Biomass conversion, a process that converts the natural raw available biomass to a hydrocarbon-based fuel such as ethanol, methanol, and etcetera.
- Downstream processing, a process that involves reformatting by converting carbon monoxide and water content in the raw biomass through either oxidation to reduce carbon monoxide concentration measured in parts per million, or remove water by condensing it to increase hydrogen concentration.

In view of the pre-treatment process, the process before the conversion process responsible for the generation of fuels, Sinha [17] details how raw biomass can be cleaned in a two-chamber reactor to remove elements considered as impurities: in chamber 1 sulphur contents are removed through a high temperature of about 350 °C, while in chamber 2 with lower temperatures of about 200 °C to 260 °C the carbon monoxide and nitrogen content are removed. The state of biomass after pre-treatment or treatment process must be free of substances considered as impurities such as sulphur and nitrogen elements [19]. According to White and Plaskett [20], the full treatment of raw biomass involves primary, secondary and tertiary processes that enable the achievement of the right content of biomass fuel to be used for the efficient generation of electricity.

Although the WRC [14] lists four treatment processes (preliminary, primary, secondary and tertiary), in this paper the preliminary and primary treatments are considered and referred to as the pre-treatment process. The purpose and aim of this paper is to illustrate the importance of pre-treatment of collected biomass before being converted for a specified application, the importance of having the appropriate pre-treatment process, and how pre- treatment positively influences efficiencies of power generation systems when properly undertaken.

Various types of biomass of different quality exist based on institutional discharge type such as industrial and/or communal (household and commercial), biomass composition, and purpose for which the biomass is to be used. Sinha [17] indicates that common impurities must be removed from all types of biomass collected before the biomass content can be converted to workable hydrocarbon based energy fuels suitable or fit for electricity generation. Impurities in relation to MFC technology are: sulphur, phosphorus, ferrous and non-ferrous elements and carbon. The first chamber of the biomass treatment reactor is dedicated to removing toxic inorganic contents such as sulphur, phosphorus, and etcetera, and the second chamber is for the down-streaming process which removes concentrations of carbon monoxide and converts it to carbon dioxide together with removing the water content resulting in hydrogen rich concentrations [17].

The main steps involved in preparing the sewage sludge for biogas production and subsequently electricity are as follows [21]:

- Pre-treatment of activated sludge through the use of a highly loaded liquid fraction that results from dewatering of digested sludge, re-introduced and mixed with raw wastewater arriving at the start of the treatment process. This process involves the process of removing nitrogen.
- The mixed sewage sludge obtained by the wastewater treatment plant for anaerobic digestion processing is collected and kept in drying beds where the sludge is sieved and then thickened to a dry solid content of up to 7% to avoid excessive water content that can result in excessively high consumption of energy for pre-treatment (heating of sludge). This is accomplished through the use of disintegration technologies with the purpose of increasing or improving the yield of biogas.
- Sludge is pumped into the continuously stirring anaerobic tank reactors (CSTR), where the sludge is digested at mesophilic temperatures of between 35 °C to 39 °C. During a retention time of about 20 days in the tank reactors, microorganisms break down part of the organic matterand produce biogas, which is composed of methane, carbon dioxide and traces of other gases.
- The raw biogas produced from sewage sludge is dried and separated, removing hydrogen sulphide and traces of other substances from the methane so that a good quality of gas is obtained and corrosion or unwanted deposition in the combustion equipment is avoided. Special attention is paid to the concentration of siloxanes, as siloxanes result in deterioration of performance of equipment. This step is a cleaning of the raw biogas to upgrade raw biogas to biomethane for the purpose of generating electricity and heat simultaneously.
- Post-treatment of digested sludge involves transforming about one third of the solid matter in the sludge into biogas, an equivalent of about 50% of the organic matter in the sludge. For the purpose of this research work, this process step is not discussed as it entails a secondary treatment to the residue sludge that is used for other purposes such as production of fertilizer for agricultural purposes and not production of biogas for electricity generation purposes.

Pre-treatment costs for pre-treatment of sewage sludge for biogas production to produce content fit for electricity generation involve [22]:

- Collection and treatment infrastructure and inventory costs, which address availability and flow proportions of biomass.
- Technology costs of existing technologies and costs of technology maintenance and improvements, which indicates and includes the cost effectiveness of selected technologies together with maintenance costs of the technologies.
- Viability costs (economies of scale) of pre-treatment of biomass processing efficiency and energy saving costs, based on received raw biomass contents, which concerns the costs of the pre-treatment process to handle increased demand in the future and the viability of the relevant technology.
- Regulation costs, which address the compliance costs regarding legislative requirements on biomass, governance commitment and renewable energy production costs. This includes other agreement costs in place in relation to removing and disposing of toxic and inorganic residue from the organic matter to be used for generation.

The goal of biotechnology is the development of new viable biotechnology that converts biomass to fuel energy more effectively and efficiently [24]. Thus, Onyekwelu and Akindele [4] are of the view that reliance on biomass and bioenergy is, among other things, dictated to by the availability and quality of collected biomass and quality of the pre-treatment process of raw biomass waste to cater for existing and projected energy demands. In order to extract the needed energy, especially in developing countries, primitive (readily available and affordable)methods of harnessing energy from readily available biomass are required [23].

The WRC [14] states that the pre-treatment processing techniques indicated by Sinha [17] for the treatment of raw biomass must be viewed in a holistic manner so as to not only view the pre-treatment types, but also the impact that each can have towards ensuring that the conversion process is effective and efficient for the generation of electricity. The WRC [14] holistically suggests that the pre-treatment of biomass involves two phases: the physical pre- treatment phase, and the subsequent electrochemical pre-treatment phase, with the second phase being heavily dependent on the effectiveness of the first phase.

2.2. Physical Pre-Treatment Phase

The physical pre-treatment phase involves mechanical techniques for removing or separating foreign objects or substances from the raw biomass content, which involves processes such as screening of metals, removing of debris and rocks, and etcetera [17]. The WRC [14] describes the four physical pre-treatment processing activities as:

- Screening, a process that involves removing foreign objects and preventing build-up of debris that can potentially damage the plant equipment, such as removing rags, plastics and wires contained in the biomass or disposed waste. Screening is basically a mechanical function that requires a constant energy supply, low labour costs, low energy consumption, and improved flow condition costs, however has potentially high equipment maintenance costs.
- Grit removal process, a process that removes sand, silt, glass, small stones, as well as large- sized organic and inorganic substances (debritus) in order to prevent pump blockages, and prevent high organic concentrations in digesters and reactors, which protects all moving mechanical equipment from abrasion.
- Comminution, a process that uses mechanical equipment such as shredders to reduce the size of solid materials in sewers or industrial discharge to manageable smaller average particle size through actions such as grinding, crushing, cutting, vibration or any other process action before separation action occurs.

- Separation, a process that actively separates collected biomass either from municipal solid waste (MSW) refuse or activated sludge resulting from sewage in wastewater plants using ponds, sedimentation or separating tanks. Each biomass is separated into a different class based on the physical properties of the product. This process normally occurs as the last activity of the physical pre-treatment activity, just before the second pre-treatment process phase is conducted. Sinha [17] indicates that the separation process is biochemical or involves combustion and/or a combination process of the two depending on the proposed use of the biomass.

The application of the each of the above is dependent on the raw biomass collected at the wastewater treatment plant. The second pre-treatment phase is a chemical or electrochemical process aimed at removing toxic and/or inorganic elements from the biomass substrate, and improves the chemical composition of the biomass for the purpose of generating energy [17]. Sinha [17] lists some of the main types of fuel-processing techniques available as being:

- Steam reforming (SR)
- Partial oxidation (POX)
- Catalytic and non-catalytic and auto thermal reforming (ATR)

Further Sinha [17] mentions techniques such as:

- Dry reforming (DR)
- Direct hydrocarbon oxidation (DHO)
- Pyrolysis

For this research project a brief description and definition where necessary is outlined of the different fuel-processing techniques as outlined by Sinha [17] and other available literature sources. Although most fuel processors use the chemical and heat energy of the fuel cell to provide heat for fuel processing, system efficiency is enhanced by the processing techniques listed below.

2.2.1. Steam Reforming (SR)

SR is a technique used to convert light hydrocarbons to hydrogen. In this process fuel is heated, vaporized and injected with superheated steam into a reaction vessel. Apart from excess steam, nickel or cobalt-based catalysts are used to complete the reaction and enhance reaction rates at lower temperatures. SR is a slow reaction technique that require large reactor chambers and is suitable for pipeline gas and light distillates that use fuel cells for stationery power generation [17].

2.2.2. Partial Oxidation (POX)

POX is a technique that uses sub-stoichiometric amounts of air or oxygen to partially combust fuel, and the resulting high-temperature reaction products are quenched using superheated steam to promote the combined water gas shift and steam-reforming reactions which cool the gas. For catalytic POX reformers, these occur at temperatures of 870 °C to 925 °C whereas for noncatalytic POX reformers, these occur at temperatures of 1175 °C to 1400°C. Sinha [17] indicates that both types of POX reformers have higher reforming efficiencies than SRs.

2.2.3. Catalytic and Non-Catalytic and Auto Thermal Reforming (ATR)

ATR is a technique that is a combination of SR and POX processes in the presence of a catalyst that control the reaction pathways and determine the relative extent of POX and SR reactions. The SR reaction of the ATR functions to absorb part of the heat generated by the POX reaction, limiting the maximum temperature in the reactor. This is a self-sustaining process with high hydrogen (H_2) concentrations. ATR fuel processors operate at lower cost and lower temperatures than POX reformers and are smaller in size, quicker starting and faster responding than SR [17].

Although sulphur is removed with ATR, sulphur containing odorants are added to fuels in order to enable leak detection. Sinha [17] states that sulphur is generally removed using zinc oxide sulphur polisher at temperatures of 350 °C to 400 °C. Zinc oxide functions to remove mercaptans and disulphides. Removal of the sulphur containing odorants involves the addition of a hydrodesulphurizer stage before the zinc oxide polisher is required. With ATR, hydrogen converts thiophane into H_2S in the hydrodesulphurizer, and the zinc oxide polisher easily removes H_2S [17].

To reduce levels of CO in the reformatted gas, water gas is shifted in two to three stages, where the first high temperature stage allows for high reaction rates, and the lower temperature converter allows for a high conversion rate. The excess steam is then used to enhance CO conversion. The ATR technique enables a toleration up to 50 parts per million (ppm) of CO levels [17].

Sinha [17] states that the following three variables are crucial to all electrochemical pre-treatment processes for producing the necessary biofuel product, namely: air management, water management, and thermal management Although the three variables are briefly shared under the ATR techniques, they are applicable to all electrochemical techniques.

Air management is critically important to both fuel and fuel cells as they both require oxidation. Air provided to the fuel cell cathode can be provided at low or high pressure. At high air pressure supply the reaction kinetics power density and efficiency of the stack are increased. In other words, increasing the air pressure increases the power required to compress the air, thereby reducing the net power available for the fuel cell stack operating at pressures of between 1 atmospheric pressure to 8 atmospheric pressure [17].

Water management is critical for fuel cell operation, and since water (H_2O) is a product of fuel cell reaction, and must be removed from the exhaust gas, water condensed from the exhaust steam is recycled for reforming and reactant humidification in a closed cycle to avoid periodic recharging with water [17].

Thermal management is management of waste heat from the fuel cell. Since the products of electrochemical reactions in a fuel cell are water, electricity and heat, the heat energy released in the fuel cell stack is approximately equal to the electrical energy generated if the fuel cell stack is maintained at optimal temperature levels. When thermal energy management is considered, waste heat from the fuel cell must be properly managed in order for the efficiency levels of the fuel cell system to be maintained or increased. At low temperatures of less than 200 °C, the fuel cell stack such as those for polymer electrolyte membrane fuel cells, methanol fuel cells, alkaline electrolyte fuel and phosphoric acid fuel cells are cooled by supplying excess air for low power systems of less than 200 W, whereas for large sized systems, liquid coolant (deionized water) is used, as the waste heat carried out by the coolant is utilized for cogeneration. At high temperatures of less than 600 °C fuel cells such as MCFC and SOFC haveall their heat reaction transferred to the reactants to maintain the stack temperature at optimal level. The thermal energy management of high temperature exhaust must be utilised to preheatincoming air stream or fuel reformation. High temperature exhaust must be used for cogeneration or electricity generation in a downstream gas turbine system [17].

2.2.4. Dry Forming

According to Jiang [25], dry forming is a technique used in the pulp and paper industry, whereby wood pulp is treated before being used. Dry forming is a 3-stage process that involves drainage, pressing and drying of biomass and requires less or no water removal, thus offering more energy efficient forming [25]. Although wet forming techniques exist and are used to treat biomass, detailed consideration of wet forming is not discussed in this paper due to the advantages presented by dry forming over wet forming. Dry forming itself requires pre-treatment processes, but some of the advantages presented by dry forming as a pre-treatment technique are as follows:

- Provides for excellent formation of feedstock as biomass contains very minute amounts of water content.
- Provides significantly lower capital and production cost, with incrementally increased production capacity.
- It is a more self-sustaining, high-efficiency process that does not require water reformation and effluent or waste disposal facilities to retain high efficiencies.
- Provides significant savings from transportation and water treatment costs, as dry forming processes are normally situated on-site. Thus, overcomes water-pollution problems and reduces energy related costs.
- Dry forming presents lower investment cost per ton on the same hourly production basis compared to a wet-laid process [26]. The costs of a wet-laid operation are four times higher than that of a dry-laid operation [25].

2.2.5. Direct Hydrocarbon Oxidation (DHO)

DHO is a process used to treat biomass that can either proceed by oxidation reaction through using oxygen at temperature ranges of between 200 °C and 300 °C or through the use of high energy oxidants such as ozone and hydrogen peroxide and/or photons that are able to generate highly reactive intermediates (oxide radicals) [27]. Hydroxyl radicals aggressively attack virtually all organic compounds found in raw biomass [28]. These radicals attack the compounds by abstracting hydrogen atoms from water, as with alkanes or alcohols, or by addingthemselves to olefins and aromatic compounds. Thus, the attack by hydroxyl radicals, in the presence of oxygen, initiates a complex cascade of oxidative reactions that lead to mineralization of organic compounds [27].

2.2.6. Pyrolysis

Pyrolysis is a thermochemical decomposition process of the organic material of biomass, heated and decomposed under inert atmospheric conditions of temperatures of between 400 °C and 900 °C in the absence of oxygen or reagents such as water to produce bio-gas products, bio-oil fraction and carbon rich charcoal residue [33, 29]. Based on the work of Demirbas and Arin [30], Brownsort [29] states that, although pyrolysis converts the organic material in biomass to volatile matter, the parameters or factors that impact the pyrolysis process are: biomass type and preparation of feed, pyrolysis temperature, required catalyst, the velocity of the sweeping gas, particle size, reactor geometry, and the heating rate of raw biomass [31]. The pyrolysis process can either be undertaken in a slow or a rapid manner [32] and exhibits the following main features: at near ambient pressure conditions, no chemicals or catalysts are required, low capital investment is required, flexibility of feedstock is exhibited, and there is variability of temperature and minimum feed pre-treatment. This technique must have low moisture content of between 14 % and 18 % to provide a suitable viscosity for the handling of biomass or feedstock, especially MSW [32]. The South African Water Research Commission report compiled by [14] states that the pyrolytic process is an endothermic process that involves splitting organic matter in biomass into gas, liquid and solid phases.

Though bio-oils are a complex mixture of higher molecular weight hydrocarbons with significant energy density, bio-oils can be used to produce direct heat energy for electricity generation. Carbonization is a pyrolytic process with the aim of biomass carbonization to promote higher charcoal production rates in order to achieve higher conversion product yields. At temperatures above 600 °C the carbon-hydrogen structures of bio-oils break evolving hydrogen, so bio-oils must be further treated for the removal of the oxygen component as well as the aquatic fraction and acidic compounds contained within them [33].

2.3. Electrochemical Pre-Treatment Phase, MFC Technology

Although the pre-treatment phase of biomass involves both physical and electrochemical processes, a very critical component of electricity generation when using MFCs, the effectiveness and efficiency of pre-treatment process is directly related to the requirements of the selected MFC electrolyte, the type of energy fuel produced from biomass treatment, biomass conversion process type, and electricity generation [14, 17].

MFC technologies convert chemical energy to electrical energy and differ depending on the electrolyte type used and the type of feed (treated biomass) requirements [34].

Curley [35] identifies and classifies fuel cells into six common types of fuel cells based on their electrolyte type:

- Alkaline fuel cells that generally operate at temperatures less than 100 °C and use aqueous sodium hydroxide or potassium hydroxide as an electrolyte.
- Phosphoric acid fuel cells that operate at temperatures up to about 200 °C and have orthophosphoric acid as an electrolyte.
- Molten carbonate fuel cells that operate at temperatures of about 650 °C and have molten potassium lithium carbonate as an electrolyte.
- Solid oxide fuel cells that operate at temperatures between 900 °C and 1000 °C and have an ion-conducting oxide such as zirconia treated with yttria as an electrolyte.
- Solid polymer electrolyte fuel cells.
- Proton exchange membrane (PEM) fuel cells.

Hirschenhofer[36] outline five types of fuel cell technologies based on electrolyte used and corresponding optimum temperature conditions that result in high energy efficiencies, as follows:

- The polymer electrolyte membrane fuel cells which use polymer as an electrolyte and has electrical efficiencies of 60 % to 65 % at temperatures of approximately 80 °C.
- The direct methanol fuel cells which use polymer membrane as the electrolyte, with efficiency of 40% at low temperatures of 60°C and current density range of 100mA/cm^2 to 120mA/cm^2.
- The alkaline electrolyte fuel cells which use potassium hydroxide as an electrolyte and has electrical efficiencies of 60 % to 70 % at temperatures of approximately 100 °C.
- The phosphoric acid fuel cells which use potassium hydroxide as an electrolyte and has electrical efficiencies of 40 %to 45 % at temperatures of approximately 200 °C.
- The molten carbonate fuel cells which use molten carbonate as an electrolyte and has electrical efficiencies of 50to % 57 % at temperatures of approximately 650 °C.
- The solid oxide fuel cells which use yttrium zirkondioxide as an electrolyte and has electrical efficiencies of 55 % to 65 % at temperatures of approximately 1000 °C.

In view of the optimum performances of fuel cell technologies, it is not simply a matter of employing a technology; a rigorous feasibility process must first be undertaken to understand the biomass type collected, the environmental conditions and operational conditions that the technology is to operate at and its potential for influencing the technology performance, the requirements of each MFC technology, and the appropriate pre-treatment process required for the selected technology to generate energy from biomass.

3. CONCLUSION

Since the scourge of insufficient energy persists, municipalities must be encouraged and supported to generate energy from collected biomass resources at their respective treatment plants. Municipalities must be encouraged to conduct feasibility studies into electricity generation processes, especially the pre-treatment phase which plays a fundamental and crucial role in the effective success of generating electricity. Thus, the success and efficiency of the pre-treatment process of biomass is dependent on the careful scrutinizing and management of all pre-treatment process and technology requirements, and subsequent generation requirements.

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Chapter 5: The impact and influence of Solar energy, Seawater and legislation on the make-up of MFCs at coastal areas like uMhlathuze municipal jurisdiction when making-up a PV-MFC hybrid system

The author examines the influence that legislation and readily available renewable energy sources at the uMhlathuze municipal jurisdiction has on the successful planning and implementation of the PV- MFC hybrid system. The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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THE IMPACT AND INFLUENCE OF SOLAR ENERGY, SEAWATER AND LEGISLATION ON THE MAKE-UP OF MICROBIAL FUEL CELLS AT COASTAL AREAS LIKE UMHLATHUZE MUNICIPAL JURISDICTION WHEN MAKING-UP A PV-MFC HYBRID SYSTEM

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ABSTRACT

Areas with high solar radiation are advantaged with having an abundant, readily available, easily convertible renewable energy source that can power any energy demand, be it existing fossil fuel based power station(s) or other renewable energy based generation applications. Solar energy has the ability to provide power to microbial fuel cells (MFC), a component of a photovoltaic microbial fuel cell (PV-MFC) hybrid system. Seawater is also an abundant renewable resource which can improve the performance of any MFC, especially multi-chambered MFCs connected in series. Since MFCs possess a dual function of bioenergy generation and the treating of wastewater, the functions must be undertaken within the confines of the relevant laws or Acts in South Africa concerning water resources and wastewater. This paper reviews critical areas in legislation that prescribe how resources must be used and how this impacts the operation of MFCs as a part of PV-MFC hybrid systems. Focus is on legislative mandates regarding solar resources and water (seawater or ocean) resources, since uMhlathuze municipality is abundantly blessed with both these resources which can be sources of energy.

KEYWORDS: Solar Energy, PV-MFC Hybrid System, Seawater, Microbial Fuel Cells & Renewable Energy

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Original Article

1. INTRODUCTION

This paper highlights the relationship between solar energy, seawater and legislation and the application ofmicrobial fuel cells (MFC) in the public sector domain, especially municipalities. uMhlathuze municipality in the Republic of South Africa is used as a case study of how MFCs can be designed and built to satisfy legal requirements, generate electricity and treat wastewater before final discharge to the environment.

Khanal (2008) predicted that world energy demand would be 563 quadrillion BTUs by 2015, and about 722 quadrillion BTUs by 2030. Sinha (2008) states global primary energy consumption was about 400 EJ (exajoules) per year in 2000, and that the same was expected to triple to about 1200 EJ/year in 2050, but the incorporation of energy efficiency practices will dampen the expected energy consumption to 800-1000 EJ/year by 2050. The author indicates that 80% of the primary energy requirements globally are met through fossil-based fuel (coal), and that fossil-based energy consumption must be limited to 300EJ/year by 2050.

Modise and Mahota (2009) from the Department of Energy (DoE) in South Africa state that in addition to the nominal energy capacity of 44 175MW, an additional target of 40 000MW capacity is required by 2025. The authors state that 92.6% of the country’s energy production is from coal-fired power stations which consumed approximately 5.5 billion tonnes of coal per year at the time of writing, and will consume approximately 15 billion tonnes of coal per year by 2025.

The Government of South Africa needs to seek cheaper and more sustainable alternative energy sources for the purpose of building-up energy capacity (Hasley & Schubert, 2017). Biomass is a feasible alternative energy source with biomass based technologies such as MFCs being particularly suitable for municipalities (Fiedler, 2014; Miah and Shin, 2006). Seawater is an abundant natural resource bordering the uMhlathuze municipal area. Miyahara, Kouzuma, & Watanabe (2015) investigated how diluted seawater has a positive effect on Geobacteraceae bacteria at the anode and improves power generation by MFC. Geobacteraceae are a community of geographically located microbes that effectively oxidizes organic matter of biomass substrate, whereas the NaCl content of diluted seawater is a major determinant of ionic strength in the electrolyte.

Internationally there has been an in increase in legislation and regulations in response to changes in environmental requirements, shifts in socio-economic and political circumstances, and changes in global demand for energy and energy efficiencies, etc. This paper thus examines how solar energy, seawater and legislation can all have a positive influence on MFC function and performance, therefore, in designing a high performing MFC the laws of South Africa must be observed, adhered to, and satisfied. Some of the identified relevant laws are the National Water Act36 of 1998, the National Environmental Management Act 107 of 1998, the National Energy Act34 of 2008, the Water Services Act 108 of 1997, and the Standards Act29 of 1993. These legislative precepts provide a framework for the planning process. South African National Standards (SANS), formally known as South African Bureau of Standards (SABS) are not discussed.

2. METHODOLOGY

With the aim of providing an understanding of the technical context of this paper, the diagram in Figure 1 is presented to assist in identifying and noting how the determinants, also referred to in this paper as external disturbances, contribute to the make-up (function and performance) of MFC. Other than solar energy and seawater, legislation is the only other observed external determinant that is discussed in this paper.

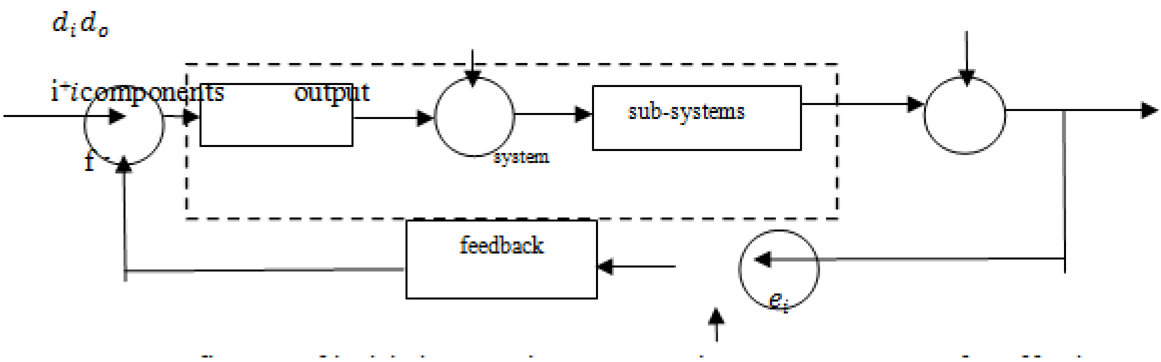

Figure 1: Influence of Legislation to Solar Energy and Seawater Resources for Effective PV-MFC hybrid system performance.
Source derived from: Hamby, Juan & Kabamba (1996)

Where i^+ is the raw input (variables), f^- is the feedback signal or improvement variables, e_i is the efficiency equipment variables resulting from assumptions made when the equipment(s) and technology used to measure and monitor were developed, i is the resulting input into the internal system (components and the various sub-systems), d_i is the internal disturbance(s) in and of the system itself, and d_o is the external disturbances or factors such as solar energy, seawater, legislation, economic standing of the country, market performances, political stability, government budget, and etcetera. Solar energy, the effects of introducing seawater, and legislation are briefly discussed.

The sun is the largest and most powerful source of renewable energy providing the earth with energy every day (Royston,2008) in the form of light, heat and other invisible energy radiations from the sun (Young & Freedman,1996).A nuclear fusion process takes place at the sun's core, that is at the sun's nucleus and photosphere at extremely high temperatures, creating and emitting enormous amounts of sustainable renewable energy (Pipe, 2014) providing clean energy of over 150 000TW of power, of which slightly more than half of it reaches the earth in approximately 8 min (Zefreh, 2013).

The nuclear reaction equation occurring as a nuclear fusion reaction process at the sun's centre is described as 411H → 42He + 2e+ + 2n +26.2MeV, where 1MeV = 1.6x10-13 J. The nuclear fusion reactions occur at temperatures of15 million °C and at rates of 700 million tons of hydrogen atoms per second to produce helium atoms (Camacho et al.2012; Pipe, 2014). Photons emitted from the core of the sun take 100 000 years to reach the surface of the same, with onlya fraction of the solar energy emitted from the sun's surface reach the earth's surface after travelling a distance of 149.6 million kilometres and yet still is more than sufficient to satisfy world-wide energy demands. The solar irradiance (rate at which solar energy reaches a unit area at the earth's surface, measured in W/m^2) from the sun's surface is about $63.3MW/m^2$ (Camacho et al. 2012). Although solar power carries both light and heat energy, the enormous amounts of solar energy from the sun reaches the earth as a mixture of heat and light in the form of electromagnetic waves and ray particles (Pipe,2014).The solar radiation passing through the earth's atmosphere is attenuated by reflection of some of the solar rays into space, absorption by the atmosphere, and scattering of the same through refraction (Stine & Geyer,2001).Solar power comprises pockets of energy atoms, and, according to quantum physics, these pockets of energy atoms can be directly converted by photovoltaic effect to electricity (Pipe,2014;Young & Freedman,1996).

Besides pH, sunlight plays an important role in ensuring microbial growth and microbial activity (oxidation reaction) in the organic matter of the substrate. Management (controlling and monitoring) of heat from sunlight is necessary to ensure that the temperature conditions in the anodic chamber are maintained at suitable levels under anaerobicconditions to support microbial growth and activity. Thus, in designing an MFC, especially the anodic chamber, heat and light from solar rays are critical for the production of the right anaerobic conditions.

Young & Freedman (1996) indicated that the rays emitted from the sun possess electromagnetic wave forms that carry pockets of solar energy that can be converted with ease to electricity when photovoltaic (PV) technology is used. Hinrichs & Kleinbach (2002) state that solar radiation emitted by the sun emits both short 'ultraviolet' wavelengths and long 'infrared' wavelengths and that the short wavelengths are the most abundant wavelengths that reach the earth's ground level at 0.65-0.12 Watts per square centimetre per micron. Short wavelengths carry more pockets of solar energy called photons than sun's rays with long wavelength. In terms of availability of sunlight, short wavelengths are most dominant during the early hours of the day till the late afternoon. Solar panels are installed with a tracker system that enables efficient harvesting of solar energy.

Solar radiation can be converted directly into electricity through the use of PV cells. The photovoltaic effect is when two dissimilar materials such as monocrystalline silicon, cadmium telluride, copper sulphide, and etcetera in close proximity to produce electrical voltage when struck by light or other radiant energy (Curley, 2012). Solar power generated from harvesting solar energy and converting it to electricity can be used to supplement energy requirements of wastewater treatment plants (Foley, 2010).

Wenham et al. (2007) (citing Gueymard, 2004, and Wilson &Hudson, 1988) state that, although solar radiation leaving the sun is constant, it undergoes absorption and scattering at the earth’s atmosphere, and reaches the earth’s surface in varied forms. For maximum radiation to be experienced at the Earth’s surface, the sun should be directly overhead the earth so that the sunlight travels the shortest path length, referred to as air-mass (AM). The angle of travel of the sun’s rays between the path length and the sun’s position is expressed as ϕ. The path length (AM) is expressed as: Path length (AM) = $\frac{1}{Cos\varphi}$ (Wenham et al., 2007).

Based on the fact that the photovoltaic effect for unconcentrated sunlight has a maximum efficiency of approximately 25% for maximum solar power intensity close to $1kW/m^2$, solar panels fitted with lenses or mirrors that function to concentrate sunlight improve efficiency and power intensity (Pulfrey,1978).Although large solar technologies are expensive and require a large land area to collect the sun’s energy at sufficient rate, the falling prices and gains in efficiency has made solar electricity viable to pay for itself in approximately five to ten years (Primo,2016).

PV cells are environmentally friendly devices that offer clean, efficient, reliable and uninterrupted sources of electrical energy. The development of PV cell technology has resulted in a decrease in capital investment (Jha, 2010). Solar PV is rapidly becoming an inexpensive, low-carbon technology to harness renewable energy from the sun; the cost of solar electricity has fallen to relatively affordable levels that facilitate the implementation of large scale solar powersystems (Primo, 2016).

Photovoltaic or solar modules used for solar energy conversion are very reliable and do not require any fuel or servicing. Solar photovoltaic ‘electric’ systems are ideal and most suitable in places with plenty sunlight and can be used as complete packages to supply facilities such as water and wastewater treatment plants (Roberts, 1991).The five basic and most crucial parts of an effective solar electric system are, as per Roberts (1991):

- **Solar modules** that are responsible for generating electricity from available sunlight by converting solar energy to electrical energy.
- **Rechargeable batteries** that store electricity for later use when sunlight is unavailable or when there is disruption in supply and energy has been depleted.
- A **control unit** that functions to switch the loads (manually or automatically), protect the battery, monitor the performance of the system, and send alerts when there are system malfunctions.
- A **distribution system** of electricity as direct current (d.c) and system voltage. To avoid energy drop, for long runs of wiring, thick cables are used, and if not, the distance between generation station and the facility supplied must be short.
- **Electrical equipment** that enable electricity use. For appliances that work on d.c at the system’s voltage, the appliances are connected directly. A voltage adaptor is used for appliances that require an increase in voltage. Since solar modules generally produce d.c, a power inverter converts d.c to alternating current a.c for ease of distribution and reduction in loss.

Solar energy through use of solar modules can be used to provide the small voltage(s) required to initialize or sustain electrochemical reactions in MFCs. Furthermore, since solar energy is readily available, reliable and easy to convert, solar energy can be used to back-up the initial energy requiring stages and power MFC if needs be so that the MFC is kept functional (sustainable) in the absence of considering other factors such as substrate availability and quality, prolonged electricity disruptions, and etcetera (Siva, Manaswini, & Makarand2011).

The results of MFC application depends on the quality of the influent that comprises of the concentration of organic matter, the biodegradability of the organic matter, temperature and the absence of toxic chemicals. The major disadvantage of MFCs is the low power output that results that become a serious limiting factor that must be critically considered when scaling up, as generally scaled up MFC plants have dampened performances that yield a decrease in power output (Barua et al., 2018). Miyahara, Kouzuma, & Watanabe (2015) found that the introduction of diluted seawater(a diluted concentration of NaCl) improves activities of anode microbes and the subsequent power generation of MFC. Theauthors found that diluted seawater determined the growth rate and supported the growth of Geobacteraceae (a specific type of geographically located community of microbes or bacteria) at the anode of MFCs, and also increased the ionic strength of the electrolytes in MFCs that favour electricity generation.

Since NaCl is a major cause of ionic strength in the electrolyte and Geobacteraceae bacteria are responsible for MFC power generation, the growth of Geobacteraceae is optimum at the right NaCl concentrations such as those of diluted seawater (between 0M to 0.1M NaCl). Miyahara et al. (2015) found that with an increase in NaCl concentration from 0M that mimics freshwater, to 0.1M that mimics diluted seawater, MFC performance in generating electricity significantly increased. The abundance ratio of Geobacteraceae relative to the total bacteria at the anode increased by over 60% in diluted seawater (0.1M NaCl concentration) conditions when compared to freshwater (0M NaCl concentration) conditions. Interpolating the abundance of Geobacteraceae at the anode and the power generated by MFC, the close correlation confirmed that Geobacteraceae bacteria are responsible for power generation. The study by Miyahara et al. (2015) reflects that the ability of the right bacteria responsible for power generation to grow at the anode is dependent on the conditions prevalent in the MFC.

A proton based current flows from the positive to the negative terminal of an MFC, this being the transfer of protons internally through the membrane that separates the cathodic chamber from the anodic chamber, from the anode to the cathode (Logan et al., 2006; Siva, Manaswini, & Makarand, 2011). According to Logan et al. (2006), a system that usesenzymes or catalysts are enzymatic biofuel cells and not MFCs. Rabaey et al. (2004) and Rabaey et al. (2005) found that MFCs that use mixed cultures achieve substantially greater power densities than those that use pure cultures. Seawater contains a variety of bacteria (Miyahara et al., 2015).

The transfer of protons in MFCs depends on the nature and effectiveness of the membrane used as it influences the transfer of protons across the membrane and prevents oxygen leakages. If the membrane is ineffective the internal resistance of the system increases and the MFC performance decreases (Siva, Manaswini, & Makarand, 2011). Membranesare costly, but the newly developed earthen pot membranes significantly reduce the costs of MFCs due to the low cost of earthen pot separators and the enhanced performance (generation of electricity) of MFCs. A study that examines the reaction of seawater and bacteria contained in seawater with an earthen pot membrane is required (Siva, Manaswini, & Makarand, 2011).

Chapter 2 of the Constitution of South Africa (1996) provides the right to an environment that is safe and that the environment must be protected for the benefit of both present and future generations by taking legislative mandates serious and also applying other practicable measures that prevent pollution and ecological degradation, but promote conservation and secure ecologically sustainable development and use of natural resources that support socio-economic development. The Constitution upholds environmental awareness on meritorious grounds. Solar radiation intensity and seawater behaviour are generally affected by land-based activities. Thus, it is necessary to look at the legislative mandates that ensure that the environment is preserved no matter what operation is undertaken. The following laws are briefly discussed especially regarding conservation of seawater and prevention of pollution and/or other factors that affects the ecological characteristic properties of the north coast seawater in the KwaZulu-Natal province.

The department of environmental affairs (DEA) responsible for providing leadership and guidance in the managing and monitoring of environmental matters for sustainable preservation and use of the natural environment in the country, facilitates harmony between land-based production activities and the environment by using and reviewing tools such as Acts, policies and compliance guidelines in managing the disposal of toxic waste to the environment. Among the 5 listed fundamental principles that DEA upholds towards the disposal of municipal effluent is preventing pollution and minimising the impact of toxic municipal waste that potentially can affect or alter the environment. Municipal effluent normally comprises of residential and household waste, however municipalities such as uMhlathuze that is heavily infested with industrial activities, the municipality carries the responsibility of monitoring and ensuring that industries treat and review their waste content against set standards and guidelines before the respective waste leave their premises and connect to the municipal effluent pipeline. Thus the 2014 national guideline by DEA provides that to achieve responsible disposal of land-based effluent, practicable customized procedures and plans approved by the DEA and the municipality must be implemented by each respective effluent contributor to prevent or minimise the production of all toxic waste and reduced impact to the environment.

