The development of the Water-Energy-Food Nexus Index and its application to the Southern African Development Community

by

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Agricultural Engineering, School of Engineering of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by the Water Research Commission (Project: K5/2959//4) and the National Research Foundation (Grant Number: 114692).

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: Professor Graham Jewitt

Date: 2020-06-08

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Signed: Gareth Beresford Simpson (Student number: 931319223)

Date: 2020-06-07

DECLARATION 2: PUBLICATIONS

My role in each paper or report section is indicated below. The * indicates the corresponding author.

Chapter 2

- Simpson GB* and Jewitt GPW (2019). *The Development of the Water-Energy-Food Nexus as a Framework for Achieving Resource Security: A Review*. Frontiers in Environmental Science, Volume 7, Article 8, pages 1-9.
- doi: 10.3389/fenvs.2019.00008 (Open Access)
- Gareth Simpson wrote the manuscript in consultation with Graham Jewitt, who supervised the project.

Chapter 3

- Simpson GB* and Jewitt GPW (2019). *The Water-Energy-Food Nexus in the Anthropocene: Moving from 'nexus thinking' to 'nexus action'*. Current Opinion in Environmental Sustainability, Volume 40, pages 117–123.
- doi: 10.1016/j.cosust.2019.10.007
- Gareth Simpson wrote the manuscript in consultation with Graham Jewitt, who supervised the project.

Chapter 4

- Simpson GB*, Badenhorst J, Jewitt GPW, Berchner M and Davies E (2019). *Competition for Land: The Water-Energy-Food Nexus and Coal Mining in Mpumalanga Province, South Africa*. Frontiers in Environmental Science, Volume 7, Article 86, pages 1-12.
- doi: 10.3389/fenvs.2019.00086 (Open Access)
- Gareth Simpson conceived and led the research, while Graham Jewitt supervised the project. Jessica Badenhorst, Marit Berchner, and Ellen Davies participated as researchers.

Chapter 5

- Simpson GB* and Jewitt GPW (2019). *Leave No One Behind: A Southern African Perspective on Water-Energy-Food Nexus Analyses and Innovations*. Environmental Policy & Science. Ready for decision (submitted 31 August 2019)
- Gareth Simpson wrote the manuscript in consultation with Graham Jewitt, who supervised the project.

Chapter 6

- Simpson GB*, Jewitt GPW, Becker W, Badenhorst J, and Neves AR (2019). *The Water-Energy-Food Nexus Index: A Tool for Integrated Resource Management and Sustainable Development*. Global Environmental Change. With Editor (submitted on 27 November 2019)
- Gareth Simpson wrote the manuscript in consultation with Graham Jewitt, who supervised the project. William Becker and Ana Neves and the remainder of the JRC-COIN team provided input into the development of the WEF Nexus Index. William Becker contributed to the final manuscript. Jessica Badenhorst assisted with the selection of indicators contained in Addendum A, as well as other involvement throughout the project.

Chapter 7

- Sections 5.2 and 5.4 from the report: Simpson GB*, Jewitt GPW and Badenhorst J, and Neves AR (2020). *Development of the Water-Energy-Food Nexus Index and its application to the Southern African Development Community*. Water Research Commission. WRC Report No. 2959/1/19. ISBN No 978-0-6392-0113-9
- Gareth Simpson wrote the manuscript in consultation with Graham Jewitt, who supervised the project. Jessica Badenhorst assisted with the selection of indicators contained in Addendum A and the literature review of the WEF nexus in South Africa, as well as other involvement throughout the project.

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Signed: Gareth Simpson

Date: 2020-06-07

ABSTRACT

This thesis commences with a review of the development and relevance of the water-energy-food (WEF) nexus as a framework for achieving resource security. Based on academic and grey literature it includes an assessment of what the WEF nexus is, a review of its novelty (or lack thereof), and describes the challenges associated with integrating and optimising the WEF nexus. The criticism that several WEF nexus conceptualisations neglect distributional justice is considered, followed by a reflection on governance aspects associated with the approach. Four short WEF nexus case studies illustrate nexus considerations.

The research subsequently assesses the status quo of opinion within the WEF nexus fraternity. The approach is not yet a decade old, and several practitioners have called for a shift in focus from 'nexus thinking' to 'nexus doing.' Various research tools to support nexus action are presented. Next, a comprehensive WEF nexus case study that includes indicators and GIS-base maps is offered. The case study is the Mpumalanga Province in South Africa, which represents a melting pot for the WEF nexus. Within this province is a strategic water area, extensive coal mining for energy generation and a considerable portion of the nation's high potential agricultural land. This nexus assessment yields a radar chart that represents a visualisation of six water-, energy- and food-related indicators.

An anthropogenic WEF nexus framework is subsequently motivated and presented. This framework has been utilised to develop the core output of this research project, namely, the development of a country-level composite indicator that has been established for 170 nations. Following an assessment of 87 globally applicable water-, energy- and food-related indicators, 21 were selected to constitute the WEF Nexus Index. This index provides a quantitative perspective of this multi-centric lens for evaluating trade-offs necessary to achieve sustainable development. To this end, it can be utilised for assessing national progress relating to integrated resource management as well as supporting decision making and policy development. The relevance and usefulness of the outcomes are demonstrated through a detailed discourse of the findings for selected regions and countries. An extended analysis is provided for the Southern African Development Community (SADC).

WEF nexus assessments in the decade leading up to the 2030 Sustainable Development Goal (SDG) target year must be more comprehensive. Qualitative studies must be conducted in parallel with quantitative assessments. There is no one-size-fits-all method for integrated resource management utilising the WEF nexus. Instead, the approach must be tailored for each unique situation, and the WEF Nexus Index can be a catalyst and entry-point for such studies. By evaluating a subset of the SDGs, the index is complementary to the SDGs. The WEF Nexus Index is not a silver bullet that will solve all the significant development or environmental challenges facing humanity. This approach can, however, be added to the sustainability toolbox that is being utilised to engineer 'the future we want'.

EXTENDED ABSTRACT

Chapter 2 presents a study of the evolution of the water-energy-food (WEF) nexus since its rise to prominence in policy and development discourses in 2011 and offers various interpretations of the concept as well as the novelty of the WEF nexus. The challenge of integrating and optimising the components of this multi-centric nexus is examined and presents four case studies. Various criticisms levelled at the WEF nexus, such as the neglect of livelihoods and the environment in assessments, are noted, together with governance considerations associated with this framework. Finally, the potential of the WEF nexus to contribute to the achievement of the Sustainable Development Goals (SDGs) is reviewed.

Chapter 3 reviews the current status of the WEF nexus approach, which has received some critique for being predominantly conceptual. The call to operationalise the nexus is heralded in many recent publications, and a common theme is that ‘nexus thinking’ must evolve into ‘nexus doing’. To this end, this chapter seeks to present opportunities to enable and achieve ‘nexus doing’ through a synthesis of approaches proposed in both contemporary academic journal articles and grey literature. The synthesis shows that there is an excellent basis to move forward to implementation and that in places, this has started. Nexus policies are being enabled at different spatial extents from regional and national scales to a city level, and appropriate mechanisms and decision support tools to achieve integrated nexus planning are evolving. However, there is no single method that fits all situations; instead, the approach must be tailored for each unique situation.

Chapter 4 presents a WEF nexus case study. The Mpumalanga Province is a crucial source of South Africa’s coal supply with over 60% of the province’s surface area either being subject to mining rights or prospecting applications. Mpumalanga also possesses almost half of the country’s high potential arable land. While South Africa is currently mostly self-sufficient in terms of cereal grains, what this assessment of Mpumalanga highlights is that food security is increasingly being threatened by coal mining interests that serve the nation’s energy needs. Water availability and quality for mining, agriculture and energy production in this province are also becoming increasingly strained. The water quality deterioration generally results from either acid mine drainage or contaminated runoff from mines and agricultural lands. This assessment of Mpumalanga highlights the interconnectedness of energy, food and water security, with their resultant trade-offs. The WEF nexus provides a focussed lens through which to evaluate resource security in a holistic manner. Only once regulators, non-governmental organisations, industry and the public view the resource security challenges in Mpumalanga in an integrated manner can planning and policies that lead to sustainable development be advanced, and objectives such as the SDGs be achieved. There is, therefore, a need for WEF nexus science and data to influence integrated public policy within this province.

The anthropogenic impact on Earth is significant in both developed and developing countries. However, in developing countries, there is a need to address both macro-level resource security

and distributional justice. In Chapter 5 it is noted that substantial focussed work remains in regions such as Southern Africa if the SDGs are to be achieved in the next ten years. The WEF nexus, which includes SDGs 2, 6 and 7 has garnered significant attention as a lens for addressing sustainable development and integrated resource management in the second decade of the twentieth century. This paper presents an anthropocentric WEF nexus framework that emphasises both the availability of and access to, water, energy and food – which are crucial development concerns in Southern Africa. This framework can be utilised in WEF nexus analyses and applications such as models, composite indicators, serious games or innovations. Finally, vignettes of selected projects in the Southern African Development Community (SADC) are presented as examples/evidence of water-, energy- or food-related innovations.

A central challenge related to the WEF nexus is how to measure it. The evaluation of a system that includes water-, energy-, and food-related parameters is complex. Not only are these resources quantified utilising different units, but they vary both spatially and temporarily. Chapter 6 presents the development of a country-level composite indicator that has been established for 170 nations. Following an assessment of 87 globally applicable water-, energy- and food-related indicators, 21 were selected to constitute the WEF Nexus Index. This index is made up of three equally weighted pillars representing the three constituent resource sectors. The WEF Nexus Index provides a quantitative perspective of this multi-centric lens for evaluating trade-offs necessary to achieve sustainable development. To this end, it can be utilised for assessing national progress relating to integrated resource management as well as supporting decision making and policy development. The relevance and usefulness of the outcomes are demonstrated through a detailed discourse of the findings for selected regions and countries.

All five Scandinavian countries ranked within the top twenty nations for the WEF Nexus Index. Five South American countries and one Asian nation also feature in the top twenty for this index. No African states featured in the top twenty nations, however, three-quarters of the bottom twenty ranking nations are from this continent.

The development of the WEF Nexus Index has demonstrated that no country is undertaking integrated resource management flawlessly. Every nation has the potential for improvement; which is evidenced by, for example, the top-ranking country for the WEF Nexus Index needing to reduce CO_2 emissions. This composite indicator is not the panacea that will solve all the significant development or environmental challenges facing humankind. It can, however, contribute to integrated resource management and is complementary to the Sustainable Development Goals.

In the final chapter prior to the conclusions and recommendations, the ranking of SADC countries according to their respective WEF Nexus Index values has South Africa ranking highest, while Madagascar is lowest at 165th. With much of the developed world having built their nations on the foundation of fossil-fuel-based energy generation, it is evident that the dearth of coal in Africa outside of South Africa has restricted its development and contributed to a poverty trap. Ironically, much of the world is moving away from coal-fired power generation, but they can do so because they have reached the point where they can afford to do so. Access to energy is indeed a pivotal enabler of economic development. In reviewing the constituent indicators of the WEF Nexus Index it is evident that most SADC nations are not utilising their available freshwater. If they could gain broader access to affordable, modern, renewable energy, then a significant benefit could result in terms of food production and economic development. The "Food-availability" sub-pillar is generally the poorest performing sub-pillar within the WEF Nexus Index for SADC countries.

In terms of this research's contribution to new knowledge, it has yielded a global country-level composite indicator related to the WEF nexus. It provides a quantitative means of ascertaining 170 different nation's progress in terms of the integrated resource management, utilising the WEF nexus as a lens. It also provides an opportunity for comparing a nation's progress with other countries, whether from the same region (e.g. SADC or the Middle East and North Africa (MENA)), at a similar level (i.e. developed or developing), or by assessing a nation relative to all of the countries included in the study (e.g. the best performing nation). By having a quantitative measure of the WEF nexus, the index provides a summary and entry point to the complex dataset upon which it is founded. This will facilitate an analysis of the constituent indicators, which will provide the researcher, policymaker or decision-maker with insights and prompts in terms of where interventions and investments are necessary.

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Sola Deo Gloria

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LIST OF ABBREVIATIONS AND ACRONYMS

AFG	Afghanistan
AGO	Angola
ALB	Albania
AMD	Acid Mine Drainage
ARE	United Arab Emirates
ARG	Argentina
ARM	Armenia
AUS	Australia
AUT	Austria
AZE	Azerbaijan
BEL	Belgium
BEN	Benin
BFA	Burkina Faso
BFAP	Bureau for Food and Agricultural Policy
BGD	Bangladesh
BGR	Bulgaria
BIH	Bosnia and Herzegovina
BLR	Belarus
BLZ	Belize
BOL	Bolivia
BRA	Brazil
BRB	Barbados
BRN	Brunei Darussalam
BTN	Bhutan
BWA	Botswana
CAF	Central African Republic
CAN	Canada
CER	Centre for Environmental Rights
CHE	Switzerland
CHL	Chile
CHN	China
CIV	Cote d'Ivoire
CMR	Cameroon
COD	Democratic Republic of Congo
COG	Republic of Congo
COIN	Competence Centre on Composite Indicators and Scoreboards

COL	Colombia
COM	Comoros
CPV	Cabo Verde
CRI	Costa Rica
CRSES	Centre for Renewable and Sustainable Energy Studies
CSIR	Council for Scientific and Industrial Research
CUB	Cuba
CYP	Cyprus
CZE	Czech Republic
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DEU	Germany
DJI	Djibouti
DMA	Dominica
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DNK	Denmark
DoE	Department of Energy
DOM	Dominican Republic
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
DZA	Algeria
ECU	Ecuador
EGY	Egypt
ESI	Environmental Sustainability Index
ESP	Spain
EST	Estonia
ETH	Ethiopia
EU	European Union
EWF	Energy-Water-Food
FAO	Food and Agriculture Organisation of the United Nations
FEW	Food-Energy-Water
FIN	Finland
FJI	Fiji
FRA	France
GAB	Gabon
GBR	United Kingdom
GDP	Gross Domestic Product
GEO	Georgia
GHA	Ghana
GHG	Greenhouse gas
GHI	Global Horizontal Irradiance
GIN	Guinea

GIS	Geographic Information System
GMB	Gambia, The
GNB	Guinea-Bissau
GNI	Gross National Income
GNP	Gross National Product
GRC	Greece
GTM	Guatemala
GUY	Guyana
GW	Gigawatt
GWh	Gigawatt Hours
GWP	Global Water Programme
HDI	Human Development Index
HDR	Human Development Report
HKG	Hong Kong SAR, China
HND	Honduras
HRV	Croatia
HTI	Haiti
HUN	Hungary
I$	International Dollar[1]
IAP	Invasive Alien Plants
IDN	Indonesia
IEA	International Energy Agency
IHE	IHE Delft Institute for Water Education
ILI	Infrastructure Leakage Index
ind.	Indicator
IND	India
INRM	Integrated Natural Resource Management
IRENA	International Renewable Energy Agency
IRL	Ireland
IRN	Islamic Republic of Iran
IRP	Integrated Resource Plan
IRQ	Iraq
ISL	Iceland
ISR	Israel
ITA	Italy
IWRM	Integrated Water Resources Management
JAM	Jamaica
JOR	Jordan

[1] An international dollar (I$) could purchase, in the cited country, a comparable amount of goods and services that a US$ would acquire in the United States of America. This term is frequently utilised in conjunction with Purchasing Power Parity data (Schmidt 2020).

JPN	Japan
JRC	Joint Research Centre
KAZ	Kazakhstan
KEN	Kenya
KHM	Cambodia
KOR	Republic of Korea
Kt	Kilo-ton
KWT	Kuwait
LAO	Lao PDR
LBN	Lebanon
LBR	Liberia
LBY	Libya
LKA	Sri Lanka
LSLA	Large-Scale Land Acquisitions
LSO	Lesotho
LTU	Lithuania
LUX	Luxembourg
LVA	Latvia
MAP	Mean Annual Precipitation
MAR	Morocco
MDA	Moldova
MDACE	Mpumalanga. Department of Agriculture, Conservation and Environment
MDG	Madagascar
MDGs	Millennium Development Goals
MDV	Maldives
MENA	Middle East and North Africa
MEX	Mexico
MKD	Macedonia, FYR
MLI	Mali
MLT	Malta
MMR	Myanmar
MNE	Montenegro
MNG	Mongolia
MOZ	Mozambique
MRT	Mauritania
Mt	Mega-tons
MUS	Mauritius
MW	Megawatt
MWI	Malawi
MYS	Malaysia
NAM	Namibia
NER	Niger
NGA	Nigeria
NGO	Non-Governmental Organisation
NIC	Nicaragua

NLD	Netherlands
NOR	Norway
NPL	Nepal
NZL	New Zealand
OECD	Organisation for Economic Co-operation and Development
OMN	Oman
PAK	Pakistan
PAN	Panama
PER	Peru
PHL	Philippines
PISA	Programme for International Student Assessment
PNG	Papua New Guinea
POL	Poland
PRK	Democratic People's Republic of Korea,
PRT	Portugal
PRY	Paraguay
PV	Photovoltaic
QAT	Qatar
ROU	Romania
RUS	Russian Federation
RWA	Rwanda
SABMiller	South African Breweries Miller
SADC	Southern African Development Community
SADCC	Southern African Development Co-ordination Conference
SAU	Saudi Arabia
SAPP	Southern African Power Pool
SDG	Sustainable Development Goals
SDN	Sudan
SDP	Spatial Development Plan
SEI	Stockholm Environmental Institute
SEN	Senegal
SGP	Singapore
SHP	Small Hydropower Plants
SIM4NEXUS	SIM4NEXUS is an EU-funded project: https://www.sim4nexus.eu/
SLB	Solomon Islands
SLE	Sierra Leone
SLV	El Salvador
SRB	Serbia
SSD	South Sudan
SSEG	small-scale embedded generation
STP	Sao Tome and Principe
SUR	Suriname
SVK	Slovak Republic
SVN	Slovenia
SWE	Sweden

SWSA	Strategic Water Source Area
SWZ	Swaziland/Eswatini
SYR	Syrian Arab Republic
TCD	Chad
TGO	Togo
THA	Thailand
TJK	Tajikistan
TKM	Turkmenistan
TLS	Timor-Leste
TTO	Trinidad and Tobago
TUN	Tunisia
TUR	Turkey
TWh	Terawatt Hour
TZA	Tanzania
UAW	Unaccounted for water
UGA	Uganda
UK	United Kingdom
UKR	Ukraine
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Emergency Fund
URY	Uruguay
US	United States
USA	United States of America
UZB	Uzbekistan
VEN	Venezuela, RB
VIP	Ventilated improved pit latrine
VNM	Vietnam
VUT	Vanuatu
WASH	Water, Sanitation and Hygiene
WCEP	Water consumption for electricity production
WEF	Water-Energy-Food
WEFDIS	W-E-F Nexus Data and Information System
WEForum	World Economic Forum
WHO	World Health Organisation
WMA	Water Management Area
WSM	Samoa
WWF	World Wide Fund for Nature
WWF-SA	World Wide Fund for Nature - South Africa
YEM	Republic of Yemen
ZAF	South Africa
ZMB	Zambia
ZWE	Zimbabwe

CHAPTER 1: INTRODUCTION

1.1 Background

Before the industrial revolution, the world's population was predominantly rural and stable in terms of numbers, estimated to be 470 million in 1650 (UN 1951). Following the industrial revolution, the world's population grew to over one billion by 1850, approximately 1.5 billion by 1900, and exceeded 2.4 billion in 1950 (UN 1951). By 2005 the global population reached 6.5 billion (Bongaarts 2009), and in 2019 it exceeds 7.7 billion people. By the middle of the current century, it is estimated it will extend to 9.7 billion (Gerland et al. 2014). Together with this exponential growth in the worldwide population, demand for resources such as metals, building materials, energy, agricultural products, and water also snowballed.

Despite there being a stark disparity in the distribution of wealth as nations developed, researchers started to realise that there are limits to anthropogenic progress (Meadows et al. 1972). People recognised that resources such as agricultural land, minerals and water are finite. Various indicators were developed to monitor aspects related to economics, development, the environment and sustainability. The required data was, and is, collected by national statistical offices, development organisations and research institutions. The Gross Domestic Product (GDP) was one of the first indicators that was widely utilised.

Later, composite indicators were developed to understand systems. A composite indicator is formed "when individual indicators are compiled into a single index on the basis of an underlying model" (OECD 2008). In 1990, for example, the Human Development Index (HDI) was developed by Pakistani economist Mahbub ul Haq to provide a more comprehensive representation of wellbeing than the GDP. He included indicators of health and education with the natural logarithm of the Gross National Income (GNI) per capita. The creation of the HDI was based on the premise that human development should focus on the three essential elements of human life; namely longevity, knowledge and decent living standards (UNDP 1990). Although the method of calculating the HDI has changed with time, it has served as a valuable tool for the United Nations Development Programme (UNDP) and other organisations in evaluating developmental progress in the many countries and regions under their jurisdiction.

Some composite indicators, in contrast to the HDI, are relatively complex. The Environmental Sustainability Index (ESI), for example, integrates 76 datasets into 21 indicators, which are subsequently condensed into a single index (Esty et al. 2005). The ESI serves as a policy tool for identifying issues that deserve focused attention within national environmental protection programs and across societies more generally (ibid.).

Many composite indicators, or indices, have been developed in the last three decades. Some groupings, for example, advocacy groups, view composite indicators as a valuable tool to further their causes. Others, such as cautious professional statisticians, are wary of composite indicators due to the potentially subjective nature of the selection of the constituent indicators, the method of aggregation, and the weighting of the indicators. Because composite indicators are not universally accepted, they must be developed transparently and used responsibly.

The core outcome of this research project is the development of a composite indicator to reflect the status and interlinkages of water, energy and food access and supply at a global level. This research has been conducted using the revised ten steps[2] set out by the Joint Research Centre's (JRC) *Competence Centre on Composite Indicators and Scoreboards (COIN)* (Saisana et al. 2018).

1.2 The water-energy-food nexus approach

Following the 2008 financial crisis, concerns were raised that if finite resources such as water are not effectually managed, then the environment, livelihoods and economic development will be adversely impacted. The interdependency of water, energy and food security was also highlighted, and since 2011 significant attention has been given to the Water-Energy-Food (WEF) nexus in the academic, policy, regulatory and development fraternities. The *Bonn2011 Conference* (Hoff 2011) and the World Economic Forum's publication of *Water Security: The Water-Food-Energy-Climate Nexus* (World Economic Forum 2011) were especially influential in this regard.

The WEF nexus is a lens through which to assess sustainable development and integrated resource management. The word *nexus* means to 'connect' (De Laurentiis et al. 2016). The view that water resources, energy generation and food production are interdependent is not novel (Allouche et al. 2015, Muller 2015, Wichelns 2017). Sušnik (2018) argues that the earliest global study on a nexus was the publication *The Limits of Growth*. In this book, Meadows et al. (1972) state that "If the present growth trends in world population, industrialisation, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years." That study, compiled during the 'Great Acceleration'[3], assessed the exponential growth in the global population and the demand for resources since the onset of the industrial revolution. Many researchers at that time were concerned about the ultimate cost of development. Schaeffer (1970), for example, stated that "if man is not able to solve his ecological problems, then man's resources are going to die."

The study of a nexus configuration - such as the WEF nexus - assesses the individual components of the system, their interactions and linkages, as well as synergies and trade-offs

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[2] The ten steps are: Developing the framework; Selection of indicators; Data treatment; Normalisation; Weighting; Aggregation; Statistical coherence; Robustness and sensitivity; Back to the data; and Visualisation and communication.

[3] The 'Great Acceleration' refers to the second half of the twentieth century during which the rate of impact of human activity upon the Earth increased significantly.

that exist between them. The interactions include water for food (e.g. irrigation) and water for energy (e.g. cooling in a power plant), energy for water (e.g. pumping and treating water) and energy for food (e.g. ploughing of land or transporting agricultural produce), and food for energy (e.g. bioenergy). The UN World Water Assessment Programme (2014) explained that "A nexus approach to sectoral management, through enhanced dialogue, collaboration and coordination, is needed to ensure that co-benefits and trade-offs are considered and that appropriate safeguards are put in place."

The process that led to the compilation of the Sustainable Development Goals (SDG) originated at the Rio+20 conference in Brazil in 2012 (Griggs et al. 2013). At this meeting, it was concluded that the Millennium Development Goals (MDG) were outdated and that the SDGs would build upon the original goals but would be more comprehensive and would involve a more inclusive participatory process. One hundred and ninety-three countries adopted the SDGs in September 2015 at the UN Sustainable Development Summit. The 2030 Development Agenda titled *Transforming our world: the 2030 Agenda for Sustainable Development* outlined 17 goals, 169 targets and 232 indicators (Schmidt-Traub et al. 2017). The most noticeable difference between the MDGs and SDGs is that the latter's aim favours collective action with universal goals as opposed to the MDGs that focused on donor-recipient relationships where richer countries would aid poorer countries (Melamed and Scott 2011). Unlike the MDGs, the SDGs include an SDG that specifically addresses energy (SDG 7). Along with SDG 7, SDGs 2 (zero hunger) and 6 (clean water and sanitation) directly relate to the WEF nexus, with SDGs 12 (responsible consumption and production), 13 (climate action), 14 (life below water) and 15 (life on land) also being indirectly related to the nexus.

1.3 Rationale for the research

A principal reason for utilising the WEF nexus as a lens for assessing sustainable development and integrated resource management is the critical importance of these three resources and the linkages between them. In this regard, the following bulleted percentages present global estimates of the proportion that each WEF nexus sector supplies or obtains from the adjacent sector (the reuse of a resource may occur in selected cases, for example, water runoff from agricultural lands may be utilised downstream for power generation or domestic consumption, or vice versa):

- The agricultural sector utilises 71% and 30% of the global water withdrawals and energy, respectively (Mohtar and Daher 2012, FAO 2014).
- One-third of all food produced globally is either lost or wasted (IRENA 2015).
- 10% of the globally available freshwater is utilised in energy production (WWAP 2020) while domestic uses constitute 14% of water utilisation (World Economic Forum 2011).
- The bioenergy sector utilises 1% of all food produced (Garcia and You 2016).
- In 2011, only 13% of the energy generated globally originated from renewable sources (Hoff 2011).

- 4% of all energy generated is utilised for the abstraction, conveyance and treatment of water (WWAP 2020), while total industrial withdrawals account for 16% of today's global water demand (World Economic Forum 2011).

These percentages indicate the profound interdependence of the constituent sectors within this nexus arrangement. Approximately 86% of the globally available freshwater is used either for food production or energy generation. That a third of food is wasted or lost indicates a significant loss of 'virtual'[4] water and energy used in agricultural production. Water shortages as a result of climate change, which are predicted for regions such as Southern Africa (Conway et al. 2015, Scholes et al. 2015) will threaten both food production (and prices) and energy generation (particularly in countries that are highly dependent on hydropower generation). The use of food to generate energy (i.e. bioenergy) can lead to an ethical dilemma, particularly in countries that experience appreciable levels of undernourishment, stunting and wasting.

Not only are there deep-rooted interdependencies between the three resource sectors within the WEF nexus, but the demand for each one of these is projected to continue to increase in the coming decades. The National Intelligence Council (2012) predicted that the global demand for water, energy and food in 2030 would grow by approximately 40, 50 and 35% respectively. Beddington (2009) projected similar increases in demand for these resources. These noteworthy increases are due to the unrelenting upsurge in the world's population, as well as a marked increase in urbanisation, and the burgeoning middle class with its associated 'Western' consumption patterns. Not only must the demand be managed, but the supply too must be actively controlled. Salam et al. (2017) argue that "The gap between future availability and demand can be closed not through the discovery of more water supplies but through effective demand-side management, which will need effective policy interventions."

Another reason for utilising the WEF nexus approach is that it is multi-centric, with each sector being treated with equal importance (Abdullaev and Rakhmatullaev 2016, Gallagher et al. 2016, Benson et al. 2017, Liu et al. 2017). Integrated Water Resources Management (IWRM), which is viewed as being water-centric, is frequently contrasted with nexus-based methods. IWRM has met with varying levels of success (de Loe and Patterson 2017), with some arguing that it is insufficient as a stand-alone tool (Bogardi et al. 2012). One goal of nexus approaches is that the trade-offs resulting from policy development in institutional 'silos' will be reduced (Belinskij 2015). Further, synergies between the resource sectors can be exploited.

A further reason for pursuing the WEF nexus is that it is a mechanism for achieving the relevant sector-related SDGs, i.e. SDGs 2 (Zero Hunger), 6 (Clean Water and Sanitation), and 7 (Affordable and Clean Energy). In the *SDG Index and Dashboard Report 2018*, it is astutely noted that "no country is on track to achieve all the goals by 2030" (Sachs et al. 2018). In this

[4] Virtual water circulates in the international economic system as an embedded ingredient of food and other globally traded products. It is the equivalent volume of water that was utilised in the production of that food or product, that is in essence 'virtually' exported with the food or product.

report, it is highlighted that while Sweden, Denmark and Finland have the best SDG Index ratings, these nations must more purposefully pursue goals such as SDG 12 (Sustainable Consumption and Production) and SDG 13 (Climate Action) if they are to achieve them within the prescribed target timeframe (ibid.).

A question posed during the workshop "Water-Energy-Food Nexus and its linkages to the implementation of the SDGs" held in Hilton, South Africa in November 2016 birthed the concept of developing a composite indicator related to the WEF nexus. The question raised was "How can we measure the nexus?" This question relates to the desire to understand a system that has components measured in different units (e.g. m^3, kWh and calories) that occur at different spatial and temporal scales. The development of a composite indicator, therefore, requires that its constituent indicators be normalised before they can be aggregated (OECD 2008).

Does the SDG Index (Sachs et al. 2016), which incorporates (amongst others) SDGs 2, 6 and 7, render the WEF Nexus Index redundant? El Costa (2015) suggested that since the SDGs seek to incorporate multiple development goals, identifying targets *at the nexus* of various sectors will be instrumental in yielding a more straightforward SDG framework. There is, therefore, a compelling argument in favour of developing an indicator framework for a *subsystem* within the SDGs, such as the WEF nexus. Boas et al. (2016) agree, arguing that "novel ways of cross-sectoral institutionalisation" are required if the *2030 Agenda for Sustainable Development* is to be attained.

1.4 Aims

The purpose of this research is to fulfil each of the following aims:

- Provide a review of the development of the WEF nexus as a framework for achieving resource security.
- Assess the status quo of thinking within the WEF nexus research and policy development fraternity in terms of its relevance, maturity and level of implementation,
- Develop a conceptual framework, with a focus on inclusivity for developing countries, for guiding the development of the WEF Nexus Index. Further, apply the WEF nexus at a sub-national scale within a developing country, utilising indicators to guide the assessment. This study will form part of the process of developing a global study.
- Present the development and application of a WEF nexus-based dashboard and composite index.

The hypothesis is: *There is sufficient, relevant water-, energy- and food-related indicator data to develop a global, country-level WEF nexus-based composite indicator that can be utilised as a means for assessing integrated resources management and informing policy*.

This thesis has been developed in accordance with the University of KwaZulu-Natal's College of Agriculture, Engineernig and Sciences's *Essential requiremetns for the preparation of dissertations and theses*. As such, some repetition within the content is inevitable but this has been minimised as far as possible. The following bullet points provide an overview of the content of this thesis:

- Chapter 2 provides a review of concepts and theory related to the WEF nexus that have been published in academic articles and grey literature over the last decade. It presents a literature review of the development of the WEF nexus as a framework for achieving resource security.
- Chapter 3 sets out the "state of the art" current opinion of the WEF Nexus in recent publications. It is an extension of the literature study provided in Chater 2, but with an emphasis on how much the concept has developed to date, and how it needs to evolve if it is to gain greater traction.
- Chapter 4 presents a WEF nexus case study for the province of Mpumalanga in South African. The area is assessed utilising national and provincial geographic information system (GIS) and statistical databases, together with a review of relevant academic and grey literature publications.
- In Chapter 5, the findings of the previous three sections are assessed to develop a conceptual framework to guide the creation of a composite indicator related to the WEF Nexus. The proposed anthropocentric framework emanates from a developing country perspective to support resource security *for all*.
- In Chapter 6, the development of the WEF Nexus Index, with global application, is presented. Additional methodological information, and a presentation of untreated data, is provided in various addendums to this thesis.
- Chapter 7 presents the application of the WEF Nexus Index to the SADC region. This was a vital outcome of this research, as evidenced by the thesis' title.
- Chapter 8 sets out reflections, conclusions and recommendations for further application of WEF nexus and index. A statement of whether this body of research has supported the hypothesis is made.

CHAPTER 2: THE DEVELOPMENT OF THE WATER-ENERGY-FOOD NEXUS AS A FRAMEWORK FOR ACHIEVING RESOURCE SECURITY: A REVIEW

2.1 Introduction

Meadows et al. (1972) warned almost half a century ago, “If the present growth trends in world population, industrialisation, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years.” Some three decades later they stated that “the human economy is exceeding important limits now and that this overshoot will intensify greatly over the coming decades” (Meadows et al. 2004). Much of the criticism levelled against their work in the early 1970s was due to their graphs not having values on the y-axis, yet the data gathered in the subsequent decades validated their research. Just a few years after the 2004 publication, average world food prices increased significantly, leaving a large portion of the global population unable to afford their basic nutritional needs (Mohtar and Daher 2012). These increased food prices are an indication of growing natural resource scarcity (Ringler et al. 2013).

The finite and indispensable nature of freshwater also came to the fore during the first decade of the twenty-first century. In their 2011 publication, *Water Security: The Water-Food-Energy-Climate Nexus*, the World Economic Forum highlighted that in many locations around the globe, water has been consistently under-priced, groundwater has been depleted, and that unlike energy, water has no substitutes or alternatives (World Economic Forum 2011). However, Sachs (2015), states that “Of all of the problems of reconciling growth with planetary boundaries, probably none is more urgent and yet more complicated than the challenge of the world’s energy system.”

Projections are that the global demand for resources is going to escalate on this “hot, hungry, crowded, and fast evaporating planet” (World Economic Forum 2011). The National Intelligence Council (2012) estimate that the growth in demand for food, water and energy by 2030 will be 35, 40 and 50 percent respectively. This is due to an increasing population, urbanisation, and an additional three billion middle-class people by 2030 (WWF and SABMiller 2014). There is also a dire need to enhance the livelihoods of the ‘bottom billion’ who are undernourished, without access to electricity and clean water (IRENA 2015).

Speaking on *World Water Day* in March 2011, the then Secretary-General of the United Nations, Ban-Ki Moon, noted that the interconnects between water, energy and food are among the greatest challenges that mankind faces. In November of that year, the *Bonn2011 Conference: Water Energy and Food Security Nexus – Solutions for the Green Economy* was convened. That meeting served as a catalyst for wider interest in the water-energy-food (WEF) nexus amongst academics, policy makers, national and international development agencies and donor countries. While some authors suggest that the WEF nexus has traits of a ‘nirvana concept’, others have identified several shortcomings in nexus thinking, labelling it as an immature approach (Allouche et al. 2015).

In this review search terms related to the paper’s title were entered into the EBSCOhost, Web of Science, Science Direct and Wiley Online databases. These searches yielded 111, 212, 135 and 53 results respectively, i.e. a total of 511 academic papers. After removing duplicates

(104), articles were excluded based on a review of their titles (284) and abstracts (38). A further 32 articles were subsequently excluded during a full screening of the texts, yielding 53 academic articles that have contributed to this literature review. Fourteen grey literature sources that were identified during the review of the academic articles were subsequently included in the literature review process. This methodology was followed to remove bias, as far as possible, from the selection of academic and grey literature for inclusion in the compilation of this manuscript.

This paper initially examines what is understood by the term 'WEF nexus'. It continues to provide an analysis of whether the WEF nexus is a unique approach, or if it is simply a repackaging of an existing framework (even though a "repackaging" would not necessarily imply irrelevance). The challenge of integrating and optimising these three resource sectors, together with their trade-offs and synergies, is subsequently presented together with four case studies. Thereafter, one of the key criticisms levelled at the WEF nexus is considered, namely, whether the resource security goal of the WEF nexus, which the global economic community is seen to be driving, accommodates the environment and livelihoods. Finally, the possible benefits of the WEF nexus approach in terms of policy development and governance are reviewed.

2.2 What is the WEF nexus?

The word 'nexus' means "to connect" (De Laurentiis et al. 2016). This word conveys the interactions between two or more elements, be they dependencies or interdependencies. The WEF nexus is, therefore, the study of the connections between these three resource sectors, together with the synergies, conflicts and trade-offs that arise from how they are managed, i.e. water for food and food for water, energy for water and water for energy, and food for energy and energy for food (Bazilian et al. 2011, Allouche et al. 2015, Leese and Meisch 2015, Smajgl et al. 2016, Kurian 2017, Albrecht et al. 2018, Cai et al. 2018).

Some authors argue that there is little agreement on the WEF nexus' composition, contending that there are many competing (and often overlapping) conceptions (Benson et al. 2015, Al-Saidi and Elagib 2017). Others suggest that the term can be viewed as a 'buzzword', i.e. a word that gains prominence due to "a combination of ambiguous meaning and strong normative resonance" (Cairns and Krzywoszynska 2016). Gain et al. (2015) report that many developing countries are not even aware of the WEF nexus. Cairns and Krzywoszynska (2016) found that within natural resource discussions in the United Kingdom, the understanding and usage of the term 'WEF nexus' is "plural, fragmented, and ambiguous". Their concern is that the broad use of the term could trivialise its importance.

Wichelns (2017) states that the selection of water, energy and food as the principal components of a nexus framework for guiding research and policy, although initially appealing, is somewhat arbitrary. Liu et al. (2018) note that while the energy sector speaks of the *energy*-water-food (EWF) nexus, hydrologists and water engineers call it the *water*-energy-food (WEF) nexus, while those in the agricultural fraternity use the term, the *food*-energy-water (FEW) nexus. Based on this variance in terminology, it is evident that the conceptual approach to the WEF nexus is generally dependent upon the perspective of the particular researcher or policy-maker (Bazilian et al. 2011). Allouche et al. (2015) agree that the term can mean different things to different people, arguing that while some consider the WEF nexus scope to be too narrow, excluding for example climate change and the environment, other authors view it as being relatively broad and link it to the green economy, poverty reduction and global resource security (Pandey and Shrestha 2017).

The World Economic Forum's primary area of concern regarding the WEF nexus was initially water security, hence it is termed by some as the WEF *security* nexus. Different groupings who have embraced the WEF nexus approach have contrasting foci, e.g. sustainability, the green economy, trade-offs, livelihoods, climate, optimisation, modelling or scarcity. Pahl-Wostl (2017) explains that the WEF nexus was strongly focused on resource security during the first four years after the *Bonn2011 Conference*, but since then the concept's use has broadened to address interdependencies and integration to achieve the sustainable management of resources.

While there is disagreement on what the term 'nexus' means, this is not the first term that the academic and development community has struggled to define. Meadows et al. (2004) note that sixteen years after the Brundtland Commission mainstreamed the concept of sustainability (Brundtland 1987) the global society was still trying to agree on what the term meant.

The debate regarding the nexus's precise meaning and application indicates that it is still an evolving concept (Allouche et al. 2015, Pandey and Shrestha 2017). While there are differing interpretations of this framework, de Loe and Patterson (2017) suggest that what is paramount is 'nexus thinking', as opposed to a specific strict definition of the WEF nexus.

2.3 Is the WEF nexus concept novel?

Many authors question whether the WEF nexus approach is novel (Allouche et al. 2015, Benson et al. 2015, Muller 2015, Wichelns 2017). The FAO (2014), for example, query whether the concept is just the "same old wine in new bottles", or if it contributes something new to the sustainable development discourse. It is also questioned whether the nexus is complete with only three sectors being represented. Climate change, the environment, land, governance, urbanisation, waste or livelihoods are some of the other components that could be, and are, assessed together with the trio of sectors that make up the WEF nexus. To this end, Wichelns (2017) questions the selection of the three resource sectors in the WEF nexus and the widespread recognition that the concept is receiving, noting that it is not yet an agreed and tested framework.

Benson et al. (2015) argue that many of the ideas presented in the nexus philosophy already appeared in other strategies which entered policy discourses in the 1990s. When sustainable development was first proposed, it was stated that population growth, food security, energy, the environment and urban development "are connected and cannot be treated in isolation one from another" (Brundtland 1987).

Muller (2015) explains that the 1977 United Nations conference proceedings reveal that the world at that time was fully cognisant of the interdependencies between water, food and energy. This is evident when reading the seminal work, *The Limits to Growth,* wherein it is highlighted that the five major areas of global concern identified "are all interconnected in many ways" (Meadows et al. 1972).

Cai et al. (2018) note that since the Harvard Water Program in the early 1960s there has been a drive to address water research utilising an interdisciplinary approach. Wichelns (2017) reports that the need for greater integration of research and policy discourse across sectors and regions was expressed in international meetings as early as the late 1940s. In terms of the interconnected nature of all subjects of study in the biosphere, Muir (1911) stated that "When we try to pick out anything by itself, we find it hitched to everything else in the universe." There is truly 'nothing new under the sun.'

If the WEF nexus is not novel, then why has there been so much interest in the approach from organisations such as the World Economic Forum, the World Wide Fund for Nature, the United Nations and companies like The Coca-Cola Company and SABMiller? Wichelns (2017) suggests that much of the interest in the nexus is as a result of the concern of the impact of climate change on water, energy and food security. Rasul and Sharma (2016) are in agreement, noting that all three resource sectors are influenced by climate change and that they, in turn, each contribute to that impact as a result of their discharges and/or emissions. Pandey and Shrestha (2017) contend that the concept of the WEF nexus has gained prominence as a contemporary way to understand and approach sustainable development.

In terms of the governance of water, one framework that was formalised in the early 1990s was Integrated Water Resources Management (IWRM). IWRM was initially embraced as the silver bullet of sustainable development because of its integrated analysis of sectors and resources (Kurian 2017). The United Nations included IWRM as a component of the Millennium Development Goals (MDGs) (Benson et al. 2015). Bogardi et al. (2012), however argue that IWRM on its own is insufficient. Benson et al. (2015) suggest that the WEF nexus framework exhibits some innovative elements, such as holistically integrating different policy sectors, and contend that it could be highly complementary to IWRM.

While several authors argue that the interdisciplinary nature of the approach is not new, the primary reason for promoting the WEF nexus approach above that of IWRM is that it is multi-centric, with each sector being treated with equal importance, while IWRM is water-centric (Allouche et al. 2015, Benson et al. 2015, Abdullaev and Rakhmatullaev 2016, Gallagher et al. 2016, Al-Saidi and Elagib 2017, Liu et al. 2017, Owen et al. 2018). Cai et al. (2018) suggest that the WEF nexus may be accepted by a broader set of stakeholders than IWRM, especially those within the agricultural and energy sectors.

2.4 Integrating and optimising the WEF nexus

Some critics of the WEF nexus argue that the analysis of one resource sector is sufficiently complex, suggesting that integrating multiple resource sectors simultaneously poses an appreciable challenge (de Loe and Patterson 2017). Wichelns (2017) concurs, contending that given the lack of success in implementing Integrated Natural Resource Management (INRM) and IWRM in practice, another call for integration should be questioned. It has, however been suggested that the critique of IWRM is well-founded because it is perceived to underestimate the importance of administrative boundaries, with its focus being hydrological catchments (Kurian 2017). de Loe and Patterson (2017) contend that IWRM has failed to achieve the goals for which it was intended. Abdullaev and Rakhmatullaev (2016) agree, stating that the active promotion of the nexus approach could assist in solving the IWRM's "water box problem." Belinskij (2015) argues for utilising a nexus approach since it removes the institutional 'silos' that are so prevalent in governance and policy circles.

Leck et al. (2015) warn that the multi-sector goal of the WEF nexus, with its associated trade-offs and interdependencies, could result in its downfall. They warn that although the nexus concept is attractive, it is challenging to implement. Yet, Wicaksono et al. (2017) argue that the fundamental notion of the WEF nexus has already been adopted in some regions and countries, although not necessarily under the banner of this framework itself. Daher et al. (2017), while acknowledging the complexity of modelling the nexus (i.e. computer-based modelling), emphasise that there isn't a one-size-fits-all model to address WEF-related issues. They continue to describe how localising and contextualising a nexus assessment will be vital to addressing trade-offs. An example of the localising and contextualising of the WEF nexus at a sub-national level is provided in the following case study.

Case Study 1:

The province of Mpumalanga in South Africa is the energy hub of the country. It is the source of significant coal resources and most of the fossil-fuel-based power stations that burn much of the coal. However, "South Africa has only 1.5% high potential arable soils (soils best suited for cash crop production), and 46.4 % of this total area is in Mpumalanga" (BFAP 2012). The development of coal mines, especially opencast operations, is continually reducing the area of high potential arable soils in South Africa (Simpson and Berchner 2017). The continued pursuit of fossil-fuel-based energy dependency in South Africa is, therefore, threatening food security. It is also negatively impacting upon air pollution (Greenpeace 2018) and water quality (McCarthy 2011). A WEF nexus-based assessment of South Africa indicates that policy related to the accelerated implementation of renewable energy generation must be adopted if the nation is to move towards a low-carbon, sustainable future.

Another challenge for WEF nexus analyses stems from globalisation. The liberalisation of trade has meant that the interactions between water, energy and food are very complex since materials and products are continually crossing international borders (Owen et al. 2018). Water moves between countries as an embedded component of food and other products as 'virtual water' (Bogardi et al. 2012). Closely linked to the concept of virtual water is large-scale land acquisitions (LSLAs). In order to secure their essential resources, several developed countries (e.g. the United Kingdom and Italy) have pursued LSLAs, predominantly in developing countries, such as Guinea, Sierra Leone and Mozambique (Siciliano et al. 2017). These LSLAs are ultimately concerned with gaining access to land and water for energy (i.e. biofuel) and food production. What is concerning is that malnutrition and economic water scarcity often exist in countries where LSLAs have occurred. In so doing the wealthier nations, in seeking to secure resources for themselves through LSLAs, reinforce the concerns of several authors regarding the securitisation agenda, i.e. that livelihoods of the poorer members of the global society are neglected in the developed world's pursuit of macro-scale resource security.

Quantifying the movement of virtual water between nations and regions isn't the only challenge. Liu et al. (2017) suggest that the scientific challenge associated with the WEF nexus is primarily related to the myriad of data required to undertake the necessary analyses. Further, water, energy and food are measured in different manners, with each having their own units of measurement.

In addition to the data and integration challenges associated with the WEF nexus, there are multiple spatial and temporal scales within which this framework can be viewed. These scales influence each other (Garcia and You 2016). In terms of the spatial extent, a WEF nexus assessment could be undertaken at a city, basin, national, regional or global level. An example of a regional assessment is provided in "Case Study 2". Although Muller (2015) questions the novelty and completeness of the WEF nexus, it is argued that what the WEF security framework does do is that it moves the spotlight of water resources management "from watersheds to problem-sheds, from what society should do for water to what water can do for society."

Case Study 2:

With less than 5% of the world's land area, South Asia has to feed about one-quarter of the global population (Rasul 2016). To ensure food self-sufficiency, many South Asian countries have adopted policies that encourage farmers to increase food production, including the provision of subsidies for irrigation, energy and fertilisers, and the guarantee of minimum prices for wheat and rice. This has resulted in an alarming rate of decline in groundwater levels since these subsidies have discouraged farmers from being efficient in their use of both water and energy. "Thus, a nexus 'no-brainer' is to review and identify candidates for the phase-out of subsidies on water, energy, land and food" (Ringler et al. 2013). Current water and energy charges are often too low to affect behaviour. The irony is that by providing water and energy for agriculture at a low cost, water security for agriculture (i.e. groundwater availability) can itself ultimately be threatened, which could threaten future food security.

Regarding the temporal nature of a WEF nexus study, an instantaneous 'snapshot' of the status of a WEF system could be developed (multiple snapshots can, in turn contribute to the understanding of the temporal nature of the nexus). Alternatively, the metabolism of a city could be provided over a period, such as a month or a year. A further challenge related to seeking to optimise the WEF nexus is that a researcher could focus on human needs, trying to attain an equilibrium, while neglecting environmental considerations, climate change or poverty alleviation.

Although much of the literature associated with the WEF nexus is dismissive of the 'silo' approach to resource management, some argue that 'the baby should not be thrown out with the bathwater.' Wichelns (2017), for example, notes that there are times when an in-depth study within a particular discipline is required. Artioli et al. (2017), however, suggest that the momentum the WEF nexus approach has attained within policy circles will be difficult to curtail.

2.5 Does the WEF nexus address resource security for all?

Gupta (2017) contends that the WEF nexus is a security nexus for societal well-being. Indeed, Hoff (2011) in the background paper for the *Bonn2011 Conference* highlighted the "need to secure local livelihoods and the non-negotiable human rights to water and food." Wichelns (2017) however, argues that livelihoods are often omitted in WEF nexus analyses, even though the poorest members of the global society are often impacted most severely by the policy changes that emanate from a nexus approach. This is because the achievement of food security at the household, city, provincial or country-level is more complex than balancing supply and demand on a macro-scale (Grafton et al. 2016).

There is an emerging resource security focus utilising the WEF nexus as the guiding framework which is motivated by the possibility that economic growth will soon be constrained by shortages of one or more of the sectors constituting this nexus (Salam et al. 2017). There has also been an increasing focus on water security within the private sector during the past decade (Leck et al. 2015), and Green et al. (2017) note that the private sector is often influential in decisions appertaining to the provision and management of water, energy and food.

Spiegelberg et al. (2017) agree that there is a general economic motivation behind the WEF nexus, explaining that the literature focuses primarily on three fields of global growth, namely, the increase in population, urbanisation, and the burgeoning middle class in developing countries with their 'Western' consumer demands. Biggs et al. (2015) go further, stating categorically that nexus frameworks have neglected to adequately incorporate livelihoods into their thinking, i.e. resource security *for all*. They suggest that this is counterintuitive since supporting livelihoods is implicit in the attainment of sustainable development. This relegation of livelihoods is in conflict with one of the three guiding principles of the WEF nexus philosophy highlighted at the *Bonn2011 Conference*, which is that people and their basic human rights must be the basis of this approach (Salam et al. 2017).

Leese and Meisch (2015) suggest that whereas sustainability has historically focused on distributional justice, it is now often viewed in terms of resource security. The risks associated with the unavailability of water, energy and food have become a global concern (World Economic Forum 2011, National Intelligence Council 2012). Leese and Meisch (2015) argue that the WEF nexus' focus on securitisation, i.e. the security agenda centred on the risk of non-supply, is one that is driven by economic considerations, not the challenges related to livelihoods, which has traditionally been within the ambit of sustainable development. Further, they contend that the sustainability focus on equitable access to resources is being usurped by the threat to global productivity and living standards.

In summary, the concern of these authors is that sustainability is being securitised, i.e. one component of sustainable development is being focused upon to the detriment of the other components. The belief is that the World Economic Forum is spearheading this agenda and that improved macro-scale food security will not *ipso facto* result in a reduction in the prevalence of undernourishment, i.e. SDG 2. Nor will improved water security at a national level necessarily lead to an increase in the levels of access to clean water and improved sanitation facilities, i.e. SDG 6. Biggs et al. (2015) explain that 'security' should not refer only to the availability of resources, but also to universal access to them. The quality of these resources is an additional dimension.

Salam et al. (2017), however, contend that the amalgamation of water, energy, and food in a nexus framework to increase resource efficiency can be considered as a necessary way to achieve the SDGs. Rasul and Sharma (2016) agree, stating that the nexus outlook can assist in aligning the SDGs with planetary boundaries. The SDGs provide a basis upon which the WEF nexus can be developed (Gallagher et al. 2016).

To sustainably achieve resource security for all, the integrity of ecosystem services and the associated resource base must be maintained while access to resources is expanded and consolidated. This is presented schematically in Figure 3-1, where all the SDGs are directly or indirectly connected to food. Rockström and Sukhdev (2016), who developed this illustration, propose that the goals for eradicating poverty (SDG 1) and hunger (SDG 2) require gender equality (SDG 5), adequate jobs (SDG 8) and a decrease in inequality (SDG 10).

Ringler et al. (2013) explain that assessments utilising a nexus approach must consider both livelihoods and the environment. de Grenade et al. (2016) comment that while the 'nexus' has various key strengths, it fails to adequately acknowledge the environment as its irreplaceable foundation. Planetary boundaries are however being threatened (Rockstrom et al. 2009). The challenge is to develop policies that support the sustainability of water, energy and food resources, while simultaneously providing access to these resources for all levels of society.

Achieving sustainability necessarily requires that the protection of the environment be prioritised.

2.6 Governance considerations associated with the WEF nexus

It could be said, "let us eat, drink, spend, extract and pollute, and be as merry as we can, and let posterity worry about the spaceship earth" (Boulding 1966). A philosophy such as this would fly in the face of sustainable development, which calls us to ensure that the needs of the current generation are not met in a manner that compromises the ability of our children to meet their own needs (Brundtland 1987). Achieving a profound goal such as this, requires a practical, holistic framework, and strong governance. Al-Saidi and Elagib (2017) suggest that a governance focus is a missing ingredient in the nexus debate.

Governance of the WEF nexus includes a wide range of private and public systems that manage the supply and demand of water, energy and food (Pahl-Wostl 2017). Providing access to improved water sources, sanitation facilities and electrification is viewed by most citizens as a barometer of good governance and is reflected in both the MDGs and SDGs. Benson et al. (2017) argue that governing for the nexus occurs when the integration of resource sectors is actively pursued, such that synergies between water availability, energy generation and food production are enhanced, while trade-offs are managed, and potential conflicts are averted. An example of the management of a WEF nexus trade-off and the dissipation of a potential international conflict is demonstrated in "Case Study 3". Although the WEF nexus approach has gained significant momentum since 2011, it is however, not yet widely adopted in either policy or development planning (Wicaksono et al. 2017).

Case Study 3:

In a WEF nexus assessment of the Mekong basin, it was determined that significant growth in the capacity and supply of power through hydropower developments could, amongst other impacts, reduce fish stocks and fish diversity, as well as the availability of water to downstream users (Smajgl et al. 2016). A policy of managing energy demand, as opposed to a focus on energy supply and capacity alone, could reduce the negative impacts of hydropower on food and water security within this large river basin. This policy intervention recommendation would probably not have been arrived at if a single-sector energy assessment, as opposed to a WEF nexus assessment, was undertaken.

Rasul and Sharma (2016) state that the nexus framework and climate change adaptation share aims and principles. Rasul (2016) suggests that one mechanism for enabling a policy framework for managing nexus challenges is to strengthen the role of the national planning commissions in the countries being assessed. This is necessary even in developed countries. Sharmina et al. (2016), for example, notes that most of the United Kingdom's land-use policies are compartmentalised, with the administration of the sectors occurring in silos.

Schreiner and Baleta (2015) in turn report that the 'nexus' philosophy is becoming an important component of development planning, with synergies existing across international boundaries within a region. Ololade et al. (2017) concur regarding the potential of regional cooperation, although they note that even though South Africa's policy allows for the implementation of a WEF nexus approach, this form of integrated governance does not yet exist at a national level. Individual countries will need to develop their own WEF nexus governance structures before they can engage in international endeavours in this regard.

In terms of the spatial extent of nexus governance, Artioli et al. (2017) note the rapid rate of urbanisation worldwide and suggest that cities can play a key role in adopting the WEF nexus approach. They continue to state that the urbanisation of the nexus approach is part of a movement towards integrated management and that the 'smart city' is the most dynamic component of that general trend (Artioli et al. 2017).

Another aspect associated with WEF nexus governance is waste. Machell et al. (2015) explain that it is possible to sustainably supply and consume more water, energy and food by addressing the mechanisms of waste. Scanlon et al. (2017) agree, noting that scarcity in these three key resources can be partially managed by reducing demands. An example of the benefit that could be derived from the processing of waste is provided in the following case study.

Case Study 4:

Machell et al. (2015) suggest that waste is an indispensable component often neglected in WEF nexus analyses and include waste as the fourth core component in their nexus framework conceptualisation. An example of waste reclamation, presented by Villarroel Walker et al. (2014) is that urine separation could possibly recover 47% of the nitrogen from the food consumed in London. This could potentially yield an income of $33 million per year from fertiliser production. This practice would reduce waste, provide revenue that will contribute to water treatment costs, and provide a key resource for use within the agricultural sector.

Pandey and Shrestha (2017) conclude that the WEF security nexus is widely accepted in international development circles. Dawoud (2017) emphasise that the challenge is how to implement a WEF nexus framework where the risks, challenges and opportunities are identified and considered by all relevant stakeholders. As Brundtland (1987) stated over three decades ago, "The real world of interlocked economic and ecological systems will not change; the policies and institutions concerned must."

The WEF nexus has also become important in both the drafting and the subsequent monitoring of the SDGs (Biggs et al. 2015). It could be said that the SDGs provide a test for the nexus approach (Ringler et al. 2013). Salam et al. (2017) argue that the interconnections between the SDGs emphasise the need for a nexus approach to achieve these goals. Boas et al. (2016) suggest that the nexus approach, together with its incorporation of the SDGs, is key to understanding why it has garnered such interest within the sustainable development fraternity.

2.7 Conclusions

The WEF nexus has been widely promoted in policy and development circles since 2011. This framework has potential strengths. It however also faces challenges if it is to be widely adopted.

While the nexus concept is not novel, novelty is not a prerequisite for relevance. If the multi-centric WEF nexus approach provides a better means of addressing the complex development and security challenges that the global community is facing than existing frameworks such as IWRM, then its potential adoption should be explored further. The WEF nexus framework is considered by many authors in both academic and grey literature as holding promise for guiding policy development and governance structures in a world that is facing climate change, population growth, and inequality in terms of access to resources. The linking of WEF nexus assessments with the SDGs is therefore imperative.

In terms of possible weaknesses associated with the WEF nexus, a concern identified in the literature is that livelihoods and the environment are often omitted from these assessments. WEF nexus studies have, to date, to a large degree focused on global macro-scale resource security. This was not the intention when the concept was first promoted. For this framework to gain traction, particularly in light of the SDGs, it must be utilised to achieve adequate resource security *for all*. It must simultaneously acknowledge and protect the environment as the irreplaceable foundation of the nexus. This is necessary because livelihoods and the environment may not implicitly be considered in macro-level resource planning, which has been one of the criticisms of the approach.

A multi-centric approach will add complexity, especially when interconnections, trade-offs and drivers are incorporated into the assessment. The fact that a WEF nexus approach cannot be a one-size-fits-all model means that it must be scaled and/or modified (sometimes significantly) for different assessments, e.g. cities, countries and regions, which is viewed as a weakness by some. The availability of complete, relevant data also poses a challenge to the practical implementation of the WEF nexus. The WEF nexus is a relatively new and developing framework.

CHAPTER 3: THE WEF NEXUS IN THE ANTHROPOCENE: MOVING FROM 'NEXUS THINKING' TO 'NEXUS ACTION'

3.1 Introduction

As a result of humanity's pervasive impact upon Earth, it was proposed at the beginning of the twenty-first century that a new geological epoch, the Anthropocene, be declared (Crutzen and Stoermer 2000). The consequences of people's activity have resulted from the exponential growth in the world's population since the industrial revolution, together with the associated demand for all manner of resources (Meadows et al. 1972). Numerous approaches have been adopted to manage the supply and demand of these resources, with various nexus configurations being promoted in the last decade. One approach, termed the Water-Energy-Food (WEF) nexus, has gained appreciable attention as a potential lens to contribute to the achievement of sustainable development and integrated resource management (Simpson and Jewitt 2019). Research interest in the WEF nexus has been so substantial that it has almost increased exponentially since 2009 (Wiegleb and Bruns 2018).

Regarding the linkages within the WEF nexus, global estimates of the proportions that each resource sector supplies or obtains from the adjacent sector are presented schematically in Figure 3-1. The connections in this diagram demonstrate the profound interdependencies within the WEF nexus. Projections indicate that the demand for resources will continue to grow in the coming decades unless there is a significant departure from 'business as usual' (Daher and Mohtar 2015). There are, however, asymmetries within this figure, with not all links being equal. Key drivers associated with these links are population growth, consumption patterns, climate change and sector-specific policies.

The values in this schematic indicate that food production is decidedly dependent upon both water availability and energy generation, with the agricultural sector requiring 71% of the former and 30% of the latter. The proportion of food waste generated worldwide is significant in itself. But it also represents the loss of crucial resources used in food production, such as water, energy, and land (IRENA 2015). In developing countries, most of the food loss occurs in-field and at the post-harvesting stages, while in developed nations the majority of the waste occurs at the retail, food-service and household level (De Laurentiis et al. 2016). Further, this schematic shows that approximately 86% of the available freshwater is utilised within the energy and food sectors (although some of this water may be reused). Both food and energy security are at risk in regions where climate change is predicted to result in a reduction of mean annual rainfall levels, e.g. southern Africa (Conway et al. 2015).

There are several robust motivations for investigating and applying the WEF nexus. The first is the global security of resources, with the World Economic Forum (2018) listing extreme weather events, natural disasters, the failure of climate-change mitigation and adaptation, and water crises as four of the top risks in their *Global Risks Report 2018*. Regarding agriculture, they explain that the prevalence of monoculture farming increases vulnerability to a collapse in the food system (ibid.). In this regard, they note that more than three-quarters of the world's food supply is sourced from only twelve plant and five animal species (ibid.). Not only is maintaining the current global supply of food a profound challenge, but the FAO (2018) project that a world population of 9.8 billion people in 2050 will require a 60% increase in food production (relative to 2012 levels).

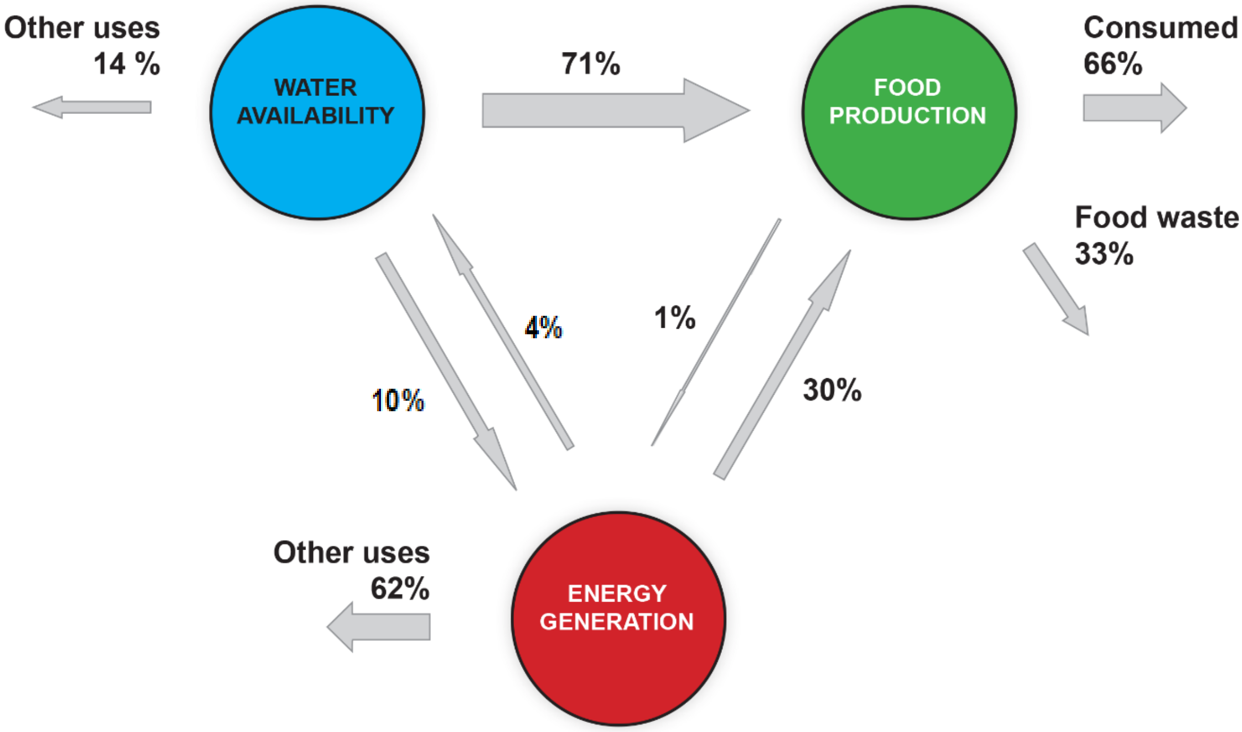

Figure 3-1: A schematic layout of global flows and dependencies within the WEF nexus, modified from Garcia and You (2016). The linkages between the three resource sectors represent water for food, food for energy, energy for food, energy for water and water for energy. The interdependencies between these three resource sectors show that if the security of one sector is threatened then the assurance of the other two sectors will also be endangered. Data sourced from (World Economic Forum 2011, Mohtar and Daher 2012), FAO (2014), (IRENA 2015, Garcia and You 2016, WWAP 2020)

A second justification for adopting a nexus approach is the trade-offs between the sectors that need to be managed and optimised. Two examples in this regard are the competition for land between agriculture and coal mining such as that in the Mpumalanga Province of South Africa (Simpson et al. 2019) and the water-energy-transportation nexus illustrated by the Eagle Ford shale and gas development in southwestern Texas (Mohtar et al. 2019).

Another reason for promoting the WEF nexus is that it is a multi-centric framework. The WEF nexus approach is often contrasted with methods such as Integrated Water Resources Management in literature, which some view as being water-focused and having failed to garner the necessary cross-sectoral support to move an integrated management concept beyond its core sector (ESCWA 2016). This view is appropriately captured by Stefano Manservisi's statement that the Sustainable Development Goals (SDGs) are obliging humanity to operate in an integrated manner and not in institutional silos (EU 2018).

Further, the WEF nexus is viewed as a mechanism for achieving the relevant sector-related SDGs, i.e. 2, 6 and 7. In the *SDG Index and Dashboard Report 2018,* it is insightfully noted that "no country is on track to achieve all the goals by 2030" (Sachs et al. 2018). In this report, it is highlighted that while Sweden, Denmark and Finland have the highest SDG Index ratings, these countries must more aggressively pursue goals such as SDG 12 (Sustainable Consumption and Production) and SDG 13 (Climate Action) if they are to achieve them within the prescribed target timeframe (Sachs et al. 2018).

3.2 Status quo

Allouche et al. (2019) contend that the governing of the nexus is probably one of the foremost challenges of the current century. Brouwer et al. (2018) agree, stating that the nexus concept is a well-founded tool to undergird integrated resource management and the achievement of the SDGs. Yet despite the attention that has been apportioned to the WEF nexus approach, some argue that it is still an evolving concept that has remained largely in the conceptual realm (Smajgl et al. 2016) with insights generally being provided at a high-level (Galaitsi et al. 2018). Some recent publications have highlighted various shortcomings in the nexus' development and implementation. The FAO (2018), for example, explains that there is a dearth of WEF nexus adoption in national policies, programmes and institutions, while also emphasising that gender aspects are often overlooked in WEF nexus assessments. Others argue that current framings of the nexus tend to "draw simplistic and often apolitical causal relations between availability and access which may render them irrelevant since nexus governance is centred on power, politics and justice" (Allouche et al. 2019).

Galaitsi et al. (2018) lament that "empirical WEF nexus research has not produced a discernible intellectual toolkit, nor has it validated claims that nexus approaches can improve resource management and governance outcomes." Albrecht et al. (2018) agree with this verdict, and following a systematic review of 245 journal articles and book chapters, they state that nexus approaches often do not capture the very interactions between water, energy and food that they conceptually aim to address. The deficiency of social science methods in WEF nexus analyses is also noted in the literature (Allouche et al. 2019). These criticisms of the WEF nexus approach can be summarised as a call to move from "nexus thinking" to "nexus doing" (McGrane et al. 2018). Operationalising the nexus means to utilise the WEF nexus to highlight linkages between water, energy and food at regional, national, sub-national, basin and city scales. It also includes the adoption of policies (at various levels) that recognise the interlinkages and enable implementation, e.g. spatial planning, allocations of resources, development projects and innovations that encompass the interlinkages and optimise trade-offs.

The EU (2018) in their *Position Paper on Water, Energy, Food and Ecosystems (WEFE) Nexus and Sustainable Development Goals (SDGs)* stress that there is a need for a structured approach, or 'Toolkit for WEFE Nexus Implementation', to aid in the identification and development of future nexus case studies. Positively, Munaretto et al. (2017) state that synergies are more prominent than conflicts in European policy objectives that are relevant to the water-land-energy-food-climate nexus. Allouche et al. (2019) argue that what is needed from future WEF nexus studies is the presentation of clearly articulated political choices regarding allocations and trade-offs between the constituent resource sectors. Nexus science needs to be better integrated into the policy and decision making realms.

A frequent criticism of the WEF nexus approach is that it is not novel, but simply a reconfiguration of previous methods. While this is partly true, novelty is not a prerequisite for relevance (Simpson and Jewitt 2019), but relevance must be conclusively demonstrated! Another concern within this field is the lack of available, comprehensive and relevant WEF indicator and monitoring data at appropriate spatial and temporal scales in order to inform water, energy, and food governance, case studies, projects and innovations (McGrane et al. 2018, Lawford 2019). In a recent project 87 water-, energy- and food-indicators were reviewed for the development of the WEF Nexus Index (Simpson et al. 2020). Following a rigorous process, 21 indicators were selected to constitute this composite indicator, with adequate data being available for 170 nations (ibid.).

Bielicki et al. (2019) make the interesting observation that in WEF nexus assessments, the importance of science, data, and integrated policy depends on the context of the stakeholders who are utilising the approach. Other authors note that livelihoods and distributional justice are frequently neglected in WEF nexus assessments (Wichelns 2017). This has led to the accusation that governments and businesses are seeking to securitise the nexus, and in so doing that they inadvertently neglect the poorest members of the global community (Leese and Meisch 2015).

In considering the WEF nexus in the Anthropocene, it must be noted that the proposed new epoch has not yet been adopted and that it too faces objections. Cook and Balayannis (2015) argue that the use of the "great acceleration" to establish the Anthropocene is alarmist in that it promotes fears of a doomsday, which they suggest is a risky strategy. They, however, add that they "in no way dispute the colossal risks facing humanity, nor the critical need for action" (Cook and Balayannis 2015). The *Anthropocene Working Group* is developing a proposal to formalise the Anthropocene as a new epoch of the Geological Time Scale. There is however, no guarantee that this proposal, once tabled, will be accepted (Zalasiewicz et al. 2018). Harte (2018) predicts that future geologists will define the Anthropocene and that a band of "plastiglomerate" lithic material may, amongst others, serve as a new worldwide marker. Cox (2018) goes further, suggesting that the term "Plasticene" could serve as an alternative to the Anthropocene. Others reject the notion of the Anthropocene and instead refer to a "Capitalocene" which conveys of the impact of capitalism, imperialism and post-colonialism on nature (Allouche et al. 2019).

3.3 Way forward

The nexus approach should not be abandoned, but rather it requires greater focus and application (Allouche et al. 2019). Part of the challenge relating to conceptual approaches, such as the WEF nexus, is that they allow for a variety of methods, and their diverse aims make it arduous for any single tool to be solely sufficient (Albrecht et al. 2018). Brouwer et al. (2018) argue that "there can be no single methodological approach or framework to implement the Nexus concept due to the diversity of cases and issues being investigated. Instead, it is important to promote the search for the most suitable and feasible approach, tool or model to represent interlinkages across sectors in every specific situation rather than struggling to find the one method that fits all situations." In determining the way forward, two fundamental questions must be answered (Allouche et al. 2019):

- *Who* does the integrating? (agency)
- *How* must the integrating be done? (process)

During a dialogue on *The Status of the Water-Energy-Food Nexus in South Africa*, held at the Water Research Commission in February 2019, where several representatives from different regulatory departments were present, the first of these questions was one of the core topics of discussion. With whom does the responsibility of integration reside? Who must catalyse the integration? The conclusion to this question, which is in line with the proposal of Rasul (2016), was that the responsibility of integration should reside within the National Planning Commission, which in South Africa is a statutory body which focuses on the country's long-term development and planning. Similar entities exist throughout the world. The custodian of the WEF nexus within the South African Water Research Commission, who is a member of the National Planning Commission, confirmed that the WEF nexus is firmly on its agenda. Successful nexus policy-making is dependant upon "political will, mindset, knowledge management and careful organisation of the process" (Witmer et al. 2018). Further, there must be a willingness to broaden the scope beyond the customary sectoral perspective, focus on shared objectives instead of narrow sectoral goals, give up individual power plays for shared interests, invest in complex and often prolonged policy-making processes and compromise in order to attain common goals (Witmer et al. 2018). Writing from a southern Asia perspective Rasul (2016) notes that poor sectoral coordination and institutional fragmentation have resulted in the unsustainable use of resources, which is threatening the long-term sustainability of food, water, and energy security in the region. It also poses challenges to achieving the SDGs. An alternative to strengthening national planning commissions could be the establishment of a high-level interdisciplinary group with representatives from the three ministries (water/irrigation, energy, and food), think tanks, researchers, and civil society (Rasul 2016). Schreiner and Baleta (2015) highlighted opportunities for a nexus approach to facilitate development across regions. In the Southern African Development Community (SADC), this approach as been strongly adopted with the establishment of a SADC Regional Nexus

Framework, the SADC WEF Working Group and the development of various decision support tools to assess future development scenarios.

With urbanisation increasing across the globe, cities are becoming important levels of implementation for the WEF nexus approach (Artioli et al. 2017). An example of a city that is seeking to pursue this path is Lisbon, Portugal. During the 2019 *European Climate Change Adaptation Conference*, the Mayor of Lisbon, Fernando Medina, explained that the responsibility of climate change adaptation (which is closely associated with the WEF nexus) resides in the Mayor's office, not as a peripheral portfolio of their environmental department. This is a structural measure that ensures that climate change mitigation is "front and central" as opposed to an afterthought or a side issue.

Regarding "how" the integration of sectors should occur, an alternative to a structural measure could be to utilise a financial instrument, such as the pricing of water or electricity, to dissuade wastage and effect demand management. To this end Schlör et al. (2018) argue that taxes are the key institutional incentive to organise and structure political, social and economic cooperation.

Integration within the WEF nexus also requires widely accessible, reliable data. In terms of obtaining access to the requisite data for WEF nexus analyses, Lawford (2019) proposes that an appropriately defined "W-E-F Nexus data and information system" (WEFDIS) that integrates and consolidates WEF nexus data could underpin the implementation of nexus approaches. Standard data collection administered by national and provincial governments and agencies can be complemented with data from remote sensing systems, such as satellites (ibid.). By providing open access to data through national and global central portals, integrated nexus approaches could be significantly enhanced. This central portal could be hosted by a research centre, a think-tank, a non-profit organisation, or a university.

Quantitative assessments on their own are, however, insufficient. Albrecht et al. (2018) emphasise that research is needed that integrates quantitative *and* qualitative methods in order to achieve a more comprehensive analysis. There is a pressing need in these assessments to analyse political systems, private and public stakeholders, and power relations (FAO 2018). In terms of facilitating the required integration, Sušnik et al. (2018) argue that a safe environment is necessary to investigate the potential cross-sectoral implications of policy decisions in one resource sector on adjacent sectors. They suggest that serious games, such as SIM4NEXUS which they developed, offer such an environment by providing realistic 'simulations' where long-term impacts of policies can be tested and rated. Further, although Albrecht et al. (2018) bemoan that the WEF nexus approach is struggling to move beyond the conceptual stage, they highlight eighteen studies that demonstrate promise in guiding future research. These include, amongst others an analysis framework developed in Matlab (Villarroel Walker et al. 2014), WEF Nexus Tool 2.0 (Daher and Mohtar 2015), stakeholder analysis methods presented by Halbe et al. (2015), participatory workshops described by Howarth and Monasterolo (2016), a mixed-method participatory approach (Smajgl et al. 2016), and various quantitative and qualitative methods proposed by Endo et al. (2015). Both quantitative and qualitative studies are included in this list. It is also imperative that gender concerns be represented in WEF nexus approaches, especially in rural developing countries (FAO 2018), e.g. in stakeholder engagement and surveys. The EU (2018) concur, emphasising that collaboration must be more than just a buzzword. Based on the presentation of five nexus case studies from the Middle East and North Africa (MENA) region, Hoff et al. (2019) note that "the evidence from the case studies can already be used by policy-makers for better coordination across sectors and improvements in terms of horizontal and vertical policy coherence. Such changes toward more integrated governance can incentivize further nexus implementations and investments and upscaling of solutions beyond pilot scale, which in turn would further strengthen the nexus evidence and knowledge base."

The use of a composite indicator, such as the WEF Nexus Index is another means of integrating the three sectors (Simpson et al. 2020). The normalisation of the constituent data renders the indicators, and the resultant index, unitless. Although this composite indicator has been developed at a national level, it provides a point of entry into the data, which can also lead to an assessment of the WEF nexus at different spatial scales.

The reason for juxtaposing the WEF nexus and the Anthropocene is that the WEF nexus is anthropocentric in nature (Simpson et al. 2020). The global supply chain juggernaut must meet humanity's ever-increasing demand for resources from the environment and its associated ecosystem services. This demand is testing, and in certain instances exceeding, planetary boundaries (Rockstrom et al. 2009). If the nexus is to be fruitfully utilised then integrated models, composite indicators, GIS-based maps, case studies, questionnaire surveys, serious games, media tools, projects, innovations, policy briefs and regulatory authority engagements that aid the governance of humanity's growth, demand, consumption and waste patterns (and ultimate achievement of the SDGs) must be developed and applied.

3.4 Conclusions

While interest in the WEF nexus has increased markedly since 2009, the approach is still evolving, and much of the research has been conceptual in nature and has yielded only high-level assessments. An appreciable proportion of the criticism levelled at this approach stems from the perception that when all is said and done regarding the nexus, far more has been *said* than done. While there are negative critiques of the WEF nexus in current literature, these publications also present promising methodologies that can be utilised and tested to further mature the approach. The nexus must be considered to be a framework, not a recipe. There is no one nexus method that fits all scenarios; rather, the approach must be tailored for each unique situation.

The need for undertaking quantitative and qualitative assessments has been highlighted in recent literature. This includes the assessment of political systems, power structures and the inclusivity of all stakeholders, ensuring that women and the poorest members of the global society are appropriately and adequately represented. The reason for this is that much of the literature appertaining to the WEF nexus to date is apolitical and technical in nature. This is considered to be a flawed perspective, and the need to engage stakeholders from the inception of WEF nexus assessments is of paramount importance. In this regard, the WEF nexus community is beginning to yield innovative approaches for integrated policy guidance, such as discourse and policy analysis, serious games, and composite indicators.

CHAPTER 4: COMPETITION FOR LAND: THE WATER-ENERGY-FOOD NEXUS AND COAL MINING IN MPUMALANGA PROVINCE, SOUTH AFRICA

4.1 Introduction

The Mpumalanga Province, which is the second smallest of the nine provinces in South Africa, contains almost half of the country's high potential arable land. Beneath its grasslands and cultivated farms are vast coalfields, which not only play a major role in the generation of this nation's electricity but also garner significant revenue from the export market. Approximately 25% of South Africa's coal is exported (Webb 2015). Most of the nation's coal-fired power stations are in Mpumalanga, strategically situated near the mines that supply them. Another large consumer of coal in this province is Sasol's coal-to-liquid fuel plants.