The White Paper on the Energy Policy sets out government's policy on the supply and consumption of energy, giving a holistic and detailed perspective of South Africa's energy needs and options, stating that an equitable level of national resources must be invested in renewable technologies in order to create energy security by diversifying energy supply. The White Paper on Renewable Energy Policy reflects government's support for the development, demonstration and implementation of renewable energy sources for small and large-scaled application, setting out, among other things, the energy economy in which modern renewable energy increases its share of energy consumed and provides affordable access to energy throughout South Africa, thus contributing to sustainable development and environmental conservation (Glazewski, 2005).

Although various departments are mandated for specified products and services under the Constitution of the country, instances exist whereby a product or service is multi-ministerial or multi-departmental whereby different aspects of a commodity are dealt with by different departments. This has resulted in the produce of various laws by various departments in addressing set goals pertaining to a particular aspect of a commodity of interest. The focus in this paper are the laws of the country that provides for energy generation, preservation of the environment, use of water and seawater and the prevention of toxic municipal waste and reduction of impact of toxic waste discharged to the environment. Thus the laws drafted and published by the Department of Water & Sanitation, Department of Environmental affairs and the Department of Energy are reflected in this paper. Some of the laws deemed applicable and discussed are; the National

Energy Act (NEA) 34 of 2008, the National Environmental Management Act (NEMA) 107 of 1998, the National Water Act (NWA), etc.

The preamble of NEA indicates that the Act is aimed at ensuring that diverse energy resources are made available in a sustainable manner and at affordable prices in support of a positive socio-economic development. This goal according to NEA must be achieved by also taking into consideration environmental management provisions, energy planning targets, contingency energy supply and the provision of adequate and committed investment resources towards affordable access to sustainable energy infrastructure and the establishment of institution(s) promoting efficient generation. Thus NEA is viewed as seeking to ensure among others that there is uninterrupted supply of energy to the Republic, facilitation of diverse of supply of energy and its sources, the collection of data and information relating to energy supply for optimal supply purposes, taking into account the transformation, transportation, storage and demand of energy that are planned, organised and implemented in accordance with a balanced thought of security of supply.

Although the NEA defines “renewable energy”, chapter 2of the same mandates that analysis must be conducted annually reviewing energy demand and supply of the previous year and forecasting the energy supply and demand for the next20-year period based on new findings and assumptions that must be modelled to ensure that predictions are accurate and credible. This provides an effective way of monitoring the country’s energy status while adopting measures on a continuous basis in addressing the availability of energy resources, optimisation of existing energy infrastructure, the need for new infrastructure and the sustainability and affordability of energy in a cost-effective manner. Thus in view of the reviews and predictions in accordance to the NEA requirements, strategies and tools such as the integrated energy plan (IEP) are developed to weigh the security of supply, the availability of energy resources, the economies-of-scale of energy resources and the contribution of the mode of energy generation to the socio-economic development of the country and to the environment.

A call for strict adherence and commitment to the mandates of NEA protects the country and its citizens from unwelcomed disruptions to quality generation and supply because predictions are in such a manner that government institutions on the ground such as uMhlathuze municipality can have confidence in the projected energy figures and devise meaningful alternatives ensuring that industries and citizens within their jurisdiction are unaffected by national energy shortages. A specialised government research unit was established in accordance with NEA to find meaningful ways of generating and supplying energy to citizens and to investors and stakeholders in a confidently sustainable and affordable manner, the South African National Energy Development Institute (SANEDI) was established and its functions outlined in section 7 of NEA. SANEDI (2017) proposed in their study an immediate and radical pursuit for renewable energy generation. However, comprehensive feasibility studies are required at municipal level that observe compliance mandates by other laws that ensure that pollution is kept minimum or eradicated and renewable energy sources such as seawater are not used in ways that affect the natural replenishing of the environment, negatively affecting the natural breeding of microorganisms in seawater. Thus applicable laws are reviewed to indicate any developments that aid clean generation thatis not harmful to environment by decreasing greenhouse gas emissions that negatively affect solar energy intensity and efficient generation of electricity. This paper thus highlights the integration of the different applicable laws that ensure optimum performance of the PV-MFC hybrid system.

In an attempt to address security of supply as referred to in chapter 5 of the NEA, sections 17 and 18 of the Act state that the minister may direct any state-owned entity to acquire, maintain, monitor and manage national strategic energy feedstocks and carriers, and that strategies or policies developed in line with this Act must reflect amongst others the minimum level of energy feedstock for production, the conditions under which the strategic energy feedstock may be built, and the cost-benefit analysis. Further, section 18 mandates that the minister may direct any state-owned entity to undertake informed security of supply measures, provide for adequate investment in energy infrastructure, invest in critical energy infrastructure, and ensure upkeep of all critical energy infrastructures. Thus, effective design of generating equipment must be undertaken, taking into consideration all maintenance ideas and comments for effective maintenance of energy infrastructure.

Coastal areas suffer from serious hydrogeological problems such as reduction of freshwater storage, groundwater pollution and seawater intrusion (SWI), over-abstraction of natural water reserves, and subsequent encroachment of saline water into coastal aquifers (Mehdizadeh, Badaruddin, & Khatibi). Besides the increase in demand due to population growth at coastal regions, tides, waves, climate changes and sea level rise are other reasons for the increase of SWI (Moustadraf et al., (2008); Shi et al., (2018); Werner et al., (2013). The quality of seawater at designated abstraction point, in one way or the other has an effect on the performance of MFC if not treated using cost-effective methods like ADR (abstraction, desalination and recharge), whereby brackish water is abstracted from saline water zones, desalinated using processes like reverse osmosis, and returned to the aquifer, thus recharging the aquifer. This process reduces the volume and concentration of saline water (Mehdizadeh, Badaruddin, & Khatibi, 2019).

NEMA mandates among other functions, that government institutions such as municipalities and government initiated agents such as wildlife (ezemvelo) must protect and promote environmental rights by incorporating environmental factors in their planning, implementation and evaluation of decisions that ensure that development serves both present and future generations. The principles highly advocated by NEMA are the prevention of pollution and ecological degradation and promotion of conservation that ensures ecological sustainability and responsible use of natural resources. The provisions of NEMA provides are such that organs of state must maintain the principles guiding the functions that affect the environment and that the law be enforced by the State and that the law should facilitate the enforcement of environmental laws by civil society.

To ensure that the application of appropriate environmental management tool is in order, an integrated environmental management plan (IEMP) of activities must be set out by uMhlathuze municipality in a manner that identifies, predicts and evaluates the actual and potential impact that PV-MFC technology has on the environment, socio- economic conditions, anticipated risks and consequences and the promotion of compliance using the principles of environmental management as set out in section 2 of NEMA. In this way, the IEMP ensures that the effects of activities on the environment receive adequate consideration. Section 23A of the NEMA mandates the minister to provide for instruments that will integrate environmental considerations into decision-making, providing for the best environmental practice, and promote progressive adoption of environmentally sound technology.

Although section 25 of NEMA reflects that the South Africa Republic is not bound by any international environment instrument which deals with available resources to ensure implementation, resulting from on-going international engagements and signing of global-climate change agreements, together with views expressed by section 24S of NEMA, reviews has set that any residue stockpiles or residue deposits must be managed in accordance with the provisions of the National Environmental Management: Waste Act No 59 of 2008. Section 28 of NEMA express that everyperson or institution that causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring or recurring by submitting to DEA a detailed plan that spells out measures in place and other potential measures that are being pursued in attempt to comply with the legislative prescripts and handling of toxic waste. Conditions under which prosecution, cancellation of permits, and other enforceable measures as deemed fit are listed in chapter 7 of NEMA for any form of non-compliance.

The preamble of the national water act (NWA) highlights the importance of conserving, monitoring, and controlling use of water. The NWA under section 6 states that public water and the control and use thereof must be in accordance to the provisions and regulations of the Act. Sections 9A and 11 of NWA state that whenever there is a water shortage or one is likely to arise, the minister may in his/her discretion from time to time by notice in a Gazette control, regulate, limit or prohibit the use of water for industrial purposes unless the industry in possession of a permit obtained from the department of water & sanitation (DWS) and endorsed by a local water services authority like uMhlathuze municipality that has the right to control and supply either public water or private water within its areas of jurisdiction. Section 12A of NWA states that, unless in possession of a permit from DWS, no person shall erect any structure that tampers with the natural course of any public water prescribed by regulation under section 26 of NWA regarding purification, treatment or disposal of water or effluent. Section 21 of the same Act states that any person using water, including seawater brought ashore for industrial purposes, shall treat the water used and any effluent produced from such use in accordance to the requirements set out by the Minister after consultation with the South African Bureau of Standards(SABS) in accordance with standards mentioned in the Standards Act in relation to effluent to be disposed of bydischarging it into any particular stream or into the sea. The above legislative rules or laws in other words mandate that the municipality must submit detailed plans for approval purposes by the departments, DEA and DWS, spelling out water abstraction processes, treatment of raw water, potential risks and mitigation plans and measures, treatment of toxins in waste and plans that ensures that the environment and living organisms self-replenish and do not face extinction due to the operations that emanate from the implementation of the PV-MFC hybrid system.

The preamble of the Water Services Act (WSA) 108 of 1997 provides that water services authorities such as uMhlathuze municipality with a framework for the monitoring of water services and interventions through the gathering of information in the national information system and the distribution of that information to repeal certain laws and to provide for matters connected with access to water and set national standards and norms. The WSA defines “basic water supply” as the prescribed minimum standard of water supply services necessary for the reliable supply of a sufficient quantity and quality of water. The same defines “industrial use” as the use of water for, amongst other purposes, the generation of electricity. Further, the WSA defines “disposal of industrial effluent” as the means of collection, removal, disposal or treatment of effluent emanating from industrial use of water.

Amongst the listed objectives of the WSA is the promotion of effective water resource management and conservation, notwithstanding the regulatory framework set for water services institution and water services intermediaries, mandating them with the tools (standards and equipment deem fit) to use (supply), manage and monitor water natural resources. The NWA provides for the governance of natural water resources, whereas the WSA provides water services providers with the means to provide guidance as to how certain functions and activities of utilising water resources, especially water supply may be employed. Section 4 of the WSA provides for the conditions for the provision of water services, and states that such services must enable effective delivery of services to the public and promote water conservation and demand management.

Section 7 of the WSA states that a person or institution that is deemed water service provider must be in consultation with the water services authority and in possession of a permit that authorises the use of raw or treated water for industrial use or supply purposes from any public source within the area of jurisdiction. Further, section 7 of the WSA mandates that no person(s) may dispose of industrial effluent in any manner other than that approved by the water services provider in accordance to set standards as prescribed by the water services authority. Section 9 (chapter 2) of WSA thus endorses that the minister must regularly review and prescribe compulsory national standards relating to the quality of water taken from or wastewater discharged to the environment.

Furthermore, section 9 of the WSA states that the standards prescribed by the minister may differ between the different water services users depending on the nature of the mega project or industry that must be implemented, the geographical location, the socio-economic and physical attributes of the respective area. In prescribing the standards, the minister may consider the operational efficiency and economic viability of water services, any other laws or any standards set-out by other government authorities such as those set by DEA, guidelines recommended by official government standard-setting institutions such as SANS, and any impact which the water services might have on the environment and the obligations of the national government as the recognised custodian of all public water resources. Thus the WSA instructs under section 9 that every all institution in possession of a permit issued by DWS must comply with the enforceable standards prescribed by the minister.

Section 11 of the WSA states that every water services authority has a duty to ensure efficient, affordable, economical and sustainable access to water and wastewater services, subject to the availability of resources, for an equitable allocation of resources to all. For uMhlathuze municipality, which is both a water services authority and water services provider, the Act mandates that the municipality draft a water services development plan (WSDP) and guidelines so that allocations or approvals are based on demand and needs that are listed in the WSDP. This enables the management and monitoring of the utilisation of the water resource within specified standards. Thus, the abstraction of seawater and the disposal of treated effluent is effectively managed and monitored are based on the law. So, in designing for the MFC hybrid system, specifications and demands are determined and aligned to legal mandates as approval must be obtained. Reporting on approved usage and implementation is conducted yearly according to section 18 of the WSA, and the monitoring of the performance of water services providers is conducted in accordance with section 27 of 1997.

The preamble of the Standards Act No 29 of 1993(Department of Trade and Industry, 1993) provides for the promotion and maintenance of standardization and quality in connection with commodities and the rendering of services, and for the continued existence of the SABS (now known as the SANS), a government mandated national institution. The objects of the SANS are, among others: to obtain the co-operation of state departments and local authorities, to assess quality systems and administer certification, to supply information and guidance, to assist a state department in the preparation and framing of any document which embodies characteristics similar to those of a prescribed standard, and to issue as a national standard or specification and code of practice.

Although the minister of Trade and Industry oversees national standards, in terms of the Standards Act, the minister on recommendation of the council is mandated to promote standardization and quality, declare a specification which has been set and issued as a standard to be a compulsory specification that must be adhered to. In consultation with other ministers such as those from DEA, DWS and DOE and their respective advisors or established committees of competent person(s) or agents, the minister as prescribed by the Standards Act may determine and review standards in the

SANS regarding to commodities such as water and services such as those of supplying electricity to comply with approved and published standards. Section 24 mandates that the President of the SANS, may, upon reasonable grounds, direct a person or institution in whose possession or under whose control that commodity, consignment or batch is, to keep it in his/her possession or under his/her control, at or upon premises mentioned in the directive the commodity until the directive is withdrawn or an instruction has been issued for the confiscation and destruction of the commodity in question has been removed after the completion of intense studies or investigation. The Standards Act indicates that specifications provided for a commodity or service as recommended by SANS is enforceable by law. An example of an enforceable standard used as a basis for compliance before treated effluent is discarded or discharged to the environment such as publicstreams or sea, is SANS 241 (Hodgson & Manus, 2006).

In 2018 the DEA published water quality guidelines, criteria and standards (GCSs) for managing water quality by providing numerical concentration limits and narrative statements for particular physicochemical properties of the various type and concentrations of nutrient and/or toxic substances found in water with the aim of maintaining coastal and marine bodies in a water environment that is as close to natural state or mimics natural water quality that can be readily used (DEA, 2018). The DEA: Ocean and Coasts section mandates that compliance with the guidelines in protecting marine aquatic ecosystems must be achieved in all coastal waters at all times and that the effluent discharged into the marine environment from land-based activities are likely to exceed the prescribed limits if the effluent undergoes ineffective dilution and dispersion at the outlet of the effluent pipeline. Although, the physicochemical properties of seawater consist among others temperature behaviour, pH, suspended solids, etc., based on international reviews, DEA decided that physicochemical properties of each coastal and marine environment must be site-specific.

Although nutrient content and the understanding of physicochemical properties of site-specific coastal marine and estuarine waters required for primary energy generation is of paramount importance in providing meaningful information for production, the numerical concentration limits and the narrative statements directed towards the abstraction of seawater and the properties of Geobacteraceae at specific coastal sites such as the coast line at the uMhlathuze jurisdiction is necessary for the effective performance of a well-designed customized PV-MFC hybrid system.

According to the DEA, the aquatic ecosystem must be protected from toxic substances by preventing toxic substance formation or by reducing and monitoring potential impact caused by toxic substances by adopting water quality GCSs based on toxicological studies and the use of modern technology and/or effective conventional methods designed to do so. Thus for aquatic toxicological studies to be effective, local conditions must be fully understood, taking into account the sensitivity of local marine species, especially in the context of this paper, the microorganisms required for power generation in MFCs. DEA indicates that toxicity tests are essential in establishing the impact of toxic substances and response (sensitivity) of microorganisms to toxins in the energy generation sector. The toxicity test can thus indicate the effects of toxic substances on microorganism as either acute which reflects how toxins affects the mortality of the microorganisms or chronic which affects the entire natural make-up, behaviour and function of the microorganisms.

In a nutshell, in establishing a holistic view with regards to PV-MFC performances and efficiencies, apart from modelling system factors described in figure 1 as internal disturbances, this paper reflects that consideration of factoring external disturbances indicated in Figure 1 such as solar energy in sun hours, seawater based on toxicity data and generally reviewed legal requirements is necessary so that non-performances can be easily corrected and discoveries based on new research studies be included to sustain optimum performances and legal compliance.

3. RECOMMENDATIONS

Chapter 4 of White Paper on the Renewable Energy Policy of South Africa (Department of Minerals and Energy, 2004) identifies and labels South Africa as a country of high levels of solar radiation. Although studies by other authors advocate for MFC systems to backup PV systems, this paper expresses that solar energy can also be used to back-up MFC systems in sunny day or use of energy stored in batteries from PV system in cloudy days during prolonged disruptions. Apart from the abundance of solar energy, energy generated from solar sources can be used satisfy the minimum activation energy required for MFC systems to function. Thus a blended energy generation approach using PV technology can be designed to supplement shortfalls of MFCs, thus the proposed implementation of the PV-MFC hybrid system for sufficient generation and supply of energy to power an identified municipal treatment plant.

To gain approval of Environmental Impact Assessment (EIA) in accordance with NEMA guidelines and the associated Regulations of June 2010, a full “Scoping and Environmental Impact Assessment (EIA) process” is required for the installation of a PV-MFC hybrid system project. The Scope of Work for the EIA process as provided by the Council for Scientific and Industrial Research (2016) entail:

- Identifying and describing potentially affected environment and determine the status quo of the site.
- Indicating how a resource or community will be affected.
- Mapping sensitive areas and mixing zones.
- Discussing identified gaps in the baseline data that have been collected as per NEMA guidelines such as the WQG (Department of Environmental Affairs, 2018).
- Assessing and listing potential impacts, including cumulative impacts and address public concerns.
- Proposing and explaining mitigation measures and summarise residual impacts after mitigation.
- Compiling detailed Environmental Management Plans (EMPs) for the proposed project.

Below are some of the regulatory requirements specific to the coastal zone and marine environment that must be considered and factored when designing for the construction and operation of a PV-MFC hybrid system that is to operate at uMhlathuze jurisdiction, requiring the use of the east coast seawater(the Indian ocean) for improved MFC performance. These are:

- NEMA, as amended by DEA, formerly known as the Department of Environmental Affairs and Tourism.
- NWA as developed by DWS, formerly known as the Department of Water Affairs and Forestry, 1998).
- National Environmental Management: Integrated Coastal Management that was developed by the Department of Environmental Affairs and Tourism, now known as DEA.
- Marine Living Resources Act (MLRA) that was developed by the Department of Environmental Affairs and Tourism, now known as DEA.
- Environment Conservation Act (ECA) that was reviewed by DEA.
- WSA developed by DWS, formerly known as the Department of Water and Forestry.

- NEA developed by DOE.
- The Standards Act, developed by the Department of Trade and Industry (DTI).

Since the Indian Ocean borders uMhlathuze, the abundance of seawater together with the tempering effect of the marine ecosystem, can sustain improved MFC performance by supporting the growth and sustenance of the *Geobacteraceae* responsible for generation, when operations and compliance are conducted within the confines stipulated by law. Thus, application of the above indicated laws enable effective functioning of the MFC component of the hybrid system with minimum negative or no impact on both environment and water resources. The above provides an added benefit to the existing advantage that MFCs produce small residues that have small or no environmental impact. Le Roy- Gleizes (2015) observes that countries are showing preparedness to commit (financially invest) to the targets set to address climate change, but calls for effective and stringent enforcement of the law especially when plants are in operation, because in most cases compliance matters are only strict during application (planning) processes for a project, not when theplant (desalination and/or PV-MFC hybrid system at coastal areas) is operational.

4. CONCLUSIONS

This paper reflects the benefit of constructing a PV-MFC hybrid system that addresses electricity generation and supply challenges within the context of relevant legislation which is designed to conserve the environment for present and future generations. Strict adherence to legislative prescribes ensures that there is no alteration of the ozone layer that permits dangerous levels of solar energy, and alteration of the natural water environment (ocean) that destroys the marineecosystem.

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Chapter 6: Impact of Municipal infrastructure conditions and maintenance programs in determiningmunicipal service delivery effectiveness, cost effectiveness and energy efficiency

The author uses literature from other authors and researchers to express the views of how poor infrastructure conditions and inadequately implemented maintenance programs on municipality's infrastructure impacts energy consumption and energy bills, energy efficiency and the municipality's ability to effectively service obligations and mandates. The article was published in the International Journal of Mechanical Engineering and Technology (IJMET).

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IMPACT OF MUNICIPAL INFRASTRUCTURE CONDITIONS AND MAINTENANCE PROGRAMS IN DETERMINING MUNICIPAL SERVICE DELIVERY EFFECTIVENESS, COST EFFECTIVENESS AND ENERGY EFFICIENCY

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ABSTRACT

Infrastructure is one of the most important economic drivers in South Africa that enables industries to produce and government to deliver services in a sustainable manner. For sustainability to be achieved, infrastructure conditions must be maintained at conditions that are acceptable for products and services to be delivered effectively and efficiently. In considering the effectiveness and efficiency of infrastructure, factors such as cost, infrastructure performance, energy consumption, and maintainability/reliability of the infrastructure must be considered. Since South Africa is faced with serious energy deficits and infrastructure backlogs due to the growing demand and increasingly weak economy, government must focus on providing quality infrastructure conditions. Because local government (municipalities) are major custodians of government infrastructure for the implementation of service delivery to communities, national and provincial government structures must supportmunicipalities through initiatives that ensure credible infrastructure conditions. Municipalities too must benchmark themselves with other similar high performing institutions and assess their infrastructure position (conditions) in terms of cost, reliability and availability. Furthermore, municipalities must undertake meaningful andcost effective infrastructure maintenance projects such as proactive maintenance methods. Once improved infrastructure conditions have been achieved, projects directed towards restoration or replacement of infrastructure will be reduced together with corresponding costs, wastage in terms of energy consumptions and high energy bills will be significantly reduced, and stakeholder confidence will be increased with regards to infrastructure reliability.

Keywords: Energy efficiency, Economic Support and Growth, and Infrastructure reliability.

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1. INTRODUCTION

Effective management and maintenance of infrastructure is essential to the public sector's core business [1]. Municipalities in South Africa are constitutionally mandated to render sustainable service delivery within their jurisdiction within affordable means, and since municipalities are the major custodians of a majority of infrastructure assets in the water and wastewater sector, municipalities are therefore to render such services to the communities through reliable infrastructure. Frequent infrastructure failures have been evident in the South African community during the service life of the infrastructure especially in municipal environment. Infrastructure failures at municipal level in South Africa unfortunately are majorcauses of community unrest (protests), environmental pollution, accumulation of exorbitant energy and financial bills, and increased demand for capital („financial investment‟) injections.

2. METHODOLOGY

Chapter 7 of the Constitution of the Republic of South Africa, section 152 sub-section 2 [2], mandates that municipalities must strive within their financial and administrative capacity to, among other objects as indicated in subsection 1, provide services to communities in a sustainable manner. The South African local government Municipal Finance Management Regulations Act (MFMA) No. 56 of 2003 [3] lists municipal institutions as organs of state and defines municipal capital assets as infrastructure assets which municipal institutions own. The Department of Provincial and Local Government [4] in a publication on municipalinfrastructure defines municipal infrastructure in broad terms as "capital works required to provide municipal services". This includes all the activities necessary to ensure that the works deliver services effectively. The American Society of Civil Engineers [5] states that there are two types of infrastructure needs: building new infrastructure to service increasing demand dueto increasing population and expanded economic activity, and maintenance and rehabilitation of existing infrastructure requiring repair or replacement.

For municipalities to be successful at their business function, municipalities must have at their backbone good performing reliable infrastructure [1]. Municipalities in South Africa are one of the highest contributing debtors to the energy sector in the past 10 years. Recent reports indicate that all 257 municipalities combined in South Africa owe ESKOM energy bills in the billions of rands.

Infrastructure reliability is strongly linked to energy management, and positive municipal infrastructure conditions have a direct impact on South African's energy status. South Africa is currently facing a massive energy crisis that is not reliable enough to support normal industrial and economic activities at municipal spheres. For this reason, the South African government must act swiftly and creatively to salvage municipal infrastructure from existing infrastructure related challenges and provide security of energy supply.

Dhillion [6] states that losses incurred from infrastructure failure are a combination of: functionality, which is dictated by the change in operations and/or demand on infrastructure capacity; technology related aspects, which are detected by the technology used and the type and quality "condition" of infrastructure used; the physical attributes of infrastructure, which is dictated by the physical properties of the infrastructure and the conditions of infrastructure that result from wear and tear (infrastructure aging), and; monetary losses that are influenced by the type and criticality of infrastructure breakage, the value of the commodity being provided, associated measurable costs of the commodity such as energy consumption, and who(the client) the commodity is being provided to.

The importance of positive municipal infrastructure conditions, keeping infrastructure in good working order, and maintaining energy efficient infrastructure at all times is paramount in rendering acceptable standards of delivery of services to consumers (communities) and support for economic growth and development activities. Thus, there is an urgent call for municipalities in South Africa to engage in comprehensive infrastructure asset management reviews and maintenance plans in order to maintain good infrastructure conditions and reduction of the exuberant energy bills related to failing or inefficient infrastructure.

The South African national government has established an agent (support institution) to support municipalities in addressing infrastructure challenges, namely, the Municipal Infrastructure Support Agent (MISA). In 2016 MISA [7] published its institutional objectives stating that, due to the importance of municipalities having an effective and successful impact on societies that they serve, MISA is mandated to provide technical support to municipalities through implementing and leading initiatives towards addressing infrastructure related backlogs by implementing identified and well-planned capital infrastructure projects and infrastructure operations and maintenance plans based on agreed resources and support plans. MISA points out that technical support is required to address infrastructure capacity challenges within municipalities in the short-to-medium term and for capacity building (infrastructure expansion).

Nellenbach et al. [8] write that the public expects effective delivery of services, yet their understanding of the complicated and expensive systems required to deliver those services is minimal. Systems or infrastructure across the country at municipal level requires critical maintenance, repairs and upgrades, but the public reflexively opposes new charges and fees, and is reluctant or unable to accept higher prices for services rendered. There is thus a challenge to raise mission-critical funding from a sceptical public while maintaining affordability for those services, which makes it difficult for municipalities to service their obligations.

According to the 2018 report by ESKOM [9] (a South African government owned energy utility entity), reflects that the accumulated energy debt of municipalities for the past 10 years to ESKOM is a staggering R13.6 billion. Although ESKOM has undertaken far-reaching strategies for conserving energy supply through load-shedding and raising public awareness regarding energy conservation, these debts have impacted investor confidence and dampened economic activities. Industries are currently facing reduced production and reduced labour resources. Unfortunately, seeking alternative sources as means of securing energy in South Africa is at embryonic stages and proves is expensive in this current ailing (weak) economy, and industries are therefore forced to rely on government initiatives and strategies to support economic and energy sustainability.

In the third quarter of South Africa's government 2018/2019 financial year (the September 2019 to December 2019 period) the South African government through its current President approached „giant" first world countries and other international platforms in an endeavour to boost investor confidence towards South Africa and acquired investment funding or deals worth over $40 billion United States dollars (approximately R580 billion) [10]. The question is, what took government such a long time to formulate strategies that would attempt to curb or address the energy crises which have had such a severe impact on municipalities as well as industries?

Various authors have attributed infrastructure failure and the country's huge energy deficit to among other reasons: poor energy and infrastructure based planning nationally and at municipality level; growing incompetence of technical personnel in government institutions; corruption; socio-economic ills of poverty which result in activities such as cable theft; inadequate government supported initiatives for alternative strategies such as having regulatory policies for renewable energy production and distribution; insufficient allocation of budget for infrastructure retention and energy conservation; and inability of executives (lack of leadership) to identify looming challenges and to formulate strategies. South Africa lacks a strategy to audit available resources and consolidate available resources with procured resources to develop national strategies and time-based implementation plans that address infrastructure backlogs (existing infrastructure conditions) and energy deficits.

A study conducted by the van Zyl et al. [11] together with the Council for Science and industrial Research (CSIR) report [22] found that the majority of challenges faced by the public sector at local municipal levels are infrastructure-based, and that the lack of maintenance and lack of comprehensive information of infrastructure (plants or facilities) in the mechanical, electrical and structural disciplines heavily affects the operations and output (energy performance and delivery capacity) of the infrastructure.

This paper attempts to highlight the strong link of infrastructure conditions to energy demand by indicating the effect that infrastructure inefficiency has on energy consumption and management. „Infrastructure" in this paper refers mainly to water and wastewater plant and pipeline infrastructure assets. Since charity begins at home, this paper makes recommendations for how government can provide initiatives for public entities (municipalities) to keep infrastructure in good working condition and service their areas of responsibility (the communities within jurisdiction) effectively but also contribute to energy conservation and possible savings on energy bills in the long run. Thus affordability, funding and financing (i.e. infrastructure improvement and establishment of acceptable infrastructure conditions) and energy conservation (i.e. maintenance of proper infrastructure conditions) are discussed in this paper.

Inadequate management and lack of oversight on infrastructure related matters results in serious violations of the rights of communities, non-compliance to legislation, and the risk of infrastructure failure impacting environmental and energy management [8].

The Oxford Dictionary [12] defines infrastructure as a system that makes it possible for a country or organisation to function properly and render required services. Goodman and Hastak [13] concur with the above definition, referring to public sector institution infrastructure as public works that function to facilitate the provision of public services to the community through substantial capital investments. The authors state that public works are government's way of solving public or citizen related problems and resolution of the challenges and problemsrelated to this is through planned programs that involve designing, constructing and operating facilities under the auspices of government agents or institutions such as municipalities.

Higgins [14] states that infrastructure maintenance is not merely preventative maintenance, nor lubrication of infrastructure, nor frenetic rush to repair broken parts of a facility or system, but is a combination of science, art, and philosophy:

- The science of executing technical solutions to infrastructure challenges that result in high energy usage and/or unavailability of infrastructure for service;

- The art of identifying and profiling all identical problems that result in infrastructure challenges and high energy demand and regularly require attention; and
- The philosophy (discipline) that provides a framework of how to apply solutions to problems with the intention of resolving the problems and or provide a way of solving challenges faced [14].

Before undertaking infrastructure condition related improvement projects and conducting of assessments for improvement projects, maintenance functions such as solving day-to-day problems must be undertaken so that the physical infrastructure condition is kept in good operating order. Lack of implementation of maintenance activities results in decreased infrastructure or facility efficiency and increases energy wastage (utilisation) [14]. Maintenance activities that preserve good infrastructure conditions throughout the service life of an infrastructure asset include but not limited to the following [14]:

- Regular inspections and annual audits;
- Facility performance profiling and monitoring;
- Updating of infrastructure and energy technologies; and
- Regular review of infrastructure audit and energy audit procedures, guidelines and policies.

Goodman and Hastak [13] propose four categories of infrastructure projects that require attention and investment [13]:

- New infrastructure projects which are aimed at expansion or addition of infrastructure to existing infrastructure to cater for increased demand.
- Infrastructure rehabilitation projects which are aimed at reconditioning and/or reconstructing existing infrastructure without changing the capacity of the infrastructure.
- Infrastructure routine inspections, audit and maintenance projects which focus on keeping infrastructure available and reliable during the course of operation or allowable working life. This is preventative maintenance and demand maintenance based projects.
- Infrastructure modification projects that are aimed at modifying the operations and management aspects of existing infrastructure facilities with the objective of improving efficiency, extend the useful life of infrastructure, introduction of alternative strategies or incorporation of new technologies or modification of existing technologies so to maximize the operational capacity of the infrastructure unit/s being modified.

South Africa is currently experiencing serious infrastructure challenges due to inefficient maintenance of existing infrastructure that was installed in the late 1960s and early 1970s [1]. For government through municipalities to effectively provide sustainable basic services that betters the life of citizens, facilitate economic growth and development activities, the following are required [1]:

- Strong public sector leadership.
- Municipal commitment and ownership of operations, infrastructure and technological developments.
- Government financial investment and support.
- Proper infrastructure planning processes and projects.
- Appropriate institutional arrangements and skills development.
- Establishment of suitable support systems, tools and technologies to render infrastructure efficiency.

The National Development Plan (NDP) was established by the South African government in 2013 [15]. The NDP in a nutshell provides a development framework for government institutions to promote economic development through provision of affordable methods and reliable infrastructure. However, the NDP fails to outline a detailed time-based comprehensive implementation plan. For instance, MISA was established to support municipalities through technical and financial aid to address municipal infrastructure challenges, but the responsibilities of MISA and that of municipalities in terms of project ownership are not clearly spelled out [15]. Chapter 7 of the constitution, section 154, sub- section 1 indicates that municipalities are sovereign and national and provincial governments by legislative and other measures must support and strengthen the capacities of municipalities for municipalities to be able to manage their own affairs and to exercise their own powers and perform their functions. Therefore, agencies mandated to support municipalities are conscious about not interfering with municipal activities but this means that often there is a grey area between support establishments and municipalities.

The Department for Environment, Food and Rural Affairs (DEFRA) of the United Kingdom [16], has called on municipalities to focus more on acquiring and providing climate resilient and robust infrastructure that increases flexibility to cope with uncertainty without massive failure and economic cost. In other words, municipal infrastructure should be modernised and effectively maintained over design „working" life through consistent monitoring of infrastructure performance (credibility of infrastructure), and incorporation of frequently reviewed strategies and techniques that maintain infrastructure reliability and at optimal operational conditions so as to meet energy efficient standards. The call by DEFRA clearly articulates the aims that municipalities should have, but the way in which government institutions operate sometimes obstruct these ideals.

Liff [17] states that a wide variety of factors and variables affect the way in which managers in government institutions (including in municipalities) effectively manage the condition and performance of municipal infrastructure. One of the factors is government's budgeting cycle which takes roughly a financial year or two from the time monies have been budgeted to the time when monies are actually allocated for each planned infrastructure project.

Based on views by Goodman and Hastak [13] of infrastructure projects, the distinct infrastructure related project types grouped and viewed by South African municipalities are: infrastructure renewal (refurbishment or rehabilitation) projects, infrastructure condition and performance (maintenance and modification) projects, and lastly new infrastructure capacity (capital expansion) projects. This paper views infrastructure renewal and condition and performance projects as low hanging fruits that government must increase focus at for the establishment of quality infrastructure that solidify the delivery of services and energy efficiency with ease. The Canadian Infrastructure Report Card [18] on municipal infrastructuresuggests that in order to assess infrastructure integrity, the following aspects must be observed and considered:

- Physical condition of infrastructure.
- Capacity review (design capacity) of how infrastructure meets current and future demands.
- Operating conditions and performance efficiency information of infrastructure.
- Maintenance, refurbishment and rehabilitation schedule and plan for infrastructure.
- Asset integrity and verification management plan, and
- Infrastructure replacement value plan.

Further, the report card indicated that, to protect and maintain good infrastructure conditions, capital and operational investment must be made available for infrastructure so as to address:

- Lack of infrastructure and asset management.
- Inefficient operating systems.
- Infrastructure performance regarding new operating conditions, e.g. the ability of the infrastructure to cope with new pollutants.
- Obsolete and costly refurbishment and replacement of existing infrastructure.
- Outdated infrastructure performance and integrity monitoring.
- Reporting and evaluation tools and technology inefficiency, and lack of knowledgeable operators [18].

Infrastructure reliability is core to delivering timeous services, and that infrastructure effectiveness must be maintained over the infrastructure's extended service life or designed available service life [19]. The key measurement of infrastructure effectiveness is infrastructure costs, i.e. costs that cater for infrastructure capital, operations, maintenance, improvement, technological advancement, and compliance.

Municipalities are facing major challenges of ageing and deteriorating infrastructure, inadequate renewal budgets to restore infrastructure, rising renewal deficits, increasing demand levels, and new requirements to comply with stricter environmental and accounting regulations [20, 21]. Therefore, municipalities are urged to allocate and invest funds to improve infrastructure conditions and the effectiveness of performance of infrastructure by forging and adopting more efficient, sustainable, and proactive infrastructure management strategies.

The CSIR report [22] on the state of municipal infrastructure in South Africa and its operation and maintenance indicates that many municipalities" knowledge of the extent and capacity of the infrastructure assets they possess is inconsistent and unreliable. In support of the statement, CSIR reported that no records could be found of any formal broad-based audits or information of municipal infrastructure. Some municipalities performed audits in respect oftheir infrastructure, whereas others only undertook ad-hoc information gathering of their infrastructure, resulting in lack of trends in municipal infrastructure state and performance and respective maintenance. The CSIR report indicates that a radical overhaul of the mind-set is required by municipalities as currently there are very poor records of infrastructure conditions in many municipalities in South Africa.

Urgent investment intervention actions are needed to combat infrastructure stress and vulnerability [23]. Among the many challenges facing efficient and effective operation of infrastructure, the most common challenges are: ageing infrastructure, lack of or no advanced technology to operate infrastructure and monitor its condition and performance, and lack of modelling and controlling of infrastructure loading [23].

In South Africa municipalities often respond to challenges such as population growth and demand by adding more infrastructure to existing. This method of doing things result in municipalities either not conducting proper feasibility study on their infrastructure capacity or lack comprehensive modification design in their infrastructure, thus straining the load-demand management of municipal infrastructure, especially in water and wastewater. In other words, the scope and general norm of extending or adding infrastructure network to existing infrastructure does not include infrastructure integrity for added loads and demand management. Sizes of infrastructure are simply used to determine the capacity of infrastructureto cater for additional loading. Thus factors such as infrastructure conditions due to infrastructure ageing and other forms of wear are not incorporated in determining the ability of infrastructure to cater for additional loads. For instance, condition assessments inside water and wastewater pipelines, including leak detection are not conducted, and if so, only a small segment of interest is conducted. This results in municipalities forfeiting valuable information of infrastructure, and especially information that enable the tracking infrastructure condition. As a result of the above, municipalities fail at gathering not only information above their infrastructure but also fail to effectively plan for their infrastructure projects due to lack necessary infrastructure information. Then the question is then, how do municipalities plan and conduct infrastructure projects that restore conditions to acceptable levels.

From observations of the nationwide procurement of technical services by municipalities to address infrastructure condition related challenges and backlogs, outsourcing has become the order of the day, putting municipalities at risks of inadequate study of their infrastructure, loss of ownership of information of infrastructure capacity, and increasing incompetency of municipal personnel in planning and budgeting for infrastructure projects. That is to say, possibilities exist that professional services providers (PSPs) such as consultants dictate the type of infrastructure project that need to be embarked on by respective municipalities. Implying that municipalities do not know or have sufficient knowledge of their infrastructure, thus cannot formulate substantiated restoration plans of infrastructure. Therefore, risk of budget waste by municipalities in embarking on over-designed infrastructure condition restoration projects and increased energy bills due to infrastructure energy inefficiencies result. Due to the prevalent infrastructure associated challenges and risks and manner that government (municipalities) conduct infrastructure restoration and improvement programs, infrastructure shortfalls and risks cannot be eradicated as long as municipalities conduct their business the way they are with lack of radical and intense determination and commitment.

A well-functioning system of infrastructure reduces transaction costs and facilitates mobility of goods. Direct investment in profitable infrastructure not only improves competitiveness by reducing transaction and trade costs, but also presents opportunities to bothqualitative and quantitative contribution of infrastructure investment [24]. The financing of public infrastructure is a key challenge for sustainable development [1, 24, 25].

The Creamer Media [26] review of South Africa's Water Sector states that government institutions, especially municipalities, have a tendency to allocate insufficient funds towards water and wastewater infrastructure management versus existing investment deficits and infrastructure ineffectiveness relating to both operational and energy efficiencies. Further, Creamer Media reported that the funds required to address infrastructure challenges totalled close to under a trillion rand nationwide with only a fraction spent of allocated public budget to address infrastructure challenges. This adds to the unfortunate approval of only a fraction of the budgets required for the ailing infrastructure by parliament in both national and provincial legislators. The review states that infrastructure challenges emanate from various backlogs due to growing demand for services, lack of maintenance, non-rehabilitation investment of infrastructure, and etcetera. Furthermore, the continuous failure of municipalities to spend allocated budgeted funds together with investment „grant‟ funding from other government infrastructure funding initiatives, exacerbates infrastructure challenges.

All government spheres in South Africa are bureaucratic in nature, therefore the allocation and flow of funds are subject to bottlenecks associated with the approval process for infrastructure capital projects and red tape in the procurement system used to procure goods and services. Currently the governance of all procurement activities in government institutionsin South Africa is centralised and subject to conditions outlined by the

Department of National Treasury (Finance) which have a limiting effect on the expenditure of capital funds at municipal level. Thus, total expenditure is nearly impossible for municipalities within a financial year cycle. This leads to ineffective spending patterns by municipalities of allocated budgets, increasing the risk of infrastructure failure as infrastructure becomes more and more unreliable during operation, and non-compliant to legislative and to technical standards of operation [26]. The overall impact that government spending-intervention on infrastructure and the lack of support for renewable-energy based initiatives result in further deterioration of infrastructure, amplified energy bills, and increasing lack of infrastructure capacity to cater for increased demand.

According to Snyman [27], the poor performance of the wastewater infrastructures in South Africa is due to unproportioned allocation of resource towards capital infrastructure, to competent technical human resource challenges (shortage of trained, skilled and experienced personnel to optimally operate and maintain wastewater plants efficiently), to conduct effective operation and maintenance works on infrastructure re-conditioning and rehabilitation, and to information (communication protocols, work procedures and policies) resources and technological advancement.

It has become apparent that corruption coupled with human resource incompetency has climbed to the top spot of factors affecting the acquiring of quality infrastructure conditions because corruption has further eroded the impact of financial investment on infrastructure. The Auditor-General (AG) Kimi Makwetu on the 20th November 2019[28] stated that from a sample audit conducted through the various government spheres (national sphere, provincial and local government), unauthorized and irregular expenditure (expenditure incurred against legal supply chain requirements) totalled R1.365 billion for national and provincial government spheres, and that from the way government business deals are being conducted, figures reflected from the previous report were expected not to differ by a significant margin for municipalities. The AG also indicated that there is an increase in litigation and claims due to irregular expenditure in the same government spheres which is a cause of concern with regards to governance. The AG further indicated that audits on municipalities are currently being finalised and signed-off and will be publicized in the third-quarter (between January and March 2020) after analysis of the 2018/2019 financial year. However, the AG indicated that there were no noticeable significant improvements within municipalities.

Since figures due to unauthorised and irregular expenditure for municipalities had not yet been released for the 2018/2019 financial year at the time this paper was submitted for publication, 2017/2018 audited figures and findings [29] are briefly reflected upon and discussed. It is worth noting that the figures reflected below are figures obtained from a sample by the AG on municipalities. In other words, if detailed expenditure was fully explored by AG for all municipalities, the figures would relatively increase, accounting for all forms of unsolicited, corrupt and fraudulent activities. A sum total of R27.65 billion was found to be wasteful and irregular expenditure (unaccounted for expenditure that also incorporates corruption and fraud) in the 2016/2017 financial year, and R 21.243 billion in the2017/2018 financial year. In addition, the AG report indicates that in the 2016/2017 financial year procurement of R1 216 million could not be audited due to missing or incomplete information, a sum of R921 million related to prohibited awards to other state officials, R79 million related to prohibited procurement awards made to employees and councilors, and awards made by municipalities to close family members of employees amounted to a sum of R501 million. R1 017 million had been lost due to false declaration of employees and suppliers.

The AG highlights maintenance of municipal infrastructure as significantly impacting the normal functioning of municipalities in achieving their objectives. The AG in the 2017/2018 audit report drew attention to the fact that there was a lack of attention to water and sanitation infrastructure, and that the condition of water and sanitation infrastructure was not being assessed by 32 % of municipalities responsible for providing water and sanitation services, and half of the municipalities did not have maintenance policies for their infrastructure.

It seems that the normal way of doing things in South Africa in terms of infrastructure investment is that huge amounts of funds are allocated towards infrastructure expansion and replacement, and little or no funds are allocated towards infrastructure maintenance and management. The Creamer Media report [26] reflects this and states that R44.75 billion of the approved R76 billion had been allocated to sanitation infrastructure expansion, and R31.25 billion of that amount for refurbishment, upgrade and replacement projects of the existing sanitation infrastructure. The report further state that the refurbishment projects were for seriously deteriorated infrastructure which was also accounted for as infrastructure backlog. For this paper, infrastructure backlog means backlog in meeting current demand or backlog in restoring infrastructure condition to original allowable operational state.

Infrastructure is important for the promotion of economic growth and poverty alleviation. Good infrastructure makes the movement of goods, services, information and people more efficient [30]. However, infrastructure conditions pose a serious challenge to reform in most economies because most countries are equipped with vast infrastructure networks that have gone through long periods of underinvestment so suffer from poor quality, outdated technologyand widespread waste. Most infrastructure in local government is financed by taxes, so municipalities lack financial capacity as new infrastructure funding models must be explored to modernise and keep the infrastructure conditions and performance as efficient as possible.

A United Nations (UN)[31] report presented in 2010 reflects that if countries and government institutions concentrate their efforts on implementing radical investment in the improvement of water and wastewater infrastructure and energy-based initiatives that protect the ecosystem and address challenges that emanate from non-efficient infrastructure in water and wastewater plants, tremendous energy savings may be realised and monies could easily be directed at exploring renewable energy based projects. Von Bormann and Gulati [15] state that to effectively address energy consumption or usage in wastewater and water treatment plants, infrastructure contributing to high energy consumption must be identified and then the necessary interventions be undertaken to repair and renovate such plants. The challenges that the UN report indicates that need to be addressed for wastewater treatment plants are:

- The need for improved financing, as ineffectively managed wastewater infrastructure receives a low and often poorly targeted share of development.
- Lack of adequate regulation and enforcement policies and guidelines.
- Ineffective (enormous disconnect) coherence and coordination between infrastructure management policies and spatial planning, which makes implementation difficult as infrastructure management requires a multijurisdictional approach.
- Outdated information relating to infrastructure design and development.
- Limited technological development and advancement due to infrastructure being operated on outdated technology that is also not energy sensitive.
- Lack of competent capacity and guidelines to operate, monitor and manage infrastructure and energy consumption [31].

Water supply infrastructure is extremely important while sanitation and electricity infrastructure follow on its heels and so having no coordinated strategy increases energy demand and constrains business activities at municipal levels [32]. Therefore, energy demand

and efficiencies are taken into account for this study in order to accurately prescribe methodologies and activities that enhance energy efficiency before assessing the impact and energy savings of developed hybrid systems that manage and monitor infrastructure conditions and performance and energy consumption.

According to a document compiled by Sustainable Energy Africa for SALGA on energy efficiency and renewable energy strategy, local government (municipalities) are key platforms for redistribution of wealth, predominantly through credible infrastructure for equitable service delivery [33]. Although the Energy White Paper (1998) [34] and Energy Act (2008) [35] were published so that the energy policy in the country addresses amongst other things energy poverty and energy security, energy efficiency through managing credible infrastructure is among the top eight key national integrated energy objectives. Energy efficiency of water and wastewater depends on the state of infrastructure at municipality level. In support of the above, the South African Local Government Association (SALGA), a key partner within the Integrated National Electrification Programme (INEP), launched the DORA-funded Municipal Energy Efficiency and Demand Side Programme [36] which seeks to address the energy efficiency component of municipal infrastructure. Hand-in-hand with SALGA, the Department of Cooperative Governance and Traditional Affairs (COGTA) established the Municipal Infrastructure Support Programme through MISA [37] in 2011 to provide technical capacity support that facilitates infrastructure development and improvement through municipal infrastructure grants for improved services to be delivered in energy efficient ways.

In terms of demand on infrastructure capacity, demand is largely influenced by population growth and economic activities, but load and energy demand regarding water and wastewater infrastructure is, in most cases, increased by hidden effects of infrastructure failures (leaks), inefficiencies and conditions. All techniques and strategies designed to enhance infrastructure performance, no matter how credible and effective, are limited by infrastructure conditions. In other words, installation of any technology on infrastructure in poor condition does not have a significant impact on energy efficacy as the poor infrastructure condition enhances inefficiency and poor performance and erodes all associated benefits of installing new technology. Thus, municipalities must arrest the notion that technology solves infrastructure problems and begin to invest in programs that improve infrastructure conditions. This exercise seems to have big costs attached, and the benefits of infrastructure reliability and energy savings are only realised in the long run. However, maintaining infrastructure integrity is far cheaper than infrastructure replacement programs that are due to neglected infrastructure that has deteriorated physical and operational conditions.

In terms of efficiency (performance) of infrastructure, infrastructure in a poor state tends to draw more energy than required from the energy source to deliver a specified output. Various factors deter infrastructure efficiency while infrastructure is in operation, including vibrations, corrosion, wear and tear, faulty components, human handling, and etcetera. To ensure excellent infrastructure efficiency, infrastructure conditions must be maintained at high standards, and improvement projects must be conducted from time to time on infrastructure with changes in operations, changes in demand, and changes in technology.

Condition-based analysis of infrastructure must be conducted before maintenance strategies are fully developed and employed by municipalities should they want to improve and maintain excellent infrastructure conditions [13]. Condition-based analysis is the comprehensive examination of infrastructure integrity and must be derived from infrastructure failure analysis which estimates future infrastructure improvement needs (in rand and cents), identifies risk characteristics of infrastructure, and stipulates the condition assessment frequencies of infrastructure in the asset register or asset management program [13]. The authors further suggest that municipalities should use a structure infrastructure management system (IMS) to periodically collect data on the physical condition of infrastructure together with the cost-benefit analysis in order to reduce the cost of maintenance programs, establish funding priorities, and review frequencies of infrastructure renewals which could reduce annual infrastructure capital related costs. Municipalities in possession of the necessary skills and using the above-mentioned tools should be enabled to allocate priority scores to maintenance programs (that determine frequency of undertaking each maintenance activity) for each infrastructure type with the purpose of improving infrastructure conditions.

Condition-based assessment involves the following aspects [38]:

- Estimation of current condition of public assets or works or infrastructure, which includes the percentage of infrastructure components in various degrees of condition.
- Determination of “acceptable” condition level for each type of infrastructure asset.
- Estimation of the cost required to bring the infrastructure items that are less than acceptable condition up to acceptable condition level.
- Quantitative estimation of implications of deferred maintenance in terms of costs and programmatic infrastructure related consequences that would be avoided in the future if the infrastructure below acceptable conditions are brought up to acceptable conditions.
- Selection of optimal maintenance/repair/rehabilitation procedures for each infrastructure item, considering factors such as the life-cycle costs and future value of money of infrastructure items.
- Adopting credible procedures to prioritize projects that restores infrastructure to acceptable conditions.
- Projections of required maintenance into the future, and projection of longer-range infrastructure needs.

With the above being effectively conducted, the typical costs of each project type that municipalities should incur for infrastructure engagement is determined based on associated infrastructure related costs types, which entails [39]:

- Design or planning costs, which are costs for conducting site-based infrastructure conditions and other feasibility approaches for rehabilitating existing infrastructure to an acceptable condition level.
- Rehabilitation or refurbishment costs, also known as implementation costs, that are associated with the actual conducting of work as dictated by infrastructure plans and specifications.
- Infrastructure maintenance costs, which are costs incurred by a municipality in maintaining infrastructure in acceptable working condition or above a set predetermined performance level. These costs include both preventative and corrective initiatives but do not include rehabilitation or refurbishment projects.
- Rehabilitation costs, also known as refurbishment costs, are periodic costs that cover the types of activities relating to restoring infrastructure, and future dates are set to restore the infrastructure to acceptable performance level.
- User costs, also known as infrastructure operations costs. These are accumulated costs of operating the infrastructure, whereby the user of the infrastructure incurs such costs based on infrastructure type, infrastructure condition, maintenance activities on infrastructure, or rehabilitation works, and etcetera.
- Salvage value costs. These costs relate to the relative value of the infrastructure at the end of the infrastructure life cycle. Salvage value of an infrastructure depend on whether the material

of the infrastructure has some economic value or whether the cost of demolition or removal exceeds any value.

- Energy use related costs. This is incurred cost relative to energy consumption for competing alternatives of the infrastructure.

Regarding the relative generation of costs for infrastructure to remain available for operation, it is notable that each of the costs has a relationship with infrastructure condition at the time of operation and assessment. Some costs can be kept minimal or almost eradicated if infrastructure conditions are retained at acceptable performance levels and conditions. Retaining good quality infrastructure conditions leads to drastically reduced costs to organisations such as municipalities while being able to adequately support economic activities.From a maintenance management point of view, the basic infrastructure maintenance strategiesthat available for municipalities to use are [40]:

- Do-nothing crisis maintenance approach, whereby maintenance work is carried out only to the part of the infrastructure that needs repairing. This is a purely reactive approach.
- Opportunistic scheduling approach, whereby repairs on infrastructure are undertaken on deficient components along with other scheduled work that can be incorporated during breakdown. This approach caters for activities such as rehabilitation or maintenance.
- Worst first approach, also known as prioritization approach, which determines that repairs or replacement of components be undertaken on components of the infrastructure that are considered to be in the worst condition. With this approach, the criticality of the component and infrastructure influences classification. In other words, depending on the criticality of the components in consideration, even of the same infrastructure, some components are allowed to run the full course of their allowable service life (very worse condition) whereas other infrastructure components are allowed to run only a fraction of their allowable service life. Depending on the role of the component, even if the component has run a fraction of its service life, if it is considered to cause catastrophic or costly failure, the component will be prioritized as worst and be scheduled for repair or replacement work.
- Pre-specified maintenance cycle “standards” approach. This approach is based on prescribed service life of infrastructure or components. However, this approach is not necessarily appropriate because infrastructure wear or aging may be influenced by various factors that influence the rate of aging, so in other words this approach poorly predicts the condition and risk of the infrastructure.
- Repair infrastructure at “risk” approach. This approach functions by identifying and conducting repair work on infrastructure and components that will most likely have major problems in the near future, even though their current condition is not known to be a significant problem. To illustrate this approach, high-risk facilities or infrastructure components must have a high inspection priority (inspection frequency and stringent criteria).
- Preventative maintenance approach, it seeks to prevent disruptions from happening. Thisstrategy is generally time-based, whereby maintenance tasks are based on the number of workinghours of components or infrastructure. Manufacturer’s recommended working hours of parts or components is normally taken into consideration when preventative maintenance is considered. Preventative maintenance uses certain maintenance activities designed to reduce theneed for major maintenance work later by scheduling maintenance activities such as regular inspections and light maintenance work.
- Another yet often forgotten or easily confused infrastructure maintenance approach is predictive maintenance. This maintenance approach focuses on monitoring and predicting or determining infrastructure conditions for possible maintenance work by taking into account the operational conditions in which the infrastructure is operating at. Predictive maintenance is largely time-based as heavy reliance is placed on developed institutional based predictive

analytic programs. According to Mobley [41] the common premise of predictive maintenance is regular monitoring of the physical condition of the infrastructure, operating efficiency, and other indicators of operating conditions using non-destructive testing techniques. Variousauthors suggest that the effectiveness of predictive maintenance strategy is largely dependent onthe accuracy of the predictive program that ensures the maximising of intervals between repairsand minimizes the number and costs of unscheduled outages created by failures.

The costs of maintenance practices that aid in retaining infrastructure quality in an acceptable condition and at good performance levels are relatively minimal compared to costs incurred in rehabilitating or refurbishing infrastructure already in bad or below acceptable conditions. User costs are also minimized. Another benefit of conducting regular institution-approved maintenance activities is that the salvage value of the infrastructure follows the depreciation curve that is of a slower rate than normal, thus resulting in infrastructure that is economic viable, and of greater value than the salvage value.

At times there is no way of telling the condition of infrastructure from outward or physical observation of defects or any other related source of infrastructure failure, but the condition of the infrastructure can be compared to baseline performance levels. One of the main and critical ways in which infrastructure performance levels can be determined is through observing and analysing energy use. If infrastructure patterns have been established and modelled, the energy required for the infrastructure to produce the same performance changes for the worse compared to when the infrastructure or component is at acceptable conditions. For any infrastructure or infrastructure component, the energy use must be monitored, especially infrastructure or infrastructure parts that have been determined as being both critical and being a major energy consumer. Having energy monitoring and management devices installed on infrastructure makes identification of problems quicker and easier and reduces energy bills. If the infrastructure conditions are at below acceptable levels, the relationship of the infrastructure performance to energy use cannot accurately be determined especially if performance and energy monitoring devices are not installed and infrastructure information is inadequate.However, if infrastructure is kept at acceptable quality levels, the relationship between infrastructure condition to energy consumption can easily be determined. By incorporating improvement devices or components on infrastructure, the direct improvement margins on energy savings can be accurately determined.

Brown et al.'s [42] high performance infrastructure guidelines state that if infrastructure is designed to be high performing and infrastructure re-conditioning programs and maintenance activities are maintained during the life of the infrastructure, the following benefits are obtained, namely:

- High service standards of the infrastructure, in terms of delivering quality products or commodities.
- Heightened confidence in the reliability and availability of infrastructure for service, and improved life cycle and depreciation curves.
- Enhanced ecological health and productivity.
- Reduced waste or losses resulting from weakened infrastructure integrity.
- Reduced potential hazards.
- Improved energy efficiency and performance of infrastructure.
- Acceptable or improved health and safety standards during the service life of infrastructure.
- Decreased operations and maintenance costs (also user costs).
- Enhanced right-of-way of infrastructure lifecycle and performance.

- Deferred or avoidance of municipal capital costs allocated for infrastructure rehabilitation and replacement.
- Increased salvage value of infrastructure.
- Enhanced compliance with statutory requirements.

3. RECOMMENDATIONS

The South African Local Government Association (SALGA) annual report for 2015 [43] recommends the following as a basis for improving infrastructure conditions at municipal level:

- Process (or best practice) benchmarking, where municipalities search for and study other municipalities, utilities or organisations that are high performers in particular areas of interest. In so doing, municipalities are able to gather information about similar infrastructure and what processes, practices and procedures they have adopted in keeping their infrastructure in acceptable condition. These processes, practices and procedures are studied and knowledge gained is taken back to the municipality and where feasible and appropriate, these good practices are adopted and incorporated into the municipality’s own processes. Process benchmarking therefore allows municipalities to understand why other municipalities are performing better in delivering services, keeping good infrastructure conditions, and consequently resulting inenergy bills free from waste.
- Metric (or performance) benchmarking involves municipalities comparing the performance levels of municipalities using performance indicators for a specific process such as energy conservation, infrastructure condition and performance standards, infrastructure preservation, sustainable delivery of services through reliable infrastructure, and etcetera. The information gathered is used for identifying opportunities for improvement, setting performance targets and understanding relative positioning in comparison to other municipalities. Metric benchmarking allows municipalities to assess the performance of various aspects of their business processes and systems and determine which of its activities are weak or strong, and how much improvement can be made.

Municipalities are urged to benchmark against high performing similar institutions or with other international local government institutions such as provisions in the national legislation of New Zealand, but the CSIR report [22] on the state of municipal infrastructure in South Africa reports that some municipalities compare well with the best practices adapted by New Zealand authorities in respect of many aspects of infrastructure maintenance such as knowledgeof assets, demand analysis, asset creation and disposal, asset utilisation, and asset maintenance,while other municipalities compare poorly in respect of strategic planning, assetaccounting, andplanning and making financial provision for improvement of infrastructure. Thus, standardisation of benchmarking of municipalities must be encouraged and supportedby provincial and national government institutions that are responsible for drafting of standards, acts, regulations and policies.

4. CONCLUSION

To accelerate change and prevent complacency, municipalities must firstly review their current operation in relation to the growing demand for services and economic development. Municipalities must take aggressive strides to improve their infrastructure in order to reach a stage of sustainable and reliable delivering of services to the community. Municipalities should be marketing their infrastructure capacity to extended or adjacent communities and potential investors and attracting economic investments through offering world class infrastructure. Thus municipalities are urged to urgently and comprehensively audit reasons for existing infrastructure challenges, determine the state of infrastructure condition, conduct feasibility studies on remedy infrastructure conditions through rehabilitation and refurbishment projects, and implement agreed upon cost effective measures that eradicate waste and improve infrastructure conditions. In doing so, all benefits associated with good infrastructure conditions such as energy conservation will be the order of the day.

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Chapter 7: Modelling and Factoring Critical system components of PV-MFC systems for improved and efficient energy generation and treatment of municipal effluent at the east coastal regions(s) of South Africa: Case study uMhlathuze municipality

The author uses literature from various authors and researchers to review critical factors and components of PV-MFC hybrid system for purposes of modelling factors and components that will result in improved and efficient generation and discharge of acceptable effluent. The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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MODELLING AND FACTORING CRITICAL SYSTEM COMPONENTS OF PV-MFC SYSTEMS FOR IMPROVED AND EFFICIENT ENERGY GENERATION AND TREATMENT OF MUNICIPAL EFFLUENT AT THE EAST COASTAL REGION(S) OF SOUTH AFRICA: CASE STUDY UMHLATHUZE MUNICIPALITY

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ABSTRACT

Developing a hybrid system that assists government institutions such as municipalities with provision of clean sustainable energy and clean water discharge to the environment from wastewater treatment plants has been an on- going goal in recent years as stringent legislative precepts have been mandated for both public and private sector institutions. However, the focus has been legislative compliance and the procurement and implementation of improved mono-systems that focus on one specific desired aspect. Recent studies and developers have indicated the cost-effective benefits of hybrid systems. Research for better and more efficient performing systems that ensure affordable and socio- economic viability so as to gain government buy-in is the foundation or platform for any business operation and improved quality of life for citizens. Procurement of affordable technology by municipalities affords citizens, industries and businesses such as small-to-medium enterprises, an opportunity to conduct social and trade activities at affordable rates, thus improving economic quality of the region under study and sustainability of life. This paper highlights areas inthe development of photovoltaic microbial fuel cell (PV-MFC) hybrid systems that can be improved for better and efficient systems, especially for municipalities in the South African east coastal regions. The areas highlighted and discussed are, however, subject to the proximity and abundance of required resources in relation to the municipality under study, such as the sea for access to seawater, biomass collection station (such as wastewater treatment plant and macerator stations) and the type of industrial wastes that are discharged to the municipal sewer pipeline. The importanceof stating the above is that each municipality has characteristic resources that are readily available and industrial discharges that carry impurities such as sulphides that the municipality, in this case, uMhlathuze municipality must treatso that the hybrid system can efficiently function when generating clean energy. Based on literature, generic equations are provided with the aim of ensuring that critical components of hybrid system(s) are critically designed and/or modified. The dual function of hybrid systems is presented in this paper to enhance municipal confidence in addressing both operational and economic viability of their function when hybrid systems such as (PV-MFCs) are critically evaluated and employed.

KEYWORDS: Energy Generation, Efficiency, PV-MFC Hybrid Technology, Photovoltaic, Microbial Fuel Cells.

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Original Article

1. INTRODUCTION

Hybrid systems are cost effective and initially cost less compared to the installation of photovoltaic (PV) systems alone (Pazmino, 2007, as cited in Fiedler, 2014). A study conducted by Promethium Carbon and the South African National Energy Development Institute (2017) describes hybridisation as the coupling of one renewable energy technology with another technology for the purpose of delivering energy services. The main purpose of employing hybridised energy systems according to this paper is introducing renewable based hybrid technology to address shortfalls in demand and to ultimately replace the existing conventional fossil fuel (coal) based energy generation. Other auxiliary reasons exist, motivating the use of hybrid systems. This paper emphasises generation and reliability of supply by reflecting on and reviewing critical aspects and components of PV and MFC systems based on studies by authors and researchers that significantly improve the efficiency and performance of hybrid systems when they are properly designed, reviewed and modelled, and implemented. The hybrid system that is critically evaluated in this paper is the photovoltaic microbial fuel cell (PV-MFC) hybrid system. The aim is to enhance government (municipality's) consideration of and buy-in on hybrid systems such as PV-MFC systems for effective delivery of services at improved efficiencies and affordable, multi-functional delivery of duties. uMhlathuze municipality located at the north east coast of the KwaZulu-Natal province of the Republic of South Africa is used to demonstrate the objects of this paper.

2. METHODOLOGY

2.1. Background

Rycroft (2016) states that most municipal wastewater treatment plants in South Africa are aerobic in nature and consume substantial amounts of energy to produce activated sludge. Pabi et al. (2013) concur and state that approximately half of energy consumption at wastewater treatment plant (WWTP) is due to the energy requirements of the aeration process. Bachamann (2015) states that biological treatment of the primary sludge in wastewater plants results in activated sludge. Gikas and Tsoutsos (2013) confirm and state that activated sludge from municipal wastewater treatment plants can be used in MFCs. Franco (2013) states that anaerobic treatment is a lucrative alternative to aerobic activated sludge treatment and that anaerobic digestion process reduce energy related costs and that residue from MFCs compared to residue from aerobic treatment processes are less harmful to the environment when discharged and require no or far less handling. Huggins et al. (2013) state that since the oxidation process of organics in the anode chamber of MFCs is anaerobic, MFCs have the advantage of generating very little biomass. Stoll, Jan, and Xu (2018) concur and state that due to low production of sludge and lower energy costs, MFC systems are amongst the best candidate technologies for generating energy and improving wastewater (grey water) and sludge quality and quantity produced.

Procurement of affordable technology by municipalities often afford citizens, industries and businesses such as small-to-medium enterprises (SMEs) with an opportunity to conduct activities at affordable rates to improve economic and quality of life sustainability. In an attempt to enhance the feasibility of technologies, the first thing that must be acknowledged is that whatever investment a municipality undertakes has a direct impact on how businesses can conduct trades and other economic activities and on the overall quality of life. In other words, municipal buy-in is fundamental to the possible achievement of any goal and dream. Thus, technology requires constant review and improvement so that value for money is achieved and most importantly relevance to time-based changing operational demands and needs is maintained at all times by municipalities.

This paper thus attempts to reflect and review critical areas in the development of PV-MFC hybrid systems that can be improved for better and efficient systems for municipalities operating at the east coastal region of the Republic of South African that are bordered by the Indian ocean. The areas highlighted and discussed are, however, subject to the proximity and availability of the type of resources at the disposal of the particular municipal jurisdiction. Each municipality has its own characteristic readily available resource that clean energy can be generated from, and also characteristic impurities contained in mostly industrial waste discharge that influence the results of and processing of the renewable resource to achieve the desired goals. The desired goals according to this paper are the generation of clean and sustainable energy and treating of effluent or sewer discharge as prescribed by legislation and the South African National of Standards (SANS) in particular SANS 241 before finally being disposed off to the environment. Generic equations are provided towards ensuring that critical components of the hybrid system are critically designed, modelled and/or modified. The dual functioning of the hybrid system as explained in this paper is intended to enhance municipal confidence in the operational and economic viability of hybrid systems when employed.

The PV and MFC technologies reviewed in this paper reflect an innovative alternative to a municipality's conventional operations in relation to the environmental impact that results from the municipality's operations. These technologies are viewed as means of having a positive impact on the safety of person(s) that are and/or can be affected by municipal operations within the workplace and outside of the workplace as prescribed by sections 8 and 9 of the Occupational Health and Safety Act (Republic of South Africa, 1998). Furthermore, such technologies help fulfil the mandates of the Constitution of the Republic of South Africa and that of the municipal finance management act (MFMA) that municipalities must do all that is within their power to procure sustainable and affordable resources in order to provide effective delivery of services to their communities. These technologies support the urgent call by the government of the Republic of South Africa that institutions both private and public must take meaningful steps to address their security of energy supply, effects of global warming/climate change, impact on the surrounding environment and the effects of unreliable energy supply. The PV-MFC technology is thus presented as a viable solution that municipalities located in the east coast region of the country such as uMhlathuze municipality that can establish the economies-of-scale of using such a technology.

Hybridisation combines different energy sources in one supply (Abd El-Aal, 2005). Primo (2016) concurs stating that hybrid systems provide a high level of energy security through a mix of generation methods that when synced together with a storage system such as a battery can ensure maximum supply reliability and a security of supply that can easily be configured to meet the desired range of power needs. Hybrid power systems are, therefore, the result of a combination of different fuel source types aimed at generating electricity.

When designing for the coupling of the different components of a hybrid system, the main elements that need to be observed are: the system's expandability, the general adaptability of the system, the compatibility of the system for the desired application, the cost reduction factor, the system control needs and advancement, and the incorporation of desired aspects of maintenance of the system (Abd El-Aal, 2005). Kleinkauf et al. (2019) adds by stating that the proper designing of and installation of an output power (current) conditioning unit such as an inverter has the potential to significantly improve efficiency and reduce energy wastage and associated costs when using and operating the technology under correctly defined operation conditions.

In agreement with the views expressed by Abd El-Aal (2005), Sahin and Okumus (2017) list among other needs that require addressing when designing for a hybrid system using renewable sources as follows:

- The purpose for wanting to generate electricity from a renewable source such as reducing energy bills, powering the treatment facility from a renewable energy source that makes supply sustainable and reliable, address energy shortages, produce energy through processes that are eco-sensitive and products that are eco-friendly, etcetera must be established.

- Determine the amount of power required and the abundantly available renewable energy source that will support the goal of powering any defined desired facility such as wastewater treatment plant.
- Determine the location and logistics of where the system will be installed with careful consideration of all resources that will make the renewable energy project profitable.
- Selection of affordable and effective technology to be used and how must it function taking into account environmental effects of the place where the project is implemented.
- Determine the feasibility of undertaking the project with full understanding of monetary and non-monetary benefits such as money-saving(s), economies-of-scale in terms of cost-benefit analysis (including financial payback models), etcetera.

In agreement with the above view reflected by Sahin and Okumus (2017), Aznar et al. (2019) states that the above is necessary and important with regards to the design of energy-efficiency and high performance systems that satisfy desired goals with ease. The authors cite Busquet (2003) regarding items that must be identified, fully understood and addressed when designing an energy hybrid system that is intended to solve unreliable supply and energy shortages. Some of the items are listed as follows:

- Define the target application because inadequate targeting may lead to misdirected energy subsidies.
- Decide on the most energy-efficiency investments that reduce long-term energy burden yet maintains adequate supply that meets the demand and phase out conventional energy generation in the long term.
- Attain adequate access, engagement and commitment of partners that support initiative at all stages so that risk is shared and capital investment opportunity is heightened.
- Secure sustainable funding source and program that are well-understood and in place, meeting as little resistance as possible.
- Ensure that the system is simple, tailor-made, flexible, can be easily integrated in phases by means of decentralisation and of multidimensional strategy that accounts for diverse participation with no or minimum resistance.
- Review the implementation strategy and application of the designed system with regards to relevancy, adaptability and productivity.

Primo (2016) recommends that MFCs must be used or sequenced to backup or supplement electricity or be a secondary supply to the PV in the PV-MFC hybrid system. That is, the hybrid system must follow the sequence of firstly using energy generated from a PV/battery system and then when the energy is exhausted. The MFC system commences supply to carry the site load. The author highlights that solar and biomass hybrid systems such as PV-MFCs are becoming popular for providing electricity, reducing costs of generating electricity, and cleaning municipal wastewater. Deval and Dikshit (2013, as cited in Barua et al., 2018) state that MFC can play a major role in green production of bioenergy and for treating waste water.

Abd El-Aal (2005) states that designing or modifying a hybrid system through simulation allows for the effective examination of various factors or system parameters that influence system performance and satisfy the system/user requirements. The mathematical and empirical expressions required to model each system component considered critical and represent the entire system operation are determined. Further, Abd El-Aal (2005) states that in simulating system functions and operations with regard to performance, technical characteristics (specification) of the system must be determined and clearly defined, climatological (weather) data obtained as well as user load demand. The author adds that in determining the size of the system components (the storage and the energy transforming units), the major influence is user load demand. Thus, to find the optimum size and operation conditions, simulations must be conducted to ensure that required conditions are maintained for the system to perform optimally. Due to the absence of comprehensive feasibility report(s) due to the required financial investments that must be committed to conduct detailed feasibility studies regarding uMhlathuze municipality which reflect actual and accurate data of resources on site, an attempt to simulate uncaptured variables would reduce the credibility of this paper. Thus, a generic approach is used.

2.2. Technical Aspects

2.2.1 Modelling and Simulating a Photovoltaic Fuel Cell Hybrid System

Boaro et al. (2013) states that hybrid systems function by interchanging supply if the other part of the system is unable to produce electricity. Abd El-Aal (2005) concurs and states that the PV-Battery-Fuel Cell hybrid system uses the fuel cell system as a back-up when the batteries reach a minimum allowable charging level and/or when the load (peak loads) exceeds the power produced by the PV system. Primo (2016) states that MFCs have gained success as a source of power for wastewater treatment plants around the world and can be used as either primary or backup power supply system. Boaro et al (2013) states that a storage system (battery) must be designed to store surplus energy generated from the system when the power required has been determined and also under conditions when there is not sufficient energy. Abd El-Aal (2005) observes that diesel generators provide the rated power to the load in a few seconds after start up, but a fuel cell system needs more time to provide the same rated power and the output should only be increased slowly after start up. The principal observation by the author calls for pursuit of an alternative approach that must be modelled for and incorporatedin simulation of the whole operation of the hybrid system for high performances and optimisation to be achieved. The author highlights that the significant advantage of the fuel cell as a back-up is that fuel cells have high conversion efficiency and very low maintenance cost.