Water that flows through this relatively high rainfall region is predominantly utilised for agriculture. Before the major rivers in this province flow across the international border with Mozambique, they pass through the Kruger National Park. Other rivers in the province result in transboundary flow to and from Swaziland. Mpumalanga is also considered to be important in terms of biodiversity, possessing approximately 5000 pan wetland systems (Ferreira 2009) and numerous other important habitats of interest, including parts of the Kruger National Park. Irrigation, energy and food security are closely related in Mpumalanga with 25% of the staple food in South Africa being grown on irrigated land, requiring high energy inputs (Bazilian et al. 2011).

4.2 The Water-Energy-Food Nexus

The global status quo is that resource and spatial planning and policy development often occur independently in 'silos' with conflicting policies being developed (Bazilian et al. 2011, Leck et al. 2015). The nexus approach, which has gained prominence in the twenty-first century (Pandey and Shrestha 2017), requires that resource and spatial planning occur in an integrated manner that seeks to consider linkages, dependencies and trade-offs (Hoff 2011). The word nexus means to 'connect' and therefore points to the interdependencies within a particular nexus configuration (De Laurentiis et al. 2016). A key consideration in a nexus assessment is that the attainment of the security of one resource sector should not compromise an adjacent resource sector (Simpson and Berchner 2017).

Amongst the various nexus configurations, the Water-Energy-Food (WEF) nexus has garnered particular interest (World Economic Forum 2011). This is due to the finite nature of each of these resources, coupled with the ever-increasing demand (and competition) for them due to population growth and changes in consumption patterns (Beddington 2009).

The primary motivation for evaluating the WEF nexus in Mpumalanga is the ongoing tension between agriculture (i.e. food security) and coal mining (i.e. fossil-fuel-based energy security) in terms of the competition for land. Related to this, and equally important is the deterioration of the quantity and quality of water in the region due largely to agricultural and mining activities (Ololade et al. 2017). The deteriorating water quality, together with the diminishing quantity thereof already has and will continue to have, a negative impact on water security in this province. This, in turn, impacts not only agriculture, mining and electricity production in terms of their input water requirements, but also poses a risk to human health and the environment and places pressure on other competing water users (including transboundary water users).

A further motivation for addressing the WEF nexus, or resource trilemma (Wong 2010, Perrone and Hornberger 2016), within Mpumalanga is the impact that climate change is predicted to have, particularly on water resources. The majority of climate models project decreases in mean annual precipitation for southern Africa by approximately 20% by the 2080s (Conway et al. 2015). Reductions in annual precipitation will threaten, amongst others, the availability of water for irrigation and hydropower. Some farmers have adopted more energy-intensive irrigated agriculture due to the reduction in available rainfed water for crop and livestock production (Grafton et al. 2016). An expected rise in temperature will increase evaporation volumes and decrease soil moisture and runoff. Lower food production, coupled with the reduced availability of water, will threaten sustainable economic development. This reduction in rainfall will also affect the achievement of several Sustainable Development Goals (SDGs), principally SDG 2 "Zero Hunger", SDG 6 "Clean Water and Sanitation" and SDG 7 "Affordable and clean energy". Other SDGs that are dependent upon freshwater resources will also be impacted (Rockström and Sukhdev 2016).

The goal of this paper is to critically review the Mpumalanga Province through the lens of the WEF nexus. This will be performed by assessing each of the three resource sectors in turn. Where interactions and tradeoffs exist, they will be identified and investigated. Following the sectoral reviews, an analysis of the nexus interactions will be undertaken. Conclusions will subsequently be drawn regarding the existing or potential threats to water, energy and food security in the province. Trade-offs between resources, i.e. where ensuring the security of one sector will impact the security of another, will be highlighted and assessed. Finally, recommendations of potential corrective actions needed to remedy possible threats to the security associated with the three sectors in Mpumalanga will be presented. The first resource sector to be reviewed is fresh water.

4.3 Water security

Since the 1990s, Integrated Water Resource Management (IWRM) has been the dominant water management paradigm (Movik et al. 2016). According to the Global Water Partnership, IWRM aims to "promote the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP 2000). IWRM approaches resource management by focussing on water as the central resource, whereas the

WEF nexus proposes resource management in a multicentric matter, providing equal weight to each resource (Ololade et al. 2017). The implementation of IWRM has been troublesome in some parts of South Africa, mostly due to a lack of capacity, innovation and experience (Claassen 2013).

South Africa is the 30th driest country in the world (DWA 2016). Ensuring adequate water supply to meet the country's social and economic needs is an ever-increasing challenge. Climate change will exacerbate this situation. Low rainfall in 2015 has resulted in "experiencing its worst drought in thirty years" (CER 2016). The drought in the first half of 2018 in Cape Town drove water reserves to the lowest levels that have been experienced in many years, with dam's levels being critically low. The principles of International Water Law (cooperation, equitable and reasonable utilisation, no-harm) become relevant when considering different water uses in international basins, as is the case with South Africa sharing four major river systems with six neighbouring countries (Belinskij 2015).

Figure 4-1 presents the Water Management Areas in Mpumalanga. In the south-west, water drains inland towards the Vaal River system. The south-eastern portion of the province flows across the national border with Swaziland. Runoff that is generated in the northern portion of the province drains predominantly in a north-easterly direction towards the Limpopo and Incomati Rivers, which pass through the Kruger National Park and subsequently into Mozambique.

Mpumalanga is characterised by annual rainfall that ranges from 400 to 600 mm per annum in the north-east, and 600 to 800 mm per annum in the west, while portions of the central zone receive annual rainfall exceeding 1000 mm per annum. This high rainfall region in the centre of the province is indicated by the hatching entitled "Strategic Water Source Areas" in Figure 4-1. Yearly potential evaporation generally increases from east to west across the province, from approximately 1800 mm to 2200 mm per annum.

Approximately 46% of the surface water in the province is utilised for irrigation, 9% is utilised for electricity generation, 9% for mining and bulk industrial users, 9% for afforestation, 8% for urban water usage (3% for rural), while approximately 16% of the surface water within this province is transferred to Gauteng (MDACE 2003). The proportion of water utilised for irrigation in Mpumalanga (i.e. renewable freshwater withdrawn, which is 46%) is less than the average global agricultural water usage, which constitutes approximately 70% of freshwater supplies (National Intelligence Council 2012).

Significant water loss in South Africa is attributed to the encroachment of invasive alien plants (IAPs). It is estimated that approximately ten million hectares of South African land is covered with IAPs, with the Western Cape and Mpumalanga provinces being the most affected (Le Maitre et al. 2000). The extent of IAPs in the Olifants River catchment in Mpumalanga was calculated by Kotzé et al. (2010) - it was determined that *Acacia* species and *Arundo donax* are the most prevalent, covering condensed areas of 6700 ha and 5 406 ha, respectively. These IAPs impact river flows and groundwater availability, thriving in warm regions with high rainfall (Le Maitre et al. 2016). IAPs reduce riparian water yields in the Olifants River catchment by an estimated 50 million cubic metres per annum (Cullis et al. 2007).

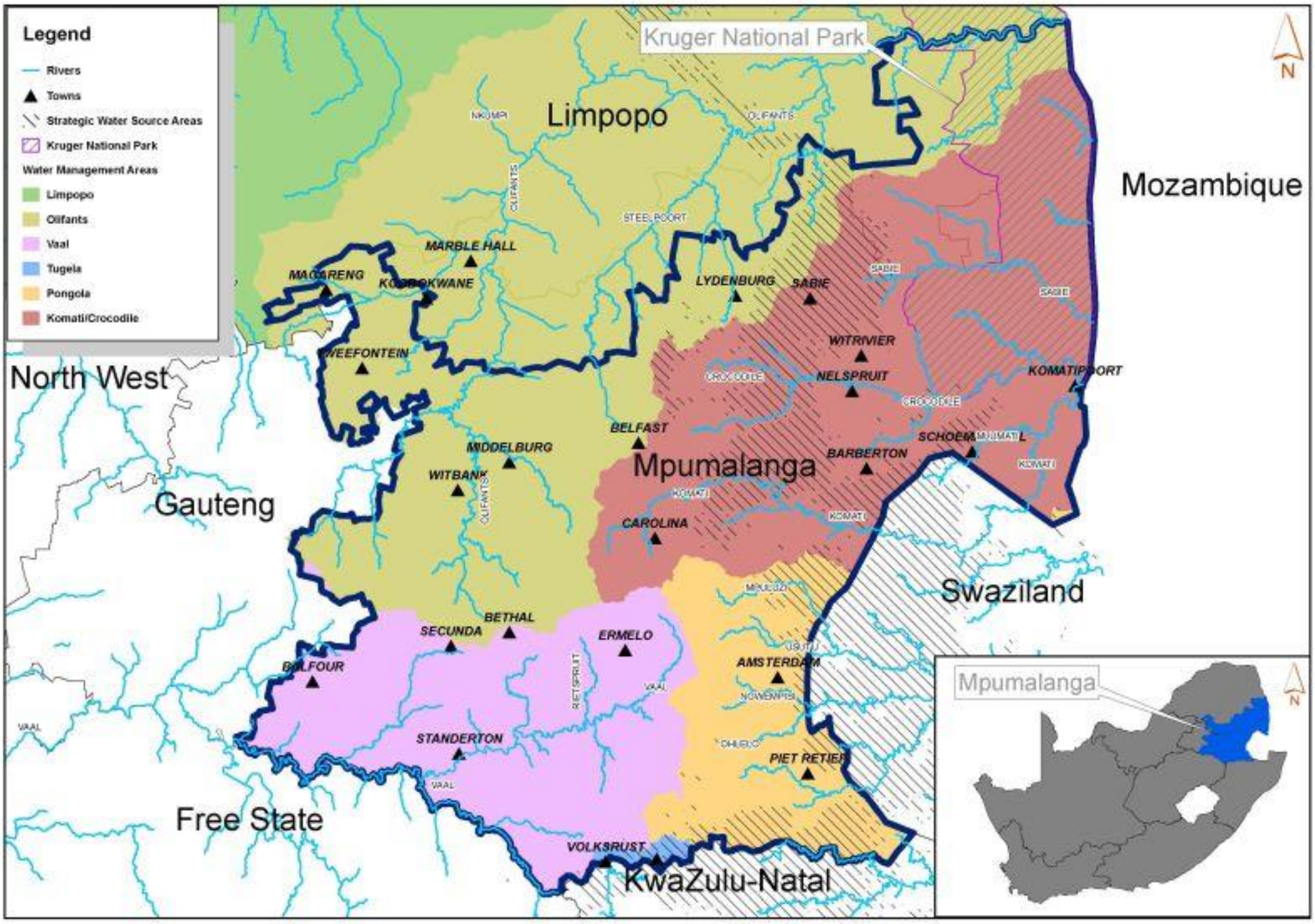

Figure 4-1: Map of the Mpumalanga Province indicating Water Management Areas, main rivers and major towns

Both agricultural and mining activities have significant impacts on the local water quality and quantity in Mpumalanga, while competing for land (Ololade et al. 2017). Ferreira (2009) explains that due to increased pressure from coal mining and agricultural activities, it is essential that perennial pan systems in Mpumalanga are protected and conserved to avoid a loss in aquatic invertebrate biodiversity. After opencast coal mines are rehabilitated "land is returned to low levels of biodiversity as rehabilitation programmes preferentially use commercially available seed, with high nutrient and water requirements" (Aken 2012). The CER (2016) argue that the Department of Mineral Resources (DMR) grants mining rights "without having regard to cumulative impacts on water resources, biodiversity, air quality, and food security, nor to the health or wellbeing of affected communities, despite the consideration of these factors being required by law." The WWF supports this view, explaining that the

"DMR does not take account of important natural assets such as biodiversity and the water provided by headwater catchments to agriculture and urban areas when issuing licences" (Colvin et al. 2011).

Mpumalanga, like much of South Africa, is characterised by a significant disparity in the income and living standards of its citizens. This is reflected in people's access to water resources and sanitation services. While 91.4% of households in Mpumalanga had access to improved drinking water sources in 2015, less than two-thirds (65.8%) of households had access to improved sanitation facilities (StatsSA 2016b). It is concerning that the percentage of people with access to improved drinking water in Mpumalanga decreased during the thirteen years leading up to 2015 from 92.9% in 2002, to 91.4% in 2015 (although this decline is small and could be within the margin of error for the census it should not be ignored since the change is negative). Equally concerning is that 16.5% of households in Mpumalanga experience water pollution (StatsSA 2016b). This pollution is related to agricultural and mining activities, as well as frequently poor levels of municipal management in terms of sewerage treatment (Lodewijks et al. 2013).

These statistics indicate that access to improved drinking water and improved sanitation facilities in Mpumalanga is not universal, and that about one in six households is directly impacted by polluted water. Based on SDG 6, which amongst other goals seeks to achieve universal and equitable access to safe and affordable drinking water and access to adequate and equitable sanitation and hygiene for all, Mpumalanga has much room for development.

The water security challenge in Mpumalanga is being further compounded by the fact that the proportion of non-revenue water, which is the sum of unbilled authorised water and system losses, between 2005 and 2010 ranged between 33.6% and 51.3% for various municipalities (Mckenzie et al. 2012). The national average is 36.8%, and although this value is close to the world average of 36.6%, this loss represents a significant volume of water. The goal of reducing the proportion of non-revenue water in municipalities within Mpumalanga through reducing water losses must become a key intervention. International best practice in real losses is generally agreed to be 15% (Bruinette and Claasens 2016). This means that municipalities in Mpumalanga have a long way to go in this regard. Water Service Providers such as Rand Water (2016) in Gauteng are seeking to train 15 000 plumbers and artisans as part of their "War on Leaks" programme, and Mpumalanga would do well to implement a similar programme. By reducing the proportion of non-revenue water losses, combined with water demand management, not only can water be saved, but significant energy savings can be realised, particularly in systems where water must be pumped at some point in the supply cycle. Water loss savings will also often result in energy savings due to a reduction in water treatment costs, which is an energy intensive process.

While the irrigation of crops is beneficial to society in that it contributes to food security, agricultural practices also negatively impact on water quality through nitrogen and phosphorous pollution resulting from chemical fertilisers, as well as erosion from agricultural lands. Eutrophication is pervasive throughout the Upper Olifants River catchment and urgent interventions are required to reduce these nutrient inputs (Lodewijks et al. 2013).

In 2015 there were 239 operating mines and 788 derelict and ownerless mines in Mpumalanga (Solomons 2016). Figure 4-2 presents the farm portions[5] where mining rights have been granted, and prospecting applications have been submitted. These mines are often the source of water pollution in the form of contaminated runoff and/or acid mine drainage (AMD). Coal mining is known to seriously degrade water by consuming, diverting and polluting the resource (Olsson 2013). River systems, such as the Olifants River, have been significantly impacted upon in terms of quality (and quantity) by extensive coal mining within its catchment area (McCarthy 2011). The Olifants River catchment has experienced over 100 years of coal mining and now has some of the poorest water quality in the country (Colvin et al. 2011). The water quality of the Olifants River is such that it will not be used by Eskom's (the national utility) new coal-fired power station Kusile because the water is too polluted (Olsson 2013). Irresponsible mining and regulatory failure are key aspects leading to the decline in water quality and quantity in Mpumalanga (Forrest and Loate 2018).

An analysis of long-term monitoring data indicates that total dissolved salt concentrations (of which sulphate is the major constituent) frequently exceed resource water quality objectives at sites upstream of the Witbank and Middelburg dams (Lodewijks et al. 2013). Surface and groundwater sources are negatively affected by AMD in Mpumalanga due to the abundance of coal mining activities (Mabhaudhi et al. 2016). The 2010 Expert Team of the Inter-Ministerial Committee, which was established to assess the threat posed by AMD, identified the Mpumalanga coalfields as one of six vulnerable areas that require monitoring (DWA 2010). Dealing with AMD in the three priority areas identified by the Expert Committee, namely the Western, Eastern and Central Basins, has been estimated to cost approximately US$770 million. In the absence of intervention in these six vulnerable areas, the financial costs required for dealing with AMD will be immense. This water quality impact, combined with a high proportion of non-revenue water, and the fact that South Africa is a water-scarce country, yield a potential crisis in terms of water security and pose a challenge to the achievement of SDG 2 in this province. These statistics need to guide the development of policies to rectify the inequalities that exist, as well as trends that point to the situation deteriorating even further.

Water security in Mpumalanga provides a useful lens through which to understand the extent of the interdependencies between the sectors included in the WEF nexus. Agriculture relies on water (both rainfall and irrigation) for food production but also contributes to the pollution of the very resource upon which it depends (Dabrowski et al. 2009). Similarly, water is a critical input in energy generation (and coal mining as part of the value chain), but these activities are exerting pressure on the water resources upon which they too rely, particularly in terms of

[5] Mpumalanga comprises 4 341 parent farms, each with a unique name and region number e.g. Kromfontein 234 IR. Over time these parent farms have been subdivided into farm portions, which keep the parent farm name and number, with the addition of a portion number e.g. Kromfontein 234 IR Portion 1. There are 76 543 farm portions in Mpumalanga (Lotter 2010).

quality (Spang et al. 2014). This in turn, directly impacts at least one in six households within this province in terms of exposure to contaminated water. Dealing with water pollution and ensuring an adequate supply of good quality water, in turn, requires energy (e.g. to pump and/or treat the water), which is the next resource sector considered.

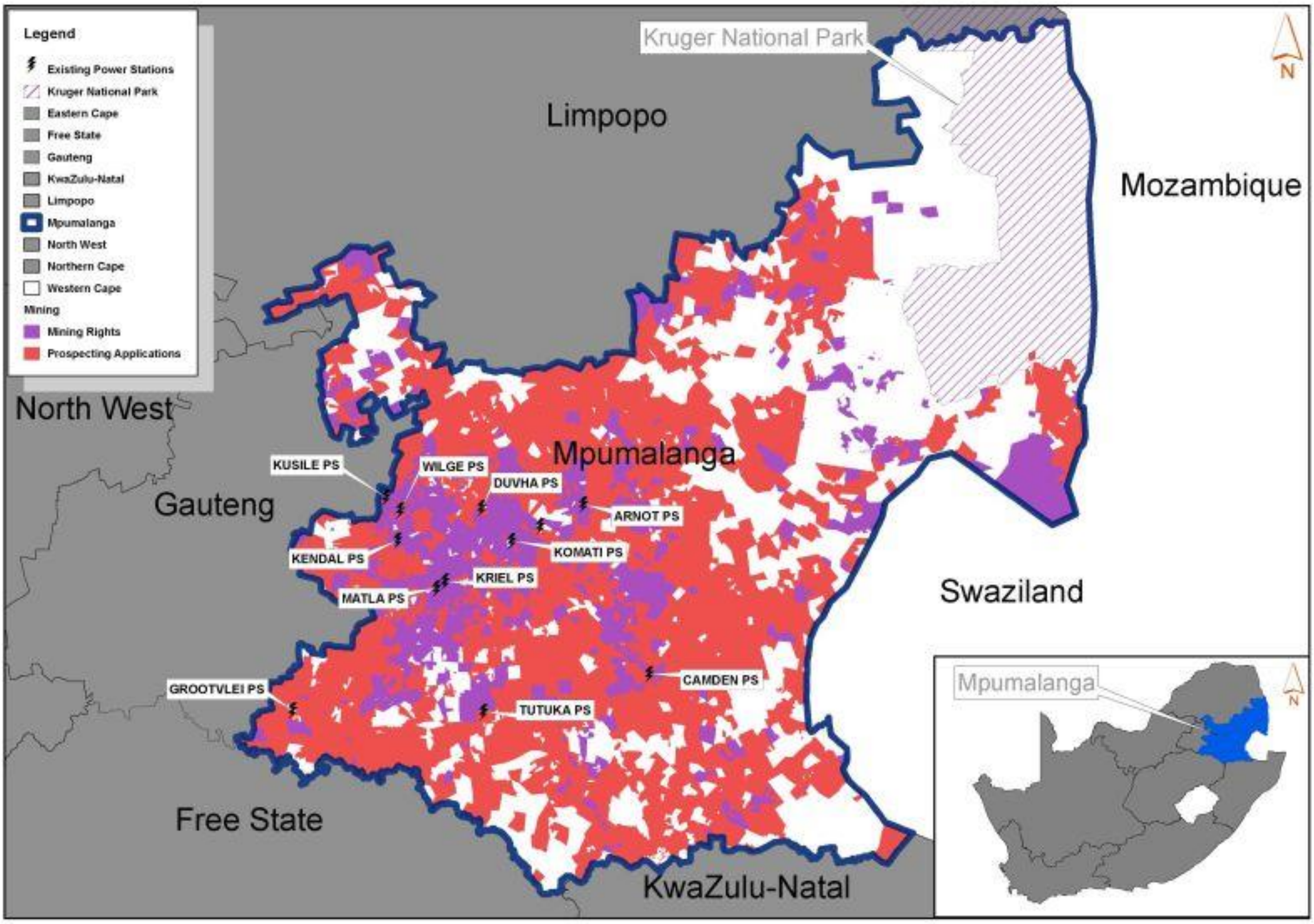

Figure 4-2: Map of the Mpumalanga Province indicating the location of power stations, mining rights areas and farm portions where prospecting applications have been submitted

4.4 Energy security

Jeffrey Sachs writes that "Of all the problems of reconciling growth with planetary boundaries, probably none is more urgent and yet more complicated than the challenge of the world's energy system" (Sachs 2015). This statement is primarily motivated by the world's dependence on fossil fuels since the industrial revolution, and the resultant emission of greenhouse gases, principally CO_2. In South Africa, energy security is inextricably linked to coal mining, since Eskom purchases approximately half of the locally produced coal (Chamber of Mines of South Africa 2018). Eskom is guaranteed a supply of water since it is listed as the only "strategic water user" under the National Water Act 36 of 1998 (Olsson 2013).

In 2014, South Africa generated approximately 253 TWh of power, almost 92% of which was generated by means of coal (Agora 2017). Based on long-term contracts which commit several coal mines to supply coal to Eskom, South Africa will probably continue to rely on coal-fired power stations for the next 30 to 50 years (Delport et al. 2015). Due to the relatively slow transition to a low-carbon economy, it would be prudent to implement retrofitting measures to increase the efficiency and flexibility of the existing relatively old coal-fired power station fleet to facilitate the addition of electricity generated from fluctuating renewable energy sources (Agora 2017). These measures could also reduce coal consumption and CO_2 emissions.

A large proportion of the coal mined, and most of the coal-fired power stations, are situated in Mpumalanga, as shown in Figure 4-2. Although South Africa has in recent years been developing numerous renewable energy systems, their capacity is dwarfed by the capacity of coal-fired power stations such as Kusile (located in Mpumalanga Province) and Medupi (located in Limpopo Province), that are currently being constructed. Each of these power stations has a gross generating capacity of nearly 4800 MW (Department of Energy 2016). Together with these state-owned coal-fired power stations, several coal-based Independent Power Producers are at varying stages of planning or constructing new facilities (Mathu 2017). Of the total volume of electricity distributed in South Africa in September 2016, 2,713 GWh (or 14.6%) was delivered to Mpumalanga (StatsSA 2016a). The percentage of households in the Mpumalanga Province that are connected to the national electricity grid increased from 75.9% in 2002 to 89.8% in 2014 (StatsSA 2015).

In contrast to the dearth of coal reserves in other African nations – South Africa has 95% of the continent's proven coal reserves (Agora 2017) and is the seventh largest producer of coal in the world (International Energy Agency 2017). Coal has played and continues to play, a very important role in South Africa's economy. Fine and Rustomjee (1996) argued in the late 1990s that the South African economy was characterised by a dependence on what they termed the Mineral-Energy-Complex. Many agree that this remains true today (Mohamed 2009, Power et al. 2016). It is estimated that between 1987 and 2011, 7.5 billion tonnes of coal were extracted from the Mpumalanga coalfields, yet it is estimated that South Africa still has a run-of-coal reserve of about 66.7 billion tonnes (Webb 2015).

While coal mining continues in the Mpumalanga Province, much of South Africa's remaining coal reserves are in the Waterberg and Soutpansberg areas, in the north-western portion of the country. It is estimated that approximately 72% of the remaining coal reserves in South Africa are located within these two areas (Webb 2015). Although coal is plentiful in these regions, there are various obstacles to unlocking these vast resources. Challenges include the general lack of water, the sensitive biodiversity, the vast distance to most of the power stations and the Richards Bay Coal Terminal, and the coal in the Waterberg area generally being of a poorer quality than the coal mined in the Mpumalanga Province (Jeffrey et al. 2014, Cullis et al. 2018).

Only a little more than 3% of South Africa's electricity is generated by means of renewable sources (Enerdata 2016), yet the cost of these technologies is falling rapidly (Walwyn and Brent 2015). South Africa is endowed with significant potential in terms of solar and wind power generation (Gies 2016). This could lead to the development of a southern African "Desertec" within the Northern Cape Province and in neighbouring Namibia. Such a system could potentially generate power for the Southern African Development Community (SADC) states situated on the mainland. Examples of systems already installed in the Northern Cape include the Khi One steam-driven solar thermal plant near Upington, the De Aar Solar PV project and Kathu photovoltaic project, near Deben (Craig et al. 2017).

The South African Department of Energy's *Integrated Resource Plan Update* recognises the vast renewable energy potential that the nation possesses, with the base case planning 55,000 MW of new renewable energy to be delivered between 2020 and 2050 (Department of Energy 2016). This comprises of 37,400 MW of wind power and 17,600 MW of solar photovoltaic power generation. There are however, some concerns regarding the constraints that are specified in this plan, particularly regarding the annual allowable capacity of renewable energy systems that may be installed. Another proposal that could result in a decreased dependency on coal recommends that South Africa lift their existing restriction on hydropower imports (Conway et al. 2015). This importation of energy could reduce the required investment in renewables. In addition, it could offset one of the main challenges associated with a high share of electricity from solar and wind power plants, namely that these are fluctuating energy sources. Hydropower can, however, result in negative impacts on aquatic ecosystems through changes to the natural flow regime and migratory routes. Couto and Olden (2018) state that 82 891 small hydropower plants (SHPs) are operating or are under construction worldwide, and "provide evidence for not only the lack of scientifically informed oversight of SHP development but also the limitations of the capacity-based regulations currently in use."

The energy and food security components of the WEF nexus are brought into sharp focus when it is realised that almost all opencast mining activities in Mpumalanga occur on high potential arable land (Collett 2013). In 2014, 61.3% of the surface area of Mpumalanga fell under prospecting and mining right applications (Solomons 2016), as presented in Figure 4-2. Large tracts of formerly high production agricultural land within this province (overlapping with areas containing high concentrations of coal reserves) have been mined to power the economic development that has taken place in South Africa (Ololade et al. 2017). Mpumalanga's coal mines and coal-fired power stations are the power-house of the nation (Winkler and Marquand 2009). Yet the insatiable hunger of these power stations is not only consuming the carbon-based fuel but is also severely impacting upon the agricultural potential of the province, as well as the water quality within its rivers.

In a country such as South Africa, where there is such a significant dependence on coal, to stop the development of new coal mines in the short- to medium-term would be tantamount to switching the lights off on a national level. Further, the coal industry in South Africa employs approximately 90,000 people (Webb 2015) and generates valuable export income. In 2015, mining was South Africa's largest foreign exchange earner (Delport et al. 2015). The value of coal to the country means that to significantly reduce coal production would result in a negative impact on the economy, in terms of jobs, energy security and export revenues. However, the environmental and human health impacts associated with the coal value chain need to be more thoroughly mitigated, especially when it is understood that "specific CO_2 emissions from power generation in South Africa are as high as 900 g CO_2 /kWh. By contrast, specific CO_2 emissions in Germany amount to 500 g CO_2/kWh" (Agora 2017). Further, the trade-offs between the sectors making up the WEF nexus need to be better understood. When the province of Mpumalanga is considered, the trade-off between energy supply and food security is of supreme concern.

4.5 Food security

Efficient agricultural production in South Africa is hampered by limited arable areas; about 30% of the land surface is classified as rangeland, used mainly for game ranching where rainfall is low (Milton and Dean 2011). Areas with high potential arable land, such as Mpumalanga, compete with coal mining for land and water use. Modern agriculture is heavily dependent on fossil fuels, which is reflected in the correlation between food and energy prices (De Laurentiis et al. 2016). Both mining and agriculture contribute to environmental damage, particularly relating to water quality, soil structure, and the loss of native habitats for ecosystem services (Foley 2005).

Less than 14% of South Africa's land is suitable for dryland cropping, with only about 3% regarded as high potential arable land (Collett 2013). It has been calculated that 46.4% of the nation's high potential arable land is situated within the Mpumalanga Province (BFAP 2012), and much of this is utilised for the production of commercial timber. Jeffrey D. Sachs notes that "there is actually an economic sector with comparable or even greater environmental impact than the energy sector: agriculture" (Sachs 2015). Since the 1970s, South Africa has considered the water needs for agriculture subordinate to those of the energy sector, urbanisation, and industrial development (Ololade et al. 2017). The area of land under various forms of cultivation in the Mpumalanga Province is summarised in Table 4-1.

There is a need for improved technology and techniques to maximise water efficiency and minimise the loss of crop production in South Africa. In the Mpumalanga Province, sugarcane is generally produced under irrigation (Jarmain et al. 2014). The areas listed as being cultivated by means of horticulture and under shade-net are assumed to be irrigated areas. Sugarcane production is a strategic crop in Mpumalanga. Based on climate change projections of a 2^{o}C increase in temperature worldwide (from pre-industrial era levels), farmers in Mpumalanga may have to change from sugarcane (heavily dependent on irrigation) to a crop that is more heat tolerant, like sorghum (Gbetibouo and Hassan 2005).

Table 4-1: Areas of various types of cultivated lands in the Mpumalanga Province (DAFF 2017)

Cultivation details	Area (Hectares)
Sugarcane	61 663.43
Rainfed annual crop grain cultivation or planted pastures	1 118 654.64
Non-pivot irrigated annual grain crop cultivation or planted pastures	2 417.12
Horticulture - vineyards, flowers, trees or shrubs (orchards)	43 421.16
Pivot irrigation - irrigation by means of centre-pivots	50 461.94
Old fields - old field boundary that is not currently planted	59 804.91
Subsistence 1 - usually close to small villages, fields are 5-10 ha	94 593.67
Subsistence 2 - usually close to commercial farms, larger hectarages	1 559.00
Shade-net - crops are grown under shade protection	377.78
Smallholdings - small portions of land in peri-urban settings	5 812.53
Total cultivation for Mpumalanga Province	**1 438 766.18**

The Department of Agriculture, Forestry and Fisheries (DAFF) developed eight land capability classes, which are presented in Figure 4-3. This map indicates that large portions of the province of Mpumalanga have a high potential for cultivation. In 2012, as part of the development of a new policy on the *Preservation and Development of Agricultural Land* DAFF conducted a spatial analysis of available agricultural land in accordance with the national land capability classification classes. This was undertaken to determine the status of agricultural land per province, and the availability thereof through the exclusion of permanently transformed areas, i.e. agricultural land that has been lost due to, for example, urban development or opencast mining. The analysis concluded that the surface area of arable agricultural land in South Africa that had been converted to non-agricultural uses through urban and mining developments “equals the size of the Kruger National Park” (Collett 2013). The area of this world-famous game reserve is almost two million hectares.

As described in the foregoing section appertaining to energy security, the available area of high potential arable land in Mpumalanga is under threat from coal mining. At the current rate of coal mining in this province, it has been calculated that approximately 12% of South Africa’s high potential arable land will be transformed, while a further 13.6% is subject to prospecting (BFAP 2012).

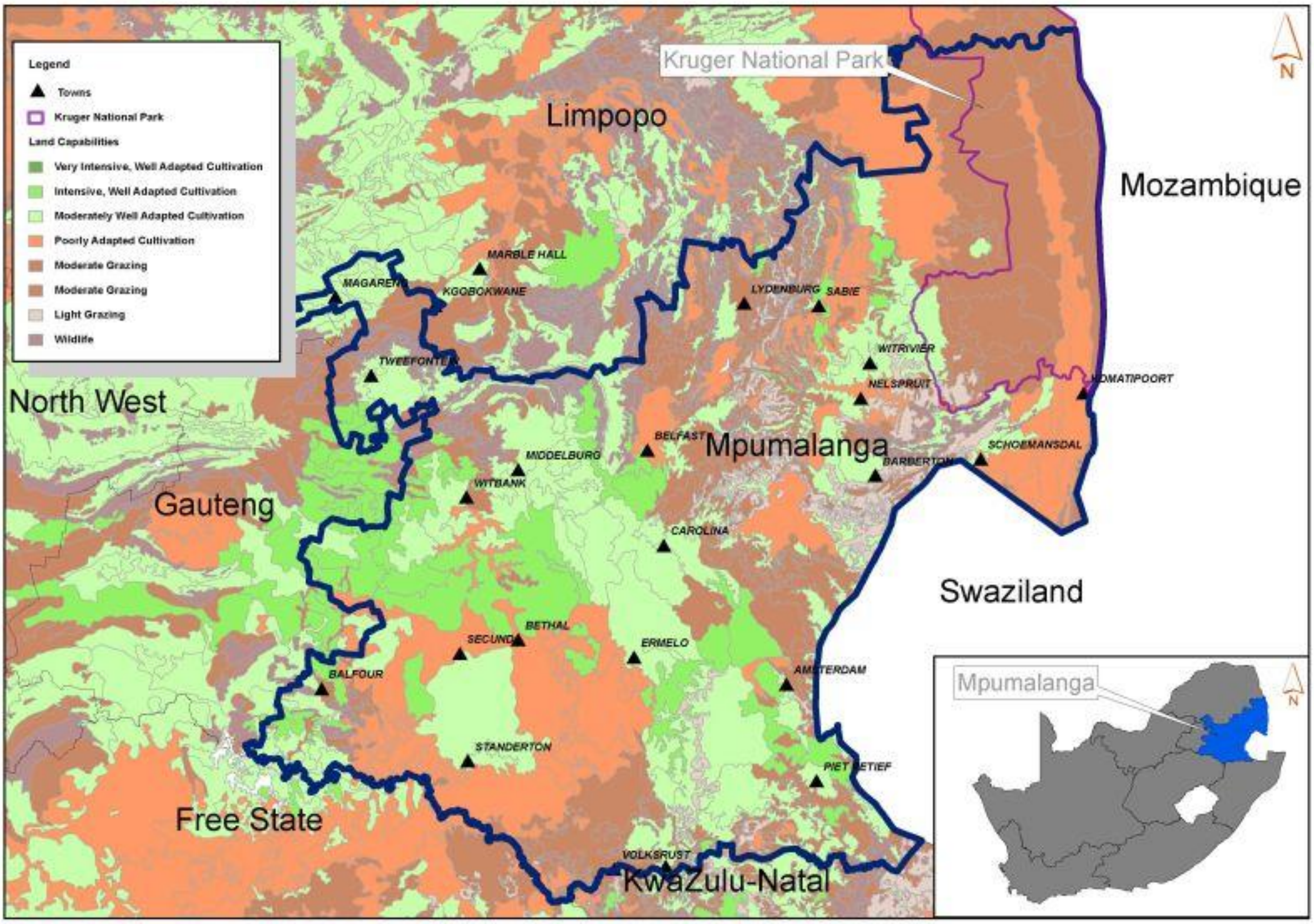

Figure 4-3: Map of the Mpumalanga Province indicating the land capability classes

The loss of arable land in Mpumalanga due to mining activities, for the highest two arable land capability classes, is presented in Table 4-2. These values indicate that current and future mining activities will have a significant negative impact on agricultural production, as well as long-term implications for food prices and food security. Even after rehabilitating an opencast mine in accordance with best-practice standards, the land capability will be significantly decreased as some effects, such as soil loss, may be latent for several years following rehabilitation (Limpitlaw et al. 2005). Inadequately rehabilitated lands are also susceptible to settlement, erosion and the establishment of invasive plant species.

The significant backlog in the rehabilitation of mined land, combined with the failure of many rehabilitation efforts, is a cause of great concern. The negative impact of mining upon agricultural lands is not limited to opencast mining operations. Underground coal mining's impact on agriculture and water is not negligible, with the potential for subsidence, cracks or sinkholes forming above areas where underground mining has taken place. The risk is significantly heightened if high extraction methods of mining are employed, e.g. high extraction or longwall mining. The impacts resulting from these forms of mining can threaten catchment runoff, wetlands, groundwater, infrastructure and animal and human safety.

Table 4-2: Loss of high-value agricultural land due to mining activities in Mpumalanga (ha) (Collett 2013)

Land capability class	I	II
Available	872 007	2 058 727
Existing mining	18 378 (2.1%)	34 868 (1.7%)
Mining and prospecting applications	751 326 (86.2%)	1 404 224 (68.2%)

The food produced in Mpumalanga is for both local and national supply, as well as for export. In terms of food security, rising food costs are a global trend. In South Africa, food prices are increasing due largely to input costs such as energy, i.e. pumping costs, thus emphasizing the importance of the nexus approach. Inadequate (8.4%) or severely inadequate (19%) access to food is experienced in Mpumalanga in 27.4% of households (StatsSA 2015). These statistics indicate that this province requires significant progress in order to achieve Sustainable Development Goal (SDG) 2, “Zero hunger.” This challenge in term of adequate access to food is more a problem related to poverty than actual food production.

Improved land management strategies and policies, as well as increased resource efficiency, will be required to produce more food with the same area of available land. The option of simply planting more food and expanding agriculture to satisfy the increasing demand, due to population growth and changing consumption patterns, is not feasible since all soils are not equal from an agricultural cultivation perspective. Further, rainfall, evaporation, topography and other factors (e.g. distance to market) that cultivated land depend on are not equally available throughout Mpumalanga. The use of degraded land will present an opportunity for renewable energy generation, specifically bioenergy production (Wicke 2011). However, it is critical to implement efficient water use strategies if bioenergy generation is to be sustainable, e.g. irrigation of bioenergy crops with mine-affected water (if this is successfully trialled and approved by the Department of Water and Sanitation).

4.6 Nexus assessment

Having presented various details relating to the three resource sectors, together with selected interactions and trade-offs, the WEF nexus is tabulated and presented graphically for the province of Mpumalanga in Table 4-3 and Figure 4-4**,** respectively. Six indicators appertaining to the Mpumalanga Province are presented. Two of these ratios have been selected for each of the three resource sectors, one representing human vulnerability and the other resource security on a provincial or national level. These indicators were selected to due both their relevance to this study and the availability of this data. These values can be tabulated and graphically represented together since they each represent different facets of Mpumalanga's WEF nexus resource security. For example, by presenting both the proportion of people with connections to national grid electricity supply (which provides an indication of infrastructural development) and the share of renewables in electricity production, an indication of progress towards SDG 7 is obtained. Similarly, the proportion of Non-Revenue Water provides an indication of municipal governance standards, while access to improved drinking water provides an indication of progress towards SDG 6.

Table 4-3: Six ratios appertaining to the WEF nexus in the Mpumalanga Province

Sector indicator	Ratio	Source
Mpumalanga households with access to improved drinking water	0.914	(StatsSA 2016b)
Average Mpumalanga Municipal Revenue Water (System input minus Non-Revenue Water and Unbilled Authorised water)	0.566	(Mckenzie et al. 2012)
Mpumalanga households with connections to mains electricity supply	0.898	(StatsSA 2015)
Share of renewables in electricity production in South Africa	0.033	(Enerdata 2016)
Mpumalanga households with adequate access to food	0.726	(StatsSA 2015)
Cereal import in-dependency for South Africa	0.972	(FAO 2016)

The reason for presenting the cereal import dependency ratio and the share of renewables as national values is that these ratios are equally applicable to all provinces in South Africa. Some ratios, such as the cereal import dependency ratio, can be greater than one. This is the case for countries that produce cereal crops in excess of their domestic requirements, such as Argentina, Canada and Bulgaria.