The suggested alternative of operating the hybrid system as one system backing-up the other, a blended approach can be ensued whereby a baseline energy requirement comprising of night load and the amount of energy required to charge the energy storage unit (battery) is determined and is supplied by the energy generated by the MFC and the rest of the total demand load being catered for by the PV system. For a municipality such as uMhlathuze that discharges an average of 25 000 m^3 per day of continuous municipal sewer discharge from both commercial and households, a 25% - 30% of the total energy demand can be satisfied through MFC generation, with the remainder of the total energy demand including peak demands being catered for by the PV system. Subject to the findings of a comprehensive feasibility study, the most feasible blend approach of either generating against night load and battery capacity or 25% - 30% of the total energy demand using MFC technology system must be determined and implemented. This approach counteracts the observation by Abd El-Aal. Thus, the viability and low costs of operating PV-MFC hybrid system for generating electricitydespite the high initial investment cost must be determined in the feasibility study for accurate and credible recommendations.

2.2.2. Determining Maximum Solar Position using an MPPT

According to Sahin and Okumus (2017), based on the views of Er (2016) and Boaro et al. (2013), solar panels must be designed and installed with a tracking system that ensures that the solar (PV) panels are always at the right angle to the sun's irradiance for maximum harnessing of solar energy to occur at all times. Er (2013) adds and states that understanding the relationship of the earth to the sun at various geographical locations is paramount for MPPT functioning as the fundamental unit of solar time is day and is comprised of sunrise (time when the upper part of the sun is visible) and sunset(when the last part of the sun is about to disappear).

Abd El-Aal (2005) states that site climate, the load profile, the characteristic of the components, and the storage volume required influences the design of the hybrid system. Considering the PV modules of the hybrid system, the maximum power point tracker (MPPT) is responsible for maximising the exposure of the module to the solar radiation. The MPPT is used to adjust the actual operating voltage and current of the PV system so that the power generated approaches maximum value at any given time with the amount of available sunlight at that particular moment in time (Abd El-Aal, 2005). Further, the author states that the operation of a PV system at its maximum power point (MPP) involves matching the impedance of the load to a PV module (electricity generator). MPPTs can be classified as direct or indirect based on the method used (Abd El-Aal, 2005):

- The direct method is algorithm based whereby the system continuously searches for an output that determine and maintain the maximum of the power curve without any interruption of the normal operation of the system. For each increment, if the power output is greater than that obtained from the previous increment, the search direction is maintained at the position where the power output has a higher value.
- The indirect method uses the outside condition to generate a signal that estimate MPP, which includes but is not limited to the measurement of solar radiation, measurement of module temperature, the short circuit current, or open circuit voltage of the reference PV cell.

Er (2016) states that in order to gain a full understanding of the sun's position relative to the solar collector, the concept of solar time must be fully understood. Solar time must be classified as apparent true solar time (sundial time) and mean solar time (clock time). When considering the installation of a solar system or the solar PV component of a hybrid system, the location of where the system must be installed is very important as the direction, angle and location of the solar collector must be determined.

Understanding the importance and correlation (effect) of the sun's position with the earth's rotation around its own axis and around the sun's orbit form the basis for the angle at which solar radiation from the sun hits the surface of theearth. This enables prediction of the sun's position and development of an algorithmic code for the solar collector movement described by angles, solar altitude, and solar azimuth (horizontal direction of the sun at sunrise and sunset) (Er, 2016). Er (2016) state that the trigonometric correlation of the different angles to determine the sun's position are: solar altitude angle (α), solar declination angle (δ), sunrise hour angle (ω_s), solar azimuth angle (γ_s) and sunset and sunrise (ω_o), and described as by using the following expressions:

- $\text{Sin}(\alpha) = \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\cos(\omega)$
- $\delta = 23.45^o \sin\left(\frac{360(284+n)}{365}\right)$

- $\omega_s = \cos^{-1}(-\tan(\varphi)\tan(\delta))$
- $\tan(\gamma_s) = \frac{\sin\omega}{\sin(\varphi)\cos(\omega) - \cos(\varphi)\tan(\delta)}$
- $\omega_o = \cos^{-1}(-\tan(\phi)\tan(\delta))$, where n is the number of days of the year starting from the first of January each year, and ϕ is the latitude of the related location (in degrees).

Er (2016) states that in order to develop an effective code for a solar collector (PV system); the two core classes that the code must consist of are the daily fixed term calculations and the daily variable algorithm calculations. The daily fixed term calculations are parameters such as calendar days and dates, altitude, latitude, declination angle, sun set degree (angle), sun clock sun rise hour, sun clock sun set hour, standard clock sun rise hour, standard clock sun set hour, day length and time difference, etcetera. The daily variable algorithm calculations consist of parameter values of time difference, declination angle based on location of where the system is set to be installed, altitude of where the system is to be installed, clock angle, sun elevation angle and azimuth angle, etcetera (Er, 2016).

According to Er (2016), the main purpose of developing and classifying software tools to be used for hybrid systems such as MFC-PV systems is to provide for either simulation or economic evaluation or selection of appropriate design and data analysis for decision-making and planning or various combinations of the mentioned factors. A clearly defined application of a system together with a full understanding of the objectives of the renewable energy project makes it possible for the software developer to program against known inputs and variables with few or no uncertainties.

Solar power derived from the PV component of a hybrid system depends on the intensity of the sun's irradiance, the trigonometrical terms between the sun and the surface of the system at known geographical location, and the meteorological data. Thus, knowledge of solar radiation data and continuous review and improvement of MPPT are important in designing systems operating on solar energy for a specified region. Solar calculations are the basis and background for forecasting and system performance. This provides system operators with more certainty about what weather and peak solar output and overall solar production that can be achieved at any particular day (Er, 2016).

2.2.3. Determining and Modelling the Flow Rate of Municipal Sewer Discharge as a Source of Biomass for Continuous Operation

Abd El-Aal (2005) states that MFCs are power generators that can operate continuously as long as the fuel and oxidant are made available and supplied to the fuel cell. Assuming that the fuel (municipal sewer discharge or influent) has undergone all the treatment processes to required quality, the feed of the same to the anodic chamber of the MFC is detrimental to the effective performance of the MFC in the hybrid system. This is to say that the fuel must be fed at required and known quantities (concentration and flow rate) so that the ratio of the microbes acting on the organic matter of the municipal sewer is kept optimal. Khaloufi (2019) states that the nature (mix and concentration) of the substrate (wastewater influent) is most important for efficiency and performance of a microbial cell as substrates are a source of nutrients for microorganisms. Modelling, monitoring and reviewing the rate of feed is crucial in avoiding the consequences of high flowrate or low flow rate of the fuel to the anodic chamber and ensure efficient functioning of the MFC in producing the desired energy. To achieve the needed quality, the influent must frequently be tested and monitored to ensure correct concentration of organic matter and the detection and treating of traces of any unsolicited elements found.

Polymer electrolyte membrane fuel cells (PEMFC) is an attractive energy generating system because of its affordability, ability to function at low temperatures, of low maintenance costs, only depend on established municipal sewer discharge volumes and that no additional cost of acquiring electrolyte is incurred when compared to other types of fuel cells such as Phosphoric acid fuel cells (PAFC). The advantages of PEMFCs with effective membrane is that they directly convert bio-chemical to electrical energy, they display excellent characteristics even during partial loading, are fuel flexible, have zero or very low noise during operation, and there is high availability of lower temperature units for use.Disadvantages of PEMFCs are, according to Abd El-Aal (2005), the relatively high initial investment cost, special treatment of fuel is required before being fed to the fuel cell, platinum is expensive and yet it is the most effective catalyst. Taylor (2003, as cited in Abd El-Aal, 2005) states that although the main barrier towards the implementation of MFCs is investment cost, related, research over the years has made MFC technology affordable. Further, Abd El-Aal (2005) states that although operational costs of MFCs are influenced by cost of acquiring the fuel (that is, costs of pumping sewage drained from residential and commercial places to the inlet of the macerator station-where the biomass waste is treated to fuel), the operation mode of both PV and MFC technologies and the cost for stack replacement for both technologies, Abd El-Aal (2005) suggests the following must be pursued as means for reducing investment costs; Improve the fuel cell stack design to increase power density in the most efficient manner, use low cost materials to construct system and minimize temperature constraints that affect electricity generation through use of lower costing material. Membrane and catalyst material must be reviewed and changed based on ongoing research to equivalently efficient low cost material and modelled for up-scaled application. Costs of acquiring biomass fuel are already incurred by the municipality and accounted for in its primary operation.

Although the initial capital investment or outlay of PV-MFC hybrid-based technologies present a barrier for the implementation of up-scaled PV-MFC hybrid systems, the benefits of having long-lasting reliable and sustainable energy supply with low or no carbon emissions and cheap electricity generation costs outweighs cost implications and thus calls for immediate pursuit. The report by Promethium Carbon and South African National Energy Development Institute (2017) reflects that the bioenergy part of the PV-MFC hybrid system is site specific and that its feasibility and appropriateness is dependent on the availability and sustainable biomass feed at low cost and the abundance of sunlight.

2.2.4. Modelling of System Components of Each of the Systems and the Hybrid System

Abd El-Aal (2005) lists three models that can be used to describe the equivalent electrical circuit of PV cell module or array: the one-diode model that represents the electrical behaviour of p-n junction, the two-diode model that describes in detail the recombination process of charge carriers on the surface and the bulk material, and the empirical model that provides the best-fit line for the measured current-voltage (I-V) curve of a PV cell module and array. The parameters reflected by the empirical model as according to Abd El-Aal (2005) are P_{max}, I_{sc}, V_{oc}, $\frac{\delta V_{oc}}{\delta T_j}$, $\frac{\delta V_{oc}}{\delta E_S}$, $\frac{\delta I_{sc}}{\delta T_j}$, where T_j is the cell temperature and E_s is the solar radiation. The empirical model not only accounts for the produce of PV cells and arrays but also the changes that result from change in voltage due to change in the cell and solar radiation collected by the cell respectively and the change in maximum current produced at no load due to change in cell temperature. The advantage of using the empirical model though not as accurate as the two other models is that the empirical model accounts for how actual conditions (changes in cell temperature [heat generated in the cell] and change in solar radiation) influence the production of the current density, and subsequently the power density from the cell.

The expression that reflects the relationship between the voltage of the PV cell and the current produced is reflected by Abd El-Aal (2005) as; Cell voltage, $V_s = V_{oc}[1 + \frac{1}{20.7} In\frac{I_{sc}-I_s}{I_{sc}}] - R_s I_s$. V_{oc} is the open circuit voltage, I_{sc} is the short circuit current, I_s is the cell current and R_s is the cell resistance. Theoretical P_{max} is the product of V_{oc} multiplied by I_{sc}, whereas actual P_{max} is the product of V_s multiplied by I_s. In light of the work conducted by various researchers and authors, an attempt to improve the conversion process of solar energy to electrical energy together with increasing the efficiency of PV modules increases costs for very small performance increase. Thus, cheaper alternative material is continuously sought for equivalent efficiencies that make PV systems more affordable. In view of the electrochemical component of the hybrid system due to MFC functioning, the author states that a reacting system that is at non-equilibrium condition will continue to react until equilibrium is achieved. The general equilibrium equation of a chemical reaction as quoted by Abd El-Aal (2005) together with the equilibrium constant expression is: $\chi A + \gamma B \Leftrightarrow \zeta C + \varepsilon D$, and equilibrium constant (EC) = $\frac{a_D^{\varepsilon} \times a_C^{\zeta}}{a_B^{\gamma} \times a_A^{\chi}}$ respectively. Where a_i is the activity of species calculated from concentration.

Abd El-Aal (2005) states that the theoretical cell voltage when converting chemical energy under spontaneous oxidation-reduction reaction conditions to electrical energy through a known electromotive force (emf) can be computed by using the expression, $V_{th} = V_{o} - \frac{RT}{nF} In[EC]$. Where V_o is the equilibrium cell voltage at standard conditions, R is the universal gas constant of 8.314 J/K/mol, T is the cell temperature measured in K, F is the Faraday's constant of 96485.309 c/mol, and n is the charge number. Abd El-Aal (2005) provides an analytical model for determining the performance of a PEMFC system by taking into account the physical and theoretical aspects that affect the functioning of the MFC system. Through this model, the ideal performance of the PEMFC is determined and the corresponding losses calculated and deducted from the overall performance, determining the actual operation performance of the PEMFC system. The actual amount of electrical energy in terms of voltage (actual cell voltage) for the current drawn from the fuel cell can be computed by using the expression, $V_{actual} = V_{th.} - V_{anode} - V_{cathode} - V_{ohm}$, the difference that results when all losses occurring at the anode, cathode, and external circuit are deducted from the ideal (theoretical) voltage. The model presented by Abd El-Aal (2005) excludes the influence of water management on the PEMFC performance and based on the views by Barbir (1997), as cited by Abd El-Aal (2005), ideal performance of fuel cells such as PEMFC are mainly influenced by the effectiveness (complete reaction and reaction rate) of the electrochemical reactions in the fuel cell under standard conditions.

Municipal sewer discharges varying concentrations of hydrogen sulphide gas and the concentration of this gas depends on the make-up of the municipal sewer system that influences the flow rate and retention of sewer in the system as sewer ferments. This fact must be taken into account and modelled for when PEMFC performance is considered. Abd El-Aal (2005) states that the theoretical (ideal) PEMFC voltage can be analysed through the use of the following expression, which accounts for the effect that changes in partial pressures of hydrogen and oxygen have on performance when the fuel cell temperature is constant at all the points in the fuel cell stack. The fuel to the anodic chamber of the MFC is the municipal sewer that produces hydrogen based gases when the organic matter is acted upon microbes (an anaerobic process). The cathodic chamber is an aerobic process that uses oxygen. The theoretical voltage, $V_{th} = V_{o-}(T - 298.15) \times \frac{\Delta S}{nF} \times \frac{RT}{nF} In[\frac{p\, p_{O2}^{0.5}}{p_O^{0.5}}]$, where ΔS is the entropy of the reaction in J/K/mol. Abd El-Aal (2005) highlights that the theoretical effectiveness of the electrochemical reaction is based on the assumption that the gases in the fuel cell behave ideally and that fuel cell variations are isothermal, whereby the change in molar enthalpy and change in molar entropy at varying temperatures are equal to their value at standard temperature. The author states that when the value of the actual cell voltage approaches the theoretical voltage value of the cell, the fuel cell is high performing. Furthermore, the author states that to have a high performance fuel cell or fuel cell with minimum over potential, modifications in the design of the fuel cell is required. Abd El-Aal (2005) lists the aspects of the fuel cell design that must be modified and modelled as including: improvement in the structure and material composition of the electrodes in terms of conductivity-durability-affordability and maintainability, improve electro-catalysis of the fuel cell, improve conductive electrolyte, reduce resistance of the nanowire (external circuit) by shortening the length and manipulating the cross-sectional area of the nanowire, etcetera. Regarding improvement of the operating conditions of the fuel cell, the author states that the concentration of fuel must be optimized in relation to the concentration of bacteria at the anodic chamber, the temperature conditions must be kept conducive and fairly constant for optimum bacterial activity and the impurities in the fuel must be minimized and even eradicated to prevent poisoning of bacteria and limiting of the reduction-oxidation (redox) reaction and reduced conductivity of ions. Abd El-Aal (2005) accounts for the efficiency of PEMFC as the ratio between the electrical power output and the fuel input (in Watts). The ideal efficiency of a microbial fuel cell is $\eta_{fc} = \frac{\Delta G}{\Delta H} = \frac{P_{fc}}{F_{in}}$. Where P_{fc} is the electrical power output of the fuel cell, F_{in} is the input fuel to the cell, ΔG is the change in Gibbs energy which represents the electrical energy output of the fuel cell and ΔH the reaction enthalpy change which represents the thermal input energy.The standard conditions for a fuel cell also known as the standard free energy of the cell reaction are indicated as temperature, T = 25 °C, pressure, P = 100kPa, thermal input energy, ΔH_o (hydrogen/oxygen reaction) = -268kJ/mole, and free energy available for useful work = 237.3kJ/mole. The maximum theoretical efficiency in a PEMFC is generally 0.83 (Abd El-Aal, 2005). Abd El-Aal (2005) states that the efficiency of the actual fuel stack, $\eta_{fc,stack} = 0.83 \times \frac{V_{actual}}{V_{th}}$. Thus, the author provides that an increase of the actual cell voltage subsequently increases the fuel cell efficiency.

Why the efficiency of the fuel cell is of utmost importance is because a decrease in the current density requires the active cell area to be increased in order to maintain the required power. Abd El-Aal (2005) states that when designing a fuel cell with high efficiency, the capital costs tend to increase, but the operating costs must be kept minimum or decreased. Bocklisch (2003, as cited in Abd El-Aal, 2005) states that in order to compute the total efficiency of the fuel cellsystem, losses of the peripheral power components such as air blower, control system, etcetera must be incorporated. The expression for computing the total efficiency of the system is: $\eta_{fc,system} = \frac{P_{fc}}{F_{in}+P_{periph}} = \frac{y_{fc.stack}}{1+[\frac{P_{periph}}{1.482\times N_S\times I}]}$, where N_s is the number of cells in the stack, I is the output current of the fuel cell, and 1.482 is the theoretical thermal voltage of the cell at standard conditions in volts.

To conclude modelling and analysing of fuel cells, the rate at which electrons are produced at the anodic chamber must also be considered. Using Faraday's law that the rate of hydrogen generated or supplied to a fuel cell is directly proportional to the rate of transfer of electrons at the electrodes, the principle of analysing the rate at which electrons are produced depends on the concentration of required organic matter (ingredient in fuel) to produce hydrogen ions when acted upon by microbes. Busquet (2003, as cited in Abd El-Aal, 2005) indicates that the concentration or flow rate of organic matter for several cells connected in series (the mass flow rate of biodegradable organic matter by these microbes) is $\dot{m} = \frac{N_s\times I}{n\times F} \times \frac{1}{y_F}$, where $\dot{m}$ is the flow rate of organic matter in the fuel or substrate that produces hydrogen when acted by the bacteria in the fuel cell, n = 2, the number of electrons per mole, ηF is faraday's efficiency.

Since in actual PEMFCs, the organic matter in the substrate responsible for the production of hydrogen ions is slightly higher than the theoretical maximum value (stoichiometry). Abd El-Aal (2005) states that the more the organic matter there is than the concentration of microbes acting on the matter (incomplete redox reaction), the current efficiency reduces or the Faraday's efficiency of the cell reduces. In relation to hydrogen production, Faraday's efficiency is described as the ratio between the theoretical maximum value of organic substance (hydrogen based elements in organic matter) consumed in the fuel cell and the actual value. Abd El-Aal (2005) expresses Faraday's efficiency in relation to hydrogen production as: $\eta_F = \frac{\dot{m}_{th.,hydrogen\ produce\ from\ substrate}}{\dot{m}_{actual\ hydrogen\ from\ substrate}}$. Thus, the concentration of organic matter in the municipal sewer must be modelled and monitored for corresponding adjustments in the flow rate. Although the Faraday's efficiency is highly dependent on the temperature conditions for bacterial activity, the concentration of organic matter must be modelled in terms of flow rate and temperature.

Temperature conditions must, according to Abd El-Aal (2005), be kept at levels that lower resistance, reduce current losses, and improves Faraday's efficiency. The empirical expression of Faraday's efficiency that accurately depicts the release of hydrogen ions after bacterial activity on substrate or fuel to produce hydrogen molecules is: $\eta_F = \zeta_i \times e^{[\frac{2+T_3}{\frac{I}{(A_c)}}+\frac{4+T_5}{\frac{I}{(A_c)}}]^2}$. Where ζ_i are Faraday's parameters, T is the temperature of the fuel cell [°C], I is the fuel cell current, and A_c is the contact or surface area of the electrode.

Hydrogen is the simplest element that aside from the photovoltaic effect in PV systems is a base element in MFC systems that makes both systems to complement each other with respect to ensuring consistent concentration of hydrogen ions (Primo, 2016). Another benefit of hydrogen is that it maintains the temperature of biomass reservoirs at temperatures that enable the production of controlled power generation as at low temperatures biomass plants collapse (Primo, 2016).

2.2.5. Modelling the Power Conditioning Unit

Since the power conditioning device formats the output of generated electricity to required form for application, the analysis provided through the modelling of the power conditioning unit (PCU) provides a characteristic efficiency curve of the entire hybrid system. According to Abd El-Aal (2005), two models exist for a power system: a model of a system without any energy storage, whereby the power output (generated) from the system equals to the load demand and a model of a system with energy storage, whereby the input effort during normal operation determines the power supplied through the PCU. The latter is applicable to this study under the expressions $\eta = f(P_{in})$ and $P_{out} = f(P_{in})$. Three models exist that can be used to describe energy conversion by PCUs. These are listed and described by Abd El-Aal (2005) as:

- The linear PCU model that functions to describe power output (P_{out}) based on examining the relation of the three parameters; input power P_{in}, the standby power consumption $P_{standby}$ that corresponds to operation at no load (open circuit), and the efficiency η_{rated} at rated power. The expression is: $P_{out} = \eta_{rated} \times (P_{in} - P_{standby})$.

  Where $P_{standby} = 0.01 \times P_{rated}$ when $P_{in} < P_{standby}$, the efficiency is assumed zero. And when P_{in} approaches the rated power P_{rated}, the standby power consumption is negligible. When $P_{in} \geq P_{standby}$, $\eta_{out} = \frac{y_{rated} \times P_{rated}}{P_{rated} - P_{standby}}$.

  However, Dumbs (1999, as cited in Abd El-Aal, 2005) highlights that this expression gives an underestimate of the inverter's efficiency of about 5 % to 10% for high values of P_{in}.

- The quadratic PCU model. Although the quadratic PCU model has limited accuracy at low input power levels, the quadratic PCU model is best-suited for high input power. Abd El-Aal (2005) states that the three parameters extracted from the experimental data are simulated in such a manner that the power curve (power output) is computed from efficiency and input power. The expressions used in this model are: $P_{out} = \{ \begin{matrix} P_{in} - P_{loss} \\ 0 \end{matrix}$, where $P_{loss} = K_0 + K_1 P_{out} + K_2 P_{out}^2$, and $P_{standby} \le P_{in} \le P_{in,max.}$ where $P_{out} = P_{in} - P_{loss}$.

According to Abd El-Aal (2005), K_0 is described as the load independent losses (self-power consumption losses) that is equal to $P_{standby}$, K_1 is the linear load proportional losses (voltage drops in semiconductors), and finally K_2 is the load Ohmic losses that includes magnetic and all other losses. Magnetic and other losses are losses that are incurred due to capacitors, inverters, etcetera. What can be depicted with this model is that when the output power is closer to the rated value, the Ohmic losses have more influence on the efficiency due to voltage drop. And that the reduction of these losses (self-power consumption parameters) mainly increases (improves) the rated power efficiency. This model best describes solar PV performances. According to Macagnan (1992, as cited in Abd El-Aal, 2005), the efficiency of PCU is expressed by the expression:

$\eta = \frac{P}{P + n_o + mP^2}$, where $P = \frac{P_{out}}{P_{rated}}$, $n_o = \frac{1}{99}(\frac{10}{y_{10}} - \frac{1}{y_{100}} - 9)$ and

$m = (\frac{1}{y_{100}}) - n_o - 1$. Where η10 is the efficiency of the PCU at 10% of the rated power, and η100 is the efficiency of the PCU at 100% of the rated power. Also, the power output relates to the average power consumption. The expression is:

$P_{out} = \{ \begin{matrix} C_o + C_1 P_{in} + C_2 P_{in}^2 \\ 0 \end{matrix}$ where $P_{standby} \le P_{in} \le P_{in,max.}$. Co is negative and indicates the average power consumption at no load (Pout = 0). The value of power consumption is 1% of the PCU rated power (Abd El-Aal, 2005).

- The piece wise linear PCU model is a value resulting from the interpolation between measured efficiency values for corresponding PCU input power values (Abd El-Aal, 2005). The advantage of using this model is that the efficiency of the PCU can be predicted over the entire range of the input power by dividing the input power into values at equal intervals that measure the PCU efficiency. Since the model computes the efficiency by linear interpolation between measured efficiency (η_{low} and η_{up}) at the lower and upper ends of the selected input power ($P_{in,low}$ and $P_{in,up}$), then efficiency η at any intermediate level of P_{in} is expressed as: $\eta = \eta_{low} + \frac{(P_{in} - P_{in,low}) \times (y_{up} - y_{low})}{(P_{in,up} - P_{in,low})}$.

2.2.6. Modelling for Storage Unit

A capacitor is an electrical component that is used to store energy. Supercapacitors are the future of storing energy (Abd El-Aal, 2005). As an integral part of PV-MFC hybrid system, it is important to describe and model their characteristic functioning and incorporate their effect on performance (Abd El-Aal, 2005). To establish the best performing energy storage unit, modelling the performance of a series of capacitors or supercapacitor must form part of any hybrid system that is intended to generate and supply energy (Abd El-Aal, 2005), hence they form a part of this study. This is because, the more efficient the storage unit, the more effective and improved the performance of the hybrid system.

The supercapacitor is, according to Abd El-Aal (2005), made-up of the equivalent series resistance (ESR) and capacitor. The supercapacitor model is expressed based on two characteristic elements: its self-discharge current (I_{dis}) and the internal equivalent series resistance (ESR). The ESR accounts for all the losses that occur in supercapacitors (Abd El-Aal, 2005).

The voltage-current relationship of a supercapacitor is expressed as: $V_{SCap} = (ESR \times I_{SCap}) + \frac{1}{C}\int_0^t (I_{SCap} - I_{dis})\, dt + V_{SCap}(0)$, where $V_{SCap}(0)$ is the initial voltage across the capacitor of capacitance C, V_{SCap} is the terminal voltage, and I_{SCap} is the current that flows into the supercapacitor. In order to achieve a higher voltage and current rating, a supercapacitor module must be developed which consists of supercapacitors that are connected both in series and parallel with the voltage across the supercapacitor module fluctuating above and below the base DC bus voltage (Abd El-Aal, 2005). These fluctuations are related to the excessive incoming and outgoing currents during operation. The self-discharge current depends on the temperature T_{SCap} and the voltage V_{SCap} of the capacitor of the supercapacitor, whereas the ESR depends only on temperature. Abd El-Aal (2005)lists the above as:

- The characteristic of the self-discharge current, $I_{dis} = f(V_{SCap}, T_{SCap})$, measured in ampere.
- The characteristic of the internal resistance, ESR = $f(T_{SCap})$, measured in ohms.

2.2.7. Factoring Improvement on MFCs for Efficient Performance of PV-MFC Hybrid System

Sinha (2008) and Khaloufi (2019) state that microbes oxidise fuel molecules of the substrate (wastewater) at the anodic chamber to produce electrons and hydrogen ions and enhance oxygen reduction at the cathode. Khaloufi (2019) indicates that the strength of produce depends on the type of electrolyte used together with the choice of electrodes, which form a basis for improved performance (electricity generation). Koroglu et al. (2019) state that MFCs generate electrical energy by the relationship between microbial metabolism and solid electron acceptors. Flimban et al. (2018) state that in order to achieve improved performance, solution (electrolyte) concentrations at the anode and cathode must be produced together with the 'right' mix of substrate that supports an improved proton concentration gradient and potential difference. Although the challenge of lower yields of energy due to loss of microbial activity from immobilisation of microbes at the electrode surface persists, research is ongoing to improve performance. Khaloufi (2019) states that PEMFC are effective under optimum conditions, but the very costly exercise of conducting feasibility studies to obtain customized data conditions for each proposed MFC plant pose as a limit. Thus, views expressed by authors and researchers form the basis for the literature review of improved performance of PV-MFC hybrid systems.

The high performance of PEMFC depends on the effectiveness of polymer electrolyte membrane (PEM) in only allowing the flow of protons (hydrogen ions) and not the flow of electrons and leak of oxygen through. The selection of an effective membrane is based on computing the impermeability of oxygen through the membrane, the mass transfer coefficient of oxygen (K_o), and oxygen diffusion coefficient. The general expressions used to determine the mass transfer coefficient of oxygen is $K_o = \frac{-V}{A.t.In[\frac{C_O - C}{C_O}]}$, where V is the volume of the substrate at the anodic chamber, A is the cross-sectional area of the PEM, C_o is the oxygen concentration at the cathodic chamber, and C is the oxygen concentration at the anodic chamber, the oxygen diffusion coefficient is, $D_o = K_o \times L_t$,, where L_t is the material's thickness of the membrane.

Miyahara, Kouzuma, and Watanabe (2015) conducted a study of how the introduction of NaCl concentration (seawater) affects the anode microbe and power generation of MFCs. The authors found that within specific seawater (NaCl concentration) thresholds, diluted seawater supported the growth and growth rate of *Geobacteraceae* (a specific typeof geographically located community of microbes or bacteria) at the anode and that the abundance ratio of *Goebacteraceae* relative to the total bacteria at the anode significantly increased. The study indicated that NaCl is a major determinant of ionic strength in the electrolyte and that since *Geobacteraceae* bacteria are responsible for MFC power generation, *Geobacteraceae* are optimum when seawater is diluted. Further, Miyahara et al. (2015) indicated that increased concentrations of NaCl (seawater) drastically reduce the open circuit potential and corresponding maximum power output. According to Naga Samrat et al. (2017), seawater contains various microbes that have the ability to reduce and oxidise substances like iron, sulphur and nitrates. This consortium of seawater bacteria can now be used in MFCs. Liu, Ramnarayanan and Logan (2004) state that microbes must be developed anaerobically. Pandit and Das (2018) concur stating that microbially operated MFCs transform organic matter anaerobically at the anode into free electrons to create a potential variance among both anode and cathode chambers that result in current generation in the MFC. According to Rahimnejad et al. (2015), MFCs are able to change over energy through accessible bio-convertible substrate through straightforward means to electricity. Primo (2016) adds that the performance of MFCs to change chemical energy to electrical energy is based on strength of the two separate electrochemical reactions that occur within the MFC: the oxidation half-reaction that occurs at the anodic chamber whereby electrons are released from the fuel substrate and the reduction half-reaction at the cathode whereby electrons are absorbed.

Ohmic losses result from internal resistance of the electrode material and that of the wire (external circuit). Khaloufi (2019) states that the potential loss due to Ohmic losses is determined using an expression by Heijne et al. (2006): Ohmic over potential, $\Delta V = \frac{\delta W . I}{\sigma}$, where δW is the distance between the anode and the cathode, I is current normalised to the anodic surface area, and σ is the solution conductivity. Khaloufi (2019) suggests that to improve MFC performance the solution conductivity must be increased and the distance between electrodes be must be reduced to reduce the Ohmic losses in MFCs. Adding to the above, Nhleko and Inambao (2020) expressed the view that designing and selecting appropriate pre-treatment processes improve MFC performance. Barua et al. (2018) adds that multi-chambered MFCs connected in series provide optimal results by yielding higher electricity than double-chambered MFC.

2.2.8. Modelling for a Hybrid System

Energy efficiency increases access to energy especially when utilities are struggling to keep up with demand, hence the importance of designing an effective energy efficiency program that is based on the performance of energy efficiency devices (that is, the effectiveness of such devices) when installed and observing (monitoring and managing) the energy efficiency based on infrastructure conditions and overall energy demand and consumption trends. Investment in such a program can provide consumers with long-term energy bill reduction (Aznar et al. 2019). To model for energy efficiency, Figure 1 derived from Hamby, Juan and Kabamba (1996) can be used as a guide for modelling each system and reducing the complexities of modelling for efficiency of a hybrid system.

Where i^+ is the raw input (variables), f^- is the feedback signal or improvement variables, e_i is the efficiency equipment variables resulting from assumptions made when the equipment(s) and technology used to measure and monitor were developed, i is the resulting input into the internal system (components and the various sub-systems), d_i is the internal disturbance(s) in and of the system such as vibrations, system technology, efficiency drop of the various components due to wear and/or application, sub-system and system, etcetera., and d_o is the external disturbances such as maintenance effectiveness, operating conditions, environmental exposures, budget constraints, etc.

$d_i d_o$

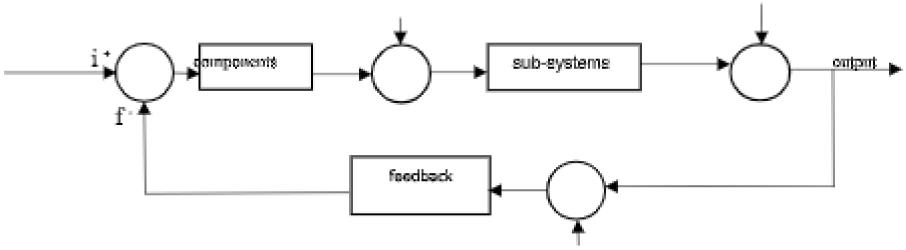

Figure 1: Modelling for the Efficiency of a Hybrid System. Source Derived from: Hamby, Juan & Kabamba (1996)

Since technologies are not all the same, modelling for considered technology is necessary to establish the correlation and effect of the technology on a defined system. Figure 1 can thus be used as a basis to factor in technological factors to system variables and harmonizing the two to get a modelling expression that defines a particular system- technology for specified applications. Although each institution has its own system requirements and specifications which depend on a lot of factors such as the environment (geographical location, climate behaviours and trends, collected impurities, etcetera), operational requirements, scale-up or expansion expectations, load forecast, legislation, socio- political and economic factors, financial muscle of the institution and goals and targets determined by the institution in consideration factoring the mentioned assists local government institution or utility to decide the approach that must be undertaken to either increase supply by modifying or building new infrastructure or by decreasing energy demand by improving energy efficiency (Xia and Zhang, 2015). The IEA (2013) report reflects that technological advancement based on precise modelling of a system's make-up and application positively influences the inclination towards energy efficacy and energy savings. This principle is also applicable in the treatment of wastewater before disposing off it to the environment.

2.2.10. Factoring in and Modelling for Anode and Cathode Surface Areas

When scaling-up MFCs, Dewan (2008, cited in Kim et al. 2012) states that the surface area of an anode is critical and must be factored in when designing large MFCs. Attempting to increase the size of the anode surface area often results in a non-linear power density decrease that affects the MFC into having low efficiency due to increased internal resistance of the cell. According to a surface area calculator by Wattyl (2004 cited in Kim et al., 2012), corrugated sheets add approximately 10.5 % to the effective flat surface area and trough section sheets of the same material add approximately 50 %. Peen, Keong and Hassanshahi (2019) found that although computations of the total surface area of a perforated carbon cylinder is tedious, perforated carbon cylinders lessen the initial surface area for microbial activity and that perforations on cylinders significantly affect the structural response and capacity of the cylinder. If solid cylinders have multiple systematic dents at the surface, the increase in surface area is negligible to increase bacterial activities. Ghasemi, Emborg and Cwirzen (2016) examined the various shapes of granules and surface areas of the same and found that when the size of the granules decreases, the surface area grows faster than the corresponding volume. The investigation by Ghesami et al. (2016) indicates that tetrahedron shaped granules are more effective when considering specific surface area (SSA) to volume or growth of surface area/volume ratio (SA/V) and in view of the various mathematical equations and calculations, Ghasemi et al. (2016) reflects that the less spherical shaped a particle is the greater and more effective is the SSA which makes tetrahedron shaped granules best suited for use for bacterial activities in MFCs. However, due to the possibility of granules getting saturated and getting lost in the system, the use of carbon granules is considered expensive and unreliable as granule concentration must be kept constant and available for microbial activities. But, once microbes react at the surface of granules, less surface area is available for microbial activities, while replenishment of granules in the anode chamber requires intense monitoring and management. With respect to examining the efficiency and maintainability of cylinders and trough section sheets, trough section sheets are efficient as they have lower internal resistance and they are easy to clean and maintain.

The other critical part that must be improved is the cathode surface area. According to Khaloufi (2019) Logan (2005, as cited in Khaloufi, 2019), when the cathode surface area is doubled power generation is increased by 62 %. Taking into consideration the relative costs of materials used for electrodes (cathodes) such as platinum and/or aluminium when scaling-up an MFC, Khaloufi (2019) indicates that since each of these materials are relatively expensive and have specific microorganisms that work like biocatalysts with each of the metal cathodes, an alternative such as bio-cathodes must be considered as alternatives to reduce the relative costs.

3. RECOMMENDATIONS

Although, the above is indicative of the criticality of observing and factoring in the latest reviews or factors that improve the performance of PV-MFC hybrid systems, the process of undertaking detailed examination and modelling of various factors is not only complex but also costly. In order to reduce the costs while yielding improved outcomes, each municipality in coastal regions must allocate appropriate budgets for detailed feasibility studies that examine and factor in all possible variables from readily available resources.

In 2015/2016 financial year, the uMhlathuze municipality through a private-public partnership (PPP) financing agreement conducted a detailed feasibility study of close to R30 million to conduct a study of “the feasibility of re-use wastewater to produce potable water”. Data from the feasibility report on using wastewater to produce potable water and the following factors are favourable in anticipating a positive outcome when conducting the feasibility study of using PV- MFC hybrid system to generate electrical energy. The factors are: consideration of wastewater volumes from the feasibility report of the re-use project will produce required and sufficient daily activated sludge towards the implementation of the PV-MFC hybrid system; use of the less than three kilometres away from a 10Ml desalination plant to obtain treated (diluted) seawater; the Indian ocean that borders the municipality; the presence of Foskor Acid Division (FAD) that produces pure sulphuric acid and phosphoric acid that can be used to amongst other functions dope (treat) electrodes in MFCs and photoelectric material in PVs. Outcomes from undertaking such a feasibility study and model development provides the conditions to improve and optimise PV-MFC hybrid system performance.

At this juncture, taking into consideration the modification and modelling of system components and parameters that must be factored in for improved performance and based on the study by Miyahara, Kouzuma, and Watanabe (2015) on improving the quality of the substrate, capital costs on a PV-MFC hybrid system can be significantly reduced and yield be improved when Figure 1 and the various expressions are used to factor-in and model each of the components considered critical in this paper for a PV-MFC hybrid system.

Er (2016) states that in order to evaluate the effectiveness and performance of software tools or systems, the "simulation", "economic evaluation-payback model" and "data analysis and planning" process must be undertaken with the appropriate funds and commitment. Promethium Carbon and South African National Energy Development Institute (2017) suggest that a PV-bioenergy hybrid system can have a payback period of between 4 to 6 years after commencement depending on financial models and fees used by financial institutions to fund such a project.

4. CONCLUSIONS

System efficiency must not be a reactive process of gathering data from energy bills, energy demand and consumption but must be planned before-hand so that all variables can be factored in and modelled to improve system performance. The process of gathering data must be used as a tool to checking performance and not for planning performance, because the culture of gathering data and attempting to improve performance results in misdiagnosis, procurement of misaligned technology, lack of commitment by government and government institutions and deterred attitudes from government personnel in procuring and operating technologies and systems that could be beneficial and loss of opportunity to correct or modify system behaviours that would result in improved systems. Hybrid systems such as PV-MFCs described in this paper offer the advantage of reduced capital or investment costs and multi-purpose function when employing reviews that re-model and factor in parameters that improve the viability and performances of PV-MFC hybrid systems.

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Chapter 8: Designing specifications and implementation of PV-MFC hybrid system project based on public-private partnership (PPP) and South Africa's procurement policies: case study uMhlathuze municipality

The author indicates legislation and government tools that can be used to conduct feasibility studies that will assist government in successfully designing for and implementing HRES (PV-MFC) project to improve energy capacity and reliability and alleviate risks and challenges associated with unreliable energy supply and energy shortages. The article was published in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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DESIGNINGTHE SPECIFICATIONS AND IMPLEMENTATION OFAPV-MFC HYBRID SYSTEM PROJECT BASED ONAPUBLIC-PRIVATE PARTNERSHIP(PPP) AND SOUTH AFRICA'S PROCUREMENT POLICIES: CASE STUDY UMHLATHUZE

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ABSTRACT

Electricity supply shortages in South Africa cause insecurity of supply, which subsequently negatively affects economic growth and increases electricity prices for energy consumers, making energy unaffordable for the effective execution of day-to-day activities. Discussions at a national level indicate that tariff increases are likely, further burdening energy consumers (business owners and citizens). Indications are that there could also be a surcharge to consumers that use the national conventional fossil fuel-based energy grid but supplement supply from other sources, and additional surcharges for users of 100% renewable. Considering the potential unrest and concerns from e nd-users of electricity, this paper proposes guidelines for the procurement of a photovoltaic-microbial fuel cell (PV-MFC) hybrid system as a means of implementing decentralized energy generation for municipalities, with the uMhlathuze municipality used as a case study. Public-private partnership (PPP) procurement is proposed as an effective vehicle for the safe acquisition of renewable technology that offers stable yet sustainable investment capital, distributed and manageable risks associated with project implementation, and profitable long-term payback strategies. The details of such specifications framework are accurately outlined after a feasibility study has been concluded that indicates the precise design of the PV-MFC technology required and the amount of capital financing for the implementation of the hybrid renewable energy system (HRES) has been established.

KEYWORDS: Public-Private Partnership, Renewable Project Specification, PV-MFC Hybrid Technology, Photovoltaics & Microbial Fuel Cells

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Original Article

1. INTRODUCTION

Ending energy poverty and achieving sustainable energy for all by 2030 are global challenges for humanity that require innovative trends in the renewable energy sector that favour and benefit future installations of up-scaled power plants [1]. The author further indicates that hybrid renewable energy systems (HRES) consist of two or more energy sources (with at least one of them renewable) integrated with power control equipment and an optional storage system. HRES can either be a standalone hybrid energy (or power) system, or off-grid, or remote, or island, or hybrid energy (or power) system, or microgrid, or mini-grid, or an autonomous power system. Musvoto et al. [2] state that the electricity shortages in South Africa in 2008 exposed the risk to both water and wastewater treatment operations posed by an unreliable power supply and continuous increases in electricity prices. This has stimulated interest in technologies such as HRES that can be used by municipalities for the purpose of recovering energy from wastewater sludge. Thus, to curb the adverse effects of electricity shortages, HRES installations should be fast-tracked with seriousness and commitment.

The majority of government-initiated energy or hybrid energy system (HES) projects in South Africa are technically driven by economic feasibility analysis focused on energy cost and return on investment; this paper attempts to cover the multiple key design aspects of HRES, in particular, that of the photovoltaic microbial fuel cell (PV-MFC) hybrid system for the uMhlathuze municipality. This PV-MFC hybrid system is the main focus in this design overview to enable procurement purposes using the type of load, energy sources, storage, availability of meteorological data, etc. Procuring and undertaking detailed feasibility projects takes a year and a half to two years, and the general construction of giant power plants takes between seven and eleven years. Modise and Mahota [7] indicate that the South African government established from electricity demand projections that an additional energy target of 40 000MW capacity is required by 2025. This can be achieved if municipalities are given the autonomy to generate energy using HRES. In the past sludge has been viewed as a nuisance in the wastewater industry yet forms a large part of wastewater operations. The consensus is that sludge and solar energy are economically feasible for energy generation [2].

2. BACKGROUND

The City of uMhlathuze (also known as Richards Bay, referred to as uMhlathuze municipality in this paper), is situatedon the northeast coast of the KwaZulu-Natal province of South Africa, about 180 kilometres north-east of the City of Durban. Emanating from the Statistician General report [8] that South Africa is rich with renewable sources and is imbued with heavy sunshine. Fig. 1 shows the meteorological report [9] indicating data for solar energy at the uMhlathuze area.

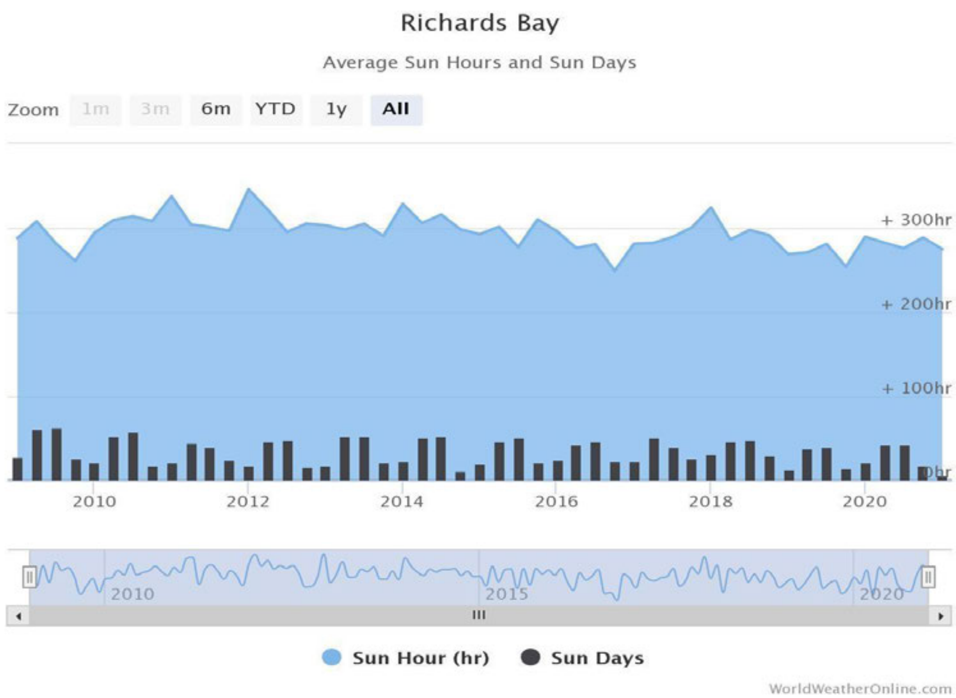

Figure 1: 10-Year Meteorological Data of Average Sun Hours

and Sunny Days at the Umhlathuze Area

Figure 1 reflects the trend of sunlight averaging over 270 sun hours per year for the past 10 years. This revealsthat uMhlathuze municipality has ample sun hours which can support the procurement and use of photovoltaic technology for the generation of electricity.

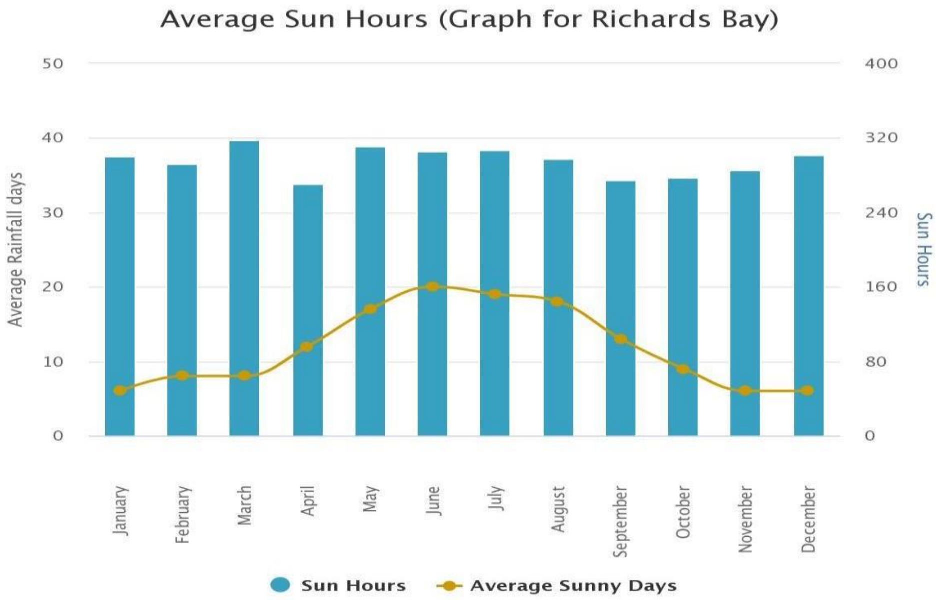

Figure 2: The 2020 Annual Meteorological Data on Average Sunny Days and Sun Hours for the uMhlathuze Area.

Figure 2 reflects the 2020 month-to-month meteorological data [9] with an annual average of 300 sun hours is per year. The least average sunny days occur during the rainy months from October to March with an average of 278 sun hours per the 6 months. The least number of sunny days according to the [9] is 4 that occur in November and December 2020. Since a day has 12 hours and the number of days considered in this paper is 30 per month, the number of hours in a day per month is 360. With the above information and the conversion efficiencies of solar energy to electricity using photovoltaics, the potential amount of energy that can be generated can be determined, however, the intended energy required and allocated budget are major determinants. Further, [9] indicates that the average temperatures in the Richards Bay area for the past 10 years are between 26.5°C during summer months and 20°C during winter months.

The above data attests that the uMhlathuze municipality is a good contender for the implementation of photovoltaic technology to generate electricity. In alignment with the aim of implementing a PV-MFC hybrid system for generation purposes, the average quantities of sustainable quality sewerage discharge (consisting of mainly organic solids) through the municipal sewer pipeline system needs to be ascertained to work out the amount of biomass that can reliably be collected and available for generation, and by how much contribution this can make towards electricity generation. In other words, apart from determining the electricity required to power the wastewater treatment plant and the minimum energies required to start up and keep the PV-MFC system operational, the amount of energy that the municipality can reduce consumption from the national grid through the implementation of the PV-MFC hybrid system must be determined in order to define energy savings and the margins by which energy bills can be reduced.

Investigations have revealed that the municipality contributes on average a total sum of about 25 000 m^3 raw domestic (residential) and commercial sewerage per day to the effluent pipeline that discharges final effluent (raw sewerage treated by dilution processes using seawater) to the Indian ocean. A study conducted by Enzani Engineers in 2014 [3] confirmed the above and indicated that municipal sewerage containing human fecal (waste), fats, oils, and greases must be processed using separation and other treatment processes in order to ensure that the residual biomass is in the required form for generations. The exact processing of collecting municipal sewerage (waste) is important in establishing if the required energy can be satisfied, however, the details can only be accurately learned once a comprehensive feasibility study has been conducted.

There are 824 municipal wastewater treatment plants in South Africa, and 55 % of the total energy consumed in the country is accounted for by municipal wastewater treatment processes [CSIR, 10]. The amount of water supplied to both commercial institutions and residential households at the City of uMhlathuze yields a proportional sewer dischargein the absence of pipe bursts and/or pipe leaks. According to [2], unprocessed sludge has the same energy content as low- grade coal, at approximately 19 MJ/kg (5.2 kWh/kg) on a dry weight basis, although the energy content varies depending on the level of sludge treatment, with untreated primary sludge having the highest energy content. The authors cite Marx et al. (2004) who state that the capital costs of sludge management can be up to 50 % of the overall investment at a wastewater treatment plant (WWTP), thus energy recovery is essential for the long-term sustainability of wastewater operations, with treated municipal waste such as waste activated sludge yielding slightly less energy content of about 14 MJ/kg (3.8 kWh/kg).

Fats, oils, and greases (FOG) discharged from commercial and domestic kitchens are clean and contain higher volumes of volatile solids (organic content) and energy potential than sewage sludge [4]. FOG has a high caloric value suitable for energy recovery or generation, but treatment and handling is necessary since waste materials produced by FOG have a negative impact because of the accumulation and blockage of sewer systems at different points in the sewer system from the kitchen to pumping stations and wastewater (sewage) treatment works. Processing of FOG together with concentrated activated sludge and normal sewer discharge from sewer pipelines must be modelled in order to obtain the required feed quality (concentration) and quantity (flow rate). Details of FOG treatment together with that of influent can be determined through feasibility studies.

Waste from kitchens is generally composed of FOG and food material and waste from toilets is composed of human waste; both are collected and discharged through the sewer pipeline to pumping stations and subsequently collected at a wastewater treatment plant or macerator station. Macerators are also used at uMhlathuze municipality, and these stations consume less energy compared to conventional wastewater treatment plants because not all the processes of treating sewage in macerator stations are highly energy consuming or require energy. Processes are screening for foreign objects, separation of sewage by directing sludge to dry beds, and dilution processes whereby seawater is used to dilute residual sewerage before being finally disposed of through an effluent pipeline that disposes it to the ocean. Thus, to holistically account for energy consumption and energy bills, the baseline is drawn from energy consumed and billed from a water scheme that comprises a water abstraction plant, water treatment plant, and pumping stations. In respect to this paper, the total energy bills of the water scheme supplying the area under investigation at the municipal area were compared with the sum of energy bills resulting from 68 small to medium and main sewer pumping stations and were found to be more-or-less the same value.

The initial costs associated with implementing renewable technology such as PV-MFC technology mainly comprise land costs, acquisition costs of procuring PV and MFC technologies, PV module and MFC structural costs, civil and general works costs, power conditioning unit costs, energy storage unit costs, legal compliance costs, etc. uMhlathuze municipality owns the identified potential sites for the implementation of the PV-MFC hybrid system project and this reduces the initial costs of implementing the HRES project by up to 20 %. [1] indicates that the cost of implementing an HRES project depends on internal and external factors and whether the technology is locally produced or not, for internationally produced renewable technology, other associated costs are incurred and are influenced by the country's financial status and rating (borrowing power) to pay interest on loans used as capital investment and for import costs, transportation costs, customs (tax) costs, and the country's socio-economic and political stability. The country's economic status plays a role in the willingness to procure renewable energy technologies. Burton et al. (2006, cited by [2]) state that the challenge of certain internationally established technologies is that they have not been demonstrated in the South African market, and due to being unproven, scalability and reliability of these technologies are hampered when attempting large scale implementation.

Since there is an urgent call for radical and affordable solutions in the Republic of South Africa to improve the persisting energy crises, this paper provides a guide to using legislation already in place in the Republic to fast-track procurement of technology and to fund HRES projects. Two procurement processes must be undertaken: firstly, procurement of a transactional advisor (TA) to conduct a comprehensive feasibility study, advice stakeholders on the feasibility of the project using a detailed report, and prepare tender documents in preparedness for the implementation of the project. Secondly, if the project is found to be affordable and viable, the TA arranges the procurement of service providers to construct, install and commission the HRES project in line with approved specifications and budget indicated by the feasibility report. The design specification of the PV-MFC hybrid system is outlined together with procurement specifications using the municipal finance management act (MFMA) and the National Treasury (NT) guidelines on supply chain management (SCM) in Nhleko and Inambao [5].

The NT guidelines [6] under section 16.1 define affordability as meaning that the financial commitments to be incurred by an institution in terms of the public-private partnership (PPP) agreement can be met by funds designated within the institution's existing budget for the institutional function to which the agreement relates, and/or funds destined for the institution in accordance with the relevant treasury's future budgetary projections for the institution. Further, the guidelines define a private party to a PPP agreement as being, among others, a municipality. The NT guidelines view a PPP agreement as a vehicle (written contract) for the government and the private sector to join efforts in acquiring services that have mutual benefit. Thus the guidelines define a PPP as a commercial transaction between an institution and a private party where the private party performs an institutional function on behalf of the institution and/or acquires the use of state property for its own commercial purposes and assumes substantial financial, technical and operational risks in connection with the performance of the institutional function and/or use of state property from which the private party receives a benefit for performing the institutional function or from utilizing the state property. This can occur either by way of consideration to be paid by the institution which derives from a revenue fund or, where the institution is a national government business enterprise or a provincial government business enterprise, from the revenues of such institution, or the collection of charges or fees by the private party from users or customers of a service provided to them,or a combination of such consideration and such charges or fees.

3. METHODOLOGY

3.1 PV-MFC Design Specifications for an HRES Project Using a PPP Agreement

Nhleko and Inambao [5] conducted a measurement of energy consumption at the water treatment plant and pump station, all located at -28º76’07.58” S 32º07’74.81” E, responsible for the supply of water to the main reservoirs. This municipal land is one of the identified potential sites where the PV-MFC hybrid system can be implemented. The other identified potential municipal site identified for the same HRES project of implementing the PV-MFC hybrid system is the Arboretum macerator station located at -28º77’98.56” S 32º06’79.74” E.

The arboretum municipal sewer system at the City of uMhlathuze discharging from both commercial and residential households, comprises pump stations, pipelines, and a macerator station, and is designed to discharge wastewater only. This system is not connected to stormwater drains (pipelines). Since macerator stations consume less energy compared to conventional wastewater treatment plants due to the fact that the separation and dilution processes happening at the macerator station require very little electricity, and that the water supplied to and consumed by residential households and commercial institutions is the same quantity as the wastewater received at the macerator station in the absence of pipe bursts and water or wastewater leaks and the introduction of unsolicited connections from unregistered (illegal) dwellings, this paper reflects energy consumptions based on Table 1 from [5]. The sum of energy consumption of the treatment plant and pump station was calculated as 75 681.98 kWhrs per day, with the monthly energy demand of the water treatment plant and pump station reflected in Table 9 of [5]. The design or scope for the PV- MFC hybrid system is as follows:

- Abd El-Aal (2005) observes that when an MFC is used as a backup system to PV generation, during disruptions MFCs take longer than diesel generators to restore electricity. In order to mitigate this fact, a blended approach is proposed whereby the MFC continuously generates the minimum required electricity equivalent to night load or energy required during peak times, assuming that PV generation normally satisfies energy demand equivalent to the sum of that of water treatment plant, pump station and energy storage unit.
- Various researchers and authors have indicated that connecting PV modules in series yields higher electricity, which is the case for MFCs as well. Upon determination of the required energy to power the treatment plant and pump station (all located in one site) by means of a feasibility study, the best-suited configuration of PV modules and MFCs in achieving the required energy must be designed, taking into account affordability and the

economies-of-scale of the hybrid system.

- Determine the most viable and affordable software to be used for the hybrid system as determined by the feasibility study, even if it is unproven.

Based on findings of the feasibility study, determine the best and most affordable design for the continuous abstraction, piping, and incorporation of seawater to the MFC plant. Planners must bear in mind the existing infrastructure of the 10 mega litre desalination plant at Alkantstrand (location -28º79'80.62" S 32º09'56.55" E) that is not being operated at the moment due to the cost implications of operating it.

3.2 Procurement Specification for TA to Design and Plan HRES Project Based on Findings and Recommendations of the Feasibility Report

Phase 1 of a PPP project cycle (the project inception stage) requires that the HRES project be registered with the relevant treasury at the NT, and a project officer and a transaction advisor (TA) be appointed by the accounting officer or accounting authority of an institution. These two appointments require a competent person(s) with skills and experience; however, the process of appointing the two persons is different. For a project officer, the accounting officer may appoint anyone within his/her personnel to oversee the whole PPP project that he/she deems trustworthy. Regarding the appointment of a TA, specifications are drafted and a tender process is followed to procure the services of a TA who then is officially appointed by the accounting officer. A TA is defined by the NT guidelines as a person or persons appointed in writing by an accounting officer or accounting authority of an institution, which has or have appropriate skills and experience to assist and advise the institution in connection with a PPP, including the preparation and conclusion of a PPP agreement.

Since the TA must be a person or service provider equipped with extensive technical, legal, and financial skills and experience, the NT guideline provides that the TA must conduct a feasibility study of the proposed HRES (PV-MFC hybrid system) that fully satisfies the needs analysis, options analysis, project due diligence, value assessment, economic valuation, and procurement plan in accordance with supply chain management and other applicable legislation.

The functions of the TA together with the specifications for the TA are directed towards the development of a comprehensive and detailed feasibility study as follows:

- Conduct an environmental impact assessment (EIA) for the project and undertake all required processes such as registration of the project with the various necessary departments, mainly the Department of Environmental Affairs and the Department of Water and Sanitation.
- Conduct options analysis of recently developed PV module technology that uses materials that render the PV modules affordable with better conversion efficiency. Further, an options analysis of proton exchange membrane fuel cell (PEMFC) technology must be conducted with other technologies such as the phosphoric acid fuel cell

(PAFC) that can be implemented or have been implemented in the South African market, considering the availability of phosphoric acid from the parastatal company Foskor. However, the use of PAFC means dependency on Foskor's production of phosphoric acid, so the trends of the level of production of phosphoric acid by Foskor must be examined for the last 10-years.

- Design and cost for the entire project, indicating costs and activities for each project phase. The TA must document and report designs, activities, and costs in a report and a GANTT chart, a project management toolthat indicates all project-related items for purposes of gaining approval from the municipality and interested potential funders.
- Look for funding from various interested private local and international institutions and evaluate the conditions of each institution and recommend an institution with affordable rates and legally conducive conditions for the successful procurement and implementation of the project. The TA must be able to negotiate payback and any other related terms or items.
- Produce a report on all technical, legal, and financial aspects of implementing the PV-MFC hybrid system project using credible needs and financial test tools such as cost-benefit analysis (CBA), net present value (NPV) analysis, payback, etc., and recommend affordable, compatible and yet easy to operate and maintain PV and MFC technologies that can operate as a hybrid unit. This report must include the feasibility of maximum power point tracking (MPPT) technology and programming of the same for maximum harvesting of solar energy and technology that will be used to manage and monitor the flow of substrate into the MFC for optimum performance and conversion efficiency of biochemical energy to electrical energy.
- The TA must get all required approvals from all parties involved in the procurement of the right technology and implementation of the PV-MFC hybrid system and report on comments and approvals received in report form to all stakeholders.

An impact assessment study must be conducted by the TA in relation to the municipality's business model and aim or initial purpose in undertaking the project.

3.3 Procurement Specification for a Service Provider for the Supply, Delivery, Construction, Installation, and Commissioning of PV-MFC Hybrid System

- Upon all required approvals, the TA must prepare procurement (tender) documents for bidding purposes (either for open or closed bidding) depending on conditions agreed upon by all stakeholders. The procurement documents must be prepared in line with the municipal finance management act (MFMA); municipal systemsact (MSA), NT guidelines with PPP processes, public sector, and municipal supply chain management processes and policies.
- The TA must conduct independent evaluations on all aspects of received bids, make recommendations to the municipality and appear at the municipal bid evaluation committee (BEC) in respect to evaluations. Due diligence shall be conducted by TA in conjunction with appointed municipal BEC members and project officers

in line with all NT guidelines and supply chain management (SCM) policies.

- The TA must perform project manager functions in line with project management body of knowledge (PMBOK) standards and SCM policies to completion and commissioning of the project. This includes reporting on progress, milestones, financials (include payment certificates), and any other project-related matters through various communication media such as meetings that have been agreed upon at the planning stage of the project.
- The TA must negotiate on prices with the potentially successful bidder where needs are, as directed by stakeholders before the final award. Also, the TA must negotiate for the training of municipal personnel with regards to operating and maintaining the hybrid system.
- The TA must oversee contingency works and any additional works after necessary approvals have been obtained. Also, the TA must oversee payments and payment of guarantee upon completion of the period indicated by the municipal SCM policy.

4. RECOMMENDATIONS

The appointment of a TA for the above functions is necessary to avoid the need for municipal personnel to cover all the required specialties to perform functions of the project which could result in such personnel multi-tasking which would not be very efficient. Appointing a TA also avoids the consequences of municipal staff turn-over and loss of information due to loss of staff. In terms of new staff, records and progress reports and other documented items can be made available from a single point of contact, the TA.

In view of the nature of the project, the anticipated financial commitment by the municipality for this project is R42 million for conducting the feasibility study (at the time of the writing of this paper). In pursuit of these funds, the municipality can approach the NT and request assistance in finding funds in this financial year from the three-year budget cycle to enable the start of the project or request full or part funding for a two-year financial period, due to the anticipated duration of the feasibility study which is between one and a half years and two years.

5. CONCLUSIONS

The appointment of a TA as soon as possible is necessary for the municipality to achieve its set goals and those of the national government of all citizens having access to electricity by the year 2030. The implementation of this HRES based project would reduce the trend and consequences of non-expenditure on allocated budgets. The location of the City of uMhlathuze in relation to the above indicated available renewable sources, together with available municipal land, makes the municipality a good candidate for improved energy bills, improved delivery of essential services to the surrounding communities, and reduced greenhouse emissions, based on energy generation using renewable sources.

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Chapter 9: Financing and payback of renewable hybrid energy project (technology) such as PV-MFC systems: Case study uMhlathuze municipality

The author uses literature from scholars and researchers in the finance discipline to provide a guide onhow the available financing tools can be used to evaluate the viability of a HRES (PV-MFC) project, focusing on financing the project and its payback. The article was published in the International Journalof Mechanical and Production Engineering Research and Development (IJMPERD).

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FINANCING AND PAYBACK OF RENEWABLE HYBRID ENERGY PROJECT (TECHNOLOGY) SUCH AS PV-MFC SYSTEMS: CASE STUDY UMHLATHUZE MHLATHUZE MUNICIPALITY

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ABSTRACT

Renewable energy based hybridised systems are considered to be the future of electricity generation and the most cost-effective means of attempting to satisfy energy generation targets and development goals in the immediate and near future. Although, the feasibility of hybridised systems seems certain in the energy sector, the sourcing of funds to finance the implementation of systems such as photovoltaic microbial fuel cells (PV-MFC) technology is difficult. This paper attempts to indicate the financing models that can be pursued with great confidence by organisations such as uMhlathuze municipality. When considering funding issues, it is appropriate to consider the targeted payback period of the 'initial' (feasibility and capital) investment made. Three funding mechanisms have been identified as potential avenues that the municipality can pursue together with identified advantages and disadvantages. The cost-benefit analysis is briefly described in evaluating the feasibility or readiness of a project for implementation. Lastly, the payback period is briefly outlined from the perspective of using different tools such as net present value (NPV), return on investment (ROI) to establish the costs of pursuing such a project against planned payback targets.

KEYWORDS: Funding, Efficiency, Payback, Renewable Energy Project, PV-MFC Hybrid Technology, Photovoltaic, Microbial Fuel Cells.

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Original Article

1. INTRODUCTION

In order to establish value-for-money when implementing a system/technology implementation project, the affordability, technological change or advancement, and relevance of the system to operations and targeted expectations or projections are of essence. A study by Fiedler (2014) found that hybrid systems are cost effective. A report by Promethium and the South African National Energy Development Institute (2017) states that hybridised systems in the energy sector are normally pursued to replace and/or augment or boost conventional technologies with improved technologies such as renewable based energy technologies. A study by Abd El-Aal (2005) found that hybridisation is the best possibility for efficient use of locally available renewable energy sources. Primo (2016) concurs and states that hybrid systems provide a high level of energy security through a mix of generation methods. Thus, the funding for the implementation of hybrid systems is outlined with the aim of assisting the uMhlathuze municipality in decision-making regarding the procurement and implementation of hybrid systems as a new technique of improving the reliability and sustainability of delivering services.

2. BACKGROUND

Timmons, Harris and Roach (2014) point out that the majority of the world's energy supply has been dominated by the low cost of fossil fuel based electricity generation, but the cost advantage that fossil fuels have over renewable energy sources has significantly decreased to the extent that renewable can now compete with fossil fuels solely on financial terms. Further, the authors indicate that the forecast based on the continuous improvement of renewable technology is that renewable energy costs will decrease further making electricity generated from the use of renewable and improved technology affordable. Donastorg, Renukappa and Suresh (2017) concur stating that the current and ongoing costreductions in renewable power generation technologies aid developing countries in achieving national and international energy and CO_2 emissions policy goals as well as reliable energy security, affordable energy targets and promotion of access to electricity for all at a lower cost than traditional sources. Maheshwari and Jain (2017) echo the above views and state that the key to satisfying expected and projected targets on CO_2 emissions and production of affordable and reliable electricity generation is the use of efficient renewable energy technology which includes photovoltaic such as in the PV-MFC hybrid system(s) to realise the shift towards de-carbonized electricity generation.

Donastorg et al. (2017) state that although the renewable energy industry faces an exponential increase in opportunity and challenge to grow the renewable energy business and financial strategies that effectively exploit renewable sources, government institutions such as municipalities must decide and commit on implementing financial strategies related to energy sector infrastructure renewable energy project. In 2009, the United Nations Environmental Program (2009) estimated that the renewable energy market is a 19-26 trillion-dollar investment opportunity. Taylor, Daniel, Ilasand Young (2014) estimate that living standards and energy demand is set to increase by 21% by 2030 making the renewable energy market a 23 trillion-dollar to 31.5 trillion-dollar investment opportunity by the year 2030. According to Donastorg et al. (2017), the above relates to how energy sector growth impacts local economies and how the energy sector directly connects to the sustainability and vibrancy of the global economy.

Considering that energy is one of the main sectors that drives economic activity, any major decision made in the energy sector has significant ripple effects throughout a country's economy, especially for developing countries. Therefore, Donastorg et al. (2017) state that governments must have a high level of understanding regarding renewable energy investments because this requires intense and detailed feasibility studies of the type of renewable energy business being considered, proper financial analysis, and funding agreements to be put in place for the entire designed duration of the project. However, because of limited public funding, Donastorg et al (2017) suggests that donor funding must be pursued with the international community and/or partnership agreements with the private sector.

A study by Griffith-Jones, Ocampo and Spratt (2012) found that in most cases social costs are neglected in financial planning regarding energy infrastructure, yet they have great significance in terms of the overall social and environmental impact. The authors are of the view that the economics of renewable energy require incentives to gain investment in renewable. One way of doing this is to not only enumerate direct and immediate costs but also enumerate any contingent liabilities in the future, also known as negative externalities.

A negative externality is, for instance, the environmental damage caused by a conventional energy generating power station but which is not factored into the price, that is, costs associated with social impact such as environmental pollution. If these costs are factored in, then the generation costs are actually higher than the actual investment and operations costs. These are the private costs of conventional power plants and are generally borne by external third parties. Griffith-Jones et al. (2012) proposes that Pigouvian taxes (named after Pigou, 1932) which align private and social costs should be introduced. In this way, the price will reflect the true costs of conventional generation. Based on the views by Petrakis et al. (1997), Griffith-Jones et al. (2012) describes three forms of Pigouvian taxes: first, second or third best. With

Pigouvian taxes in place, a shift from fossil fuel based generation to renewable energy based generation is inevitable (Griffith-Jones et al., 2012). Further, Griffith-Jones et al. (2012) state that since renewable based energy generation has extremely low social costs compared to fossil-fuel based costs, a well-calibrated Pigouvian tax on CO_2 emissions (second best) or on fossil fuels (third best) would be sufficient for government to capture the true reflection of the costs associated with fossil-fuel based generation which will increase the electricity price and stimulate and encourage investment in renewable technology based generation. Thus, when planning finance for a renewable investment, Griffith-Jones et al. (2012) suggest that subsidies must be factored in or accounted for in a "blended finance" model through private public partnership (PPP) agreements to reflect both direct and indirect costs.

A study by Zvimba and Musvoto (2020) found that 55% of the total energy used in South Africa is accounted for by municipal wastewater treatment processes (there are 824 municipal wastewater treatment plants). However, government institutions such as municipalities are wary of pursuing large-scale renewable energy projects because of the high initial investment costs. Costs associated with renewable technology in the preliminary stages are: feasibility costs that include establishing all the costs of procuring the technology required, costs of undertaking assessments and mitigating outcomes from risk and environmental impact assessments, legal and compliance costs, land costs, and all financing costs taking into account the viability of financing renewable energy technology and maintaining the finance agreement.

According to (CERC, 2013, as cited in Maheshwari and Jain, 2017), the initial costs associated with renewable technology such PV-MFC technology mainly comprise land costs, acquisition costs of procuring the technology, PV module and MFC plant costs, civil and general works costs, power conditioning unit costs, evacuation costs, and etcetera. The advantage that municipalities such as uMhlathuze municipality have is that the majority of the land in the area is municipality (government) owned and no evacuation is required, thus reducing initial costs by approximately 20%. Maheshwari and Jain (2017) state that the actual amount depends on both internal and external factors including whether the technology is locally produced or not. Internationally produced renewable technology have associated costs that are influenced by the country's financial status and rating, and socio-economic and political factors such as import costs, transportation costs, customs (tax) costs, etcetera. In the context of this paper, initial means budgeted and allocated. Budgeted funds are funds that have been earmarked for allocation but have not yet been committed. Allocated funds are finances that have been identified and committed for undertaking the project concerned.

The study by the South African National Energy Development Institute (2017) reflects that employing a PV-bioenergy hybrid system can have a payback period of between 4 to 6 years depending on the applicable grid-electricity fee structure and the demand profile. Although, the initial capital investment or outlay of PV-MFC hybrid-based technologies presents a barrier for the implementation of large projects, the benefits of having long-lasting, reliable and sustainable energy supply with very low or no carbon emissions and cheap electricity generation costs, according to South African National Energy Development Institute (2017), outweighs cost implications. Aznar, Logan, Gagne and Chen (2019) concur and state that some projects when evaluated might seem to be non-viable in terms of profits and/or energy saving, but non-energy benefits can qualify a project for implementation.

From a technical point of view, South African National Energy Development Institute (2017) indicates that bioenergy generation using a PV-MFC hybrid system is site specific and its feasibility and appropriateness is dependent on the availability and sustainability of renewable sources and the low cost of generating energy. According to Aznar et al.