The radar chart in Figure 4-4 indicates that South Africa is currently largely self-sufficient in terms of cereal production. A significantly large proportion of the households in the Mpumalanga Province have access to improved drinking water and mains electricity supply, especially when the backlog in the provision of basic services to the majority of the population in South Africa, post-Apartheid, is considered. What is concerning is that just over a quarter of this province's population has inadequate or severely inadequate access to food.

South Africa's dependency on coal for power generation, which in turn requires land for the development of mines – which in Mpumalanga is often high potential arable land – means that food security is being threatened by the pursuit of coal-based energy security. This may in time negatively impact the cereal import dependency ratio, which will raise food prices, resulting in increased pressure on the vulnerable members of society.

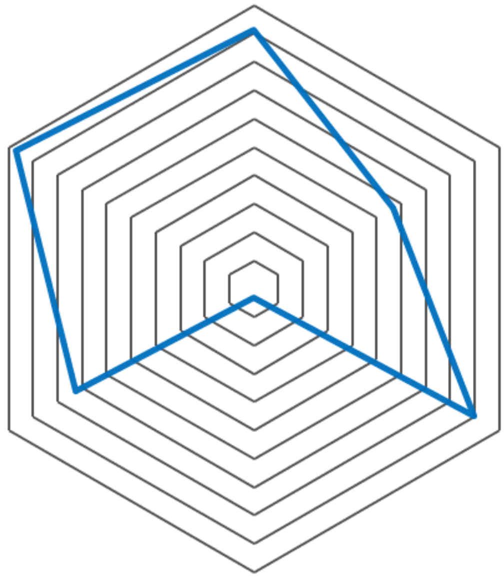

Figure 4-4: Radar chart of two indicators for each of the WEF resource sectors

The radar chart also presents the average Revenue Water associated with municipalities in Mpumalanga Province. The Non-Revenue Water values ranged from 33.6% to 51.3% in the assessment undertaken in this province (Mckenzie et al. 2012). These values indicate that much can be achieved at a local government level to reduce water leaks and improve cost recovery. When water losses are considered in conjunction with the 16.5% of households in the province who experience water pollution (StatsSA 2016b), it is evident that water security is being threatened by not only poor governance but also by the pursuit of energy and food security. This is because much of the water pollution results from AMD, contaminated runoff from mines, agricultural chemical fertilisers, and the poor management of municipal sewerage treatment works.

4.7 Conclusions and recommendations

This semi-quantitative WEF nexus assessment of the Mpumalanga Province yields several interconnections between the three constituent sectors. When considering the importance of the region for coal mining and agriculture, and the cross-cutting relevance of water to both, this analysis has shown that an integrated approach is necessary to facilitate any movement towards resource management and the attainment of SDGs 2, 6 and 7.

When sensitive natural systems are considered in parallel with conservation areas such as the Kruger National Park, trans-boundary water considerations, decreasing arable hectarages, and the need to continue mining coal for the medium to long-term, it is essential that regional planning and policies be developed to balance the competing sectors, and to introduce an element of sustainability to this potentially volatile situation. One such effort from DAFF is the *Preservation and Development of Agricultural Land Bill*, which aims, amongst others, to promote the preservation and sustainable development of agricultural land.

The integration of several key regulatory departments associated with the WEF nexus, together with industry, NGOs and the public, in a regional planning initiative is imperative to enable this region to balance its, and the nation's, competing requirements. Ideally, this effort should be integrated with a regional land use and mine closure strategy. The WWF already stated this in 2011, when they wrote that the National Planning Commission and Departments of Water and Sanitation, Environmental Affairs and Mineral Resources must agree at the highest level to restrict mining in critical water source areas in order to mitigate the impacts of water pollution (Colvin et al. 2011). Further, the WWF also emphasized that spatially explicit development plans are needed at a provincial level that takes into account high yield catchment areas, critical biodiversity areas and high-value agricultural areas.

Because of the continued dependence on coal in South Africa for the foreseeable future, it is imperative that any policy and planning initiatives be accompanied by mitigation measures. Such mitigation measures could include retrofits to the existing coal-fired power plants to increase their efficiencies and flexibility, thereby reducing their coal consumption and CO_2 emissions. Flexibility does not make coal clean, but making existing coal-fired plants more flexible enables the integration of more wind and solar power in the system (Agora 2017).

Alternative solutions, such as a significantly increased share of electricity from renewable sources, must be accelerated. This could be achieved if the implementation of the 55 000 MW renewable component of the Department of Energy's *Integrated Resource Plan Update* (Department of Energy 2016) is brought forward. This will not only decrease the reliance on coal-fired power generation but can also be an accelerator for innovation and a provider of so-called "clean jobs" (including the manufacture of components of renewable energy systems), thus not only yielding environmental but also socio-economic benefits.

Many studies and much monitoring has taken place in the Mpumalanga Province (Colvin et al. 2011, McCarthy 2011, BFAP 2012, Collett 2013, Lodewijks et al. 2013, Delport et al. 2015, CER 2016, Solomons 2016, StatsSA 2016b, Agora 2017, Simpson and Berchner 2017). Many of these calls for change have fallen on deaf ears due to the energy security, jobs and economic benefit that fossil-fuel-based energy production delivers. There is however a need for WEF nexus science and data to influence integrated public policy in order to promote the long-term sustainability of this resource-rich province.

CHAPTER 5: LEAVE NO ONE BEHIND: A SOUTHERN AFRICAN PERSPECTIVE ON WATER-ENERGY-FOOD NEXUS ANALYSES AND INNOVATIONS

5.1 Introduction

The exponential growth in the global population has resulted in a corresponding demand for innumerable resources, including building materials, minerals, water, energy, and food (UN 1951, Bongaarts 2009, Gerland et al. 2014). With the planet's development showing no signs of tapering off, combined with the snowballing consumption of a burgeoning middle class, increasing pressure is being placed on the planet's limited resources (Rockström et al. 2014). It has been estimated that the worldwide demand for energy will practically double by 2050, while water and food demand is projected to rise by over 50% (IRENA 2015)

While much growth and economic development has occurred during over the past two and a half centuries, there has been a marked disparity in the distribution of the latter. In the world's least developed countries (33 of which are in Africa):

- 1.4 billion people still do not have access to electricity,
- 3 billion are without access to modern fuels or technologies for cooking and heating,
- 900 million people lack access to safe water,
- 2.6 billion do not have improved sanitation facilities,
- More than 900 million people are chronically hungry because of extreme poverty, and
- 2 billion people intermittently lack food security (Bazilian et al. 2011)

In high-income countries, several indicators such as the prevalence of undernourishment and the proportion of children under five years of age who are affected by wasting or stunting are not monitored. This is because the incidence of these conditions in these countries is negligible. In contrast, much of Africa still faces these developmental challenges. Globally, over 95 million fewer children were stunted in 2016 than in 1990, yet in Sub-Saharan Africa, the number of stunted children has increased mainly because of the region's increasing population (World Bank 2018a). Further, population growth has outpaced energy infrastructure development in Sub-Saharan Africa, where more people now live without electricity than in 1990 (ibid.). The 'Leave No One Behind' (UN Water 2018) programme seeks to harness momentum to ensure that the Sustainable Development Goals (SDGs) are achieved. It is therefore imperative that any sustainability framework being applied to developing regions such as Southern Africa has an explicit emphasis on distributional justice and the achievement of these seventeen bold goals.

This paper presents the perspective that the WEF nexus is inherently anthropocentric, and to provide the necessary background, the proposed Anthropocene will be briefly described. The WEF nexus will then be described with selected published frameworks being summarised. Finally, a WEF nexus framework developed from an anthropocentric perspective, informed by our experience and knowledge from Southern Africa, aimed at guiding models, indices, innovations and assessments will be presented. The motivation for positioning humans at the centre of a WEF nexus conceptualisation is that their demand for, access to, and governance of, water, energy and food is a (if not *the*) foremost direct driver of growth within these resource sectors. The anthropocentric framework should not be viewed as an isolated contribution that merely adds to the number of existing frameworks. Rather, it is the first framework that places human influences at the core of the nexus and links this to the formal reporting of the SDGs. It is presented from a developing country perspective, or more specifically, a Southern African viewpoint. Further, it serves as a vital cog in the process of developing nexus tools such as a WEF nexus composite indicator, dashboard, innovation or quantitative model. To that end, several vignettes of innovative WEF nexus projects in Southern Africa are presented.

5.2 Background

UN Water (2018) state that 24% of people in sub-Saharan Africa have access to safely managed drinking water services. Figure 5-1 presents the percentage of the population in each of the Southern African Development Community (SADC) nations (excluding Comoros, for which no data is available) that had access to improved water sources between 1990 and 2015.

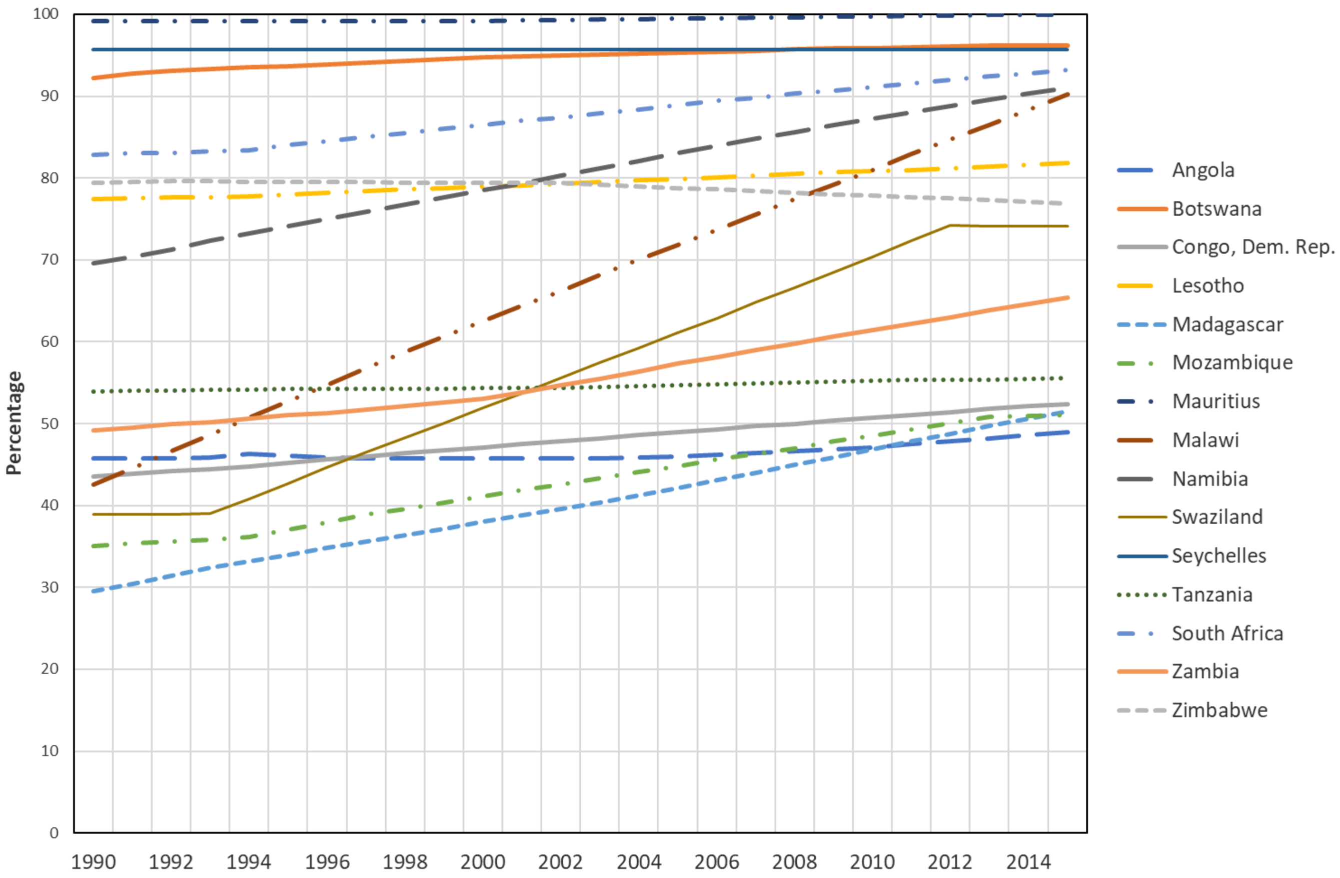

Figure 5-1: Percentage of population with access to improved water sources in SADC countries: 1990 to 2015 (World Bank 2018b)

While Mauritius, Botswana and Seychelles have high levels of access to improved water sources, and South Africa's service delivery has increased progressively since the end of Apartheid, several SADC nations have relatively low (<60%) levels of access to improved water sources. What is even more concerning is that Zimbabwe's provision of access to improved water sources has declined during the period. Based on access to improved drinking water sources, the SADC region has much work remaining to attain SDG 6.1 i.e. "By 2030, achieve universal and equitable access to safe and affordable drinking water for all" (UN Water 2018), especially when it is understood that "an acute lack of capacity is constraining water resources development and management in all its facets, across most developing countries, particularly in sub-Saharan Africa and South and South-eastern Asia" (ibid.)

SDG 6 addresses access to both improved water sources and improved sanitation facilities. Figure 5-2 presents the proportion of the SADC countries' (excluding Comoros) with access to improved sanitation facilities between 1990 and 2015. Seychelles and Mauritius both have significant levels of access to improved sanitation facilities. While the trajectory of the implementation of access to better sanitation facilities is positive for nearly all countries (except Zimbabwe), there remains much work to do, with all other nations having less than 70% access to improved sanitation facilities. More than half of the nations in the SADC region have less than 50% of their population having access to improved sanitation facilities. UN Water (2018) report that 220 million people in sub-Saharan Africa still practice open defecation. SDG 6.2 specifically addresses this practice, stating that "By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations " (UN Water 2018, World Bank 2018a).

Figure 5-3 presents the proportion of the population with access to electricity per SADC country from 1990 to 2014 (excluding Comoros). Access to electricity is very high for Mauritius and Seychelles, while Swaziland, Namibia, Botswana and South Africa's service delivery in terms of electricity has enhanced significantly since 1990. While there has been a general upward trend in access to electricity levels, these levels are below 45% for nine of the SADC countries. Alarmingly, the level of provision of access to electricity for the population of Angola has steadily and markedly decreased since 1990."

Sachs (2015) laments that more than one-third of the population in tropical Africa, especially central and southern Africa, is undernourished. UN Water (2018) explain that sub-Saharan Africa experiences the highest level of food insecurity, affecting almost 30% of the population. The prevalence of undernourishment in SADC countries (except Comoros), from 1991 to 2015, is presented in Figure 5-4. Schreiner and Baleta (2015) suggest that the agricultural potential of countries like Zambia could be exploited for the benefit of the entire region. While this position has merit, it is ironic that fertile countries such as Zambia experience such high levels of undernourishment - that have increased since the late 1990s! The *Joint Child Malnutrition Estimates Report* states that "Malnutrition rates remain alarming: stunting is declining too slowly while wasting still impacts the lives of far too many young children"

(UNICEF/WHO/World Bank 2019). Further, they report that Africa is the only region where the number of stunted children has risen between 2000 and 2018 (ibid.). Much work, therefore, remains for SDG 2 to be achieved, with SDG 2.1 stating: “By 2030, end hunger and ensure access by all people, in particular, the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round ” (World Bank 2018a).

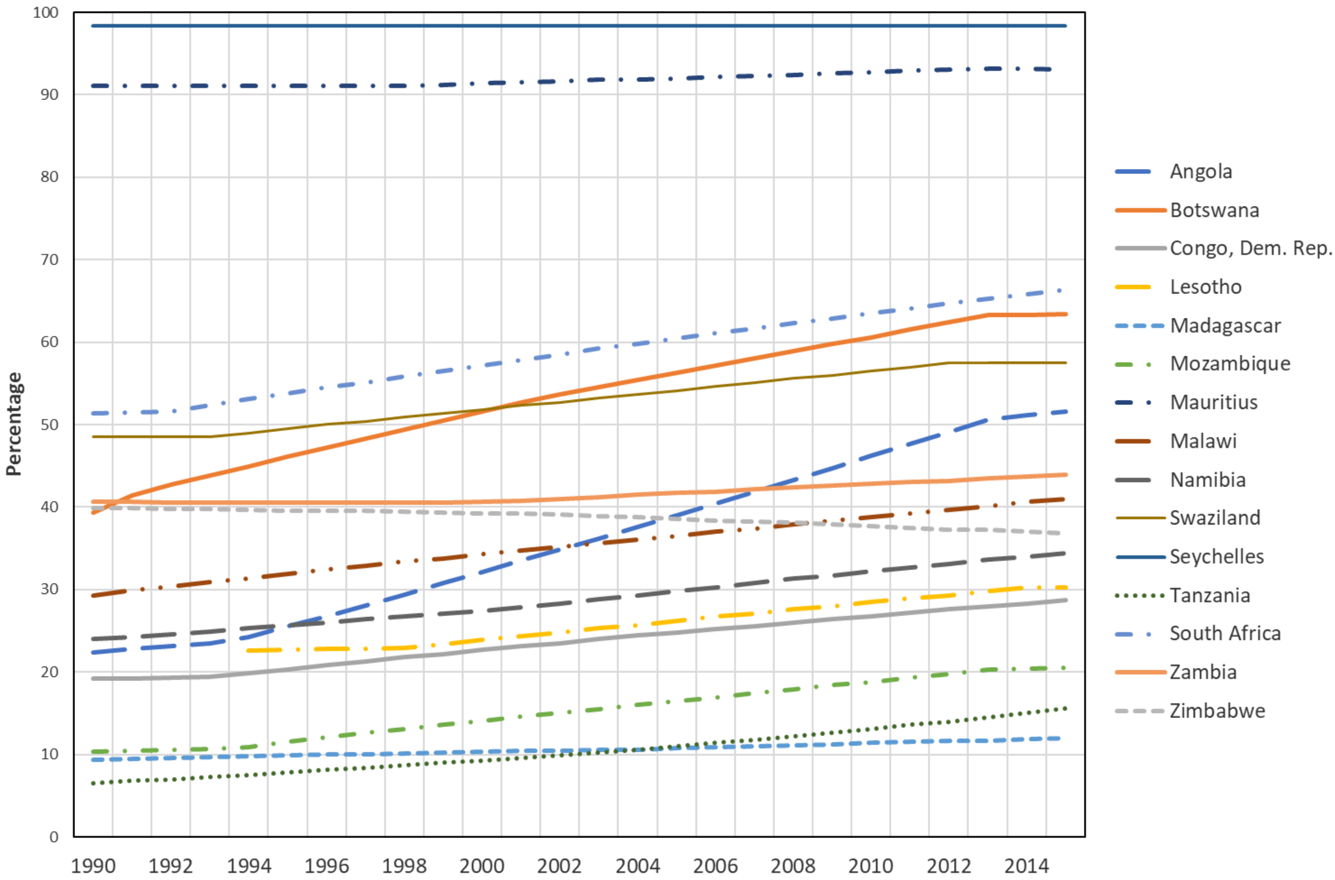

Figure 5-2: Percentage of population with access to improved sanitation facilities in SADC countries: 1990 to 2015 (World Bank 2018b)

5.3 The challenge

Which sustainable development approach should policymakers, researchers and development agencies adopt to measure, manage and mitigate humanity’s insatiable appetite for resources that are directly or indirectly obtained from a finite natural resource base, while simultaneously pursuing equitable access to resources for the ‘bottom billion’? Traditionally, development activities and resources have been governed on a sectoral basis, often termed institutional ‘silos.’ The arbitrary separation of their domains of activities and responsibilities is evidenced by separate departments, or ministries, for the governance of, e.g. the mineral extraction, land, water, energy, environmental and agricultural sectors (Gupta 2017). Since 2008, there has been growing recognition of the relevance and importance of nexus thinking in dealing with the complex challenge of attaining 'the world we want', enabling decision-makers to holistically address sustainability challenges (Simpson and Jewitt 2019).

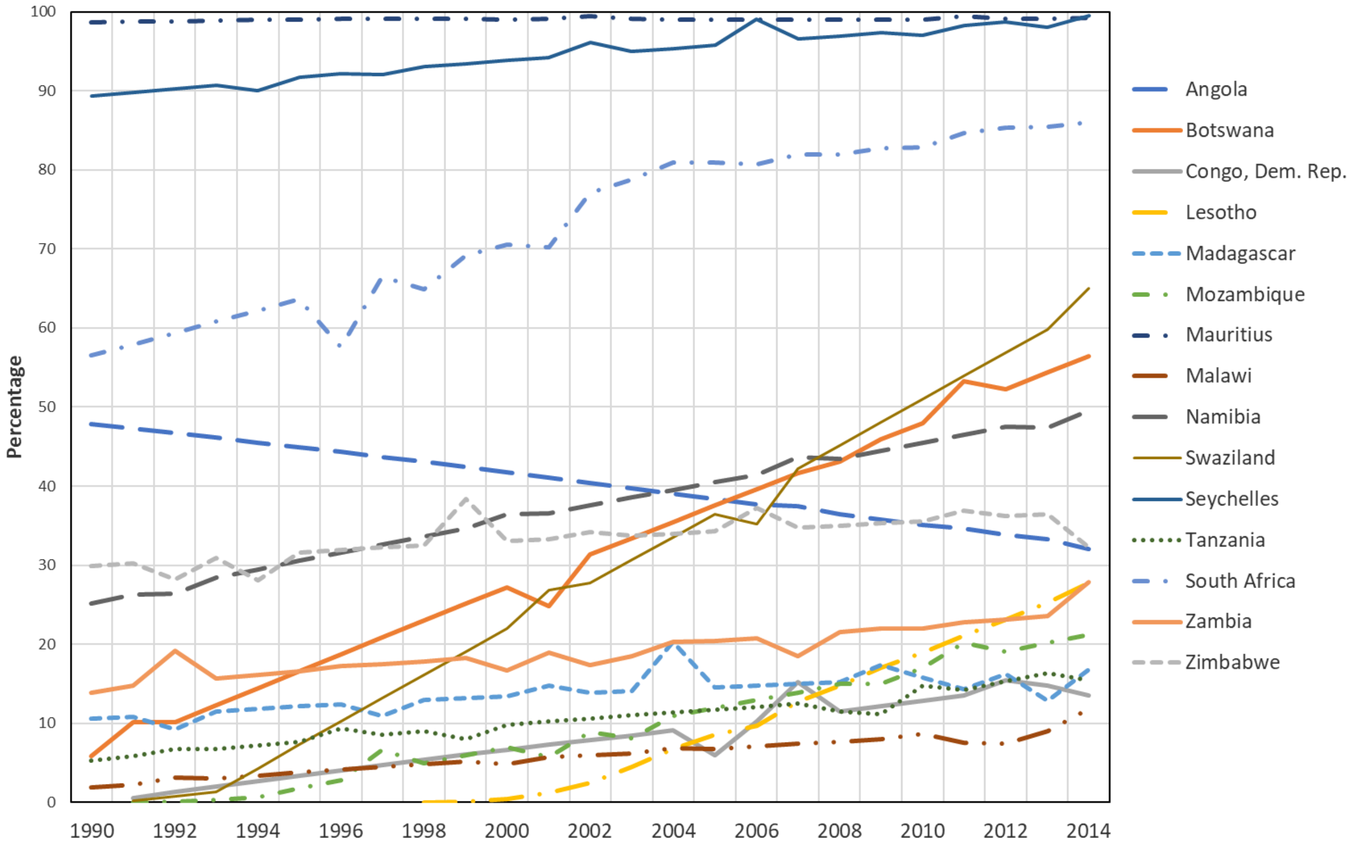

Figure 5-3: Percentage of population with access to electricity in SADC countries: 1990 to 2014 (World Bank 2018b)

A nexus configuration that has garnered notable interest within the academic, development and policy-making fraternities since the *Bonn2011 Conference* is the water-energy-food (WEF) nexus (Hoff 2011). In seeking to understand the WEF nexus, a pivotal research question is "What is driving the entire WEF system?" It is herein proposed that *humanity*, with its insatiable demand for a myriad of products and services, is the principal driver of this system. Whilst this may seem self-evident, this reality has not been the focus of attention in many WEF applications. Ironically, humans are also the custodians of the system and policies that determine how the environment and resources are managed (or mismanaged). For better or worse, humanity is both the player *and* the referee in administering Earth.

5.4 The Anthropocene

Homo sapiens' impact on "spaceship earth" (Boulding 1966) has been so profound that it has been proposed that a new epoch, termed the Anthropocene, be formalised (Crutzen and Stoermer 2000, Crutzen 2002). Crutzen (2002) proposed that the Anthropocene started in the latter portion of the eighteenth century. While this new geological epoch has not yet been formally adopted, there has been much interest in the proposition within academic, political, media and public spheres (Davidson 2019), evoking debates within the earth and environmental sciences (Kaika 2018).

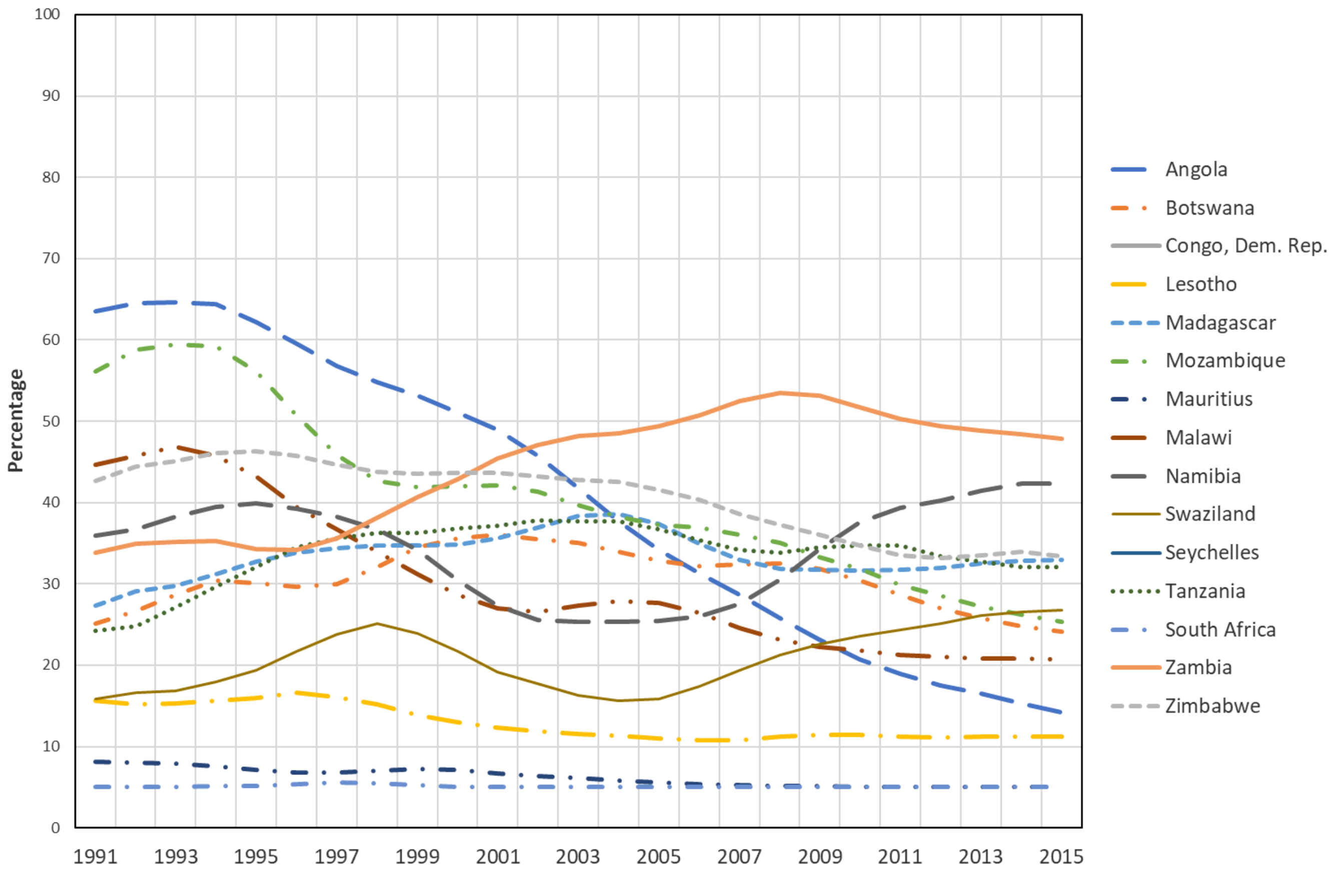

Figure 5-4: Prevalence of undernourishment in SADC countries: 1991 to 2015 (World Bank 2018b)

In considering the case for the Anthropocene from a geomorphological perspective, Brown et al. (2013) note that accelerated hillslope erosion and the associated sediment transport has resulted from agricultural practices, mining, urbanisation and reservoir construction. Other forms of human-modified landscapes include buildings, spoil heaps, landscaped gardens, rural landscapes, engineered embankments and rubbish dumps (Jordan and Prosser 2014). Zalasiewicz et al. (2018) list 'mineraloids' such as plastics, and novel rock types such as concrete, ceramics, and brick as some of the signatures of the Anthropocene. Harte (2018) suggests that a band of 'plastiglomerate' lithic material or the growth in radionuclides in sediments could provide a marker for the Anthropocene. In terms of distributional justice within the Anthropocene, Sušnik (2018) shows that "in general, resource-rich, less-developed countries transfer resources to resource-poor, well-developed countries." This finding leads to what Meadows et al. (1972) demonstrated almost half a century ago, that the "rich get richer and the poor get children." This saying holds true today! The UN (2014) has reported that the continuing urbanisation and growth of the world's population are projected to add two and a half billion people to the urban population by 2050, with nearly 90% of the increase concentrated in Asia and Africa. Despite this mammoth urban migration, 90% of the world's rural population will also live in Africa and Asia (UN 2014).

Sachs (2015) suggests that "The Anthropocene is the era - our era - in which humanity, through the massive impacts of the world economy, is creating major disruptions of Earth's physical and biological systems." Zalasiewicz et al. (2018) conclude that "Whether formal or informal, though, the Anthropocene is clearly a major new phase in our planet's history." Perhaps this is the best way to view the Anthropocene until a decision is made regarding whether it will formally succeed the Holocene epoch.

5.5 Existing WEF nexus frameworks

There is a need to translate the nexus concept into a comprehensible framework that can be applied to decision making (Martinez-Hernandez et al. 2017). This configuration must take into account both the anthropocentric nature of the world and the aim of enabling developing countries to achieve the SDGs. A framework facilitates the understanding and defining of the multidimensional phenomenon to be measured by structuring the sub-groups of the phenomenon (if required), and in composing a list of selection criteria for the underlying variables, e.g., inputs, outputs, and processes (OECD 2008). It also aids in guiding the choice of components that will be utilised to assess the approach for which the framework has been developed, e.g. in the development of WEF nexus-based assessments, innovations, models or a composite indicator.

Sušnik (2018) contends that the seminal work *The Limits to Growth* (Meadows et al., 1972) was arguably the earliest study of a nexus. Nexus thinking in various configurations has become a recurrent conceptual approach to integrated resource management and sustainable development over the past decade, with the WEF nexus being dominant (Wong 2010, Hoff 2011, Lal 2013, Ringler et al. 2013, Cader et al. 2016, Carvalho et al. 2016, Chen and Chen 2016, Rulli et al. 2016, Sanders and Masri 2016, Smajgl et al. 2016, Yang et al. 2016, Chinese et al. 2017, Rambo et al. 2017, Chen et al. 2018, Dai et al. 2018). While some authors have found no clear methodological basis uniting WEF nexus studies (Galaitsi et al. 2018), proponents argue that several sustainability issues, such as water scarcity, fossil fuel dependence, and food security can be assessed utilising a WEF nexus perspective (Halbe et al. 2015, Brouwer et al. 2018).

Benson et al. (2015) proposed that the WEF nexus should focus on securitisation, i.e. macro-scale resource security, to complement Integrated Water Resource Management (IWRM). Rasul and Sharma (2016) argued that focusing on trade-offs and synergies utilising a nexus approach could facilitate improved climate change adaptation and assist in the achievement of food, water, and energy security by enhancing resource use efficiency and encouraging greater policy coherence. de Loe and Patterson (2017) state that a new framework that moves beyond water-centric assumptions (such as IWRM) is needed and that the multi-centric focus of the WEF nexus meets this requirement.

Several conceptual WEF nexus frameworks emphasise the interlinkages between the three resource sectors (Gulati et al. 2013, Smajgl et al. 2016, Liu et al. 2017). Others have the core of their frameworks aligned with the area of expertise and sectoral focus of their developers. The WEF nexus can serve as a relevant approach for informing policy related to resource security, but only if it is framed in a manner that captures its potential shortfalls, such as the neglect of livelihoods or ecosystem services (Simpson and Jewitt 2019). Hoff (2011) selected the available water supplies as the focal point of his nexus framework. Leck et al. (2015) argued that it would be equally valid to have other central goals such as sustainability or equity. Mirzabaev et al. (2015), who modified the framework presented by Hoff, centred their framework on households and communities and included policies, actions, drivers and impacts. Ringler et al. (2013) proposed a food-energy-land-water nexus framework with food at its centre.

Larcom and van Gevelt (2017), who modified the framework developed by Bazilian et al. (2011), sought to present regulatory aspects related to the WEF nexus. Machell et al. (2015) meanwhile proposed that waste is a vital factor that is often overlooked in WEF nexus assessments, and included it as the fourth core component in their nexus conceptualisation. Halbe et al. (2015) included the selection of stakeholders and innovations in their proposed methodological framework. Other frameworks are aimed at modelling the WEF nexus. Martinez-Hernandez et al. (2017), for example, adopted a generic WEF nexus framework for modelling local production systems utilising the NexSym nexus simulation tool. Biggs et al. (2015) presented a framework with livelihoods at the heart of the WEF nexus, which is aligned with the philosophy put forward in this paper.

Others are concerned that having resource security as the focus of the WEF nexus approach could lead to the neglect of the poorest members of the global society (Leese and Meisch 2015, Simpson and Jewitt 2019). This argument is based on the belief that the WEF nexus agenda is being driven by economic interests, i.e. multinational companies, as opposed to facilitating social justice and environmental sustainability (Allouche et al. 2015). Allouche et al. (2019) explain that “The business logic is as follows. To grow, economies should shift their water allocations away from farming and towards uses that deliver higher economic value per litre, especially energy production, industry, and manufacturing.”

If the nexus is to be used as a lens for sustainable development, as it was originally envisaged (Brundtland 1987), a conceptual framework for the WEF nexus should address the disparity in access to resources and the protection of the environment (Biggs et al. 2015, de Grenade et al. 2016). Further, any framework utilising the WEF nexus approach should ideally include both direct (e.g. climate change) and indirect (e.g. population growth; urbanisation) drivers.

5.6 The anthropocentric WEF nexus framework

de Grenade et al. (2016) were concerned that most nexus research, policy, and management approaches assess environmental sustainability from a human-centric perspective. Yet water, energy, and food security *are* centred on satisfying humanity's constantly-mushrooming demand for both livelihoods and economic development, particularly in developing regions such as Southern Africa where safe and reliable access to resources is not yet universal. The profound anthropogenic impact on the world is captured very aptly in the response of a renowned author to a question posed in a newspaper about a century ago. The question was 'What's Wrong with the World?', which received the written response 'Dear Sirs: *I am*. Sincerely Yours, G. K. Chesterton' (Keller 2008)

The global challenge is to achieve an equilibrium between the supply and demand of water, energy, and food while population growth, urbanisation, pollution and living standards continue to escalate – all without exceeding planetary boundaries (Rockstrom et al. 2009). The SDGs, endorsed by the UN, are a global response to address sustainability and equity concerns. Among the key concerns is equitable access to healthy food, safe water and clean energy (SDG 2, 6 and 7 respectively). Sachs et al. (2018) explain that "Achieving the SDGs will require deep transformations of education systems, healthcare, energy use, land use, urban planning, and deployment of information technologies." This is especially true of regions such as Sub-Saharan Africa, where more than 390 million people lived on less than $1.90 a day in 2013 (World Bank 2018a). Access to, and availability of, the trio of resources in this nexus are arguably the two sub-pillars upon which water, energy and food security are each built (Willis et al. 2016).

Salam et al. (2017) argue that the interconnections between the SDGs emphasise the need for a nexus approach. In support of the inclusion of the relevant SDGs in a WEF nexus framework, it was one of the primary approaches considered by the UN in establishing these goals (Benson et al. 2015). Ringler et al. (2013) contend that the SDGs provide an important test for implementing nexus thinking and governance at an international level. El Costa (2015) suggested that since the SDGs seek to incorporate multiple development goals, identifying targets *at the nexus* of various sectors can be instrumental in yielding a less complex SDG framework. A reasoned, practical WEF nexus framework can, therefore, serve as a basis to develop innovative water-, energy- and food-related projects, a composite indicator, dashboard, serious game and/or integrated model that aids in the assessment and achievement of progress towards a subset of the SDGs.

Figure 5-5 presents an anthropocentric WEF nexus framework through which the different perspectives and elements within this system are considered and represented. The basis of this framework's development was a consideration of what lies at the centre of this nexus. It was concluded that mankind lies its centre. Water, energy, and food are ultimately obtained from the natural resource base (Rockström and Sukhdev 2016) and the flow of resources from the environment to the source of demand, i.e. humans, is, therefore, the dominant driver within this system. In addition, the climate and environment are managed and regulated through sound (or poor) governance and policies, as shown by the two intermediate layers within the proposed framework. At the core of this framework is ‘access’ and ‘demand’ related to the three core resource sectors, i.e. ‘leave no one behind’ and managing the global supply chain system. This proposed framework is especially applicable to Southern Africa due to its emphasis on SDGs 2, 6 and 7, as well as the all-encompassing role of governance and policy that promotes sustainable development and the protection of the environment. Equitable access to resources remains a critical issue in the SADC, especially given the region’s colonial past and the skewed access to resources that will persist into the third decade of the twentieth century. This is in line with African Union’s *Agenda 2063* which is distinctly contrasted with the often romanticised Western view of this continent as a safari destination. *Agenda 2063* envisions, amongst other targets, a “continent with free movement of people, goods, capital, and services and infrastructure connections” (African Development Bank 2019).

What is challenging is that a lack of access to, for example, food, could be because of poverty and not the lack of available food, hence the need for the SDG 8 (amongst others). This implies that any model, innovation or indicator utilising this framework must incorporate economics, job creation and/or investor sentiment (together with stakeholder engagement) into the analysis.

5.7 Innovation vignettes

Hoff et al. (2019) provide five WEF nexus case studies and then call for examples of additional innovations to develop “a solid and generalisable evidence base for successful nexus implementation.” Allouche et al. (2019) meanwhile note that “for the nexus to become more inclusive as a policy agenda, it must first be grounded in local realities and human needs, and far more concerned with social justice, which links it with concerns of ethics.” In response to these two statements, and utilising the anthropocentric WEF nexus framework as a lens, a series of vignettes describing innovative WEF nexus innovations in the SADC region are herewith presented.

The Lake Chilwa basin in Malawi has in recent years been experiencing longer droughts and lower yields. Where rain-fed cultivation was previously relied upon for food production, farmers in the Zomba district have been installing solar-powered groundwater pumps and 10 000 litre water storage dams (Reuters 2018). The water is utilised for irrigation, aquaculture and the provision of safe drinking water in an area where both fruit and vegetables can readily grow. The goal of this Global Environment Facility backed project is to assist 5 800 households to become more resilient to climate pressures (ibid.). By viewing this programme through the lens of the anthropocentric WEF nexus framework (refer to Figure 5-5), it is evident that climate change is threatening both water supply and crop yields in an area where access to electricity is not universal. This project addresses water, energy and food security and the distributional justice thereof.

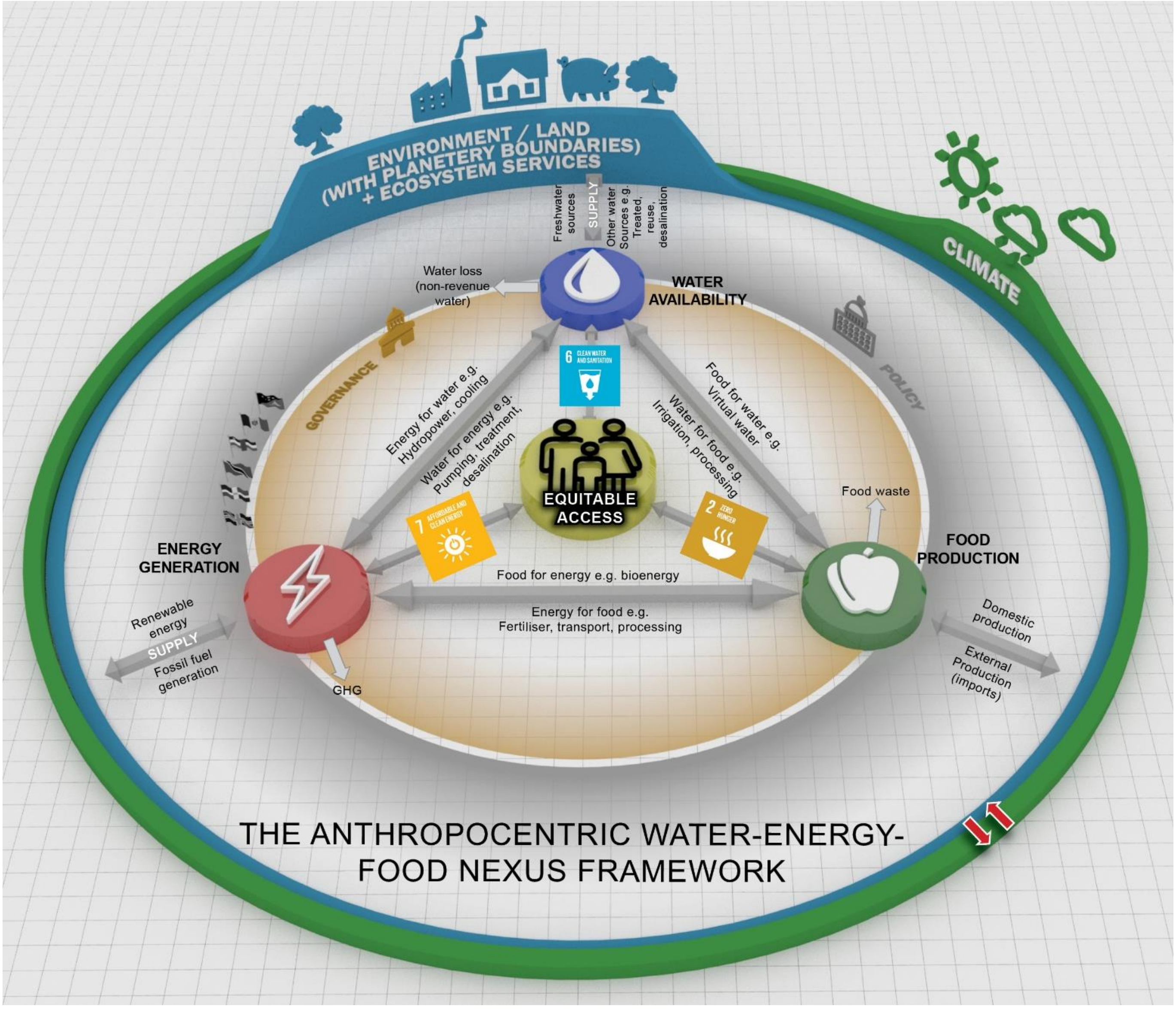

Figure 5-5*: The anthropocentric WEF nexus framework: Humankind, with the associated drivers of change, namely equity, population growth and urbanisation, are at the centre of this proposed framework. People receive water, energy, and food in order to sustain their livelihoods. The link between each of these resources and the core of the framework is however, not limited to the supply of water, energy, and food. Equitable access, represented by SDGs 2, 6 and 7, form the second component of the link between the respective resources and people. The interdependencies between the three sectors are represented by the direct links between water availability, energy generation, and food production. Noteworthy by-products associated with the three sectors are water loss (e.g. pipe leaks), greenhouse gases and food wastage, respectively. The supply of water, energy, and food are ultimately obtained from the natural realm. The climate influences the environment which is in turn influenced by how these resources are 'procured' (red arrows). This supply can be either renewable or non-renewable. In the case of food, it could be domestic production thereof or imported food. All levels of the system, including the environment and/or land use, are influenced by policies and governance, which are dependent on people. Humanity, therefore, drives the global supply chain system from the centre of this framework, while yielding momentous influence throughout the framework. If people are to obtain all that they demand from Earth in the long-term, then they must, in turn, govern wisely and develop appropriate, integrated policies. Resource demand management, sustainable supply, and the reduction of greenhouse gases and food waste are also imperative.*

Less than sixteen per cent of Tanzania's population had access to electricity in 2014 (refer to Figure 5 3). Zola Electric, formerly Off-Grid Electric, launched in 2012 in Tanzania. They provide 'solar plus storage' systems for off-grid households and businesses across Sub-Saharan Africa and have installed 1.17 million kilowatts of solar energy generation capacity that is benefiting one million people (Zola Electric 2019). Further, on 11 December 2018 Zola announced that they had secured a US$ 32.5 million credit facility to finance its activities in Tanzania over the next five years, which will enable them to provide electricity to an additional 145 500 Tanzanian homes (Burger 2019). Pre-Paid financing is built into all of Zola's energy systems, allowing customers to buy them over time (Zola Electric 2019). This project directly addresses equitable, scalable access to affordable, reliable, sustainable and modern energy, which is the grand aim of SDG 7.

Johannesburg has experienced significant population growth and urbanisation over several decades, not only from rural areas in South Africa but also from across Africa. City officials are, therefore, facilitating the establishment of rooftop vegetable gardens "to ensure food security for vulnerable people in the inner city and promote entrepreneurship" (Burger 2017). Numerous rooftop vegetable garden projects have been developed, including hydroponic systems. Some of the projects generate income for the farmworkers by selling fresh produce to the local community and restaurants. Others have the express purpose of donating a portion of their produce to a homeless shelter (ibid.). This project is a direct response to drivers of the anthropocentric WEF nexus system (refer to Figure 5-5), i.e. population growth and urbanisation, in order to diversify methods for the achievement of SDG 2.

Following droughts in many parts of South Africa over several years there has also been significant growth in rainwater harvesting from the rooftops of residential and commercial properties (Breytenbach 2016). This practice can aid water security at a domestic level, including small-scale agriculture.

A fruit farm in the Western Cape province of South Africa has built the first floating solar park in Africa (Caboz 2019). This 60-kilowatt system is utilised for providing power to irrigation pumps and packaging operations. This region was recently impacted by a crippling drought that resulted in Cape Town rallying to avoid 'Day Zero.' Additional benefits of this floating solar system are reduced evaporation from the dam, cooling of the solar plant components, a habitat for birds and fish, and not utilising potentially productive land for the solar development. The farm has also developed a 534-kilowatt solar park on adjacent unused land (ibid.). This innovative project has enabled this farm to significantly reduce its dependence on the national grid, which is principally supplied by coal-fired power plants (which have been relatively unreliable in recent years).

The Government of Seychelles has recently launched a request for proposals for the development of a floating solar park, with a capacity of 3.5 to 4 MW. It will be installed in the Providence lagoon on Mahé Island (Bulbulia 2019). The goal of this project is to support the country's transition to renewable energy, i.e. SDG 7.

5.8 Conclusions

Anthropogenic impacts on the world have been so profound that it has been proposed that a new epoch is proclaimed. The WEF nexus is a multi-centric sustainable development conceptualisation aimed at ensuring both the security of, and equitable access to, water, energy, and food. The active, integrated management of these resource sectors is of paramount importance, especially in developing regions such as Southern Africa. This is because of the projected increase in the demand for these resources in the approaching decades, as well as the planetary boundaries that are being tested (and in some cases exceeded). Because the WEF nexus is ultimately concerned with assured and equitable access to water, energy and food, an anthropocentric framework where humans drive and govern the global supply chain system is proposed. The sustainable provision of fresh water, clean energy, and healthy food necessitate that the environment is protected and managed and that broader access to these vital resource sectors must be attained. The SDGs are therefore integrated into, and integral to, the proposed WEF nexus framework. The framework can be utilised to aid in the development of models, WEF nexus data and information portals, composite indicators, stakeholder engagement and policy discussions. This is demonstrated through the presentation of selected vignettes in this paper.

CHAPTER 6: THE WATER-ENERGY-FOOD NEXUS INDEX: A TOOL FOR INTEGRATED RESOURCE MANAGEMENT AND SUSTAINABLE DEVELOPMENT

6.1 Research problem and objective

The purpose of this chapter is to test the hypothesis: *There is sufficient, relevant water-, energy- and food-related indicator data to develop a global, country-level WEF nexus-based composite indicator that can be utilised as a means for assessing integrated resources management and informing policy.*

6.2 Introduction

In the past decade, the Water-Energy-Food (WEF) nexus has emerged as a multi-centric lens for assessing integrated resource management and sustainable development (Weitz et al. 2017, Simpson and Jewitt 2019). For example, Brouwer et al. (2018) state that "the Nexus concept is a sound tool to support the sustainable management of resources across sectors, suitable for addressing the challenge of the next few years, namely achieving the Sustainable Development Goals." While there has been much effort to develop tools to monitor progress towards the Sustainable Development Goals (SDGs) (Sachs et al. 2019), there is less progress in assessing trade-offs between different SDGs or sub-sectors such as the WEF nexus. Humanity, for better or worse, is at the centre of the global supply chain system while also being the regulator of this multifaceted configuration. In order to manage this system, the linkages, inequalities, synergies, trade-offs, and limits to growth must be monitored, understood, communicated, managed and regulated. A means of indicating whether a country is achieving a balance in securing these resources, and assessing change over time would be a valuable policy tool.

Evaluating and illustrating the level of trade-off between the water, energy and food sectors is complicated because the individual sectors within this system are quantified with different units of measurement (de Loe and Patterson 2017, Wichelns 2017). One means of assessing such a multifaceted approach is through the development of a composite indicator (or index), which results "when individual indicators are compiled into a single index on the basis of an underlying model" (OECD 2008). This methodology identifies a conceptual framework, together with a set of relevant indicators. These indicators are normalised, weighted and aggregated, thereby yielding a unitless index that embodies the context being appraised, i.e. in this case, the WEF nexus. This index is complementary to the underlying data and can be used as a summary, as well as an access point to the complex data set upon which it is based, and to identify patterns and trends. Indices must be developed sensibly and transparently and used responsibly, since they can be misused (Saisana et al. 2018). Figure 6-1 shows that indicators and indices are developed from data in order to yield information that can ultimately be used for decision- and policy-making. This figure could include various feedback loops, such that policy-makers can require that certain data be collected to provide the indicators necessary to inform the decision-making process.

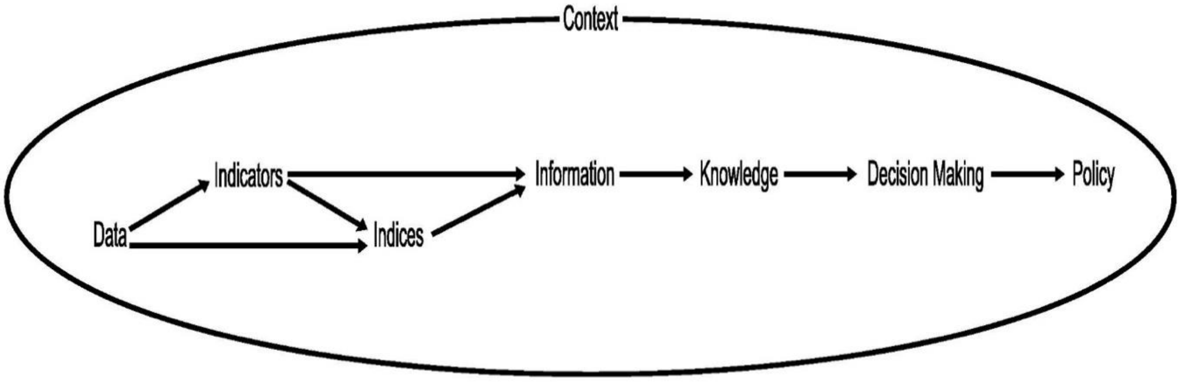

Figure 6-1: From data to policy; modified from Segnestam (2002) and Waas et al. (2014)

This article describes the development of a global WEF Nexus Index (Simpson et al. 2020). Associated with this academic paper are four addendums:

- *Addendum A*: The indicator selection table, which presents the 87 indicators reviewed in the development of the WEF Nexus Index, as well as their definitions, source, data adequacy, reference year, and a motivation of why each indicator was, or was not, included in the composite index.
- *Addendum B*: The untreated indicator data table includes the published data (e.g. by the World Bank, International Energy Agency (IEA) and the Food and Agriculture Organization of the United Nations (FAO)) for the 21 indicators that constitute the WEF Nexus Index, for the 170 nation that have adequate data.
- *Addendum C*: A table presenting the conceptual framework associated with the WEF Nexus Index's composition. This table includes the index, pillars, sub-pillars and indicators with each of their weights, forms of aggregation, and direction presented, as described in Simpson et al. (2020).

  Addendum D: A dashboard; the published data for the 21 indicators have been treated by normalising each of the data sets (using the min-max method, which normalises the indicators by subtracting the minimum value and dividing by the range of the indicator's values) so that they conform to a range from 0-100. The normalising of the data is also necessary to ensure that each indicator's data set is unitless such that it can be combined in a composite indicator. The data treatment includes the minimising of the distorting effect of outliers on the data using statistical methods. The dashboard has different colours for the treated data for each indicator in the following ranges: 0-25%; 25-50%; 50-75%; and 75-100%.

6.2 Methodology

The WEF Nexus Index was created based on the methodology expounded by the Joint Research Centre's *Competence Centre on Composite Indicators and Scoreboards* (OECD 2008, Saisana et al. 2018).

6.2.1 Development of the framework

The first step in forming a composite indicator is the development of a framework for the system under assessment. To this end, the anthropocentric WEF nexus framework, presented in Figure 5-5, was utilised as the basis for the WEF Nexus Index's construction. At the core of this framework is humanity, i.e. Anthropos (Greek for *human*), with its insatiable demand for resources. Globally, access to resources such as water, energy and food is not equitable, hence the inclusion of three water-, energy- and food-related SDGs in this framework. Each SDG has targets that "are universally applicable and aspirational" (UN Water 2018). SDG 6, for example, has eight global targets. The framework also reflects the priorities of the global South in achieving both access to and provision of resources (Simpson et al. 2020).

Further, these resources are procured from the environment in manners that are either renewable or non-renewable. The environment and climate are represented by the outer layers of this framework. In some cases, planetary boundaries are being tested or even exceeded (Rockstrom et al. 2009). This framework also demonstrates that while humanity is at the centre of the global supply chain system, they are also custodians of the governance and policies related to these three interdependent resources.

Based on this framework, the index has three equal pillars representing water, energy and food, as presented in Figure 6-2. Each of these resource sectors, in turn, have "Access" and "Availability" sub-pillars. The "Access" component of the WEF nexus relates to the urgent need for worldwide distributional justice in terms of access to resources. Access to resources is especially applicable to developing countries. This is the perspective from which the WEF Nexus Index was formed. While equitable access to resources is essential, the physical availability thereof is of equal importance.

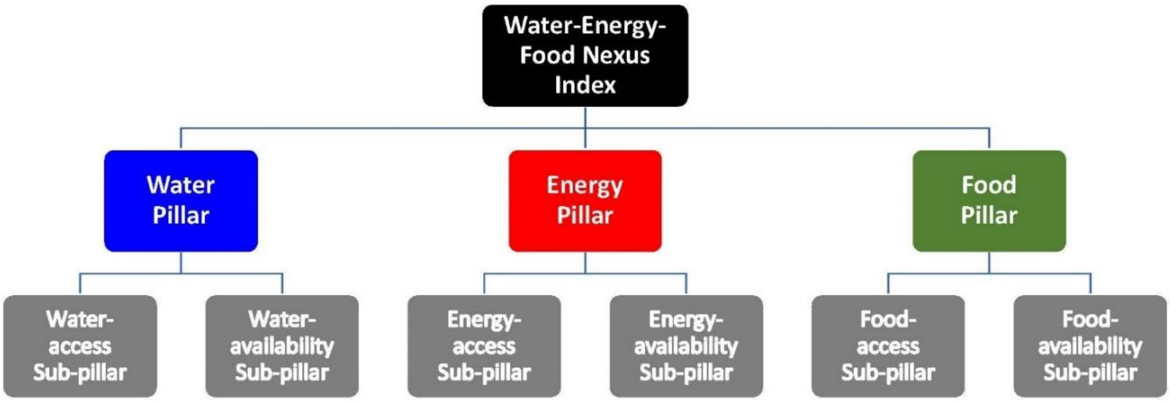

Figure 6-2: Pillars and sub-pillars associated with the construction of the WEF Nexus Index

6.2.2 Selection of indicators

The next stage in the development of a composite indicator is the selection of the indicators that will make up the index, utilising the framework and index pillar and sub-pillar structure developed for the system under assessment to guide the selection process. Internationally, data are collected by various organisations such as national statistical offices, government departments, non-governmental organisations and international organisations such as the World Bank, FAO, IEA and World Health Organisation (WHO). A global search of these databases resulted in a list of 87 water-, energy- and food-related indicators that were subsequently reviewed for both relevance and data availability at a national scale via a rigorous and iterative process.

Selection criteria included relevance, added value, data availability, and reliability, together with a correlation analysis to identify possible aggregation issues or double counting. Correlation is a statistical measure that demonstrates the degree to which two or more variables increase and decrease with one another. A positive correlation indicates that greater values of one variable are usually associated with higher values of the other variable, whereas a negative correlation would imply that higher values of one are associated with lower values of the other. In this context, if the correlation of the indicators is too high, taken to be equal to or greater than 0.92 in this study, then this constitutes double-counting, i.e. effectively including the same variable twice (OECD 2008). Details of each indicator evaluated, and a rationale for its inclusion or exclusion in the WEF Nexus Index is provided in **Addendum A**. The outcome of this analysis was a set of 21 indicators that were selected to compose the WEF Nexus Index, which is presented in Figure 6-3. Adequate data is available for the index to be calculated for 170 nations. The untreated indicator data for the 21 indicators that make up the WEF Nexus Index are presented in **Addendum B**. The latest available data has been utilised for the calculation of the WEF Nexus Index, with the reference year varying between indicators (which is a limitation when constructing composite indicators). For example, the data relating to the *Percentage of people using at least basic drinking water services* has a 2015 reference year, while the *Degree of Integrated Water Resources Management implementation* data is from 2017. Other data, such as for the indicator *Annual freshwater withdrawals*, have different reference years for different countries, varying from 2002 to 2014. The majority of the selected indicators have the same reference year, and with SDG indicators gaining momentum there will be more consistency in the reporting of key indicators more regularly.

6.2.3 Data treatment and normalisation

Following the selection of indicators, missing data were imputed where appropriate/necessary, predominantly where certain data is not collected in countries because the occurrence of a particular phenomenon is almost negligable, e.g. stunting in high-income countries. One case of imputation was for levels of undernourishment in high-income countries: here, average values reported by UNICEF are utilised, e.g. the average prevalence of undernourishment in high-income countries is 1.2% (Sachs et al. 2018). For more detail refer to **Addendum C**.

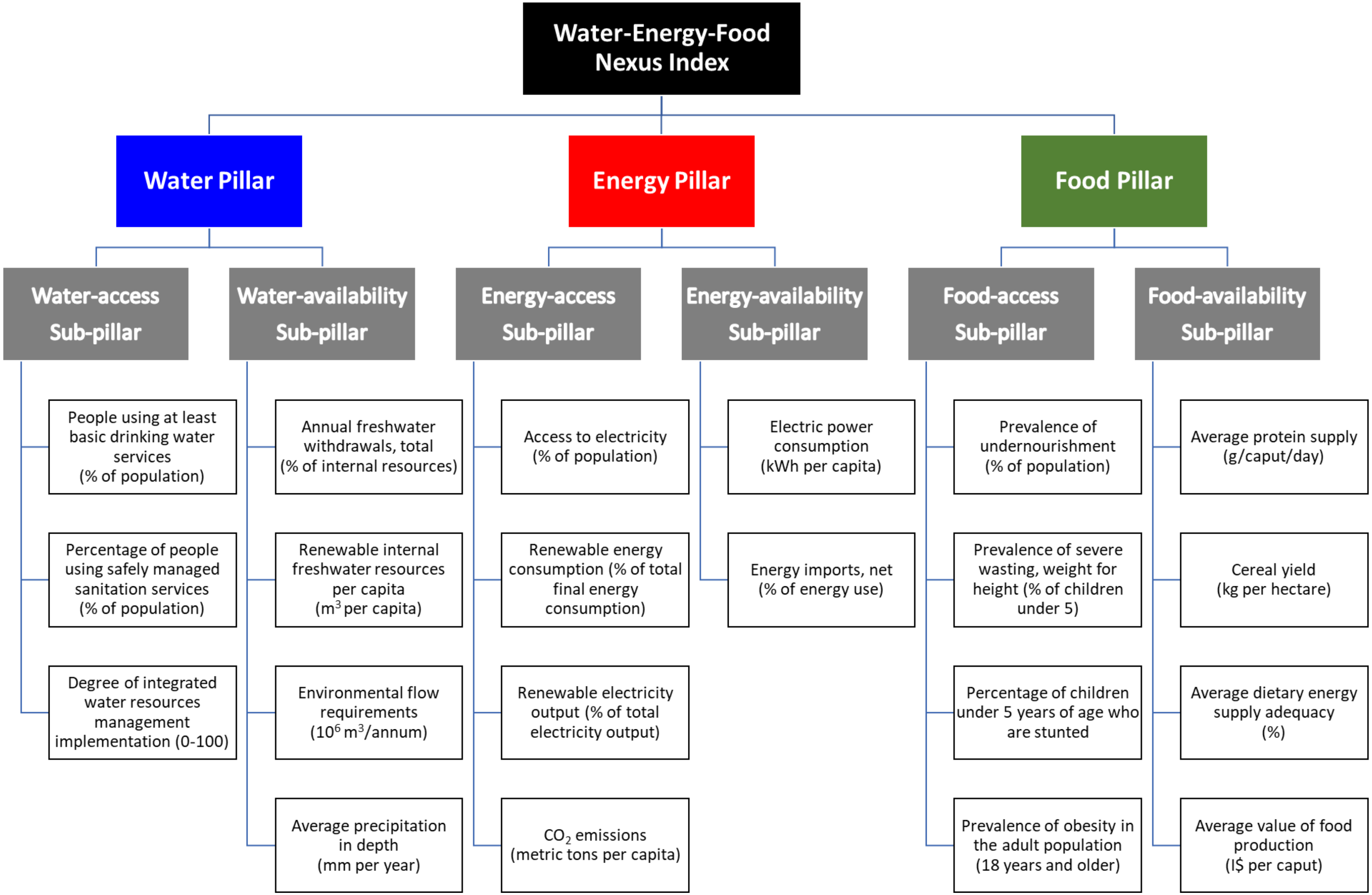

Figure 6-3: Schematic layout of the WEF Nexus Index, with its constituent pillars, sub-pillars, and indicators

All indicators were then normalised in order to transform them into a common scale: [0:100] (OECD 2008). This is standard practice in composite indicator construction, since not only are the indicators measured in different units, but their values range markedly, e.g. the indicator *Percentage of children under five years of age who are affected by wasting* varies from 0.3% to 22.7%, whereas the *Renewable internal freshwater resources per capita* varies from 2.5 to 519 265 cubic metres. In this project, the min-max method was utilised to normalise the data. Where there is no data for an indicator, and the imputation of data cannot be justified, that value is treated as being equal to zero.

Outliers were treated in particular cases where this would lead to difficulties in aggregation. This practice is necessary since outliers "generally spoil basic descriptive statistics such as the mean, the standard deviation, and correlation coefficient, thus causing misinterpretation" (Saisana et al. 2018). Where the skewness and kurtosis of an indicator's data set exceeded the generally accepted range, i.e. |<2| and |<3.5| respectively, a process of either Winsoristion (where there are five or fewer outliers) or a Box-cox transformation (if the number of outliers exceeds five) was adopted (ibid.).

6.2.4 Weighting and aggregation of indicators

The sub-pillar scores were obtained by determining the weighted arithmetic average of the indicators in each sub-pillar. Pillar scores were calculated using the arithmetic average of the corresponding sub-pillar scores, and the final index score was an arithmetic average of the pillar scores. Equal weighting was used to preserve the multi-centric philosophy of the WEF nexus, such that each resource sector has equal importance (Allouche et al. 2015, Benson et al. 2015, Owen et al. 2018); which was applied at the index and pillar levels of aggregation. Given that some sub-pillars contain more indicators than others and the fact that some indicators in a sub-pillar have stronger weightings than others, the final weight of each indicator in the overall index is unequal. The final weights, per aggregation level, and more detail regarding the development of the index, are presented in Table 6-1 and **Addendum C**.

The arithmetic mean was used despite its known properties of compensability. Compensability refers to the extent to which a decrease in one indicator can be compensated for by an increase in another indicator. If the indicators are summed, i.e. using the arithmetic mean, there is a higher degree of compensability than if they are multiplied, i.e. using the geometric mean, since the latter method 'penalises' lower scores in indicators to a greater extent. The use of the arithmetic mean to calculate the WEF Nexus Index is, however, motivated, in accord with Sachs et al. (2016) in their development of the SDG Index; by noting that there is a reasonable degree of substitutability between SDGs and that the arithmetic mean is more straightforward to communicate than the geometric mean.

Table 6-1: Contribution of indicators, sub-pillars, and pillars to the WEF Nexus Index

Indicator	Indicator weight in the index	Sub-pillar	Sub-pillar weight in the index	Pillar	Pillar weight in the index
1	0.056	Water-access	$^{1}/_{6}$	Water	$^{1}/_{3}$
2	0.056				
3	0.056				
4	0.042	Water-availability	$^{1}/_{6}$		
5	0.042				
6	0.042				
7	0.042				
8	0.083	Energy-access	$^{1}/_{6}$	Energy	$^{1}/_{3}$
9	0.028				
10	0.028				
11	0.028				
12	0.083	Energy-availability	$^{1}/_{6}$		
13	0.083				
14	0.056	Food-access	$^{1}/_{6}$	Food	$^{1}/_{3}$
15	0.028				
16	0.028				
17	0.056				
18	0.042	Food-availability	$^{1}/_{6}$		
19	0.042				
20	0.042				
21	0.042				

6.3 Results

The WEF Nexus Index was calculated for 170 nations, as presented in the annotated world map in Figure 6-4. The index values for these countries are presented in a dashboard in **Addendum D**, which also includes the treated data per nation. The highest- and lowest-twenty ranking countries for the WEF Nexus Index are shown in Table 6-2 and Table 6-3, respectively. The median WEF Nexus Index value is 55, while the average is 54.

The five Scandinavian countries rank in the top ten. These nations are characterised by high levels of service delivery in terms of improved drinking water services, safe sanitation facilities, and access to electricity. They also generally have high levels of renewable freshwater resources with low withdrawal levels, together with high renewable energy output.

While the twenty highest-ranking nations are predominantly developed countries, there are five South American countries and one Asian state on this list. The five South American countries in the top twenty are Brazil (tenth), Columbia (fourteenth), Paraguay (fifteenth), Argentina (nineteenth) and Uruguay (twentieth). These nations, in comparison to several developed countries, have relatively low CO_2 emissions levels per capita, with Argentina being the only one of these nations that has a CO_2 emission level that exceeds the median value for the countries assessed. Brazil and Columbia rank very well in terms of the water availability indicators due to large river systems such as the Amazon and Orinoco basins. Columbia has the highest Mean Annual Precipitation (MAP) of the 170 countries evaluated (3 240 mm per annum). Paraguay, meanwhile, has a significant proportion of its population with access to electricity (98.4%), with 100% of the total electricity output being obtained from renewable sources. In terms of food availability, Argentina and Uruguay have a very high average value of food production. Argentina's is I$ 1 030 per capita while Uruguay's is I$ 1 152 per capita, both of which exceed the 90th percentile value (I$ 575 per capita) for the 170 states included in this study. An international dollar (I$) could purchase, in the cited country, a comparable amount of goods and services that a US$ would acquire in the United States of America. This term is frequently utilised in conjunction with Purchasing Power Parity data.

While there are no African countries featured in the highest twenty ranking nations for the WEF Nexus Index, three-quarters of lowest-ranking countries are from Africa. These countries are low emitters of CO_2 per capita, primarily due to the dearth of proven coal reserves outside of South Africa (Agora 2017), together with generally low levels of development (although several African nations utilise oil or gas for electricity generation). The food-availability sub-pillar scores are low for these countries. Within the twenty bottom-ranking nations, only Djibouti, Mauritania, Yemen, and South Sudan are from the Middle East and North Africa (MENA) region. The MENA region is characterised by severe water scarcity and a steady transition toward renewable energy (Hoff et al. 2019). Mauritania in north-western Africa, for example, has a MAP of only 92 mm per annum (less than half of the 10th percentile value for the nations assessed), while its annual freshwater withdrawals are more than three times their total internal freshwater resources. The MENA is the only region that has seen an upsurge in the prevalence of hunger, with and a doubling in the number of hungry people between 2000 and 2015, which was 33 million at the end of this period (FAO 2015).

The country with the lowest WEF Nexus Index value is the landlocked Central African nation of Chad, with a value of 27.0. The results of this WEF nexus assessment highlight the stark inequalities in the world between countries that have good access to, and availability of, resources, and those that do not. Further, coal and oil have been utilised as a means to develop numerous nations. Many of the nations that have built their wealth on the back of fossil fuel-based energy generation and the colonising of other countries are now steadily transitioning to low-carbon developed economies. Other factors, such as political instability and wars, also affect access to resources. It is essential that the WEF Nexus Index be utilised as an entry point into analyses and not an end in itself. This is because the index provides a lens, and not a 'silver bullet' to aid in sustainable development assessments.

Another factor which results in a lower WEF Nexus Index value for the nations listed in Table 6-3 is the absence of data for various indicators. For example, twenty of the 23 bottom-ranking nations do not have data for any of the indicators related to the energy-availability sub-pillar, and the imputation of data in these cases is not straightforward. Not only will a broad-based improvement in the monitoring of data provide a more accurate representation of these nation's

WEF Nexus Index scores, but more nations could be added to the list of countries for which there is adequate data. As a rule of thumb, at the indicator level, at least 65% of countries should have valid data, and at the country level, at least 65% of indicators should have valid data (Saisana et al. 2018). What follows is a description of the WEF nexus for selected countries and regions:

6.3.1 Norway

Norway, which is the only nation with a WEF Nexus Index exceeding 80, only withdraws 0.79% of its internal freshwater resources, which amounts to over 74 300 cubic meters per capita (refer to **Addendum B**). This renewable internal freshwater resource value, per capita, is more than double the 90th percentile value for the 170 countries assessed. Norway has a MAP of 1414 mm per annum which exceeds the 60th percentile value for the nations appraised.

In terms of energy, Norway's renewable electricity output is 97.7% of the total electricity output, with electric power consumption at 23 000 kWh per capita (this latter value is more than double the 90th percentile value for the countries evaluated, which is 9 235 kWh). It is a net energy exporter that produces almost six times its domestic energy production. Not only is its power supply primarily renewable, but the World Economic Forum states that almost half of new passenger car sales in Norway during 2018 were electric or hybrid vehicles (Fleming 2019).

In terms of food availability, Norway has average protein supply, cereal yield, dietary energy supply and value of food production indicators that exceed the 90th, 70th, 80th percentile and median values respectively. The level of undernourishment in this nation is low.

Based on an assessment of Norway, the top-ranking nation in terms of the WEF Nexus Index (with an index value of 80.9) the question may be asked: Is this nation simply well-endowed with natural resources or has it implemented exceptional management systems? Or are the answers to both of these questions in the affirmative? Norway's vast renewable internal freshwater resources and low withdrawal rates position it positively in terms of access to resources. Its proximity to the United Kingdom and vast seaboard allowed it to enter into the development associated with the industrial revolution early than, for example, landlocked nations on distant continents such as Bolivia or Chad. Having appreciable oil reserves has also assisted Norway's development. Norway's average value of food production exceeds the median value for the 170 nations assessed. Based on this short assessment, the data suggests that Norway's location on the globe has been beneficial in enabling both access to freshwater and the development of electrical infrastructure, both of which are crucial enablers of economic development and food production.

Norway, however, emits 9.3 metric tons of CO_2 emissions per capita per annum, a value that is only 0.65 metric tons below the 90th percentile value for the nations assessed in this study. Moreover, a quarter of the adults aged eighteen years and older in this country are obese. These values indicate that, as for the SDG Index, "no country is completely on track to achieve all

SDGs" (Sachs et al. 2018). It also demonstrates that much work remains if equitable and sustainable global access to economic-enabling resources is to be achieved.

6.3.2 Brazil

Since Brazil is the highest-ranking developing nation in terms of the WEF Nexus Index, this country must be evaluated in more detail. In terms of basic drinking water services, safely managed sanitation facilities and access to electricity Brazil provides 97.5%, 86.1% and 100% of its population with these services, respectively. Brazil has the highest environmental flow requirements of any nation (6 532 million cubic metres per annum) and has a MAP a little below the 80th percentile value for the countries assessed. While its renewable energy output is 74% of the total electricity output, its CO_2 emissions per capita are the median value in the dataset (2.6 metric tons per capita). Hoff (2011) noted that Brazil was seeking to significantly increase both its hydropower generation potential and soybean cultivation, with much of the latter to be exported to China (Scanlon et al. 2017).

Brazil has a relatively high cereal yield of 4 181 kilograms per hectare (8 kg short of the 70th percentile value) while its average value of food production (I$ 684 per capita) exceeds the 90th percentile value for the nations evaluated. While the prevalence of stunting in children under five years of age is 7.1%, 22.3% of the adult population eighteen years of age and older is obese.

Brazil, therefore, is a water-rich nation with a relatively high level of renewable energy adoption. Because of its successful agricultural systems, it can provide average protein and dietary energy supplies that both exceed the 70th percentile values for the countries assessed in this study.

6.3.3 Malaysia

Malaysia, ranking eighteenth for the WEF Nexus Index, is the only Asian country in the top twenty. This nation has a substantial MAP of 2 875 mm per annum, and only withdraws 1.9% of its total internal freshwater resources. Malaysia has high levels of service delivery in terms of drinking water services, safe sanitation facilities and access to electricity, which are 96.4%, 99.6%, and 100%, respectively.

While the level of electric power consumption per capita is just below the 70th percentile value for the dataset, at 4 596 kWh per capita, the CO_2 emissions per capita are near the 85th percentile value. This latter value of eight metric tons per capita is the result of the renewable electricity output being only 10% of the total electricity output (which is less than the 30th percentile value for this indicator). Despite a relatively high average value of food production (I$ 470, which is above the 80th percentile value), the percentage of children under five years of age affected by wasting and stunting are 11.5% and 20.7%, respectively. In addition to the high value of food production, Malaysia is also one of Asia's dominant biofuel-producing countries (China, Indonesia, India and Thailand are the others) and together with Indonesia, it accounts for 85% of the worldwide palm oil production (Mirzabaev et al. 2015).

6.3.4 The Southern African Development Community

Five of the twenty bottom-ranking nations are from the Southern African Development Community (SADC). South Africa, despite its substantial reliance on fossil-fuel-based energy generation and its challenges with water scarcity, is the highest-ranking of the SADC nations, in 72nd place, with a WEF Nexus Index value of 56.1. The highest-ranking sub-pillar for this nation is the water-access sub-pillar due to the relatively high proportion of people having at least basic drinking water services (84.7%) and safely managed sanitation services (73.1%), together with a reasonably high degree of Integrated Water Resources Management (IWRM) implementation (65.5%). While Mauritius, Botswana and Seychelles have high levels of access to improved water sources, and South Africa's service delivery has increased steadily since the end of Apartheid, several SADC nations have relatively low (<60%) levels of access to improved water sources (World Bank 2018b).

In terms of future water security in this region, Conway et al. (2015) explain that most climate models project decreases in annual rainfall for southern Africa, typically by as much as 20% by the 2080s. Scholes et al. (2015) warn that projections of future warming in southern Africa are a further 3 to 6°C within the twenty-first century, with the most significant warming occurring in the western interior of the subcontinent, particularly in the Kalahari region.

Renewable energy accounts for a large proportion of energy consumption in SADC countries, but this is generally because of the burning of biomass in traditional ways in open fires (World Bank 2018a). Conway et al. (2015) state that almost 100% of electricity production in the Democratic Republic of Congo, Lesotho, Malawi and Zambia is generated using hydropower. The SADC nations share an energy grid, termed the Southern African Power Pool, and several countries within the region export and import power from each other to meet their local demand (Mabhaudhi et al. 2016). SADC has identified four hydropower plants as priority developments. They are the Mpanda-Nkuwa in Mozambique, Inga III in the Democratic Republic of Congo, the Batoka Gorge project between Zambia and Zimbabwe, and the Lesotho Highlands Water Project Phase II in Lesotho (Schreiner and Baleta 2015). SADC nations are endowed with significant potential in terms of solar and wind power generation (Gies 2016), while in specific zones, geothermal, pumped storage and bioenergy projects are feasible.

Most of the agriculture in SADC is rainfed, primarily being produced by small scale or subsistence farmers. Land ownership has been a source of tension in many African nations since the colonial era. There are millions of smallholder farmers in the region, and more than 60% of the workforce in this zone is engaged in agriculture-related activities (UN Water 2018).