(2019), the following points need to be fully understood and addressed when designing and implementing a hybrid system that is intended to address energy shortages and exponentially growing energy demands:

- Define the target application because inadequate targeting may lead to misdirected energy subsidies.
- Decide on the most energy-efficiency investments that reduce long-term energy burden, yet maintain adequate supply that meets the demand and phase out conventional energy generation and bill assistance related subsidies in the long term.
- Attain adequate access, engagement and commitment of partners that support initiative(s) at all stages so that risk is shared and capital investment opportunities are heightened. That is, financial institutions and utilities must have full participation in the financing and delivering of identified feasible energy-efficiency initiatives.
- Ensure that a sustainable funding source and program are in place and well understood so as to meet as little resistance as possible.
- Ensure that the system is simple and can be easily integrated in phases by means of decentralisation.
- Ensure that the initiative (system or project) satisfies a tailor-made, flexible, multidimensional strategy that accounts for diverse participation with no or minimum resistance.
- Review the implementation strategy and application of the designed system with regards to relevancy, adaptability and productivity (Aznar et al., (2019).

Sweeney describes energy demand as being derived from preferences for energy services that depend on the properties of conversion technologies and costs. Energy economics involves looking at the forces influencing the use of energy resources, supply, demand, efficient use, and the economic distributional and environmental consequences. Energy is in economic terms referred to as an essential good that is always needed to sustain life and has a positive demand irrespective of how high its price becomes.

Project financing involves modelling and projecting anticipated income, and computing the internal rate of return of the project. Groobey, Faber and Klaus (2012) define project finance as the process whereby lenders loan money for the development of a project based on identified risks and future benefits such as cash flow and non-monetary benefits of implementing the renewable energy project. Capital project finance is a method that is described by Groobey et al. (2012) as involving the financing of a project in which the lender (in this case, the municipality) has either no recourse or limited recourse to the project funder that the lender is in agreement with.

3. FUNDING FOR HYBRID SYSTEM

Cost management according to Ramabodu (2014) involves:

- Cost design is the process whereby a renewable energy project is designed in such a manner that it satisfies all the outlined key parameters in the design, implementation and operation of the project based on the needs cost, opportunity cost and cost of acquisition of the renewable energy technology.
- Cost planning is the process used to ensure that all the anticipated final costs related to the completion and operation of the renewable energy project for the stipulated payback duration are completely covered in the

feasibility study including cost of proposed land, legal compliance costs such as costs of conducting EIAs, site preparation costs, construction costs, tax costs (and for imported technology, all custom tax related costs including costs of checking technology against South African National Standards (SANS), and financing and management costs. This process aids budgeting by clearly setting out cost and budget targets.

- Cost control and cost checking process which is an audit exercise undertaken to correlate cost accountability to decision-making and vision (expectations) by both the municipality and other stakeholders such as the private entity and the community. This process ensures that all stakeholders (including the funder) are kept informed and that methods are regularly reviewed depending on the criticality to achieve best (desired) outcomes.
- Cost analysis involves analysis of items to provide useful cost information and data so as to identify major cost items, analyse annual user cost of ownership and shared resources and risks, funding type agreement costs and identify the groups of items of cost importance. This process examines and suggests the most cost-effective option that will enable successful achievement of targeted goals regarding completion and operation of the renewable energy technology project.
- Cost-benefit analysis, a complex process (based on views by Ashworth, 1994) that evaluates the economics of costs incurred in relation to the targeted benefits. This process (based on views by Ferry and Brandon, 1991) evaluates the monetary value of intangible aspects such as opportunity costs, social benefits, environmental impact costs, etcetera.
- Life-cycle appraisal and cost reporting, a process known as "cost-in-use", designed to model and evaluate the mixture of capital costs, running costs and cost of ownership of the renewable energy technology throughout its lifespan. This process uses forecasting of future value that reflects value for money giving full consideration to maintenance aspects and future costs. Based on the on-going costs relating to the renewable energy investment, accurate cost information and cost reporting are undertaken to all stakeholders for continuous proactive actions and reviews and the effective management of stakeholder expectations with regards to the effectiveness and efficiency of the renewable energy technology project (Ramabodu, 2014).

In light of the above views by Ramabodu (2014), the objective of this paper is to evaluate the financial viability of implementing a PV-MFC hybrid system to supplement electricity shortages, the financing models for renewable energy projects together with possible repayment or payback methods using net present value (NPV), return on investment (ROI) and payback period must be rigorously undertaken. Aznar et al. (2019) states that three main funding streams may be considered: government-directed taxpayer funding, state and utility directed funding by means of a surcharge, and leveraging private sector investment. Aznar et al. (2019) further state that conducting evaluations based on financing models provide an understanding of the project roll-out, integration and impact of the system on conventional generation, and the effectiveness of the revenue collecting method directed towards repayment against planned (expected) repayment goals.

Aznar et al (2019) states that the key yardstick for government in determining and prioritising the design and implementation of renewable PV-MFC projects that take into account energy efficiency is the use of cost-benefit analysis. Raissicharmakani (2018) points out that project viability may be compromised if the infrastructure condition subsequently requires improvement as embarking on such improvement can be costly and results in the project not passing the cost-benefit test. Government mandates utilities with a framework of how to generate revenue by means of billing, even though there may be other streams of income in place such as donor funding and/or government bailouts. In the context of this paper, the same principle can be applied to municipalities if they are given autonomy to generate their own energy for the purpose of providing services to the community and generating an income.

According to Shively (2012), benefit-cost analysis (BCA) is a technique commonly used to evaluate the economic merit of a project or an investment by comparing the economic benefits of undertaking an activity with the economic costs of the same. Although, the BCA can be used to compare competing projects, the principles of BCA in the context of this paper is to indicate how the benefits of implementing aPV-MFC hybrid system can be economically viable so that the uMhlathuze municipality can make an informed decision on behalf of the public they are serving regarding reliable and sustainable energy generation and supply, affordable energy access, conservation of natural resources by utilising resources that naturally replenish, climate management and reduction of CO_2 emissions, legal compliance, and improved quality of life.

Shively (2012) states that it is important to know when benefits are realised and when costs are incurred. Shively (2012) introduces the concept of discounting, which is a technique of converting all benefits and costs into their value in the present time. This concept basically indicates that the future value of a benefit is discounted, thus the benefit received in the future is not of the same worth as the benefit received in the present. Although, discounting is the opposite of compounding present value of a benefit (amount) using an interest rate, the present value (PrV) of a benefit or an amount (P_t) at some time in future is expressed by Shively (2012) as:

$$PrV = \frac{P_t}{(1+r)^t}.$$

Where PrV is the present value of the investment amount, P_t is the value of the future amount in time or period *t*, *r* is the pre-determined discounted future rate, and *t* is the year in which P_t is realised.

Although PrV is also used to evaluate between two investments in preparation for the best-suited investment, for this paper, the focus is establishing if the future value of the benefits of implementing a hybrid system exceeds the initial investment cost. The other aspect of PrV relevant to this paper is establishing the opportunity cost of capital investment at the discounted rate determined by the type of agreement entered to. Shively (2012) describes opportunity cost of capital investment as the returns (amount of benefits) that would be received if the funds were directed or invested elsewhere, say in another project. With the latter view, often the discounted rate is set equal to the interest rate. The discounted rate, according to Shively (2012) when looking at the opportunity cost, is called the social rate of time preference (SRTP), which indicates how society at large ought to value the future. Shively (2012) states that the SRTP is normally lower than the discount rate because in general society prefers to consume the project related benefits sooner rather than later. Thus, communities are biased or inclined towards projects that exhibit benefits now (at the present moment). Due to this fact, municipalities tend to choose projects that will bring the community immediate benefits such as increasing the house connections for community members to have access to water rather than building a reservoir.

Amongst other tools that can be used to aid investment decisions or project implementation when using BCA are:

- The net present value (NPV) computes the current value of a project's net benefits in any period of time by using the expression:

$$NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+r)^t}$$

Where *B* is the benefit and *C* is the cost. The NPV tool determines if a project can be implemented. Thus, Shively (2012) states that when NPV is greater than zero then the project can be undertaken.

- The benefit-cost ratio (BCR) determines if the benefits outweighing the costs can be calculated by using the expression that indicates the ratio of the PrV benefits divided by the PrV of costs. The expression is:

$$BCR = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}.$$

When *BCR* is greater than one, the project can be accepted for implementation.

- The internal rate of return (IRR) reflects the maximum interest that can be paid for the project resources and pay for the investment and operating costs but still allow for the municipality to break even. Shively (2012) describes IRR as the discount rate for which the present value of total benefits equals the present value of the total costs. The IRR is computed using the expression:

$$PrV\ (benefits) - PrV\ (costs) = 0.$$

When the IRR is greater than the discounted rate, the project can be approved similarly to when calculating BCR.

Aznaret al (2019) provides an additional analysis or test that can be employed by any country or government attempting to increase its energy security and sustenance and improved energy efficiencies, the savings-to-investment ratio (SIR). When the savings-to-investment ratio is 1 or greater, the present value of the system and energy efficiency measure during its lifetime is greater than the costs, so the investment can be undertaken as this means that the energy that the system generates together with associated energy efficiencies is fully recoverable in terms of energy savings. Further, based on the views of Lazar and Colbrun (2013), Aznaret al (2019) indicate that some systems or projects might not exceed the benefit-cost ratio of 1 when accounting solely for the energy benefits, but when non-energy benefits (which are complex to quantify) are considered, the system or project becomes viable for implementation. Aznaret al (2019) suggests that survey and site evaluation methods must be used to estimate the value of non-energy benefits.

Although utilities in most cases design and source their own funding mechanisms, government still play a vital role by acting as surety to financial institutions such as the World Bank and IMF when loan arrangements are pursued, regulating charges levied to consumers and promoting and protecting local generation from competition from multinationalcompanies that seek to take revenue and profits generated elsewhere. Karekezi, Lata and Coelho (2004) (2004) (citing Zhou, 2003) state that the problem faced by Africa is not the increase in energy consumption per se, but the lack of attention that renewable energy based projects receive from the various government structures in the African continent in terms of funds and research that has resulted in energy supply paradigms being unaffordable. In support of the above views, Onyekwelu and Akindeke (2006) state that the economies of various African countries together with their governments are dominated by a few profit-driven multinational corporations that African governments tend to pay allegiance to, to the detriment of their citizens.

While the investment modes and tools reflected above assist in decision-making towards the implementation of a hybrid system, the payback period must be indicated as no project can be undertaken to have indefinite payback period, thus the payback aspect of financing renewable energy projects must be critically evaluated as an important component. Zamfir, Manea and Ionescu (2016) state that return on investment (ROI) is an important tool or technique that investorscan use to assess the extent to which an investment will produce gain from the use of capital. Thus, ROI is used in performance analysis and decision-making to aid in determining the efficiency of the capital amount invested. Zamfiret al (2016) indicates that the ROI can be computed using the expression:

$$ROI = \frac{(Revenues\ after\ investment - amount\ invested)}{amount\ invested} \times 100 = \frac{Profit\ (after\ investment)}{invested\ capital} \times 100, \text{ or } ROI = \frac{(Estimated\ time\ period\ benefits - Estimated\ time\ period\ costs)}{Estimated\ time\ period\ costs}.$$

The operating cycle of an initial capital investment requires short-term funding called working capital (WC).WC is the difference between initial invested capital (IC) and fixed assets (FA) and is expressed as WC=IC-FA. Computation of WC creates a holistic investment outlay for the renewable energy project because the balance of the invested capital available after financing fixed assets is then a funding resource that covers the capital needs generated by the operating cycle.

Rashford, Macsalka and Gieger (2013) state that the general norm when procuring renewable energy technologies is that the decision to purchase is rarely based on costs alone, but other factors such as social and environmental aspects. Furthermore, the authors state that one of the most requested measures of capital budgeting for a renewable energy system's economic feasibility is payback. Payback is the point in time at which initial investment is paid off, so calculating the payback determines the number of years for the energy savings from the renewable energy system to completely off setthe initial investment cost. Payback can be computed using the expression:

$$Payback\ (years) = \frac{Initial\ investment\ cost\ (in\ Rands)}{\left[\left(annual\ energy\ production\ in\ \left[\frac{kWh}{year}\right]\right) \times market\ price\ paid\ for\ energy\right] - (Operations\ and\ maintenace\ costs\ in\ rands/year)}$$

In agreement with the view by Rashford et al (2013), Kessler (2017) states that although the term 'payback' is loosely used, the technical and financial aspects of a project must be addressed and the simple payback period (SPB) provides an estimate of expenses and returns, and energy payback (EPB) must be considered for renewable energy projects. Based on views by Suri, Huld, Dunlop and Ossenbrink (2007), Kessler (2017) states that the SPB may be computed using the expression:

$SPB = (C_{system}) (Q_{year}^{-1}) (PR^{-1}) (P^{-1}) (C_{elec}^{-1})$.

Where C_{system} is the un-subsidized installed system cost, Q_{year} is the total annual renewable resource collected annually using optimal harnessing of renewable energy such as maximum irradiation collected at optimally inclined array of modules at a specific location, PR is the system's annual DC to AC performance ratio (Marlon et al., 2005 as cited by Kessler (2017)), P is the system DC capacity in Watts, and C_{elec} is the cost of electricity at the market electricity rate.

When examining the viability of energy investment, the EPB is expressed as:

$EPB = (E_M + E_{INV} + E_{BOS}) (Q_{year}^{-1}) (PR^{-1}) (P^{-1})$.

Where according to Peng, Lu and Yang (2013), E_M, E_{INV}, and E_{BOS} represent the embodied energy of the renewable technology such as that of the solar modules of the PV-MFC hybrid system, the DC-to-AC inverters, and the balance of system (BOS), respectively. Kessler (2017) indicates that SPB is a tool that estimates the period of time required to recoup the initial capital outlay, whereas EPB computes the time required for the hybrid system to generate an amount of energy that is equivalent to the initial energy inputs and start net energy production.

Payback calculations have limitations in not being able to factor in some critical investment characteristics such as time value of money (which includes inflation), associated investment risk and the opportunity cost of investment; escalations in energy prices. Nevertheless, the payback technique gives a quick evaluation of project(s) feasibility in terms of recovering initial investment made. However, an additional measure is required to provide a detailed assessment of the project feasibility. Since the initial investment involves capital budgeting (a process that Rashford et al. (2013) describe as being used to evaluate specific investment decisions), detailed investment characteristics must be accounted for, using NPV. NPV computes the difference between the present value of the future net cash flow of an investment made on a project and the net initial cash outflow using the discount rate. For a significant investment such as that of implementing a scaled-up renewable PV-MFC hybrid system, the profitability index of the project must be established. The project profitability index is the ratio of NPV of the project's future cash flows to the initial investment required. Zamfiret al. (2016) echo the above and states that NPV enables the analysis of investment for different dates and times of the renewable energy project by quantifying the flow that will achieve future anticipated value with current investment value. The updated expression that quantifies the influence of time on the efficiency investment is according to Zamfiret al. (2016):

$$NPV_{ta} = I_t + \sum_{h=1}^{D} CF(1 + i)^{-h}.$$

Where NPV_{ta} is the total net present value, I_t is the total investment, *CF* is the discounted net cash flow accumulated during the effective period of functioning of the investment objective, *D* is the number of effective periods of functioning of the objective, *h* is the period of investment, *i* is the discount rate. Zamfiret al. (2016) states that for each investment period it is calculated, the discount coefficient is $c = (1+0,1)^{-h}$.

McGee (2014) indicates that when undertaking due-diligence on project feasibility, multiple tools must be employed to ensure that the project pursued satisfies all expectations, including break-even analysis. Break-even analysis isdescribed by McGee (2014) as an attempt to estimate the point at which the benefits equal the costs of undertaking the project. This is very complex when factoring in non-monetary value (non-energy profit) and auxiliary benefits such as community and industrial relief and confidence in a new energy supply endeavour, the long-run (accumulated) environmental impact of apparently insignificant (often treated as neglected) discharges to the environment, the increased population attraction due to increased security of supply, etcetera. The break-even method assists in evaluating the requiredvolumes of generated and supplied energy at particular discounted rates (rates normally used by utilities, in this case ESKOM) to break even in relation to the opportunity cost of expanding the national grid that generates energy conventionally (using coal) by the same capacity. Although some aspects might be complex to quantify, McGee (2014) states that when using the cost structure in undertaking the break-even analysis, the cost items that make up most of the total expenditure are easily identified, ways of by how much (and how) the costs can be reduced become evident, and the costs that are controllable (and which are not) can be identified for overall decision-making.

In support of using break-even analysis, McGee (2014) suggests that demand tests and sensitivity tests must be conducted. The demand test, according to McGee (2014), can be conducted to establish the break-even point, both theoretically and practically, and the discounted price value must be used to accommodate potential risks and targeted profits when financing the project. Further to the demand test, McGee (2014) states that a sensitivity test must be undertaken on price to assess the impact on contribution margins and the consequent effect required to reach the break- even point and the corresponding market performances.

Saywell, Culler and Woods (1995) state that when conducting a break-even analysis using the cost structure, the associated costs of implementing and operating a project must be based on two cost categories, namely, variable costs that are highly dependent and influenced by the energy generation yield and fixed costs that can either be direct or indirect but do not vary with energy produced. The authors identify direct fixed costs as being wages of personnel that are responsible for the production of energy from the use of the hybrid system and indirect fixed costs as infrastructure costs such as equipment depreciation. Classifying costs as above and accounting for each respective cost item together with conducting the demand and sensitivity tests enables the effective management of fiscal viability and reduction of identified cost drivers.

Tongsopit, Mounghareon, Aksornkij and Potisat (2015) state that business models and financing options play a significant role in driving the implementation of a scaled-up renewable energy power generating hybrid system. The authors list appropriate business models as:(1) entering either into a lease agreement, or rental arrangement, or purchase agreement whereby the system is procured for implementation and operation purposes under the total ownership of the municipality or (2) a stakeholder (community and/or industry) initiative partnership whereby industry and the community commit funds and the municipality commits land and/or funds towards purchasing and co-owning the system that the municipality operates on behalf of all shareholders. Normally, government institutions such as municipalities do not lease or rent capital infrastructure projects in the energy generation and supply sector. Thus, the financing options of either using a financial institution to loan or donor funding or public-private partnership (PPP) to get funds for the renewable energy power project must be matched with the selected business model to satisfy expectations.

The three pillars that fully and effectively address expectations related to implementing a renewable energy power plant are: (1) targeted output of the product and end-user needs and demands; (2) the business model which directly influences the financing option, profits, and payback period of the project; and (3) the financing option which influences the feasibility of the project in terms of repayment agreements (amounts and conditions of repayment). Fundamental components of this approach are the use of payback and NPV to stimulate management decision making towards implementing the project and the use of cost-benefit analysis to effectively conduct the break-even analysis with all factors considered (including risk profile and demand and sensitivity tests) so that stakeholders can know, by when the benefits at discounted future rates are likely to break-even with the initial investment costs. Upon establishing the above, Tongsopit and Greacen (2013) support the ‘adder scheme’ that gives power producers that sell electricity produced by renewable energy means certain tariffs for a specified period of time allowing power producers to incorporate an adder rate for every kilowatt hour (kWh) produced on top of the utility electricity price. Cory, Couture and Kreycik (2009) termed the incorporation of the adder rate the premium-price feed-in tariff.

Although self-financing is commonly used world-wide as a conventional way of financing, due to the heavy burden posed by the associated risks of self-financing, the 2019 National Business Initiative Report (2019) states that in

1999 the South African government through the National Treasury introduced the PPP concept for procurement purposes. APPP is aimed at leveraging private party capital to fund infrastructure and private sector skills to supplement government institutions to reduce concentrated financial risk to government and spread the financial risk over the lifecycle of the project, and create budgetary certainty. Since conducting a feasibility study and implementing a renewable energy power generating project at up-scaled magnitudes is extremely costly and sensitive to government and community interest, PPP agreements are becoming more common in addressing financing of local government (municipality) initiatives. PPPs have played a key role in accelerating the adoption (decision-making and approval) of energy efficiency, water conservation, and energy generation projects. The RES4MED & Africa (2018) report concurs with the above and states that PPP agreements are preferred by most government institutions or agents because they carry build-own-operate (BOO) contracts that ensures shared liability initially as the asset only changes to the asset register of the municipality when the payback is completed. The study by (2012) reflects that there is a growing trend of PPP agreements in developing countries in financing renewable energy projects and technologies. However, third-party financing that involves government in South Africa has caused a lot of controversies and scepticism when it comes to the procurement of renewable energy technology such as PV-MFC hybrid systems, thus there is resistance towards this mode of financing.

According to Timmons, Harris and Roach (2014), the levelized cost of energy (LCOE) is the cost (at present value) of building and operating a renewable power plant over an assumed lifetime. Timmons et al (2014) states that the purpose of LCOE at present value is to mitigate the effects of inflation. The levelized cost (LC) of implementing and operating the power plant, according to Timmons et al. (2014), is divided by the total energy obtained so that direct comparisons across the different energy sources can be made. The LCOE provides an indication of the wholesale electricity price (Timmons et al., 2014). South African National Energy Development Institute (2017) suggests that hybrid systems are becoming more cost effective and efficient in generating electricity, more so than fossil fuel based electricity. The current challenges of renewable energy based generation are high initial investment costs, the energy costs of meeting current energy demands from communities and various other users, the opportunity costs associated with reluctance of government buy-in on renewable energy generation, and the opportunity cost of undertaking capital refurbishment or rehabilitation on 'live' conventional (fossil-fuel based) power generating plants.

It takes energy to produce energy; net energy ratio (NER) is the energy available for final consumption divided by the energy required to produce it (Timmons et al., 2014). The NER indicates the margins of energy from an investment: when the NER is a large value this means that there is a significant amount of energy produced from a small energy investment. Timmons et al. (2014) further states that net energy is a physical attribute of an energy source, a component of energy cost that relies on the efficiency of the technology used to reduce energy required because efficiency results in the fall in cost(s) of generating electricity.

Zamfir et al. (2016) state that the limitations of capital financing tools such as ROI and other financing options is that the focus is on the financial side of investment(s) which ignores other project related benefits such as improved quality of life and satisfaction of the community, positive project impact on the environment, positive image or credibility of the municipality regarding effective and efficient delivery of energy and technical services to the community, energy and resource conservation through improved efficiency savings, etcetera.

4. RECOMMENDATIONS

Renewable energy projects are critical to the reliable development and socio-economic welfare of the residents and industries served by local government institutions such as uMhlathuze municipality. Renewable energy projects are multi- disciplinary in nature and require the appointment of municipal specialists that will deal with forecasting the energy and other technical needs by the municipality in providing effective services. Although the municipality has planning divisions in the water and sanitation section and the electricity section, the municipality needs to establish a research and development (R&D) division that will look at how municipal services can be improved using innovative means such as procuring PV-MFC hybrid technology for the municipality to be efficient in serving the community. Thus, the municipalityshould hire competent specialists and advisors such as industrial engineers (who are generally not hired in the municipal environment) and other specialists to provide the municipality with a map or guide on how to serve future demands in the energy and water sectors.

The personnel involved in large capital investments must be kept separate from operational matters so that such personnel can focus on effective innovations that are communicated regularly to the Council based on developing or new demand, changes in socio-economic activity, and alignment with legislative prescripts. The R&D team should comprise project managers, technical financial officers that deal with technical procurement and large projects, industrial engineers and economists that focus on forecasting on all essential services and seek for financial aid on capital projects, legal personnel that focus on government initiatives such as the PPP agreements and large scale contracts, and environmental specialists that deal with the impact of large-scale projects on the environment. The hiring of the above-listed personnel in- house reduces the risks and liabilities that the municipality currently encounters with agreements such as PPP agreements, and the costs of hiring professional service providers (consultants) to conduct feasibility studies and finance agreements that advantage the same service providers and prejudice the municipality in one way or the other as different financial institutions have different requirements. The scope of the R&D team would be to conduct due diligence on capital project matters using, among others, the tools discussed in this paper to evaluate the feasibility, profitability and cost-effectiveness of the intended capital investment and disclosing the associated benefits of embarking on the such an investment.

5. CONCLUSIONS

Promethium Carbon and South African National Energy Development Institute (2017) states that in order to access clean and stable energy and meet sustainable development goals in the energy sector requires migration by developing countries from fossil fuel dependency to renewable energy source(s) engagement. Access to and financing of renewable energy projects are major challenges for many developing countries such as South Africa, but PPP agreements using well- structured financing models that account for discounted future value of renewable energy projects in terms of money and socio-economic impact is a step in the right direction.

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Chapter 10: Energy audit on Primary Municipal Facilities: Reflection of Municipality's Energy Consumption as a Direct Consumer of the Energy Utility (Eskom)

The author uses on-site data of energy consumptions, energy demand and energy bills to analyse energy usage by municipal facilities to deliver services to the community. The article was published in the International Journal of Engineering Research and Technology (IJERT).

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Energy Audit On Primary Municipal Facilities: Reflection of Municipality's Energy Consumption as a Direct Consumer of the Energy Utility (Eskom)

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Abstract

Due to excessive electricity bills as a result of Eskom's high tariff increases (higher than CPI) and South Africa's electricity supply crisis, institutions have begun to consider alternative short-to-medium strategies in an attempt to curb energy consumption and reduce energy bills. Wastewater and water treatment works are municipal facilities that are amongst the biggest energy consumers after industry. Municipalities, therefore, need to focus their efforts on how to save energy in their operations in order to reduce their environmental impact, improve resource efficiency, and avoid excessive electricity bills. Energy audits are a useful tool in this regard, leading to the implementation of effective strategies and installation of more energy efficient technologies. In this paper a municipal water scheme is used for the purpose of illustrating consumption and bills incurred by a category A or B or C municipality and the results of an energy audit exercise are discussed and recommendations presented to assist municipalities to reduce energy consumption and bills.

Keywords: Energy audit, energy utility, energy consumption, energy demand, energy bills.

I. INTRODUCTION

A water scheme is used to illustrate municipal consumption and energy management through providing in-depth understanding and details of energy demand, energy consumption, and corresponding charges and bills that keep these essential municipal plants operational to produce and supply potable water to communities. The focus of this paper is the expenditure by the municipality as a direct consumer of energy to keep its basic operations functional. In this paper municipal buildings are also incorporated as the head office expenses paid for by the municipality. Water plant(s) from abstraction to treatment works and subsequently to pumping (supply) plant are used as the basis for this paper. An energy audit was undertaken to observe operations and verify measurements on all sites mentioned above. Possible generic solutions are proposed to improve municipal energy consumption and reduce energy bills

II. METHODOLOGY

A. Background

Water and energy are inextricably linked and are both essential commodities at the very core of life [10]. Water is used to generate energy and energy to provide water [3]. Users are grappling with measures to transition from heavy dependence on fossil fuels so as to address global climate change by capping carbon emissions [3]

Global energy and water demands are increasing demand for more energy which drives demand for more water and vice versa; thus, a holistic understanding is necessary to model the adverse impact that industrial, agricultural and domestic water and energy uses have on the ecosystem [3]. The majority of water problems in South Africa are symptomatic of the gap between national policies on the supply of reliable and quality water by municipalities, and the support offered by national government institutions to municipalities to keep their infrastructure in an acceptable condition for good performance and efficiency [1]. Furthermore, the drive to achieve universal access to water and sanitation sets municipalities in a reactive mode of attending to breakages when they occur to keep the infrastructure operational at all times for basic services to be delivered. Thus, municipalities do not pay enough attention to infrastructure performances and the economy of providing such services [1], [2]. However, for suitable access to reliable supply and distribution of water, infrastructure must be effectively operated and maintained in order to obtain high performance and optimal reduction in energy bills [1].

Ashton [4] states that "we cannot simply walk away from problems and expect our descendants to bear the burden of solving them" and goes on to state that South Africa's future growth and development depends entirely on how water and energy resources are used and managed. Considering that these complex problems cannot be dealt with by a simple quick-fix one-size-fits-all solution, the prevailing conditions that result from the excessively burdened water and energy resources together with corresponding processes must be carefully evaluated and risk managed and a series of affordable solutions must be designed and effectively implemented [4]. It is clear that shortages of skills and funds to support efficient performance of municipal facilities reduces municipalities' ability to effectively and efficiently render affordable provision of services. This is compounded by the lack of implementation

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of advanced infrastructure performance and energy management and monitoring technologies.

Technological research is one of the four main branches of sustainability science which aims to reduce environmental harm [3]. Energy-related technologies with sensitivity to energy management and capacity to monitor high consuming municipal facilities can lead to efficient and economical provision of water and produce energy savings and a gain in efficiency yields [3]. Sustainability science is a systematic approach to innovation and learning that ensures ecological and social sustainability. This approach seeks to understand the relevant technological, sociological, ecological, economic, and institutional complexity and develop assessment frameworks and methods to assist decision- and policy-makers of energy and water technologies [3].

Because of the high energy consumption at municipal water and wastewater treatment facilities it is crucial to reduce energy consumption and possibly achieve energy independence at these facilities [5]. This paper reports on activities undertaken in an attempt to reflect the true energy management and bills of keeping a municipal water scheme, where the municipality itself consumes energy and pays for energy consumed to be able to deliver basic services to the community. Energy management in this case refers to management at the levels of abstraction of water at the weir, treatment of the same at the treatment plant, and pumping plants. This study involved an energy audit comprising: site screening and observation of operations and infrastructure condition, viewing of maintenance and operations records, analyzing of energy management (demand and consumption) records and energy bills, and proposal of generic recommendations that will assist the municipality in arresting high energy consumption and reduction of energy bills where possible. It was disappointing to notice that most energy saving initiatives in place were conducted in municipal buildings that have far less consumption levels than the above-mentioned plants.

Zhang and Wang [14] state that there are three effects to consider in the analysis of electricity consumption: economic activity effect, sector electricity share effect, and energy intensity effect. The authors further state that rapid growth in electricity consumption can lead to supply constraints and costly brownouts if uncontrolled, thus the driving forces governing energy consumption levels and their evolution must be investigated and managed or considered for possible risk mitigation. To mitigate this rapid energy growth, according to the authors, deconstructing the growth of electricity consumption into the possible affecting factors needs to occur.

The factors that influence electricity consumption in South Africa include the nature and pace of economic growth, the upward trend in real electricity prices, the evolution and adoption of more energy-efficient process and technologies, and supply-side surpluses or constraints [15]. Based on data compiled by the Department of Energy (DoE) on South Africa's national energy balances, [15] reflects that households in South Africa are responsible for 20 % of total electricity consumption while government services institutions servicing commercial sectors in aggregate are responsible for a further 15%. In a nutshell, municipalities have an energy consumption of 35% part of which is directed at supplying households and commercial institutions and the other at providing basic commodities (water supply and sewer discharge) to communities. [15] defines electricity intensity as the amount of electricity consumed (e.g. in kWh) to produce a given unit of output (e.g. GDP in South African Rands). The South African economy has gradually transitioned away from its historical dependence on relatively energy-intensive economic or sector activities such as mining and manufacturing to a more diverse and increasingly services-related range of activities which accounted for just over two thirds (67 %) of the GDP in 2015 [15]. [15] indicates that the energy intensity of the country has declined significantly together with the decline of the primary and secondary sectors (mainly mining manufacturing and construction) that once accounted for almost half of GDP (45 %), but today contributes just under a third of GDP (30 %).

Municipal water and wastewater plants contribute on average of between 30 % to 40 % of the total energy consumed by a municipality [5]. The primary purpose of energy auditing is to postulate interventions that improve the energy footprint of municipal facilities. This paper thus reflects a scenario of two consecutive years of general energy profile of municipal water facilities. Detailed energy analysis was conducted and the overall energy consumption of the municipal water scheme was reviewed. Consumption and demand of the municipal buildings referred to as 'head office' was included as part of the direct energy consumptions payable by the municipality to administer delivery of services from the same water scheme. Ina nutshell, in order to satisfy the objects of this paper, only the municipal energy consumption directly paid for by the municipality from the selected water scheme was examined. Energy supplied and/or distributed by the municipality and paid for by municipal clients did not form part of the aim of this paper.

A study report conducted by van Zyl et al. for the Council for Science and industrial Research (CSIR) [7] found that the majority of challenges faced in water and energy security of supply, especially at municipal and water boards (government water supply agents) level, are mainly energy performance of plants delivery capacity of infrastructure based on infrastructure integrity and the energy usage index. A CSIR report [9] on the state of municipal infrastructure in South Africa and its operation and maintenance further indicated that many municipalities have highly inadequate or no records of any formal broad-based audits or information of municipal infrastructure performances. The report by [9] indicates that there is no care of infrastructure integrity and energy management by municipal personnel which can be seen from the lack of interest displayed by personnel during site-visitations. This ad hoc and inadequate information on infrastructure performance means there is a lack of performance trends regarding municipal infrastructure and the state of infrastructure from the point of view of maintenance. The CSIR report [9] indicates that the current municipal records on infrastructure performance and condition in many municipalities in South Africa are very poor. In addition, there is a lack of capacity (skills and finances) to support effective maintenance of state infrastructure [1].

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According to [15], there are several factors that influence the demand for electricity, including: the price of electricity growth in relation to the level of economic production or output, population growth, climate vulnerability and weather patterns, and technological change. The dynamics and influences ofthese factors on energy demand are not discussed in this paper as the focus is on reflecting energy expenditure incurred by municipalities based on assessment of water and wastewater plants and uMhlathuze municipality plants as a basis and making recommendation regarding what can be done to reduce energy related expenditures at uMhlathuze municipality and other municipalities in South Africa in the same or higher category.

According to the uMhlathuze municipality's annual report of 2018/2019 [8] the municipality as a customer of the energy utility (Eskom) and directly consumes and distributes or supplies energy received from Eskom, the total energy required for the municipality to be able to perform both of its functions was as follows in terms of energy demand: municipal customers consumed a total of 978 GWh (a decrease of 12 GWh from the 2017/2018 financial year of 990 GWh of electricity). The 1040 GWh that was purchased from Eskom in the 2018/2019 financial year was less than the 1054 GWh purchased in the 2017/2018 financial year, a 14 GWh decrease. The report further accounts for total losses indicating that the total energy loss made up of both technical and non-technical losses amounted to 63 GWh, an average loss of 6% over the 2018/2019 financial year. In addition, although the energy consumption profile of the municipality is the focus in this study, it is important to compare the energy ordered from Eskom and the notified maximum demand (NMD), which is the actual demand from month to month. The municipality's provision of electricity for its total NMD to the various areas (without taking into account new household or industrial connections) is as follows:

- Richards Bay 151 MVA a decrease from 230 MVA due to Richards Bay Alloys reducing its operations due to financial constraints on account of among other things, the depressed state of the South African economy;
- Empangeni Main 20 MVA: Maximum (11 MVA);
- Empangeni Western 20 MVA: Maximum (20 MVA);
- Felixton 0.7 MVA: Maximum (0.5 MVA);
- Vulindlela 1 MVA: Maximum (0.86 MVA);
- Esikhaleni 16 MVA: Maximum (19 MVA of which 11 MVA is Eskom load);
- Nseleni 2.7 MVA: Maximum (2.65 MVA); and
- Ngwelezane 7 MVA: Maximum (6.43 MVA).

On account of the above information and the objectives of this paper, a baseline energy consumption analysis was established based on visits (assessments) and measurements conducted at the various plants of a water scheme. The energy consumption exercise was conducted as follows:

- A synoptic visual assessment of the conditions of the infrastructure to factor in or account for any infrastructure condition or influence to energy consumption and wastage.
- Installation of a power meter to take a 24-hr recording of all power parameters at the various plants of the water scheme.
- Review of electricity consumption and power quality data.
- Review of energy bills for the various plants of the water scheme that the municipality manages and pays for directly in order to provide service delivery.
- Compare results with best practices and establish how to improve each plant performance and/or the energy efficiency of each plant.

For the verification process the detailed operation of each plant was ascertained and the audit process comprised the following steps:

- Confirmation of the induction motor data of each pump from the motor label/tag.
- Review of other electricity consuming components of each of the municipal facilities.
- Inspection of the motor control centres (MCCs) and switchgear.
- Installation of power measurement recorder.
- Tabulation and analysis of results obtained then comparison of these results with energy bills and discussion of energy readings and/or measurements and energy efficiency (energy output or performance) based on energy bills and recordings obtained.

In view of the conventional method of operation of the municipal facilities and the type of technology installed at each of the plants, the instrument used for independent on-site measurement of consumption was the A-EBERLE PQ BOX 100 (Fig. 1) which was used to take a 24-hour recording of the consumption at each of the plants. The instrument defined by SANS 474 [11] as a watt-hour meter is an instrument used to measure active energy by integrating active power with respect to time.