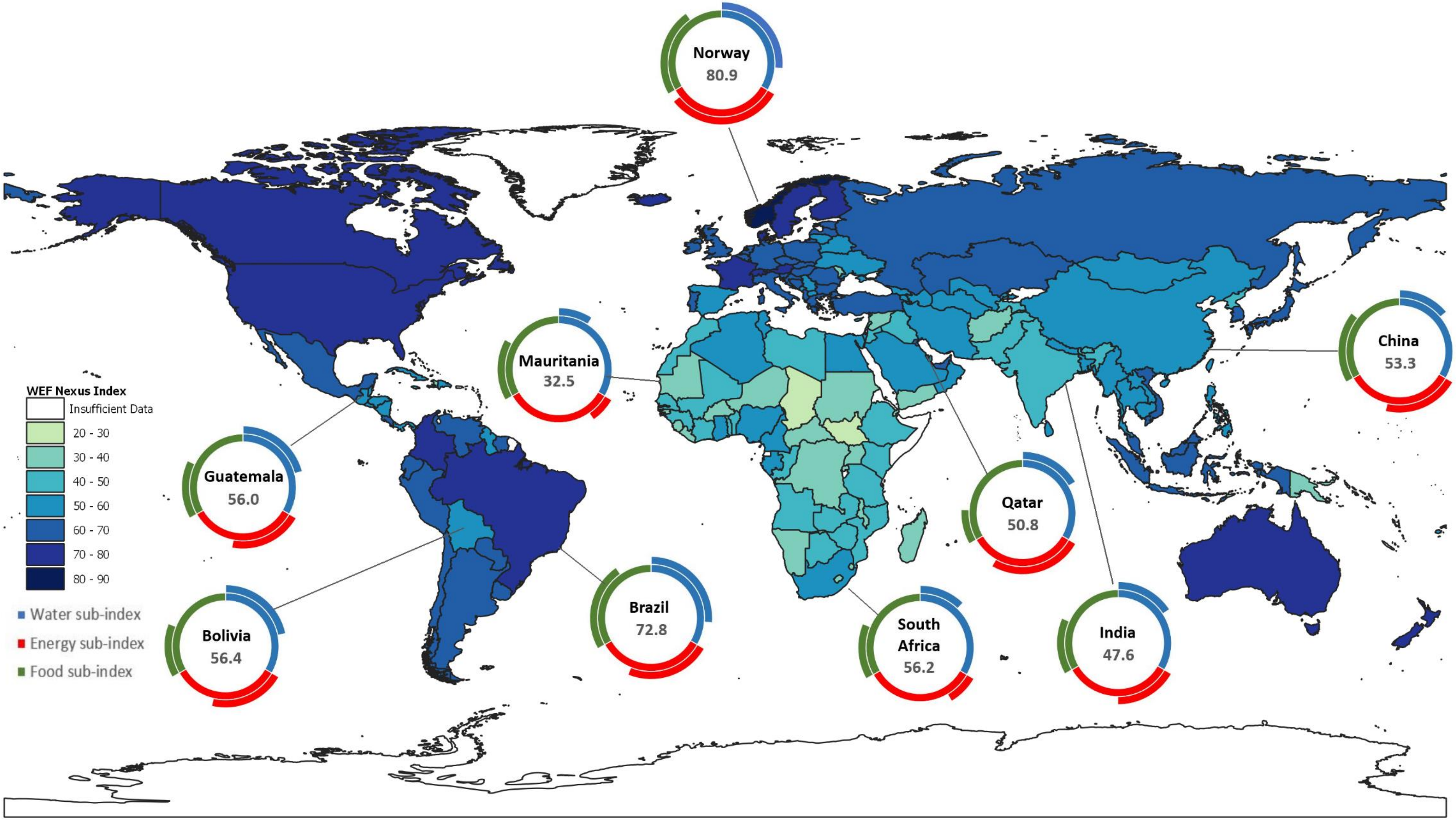

Figure 6-4: World map indicating the WEF Nexus Index per country (with selected countries featured in doughnut plots)

Table 6-2: WEF Nexus Index values for the twenty highest-ranked countries

Rank	Country	WEF Nexus Index	Water Pillar	Energy Pillar	Food Pillar
1	Norway	80.88	79.10	93.02	70.53
2	New Zealand	77.29	79.12	74.58	78.17
3	Sweden	76.87	78.18	82.33	70.11
4	Iceland	76.57	79.38	93.17	57.16
5	Canada	75.51	68.50	84.81	73.22
6	Denmark	75.32	70.64	73.53	81.80
7	Australia	74.10	78.55	70.89	72.87
8	Austria	74.06	77.85	62.64	81.69
9	Finland	72.83	74.16	75.97	68.35
10	Brazil	72.75	78.81	68.53	70.92
11	United States of America	72.67	65.40	73.33	79.28
12	France	71.74	77.73	59.24	78.24
13	Switzerland	71.19	77.01	63.67	72.88
14	Colombia	70.12	82.64	67.20	60.53
15	Paraguay	69.99	68.97	73.78	67.21
16	Croatia	68.96	78.48	59.70	68.69
17	United Kingdom	68.53	75.56	58.29	71.74
18	Malaysia	67.79	79.37	64.06	59.94
19	Argentina	67.63	67.60	61.41	73.87
20	Uruguay	67.52	65.93	63.74	72.89

Brown (1970) wrote fifty years ago, that "As agriculture emerges from its traditional subsidence state to modern commercial farming … it becomes progressively more important to ensure that adequate rewards accrue directly to the [person] who tills the soil. It is hard to see how there can be any meaningful modernisation of food production in Latin America and Africa south of the Sahara unless [the] land is registered, deeded, and distributed more equitably."

The African Union's *Agenda 2063* is titled "The Africa We Want." It calls for "a prosperous Africa based on inclusive growth and sustainable development" (African Development Bank 2019). Much work remains to achieve this goal in sub-Saharan Africa, where more than 390 million people survived on less than $1.90 a day in 2013 (World Bank 2018a). UN Water (2018) warns that "an acute lack of capacity is constraining water resources development and management in all its facets, across most developing countries." The UN also reported that only 24% of people in sub-Saharan Africa have access to safely managed drinking water services and that 220 million people in this region still practise open defecation (ibid.).

Table 6-3: WEF Nexus Index values for the twenty lowest-ranked countries

Rank	Country	WEF Nexus Index	Water Pillar	Energy Pillar	Food Pillar
151	Lesotho	37.93	43.68	26.52	43.60
152	Malawi	37.75	45.73	23.80	43.72
153	Rwanda	37.62	46.25	26.23	40.37
154	Uganda	36.27	40.51	28.69	39.61
155	Afghanistan	36.14	32.62	37.66	38.13
156	Timor-Leste	36.08	43.01	24.75	40.49
157	Liberia	36.03	50.40	18.57	39.10
158	Burkina Faso	35.74	39.55	18.36	49.32
159	Guinea-Bissau	35.18	42.49	17.45	45.61
160	Solomon Islands	35.05	36.59	24.63	43.92
161	Comoros	34.31	42.64	31.14	29.13
162	Yemen, Rep.	33.98	22.92	50.74	28.28
163	Namibia	33.39	32.27	38.66	29.24
164	Central African Republic	33.15	45.71	24.69	29.05
165	Madagascar	32.94	43.33	22.82	32.69
166	Mauritania	32.54	27.40	21.01	49.22
167	Djibouti	32.13	36.42	21.17	38.81
168	Papua New Guinea	32.00	49.04	19.36	27.61
169	South Sudan	26.97	37.17	36.79	6.95
170	Chad	26.96	29.94	16.10	34.84

6.3.5 China and India

Approximately 35% of the total global population lives in China and India, and both of these nations have exploited the majority of their land and water resources available for agriculture

(Bazilian et al. 2011). China, currently the world's most populous nation, ranks 97th for the WEF Nexus Index. In terms of water availability, the MAP in China is 645 mm per annum, while the median MAP for the 170 countries assessed is 1 010 mm per annum. The renewable internal freshwater resources in China are 2 062 cubic metres per capita, which is less than the 40th percentile value.

While China is the highest global CO_2 emitter, it does not rank in the top twenty when the CO_2 emissions are reported per capita. China emits 7.5 metric tons of CO_2 per capita, which is higher than the 80th percentile value. While it has developed remarkable renewable energy generation capacity, its renewable electricity output as a proportion of total electricity output is relatively low, at 23.9%. This value is less than the median value (31.4%) for the countries evaluated. The reason for this value being comparatively low is that coal-fired power stations still constitute about 60% of the installed energy share (Edmond 2019). According to the data, 100% of China's population has access to electricity, with electric power consumption at 3 927 kWh per capita. This value is higher than the 60th percentile value for the countries evaluated.

In terms of accessibility to food, China has a cereal yield of 6 029 kilograms per hectare, which is just below the 90th percentile for the 170 nations assessed. The average value of food production is I$ 379, which exceeds the 70th percentile value for this indicator. The prevalence of undernourishment in China is 8.7%, while 6.6% of adults aged eighteen years or over are obese. The median proportions of undernourishment and obesity for the countries included in this study are 6.5% and 20.5%, respectively. Sachs (2005) noted early in the new Millenium that "China is likely to be the first of the great poverty-stricken countries of the twentieth century to end poverty in the twenty-first century. Its rate of extreme poverty has already plummeted, and the proportions continue to drop rapidly."

India ranks 115th in terms of the WEF Nexus Index. The percentage of people who have access to basic drinking water services and safely managed sanitation facilities are 87.6% and 44.2%, respectively. In terms of the latter of these values, India achieved a significant reduction in the occurrence of open defecation from 66% in 2000 to 40% in 2015 (World Bank 2018a). However, it remains the nation with the most significant number of people practising open defecation. While India has a MAP of 1 083 mm per annum, the renewable internal freshwater resources amount to 1 118 cubic metres per capita, which is below the 30th percentile value for the 170 countries evaluated. Rasul and Sharma (2016) state that India and China are extracting groundwater more rapidly than it can be replenished.

India, which is the third-highest absolute emitter of CO_2, features lower in the rankings for this indicator when the value is normalised per capita. Its emissions amount to 1.7 metric tons of CO_2 per capita, which is less than the median value for the nations assessed in this study. While India's renewable energy growth has also been noticeable, like China, it is also dwarfed by its fossil fuel-based power capacity. Only 15.3% of India's total electricity output is obtained from renewable sources. Approximately 84.5% of India's population has access to electricity, although electrical power consumption in this state is 806 kWh per capita. This value is less than the 30th percentile value for the nations assessed.

India has comparatively high levels of wasting and stunting amongst children under five years of age at 21% and 38.4%, respectively. Both values exceed the 90th percentile for these indicators for the countries evaluated. The average protein supply per capita in India is 52 grams per capita per day, which is less than the 20th percentile value for the countries assessed in this project. The cereal yield for India, at 2 993 kg per hectare, is below the median value (3 076 kg per hectare) for the 170 nations appraised.

6.3.6 The WEF Nexus Index versus the Human Development Index

To understand how the WEF Nexus Index is related to human development, Figure 6-5 shows a plot of this composite indicator against the Human Development Index (HDI) (UNDP 1990, 2018b). Together with the data points on this plot, a linear trendline and the associated R-squared value are included on the graph. The R-squared value for the HDI versus the WEF Nexus Index plot is 0.66. This value indicates that there is a moderate to high correlation between the HDI and the WEF Nexus Index. Notwithstanding this, the WEF Nexus Index adds new information and a different perspective.

When evaluating the graph of the HDI versus the WEF Nexus Index, there are some stark outliers. Two examples in this regard are Singapore and Hong Kong. These two nations both rank in the top ten nations for their HDI while they rank 115th and 140th for the WEF Nexus Index, respectively. This contrast in scores between the two indices indicates that despite their high levels of human development, these nations are facing (and will continue to face) significant issues relating to resource availability and management. Other nations in a similar (but less extreme) position include Qatar, Oman, Israel and Malta.

Examples of nations that have low levels of human development relative to their resource base (i.e. below the trendline in Figure 6-5) are Brazil, Columbia, Paraguay, Cameroon, Mozambique, and Nepal. Norway, New Zealand, Iceland, and Canada also plot below the linear regression line, yet these countries have high HDIs when compared to the majority of nations assessed. Countries that plot close to the trendline of the graph of the HDI versus the WEF Nexus Index include France, India, the Russian Federation, the Comoros and Djibouti. Although these states individually have comparable levels of living standards and resource bases, there is a substantial difference between their respective levels of attainment of both the HDI and the WEF Nexus Index. Further analysis provides some useful insights for Singapore and Qatar.

6.3.6.1 Singapore

Singapore is a resource-poor nation. While its MAP is high at 2 497 mm per annum, the renewable internal freshwater resources are only 110 cubic metres per capita. This latter value is less than half of the 10th percentile value for the countries appraised. The average value of food production in the country is only I$ 5 per capita, which is the lowest value for any of the 170 nations assessed. Notwithstanding this lack of natural resources, Singapore provides its entire population with at least basic drinking water services, safely managed sanitation services and electricity. A high HDI ranking and relatively low WEF Nexus Index value indicate that Singapore is very dependent upon other nations to obtain sufficient food.

How does Singapore achieve such a high HDI when it has a dearth of resources? Lee Kuan Yew (2000), who governed Singapore for three decades, wrote “that talent is a country’s most precious asset. For a small resource-poor country like Singapore, with 2 million people at independence in 1965, it is the defining factor.” Quah (2018) confirms this, stating that “Singapore has compensated for its absence of natural resources by investing heavily in education to enhance the skills of its population.” Quality education, together with other policies, has continued to bear much fruit, with Singapore topping the Global Competitiveness Index 4.0 rankings in 2019 (Schwab 2019).

Secondly, foreign direct investment was crucial to Singapore achieving a high HDI, but effectively eliminating corruption was key to sustaining the country’s economy and achieving the intended outcomes. This anti-corruption policy has resulted in Transparency International (2018) consistently ranking Singapore as one of the least corrupt nations on earth. In 2018 it ranked as the joint third least corrupt country in the world.

6.3.6.2 Qatar

Another country that has a high HDI ranking compared to its WEF Nexus Index value is Qatar, which ranks 105th for the WEF Nexus Index. This nation has the highest CO_2 emissions per capita, at 45.4 metric tons. It has a MAP of 74 mm per annum, resulting in an annual freshwater withdrawal of almost four times its available internal freshwater resources. The minimal rainfall in Qatar results in the average value of food production being low (I$ 26 per capita). Other countries, e.g. Turkmenistan and the United Arab Emirates, have annual freshwater withdrawals of almost 2 000% of their internal freshwater resources. In Qatar, as in several other arid countries, groundwater is the dominant water source for the agricultural sector (Linke 2014). Qatar, like Singapore, provides 100% of its population with access to at least basic drinking water services, safely managed sanitation services and electricity. Its degree of implementation of IWRM is 82.2%, which is equivalent to the 90th percentile for the 170 nations assessed.

While Qatar consumes 15 309 kWh per capita, it produces almost 400% of its domestic energy requirements. While the levels of wasting and stunting in children under five years of age are low, the level of obesity in this nation exceeds one-third of the adult population.

Several of the countries in the position of Qatar and Singapore, i.e. high HDI but relatively low WEF Nexus Index, are smaller countries. Because they are small nations, they are dependent on imports and connections with other countries for food and raw materials. (Becker et al. 2019). International connectivity is, therefore, a key policy objective for resource-poor nations.

As noted earlier, so too is a substantial investment in education, a firm anti-corruption record and the institution of economic measures that promote global competitiveness.

6.4 Conclusions

This research has yielded a country-level composite indicator related to the WEF nexus that highlights water-, energy- and food-related issues. It provides a quantitative means of ascertaining 170 different nation's progress in terms of integrated resource management, utilising the WEF nexus as a lens. It also provides an opportunity for comparing a nation's progress with other countries, whether from the same region (e.g. SADC or MENA), at a similar level (i.e. developed or developing), or by assessing a nation relative to a specific country included in the study. By providing a quantitative measure of the WEF nexus, the index provides a summary and entry point to the complex dataset that underlies it. A more detailed analysis of the constituent indicators will provide the researcher, policy-maker or decision-maker with insights and prompts in terms of where interventions and investments are necessary.

The WEF Nexus Index reveals countries and regions that are strong and those that are weaker in terms of the WEF nexus. It also illustrates trade-offs that must be considered when developing policy, and managed when making planning decisions. The index also identifies countries where a determined effort is required in order to achieve the SDGs, principally SDGs 2, 6 and 7. To this end, future work associated with the WEF Nexus Index will include detailed studies at various spatial scales, i.e. not only a national scale, using the index as a catalyst and foundation for the investigation. Further work could include the development of an interactive web-based WEF Nexus Index tool that would facilitate the evaluation of "What if?" scenarios. The index can be employed to motivate innovative water-, energy- and food-related projects that will enhance the equitable, sustainable supply of resources to areas, countries or regions.

Having plotted the WEF Nexus Index against the HDI, it is evident that the former index has a moderate-to-strong correlation with the latter one. This correlation demonstrates that despite some parallels, the WEF Nexus Index provides a different perspective to the HDI, focusing on multi-centric integrated resource management.

WEF nexus assessments in the decade leading up to the 2030 SDG target year must be more comprehensive. Qualitative studies must be conducted in parallel with quantitative assessments. There is no one-size-fits-all method for integrated resource management utilising the WEF nexus. Instead, the approach must be tailored for each unique situation, and the WEF Nexus Index can be a catalyst and entry-point for such studies. By evaluating a subset of the SDGs, the index is complementary to the SDGs. The WEF Nexus Index is not a silver bullet that will solve all the significant development or environmental challenges facing humanity. This approach can, however, be added to the sustainability toolbox that is being utilised to engineer 'the future we want'.

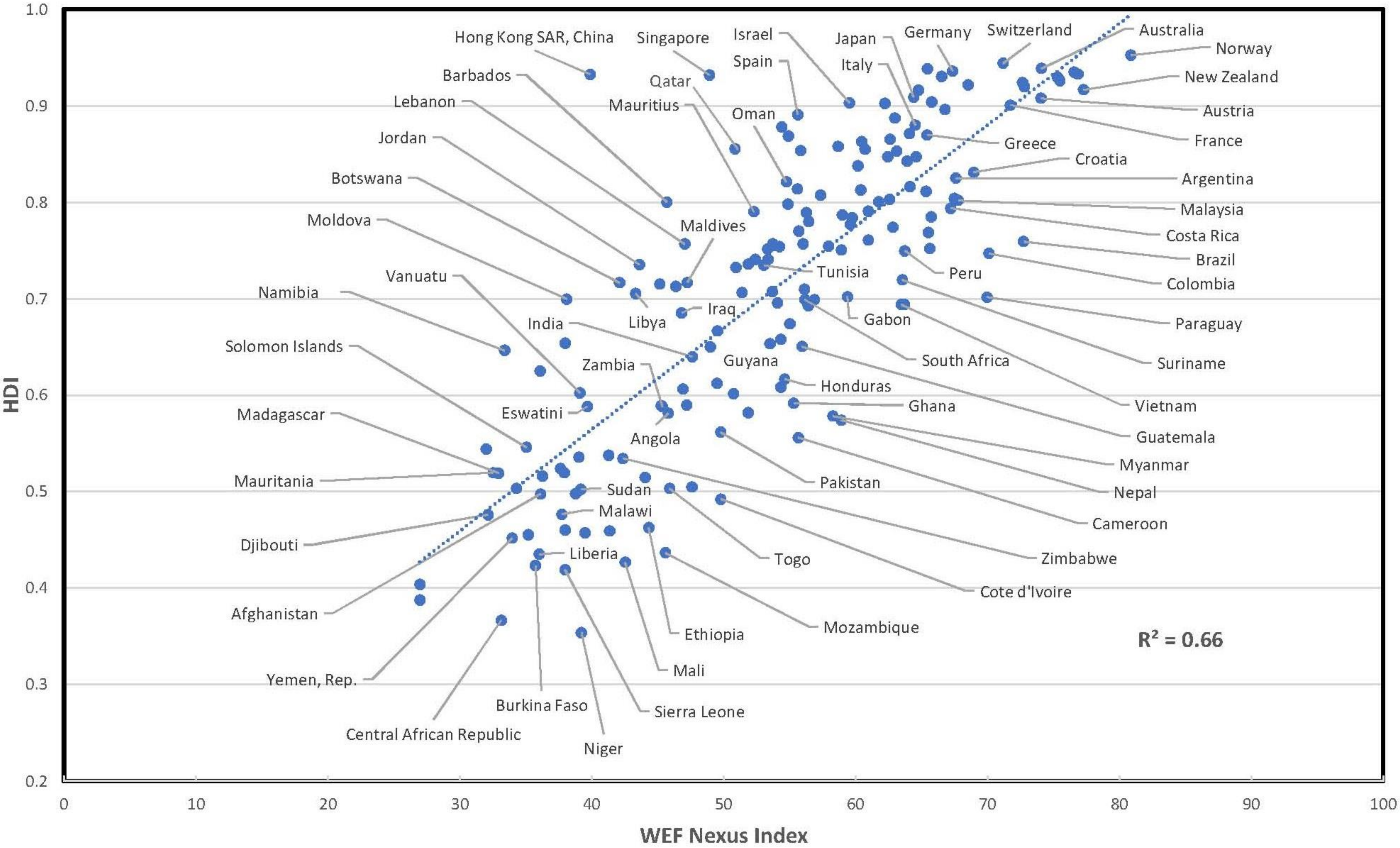

Figure 6-5: Plot of the HDI (UNDP 2018a) versus the WEF Nexus Index for selected countries

CHAPTER 7: THE APPLICATION OF THE WATER-ENERGY-FOOD NEXUS INDEX TO THE SOUTHERN AFRICAN DEVELOPMENT COMMUNITY

7.1 Status of WEF Nexus in SADC

The African Union's *Agenda 2063* is titled "The Africa We Want." It calls for "a prosperous Africa based on inclusive growth and sustainable development" (African Development Bank 2019). Much work remains to achieve this goal in a region such as Sub-Saharan Africa where more than 390 million people live on less than $1.90 a day in 2013 (World Bank 2018a). The Southern African Development Community (SADC), which is part of the African Union, was established as a development coordinating conference (SADCC) in 1980 and subsequently transformed into a development community in 1992. It is made up of sixteen member states, namely Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, United Republic of Tanzania, Zambia and Zimbabwe, as presented in Figure 7-1.

There have been various WEF nexus workshops, dialogues and consultations within Southern Africa, starting with the *Nexus Dialogue on Water Infrastructure Solutions* in 2013 (Mabhaudhi et al. 2018). These meetings have highlighted the interdependencies within the three resource sectors that constitute the WEF nexus. The necessity of regional cooperation in integrated resource management is highlighted by six of these countries being landlocked and three of them being island states. Schreiner and Baleta (2015) emphasise that the nexus approach has become a significant part of the current development discourse in Southern Africa, noting that there are clear opportunities for sharing resources internationally for the mutual benefit of the region. Mabhaudhi et al. (2016) however explain that there has been a gap between water and energy sector planning in terms of policy alignment and technical convergence, which hinders progress towards the SDGs.

7.1.1 Water availability

The national boundaries within SADC were determined politically and not hydrologically. This is evident when it is understood that 85% of the region's water resources are transboundary in nature (Mabhaudhi et al. 2016). SADC coordinates transboundary water cooperation in fifteen basins across Southern Africa (UN Water 2013), as shown in Table 7-1. These shared basins present (or necessitate) ample opportunities for cooperation to enhance socio-economic security and ensure further progress with achieving the SDGs. However, the availability of resources within the region is not evenly distributed. Over 70% of SADC's freshwater resources are shared between two or more member states (Schreiner and Baleta 2015).

The ratification of SADC's revised protocol on shared watercourses together with the establishment of various river basin organizations has promoted cooperation and the sharing of benefits from these basins (Claassen 2013). Hoff (2011) explains that one of the early nexus analyses focussed on the Zambezi River basin. This integrated project included the co-development of hydropower, new irrigation schemes and other water-related sectors, including wetlands and their ecosystem services.

Figure 7-1: Map of the SADC countries (Konstantinus et al. 2019)

UN Water (2018) state that 24% of people in Sub-Saharan Africa have access to safely managed drinking water services. Figure 5-1 presents the percentage of the population in each of the SADC nations (excluding Comoros[6], for which no data was available) that had access to improved water sources between 1990 and 2015. This indicator is defined as:

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[6] Comoros had data for the graphs plotted, but not sufficient for the calculation of the WEF Nexus Index due to the JRC:COIN's 60% rule of thumb. The converse is true for Seychelles.

“Access to an improved water source refers to the percentage of the population using an improved drinking water source. The improved drinking water source includes piped water on premises (piped household water connection located inside the user’s dwelling, plot or yard), and other improved drinking water sources (public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs, and rainwater collection)” (World Bank 2018b).

Table 7-1: Transboundary river basins in the SADC region (Mabhaudhi et al. 2016)

River Basin	Sharing States
Buzi	Mozambique, Zimbabwe
Congo	Angola, Democratic Republic of Congo, Tanzania, Zambia
Cuvelai	Angola, Namibia
Incomati	Mozambique, South Africa, Swaziland
Kunene	Angola, Namibia
Limpopo	Botswana, Mozambique, South Africa, Zimbabwe
Maputo	Mozambique, South Africa, Swaziland
Nile	Democratic Republic of Congo, Tanzania
Okavango	Angola, Botswana, Namibia
Orange	Botswana, Lesotho, Namibia, South Africa
Pungwe	Mozambique, Zimbabwe
Ruvuma	Malawi, Mozambique, Tanzania
Save	Mozambique, Zimbabwe
Umbeluzi	Mozambique, Swaziland
Zambezi	Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, Zimbabwe

While Mauritius, Botswana and Seychelles have high levels of access to improved water sources, and South Africa’s service delivery has increased steadily since the end of Apartheid, several nations have relatively low (<60%) levels of access to improved water sources. What is even more concerning is that Zimbabwe’s provision of access to improved water sources has declined during the period (1990 to 2014). Based on access to improved drinking water sources, the SADC region is, without doubt, a developing region with much work remaining to meet SDG 6.1 (“By 2030, achieve universal and equitable access to safe and affordable drinking water for all.”). UN Water (2018) warns that “an acute lack of capacity is constraining water resources development and management in all its facets, across most developing countries, particularly in sub-Saharan Africa and South and South-eastern Asia."

SDG 6 addresses access to both improved water sources and improved sanitation facilities. Figure 5-2 presents the proportion of the SADC countries' (excluding Comoros, for which there was no data) access to improved sanitation facilities, which is defined as follows:

"Access to improved sanitation facilities refers to the percentage of the population using improved sanitation facilities. Improved sanitation facilities are likely to ensure hygienic separation of human excreta from human contact. They include flush/pour flush (to the piped sewer system, septic tank, pit latrine), ventilated improved pit (VIP) latrine, pit latrine with slab, and composting toilet" (World Bank 2018b).

Seychelles and Mauritius both have very high levels of access to improved sanitation facilities. While the trajectory of the implementation of access to better sanitation facilities is positive for nearly all countries (except Zimbabwe), there remains much work to do, with all other nations having less than 70% access to improved sanitation facilities. More than half of the nations in the SADC region have less than 50% access to improved sanitation facilities. UN Water (2018) report that 220 million people in Sub-Saharan Africa still practice open defecation. SDG 6.2 specifically addresses this practice, stating that "By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations."

In terms of future water security, Conway et al. (2015) explain that most climate models project decreases in annual precipitation for Southern Africa, typically by as much as 20% by the 2080s. Scholes et al. (2015) state that the average annual air temperature in South Africa has risen by approximately 1.2°C during the time period within which accurate records have been maintained. They warn that projections of future warming in Southern Africa are a further 3-6°C within the twenty-first century, with the greatest warming occurring in the western interior of the subcontinent, particularly in the Kalahari region (ibid.).

7.1.2 Energy generation

Renewable energy accounts for a large proportion of energy consumption in Sub-Saharan Africa, but this is generally because of the burning of biomass in traditional ways in open fires (World Bank 2018a). In Southern Africa, water and energy are inextricably linked. Conway et al. (2015) note that almost 100% of electricity production in the Democratic Republic of Congo, Lesotho, Malawi and Zambia is generated by means of hydropower. The SADC nations share an energy grid, termed the Southern African Power Pool (SAPP), and several countries within the region export and import power from each other to meet their local demand (Mabhaudhi et al. 2016). Hydropower forms a major component of the regional energy supply through extensive sharing within the SAPP. South Africa is the largest energy generator and consumer within the region and its focus and challenges in managing its own internal electricity generation have served to undermine the functionality of the SAPP master plan (Schreiner and

Baleta 2015). Regarding energy in the SADC region, "challenges include low tariffs, poor project preparation, issues with power purchase agreements, and absent regulatory frameworks that stunt investment and financing in the energy sector" (ibid.).

Figure 5-3 presents the proportion of access to electricity per SADC country (excluding Comoros, for which there was no data). Access to electricity is very high for Mauritius and Seychelles, while Swaziland, Namibia, Botswana and South Africa's service delivery in terms of electricity has been significant since 1990. While there has been a general upward trend in access to electricity levels, these levels are below 45% for nine of the fifteen countries. Alarmingly, the level of provision of access to electricity for the population of Angola has decreased markedly since 1990.

Southern Africa is endowed with significant potential in terms of solar and wind power generation (Gies 2016). This could lead to the development of a SADC "Desertec" (Simpson et al. 2019) similar to the large-scale renewable power generation and distribution project that was touted for North Africa, the Middle East and Europe. Another project that could transform the SADC region is the development of the vast hydropower potential of the Inga Falls in the Congo River. The Grand Inga Dam Project, which has been discussed for half a century, could produce 40 GW of hydroelectric power, more than one-third of the total electricity currently generated in Africa (Sachs 2015). Political obstacles have, until now, limited the development of this project. SADC has identified four hydropower plants as priority developments. They are the Mpanda-Nkuwa in Mozambique, Inga III in the Democratic Republic of Congo, the Batoka Gorge project between Zambia and Zimbabwe, and the Lesotho Highlands Water Project Phase II in Lesotho (Schreiner and Baleta 2015).

Hoff (2011) explains that one of the first nexus trade-off studies was an analysis of sugar versus biofuel production in Mauritius. This study indicated that this island state could improve its economic water use efficiency by changing sugar production to bio-ethanol production.

7.1.3 Food production

Sachs et al. (2016) lament that more than one-third of the population in tropical Africa, especially central and southern Africa, is undernourished. UN Water (2018) explain that Sub-Saharan Africa experiences the highest level of food insecurity, affecting almost 30% of the population. Much of the SADC region is characterised by economic scarcity. If future developments of water infrastructure related to agricultural production could focus on domestic consumption (rather than the export market) this could go a long way to reducing poverty and malnutrition in this region (Siciliano et al. 2017).

Most of the agriculture in the SADC region is rainfed, largely produced by small scale or subsistence farmers. Land ownership has been a source of tension in the SADC region since the colonial era. There are millions of smallholder farmers in the region, and it is estimated that more than 60% of the workforce in Sub-Saharan Africa is engaged in agriculture-related activities (UN Water 2018). Brown (1970) wrote almost fifty years ago, that "As agriculture emerges from its traditional subsidence state to modern commercial farming … it becomes progressively more important to ensure that adequate rewards accrue directly to the man who tills the soil. Indeed, it is hard to see how there can be any meaningful modernisation of food production in Latin America and Africa south of the Sahara unless [the] land is registered, deeded, and distributed more equitably."

Sachs (2015) explains that on average, smallholder farmers in sub-Saharan Africa produce yields of between half a ton and one ton per hectare, which is very low when compared to international norms. He notes that other parts of the developing world achieve four- to five-times higher yields than that and lists key development challenges as being soil-nutrient depletion and a general lack of irrigation and good seed varieties. For many African countries, policies that support investments in energy supply projects, both large and small, are needed to unlock available freshwater resources to meet their food requirements. Both the drought-proofing of rainfed agriculture and a steady increase in irrigation development are required in Africa.

The prevalence of undernourishment in SADC countries, from 1991 to 2015, is presented in Figure 5-4. Schreiner and Baleta (2015) suggest that the agricultural potential of countries like Zambia could be exploited for the benefit of the entire region. While this is true, it is ironic that fertile countries such as Zambia experience high levels of undernourishment that have increased since the late 1990s. The *Joint Child Malnutrition Estimates Report* states that "Malnutrition rates remain alarming: stunting is declining too slowly while wasting still impacts the lives of far too many young children" (UNICEF/WHO/World Bank 2019). Further, they report that Africa is the only region where the number of stunted children has risen between 2000 and 2018 (ibid.). Based on these statements, as well as the high levels of undernourishment in SADC countries, much work remains for SDG 2 to be achieved. SDG 2.1 is: "By 2030, end hunger and ensure access by all people, in particular, the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round."

UN Water (2018) state that "Poor WASH[7] contributes to undernutrition, which is both a rural and an urban health issue (but which is worse in rural communities). It is endemic among the poor in sub-Saharan Africa and Asia, where many people live in unsanitary conditions and do not get enough calories, protein and micronutrients in their diet."

7.2 WEF Nexus Index for SADC

There was adequate data at both a country and indicator level to ascertain the WEF Nexus Index for fifteen of the sixteen SADC countries. The country that did not have adequate data was Seychelles. Of the fifteen countries assessed:

[7] Water, Sanitation and Hygiene

- Twelve are located on the mainland, with six being landlocked nations; and
- Three are island states, namely Comoros, Mauritius and Madagascar, with the latter being the fourth largest island in the world.

The ranking of SADC countries in terms of the WEF Nexus Index is presented in Table 7-2, with South Africa being ranked in 72nd position while Madagascar is 165th. The WEF Nexus Index values are presented graphically in Figure 7-2. The dashboard is presented in Table 7-3, while presents Table 7-4 the untreated data for the fifteen SADC countries assessed. Five of these nations are ranked in the lowest twenty nations for this composite indicator. A radar chart of the WEF Nexus Index sub-pillars for the SADC countries is presented in Figure 7-3. Individual radar charts for each of the fifteen SADC nations analysed are provided in **Addendum E**.

Table 7-2: WEF Nexus Index ranking and index values for fifteen SADC countries

Country	WEF Nexus Index	Rank
Angola	45.8	124
Botswana	42.1	136
Comoros	34.3	161
Congo, Dem. Rep.	39.5	141
Eswatini	39.7	140
Lesotho	37.9	151
Madagascar	32.9	165
Malawi	37.7	152
Mauritius	52.3	100
Mozambique	45.6	126
Namibia	33.4	163
South Africa	56.1	72
Tanzania	41.3	138
Zambia	45.3	127
Zimbabwe	42.4	135

In terms of the "Water-access" sub-pillar, Mauritius has, by some margin, the highest percentage of people having access to at least basic drinking water services and safely managed sanitation (99.9% and 93.1% respectively). South Africa and Botswana have a moderate level of service delivery related to both SDG indicators, while several of the other nations have very poor levels of provision of both amenities (or they score well for one, and poorly for the other, e.g. Comoros). Regarding indicator "ind.03", only South Africa (65.5%), Mauritius (64.4%), Zimbabwe (61.0%) and Namibia (59.1%) have reasonable levels of implementation of IWRM. Mauritius has the highest "Water-access" sub-pillar value at 84.1 while South Africa's is 69.3.

Annual freshwater withdrawals is a crucial indicator of potential future water scarcity. While eleven of the fifteen SADC nations analysed have very low withdrawal levels (< 9%) Eswatini (39.5%) and South Africa (34.6) withdraw comparatively high volumes. Also affecting the "Water-availability" sub-pillar is the volume of rainfall that falls annually. The three countries that receive the lowest mean annual precipitation are Namibia (285 mm), Botswana (416 mm) and South Africa (495 mm). These annual rainfall depths can be contrasted with Mauritius (2041 mm), the Democratic Republic of Congo (1543 mm) and Madagascar (1513 mm). As evident from Figure 7-3, the Democratic Republic of Congo and Madagascar have the highest values for SADC countries for the "Water-availability" sub-pillar.

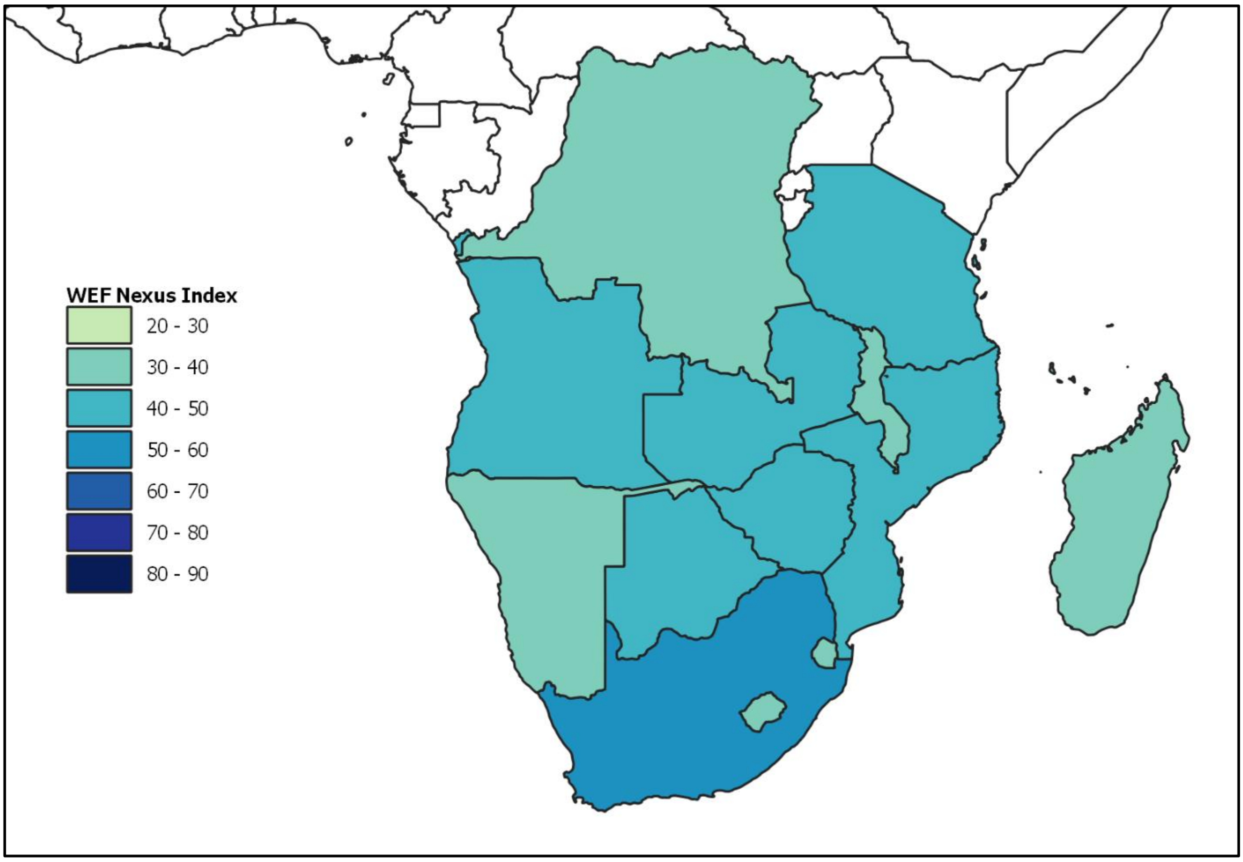

Figure 7-2: Map of SADC countries presenting the relative WEF Nexus Index values

The "Energy-access" sub-pillar represents SDG 7, namely access to clean, affordable energy. Mauritius (98.8%), South Africa (84.2%) and Comoros (77.8%) provide at least three-quarters of their respective populations with electricity. In terms of *Renewable electricity output*, Lesotho (100%), the Democratic Republic of Congo (99.8%), Namibia (97.8%), Zambia (97.0%) and Malawi (91.3%) provide all, or the vast majority, of their electricity from renewable sources. South Africa's CO_2 emissions per capita (9.0 metric tons per) are significantly higher than any of the other SADC nations, despite it having a population vastly larger than Mauritius and Botswana, which have the second and third highest CO_2/capita values at 3.4 and 3.2 metric tons per capita respectively. Mauritius and Eswatini have the highest "Energy-access" sub-pillar values at 69.3 and 66.5, respectively.

With its vast coal reserves and thirteen coal-fired power stations, South Africa is self-sufficient in terms of power generation, despite it importing additional capacity. Its *Electric power consumption per capita* is relatively low (4 198 kWh/capita) when compared to first world countries (e.g. Iceland, 53 832 kWh/capita), but is almost twice as much as the next highest SADC country, i.e. Mauritius (2 183 kWh/capita). Ironically, Mozambique exports power to South Africa, yet only 24.2% of its population has access to electricity.