Fig. 5.1. A-EBERLE PQ BOX 100 used for the power audit

Before proceeding to the numbers relating to energy usage at the municipal facilities, it is important at this stage to reflect on

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the make-up of a utility in order to provide a perspective on energy related charges.

Generally speaking, the main utility bill consists of the following charges as per electricity pricing definitions by Eskom:

- Administration Charge. That is a standard fixed rate charge that is levied to all energy consumers. This charge is levied to cover the cost of administration of consumers' accounts irrespective of whether electricity is consumed or not. Services charged for under administrative charges are services such as meter reading, billing, and meter capital.
- Network Capacity Charge. This charge is levied to all consumers for the electrical infrastructure over which reserved energy from the utility is transported from source to the consumption point. That is the network capacity costs of providing the required energy. Associated costs include capital costs, operations costs, maintenance and refurbishment costs.
- Network Demand Charge. This is a variable monthly charge that is based on the actual demand measured in all peak and standard periods. That is the actual energy demand incurred in that particular month.
- Ancillary Service Charge. This is also known as reliability charge that is concerned with providing the right services for energy supply. This charge is allocated for services such as frequency control, voltage control, generation, standby plant emergency reserves, and black-start capability generation.
- Standard energy consumption charge. This charge regards to the active energy in kWh used by customers during a specific period in peak off-peak and standard times. In other words, this charge depends on the season when energy is consumed.
  - ✓ High Season Energy Charge. This charge is levied during the winter and spring seasons. The charge varies with times of consumption as follows:
    - ➢ Energy charges during peak times;
    - ➢ Energy charges during standard times; and
    - ➢ Energy charges during off-peak times.
  - ✓ Low Season Energy Charge. This charge is levied during the summer and autumn seasons. The charge varies with times of consumption as follows:
    - ➢ Energy charges during peak times;
    - ➢ Energy charges during standard times; and
    - ➢ Energy charges during off-peak times.
- Energy Demand Charge. This charge is seasonally differentiated and is based on chargeable demand registered during the month in order to recover peak energy costs. Energy demand is normally measured in kVA.
- Service Charge. This charge is levied to all consumers; it is a compulsory fixed charge payable per account to recover service-related costs.

The consumption details of the Eskom energy bills are as follows:

- Energy consumption measured in kWh. This charge pertains to energy consumption and is the charge levied regarding active energy consumed by a customer during a specific period on a month to month basis. This charge comprises the following:
  - ✓ Baseline. This is the minimum considered charge levied to all customer accounts whether electricity has been consumed or not;
  - ✓ Energy consumption charge for energy consumed during peak times;
  - ✓ Energy consumption charge for energy consumed during standard times; and
  - ✓ Energy consumption charge for energy consumed during off-peak times.
- Demand reading which relates to the reading of electricity meters for the average value of power that must be planned for and allocated over a specified interval of time such as on a monthly basis.
- Reactive energy charge is basically a charge based on the amount of reactive energy used and this charge consists of the following:
  - ✓ Baseline charge. This is a flat rate that is charged independent of when the electricity is consumed;
  - ✓ Peak charge;
  - ✓ Standard charge; and
  - ✓ Off-peak charge.
- Load factor. This is a ratio that reflects the potential use of supply capacity based on maximum demand. This ratio is of the average load (actual energy consumed) over a given period to the maximum demand (peak load) occurring at that time, or the energy that could have been consumed had the demand remained at the maximum for a period. It measures the efficiency of electricity usage. If the load factor is high this means that the system uses energy efficiently and that there is no under utilisation of energy.

Thus, the average price for electricity is based on the overall cost of supply. The common cost drivers of energy supply are: administration costs (Rands/customer/month), network costs (Rands/kVA or Rands/kW), energy costs (cost/kWh), reactive energy costs (cost/kvarh), and energy loss costs that take into account all supply and transmission factors that contribute to energy loss [13]. The cost of providing electricity to customers according to [13] varies according to the quantity of electricity used, the period (time or season) when the electricity is used, the size or capacity of the supply required, the geographic location of the customer, the voltage at which supply is provided, the cost of connecting the supply, and the density of the points of delivery where the customer's supply is located.
[13] comments that the effective management of electricity

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bills saves money through effectively managing energy consumption.

[13] states that electricity is billed as a charge per kilowatt hour (kWh) and describes and distinguishes measurement units of energy consumption and demand, stating that energy consumption measured in kilowatt-hour (kWh) is the total energy that is transmitted or used at a constant rate (power) over a period of time. It is the electrical power in kilowatts multiplied by the time in hours, electrical power (kW) being the energy per unit time or energy rate at which electrical energy is transmitted. The authorized maximum energy demand measured in kVA is defined by [11] as maximum load that the customer is authorized by the licensee to take from that point of supply (POS). The above indicated fixed costs cannot be redirected oravoided as these costs are related to the utility (Eskom) for costsrelated to generating electricity. Changes in consumption and periods (seasons) and duration of consumption (peak or off- peak or standard), and adopting and incorporating energy saving methods and devices are variables that can be manipulated for optimal energy usage.

Basic energy usage according to [13] is the actual energy consumed. The real time electricity usage index is the performance measurement of a plant whereby the throughput of a plant is measured versus electricity consumption of the same [13]. Another way of putting it is to say that the measurement of energy utilisation index or use index is the amount of energy consumed to produce a desired output or condition [10]. The electricity usage index reflects the energy efficiency of a plant and acts as a tool that aids the monitoring of energy performance. [18] comments that any installation of a power consumption monitoring tool in each individual inductive device such as motors have significant positive impacts on energy savings in the long run. [20] states that energy efficiency must be viewed as an energy resource that canreduce the need for new energy supplies and infrastructure as energy efficiency is also viewed as a major element that enables the reduction of emissions of carbon dioxide emissions and attendant global climate change. Thus, the initial energy audit exercise related to this study was conducted to determine suitable recommendations that not only focus on assisting with energy saving but also with monitoring the energy usage trend of each municipal primary plant.

B. Measurements and Results

The measurements obtained using the A-EBERLE PQ BOX100 and records of readings taken from the flow meters and data-loggers at each of the respective municipal facilities are shown in Table I.

TABLE I. 24-HR RECORDINGS AT EACH PLANT OF KNOWN THROUGHPUT THAT REFLECT THE ENERGY CONSUMPTION AND CORRESPONDING COMPUTED ELECTRICITY USAGE INDEX (PERFORMANCE)

No	Municipal facilities	Throughput (kl/day)	Duration of recording (hrs)	Measured - kWhrs consumed	kWhrs consumed/day	Electricity usage index (Performance) kl/kWhrs
1	Abstraction at weir (capacity)	225 000	-	Not applicable	-	-
	Abstraction at weir (actual)	≈42 000	23.15	1 658.50	38 394.28	1.09
2	Water treatment plant (capacity)	180 000	-	Not applicable	-	-
	Water treatment plant (actual)	38 000	23.3	1 589.75	37 041.10	1.03
3	Pump station (capacity)	180 000		Not applicable		
	Pump station (actual)	3 8000	22.75	1 698.50	38 640.88	0.98
4	Municipal building	-	24	125.64	3 015.35	-

Regarding the interpretation of the above table: when considering performance, the higher the performance(kl/kWhr) the more efficient the specific plant is. From the above table it is evident that the pump station is the least efficient plant when compared with the other two plants.

It is important to note that measurements are based on the actual flows (actual demand for portable water) and not the design capacity of each of the municipal facilities as indicated in Table I. Thus, the measurements in that table reflect the actual consumption for that particular day. Attention is drawn to the fact that the water system reflected in the table relates to the supply of potable water (drinking water) and excludes the supply of both clarified water and raw water. For clarity, clarified water is water that is mainly supplied to industries. This type of water does not undergo such stringent treatment processes as potable water. Raw water is chemically untreated water that has undergone physical treatment such as screening to remove solid debris. Raw water is generally supplied to customers whose operations are not sensitive to water quality such as the agricultural and mining sectors.

Although the power audit exercise was conducted using the A-EBERLE PQ BOX100 instrument, it is notable that electricity consumption (kWhr) meters (STRIKE TECHNOLOGIES' ENERMAX meters) are used by the municipality to measure consumption of each primary municipal facility or plant. The ENERMAX meters are wirelessly connected to a central site

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and readings obtained from the SCADA system.

In order to obtain a holistic view of energy usage the key component factors required to conduct a holistic analysis of the municipality's monthly energy management include energy demand, energy consumption, and energy bills. Table II illustrates the key components considered for the monthly billing of these facilities. Readings for the month of March 2020 (a 31-day period) are reflected in Table II.

TABLE II. THE THROUGHPUT ENERGY DEMAND, ENERGY CONSUMPTION, AND CORRESPONDING ENERGY BILLS FOR EACH OF THE RESPECTIVE MUNICIPAL FACILITIES

No	Municipal facilities	Design capacity: throughput (kl/day)	Monthly energy demand: kVA/month	Monthly consumed energy: KWhrs/month	Total cost (R)
1	Water treatment plant (actual)	65 000	2 762.50	1 216 560	1 142 083.00
2	Pump station (actual)	70 000	1 938.40	1 362 808	1 479 454.00
3	Weir (abstraction)	85 000	2 427.85	1 142 585	1 234 596.80
4	Municipal building	Gravity feed from 60 Ml reservoirs	349.50	97 210	256 787.50

The throughput values were obtained from the SCADA system and verified using onsite records obtained from data-loggers together with respective pressure readings. Thus, average daily throughput or pump rates are averages of the actual flow rates or typical flow rates.

It is important to note that each plant's performance measure is specific to that plant and although some comparison can be made between similar plants the objective is for each plant to measure itself with a view to improving itself.

A two-year data cycle is collected to reflect the relative demand consumption and bills of the municipal facilities. This is conducted to indicate the general efficiencies of the plants and assess whether there are any abrupt changes in efficiencies and also in order to enable the prescription of solutions that can improve consumption and reduce energy bills. The data in Table III and Table IV and Fig. 1 reflect consumption and together with on-site observations reveal any possible contributing factors to high energy consumptions (low efficiencies) and/or energy wastages.

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TABLE III. AVERAGE ENERGY DEMAND PER ANNUM OF EACH MUNICIPAL FACILITY (WEIR, WATER TREATMENT PLANT [WTP], PUMP STATION AND MUNICIPAL BUILDING HEAD OFFICE])

Description	WTP	Pump station	Weir	Head Office
2019/20 Annual demand	32 730.81	24 091.21	28 609.87	3 565.25
2018/19 Annual Demand	30 687.39	24 181.03	23 226.93	3 067.30
Energy Demand Increase	6.24 %	-0.37 %	18.81 %	13.97 %

TABLE IV. MONTHLY ENERGY DEMAND FOR EACH MUNICIPAL FACILITY

MONTHS	kVA	kVA	kVA	kVA
	WTP	Pump station	Weir	Head Office
Jan-18	1 949.58	1 983.00	1 658.47	235.20
Feb-18	2 259.00	2 013.00	1 736.89	215.00
Mar-18	1 909.00	2 018.00	1 645.20	312.14
Apr-18	2 124.00	2 025.00	1 615.42	321.94
May-18	2 416.00	2 003.00	1 567.04	292.06
Jun-18	2 808.50	1 979.70	1 699.32	223.65
Jul-18	2 656.00	1 997.00	1 671.98	215.22
Aug-18	3 409.00	2 039.00	2 236.66	203.37
Sep-18	2 845.62	2 043.51	2 328.08	231.48
Oct-18	2 958.66	2 038.12	2 414.26	276.12
Nov-18	2 473.74	2 020.85	2 280.16	250.96
Dec-18	2 878.29	2 020.85	2 373.45	290.16
Jan-19	2 832.70	2 020.94	2 373.46	309.55
Feb-19	2 937.64	2 064.22	2 411.86	340.55
Mar-19	2 703.54	2 022.08	2 242.45	344.22
Apr-19	2 638.21	2 037.95	2 424.71	316.01
May-19	2 859.64	2 033.23	2 378.94	270.65
Jun-19	2 915.52	1 978.89	2 354.05	238.28
Jul-19	2 626.26	2 033.15	2 262.06	226.08
Aug-19	2 582.14	1 935.97	2 580.50	266.91
Sep-19	2 807.68	2 004.58	2 343.37	282.94
Oct-19	2 480.55	2 014.35	2 414.56	306.35
Nov-19	2 382.93	1 950.52	2 409.11	322.97
Dec-19	2 964.00	1 995.33	2 414.80	340.74

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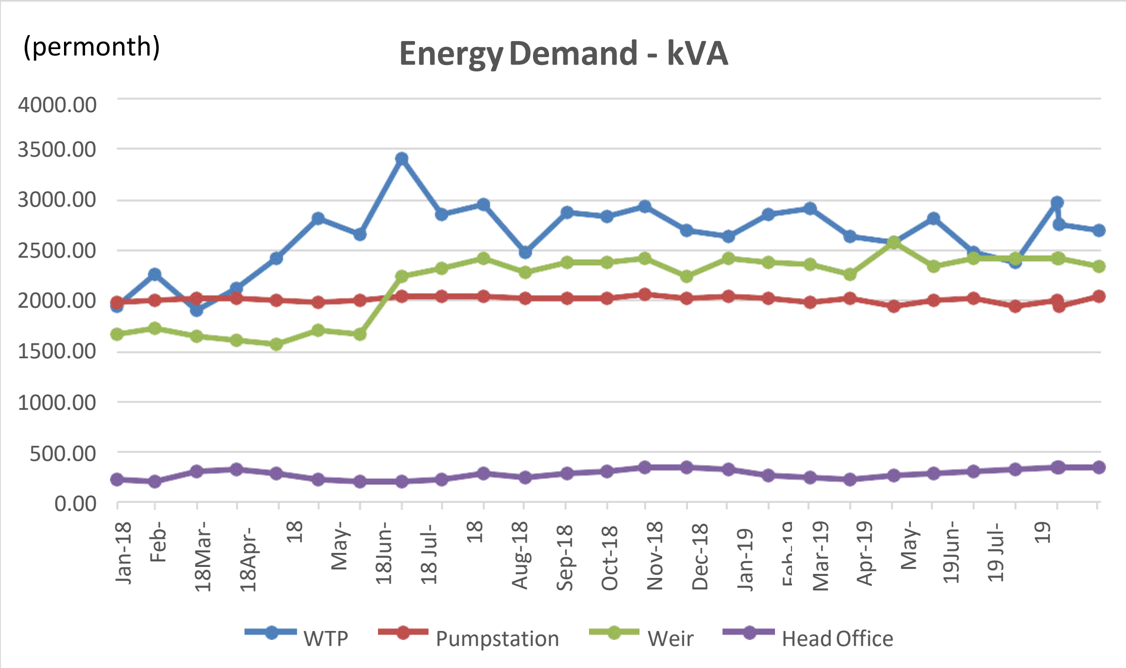

Fig. 5.2. Energy demand per month of each municipal facility for a two-year period

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The above tables and corresponding figure show that the municipal facilities responsible for high energy demand are the plants responsible for abstraction of raw water treatment of water, and distribution plants. The municipal head office is the lowest with almost insignificant demand.

The municipality is responsible for both consumption and supply (and/or distribution) of energy but for the purposes of this paper the aspect of the municipal function is the municipality itself consuming energy and paying for the energy used. The municipality supplying or distributing energy to citizens and industries is considered as outside the scope of this paper as the bills are not paid for by the municipality but by the municipal clients.

The average demand for the plants as indicated in Fig. 1indicate that the demand by the pump station plant together with that of the weir are relatively constant, whereas that of the treatment plant varies. The variations in energy demand has little to do with water demand but the treatment process of raw water depends on environmental factors such as high turbidity due to recorded rainfalls seasons and etcetera. The average annual energy demand reflects a 9.66 % increase within the two financial years.

In order to illustrate the amount of energy usage by the municipality in keeping its facilities operational, monthly energy demand and energy consumption measurements are reflected in the tables and figures below to reflect the amount of energy the municipal facilities consume at their condition in providing portable water. Monthly energy bills are also indicated to reflect the exorbitant amount of bills payable by the municipality to ESKOM for this water scheme.

The municipality has 3 relatively sized water schemes and the below tables assist in estimating the relative amount of bills for the water schemes, excluding the amounts paid for 5wastewater treatment plants, 2 macerators and 68 pump stations of which 5 are main sewage discharge pump stations.

The below table is the monthly energy consumption by the water scheme reflecting the amount of energy required from ESKOM by the municipality.

TABLE V. MONTHLY ENERGY CONSUMPTION RECORDINGS OF EACH MUNICIPAL FACILITY. KWHR READINGS ARE AN ACCURATE RECORDING OF THE CONSUMPTION (WEIR, WATER TREATMENT PLANT [WTP], PUMP STATION, MUNICIPAL BUILDING [HEAD OFFICE])

MONTHS	**kWh**	**kWh**	**kWh**	**kWh**
	WTP	**Pump station**	**Weir**	**Head Office**
Jan-18	956 588.00	1 338 000.00	649 279.00	157 711.00
Feb-18	1 064 923.00	1 415 052.00	629 942.26	82 172.00
Mar-18	922 669.00	1 048 990.00	721 779.21	88 616.00
Apr-18	1 022 701.00	1 395 830.00	816 899.85	82 653.00
May-18	1 129 635.00	1 380 705.00	647 804.83	1 348.00
Jun-18	1 247 737.68	1 377 015.00	821 306.00	69 197.00
Jul-18	1 227 842.00	1 270 442.00	703 102.00	61 135.00
Aug-18	1 529 499.00	1 301 646.00	1 160 069.00	64 684.00
Sep-18	1 420 637.62	1 451 345.51	1 162 650.59	66 986.48
Oct-18	1 346 877.00	1 381 614.00	1 412 534.00	67 634.00
Nov-18	1 365 574.00	1 282 417.00	1 033 575.00	68 881.00
Dec-18	1 305 039.00	1 292 500.00	1 285 265.90	71 129.00
Jan-19	1 429 817.00	1 430 597.00	1 413 911.00	85 305.00
Feb-19	1 479 475.00	1 355 058.00	1 193 425.00	91 525.00
Mar-19	1 265 401.00	1 265 354.00	1 337 133.38	82 670.00
Apr-19	1 290 926.00	1 359 651.00	1 275 158.93	96 696.00
May-19	1 350 997.00	1 386 976.00	1 370 220.13	73 466.00
Jun-19	1 364 346.00	1 352 333.00	1 30 0940.95	42 734.00
Jul-19	1 253 310.00	1 064 779.00	1 295 103.10	69 441.00
Aug-19	1 226 521.00	1 191 869.00	1 215 968.96	71 865.00
Sep-19	1 161 646.00	1 289 567.00	1 326 399.20	72 030.00
Oct-19	1 237 978.00	1 362 324.00	1 23 4310.04	83 300.00
Nov-19	1 158 970.00	776 178.00	1 210 456.03	76 809.00
Dec-19	1 266 410.00	1 331 782.00	1 195 126.82	95 994.00

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TABLE VI. AVERAGE ENERGY CONSUMPTION PER ANNUM OF EACH MUNICIPAL FACILITY (WEIR, WATER TREATMENT PLANT [WTP], PUMP STATION, MUNICIPAL BUILDING [HEAD OFFICE])

	WTP	Pump station	Weir	Head office
2019/20 annual consumption	15 485 797	15 166 468	15 368 153.54	941 835
2018/19 annual consumption	14 539 722.3	15 935 556.51	11 044 207.64	882 146.48
Energy consumption increase	6.11 %	-5.07 %	28.14 %	6.34 %

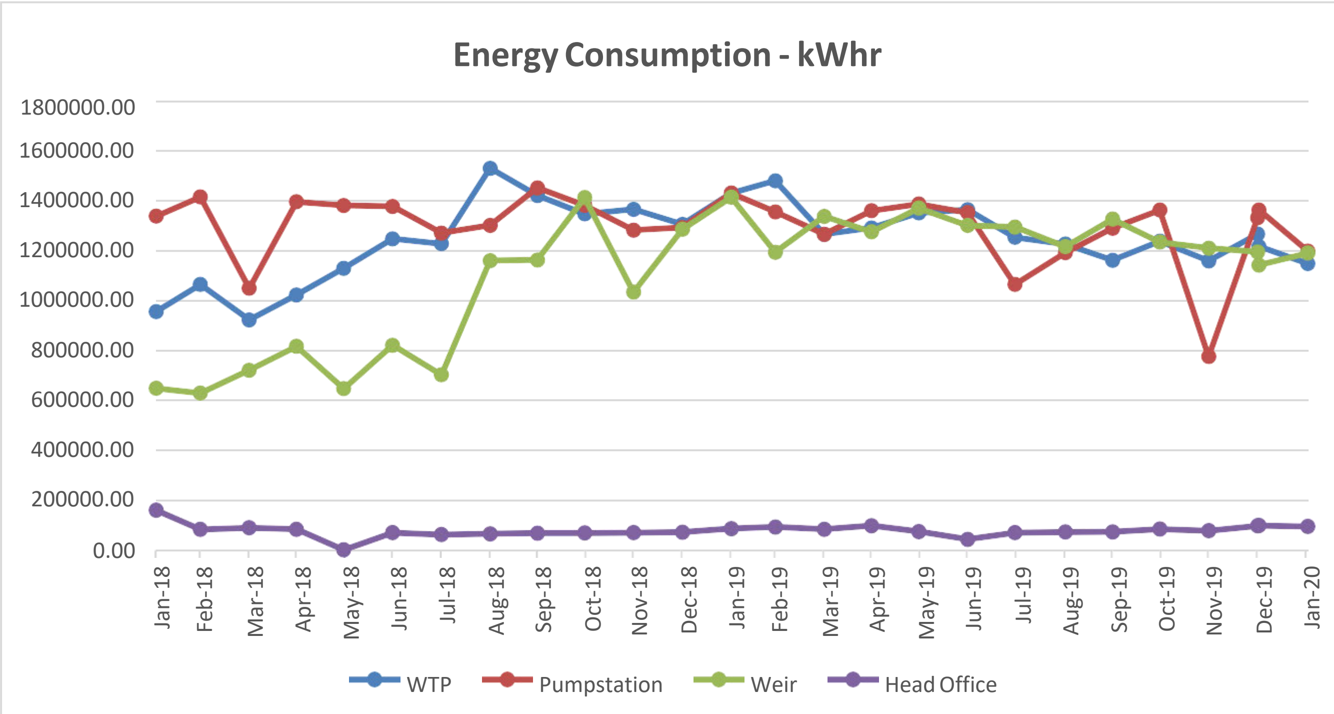

Fig. 5.3. Energy consumption per month of each municipal facility for a two-year period

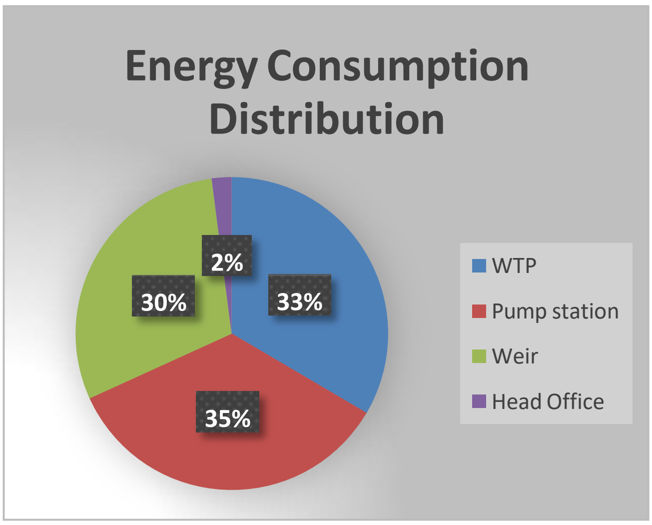

Fig. 5.4. Monthly energy consumption distribution of each of themunicipal facilities

From Fig. 3 and Fig. 4 it is evident that the municipal head office is the lowest almost insignificant contributor to energy consumption compared to the other municipal facilities, accounting for only 2 % of consumption. These figures also reflect that the highest municipal energy consuming plants are the weir treatment plant and the pump station plants recording an annual average energy consumption of slightly above 15 million kWhr. The total energy consumption of the three plants is slightly above 46 million kWhr. This reflects how much electricity the municipality consumes in order to provide services to citizens (residential), commercial and industrial institutions. The energy consumption of the weir in the 2018/2019 financial year accounts for the period where there were low water levels at the river and the pumps had to be stopped for longer periods. The average annual municipal energy consumption reflects an 8.88% increase from the 2018/2019 financial year to the 2019/2020 financial year. The plants used by the municipality to provide basic services have almost the same percentage consumption indicating equal importance of these plants. The municipal head office is the

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lowest energy consumer.

When considering the energy consumption profiles of category A, category B, and category C municipalities as spelled out in section 155 of the Constitution of the Republic of South Africa (RSA) [21] and the Municipal Structures Act 117 of 1998, [22] the energy consumption distribution of most of these municipalities follow a similar pattern to the above reflected energy consumption profile. The CSIR [9] report on condition assessments of water and wastewater plants across South Africa the report indicates that most municipal facilities' treatment plants together with pump stations are in poor conditions receiving little or no maintenance attention. What was observed in this municipal plant under study is that the plants are at average to poor condition with some components missing in some of the equipment. In terms of technology, most municipal plants have not undergone technological upgrades or been installed with the latest technology that is energy management sensitive. When viewing the municipality's capital project(s) plan it was of concern to see that there is no sight or hint of any future upgrade or installation of the latest energy management technology that would arrest energy wastage and improve energy consumption. In other words, most municipalities in South Africa, like the one under study, conduct energy audits and implement energy conservation or saving strategies on municipal buildings but pay less attention to or no attention at all to municipal facilitiesthat have high energy consumption.

Table VII and Table VIII and Fig. 4 reflect the energy bills that the municipality incurs on a month-to-month basis and corresponding annual bills for the two-year period.

TABLE VII. MONTHLY ENERGY BILLS FOR EACH MUNICIPAL FACILITY FOR ENERGY CONSUMED (WEIR, WATER TREATMENT PLANT [WTP], PUMP STATION, MUNICIPAL BUILDING [HEAD OFFICE]) (SOUTH AFRICAN RAND).

Month	Energy Costs	Energy Costs	Energy Costs	Energy Costs
	WTP	Pump Station	Weir	Head Office
Jan-18	R751 279.00	R1 177 815.00	R610 967.55	R226 338.00
Feb-18	R852 409.00	R1 199 227.80	R605 919.15	R184 940.00
Mar-18	R742 444.00	R1 032 903.00	R655 612.65	R185 293.00
Apr-18	R806 319.00	R1 19 5634.00	R766 672.97	R18 361.00
May-18	R885 040.00	R1 203 034.00	R648 790.95	R216 127.96
Jun-18	R995 559.00	R1 172 499.00	R1 056 497.10	R15 6388.00
Jul-18	R1 399 699.00	R1 609 518.00	R962 467.05	R171 024.00
Aug-18	R2 024 915.00	R1 862 374.00	R1 456 783.15	R183 411.00
Sep-18	R1 743 963.17	R1 92 3780.46	R1 097 350.45	R186 918.72
Oct-18	R1 094 656.00	R1 278 899.00	R1 265 123.75	R200 878.00
Nov-18	R1 100 297.08	R1 252 537.95	R989 771.70	R178 679.11
Dec-18	R1 042 700.12	R1 249 658.00	R1 175 348.95	R182 920.88
Jan-19	R1 125 648.80	R1 337 635.00	R1 260 863.60	R194 546.00
Feb-19	R1 173 757.00	R1 290 269.00	R1 119 688.70	R203 895.00
Mar-19	R1 026 077.00	R1 232 165.00	R1 194 907.40	R199 939.00
Apr-19	R1 041 679.00	R1 304 337.00	R1 324 094.30	R202 611.00
May-19	R1 069 364.00	R1 305 380.00	R1 394 901.55	R180 429.00
Jun-19	R1 092 938.00	R1 294 755.64	R1 791 784.55	R157 560.96
Jul-19	R1 836 221.00	R1 845 373.00	R1 774 574.45	R214 123.00
Aug-19	R1 736 253.53	R1 944 378.91	R1 341 051.90	R224 192.03
Sep-19	R1 130 913.00	R1 461 758.00	R1 352 299.95	R207 779.00
Oct-19	R1 182 556.00	R1 523 875.00	R1 289 673.90	R233 350.00
Nov-19	R1 182 555.27	R1 523 874.96	R1 284 064.10	R233 349.82
Dec-19	R1 198 403.00	R1 500 438.00	R1 272 449.45	R255192.00

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TABLE VIII. AVERAGE ENERGY CONSUMPTION PER ANNUM OF EACH MUNICIPAL FACILITY (WEIR, WATER TREATMENT PLANT [WTP], PUMP STATION, MUNICIPAL BUILDING [HEAD OFFICE])

Description	WTP	Pump station	Weir	Head office
2018/19 Average monthly Costs	13 439 280.37	16 157 880.21	11 291 305.42	2 091 279.67
Total 2018/19 Annual Costs				42 979 745.67
2019/20 Average monthly Costs	14 796 365.60	17 564 239.51	16 400 353.85	2 506 966.81
Total 2019/20 Annual Costs				51 267 925.77

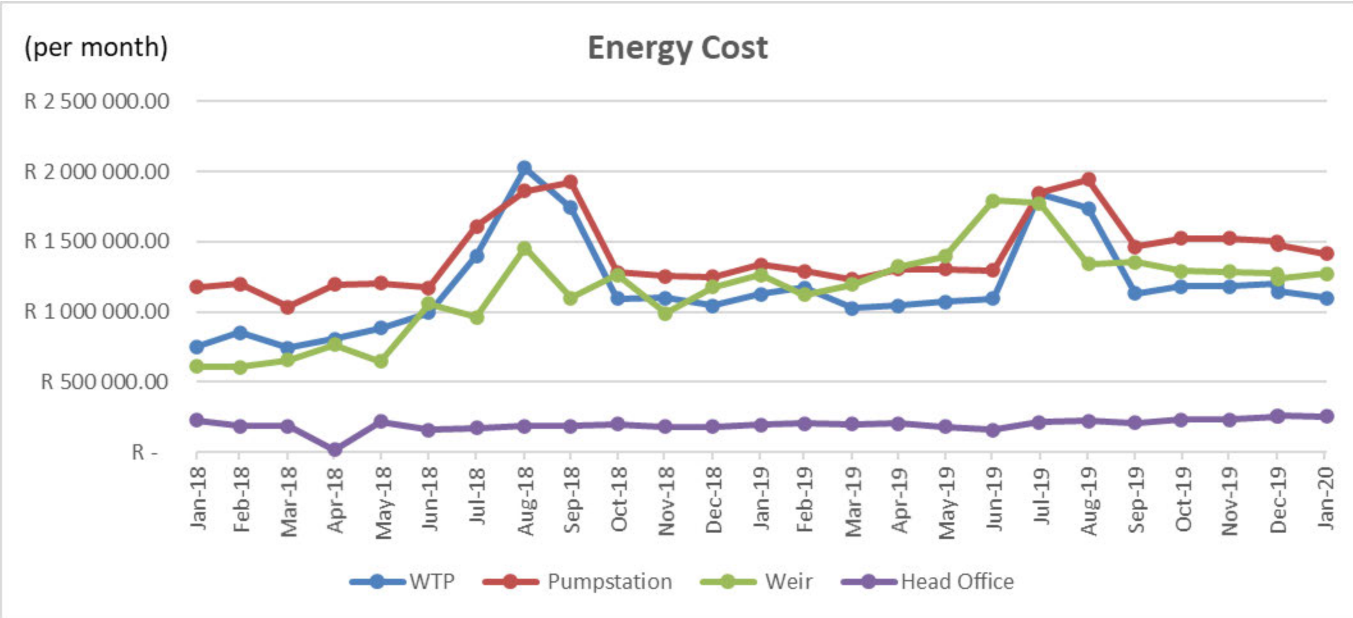

Fig. 5.5. Monthly energy consumption bills for each municipal facility for a two year period

In view of the financial cost of each of the municipal facilities (plants) above, it is evident that the water treatment plant together with the pump station and the weir carry the majority of the municipal expenditure. Table VII and Table IX depict that about R50 million per annum must be dedicated by the municipality to keep this essential water system running so as to be able to provide basic services from this water scheme. This examination of the energy bills excludes energy bills of other water supply schemes, distribution and reticulation networks, municipal wastewater schemes responsible for removing sewerage from residents, commercial and industrial institutions, discharging of sewage from municipal pump station plants, macerators, wastewater treatment plants, and effluent discharge systems.

The above tables and corresponding figure reflect that the three plants of this water scheme consume energy worth slightly over a million Rand each a month, with the municipal head office having an average bill of little more than R175 000. In a nutshell, the municipality pays about R3.5 million for this water scheme per month. The municipality under study for this paper has three water schemes with similar plants, five wastewater schemes with each having no less than twelve sewer pump station plants, two macerators and a final effluent discharge pump station plant. Without getting into details of the amount of energy consumption and energy bills that this municipality incurs, the municipal total energy expenditure to keep the above mentioned plants operational is slightly less than half a billion Rands. The question is, then, how much doesthis municipality together with other municipalities across the country allocate towards electricity to keep all it's essential plants operational in order to provide basic services? It must be born in mind in the context of this paper that the bills associated with the above operations are apart from energy charges that the municipality incurs to be able to provide energy to its clientsthat the clients pay for.

In view of Tables IV and Table VI, it is evident that there is an average positive increase in energy demand and energy consumption, except the pump station plant which reflects a negative increase when comparing 2018/19 with 2019/20. The negative energy demand and consumption at the pump station is due to the number of breakages (pump failures) that had been experienced. The percentage energy increase of the treatment plant, the weir and head office, was on average greater than 5 %. The head office and treatment plant had an

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average increase of 6 %, implying that general 'low hanging fruits' interventions are required, for example a change of lights to LED, and installation of a timer on the geyser at the municipal building (head office). However, energy savings from the municipal building resulting from implementation of interventions is very minute when compared to possible savings at primary plants.

The weir exhibits the highest average energy demand and consumption, indicating that major energy saving interventions are required such as improving power factors, installing capacitive components on inductive loads, and other possible technical-, human resource- and technology-related interventions. Since the weir abstracts raw water from the river, river level and concentration of objects may contribute to demand and consumption, thus project-oriented interventions in addition to general seen-as-fit interventions must be undertaken to reduce demand and consumption to less than 5 %.

The review of the connected load, demand factor and energy supply type are of importance. Connected load is the rating at the name plate of the apparatus installed on the consumer's premises (municipal primary facilities), measured either in kW or kVA. Maximum demand is the highest average kVA that is recorded using a digital energy meter or tri-vector meter during any demand interval within a specified time. The demandfactor is the maximum demand over the connected load.

Equation 1: Load-factor (l.f.) equation

The load factor is computed as: Load Factor (l.f) =

$$\frac{\text{Average load}}{\text{Maximum load}} = \frac{\text{Energy consumed during 24hrs}}{\text{Max. load recorded X 24hrs}}$$

The l.f. is basically the average energy consumed over the maximum recorded demand during the duration of measurement.

Load factor = Energy Consumed / (Maximum Demand x Time Period in Hours). Table IX indicates the values of monthly demand and consumption used to compute the average load factors of each primary municipal facility.