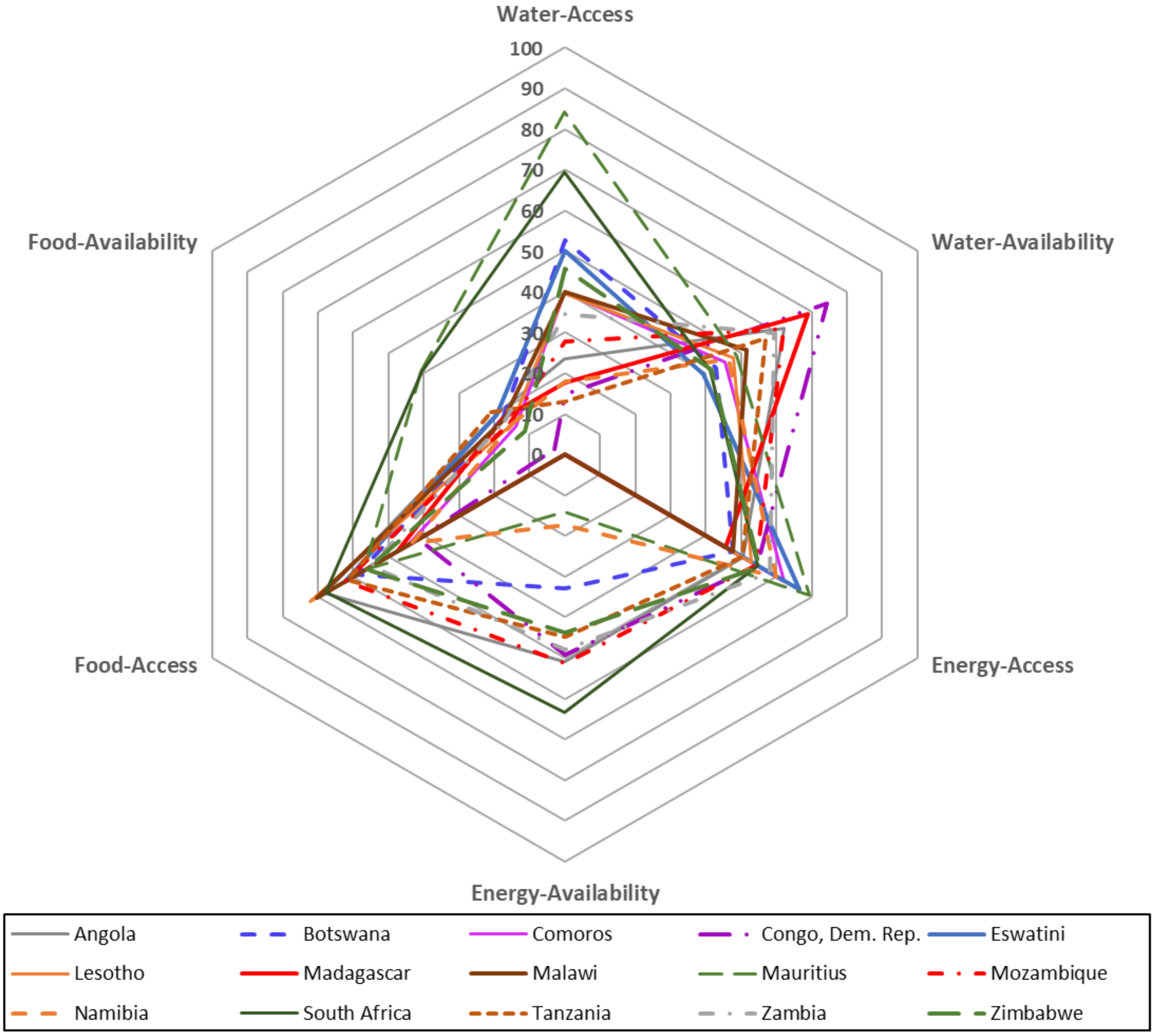

Figure 7-3: Radar chart of the WEF Nexus Index sub-pillars for the SADC countries

The SADC country with the highest value for the "Food-access" sub-pillar is Lesotho, followed by Malawi and South Africa. This is because although South Africa has lower levels of undernourishment, wasting and stunting than Lesotho or Malawi, South Africa has a comparatively high level of obesity in their adult population (27.4%). The SADC country with the second and third highest percentages of their adult population with obesity are Botswana (16.1%) and Namibia (15.0%). Five SADC nations do not currently report on the level of stunting for children under five years of age, namely, Mauritius, Tanzania, Eswatini, the Democratic Republic of Congo and Namibia.

The dashboard in Table 7-3 shows that for the “Food-availability” sub-pillar (ind.18 to ind.21) most of the countries fair very poorly, with only Mauritius and South Africa performing moderately well. An example of this is the *Cereal yield* indicator, where the maximum yield in SADC nations is less than 4000 kg/ha per country (in seven nations it is less than 1000 kg/ha). Several first world countries achieve more than double the maximum cereal yield that SADC countries have reported (refer to **Addendum B**). Examples in this regard include New Zealand (8 384 kg/ha), Ireland (8 223 kg/ha) and the United States of America (8 143 kg/ha). The *Average value of food production* is similarly comparatively low in SADC nations, with the highest value being I$ 237 in Eswatini. These values are significantly lower than those achieved in the Netherlands (I$ 2425), Uruguay (I$ 1152), Denmark (I$ 1067), Argentina (I$ 1030) and Australia (I$ 1009).

In evaluating a composite indicator, it is essential to ascertain if there is any correlation with other related indicators. To this end, the WEF Nexus Index has been plotted on the same set of axes as the SDG Index and the HDI for the SADC countries, in Figure 7-4 and Figure 7-5 respectively. Following the adoption of the seventeen SDGs by all member states of the UN in September 2015, a country-level SDG Index was developed for 149 of the 193 UN member states with adequate data coverage to provide a “shorthand way” of tracking SDG progress (Sachs et al. 2016). In the plot of the SDG Index against the WEF Nexus Index for SADC countries, all fifteen countries have SDG Indices that are higher than their corresponding WEF Nexus Index. This suggests that these nations tend to perform better in the remaining fourteen SDGs than in the three represented by the WEF Nexus Index, i.e. SDGs 2, 6 and 7. Nations that outrank a certain nation for the SDG Index do not necessarily outrank it for the WEF Nexus Index, e.g. Mauritius and South Africa, Zambia and Botswana, or the Democratic Republic of Congo and Madagascar.

A similar pattern emerges for the plot of the HDI against the WEF Nexus Index (Figure 7-5), with Mozambique being the only country that has a higher WEF Nexus Index than HDI. This nation does have the lowest HDI out of all the SADC countries assessed and ranks 180th out of 189 countries in the UNDP (2018a) report. All nine of the nations ranking lower than Mozambique for the HDI are African, which emphasises the development backlog on this continent. As with the relationship with the SDG Index, several nations that outrank another country for one composite indicator do not necessarily outrank it for another, with many of the same relationships being true for these two indices, i.e. Mauritius and South Africa, Zambia and Botswana, or the Democratic Republic of Congo and Madagascar.

Table 7-3: WEF Nexus Index Dashboard for the SADC countries

Water Sub-index

Rank	Country	The percentage of people using at least basic drinking water services (ind.01)	Percentage of people using safely managed sanitation services. (ind.02)	Degree of IWRM implementation (1-100) (ind.03)	Annual freshwater withdrawals, total (% of internal resources) (ind.04)	Renewable internal freshwater resources per capita (cubic meters) (ind.05)	Environmental flow requirements (10^6 m^3/annum) (ind.06)	Average precipitation in depth (mm per year) (ind.07)
72	South Africa	Green	Yellow	Yellow	Yellow	Yellow	Orange	Red
100	Mauritius	Green	Green	Yellow	Yellow	Yellow	Grey	Yellow
124	Angola	Red	Orange	Orange	Green	Yellow	Yellow	Orange
126	Mozambique	Red	Red	Orange	Green	Yellow	Yellow	Orange
127	Zambia	Orange	Orange	Orange	Green	Yellow	Orange	Orange
135	Zimbabwe	Orange	Orange	Yellow	Yellow	Yellow	Orange	Red
136	Botswana	Yellow	Yellow	Orange	Green	Yellow	Red	Red
138	Tanzania	Red	Red	Grey	Green	Yellow	Orange	Orange
140	Eswatini	Orange	Yellow	Orange	Yellow	Yellow	Red	Red
141	Congo, Dem. Rep.	Red	Red	Red	Green	Yellow	Green	Orange
151	Lesotho	Yellow	Orange	Red	Green	Yellow	Red	Red
152	Malawi	Orange	Orange	Orange	Green	Yellow	Orange	Orange
161	Comoros	Yellow	Orange	Red	Green	Yellow	Grey	Orange
163	Namibia	Grey	Grey	Yellow	Green	Yellow	Red	Red
165	Madagascar	Red	Red	Orange	Green	Yellow	Yellow	Orange

Energy Sub-index

Rank	Country	Access to electricity (% of population) (ind.08)	Renewable energy consumption (% of total final energy consumption) (ind.09)	Renewable electricity output (% of total electricity output) (ind.10)	CO_2 emissions (metric tons per capita) (ind.11)	Electric power consumption (kWh per capita) (ind.12)	Energy imports, net (% of energy use) (ind.13)
72	South Africa	Green	Red	Red	Yellow	Orange	Green
100	Mauritius	Green	Red	Red	Green	Red	Red
124	Angola	Orange	Yellow	Yellow	Green	Red	Green
126	Mozambique	Red	Green	Green	Green	Red	Green
127	Zambia	Red	Green	Green	Green	Red	Green
135	Zimbabwe	Orange	Green	Yellow	Green	Red	Green
136	Botswana	Yellow	Orange	Red	Green	Red	Yellow
138	Tanzania	Orange	Green	Orange	Green	Red	Green
140	Eswatini	Yellow	Yellow	Orange	Green	Grey	Grey
141	Congo, Dem. Rep.	Red	Green	Green	Green	Red	Green
151	Lesotho	Red	Yellow	Green	Green	Grey	Grey
152	Malawi	Red	Green	Green	Green	Grey	Grey
161	Comoros	Green	Orange	Grey	Green	Grey	Grey
163	Namibia	Orange	Orange	Green	Green	Red	Red
165	Madagascar	Red	Yellow	Yellow	Green	Grey	Grey

Food sub-index

Rank	Country	Prevalence of undernourishment (%) (ind.14)	Percentage of children under 5 years of age affected by wasting (%) (ind.15)	Percentage of children under 5 years of age who are stunted (%) (ind.16)	Prevalence of obesity in the adult population (18 years and older) (ind.17)	Average protein supply (gr/caput/day) (ind.18)	Cereal yield (kg per hectare) (ind.19)	Average Dietary Energy Supply Adequacy (ADESA) (%) (ind.20)	Average value of food production (I$ per caput) (ind.21)
72	South Africa	Green	Green	Orange	Orange	Orange	Orange	Yellow	Red
100	Mauritius	Green	Grey	Grey	Green	Orange	Orange	Yellow	Red
124	Angola	Yellow	Green	Orange	Green	Red	Red	Orange	Red
126	Mozambique	Yellow	Yellow	Red	Green	Red	Red	Orange	Red
127	Zambia	Orange	Yellow	Red	Green	Red	Orange	Red	Red
135	Zimbabwe	Orange	Green	Orange	Green	Red	Red	Red	Red
136	Botswana	Yellow	Yellow	Orange	Yellow	Orange	Red	Red	Red
138	Tanzania	Orange	Green	Grey	Green	Red	Red	Orange	Red
140	Eswatini	Yellow	Green	Grey	Yellow	Red	Red	Orange	Red
141	Congo, Dem. Rep.	Grey	Yellow	Grey	Green	Grey	Red	Grey	Red
151	Lesotho	Green	Green	Orange	Yellow	Red	Red	Orange	Red
152	Malawi	Yellow	Green	Orange	Green	Red	Red	Orange	Red
161	Comoros	Grey	Yellow	Orange	Green	Grey	Red	Orange	Red
163	Namibia	Yellow	Grey	Grey	Yellow	Red	Red	Red	Red
165	Madagascar	Orange	Orange	Red	Green	Red	Orange	Red	Red

Legend: Quartiles

- Red: values between 0 and 25
- Orange: values between 25 and 50
- Yellow: values between 50 and 75
- Green: values between 75 and 100
- Grey: insufficient data

Table 7-4: Untreated data for indicators that constitute the WEF Nexus Index for SADC countries

	Water Sub-Index							Energy Sub-Index						Food Sub-index							
	ind.01	ind.02	ind.03	ind.04	ind.05	ind.06	ind.07	ind.08	ind.09	ind.10	ind.11	ind.12	ind.13	ind.14	ind.15	ind.16	ind.17	ind.18	ind.19	ind.20	ind.21
	The percentage of people using at least basic drinking water services	Percentage of people using safely managed sanitation services.	Degree of IWRM implementation (1-100)	Annual freshwater withdrawals, total (% of internal resources)	Renewable internal freshwater resources per capita (cubic meters)	Environmental flow requirements (106 m3/annum)	Average precipitation in depth (mm per year)	Access to electricity (% of population)	Renewable energy consumption (% of total final energy consumption)	Renewable electricity output (% of total electricity output)	CO2 emissions (metric tons per capita)	Electric power consumption (kWh per capita)	Energy imports, net (% of energy use)	Prevalence of undernourishment (%)	Percentage of children under 5 years of age affected by wasting (%)	Percentage of children under 5 years of age who are stunted (%)	Prevalence of obesity in the adult population (18 years and older)	Average protein supply (gr/caput/day)	Cereal yield (kg per hectare)	Average Dietary Energy Supply Adequacy (ADESA) (%)	Average value of food production (I$ per caput)
Angola	41.0	39.4	37.1	0.48	5498	110.7	1010	40.5	49.6	53.2	1.3	312	-541.0	23.9	4.9	37.6	6.8	52.0	935	108	137
Botswana	79.2	60.0	41.1	8.1	1107	2.7	416	60.7	28.9	0.0	3.2	1749	44.5	28.5	7.2	31.4	16.1	64.0	453	98	172
Comoros	83.7	34.2	25.7	0.8	1580	n/a	900	77.8	45.3	n/a	0.2	n/a	n/a	n/a	11.1	32.1	6.9	n/a	1356	105	90
Congo, Dem. Rep.	41.8	19.7	31.3	0.08	12208	981.7	1543	17.1	95.8	99.8	0.1	109	2.0	n/a	8.1	n/a	5.6	n/a	772	n/a	51
Lesotho	71.6	43.8	32.9	0.8	2437	1.3	788	29.7	52.1	100.0	1.2	n/a	n/a	12.8	2.8	33.2	13.5	32.0	508	114	73
Madagascar	50.6	9.7	36.5	4.02	14286	217.5	1513	22.9	70.2	54.6	0.1	n/a	n/a	43.1	15.2	49.2	4.5	24.0	3920	89	137
Malawi	67.2	43.5	40.3	8.4	946	9.5	1181	11.0	83.6	91.3	0.1	n/a	n/a	26.3	2.7	37.1	4.7	39.0	1347	104	139
Mauritius	99.9	93.1	64.4	26.4	2182	n/a	2041	98.8	11.5	22.7	3.4	2183	84.5	5.8	n/a	n/a	11.5	92.0	3455	125	190
Mozambique	47.3	23.6	54.6	0.9	3686	133.0	1032	24.2	86.4	86.4	0.3	463	-54.6	30.5	6.1	43.1	6.0	41.0	824	106	97
Namibia	n/a	n/a	59.1	4.6	2598	7.2	285	51.8	26.5	97.8	1.6	1585	74.4	25.4	n/a	n/a	15.0	49.0	453	98	168
South Africa	84.7	73.1	65.5	34.6	821	20.1	495	84.2	17.2	2.3	9.0	4198	-14.5	6.1	2.5	27.4	27.0	83.0	3810	123	229
Eswatini	67.6	58.0	52.6	39.5	2038	3.1	788	65.8	66.1	46.6	0.9	n/a	n/a	20.7	2.0	n/a	13.5	44.0	1138	103	237
Tanzania	50.1	23.5	n/a	6.2	1608	56.3	1071	32.8	85.7	34.2	0.2	99	10.7	32.0	4.5	n/a	4.1	46.0	1541	106	193
Zambia	61.2	31.1	46.1	2.0	5134	49.4	1020	27.2	88.0	97.0	0.3	707	8.3	44.5	6.3	40.0	6.5	41.0	2418	93	118
Zimbabwe	66.6	38.6	61.0	29.1	796	9.3	657	38.1	81.8	52.7	0.8	537	15.3	46.6	3.2	26.8	12.3	58.0	580	87	75

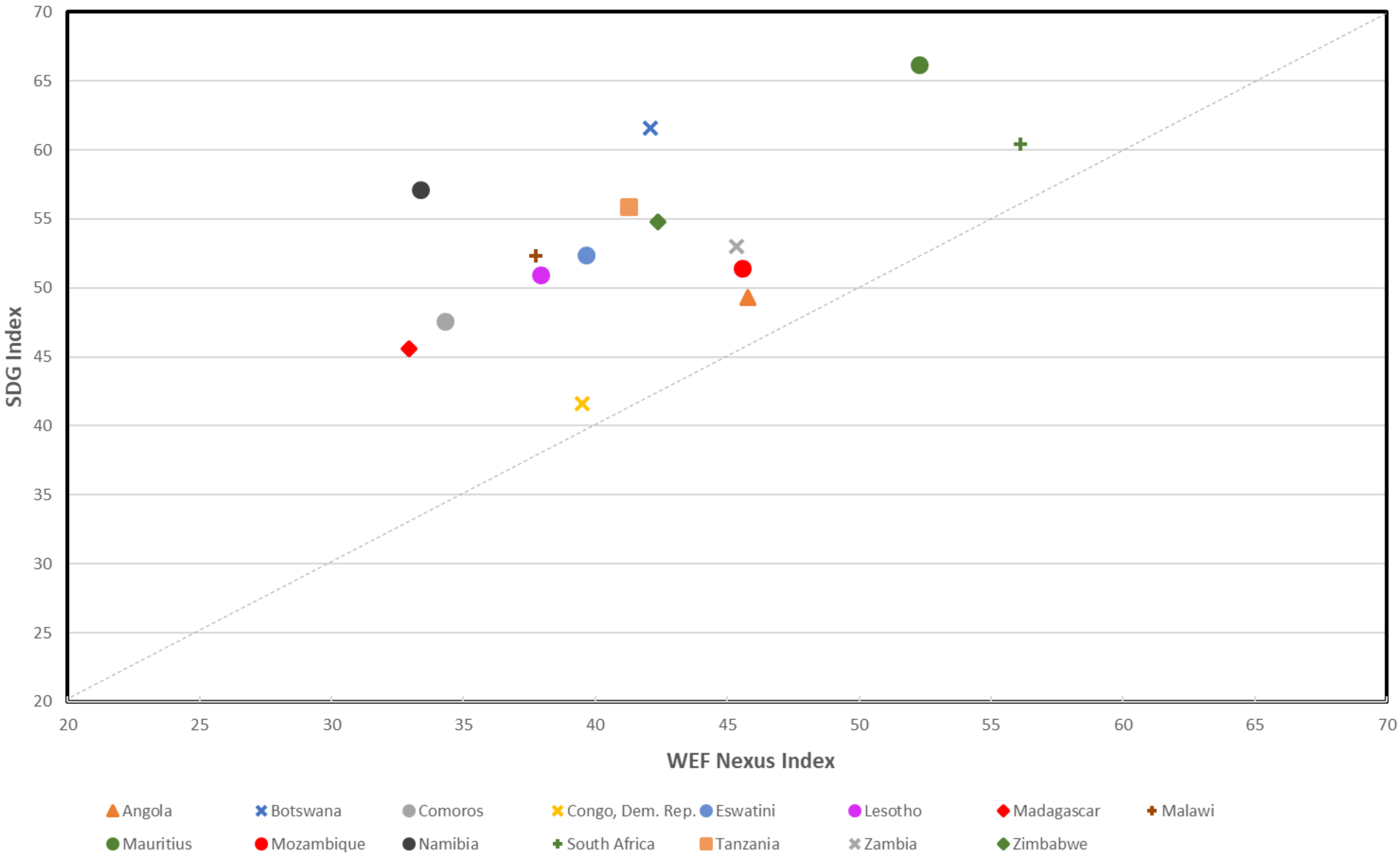

Figure 7-4: Plot of SDG Index (Sachs et al. 2018) against the WEF Nexus Index for the SADC nations

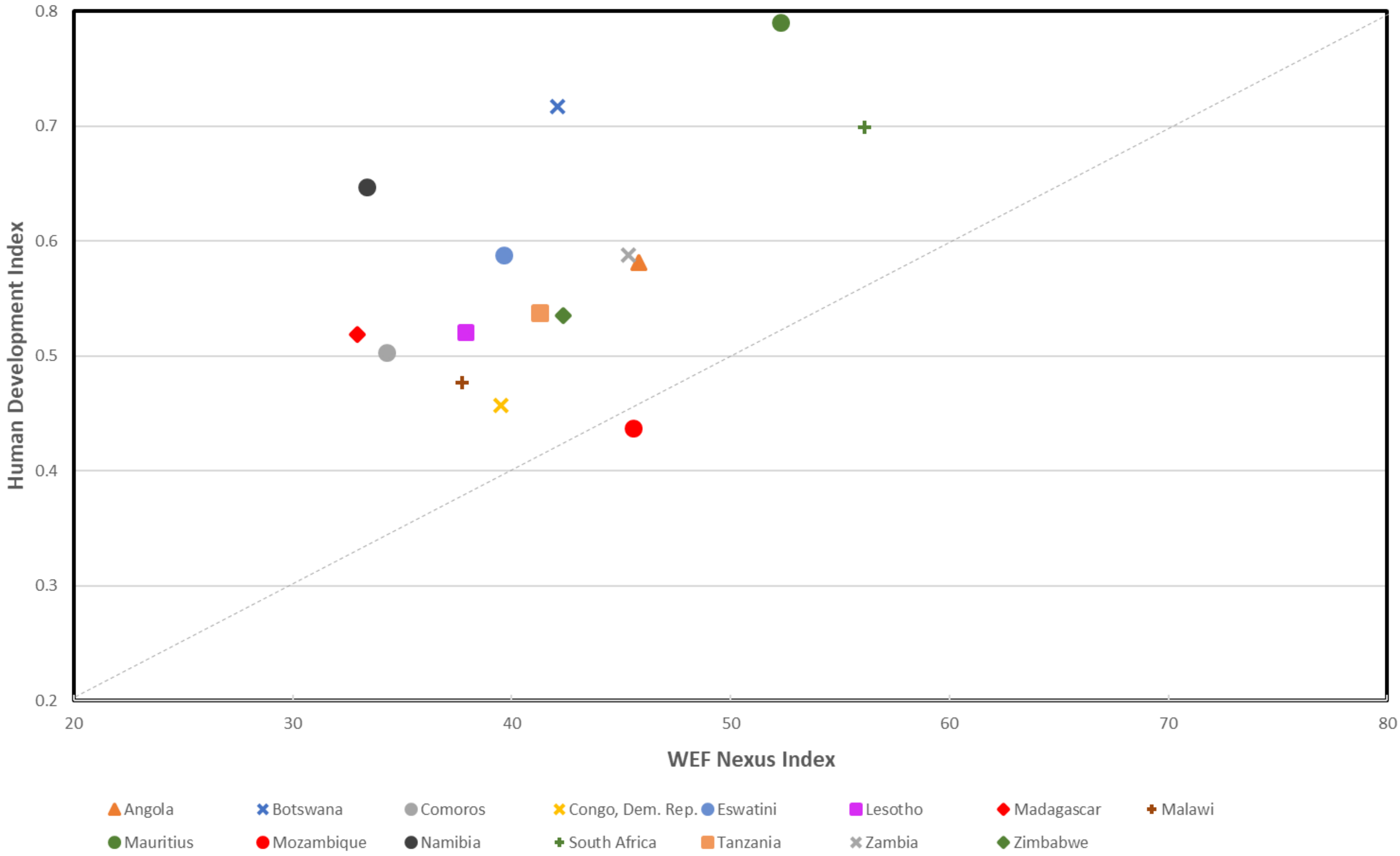

Figure 7-5: Plot of Human Development Index (UNDP 2018a) against the WEF Nexus Index for SADC countries

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The nexus concept has gained noteworthy attention in policy, development and academic circles since 2011. If it is to be utilised as a lens for integrated resource management and sustainable development, then livelihoods and the environment must be integrated into the framework. Various quantitative and qualitative approaches have been proposed for assessing the WEF nexus, and there is no one-size-fits-all methodology. Recent literature has highlighted that there is a need for the WEF nexus approach to graduate from high-level conceptual assessments to implementation and innovation. Within this thesis, a nexus "melting pot" case study is presented for the province of Mpumalanga in South Africa. This assessment highlights trade-offs within the WEF nexus, and that the achievement of resource security in one sector should not compromise the security of adjacent sectors.

Critical to the development of the WEF Nexus Index was the creation of the anthropocentric WEF Nexus framework. Humanity, as the driver and custodian of the global resource supply chain, must be central if consumption patterns are to become sustainable, and if policies (at various spatial extents) are to align with the aspirational SDGs. The hypothesis of this research was that there is sufficient, relevant water-, energy- and food-related indicator data to develop a global, country-level WEF nexus-based composite indicator that can be utilised as a means for assessing integrated resources management and informing policy. The development and application of the WEF Nexus Index have supported this hypothesis. Through the application of the index to various countries and regions, it has been demonstrated that its strength is that it can serve as a uniform point-of-departure or entry-point into the underlying assessment (including the sub-indices and indicator data), which can then be tailored for the specific case study.

8.1 Revisiting the aims and objectives

The aims of this research, together with how these aims were addressed in the research (in italics), are presented in the following bullet points:

- Provide a review of the development of the WEF nexus as a framework for achieving resource security. *This was undertaken in Chapter 2. It was shown that while that WEF nexus approach is not entirely new, novelty is not a prerequisite for relevance. While the nexus introduces complexity, this complexity is necessary to address the system if integrated resources management is to be realized. The need to address distributional justice within the global resource supply chain system is imperative, especially in light of the SDGs.*
- Assess the status quo of thinking within the WEF nexus research and policy development fraternity in terms of its relevance, maturity and level of implementation.

In Chapter 3, it was demonstrated that following eight years of growth in thought relating to the WEF nexus more has been said than done regarding this framework. There is a general call from several leading voices for a move from nexus concepts to nexus innovations and projects, i.e. from 'nexus thinking' to 'nexus implementation.'

- Develop a conceptual framework, with a focus on inclusivity for developing countries, for guiding the development of the WEF Nexus Index. *Within Chapter 5, the anthropocentric nature of resource supply and demand was described. The growth in the global population with a large urbanised population having 'Western' consumption patterns is threatening, and at times exceeding planetary boundaries. While this is occurring, one-seventh of the world's population remains disenfranchised. The 'Anthropocentric WEF Nexus Framework' presented in this chapter was derived from a developing nation perspective. This framework can be utilised to guide WEF nexus-related initiatives that range from case studies, serious games, innovative projects and qualitative assessments to composite indicators. The framwork has been well received when it has been presented in WRC forums, at a conference in Lisbon, and at a lunch time lecture in Delft. It resonates with people that if we are at the centre of the framework then we must make changes to our governance, policies and consumption patterns in order to attain a sustainable future.*
- Present the development of a WEF nexus-based dashboard and composite index:
    - For assessing national progress towards the constituent SDGs. *The WEF Nexus Index and its associated dashboard were developed for 170 countries with adequate data. These two tools were derived at a national scale, and the three pillars that make up the WEF Nexus Index, i.e. water, energy, and food, provide an alternative means (i.e. an integrated means) of assessing progress towards SDGs 2, 6 and 7.*
    - Apply the WEF nexus at a sub-national scale within a developing country, utilising indicators to guide the assessment. *The Mpumalanga Province within South Africa was utilised as a case study. Indicators and GIS-maps were utilised within this nexus assessment. In conclusion, in Chapter 4, it was noted that one resource sector should not be secured to the detriment of the adjacent sectors. To this end, it was noted that the relentless pursuit of fossil-fuel-based energy security could threaten both food and water security within this strategic province, and ultimately within South Africa.*
    - Include an assessment of selected nations and regions in terms of the WEF nexus, based on the results from the WEF Nexus Index. *The top-twenty, and bottom-twenty, ranking nations in terms of the WEF Nexus Index were presented in Chapter 6. Further assessments were undertaken for selected regions (e.g. SADC – refer to Chapter 7 - and MENA) and selected nations (e.g. Norway,*

Brazil, Malaysia, China, India, Singapore and Qatar). Various lessons and insights relating to the WEF nexus were offered for each of these case studies.

- The visualisation of the indicator data making up the composite index will provide a representation of both country- and regional-level progress towards integrated resource security and livelihood vulnerability associated with the system under assessment (i.e. the WEF nexus), while also highlighting actual or potential trade-offs, and synergies, that exist between the resource sectors. *The visualisation of the WEF Nexus Index includes:*
  - *A schematic layout of the WEF Nexus Index, with its constituent pillars, sub-pillars, and indicators.*
  - *A world map with selected countries highlighted in doughnut plots is presented in Chapter 6. This map presents each nation's WEF Nexus Index value in a shade of blue, with the darker shade indicating a higher score. Lighter shading, and hence lower index scores, are evident in regions such as Africa and South-East Asia. Doughnut plots are presented on the map for selected nations.*
  - *A ranking table for the top-twenty and bottom-twenty nations in terms of WEF Nexus Index has been provided in the research. It is evident in these tables that there is a general tradeoff between the level of development and the level of CO_2 emissions in a country.*
  - *A plot of the Human Development Index versus the WEF Nexus Index for selected countries presents the degree of correlation between these two indices. Outliers within this plot provide an entry point for evaluating how some resource-poor nations have achieved a noteworthy level of human development.*
  - *A table with the untreated indicator data for the 21 indicators included in the WEF Nexus Index is presented in Addendum B.*
  - *A dashboard with the treated data, with different colours for the treated data for each indicator in the following ranges: 0-25% (red); 25-50% (yellow); 50-75% (orange); and 75-100% (green). The dashboard is included in Addendum D. Livelihood vulnerability is starkly evident for the lower ranking nations when the food-availability sub-pillar is considered. Nearly all of the treated data values are in the lowest quartile for all four indicators that make up this sub-pillar for the lower-ranking countries. In contrast, top-ranking nations are characterised by very high levels of service delivery (access to improved drinking water services, safe sanitation facilities and electricity) and low levels of undernourishment.*

8.2 Contributions to new knowledge

This research has yielded a global country-level composite indicator related to the WEF nexus. It provides a quantitative means of ascertaining 170 different nation's progress in terms of the integrated resource management, utilising the WEF nexus as a lens. It also provides an opportunity for comparing a nation's progress with other countries, whether from the same region (e.g. SADC or MENA), at a similar level (i.e. developed or developing), or by assessing a nation relative to all of the countries included in the study (e.g. the best performing nation). By having a quantitative measure of the WEF nexus, the index provides a summary and entry point to the complex dataset upon which it is founded. This will facilitate an analysis of the constituent indicators, which will provide the researcher, policymaker or decision-maker with insights and prompts in terms of where interventions and investments are necessary.

8.3 Future possibilities

Because the WEF Nexus Index is determined for a reference year, namely 2019, it will be appropriate to update it annually. This will allow nations to ascertain whether policies and/or projects that they have implemented are making a material difference in service delivery or integrated resource management. It will also serve as an additional measure of progress towards SDGs 2, 6 and 7, which can inform policy briefs to national planning commissions related to integrated resource management, especially for poorer countries. Undertaking a sensitivity analysis regarding data imputation, insufficient data for an indicator, and the weighting of pillars and sub-pillars will add value to future research.

Selected WEF nexus analyses of a province and various nations and regions are presented in Chapters 4, 6 and 7. These assessments can be expanded upon significantly by academics, development agencies and policymakers in specific countries or regions. Research organisations with specific focuses such as small island states, the MENA region, or South-East Asia can use the composite index as a point of departure for regional studies. Further, lessons from resource-poor nations such as Singapore and Hong Kong can be expanded, with books, journal articles or workshops being developed to exchange ideas and propose roadmaps. The WEF Nexus Index should ideally be utilised as an entry point into the underlying sub-indices and constituent indicators. Any WEF nexus analysis utilising this index can, and should, be accompanied by additional studies that may be quantitative and/or qualitative in nature, and may include adjacent disciplines such as economic, social or governance assessments. Further, in future studies the WEF Nexus Index's correlation with other indices such as GDP or level of urbanisation plotted in addition to the plots against the HDI and SDG Index.

An interactive web-based WEF Nexus Index tool could be developed for users to undertake "What if?" scenarios. A country could be selected, and the 21 indicator values that make up the most recent composite indicator for that country could appear in the indicator view-panes. The user could then determine the resultant difference that would result if specific indicators improved with time, and how that would impact the nation's index value. If the web-based tool is linked with the tool developed in the SIM4NEXUS project, then changes in policy could be related to potential changes in indicators and the resultant change to the WEF Nexus Index. The SIM4NEXUS project had case studies in Azerbaijan, the Island of Sardinia (Italy), the Region of Andalusia (Spain), the Southwest of the United Kingdom (the Counties of Devon and Cornwall), the Upper Rhine (France-Germany), The Netherlands, Latvia, Sweden, Greece, and Eastern Germany, Czech Republic and Slovakia. Following discussions with the developers, there are plans to utilise the SIM4NEXUS tool in other countries, regions and continents (such as a catchment in eastern South Africa).

8.4 Final comments

The motivation for developing a composite indicator related to the WEF nexus was birthed by a question that was raised during the workshop *Water-Energy-Food Nexus and its linkages to the implementation of the SDGs* in Hilton, South Africa in November 2016. The question raised was "How can we measure the nexus?" This question related to the desire to understand a system that has components measured in different units (e.g. m^3, kWh and calories) that occur at different spatial and temporal scales. It also stemmed from a sense of being overwhelmed by the sheer number of SDG indicators and targets, and how these should be assessed coherently. At that time, the SDGs had recently been launched. Three years later, only ten years remain to achieve the SDGs within the stipulated timeframe.

WEF nexus assessments in the decade leading up to 2030 must be more comprehensive. Qualitative studies must be conducted in parallel with quantitative assessments. The former of these will need to include the marginalised (due to their socio-economic situation or gender), stakeholders from each resource sector (together with those in adjacent sectors), as well as an assessment of policies and regulatory or political power struggles. Further, there is no one-size-fits-all method for integrated resource management utilising the WEF nexus. Instead, the approach must be tailored for each unique situation. There is a need for nations to learn from one another, as noted in the discussion of Singapore (see Chapter 6). There is a pressing need to find innovative funding mechanisms for renewable projects in developing countries, as evidenced by the credit facility set up by Zola Electric in Tanzania (see Chapter 5).

The development of the WEF Nexus Index has demonstrated that no country is undertaking integrated resource management perfectly. Every nation has the potential for improvement. This is evidenced by, for example, the top-ranking country for the WEF Nexus Index needing to reduce CO_2 emissions. The WEF Nexus Index is not the panacea that will solve all the significant development or environmental challenges facing humankind. It can, however, contribute to the quest to 'leave no one behind.'