TABLE IX. MONTHLY ENERGY DEMAND (KVAH) AND CONSUMPTION (KWH) FOR EACH MUNICIPAL FACILITY

MONTHS	kVAh	kWh	kVAh	kWh	kVAh	kWh	kVAh	kWh
	WTP	WTP	Pump station	Pump station	Weir	Weir	Head Office	Head Office
Jan-19	2 107 528.80	1 429 817.00	1 503 579.36	1 430 597.00	1 765 854.24	1 413 911.00	230 305.20	85 305.00
Feb-19	1 974 094.08	1 479 475.00	1 387 155.84	1 355 058.00	1 620 769.92	1 193 425.00	228 849.60	91 525.00
Mar-19	2 011 433.76	1 265 401.00	1 504 427.52	1 265 354.00	1 668 382.80	1 337 133.38	256 099.68	82 670.00
Apr-19	1 899 511.20	1 290 926.00	1 467 324.00	1 359 651.00	1 74 5791.20	1 275 158.93	227 527.20	96 696.00
May-19	2 127 572.16	1 350 997.00	1 512 723.12	1 386 976.00	1 769 931.36	1 370 220.13	201 363.60	73 466.00
Jun-19	2 099 174.40	1 364 346.00	1 424 800.80	1 352 333.00	1 694 916.00	1 300 940.95	171 561.60	42 734.00
Jul-19	1 953 937.44	1 253 310.00	1 512 663.60	1 064 779.00	1 682 972.64	1 295 103.10	168 203.52	69 441.00
Aug-19	1 921 112.16	1 226 521.00	1 440 361.68	1 191 869.00	1 919 892.00	1 215 968.96	198 581.04	71 865.00
Sep-19	2 021 529.60	1 161 646.00	1 443 297.60	1 289 567.00	1 687 226.40	1 326 399.20	203 716.80	72 030.00
Oct-19	1 84 5529.20	1 237 978.00	1 498 676.40	1 362 324.00	1 796 432.64	1 234 310.04	227 924.40	83 300.00
Nov-19	1 715 709.60	1 158 970.00	1 404 374.40	776 178.00	1 734 559.20	1 210 456.03	232 538.40	76 809.00
Dec-19	2 205 216.00	1 266 410.00	1 484 525.52	1 331 782.00	1 796 611.20	1 195 126.82	253 510.56	95 994.00
Average	1 990 195.70	1 290 483.08	1 465 325.82	1 263 872.33	1 740 278.30	1 280 679.46	216 681.80	78 486.25
Total	23 882 348.40	15 485 797.00	17 583 909.84	15 166 468.00	20 883 339.60	15 368 153.54	2 600 181.60	941 835.00

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TABLE X. AVERAGE LOAD FACTOR OF EACH OF THE MUNICIPAL FACILITIES

Facilities	Load factor
WTP	0.648
Pump station	0.863
Weir	0.736
Head office	0.362

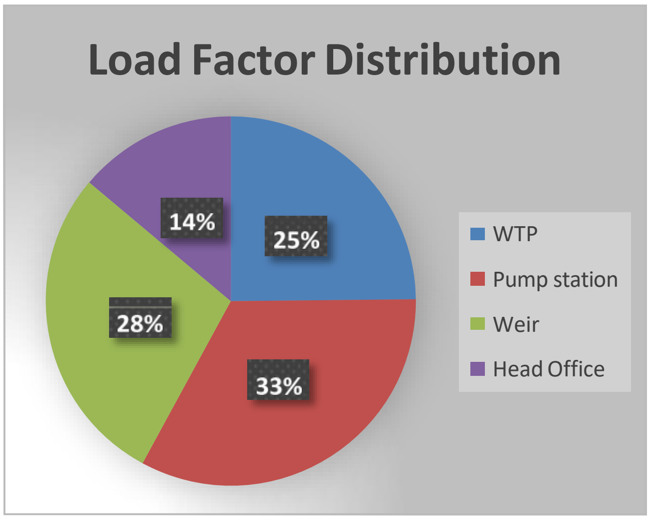

Fig. 5.6. Distribution of load factor contribution of the municipal facilities

The average load factor for all the municipal facilities listed above is 0.652. Table X shows that the pump station and weir have the highest load factors which indicates that the municipality has no underutilization of energy and the general power usage is relatively constant, thus the municipality attracts less charges from the utility. Because the water treatment plant, pump station and weir are not operating at fullcapacity for the entire duration of the day and/or month, and also because the maximum energy demand is always higher than the average energy demand, the load factor is less than 1. With regards to the municipal building (Head office), the load factor indicates that there is strong underutilization of energy. The important factor to note is that the municipal building contributes 14% of the load factor which shows that the least contribution to energy utilization is the municipal head office.

In ascertaining the energy efficiencies of each of the plants, Eq. 2 is used.

<u>Equation 2: Energy efficiency (e.e.) equation</u>

$$\text{Energy Efficiency} = \frac{(\text{consumption} - \text{demand})}{\text{consumption}}.$$

TABLE XI. AVERAGE ENERGY EFFICIENCIES OF THE MUNICIPAL PLANTS TOGETHER WITH THE HEAD OFFICE

Plant efficiency	WTP	Pump station	Weir	Head office
2019/20 efficiency	0.998	0.998	0.998	0.996
2018/19 efficiency	0.998	0.998	0.998	0.997

Table XI indicates that, in terms of how the plants are supposed to run, they have an average of 99.8% efficiency and99.7% for the municipal head office. The question is, then, how will the municipality craft and implement energy saving strategies in order to harvest a decrease in consumption and bills? Laid out below are generic recommendations together with brief explanations that municipalities should employ in order to control energy consumption and arrest possible energywastage.

III. RECOMMENDATIONS

Energy improvement strategies recommended for the municipality to implement are in line with world class energy saving strategies. Bearing in mind the whole water network and how each is uniquely operated, and detailed operations of other municipal plants and/or schemes, the following generic strategies are proposed for municipalities with similar functions. The recommendations are grouped into: generic energy efficiency equipment related interventions or strategies, generic energy conservation strategies based on human behaviour, and generic energy saving strategies based on technology. It must be born in mind that the core is the in- depth understanding of all water and wastewater schemes and plants operated by the municipality for effectiveness in the prescription of recommendations. This aids the municipality in being able to ascertain if the prescribed strategies will result in energy efficiency improvements and savings, and by how much. These energy saving and energy bills reducing strategies are grouped and recommended as follows:

A. Generic Energy Efficiency Equipment Related Strategies

- Power factor correction installation. Power factor, according to [17], describes how effectively a facility utilizes all of the electrical power it consumes. [17] further states that the demand components (kVA) within the bulk electricity tariffs perspective are directly affected by the power factor of operation. That is, the power factor in the interest of the consumer, in this case the municipality, must be kept as close to unity as possible because the kVAof operation increases as the power factor decreases resulting in the customer paying higher network demand charges and higher network access charges than necessary.

  Low power factors are caused by inductive loads such are induction motors, and in order to compensate for these inductive loads, capacitive components commonly known as power factor correction capacitors are introduced into the system. In other words, the municipality must improve

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the typical power factor of 0,85 to 0.95 or 0.995 for all induction motor dominant loads.

- Automate all component systems or components that can be automated in each of the plants.
- Due to low performing and poor infrastructure conditions, refurbish and/or replace all redundant or aged infrastructure with parts or components that have improved allowable life.
- Install energy management and performance monitoring systems or devices. Also include the installation of bulk check meters and/or zone meters to configure a baseline.
- Installation of variable speed drives where possible.
- Check and lubricate all moving components and change and/or refill oil in gearboxes and cylinders. Check, repair and refill all leaks in hydraulic cylinders and tubes.
- Repair and maintain all mechanical components, and audit conditions of all electrical components and check for efficiencies and replace where necessary.
- Recondition or replace aged or weak windings as they tend to be a major source of energy wastage. Also replaceaged and faulty circuit breakers.
- Recondition or replace pumps with new and improved pumps with improved pumping system efficiency. Pump efficiency can differ in definition depending on the various parameters used to determine efficiency, however, pump efficiency is critically dependent on maintenance and operational aspects. Decision-making and pump selections must take into consideration energy efficacy and low operational and maintenance costs. Optimal energy savings can be achieved by combining newer, more efficient pumps with variable speed drives and with EFF1 (high efficiency) motors.

B. Generic Energy Conservation Based on Human Behaviour Strategy

- Capture accurate data of plant performances in terms of plant efficiency, management (including maintenance work scheduling) and modelling in order to achieve optimal performances based on extensive historical records.
- Schedule periodic auditing of plant and corresponding energy performances, and arrange for appropriate works.
- Conduct annual benchmarking exercises with similar type world class institutions for latest best practices and new standards.
- Allocate adequately skilled labour to detailed operations functions, and allocate competent skilled and semi-skilled labour to repair and replace faulty or dilapidated parts or fixtures for water treatment plants, water abstraction weirs and pump station plants. Skilled operators must at alltimes use the electricity usage index and consumption measurements as tools at the various plants to identify problem areas as this exercise facilitates more efficient energy management (cost saving) and improved environmental impacts
- Adoption of an established, detailed organizational Energy Management Strategy (EMS) that links throughput, plant processes and energy management, and other areas of facility management into an integrated approachespecially during unplanned emergencies and load- shedding.
- Upgrade electricity grid and installation of consumption metering in real time, and a management system. Identify units with high energy consumption during maximum demand periods when high tariffs apply.
- Negotiate and have an annual review of tariffs and supply lines where possible for reduction of energy bills.
- Shift the off-work periods of identified equipment to time spans when lower tariffs apply.
- Maintain supply MVA against set point MVA, revert to load shedding when exceeding set point.
- Install energy sensitive devices where necessary. Include energy saving devices on high energy consuming parts and parts that have high maximum energy demand during periods when tariffs are high.

IV. CONCLUSION

Excessively high amounts of energy bills are incurred by municipalities in order to provide basic services. This results in excessive demand in the national grid, and yet some measures can be implemented to arrest energy wastage and uncapped consumptions. The recommendations above indicate three key strategies that institutions such as municipalities should use as a guide for effective introspection in terms of how they conduct and monitor their operations and energy management systems. Unchecked performances generally lead to disastrousoutcomes that, unfortunately municipalities choose to live withrather than find meaningful solutions that ensure that basic services are provided at affordable rates. If a single unmodified water scheme with only three main consuming facilities is capable of such exorbitant bills, what effects do municipal actions country-side have on the national grid, end-users or beneficiaries of basic services provided by municipalities, and what is the economic impact on municipalities? The importanceof periodicaudits is highlighted together with possible measures of addressing identified challenges or issuesusing theabove listed recommendations.

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Chapter 11: Feasibility Studies as an important part of planning for hybrid renewable energy system (HRES) projects: Case Study uMhlathuze

Feasibility studies are core to effective planning that must be undertaken with great commitment for accurate forecasting and implementation of HRES based projects. The absence of government's leadership and commitment to allocating the needed funding for renewable based feasibility studies results in the undertaking of solutions that are at the detriment of the general citizenry and the worsening of the near catastrophic energy collapse as infrastructure fails. Recommendations are proposed to enhance government buy-in towards these sustainable energy resources and the decentralisation of energy generation, giving municipalities the autonomy of generating their own electricity. The city of uMhlathuze is used as a classical location to implement a pilot HRES project. This article was accepted for publication in the International Journal of Mechanical and Production Engineering Research and Development (IJMPERD).

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FEASIBILITY STUDIES AS AN IMPORTANT PART OF PLANNING FOR HYBRID RENEWABLE ENERGY SYSTEM (HRES) PROJECTS: CASE STUDY CITY OF UMHLATHUZE

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ABSTRACT

Electricity supply shortages in South Africa are a result of poor strategic planning in relation to energy forecasting. This unfortunately has compromised the security of supply of the country which negatively affects its economic stability. Feasibility studies may be viewed as a tedious and expensive exercise, but they are necessary to develop strategies to resolve the country's energy crises. Feasibility studies in the energy sector would enable accurate and informed procurement of hybrid renewable energy technologies. To further aid planning, Benchmarking, as suggested by the South African Local Government Association, is also a useful planning tool. Effective feasibility studies depend on the efficiency of procurement systems, adequate policies and funds being available. This paper proposes the capacitation of the planning departments in municipalities through the formation of renewable energy project teams that comprise technical, legal, finance (procurement) and project/contract management personnel in order to effectively address complex energy problems and related project issues. The details of any hybrid renewable energy system (HRES) project can be accurately outlined after a feasibility study has been conducted and concluded.

KEYWORDS: Feasibility Studies, Hybrid Renewable Energy System (HRES) & PV-MFC Hybrid Technology

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1. INTRODUCTION

The assertiveness and commitment required from the South African government in taking a leadership role in resolving the country's energy challenges is to pursue the full exploration of renewable energy sources for generation and supply purposes. Together with the municipal Supply Chain Management (SCM) and Public Private Partnership (PPP) policies in place, the country can be rated among other world-class (developed) countries that have the capacity to satisfy high energy demands, thus being able to reliably and sustainably cater for fast growing economic trade activities at affordable rates that promote 'clean' energy and improve the quality of life of citizens.

To accelerate change and prevent complacency, municipalities must, according to this study, review their current operation in relation to the growing demand for services and economic development. Municipalities must take aggressive strides to improve their infrastructure in order to reach a stage of sustainable and reliable delivery of services to the community. Municipalities should reach a stage where they are able to market their infrastructure capacity to adjacent communities and potential investors by attracting economic investments through offering world class infrastructure and energy capacity. Thus, municipalities are urged in this study to urgently and comprehensively audit reasons for existing infrastructure challenges, determine the state of infrastructure, conduct feasibility studies on remedying the infrastructure conditions through rehabilitation and refurbishment projects, and implement agreed upon cost effective measures that eradicate energy wastage and improve infrastructure conditions. In doing so, all benefits associated with good infrastructure conditions such as energy conservation and efficient use of energy will be the order of the day.

Since the scourge of insufficient energy persists, municipalities must be encouraged and supported by both national and provincial government spheres to generate energy from renewable sources within their municipality such as biomass resources collected at treatment plants. Municipalities must be encouraged to conduct feasibility studies as part of their planning towards preparing for electricity generation implementation. The pre-treatment phase which comprises of removing impurities, plays a fundamental and crucial role in the effective success of generating electricity. Thus, the success and efficiency of the pre-treatment process of biomass is dependent on the careful scrutinizing and management of all pre-treatment processes and technology requirements, and subsequent generation requirements.

Excessively high energy bills are incurred by municipalities in order to provide basic services. The need to provide these services results in excessive energy demand from the national grid, and yet some measures can be implemented to arrest energy wastage and uncapped consumption. Unchecked performances generally lead to disastrous outcomes that, unfortunately municipalities choose to live with rather than find meaningful solutions that ensure that basic services are provided at affordable rates. Imagine a municipality that has a wastewater treatment plant or a water treatment plant that has not been modified by installing energy saving (efficiency) devices and respective infrastructure not made anew through rehabilitation/refurbishment projects, the municipal equipment or facilities tend to be intense energy consuming resulting in excessively high bills. Now, if a municipality is in possession of a number of such facilities or equipment that have not been reconditioned and modified to be energy sensitive or efficient, the municipality is capable of incurring exorbitant bills. Having a number of municipalities country-wide with facilities that are in poor condition and have no energy efficiency devices installed, what effect do the collective municipalities have on the national grid and economy of the country, end-users or beneficiaries of basic services provided by municipalities, and the impact on affordable functioning of municipalities? The importance of periodic energy and infrastructure audits is highlighted as possible measures in addressing identified challenges or issues.

System efficiency must not be a reactive process of gathering data on energy bills and trending energy demand and consumption, but must be planned before-hand so that all variables can be factored in and modelled to improve system efficiency performance. The process of gathering data must be used as a tool for checking performance and not for planning performance, because the culture of gathering data and attempting to improve performance in most cases results in misdiagnosis, procurement of misaligned technology, lack of commitment by government and other government institutions or departments, and negative attitudes from government personnel in procuring and operating technologies and systems that can be beneficial as well as loss of opportunity to correct or modify system behaviours that result in improved systems. Hybrid systems such as photovoltaic microbial fuel cells (PV-MFC) offer the advantage of reduced capital or investment costs yet provide effective multiple functions when employing reviews that re-model and factor in parameters that improve the viability and performances of the PV-MFC hybrid system.

Promethium Carbon and the South African National Energy Development Institute (2017) state that in order to access clean and stable energy and meet sustainable development goals in the energy sector, migration by developing countries from fossil fuel dependency to renewable energy source(s) engagement is necessary. Access to and financing of renewable energy projects are major challenges for many developing countries such as South Africa, but PPP agreements together with using well structured financing models that account for discounted future value of renewable energy projects in terms of money and socio-economic impact is a step in the right direction.

This paper reflects the benefit of a PV-MFC hybrid system that addresses electricity generation and supply challenges within the context of relevant legislation which is designed to conserve the environment for present and future generations. Strict adherence to legislative prescripts ensures that there is no alteration of the ozone layer that permits dangerous levels of solar energy, and alteration of the natural water environment (ocean) which then destroys the marine ecosystem.

The appointment of a Transactional Advisor (TA) as soon as possible is necessary for the municipality to achieve it's set goals and those of the national government of all citizens having access to electricity by year 2030. The implementation of this hybrid renewable energy system (HRES) based project would reduce the trend and consequences of non-expenditure on allocated budgets. The location of the City of uMhlathuze in relation to the above indicated available renewable sources, together with available municipal land, makes the municipality a good candidate for improved energy bills, and improved delivery of essential services at affordable rates to itself and surrounding communities from use of renewable sources along with reduced greenhouse emissions. However, limitations to this study are the financial resources required to appoint a TA that would comprise professional legal institutions, professional financial institutions or agencies and a professional technical team that will conduct feasibility studies at professional fees which are unaffordable at this stage of this research work.

Although the country faces a lot of energy and socio-economic challenges which drag the country into a pit of lost hope and ailing confidence, the call by government for joint efforts in solving the country's energy crises provides the motivation for this paper, of having the municipality decrease demand from the national grid, generate its own electricity using renewable energy hybrid technology to power its treatment plant, reduce energy bills, have adequate and sustainable security of energy supply, thereby enabling the municipality to function in a reliable manner and deliver services as mandated.

The national treasury (NT) guide together with Eskom's 2020 annual financial report indicate that government's guarantee towards resolving energy challenges and related issues is R300 billion of which a sum or amount of R274 billion has already been committed in resuscitating Eskom's plans of improving the energy supply of the country. Immediate robust pursuit of as many feasibility studies as possible regarding hybrid renewable energy generation implementation at municipal institutions is of paramount importance using the guide provided by this paper of uMhlathuze municipality, and the utilization of the remainder of the government's guarantee of R26 billion over a 2-year budget cycle, will fast-track the gaining of global investor confidence in the country and achievement of the 2030 energy targets. In the context of this paper, PV-MFC hybrid technology is deemed viable to power the wastewater treatment plant in uMhlathuze municipality, and constructing such a facility at up-scaled magnitudes will take 7-9 years, thus making it possible to meet the envisaged 2030 target. The evaluations and guide arising from this paper are proposed to enable the implementation of PV-MFC renewable projects at the municipality from feasibility to construction and commission stages.

2. BACKGROUND

This study provides an overview of the importance of creative thinking in the energy sector and how innovative exploration of renewable energy sources is an important and crucial advancement in the present energy standing of South Africa. This provides insight into how energy sustainability can be implemented to improve reliability of municipal treatment facilities through the use of HRES.

Considering the broadness of the subject area of generating electricity at municipal institutions using renewable energy sources, detailed feasibility studies must be conducted for each of the category A and B municipalities (as described by the Municipal Finance Management Act [MFMA], [South Africa, 2003]) that have already established good customer based profiles, excellent electricity revenue collection data and trends, and have competent high performing electricity planning sections that implement energy related projects effectively. Examining the above mentioned indicates the health of the municipality's business profile on electricity related matters, thus the capacity of the municipality to implement and operate specialised mega renewable energy projects. Although it has become a norm that planning divisions or sections in municipalities are generally concerned with planning and implementing operations and maintenance projects, the research and development (R&D) aspect of planning gets neglected to the extent that procurement of technology is based on convincing presentations by marketers of technology rather an objective feasibility studies, often resulting in the purchasing of ineffective technology.

One of the limitations of this research study is the lack of leadership and commitment by government 'municipal' personnel in allocating and committing necessary budgets that can facilitate the undertaking of detailed feasibility studies that will assist the municipality in dealing with its energy challenges. Thus, initiatives such as conducting regular infrastructure monitoring exercises together with installing devices that seek to improve energy efficiency are lacking.

The following is a compilation of recommendations arising from the study. The recommendations fall into two categories:

- Energy improvement strategies recommended for the municipality to implement in line with world class energy saving policies and targets, with the following generic solutions proposed:
- Introduction of energy efficient equipment as an energy saving strategy;
- Improvement of infrastructure conditions and performance as an energy conservation strategy; and
- Technological advancement as an energy intervention strategy to improve efficiency and reduce energy consumption.
- Establish research and development (R&D) strategies for municipalities to utilise and implement benchmarking measures regarding energy saving with high performing institutions globally. R&D seeks to propose meaningful endeavours for the purpose of gaining approvals and finding lasting solutions through, among others, the use of the latest technologies. Proposed solutions are:
- Allocation of dedicated human resources such as energy planners, procurement officers, legal practitioners and project/contract management personnel.
- Allocation and commitment of financial resources towards the planning (conducting of feasibility studies) and implementation of R&D recommendations, and
- Organisational (executive) commitment and participation in the examination of technologies so as to enable proactive decisions and approval of best-suited technologies.

Emphasising the above view, South African Local Government Association (SALGA) an institution that was established to support and aid municipalities, in their 2015 annual report recommended the following:

- Process (or best practice) benchmarking, where municipalities search for and study other municipalities, utilities or organisations that are high performers in particular areas of interest. In so doing, municipalities are able to gather information about similar infrastructure and what processes, practices and procedures they have adopted in keeping their infrastructure in acceptable condition. These processes, practices and procedures are studied and knowledge gained is taken back to the municipality and where feasible and appropriate, these good practices are adopted and incorporated into the municipality's own processes. Process benchmarking therefore allows municipalities to understand why other municipalities are performing better in delivering services, keeping good infrastructure conditions, and consequently resulting in energy bills free from waste.
- Metric (or performance) benchmarking involves municipalities comparing the performance levels of municipalities using performance indicators for a specific process such as energy conservation, infrastructure condition and performance standards, infrastructure preservation, sustainable delivery of services through reliable infrastructure, etc. The information gathered is used for identifying opportunities for improvement, setting performance targets and understanding relative positioning in comparison to other municipalities. Metric benchmarking allows municipalities to assess the performance of various aspects of their business processes and systems and determine which of their activities are weak or strong, and how much improvement can be made.

Municipalities are urged to benchmark against high performing similar institutions or with other international local government institutions, but the Council for Scientific and Industrial Research (CSIR) (2007) report on the state of municipal infrastructure in South Africa indicated that among other things, municipalities compare poorly in respect of strategic planning, asset accounting and making financial provisions for improvement of infrastructure condition and resolving energy related challenges.

The core of this study is gaining the depth of understanding required of water and wastewater schemes and plants, even if they are of conventional make-up, to use for the purpose of making the municipal facilities energy self-sustaining so that services are effectively delivered and bills reduced. This will enable the municipality to determine the effectiveness of prescribed or proposed strategies in yielding desired efficiency improvements and energy savings, and by how much. These energy-saving and energy-bills-reducing strategies are grouped and recommended as follows:

A. Generic Energy Efficiency Equipment Related Strategies

- Kowalska-Pyzalska and Byrka (2019) describe the power factor as being how effectively a facility utilizes all of the electrical power it acquires. Kowalska-Pyzalska and Byrka (2019) further state that the demand components (kVA) within the bulk electricity tariffs are directly affected by the power factor of operation. Therefore, the power factor is in the interests of the consumer, in this case the municipality, and must be kept as close to unity as possible because the kVA of operation increases as the power factor decreases resulting in the customer paying higher network demand charges and higher network access charges than necessary. Low power factors are caused by inductive loads such are induction motors, and in order to compensate for these inductive loads, capacitive components commonly known as power factor correction capacitors are introduced into the system. In other words, the municipality must improve the typical power factor of 0.85 to 0.95 or 0.995 for all induction motor dominant loads. Thus, recommendation of to install power factor correction capacitors.

- Automate all component systems or components that can be automated for the purpose of improving efficiency.
- Due to low performing and poor infrastructure conditions, refurbish and/or replace all redundant or aged infrastructure with parts or components that will have an improved allowable life.
- Install energy management and performance monitoring systems or devices together with bulk check meters and/or zone meters to configure the baseline.
- Install variable speed drives where possible.
- Monitor and regularly lubricate all moving components and change and/or refill oil in gearboxes and cylinders. Check, repair and refill all leaks in hydraulic cylinders and tubes.
- Repair and maintain all mechanical components, and audit conditions of all electrical components and check for efficiencies and replace when necessary.
- Recondition or replace aged or weak windings as they tend to be a major source of energy wastage. eplace aged and faulty circuit breakers.
- Recondition or replace pumps with new and improved pumps to improve pumping system efficiency. Pump efficiency can differ in definition depending on the various parameters used to determine efficiency, however, pump efficiency is critically dependent on maintenance and operational aspects. Decision-making and pump selections must take into consideration energy efficacy and low operational and maintenance costs. Optimal energy savings can be achieved by combining newer, more efficient pumps with variable speed drives and with high efficiency motors.

B. Generic Energy Conservation Based on Human Behaviour Strategy

- Capture accurate data of plant performance in terms of plant efficiency, infrastructure and energy management and modelling in order to achieve optimal performances based on extensive historical records.
- Schedule periodic infrastructure and energy auditing of plant and corresponding energy performances, and arrange for appropriate works.
- Conduct annual benchmarking exercises with similar type world class institutions for latest best practices and standards.
- Allocate adequately skilled labour to detailed operational functions, and allocate competent skilled and semi-skilled labour to repair and replace faulty or dilapidated parts or fixtures for water treatment plants, water abstraction weirs and pump station plants. Skilled operators must at all times use the electricity usage index and consumption measurements as tools at the various plants to identify problem areas as this exercise facilitates more efficient energy management (cost saving) and improved environmental impacts.
- Adopt an established, detailed organizational Energy Management Strategy (EMS) that links throughput, plant processes and energy management, and other areas of facility management into an integrated approach especially during unplanned emergencies and load-shedding.

- Upgrade electricity grid and installation of consumption metering in real time, and a management system. Identify units with high energy consumption during maximum demand periods when high tariffs apply.
- Negotiate and have an annual review of tariffs and supply lines where possible for reduction of energy bills.
- Shift the off-work periods of identified equipment to time spans when lower tariffs apply.
- Maintain supply MVA against set point MVA, revert to load shedding when exceeding set point.
- Install energy sensitive devices where necessary. Include energy saving devices on high energy consuming parts and parts that have high maximum energy demand during periods when tariffs are high.

Er (2016) is of the view that in order to evaluate the effective impact and performance of a technology, "simulation", "economic evaluation-payback model" and "data analysis and planning" processes must be undertaken with an established appropriate funding schemes in place such as a PPP. The 2019/2020 annual uMhlathuze municipality report reflected that the municipality has a 99 % revenue collection rate on its electricity. Bearing in mind the view expressed by Promethium Carbon and the South African National Energy Development Institute (2017) that PV-bioenergy hybrid systems can have a payback period of between 4 to 6 years after commencement (depending on financial models and fees agreed upon with the financial institution to fund the HRES project), installation of a PV-MFC hybrid system can be lucrative for the municipality and can be pursued with great confidence as HRES projects offer cheaper electricity rates and a shorter payback period.

Based on the views of Pakenas (1995) that wastewater treatment plants consume large amounts of energy but also have the capacity to produce large amounts of energy from sewage sludge, Hampton (2007) states that the process of harvesting energy from natural reserves such as from human waste for the purpose of generating electricity is important as municipal facilities mainly collect sewage largely comprising of human waste. The use of improved appropriate hybrid technologies such as a PV-MFC hybrid system deserves investment in order to enhance energy generation. Baker and Philips (2019) state that the time has come to challenge the conventional electricity utility business model which is based on a centralised system of generation, transmission and distribution, through the use of disruptive technologies (innovations that when scaled up cause disruption to the basic architecture of the electricity generation system) and 'prosumer' (producer-consumer) electrification. When a disruption occurs in a centralised system the whole grid (nation) gets affected whereas when disruption occurs in a decentralised system, the problem is localised in that area. The benefits of decentralised generation are reduced repair time, reduced transaction costs and reduced impact on the general economy, etc. Atkins et al. (2017) propose decentralised generation and distribution of the primary grid component with smaller macro-grids being supported by mini-grids.

3. RECOMMENDATIONS

The following suggestions and recommendations drawn from the study are put forward for future research.Since MFC technologies together with improvement measures for MFCs are mainly at laboratory scale and have been unproven for implementation at large scale in the South African market, and PV technologies are efficient but very expensive to implement on a large scale, feasibility studies are required to determine:

- The characteristic properties of microbes (since they are location specific) found on the north-east coast (Indian ocean) of South Africa must be examined, and how that group of bacteria can contribute to the generating of current in MFCs.
- Cheaper but efficient materials for internal proton transfer in MFCs that can easily be operated and maintained.

- Cheaper pure or alloy materials that concentrate solar energy and convert solar energy to electrical energy but generate little or no heat energy that gets dissipated as heat in the solar module.

Conducting the above detailed feasibility studies require specialists in the field and highly specialised and fully equipped research institutions, so at the writing of this paper were beyond the scope of this study. Such studies must be conducted and handled with suitable funding and sponsorship. Emanating from the 2007 CSIR report on the state of municipal infrastructure in South Africa, further studies must be undertaken to understand why municipalities compare so poorly in respect of strategic planning, asset accounting and making financial provisions for improvement of infrastructure condition and resolving energy related challenges.

4. CONCLUSIONS

In the absence of detailed feasibility studies, complex energy related issues may often result in misdiagnosis and procurement processes that are later met with objections. Thus, to eliminate resistance of any form and to gain committed support or backing from the executive, stakeholders and general citizenry, municipal planning departments must be properly capacitated and equipped for the task of conducting effective planning functions through feasibility studies emanating from R&D.

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Chapter 12: General Discussion, Conclusions and Recommendations

12.1 General Discussion

The South African government needs to take a more assertive leadership role in resolving the country's energy challenges by radically pursuing the full exploration of renewable energy sources for generation and supply purposes. The government claims that all strides are being undertaken to enable all to have access to reliable energy. However, will government initiatives and assertiveness yield electricity that citizens can afford, and that is environmentally friendly?

The financial news site, Fin24, recently carried a Bloomberg news story that the South African government is moving ahead with acquiring the services of Karpowership, an Istanbul-based company that won the bulk of the tender bids conducted in March 2021 by ESKOM, together with services of a Turkish supplier that supplies gas-fired power plants on ships, to provide a combined emergency supply of 1220 megawatts of power for 20 years (Burkhardt, 2021). This is despite the outcry from environmental groups to halt investment in fossil fuel-based generation. Karpowership is expected to secure funding and necessary approvals and agreements by the end of July 2021, with the World Bank's International Finance corporation expressing its interest in funding the potential emergency energy providers. The costs and consequences of undertaking such is estimated by the Council for Scientific and Industrial Research to be R218 billion. Considering the implementation of the Karpowership as an emergency attempt by government to improve electricity supply in South Africa, what environmental impact (cost) will it have on the coastal shores of South Africa?

Short-cuts to proper and effective planning lead to reactive controversial endeavours and exorbitant costs for South African citizens and enormous profits for multi-national companies. There is nothing worse than what the country is currently experiencing in terms of its energy status, thus efforts must be focused on conducting meaningful feasibility studies as outlined in this research for efficient and successful implementation of PV-MFC (HRES) projects in the next 2 to 3 years that will benefit the country and its citizens in remedying the energy status, and have a positive impact on environmental health and a positive effect to the economy and citizens. As alluded to by Promethium Carbon and South African National Energy Development Institute (2017), hybrid systems such as PV-MFCs offer the advantage of reduced capital or investment costs yet provide effective multiple functions. Renewable technology using PPP financing models and other legislated tools make HRES projects viable in the South African market, and a PV-MFC project viable for the City of uMhlathuze. Feasibility studies for planning and establishing renewable energy projects and renewable hybrid technologies such as PV-MFC are essential to solving energy shortages at a municipal level.

12.2 Conclusions

In an attempt through this study to explore the exacerbated effects of unsustainable generation and unreliable supply of electricity in the country resulting in outages that disrupt trading activities and quality of life of citizenry at the City of uMhlathuze. It is evident from the findings and discussions that there are leadership gaps and limited strides aimed by government at resolving the energy challenges faced by municipalities in delivering affordable services to communities without the uncertainties of energy shortages. Highlighted by the study is how municipal infrastructure maintenance actions and procurement of energy has on the affordability of citizens in consuming goods and services mandated by the Constitution to municipalities.

To circumvent the effects of government’s ineffective blanket approach in solving energy challenges and the unfortunate perception that feasibility studies are time wasting and require exorbitant amounts of money that yield meaningless solutions, the study highlights the benefits of selecting renewable energy as an alternative solution to power municipal wastewater plants using customized renewable hybrid energy technology. Further, the study indicates among others the finance tools and government developed supply chain (procurement) policies in the National Treasury’s private-public partnership (PPP) section that can determine the most feasible and affordable mode of implementing HRES projects as a medium-long term solution to energy challenges and unreliable municipal functioning.

For the country to recover from the near catastrophic energy crises, the study proposes that energy generation be decentralised to municipalities and autonomy given to the same to determine their own energy requirement and generate electricity to power facilities such as treatment plants for effective delivery of services and improved quality of life. Thus the study expresses the view that with all the already existing tools in place, municipalities supported by legislation, feasibility studies conducted by TA and financial resources can enable sustainable and reliable energy supply and delivery of services.

In view of this study objective and taking into consideration the findings and discussions centered around energy challenges and municipal operations dependent on the credibility of energy supply, it is important that radical ‘out-of-the-box’ solutions are cascaded by government right down to municipal spheres and comprehensive strategies are implemented to gain competitive advantage in forecasting energy challenges and building needed capacity (security of supply).

12.3 Recommendations

Recommendation 1

This study provides a necessary guide for leaders and decision makers in the South African government to have the country’s best interests at heart and provide the needed solutions to circumvent the negative impact of energy shortages. In order to have meaningful solutions in place, planning, accountability and due diligence must be the order of the day for every proposed solution. A recommendation arising from the above, aimed at resolving the energy challenges of the country, is the formation of an independent national technical team of experts (NTTE) comprising engineers, scientists and researchers that are specialists or experts in the energy sector in all forms of energy resources and technologies, to advise parliament and the President of the country regarding viable energy systems that can be employed. The NTTE must be delegated with powers to use resources of both the Council for Scientific and Industrial Research (CSIR) and the South African National Energy Development Institute (SANEDI) as appropriate. This recommendation diffuses the reliance on political figureheads such as ministers which up until now has delayed approvals and the implementation of technical solutions.

Various authors and researchers have reflected on the importance of multitasking, which the Oxford Advanced Learner's Dictionary (2021) defines as "the ability to do several activities at the same time". However, disadvantages of team members' multitasking are that the required performance from individual team members may not be high performance enough. Altschuller and Benbunan-Fich (2017, citing Chan, 2014) state that fragmented attention results in poor team performance. At the same time, the authors (citing Cummings & Haas, 2012), state that team performance is improved or high if team members are dedicated to one team formation and dedicate more of their time and attention to the team and the set goals. Thus, the NTTE must be removed from other functions and work-related obligations of the individual members so that the team can be 100 % dedicated and high performing in order to achieve the most practical solutions. Even when establishing a turn-around or recovery plan, an effective team dedicated at achieving required goals must be established to see through the best-suited solution for these energy crises.

Recommendation 2

It is evident that planning through the use of comprehensive feasibility studies and formulation of dedicated expert-based teams at provincial and national levels is lacking. The leadership role of government is absent in the face of the electricity challenges currently existing which can be addressed using readily available resources such as renewable sources. Irrespective of legislative tools in place, leaders and decision-makers in the country are unfortunately more engaged in political discourse rather than solving the technical challenges facing the country. A study needs to be undertaken on how politicians solve technical problems, leaving technical experts out of the problem-solving process in South Africa.

Recommendation 3

The main improvement measures for MFC technologies are still at laboratory scale and remain unproven for implementation at large scale in the South African context at municipal level, therefore feasibility studies are required to determine:

- The economies-of-scale of designing and implementing a municipal based (large-scale) HRES such as a PV-MFC hybrid system dedicated to generating electricity for the municipality to power it's energy demanding equipment and/or facilities.
- Cheaper and more energy efficient materials for the PV-MFC hybrid system that are affordable and easy to maintain by the City of uMhlathuze and other potential municipalities to implement the same in South Africa.
- Models that will aid the municipality to operate the hybrid system in an affordable manner that enables the municipality to gain a return on capital investment within a reasonable payback period, and to have long-term profits and energy-savings. This avoids situations whereby the municipality constructs an HRE plant but which the same municipality cannot afford to operate. An example of this is the construction of a 10 mega-litre (Ml) desalination plant in uMhlathuze municipal area in an attempt to solve water related challenges, but operating the desalination plant is too expensive and the municipality cannot afford to do so.

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APPENDICES

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Mar 05, 2021

To

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VAT NUMBER – 4860209305

Dear Professor Freddie L. 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:** "**FINANCING AND PAY-BACK OF RENEWABLE HYBRID ENERGY PROJECT (TECHNOLOGY) SUCH AS PV-MFC SYSTEMS: CASE STUDY UMHLATHUZE MUNICIPALITY**" authored by **Melusi Nhleko & Freddie L. Inambao"** submitted to us for an evaluation by you on **Mar 03, 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): 8.8746; NAAS Rating: 3.11; IBI Factor: 3.2; ICV 2015:60.6.**

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