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ADDENDUM A: INDICATOR SELECTION TABLE

Addendum A: WEF Nexus Index - Indicator selection table

No.	Sector	Indicator	Definition[1]	Source	Units	Data availability	SDG Indicator? (Y/N)	Reason/motivation for inclusion/exclusion
1	Water (SDG 6)	The percentage of people using at least basic drinking water services	This indicator encompasses both people using basic water services as well as those using safely managed water services. Basic drinking water services are defined as drinking water from an improved source, provided collection time is not more than 30 minutes for a round trip. Improved water sources include piped water, boreholes or tube wells, protected dug wells, protected springs, and packaged or delivered water (*FAO.org 2018, Accessed 2019-03-01*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** World Bank: http://data.worldbank.org/indicator/SH.H2O.BASW.ZS. **Original source:** WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene (washdata.org). Accessed 2019-03-01	%	2015 Very good data coverage. The indicator is utilised in SDG Index for SDG 6	No, but 6.1.1 (Proportion of population using safely managed drinking water services) and 6.3.2 are SDG indices. It is FAO indicator I_4.1	**Yes**; very good data, and the indicator is relevant to SDG 6. Alternative to official indicator 6.1.1 since it has better data coverage for many nations
2	Water (SDG 6)	People using safely managed drinking water services	The percentage of the population using drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination (*FAO.org 2018, Accessed 2019-03-01*)	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** World Bank: http://data.worldbank.org/indicator/SH.H2O.SMDW.ZS **Original source:** World Health Organization and United Nations Children's Fund, Joint Measurement Programme (JMP) (http://www.wssinfo.org/). Accessed 2019-03-01	%	2015 Data coverage relatively sparse	Yes, 6.1.1. It is FAO indicator I_4.2	No; rather use "The percentage of people using at least basic drinking water services" as equivalent indicator since it has better data coverage
3	Water (SDG 6)	Percentage of people using at least basic sanitation services.	The percentage of people using at least basic sanitation services, that is, improved sanitation facilities that are not shared with other households. This indicator encompasses both people using basic sanitation services as well as those using safely managed sanitation services. Improved sanitation facilities include flush/pour flush to piped sewer systems, septic tanks or pit latrines; ventilated improved pit latrines, compositing toilets or pit latrines with slabs (*FAO.org 2018, Accessed 2019-03-01*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** World Development Indicators: World Bank: http://data.worldbank.org/indicator/SH.STA.BASS.ZS. **Original source:** World Health Organization and United Nations Children's Fund, Joint Measurement Programme (JMP) (http://www.wssinfo.org/). Accessed 2019-03-01	%	2015 Very good data coverage. The indicator is utilised in SDG Index for SDG 6	No, but 6.2.1 and 6.3.1 are SDG indices. It is FAO indicator I_4.3	No; very good data, and the indicator is relevant to SDG 6, but "Percentage of people using safely managed sanitation services" is an official SDG indicator, 6.2.1, and FAO lists the exact same data for the two.
4	Water (SDG 6)	Percentage of people using safely managed sanitation services.	The percentage of the population using improved sanitation facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site (*FAO.org 2018, Accessed 2019-03-01*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** World Development Indicators: World Bank: http://data.worldbank.org/indicator/SH.STA.SMSS.ZS. **Original source:** World Health Organization and United Nations Children's Fund, Joint Measurement Programme (JMP)	%	2015 Very good data coverage. Data is identical to "Percentage of people using at least basic sanitation services."	Yes, 6.2.1 and it is FAO indicator I_4.4	**Yes**; very good data coverage and indicator is an official SDG indicator

[1] Definitions from websites listed in "Source" column of table

				(http://www.wssinfo.org/). Accessed 2019-03-01				
5	Water (SDG 6)	Infrastructure leakage index	Performance indicator for real losses, which measures the ratio of current annual real losses to system-specific unavoidable annual real losses. It is the ideal indicator for making international comparison (Winarni, 2009). The Infrastructure Leakage Index (ILI) is a performance indicator that is used to indicate the level of Real Losses (i.e. Physical leakage) in a water distribution system (Mckenzie et al. 2012). The ILI is a non-dimensional indicator and ranges from 1 to over 100 and could be considered as an alternative to the Non-Revenue Water value. An ILI value of 1 equates to the "world's best practice" and indicates that the level of physical leakage in a system is as low as it can be, while a value of ten would indicate that the physical leakage is ten times larger than the lowest value.		-	On an international level uniformity in measuring, interpreting or reporting of the ILI does not exist.	No	No, data not comparable on an international level
6	Water (SDG 6)	Non-Revenue Water	A measure of the municipal efficiency of water management, Non-Revenue Water is the sum of unbilled authorised water, commercial losses and real or physical losses.		Million m^3/annum	On an international level uniformity in measuring, interpreting or reporting of the non-revenue water does not exist.	No	No, data not comparable on an international level
7	Water (SDG 6)	Annual freshwater withdrawals, total (% of internal resources)	Annual freshwater withdrawals refer to total water withdrawals, not counting evaporation losses from storage basins. Withdrawals also include water from desalination plants in countries where they are a significant source. Withdrawals can exceed 100 percent of total renewable resources where extraction from nonrenewable aquifers or desalination plants is considerable or where there is significant water reuse. Withdrawals for agriculture and industry are total withdrawals for irrigation and livestock production and for direct industrial use (including withdrawals for cooling thermoelectric plants). Withdrawals for domestic uses include drinking water, municipal use or supply, and use for public services, commercial establishments, and homes *(World Bank 2019-03-01)*	https://data.worldbank.org/indicator/ER.H2O.FWTL.ZS?view=chart **Source:** Food and Agriculture Organization, AQUASTAT data	%	2002-2014 Limited data coverage. Indicator utilised in SDG Index for SDG 6. Need to use the most recent values from the database	Yes, 6.4.2 C060402	**Yes**, this is an official SDG indicator, and utilising the most recent values from 2002-2014 a good coverage of data is obtained. This dataset will however require Winsorization in order to remove the distorting effect of outliers, and to avoid too large a space in the dataset. Data could be truncated at 200%, which represents double the available fresh water resources of the country.
8	Water (SDG 6)	Water withdrawal in the agriculture sector	Annual quantity of self-supplied water withdrawn for irrigation, livestock and aquaculture purposes. It can include water from primary renewable and secondary freshwater resources, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of agricultural drainage water, direct use of (treated) wastewater, and desalinated water. Water for the dairy and meat industries and industrial processing of harvested	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	10^9 m^3 /year	Data available from 1965-2017 with many missing data per year. Most data are available for 2000 for 68 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.

			agricultural products is included under industrial water withdrawal *(FAO 2019-05-25)*					
9	Water (SDG 6)	Water withdrawal in the industry sector	Annual quantity of self-supplied water withdrawn for industrial uses. It can include water from primary renewable and secondary freshwater resources, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of agricultural drainage water, direct use of (treated) wastewater, and desalinated water. This sector refers to self-supplied industries not connected to the public distribution network. The ratio between net consumption and withdrawal is estimated at less than 5%. It includes water for the cooling of thermoelectric and nuclear power plants, but it does not include hydropower. Water withdrawn by industries that are connected to the public supply network is generally included in municipal water withdrawal. *(FAO 2019-05-25)*	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	10^9 m^3 /year	Data available from 1965-2017 with many missing data per year. Most data are available for 2000 for 93 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
10	Water (SDG 6)	Water withdrawal in the industry sector	Annual quantity of water withdrawn primarily for the direct use by the population. It can include water from primary renewable and secondary freshwater resources, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of agricultural drainage water, direct use of (treated) wastewater, and desalinated water. It is usually computed as the total water withdrawn by the public distribution network. It can include that part of the industries and urban agriculture, which is connected to the municipal network. The ratio between the net consumption and the water withdrawn can vary from 5 to 15% in urban areas and from 10 to 50% in rural areas. *(FAO 2019-05-25)*	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	10^9 m^3 /year	Data available from 1965-2017 with many missing data per year. Most data are available for 2000 for 91 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
11	Water (SDG 6)	Fresh groundwater withdrawal (primary and secondary) - Total	Annual gross amount of water extracted from aquifers. It can include withdrawal of renewable primary and secondary groundwater, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater.*(FAO 2019-05-25)*	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	10^9 m^3 /year	Data available from 1965-2017 with many missing data per year. Most data are available for 2000 for 91 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
12	Water (SDG 6)	Desalinated water produced	Water produced annually by desalination of brackish or salt water. It is estimated annually on the basis of the total capacity of water desalination installations..*(FAO 2019-05-25)*	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	10^9 m^3 /year	Data available from 1980-2015 with many missing data per year. Most data are available for 2000 for 49 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
13	Water (SDG 6)	Treated municipal water	Treated wastewater (primary, secondary and tertiary) annually produced by municipal wastewater treatment facilities in the country. Primary treatment:municipal wastewater effectively treated by a physical and/or chemical process involving	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	10^9 m^3 /year	Data available from 1967-2017 with many missing data per year. Most data are	No	No, although data is available for many countries, the data is missing for many monitoring years

			settlement of suspended solids, or other process in which the BOD5 of the incoming wastewater is reduced by at least 20% and the total suspended solids of the incoming wastewater are reduced by at least 50% before discharge. Treatment processes can include: sedimentation tank, septic tank, skimming, chemical enhanced primary treatment. Secondary treatment:municipal wastewater effectively treated by a process generally involving biological treatment with a secondary settlement or other process, resulting in a BOD removal of at least 70% and a COD removal of at least 75% before discharge. Treatment processes can include: aerated lagoon, activated sludge, up-flow anaerobic sludge blanket, trickling filters, rotating biological contactors, oxidation ditch, settling basin digester. For the purpose of this database natural biological treatment processes are also considered under secondary treatment as the constituents of the effluents from this type of treatment is similar to the conventional secondary treatment. Natural biological treatment refers to the process other than conventional wastewater treatment (primary, secondary, tertiary). This treatment makes use of natural bio-chemical processes to treat wastewater and can include: waste stabilization pond, constructed wetlands, overland treatment, nutrient film techniques, soil aquifer treatment, high-rate algal pond, floating aquatic macrophyte systems. Tertiary treatment:municipal wastewater effectively treated by a process in addition to secondary treatment of nitrogen and/or phosphorous and/or any other specific pollutant affecting the quality or a specific use of water: microbiological pollution, colour, etc. This treatment is meant to remove at least 95% for BOD and 85% for COD and/or a nitrogen removal of at least 70% and/or a phosphorus removal of at least 80% and/or a microbiological removal. Treatment process can include: membrane filtration (micro-; nano-; ultra- and reverse osmosis), infiltration / percolation, activated carbon, disinfection (chlorination, ozone, UV). ..*(FAO 2019-05-25)*			available for 2012 for 25 countries.		resulting in an incomplete dataset.
14	Water (SDG 6)	Direct use of treatment municipal water	Treated municipal wastewater (primary, secondary, tertiary effluents) directly used, i.e. with no or little prior dilution with freshwater during most of the year.	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	10^9 m^3 /year	Data available from 1967-2013 with many missing data per year. Most data are available for 2000 for 15 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
15	Water (SDG 6)	Environmental flow requirements	The quantity and timing of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	10^9 m^3 /year	Data available from 1962-2017 with many missing data per year.	No	Yes, it is important that water's contribution required for sustaining the environment is taken

			livelihoods, and wellbeing" (Adapted from Arthington, A.H., et al. 2018).			Most data are available for 2017 for 154 countries.		into account. Good correlation with renewable internal fresh water resources (0.58)
16	Water (SDG 6)	Percentage of area equipped for irrigation by surface water	Area equipped for irrigation irrigated by surface water as percentage of the total area equipped for irrigation	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	%	Data available from 1962-2014 with many missing data per year. Most data are available for 1994 for 19 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
17	Water (SDG 6)	Percentage of area equipped for irrigation by ground water	Equipped for irrigation area irrigated by groundwater as percentage of the total equipped for irrigation area.	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	%	Data available from 1962-2014 with many missing data per year. Most data are available for 1994 for 17 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
18	Water (SDG 6)	Percentage of total grain production irrigated	Percent of the total grain production of the country (rainfed and irrigated) that is irrigated in a given year, expressed in percentage.	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en **Source:** Food and Agriculture Organization, AQUASTAT data	%	Data available from 1984-1995 with many missing data per year. Most data are available for 1994 for 13 countries.	No	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
19	Water (SDG 6)	Renewable internal freshwater resources per capita (cubic meters)	Renewable internal freshwater resources flows refer to internal renewable resources (internal river flows and groundwater from rainfall) in the country. Renewable internal freshwater resources per capita are calculated using the World Bank's population estimates (*World Bank 2019-03-01*).	https://data.worldbank.org/indicator/ER.H2O.INTR.PC?view=chart **Source:** Food and Agriculture Organization, AQUASTAT data	m^3/capita	2014 Very good data coverage	No	**Yes**, very good data coverage, and the "per capita" unit provides a helpful measure between countries with an indicator of relative scarcity. Good correlation with annual fresh water reseources, but not too high to warrant exclusion (0.78)
20	Water (SDG 6)	Renewable internal freshwater resources, total (billion cubic meters)	Renewable internal freshwater resources flows refer to internal renewable resources (internal river flows and groundwater from rainfall) in the country (World Bank 2019-03-04).	https://data.worldbank.org/indicator/ER.H2O.INTR.K3?view=chart **Source:** Food and Agriculture Organization, AQUASTAT data	Billion m^3	2014 Very good data coverage	No	No, this is the same data as the "Renewable internal freshwater resources per capita (cubic meters)" but as a quantum instead of per capita
21	Water (SDG 6)	Hydropower electricity capacity (MW)	Hydropower and renewable hydropower	https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies **Source**: Source: IRENA (2019), Renewable capacity statistics 2019; and IRENA (2018), Renewable Energy Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.	MW	Data available from 2000-2018 with minimal missing data per year. Most data are available for 2018 for 159 countries.	No	No, this data is included in the renewable energy consumption and output indicators

22	Water (SDG 6)	Hydropower electricity generation (GWh)	Hydropower and renewable hydropower	https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies **Source**: Source: IRENA (2019), Renewable capacity statistics 2019; and IRENA (2018), Renewable Energy Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.	GWh	Data available from 2000-2016 with minimal missing data per year. Most data are available for 2016 for 159 countries.	No	No, this data is included in the renewable energy consumption and output indicators
23	Water (SDG 6)	Average precipitation in depth (mm per year)	Average precipitation is the long-term average in depth (over space and time) of annual precipitation in the country. Precipitation is defined as any kind of water that falls from clouds as a liquid or a solid (*World Bank 2019-03-04*).	https://data.worldbank.org/indicator/AG.LND.PRCP.MM **Source:** Food and Agriculture Organization, electronic files and website	mm/ year	2014 Very good data coverage	No	**Yes**; this data is widely available and provides a good indication of available fresh water. This indicator directly influences food production and energy generation. Good correlation with annual freshwater withdrawals
24	Water (SDG 6)	Proportion of wastewater safely treated	Percentage of wastewater generated by households (sewage and faecal sludge) and economic activities (based on ISIC categories) that is safely treated (UN Water, 2016).	http://www.fao.org/nr/water/aquastat/data/query/results.html Source: FAO. 2016. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Website accessed on [13/03/2019 8:28]	10^9 m^3/year	Data available from 1993-2017 for 93 countries with missing data entries for most years	Yes; indicator 6.3.1	No, although data is available for many countries, the data is missing for many monitoring years resulting in an incomplete dataset.
25	Water (SDG 6)	Proportion of bodies of water with good ambient water quality	Percentage of water bodies (area) in a country with good ambient water quality. "Good" indicates an ambient water quality that does not damage ecosystem function and human health according to core ambient water quality parameters. Overall water quality is estimated based on a core set of five parameters that inform on major water quality impairments present in many parts of the world: electric conductivity/total dissolved solids; percentage dissolved oxygen; dissolved inorganic nitrogen/total nitrogen; dissolved inorganic phosphorus/total phosphorus; and faecal coliform/Escherichia coli bacteria (UNWater, 2016).	UNEP GEMStat		Initial baseline data collected in 2017 for 48 countries. Data is not accessible yet	Yes; indicator 6.3.2	No, only baseline data has been collected for 48 countries. The baseline data is not accessible and cannot be used.
26	Water (SDG 6)	Change in water-use efficiency over time	Output from a given economic activity (based on ISIC categories), per volume of net water withdrawn by the economic activity. This indicator includes water use by all economic activities, focusing on agriculture (excluding the portion generated by rain-fed agriculture), manufacturing, electricity, and water collection, treatment and supply (looking at distribution efficiency and capturing network leakages). By assessing changes over time, the sectoral values can be aggregated into one (UNWater, 2016).	http://www.fao.org/nr/water/aquastat/data/query/results.html	USD/m^3	Data can be calculated from water used per sector and economic contribution, but data specific for this indicator is not available.	Yes; indicator 6.4.1	No; this indicator is calculated per economic sector in a country and not as one value per country.
27	Water (SDG 6)	Degree of integrated water resources	The degree to which IWRM is implemented, by assessing the four components of policies, institutions, management tools and financing. It takes into account	http://iwrmdataportal.unepdhi.org/dataoverview.html	%	Data is available for 2017 for 175 countries.	Yes; indicator 6.5.1	**Yes**; IWRM implementation provides a good indication of

		management implementation (0-100)	the various users and uses of water, with the aim of promoting positive social, economic and environmental impacts at all levels, including the transboundary level, where appropriate (UNWater, 2016).					water governance, and has a strong correlation with the implementation of basic drinking water and sanitation facilities.
28	Water (SDG 6)	Proportion of transboundary basin area with an operational arrangement for water cooperation	Percentage of transboundary basin area within a country that has an operational agreement or other arrangement for water cooperation. For the purpose of the indicator, "basin area" is defined for surface waters as the extent of the catchment, and for groundwater as the extent of the aquifer. An "arrangement for water cooperation" is a bilateral or multilateral treaty, convention, agreement or other formal arrangement among riparian countries that provides a framework for cooperation on transboundary water management. The criteria for the arrangement to be considered "operational" are based on key aspects of substantive cooperation in water management, such as the existence of institutional mechanisms, regular communication among riparian countries, joint or coordinated management plans or objectives, as well as a regular exchange of data and information (UNWater, 2016).	http://geftwap.org/data-portal	%	Data is not included in the National Statistical Systems yet.	Yes; indicator 6.5.2	No; there is no usable data available yet, but this indicator will play an important role in terms of catchment management.
29	Water (SDG 6)	Change in the extent of water-related ecosystems over time	Changes over time in (1) the spatial extent of water-related ecosystems (wetlands, forests and drylands); (2) the quantity of water in ecosystems (rivers, lakes and groundwater); and (3) the resulting health of ecosystems. In addition, indicator 6.3.2 on ambient water quality and indicator 6.4.2 on environmental water requirements are critically important for understanding ecosystems and need to be factored into the assessment of indicator 6.6.1 (UNWater, 2016).	Not available yet	-	Data not available or not easily accessible.	Yes; indicator 6.6.1	No, insufficient data at this time.
30	Water (SDG 6)	Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan	Amount and percentage of ODA that is included in a government coordinated spending plan, whether: (1) on treasury or (2) on budget. ODA flows are official financing with the main objective of promoting economic development and welfare of developing countries; they are concessional in character with a grant element of at least 25%. By convention, ODA flows comprise contributions from donor government agencies, at all levels, to developing countries, either bilaterally or through multilateral institutions. A government coordinated spending plan is defined as a financing plan/budget for water and sanitation projects, clearly assessing the available sources of finance and strategies for financing future needs (UNWater, 2016).	https://datacatalog.worldbank.org/ Source: The World Bank	US$ per year	Data available from 2002-2011 for 59 countries	Yes; indicator 6.a.1	No; data is specific to developing countries and only covers 59 countries which is inefficient for the purpose of developing the WEF nexus index.
31	Water (SDG 6)	Proportion of local administrative units with established and operational	Percentage of local administrative units within a country with established and operational policies and procedures for participation of local communities in water and sanitation management. Local	Not available	%	None	Yes; indicator 6.b.1	No; there is no usable data available yet.

		policies and procedures for participation of local communities in water and sanitation management	administrative units refer to subdistricts, municipalities, communes or other local community level units covering both urban and rural areas to be defined by the government. Policies and procedures for participation of local communities in water and sanitation management define a mechanism by which individuals and communities can meaningfully contribute to decisions and directions on water and sanitation management (UNWater, 2016).					
32	Water (SDG 6)	Average evapotranspiration in volume (mm per year)	Important for water management policies in arid countries. Would affect water allocation	http://data.un.org/Data.aspx?d=ENV&f=variableID%3A7 **Source**: United Nations Statistics Division	Million m^3/annum	1990-2015 Fair coverage Data available for approximately 64 countries	No	No; data is only available for 64 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.
33	Water (SDG 6)	Dam storage capacity	Water storage capacity as a proxy for ability to manage Rainfall variability between seasons. Underscores the importance of a basic platform of hydraulic infrastructure, but insensitive application may encourage 'hydraulic mission' and heavy engineering at the expense of other solutions	http://www.fao.org/nr/water/aquastat/data/query/index.html Source: FAO. 2016. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Website accessed on [13/03/2019 8:28]	km^3	Data available from 1990-2017 for 130 countries, with missing data for some years.	No	No; although there is data per country available, it is fragmented. Also, it is uncertain whether dam storage is positive or negative, since there is a conflict between system flows and storage
34	Water (SDG 6)	Virtual water footprint	Many potential policy applications and implications, e.g. could be used to focus attention on the potential for virtual water trade to mitigate against localised water scarcity, but thinking is relatively young and virtual water footprint data needs careful interpretation	Mekonnen, M.M. and Hoekstra, A.Y. (2010) The green, blue and grey water footprint of crops and derived crop products, Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands. http://www.waterfootprint.org/Reports/Report47-WaterFootprintCrops-Vol1.pdf **Source**: Water Footprint Network	ton of crop or derived crop product	1996-2005 (collated data)	No	No; data is available, but it has been collated into a single dataset instead of data per country.
35	Water (SDG 6)	Total agricultural water managed area	Sum of total area equipped for irrigation and areas with other forms of agricultural water management (non-equipped flood recession cropping area and non-equipped cultivated wetlands and inland valley bottoms) (FAO, 2019-03-13)	http://www.fao.org/nr/water/aquastat/data/query/index.html Source: FAO. 2016. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Website accessed on [13/03/2019 8:28]	1000 ha	Data available from 1988-2017 for 52 countries, with missing data for some years.	No	No; data is only available for 52 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.
36	Water (SDG 6)	Population affected by water related diseases	Three types of water-related diseases exist: (i) water-borne diseases are those diseases that arise from infected water and are transmitted when the water is used for drinking or cooking (for example cholera, typhoid); (ii) water-based diseases are those in which water provides the habitant for host organisms of parasites ingested (for example shistomasomiasis or bilharzia); (iii) water-related insect vector diseases are those in which insect vectors rely on water as habitat but transmission is not through direct contact with	http://www.fao.org/nr/water/aquastat/data/query/index.html Source: FAO. 2016. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Website accessed on [13/03/2019 8:28]	1000 inhabitants	Data available from 1992-2011 for 32 countries, with most data missing for some years.	No	No; data is only available for 32 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.

			water (for example malaria, onchocerciasis or river blindness, elephantiasis).					
37	Energy (SDG 7)	Access to electricity (% of the population)	Access to electricity is the percentage of population with access to electricity. Electrification data are collected from industry, national surveys and international sources (*World Bank 2019-03-04*)	https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?view=chart **Source:** World Bank, Sustainable Energy for All (SE4ALL) database from the SE4ALL Global Tracking Framework led jointly by the World Bank, International Energy Agency, and the Energy Sector Management Assistance Program.	%	2016 Very good data coverage. Indicator utilised in SDG Index for SDG 7	Yes, Indicator 7.1.1 (C070101)	**Yes**; essential indicator for SDG 7 with good data coverage.
38	Energy (SDG 7)	Renewable energy consumption (% of total final energy consumption)	Renewable energy consumption is the share of renewables energy in total final energy consumption (*World Bank 2019-03-04*).	https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS **Source:** World Bank, Sustainable Energy for All (SE4ALL) database from the SE4ALL Global Tracking Framework led jointly by the World Bank, International Energy Agency, and the Energy Sector Management Assistance Program.	%	2015 Very good data coverage. Indicator utilised in SDG Index for SDG 7	Yes, Indicator 7.2.1 (C070201)	**Yes**; essential indicator for SDG 7 with good data coverage.
39	Energy (SDG 7)	Renewable electricity output (% of total electricity output)	Renewable electricity is the share of electricity generated by renewable power plants in total electricity generated by all types of plants (*World Bank 2019-03-04*).	https://data.worldbank.org/indicator/EG.ELC.RNEW.ZS?view=chart **Source:** IEA Statistics © OECD/IEA 2018 (http://www.iea.org/stats/index.asp)	%	2015 Very good data coverage	No	**Yes**; since "Renewable energy consumption" refers to energy, while this indicator considers electricity only. Correlation with Renewable energy consumption is good, but not too high
40	Energy (SDG 7)	Total greenhouse gas emissions (kt of CO_2 equivalent)	Total greenhouse gas emissions in kt of CO_2 equivalent are composed of CO_2 totals excluding short-cycle biomass burning (such as agricultural waste burning and Savannah burning) but including other biomass burning (such as forest fires, post-burn decay, peat fires and decay of drained peatlands), all anthropogenic CH_4 sources, N_2O sources and F-gases (HFCs, PFCs and SF6). (*World Bank 2019-03-04*)	https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE?view=chart **Source:** European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), EDGARv4.2 FT2012: http://edgar.jrc.ec.europa.eu/	kt of CO_2 equivalent	2012 Very good data coverage	No	No; since this indicator represents all of the GHGs as CO_2 equivalent and includes biomass burning, methane, and other non-energy related GHG sources.
41	Energy (SDG 7)	CO_2 emissions (metric tons per capita)	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring (*World Bank 2019-03-05*).	https://data.worldbank.org/indicator/EN.ATM.CO2E.PC **Source:** Carbon Dioxide Information Analysis Centre, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States. https://data.worldbank.org/indicator/EN.ATM.CO2E.PC	metric tons per capita	2014 Very good data coverage. Similar indicator utilised in SDG Index for SDG 7	No	**Yes**; this data provides an indication of fossil fuel-related power generation. The per capita rating takes cognisance of the size of the impact relative to the population
42	Energy (SDG 7)	CO_2 emissions (kt)	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring (*World Bank 2019-03-05*).	https://data.worldbank.org/indicator/EN.ATM.CO2E.KT?view=chart **Source:** Carbon Dioxide Information Analysis Centre, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States.	kt	2014 Very good data coverage	No	No; same parameter being measured as CO2 emissions (metric tons per capita), except that this is not per capita, but

								the quantum per country.
43	Energy (SDG 7)	Energy use (kg of oil equivalent per capita)	Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport (*World Bank 2019-03-05*).	https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE?view=chart **Source:** IEA Statistics © OECD/IEA 2014 (http://www.iea.org/stats/index.asp)	kg of oil equivalent per capita	2015,2014,2013 Good data coverage, although will need to utilise latest data since very limited data for 2015.	No, but consider including 7.1.2 "Proportion of population with primary reliance on clean fuels and technology"	No; although this is a relevant indicator with readily available data it has a very high correlation (0.94) with electric power consumption per capita, and would therefore constitute 'double accounting'. It is therefore excluded
44	Energy (SDG 7)	Energy imports, net (% of energy use)	Net energy imports are estimated as energy use less production, both measured in oil equivalents. A negative value indicates that the country is a net exporter. Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport (*World Bank 2019-03-05*).	https://data.worldbank.org/indicator/EG.IMP.CONS.ZS?view=chart **Source:** IEA Statistics © OECD/IEA 2014 (http://www.iea.org/stats/index.asp)	%	2015,2014,2013 Good data coverage, although will need to utilise latest data since very limited data for 2015.	No	**Yes**; this indicator provides a helpful indication of national energy security. But this indicator will be truncated at zero to exclude exports, since the primary concern is energy security and the indicator is essentially measuring imports and exports.
45	Energy (SDG 7)	Firms experiencing electrical outages (% of firms)	Percent of firms experiencing electrical outages during the previous fiscal year (*World Bank 2019-03-05*).	https://data.worldbank.org/indicator/IC.ELC.OUTG.ZS **Source:** World Bank, Enterprise Surveys	%	2013-2017 Relatively poor data coverage. Will need to use the latest value	No	No, relatively poor data coverage.
46	Energy (SDG 7)	Electric power consumption (kWh per capita)	Electric power consumption measures the production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants (*World Bank 2019-03-05*).	https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?view=chart **Source**: IEA Statistics © OECD/IEA 2014 (http://www.iea.org/stats/index.asp)	kWh per capita	2014 Very good data coverage	No	**Yes**; very good data coverage and very relevant, since it provides a helpful indication of a nation's generation capacity.
47	Energy (SDG 7)	Proportion of population with primary reliance on clean fuels and technology	This is measured as the share of the total population with access to clean fuels and technologies for cooking. Access to clean fuels or technologies such as clean cookstoves reduce exposure to indoor air pollutants, a leading cause of death in low-income households (UN Stats, 2018)	Households that use solid fuels for cooking: http://apps.who.int/gho/data/view.main.vEQSOLIDFUELSTOTv Source: World Health Organization (MICS and DHS)	%	Data available from 1998-2013 for 93 countries, with data missing for some years.	Yes; indicator 7.1.2	No; data is only available for 93 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.
48	Energy (SDG 7)	Energy intensity measured in terms of primary energy and GDP	This is measured as the energy intensity of economies (collectively across all sectors). Energy intensity is measured as the quantity of kilowatt-hours produced per 2011 international-$ of gross domestic product (kWh per 2011 int-$) (UN Stats, 2018). Total primary energy supply is defined as the sum of production and imports subtracting exports and storage changes.	https://www.iea.org/statistics/?country=WORLD&year=2016&category=Energy%20supply&indicator=TPESbyGDP&mode=map&dataTable=BALANCES **Source**: International Energy Agency	TPES/GDP	Data available for 2016 for 142 countries, with data missing for some years.	Yes; indicator 7.3.1	No; this indicator is an SDG indicator and data are available for 142 countries, but it has a negative, low correlation with all other indicators associated with availability.

49	Energy (SDG 7)	International financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems	The flows covered by the OECD are defined as all official loans, grants and equity investments received by countries on the DAC List of ODA Recipients from foreign governments and multilateral agencies, for the purpose of clean energy research and development and renewable energy production, including in hybrid systems extracted from the OECD/DAC Creditor Reporting System (CRS). The flows covered by IRENA are defined as all additional loans, grants and equity investments received by developing countries (defined as countries in developing regions, as listed in the UN M49 composition of regions) from all foreign governments, multilateral agencies and additional development finance institutions (including export credits, where available) for the purpose of clean energy research and development and renewable energy production, including in hybrid systems. These additional flows cover the same technologies and other activities (research and development, technical assistance, etc.) as listed above and exclude all flows extracted from the OECD/DAC CRS (UN Stats, 2018)	http://resourceirena.irena.org/gateway/dashboard/?topic=6&subTopic=8 **Source**: International Renewable Energy Agency	Million USD	Data is available from 2006-2017 for 141 countries with data missing for some years.	Yes; indicator 7. a.1	No; although this indicator is an SDG indicator and data are available for 141 countries developed/donor and developing countries who have significant domestic expenditure on renewable energy projects are 'penalised' in the calculation of this index. It was therefore decided to exclude this indicator from the composite indicator
50	Energy (SDG 7)	Investments in energy efficiency as a percentage of GDP and the amount of foreign direct investment in financial transfer for infrastructure and technology to sustainable development services	Not defined yet.	Not available	%	None	Yes; indicator 7. b.1	No; the definition for this indicator is not yet well defined and therefore not well understood yet. There is no data easily available for this indicator.
51	Energy (SDG 7)	Amount of fossil-fuel subsidies per unit of GDP (production and consumption) and as a proportion of total national expenditure on fossil fuels	In order to measure fossil fuel subsidies at the national, regional and global level, three sub-indicators are recommended for reporting on this indicator: 1) direct transfer of government funds; 2) induced transfers (price support); and as an optional sub-indicator 3) tax expenditure, other revenue foregone, and underpricing of goods and services. The definitions of the IEA Statistical Manual (IEA, 2005) and the Agreement on Subsidies and Countervailing Measures (ASCM) under the World Trade Organization (WTO) (WTO, 1994) are used to define fossil fuel subsidies. Standardised descriptions from the United Nations Statistical Office's Central Product Classification should be used to classify individual energy products. It is proposed to drop the wording "as a proportion of total national expenditure on fossil fuels" and thus this indicator is effectively "Amount of fossil fuel subsidies per unit of GDP (production and consumption)". (UN Stats, 2018)	Not available	USD/GDP	None; baseline assessment was conducted. Reporting on induced transfers started in 2018; reporting on data for direct transfers and tax revenue will take place in 2020.	Yes; indicator 12.c.1	No; no data readily available

52	Food (SDG 2)	Prevalence of undernourishment[2]	The prevalence of undernourishment expresses the probability that a randomly selected individual from the population consumes a number of calories that is insufficient to cover her/his energy requirement for an active and healthy life. The indicator is computed by comparing a probability distribution of habitual daily dietary energy consumption with a threshold level called the minimum dietary energy Requirement. Both are based on the notion of an average individual in the reference population (*FAO 2019-03-05*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** FAOSTAT and ESS calculations:	%	2015-2017 Very good data coverage. Indicator utilised in SDG Index for SDG 2	Yes, 2.1.1 (C020101). Could consider a health indicator such as 3.2.1 "Under-5 mortality rate" as an additional indicator of 'healthy' food?	**Yes**; it was the official Millennium Development Goal indicator for Goal 1, Target 1.9, and is now an SDG indicator
53	Food (SDG 2)	Percentage of children under 5 years of age affected by wasting[3] [4]	Wasting prevalence is the proportion of children under five whose weight for height is more than two standard deviations below the median for the international reference population ages 0-59 months (*FAO 2019-03-05*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** World Development Indicators: http://data.worldbank.org/indicator/SH.STA.WAST.ZS + UNICEF et al. (2016) report an average prevalence of wasting in high-income countries of **0.75%**, which has been assumed for high-income countries with missing data. The classification as a high-income country is based on the World Bank's listing of high-income countries: https://data.worldbank.org/income-level/high-income	%	2016 Limited data. Need to utilise latest since coverage for the final year alone is scarce. Indicator utilised in SDG Index for SDG 2	No	**Yes**; if there is a strong correlation of data with SDG indicator 2.2.1's data, one of the two indicators will be used to avoid noise in the dataset. However the correlation is good, but not too high. Both indicators can therefore be retained.
54	Food (SDG 2)	Percentage of children under 5 years of age who are stunted[5]	Percentage of stunting (height-for-age less than -2 standard deviations of the WHO Child Growth Standards median) among children aged 0-59 months (*FAO 2019-03-05*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** World Development Indicators: http://data.worldbank.org/indicator/SH.STA.WAST.ZS + UNICEF et al. (2016) report an average prevalence of wasting in high income countries of **2.58%**, which has been assumed for high-income countries with missing data. The classification as a high-income country is based on the World Bank's listing of high-income countries: https://data.worldbank.org/income-level/high-income	%	2016 Limited data. Need to utilise most recent coverage for the final year alone is scarce. Indicator utilised in SDG Index for SDG 2	Yes, 2.2.1 (C020201)	**Yes**; this is an SDG indicator with sufficient data available for 153 countries.
55	Food (SDG 2)	The depth of the food deficit	The depth of the food deficit indicates how many calories would be needed to lift the undernourished from their status, everything else being constant. The	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk Version 15 Sep 2017	kCal/ day	2014-2016 Very good data coverage.	No	No – Many countries, such as Denmark, Finland, Switzerland,

[2] "This is the traditional FAO hunger indicator, adopted as official Millennium Development Goal indicator for Goal 1, Target 1.9." (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk).

[3] "Child growth is the most widely used indicator of nutritional status in a community and is internationally recognized as an important public-health indicator for monitoring health in populations. In addition, children who suffer from growth retardation as a result of poor diets and/or recurrent infections tend to have a greater risk of suffering illness and death." (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk)

[4] The "two official indicators for the hunger target [are] the prevalence of undernourishment and the proportion of underweight children under 5 years of age" (http://www.fao.org/3/a-i4671e.pdf)

[5] "This indicator belongs to a set of indicators whose purpose is to measure nutritional imbalance and malnutrition resulting in undernutrition (assessed by underweight, stunting and wasting) and overweight. Child growth is the most widely used indicator of nutritional status in a community and is internationally recognized as an important public-health indicator for monitoring health in populations. In addition, children who suffer from growth retardation as a result of poor diets and/or recurrent infections tend to have a greater risk of suffering illness and death." (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk)

		(kilocalories per person per day)[6]	average intensity of food deprivation of the undernourished, estimated as the difference between the average dietary energy requirement and the average dietary energy consumption of the undernourished population (food-deprived), is multiplied by the number of undernourished to provide an estimate of the total food deficit in the country, which is then normalized by the total population (*World Bank 2019-03-06*).	**Source**: ESS calculations				Sweden, Norway have no data but are assumed to be close to zero (patched to 2.5 for geometric mean). Although this indicator has very good data, it has a very high correlation with the prevalence of undernourishment (0.95), and it has therefore been excluded in order to avoid double accounting
56	Food (SDG 2)	Average protein supply[7]	National average protein supply (expressed in grams per caput per day) (*FAO 2019-03-06*)	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source**: FAOSTAT	gr/caput/day	2011-2013 Very good data coverage	No, but it is FAO Indicator I_1.4	**Yes**; very good data availability and provides an indication of a healthy, varied diet
57	Food (SDG 2)	Prevalence of obesity in the adult population (18 years and older)	Prevalence of obesity in the adult population is the percentage of adults ages 18 and over whose Body Mass Index (BMI) is more than 30 kg/m^2. Body Mass Index (BMI) is a simple index of weight-for-height or the weight in kilograms divided by the square of the height in meters (*FAO 2019-05-06*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source**: World Health Organization Global Health Observatory (GHO) http://apps.who.int/gho/data/node.main.A900A?lang=en	%	2016 Very good data coverage. Indicator utilised in SDG Index for SDG 2	No, but it is FAO Indicator I_4.8	**Yes**; since it is utilised within the SDG Index. Although it has a negative correlation with the levels of undernourishment, stunting and wasting, it measures a different portion of the population, i.e. adults >18 years old vs children <5 years old. It is viewed as being a key indicator of access to food despite the negative correlation with the other indicators listed in the access to food sub-index
58	Food (SDG 2)	Average dietary energy supply adequacy[8]	The indicator expresses the Dietary Energy Supply (DES) as a percentage of the Average Dietary Energy Requirement (ADER). Each country's or region's average supply of calories for food consumption is normalized by the average dietary energy requirement estimated for its population to provide an index of adequacy of the food supply in terms of calories (*FAO 2019-05-06*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source**: FAOSTAT and ESS calculations	%	2015-2017 Very good data coverage	No, but it is FAO Indicator I_1.1	**Yes**; less than 10% missing data

[6] "Complementary indicator to assess the multiple dimensions and manifestations of food insecurity and the policies for more effective interventions and responses" (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk – *not available in latest update of downloadable data)

[7] "This indicator provides information on the quality of the diet" (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk)

[8] "Analysed together with the prevalence of undernourishment, it allows discerning whether undernourishment is mainly due to insufficiency of the food supply or to particularly bad distribution." (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk)

59	Food (SDG 2)	Cereal import dependency ratio	The cereal imports dependency ratio tells how much of the available domestic food supply of cereals has been imported and how much comes from the country's own production. It is computed as (cereal imports - cereal exports)/(cereal production + cereal imports - cereal exports) * 100 Given this formula the indicator assumes only values <= 100. Negative values indicate that the country is a net exporter of cereals (*FAO 2019-03-06*).	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96UkBU: **Source:** FAOSTAT and ESS calculations	%	2011-2013 Good data coverage	No, but it is FAO indicator I_3.1	No; it is a good indicator, but several high-income countries do not measure this ratio since it is not relevant to them (30.9% missing data for 181 countries). This indicator can be truncated at zero in order to exclude exports from this indicator, since the indicator is essentially measuring both imports and exports. Imports are important to this index as they speak of the level of self-sufficiency in food production and security. Yet this indicator has a negative correlation with the other indicators within the "Access" sub-pillar of the "Food"sub-index, and is therefore excluded.
60	Food (SDG 2)	Prevalence of severe food insecurity in the total population[9]	The prevalence of severe food insecurity in an estimate of the percentage of people in the population who live in households classified as severely food insecure. The assessment is conducted using data collected with the Food Insecurity Experience Scale or a compatible experience-based food security measurement questionnaire (such as the HFSSM, the HFIAS, the EBIA, the ELCSA, etc.). The probability to be food insecure is estimated using the one-parameter logistic Item Response Theory model (the Rasch model) and thresholds for classification are made cross country comparable by calibrating the metrics obtained in each country against the FIES global reference scale, maintained by FAO. The threshold to classify "severe" food insecurity corresponds to the severity associated with the item "having not eaten for an entire day" on the global FIES scale. In simpler terms, a household is classified as severely food insecure when at least one adult in the household has reported to have been exposed, at times during	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** National surveys/Gallup World Poll and ESS calculations	%	2015-2017 Data missing for many countries	Yes, indicator 2.1.2 (C020102) and FAO indicator I_2.4	No; >60% of countries do not have records for this indicator. This is very low. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data. On this basis, this indicator is unfortunately excluded. It is unfortunate because this is an official SDG indicator.

[9] "This is indicator 2.1.2 in the SDG framework, to monitor target 2.1 ("By 2030, end hunger and ensure access by all people, […], to safe, nutritious and sufficient food all year round")." (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk)

			the year, to several of the most severe experiences described in the FIES questions, such as to have been forced to reduce the quantity of the food, to have skipped meals, having gone hungry, or having to go for a whole day without eating because of a lack of money or other resources. It is an indicator of lack of food access (FAO 2019-03-06)					
61	Food (SDG 2)	Number of severely food insecure people	Estimated number of people living in households classified as severely food insecure. It is calculated by multiplying the estimated percentage of people affected by severe food insecurity (I_2.4) by the total population.	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** ESS calculations	Millions of people	2015-2017 Poor data coverage	No	No, for same reason as "Prevalence of severe food insecurity in the total population"
62	Food (SDG 2)	The share of food expenditure of the poor[10]	The proportion of food consumption over total consumption (food and non-food) for the lowest income quintile of the population. Due to the way in which the share of food expenditures is defined in the sources of data, this indicator captures the monetary value of food obtained from all the possible food sources (purchases, own-production, gift, in-kind payment, etc.), rather than just the monetary value of purchased food. Total consumption expenditures include both food and non-food expenditures and exclude non-consumption expenditures such as taxes, insurances, etc.	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk **Source:** ESS calculations	%	2014* Very poor data coverage	No	No, very poor data coverage, and this indicator is not included in latest list of FAO indicators.
63	Food (SDG 2)	Cereal yield	Cereal yield, measured as kilograms per hectare of harvested land, includes wheat, rice, maize, barley, oats, rye, millet, sorghum, buckwheat, and mixed grains. Production data on cereals relate to crops harvested for dry grain only. Cereal crops harvested for hay or harvested green for food, feed, or silage and those used for grazing are excluded. The FAO allocates production data to the calendar year in which the bulk of the harvest took place. Most of a crop harvested near the end of a year will be used in the following year (*World Bank 2019-03-06*).	https://data.worldbank.org/indicator/AG.YLD.CREL.KG?view=chart Source: World Bank	kg per hectare	2016 Very good data coverage. Indicator utilised in SDG Index for SDG 2	No	**Yes**; good data availability and the indicator is relevant to food security
64	Food (SDG 2)	Volume of production per labour unit by classes of farming/pastoral/forestry enterprise size	Volume of agricultural production of small-scale food producer in crop, livestock, fisheries, and forestry activities per number of days (UN Stats, 2018)	Not available	Volume/ production unit	None	Yes; indicator 2.3.1	No; there is no usable data available yet
65	Food (SDG 2)	Average income of small-scale food producers, by sex	measures income from on-farm production activities, which is related to the production of food and agricultural products. This includes income from crop	Not available	Annual income	None; data is still not available in a systematic and	Yes; indicator 2.3.2	No; there is no usable data available yet

10 "According to the Engel's Law, the higher the income of a household, the lower the proportion of income spent on food. When applied at the National level, this indicator reflects the living standard of a country, as well as the vulnerability of a country to food price increases. Due to the lack/unreliability of income data, this indicator has been built as the ratio between food consumption and total consumption, hence using total consumption as a proxy income. Finally, given the higher vulnerability of the poorer households to food price increase, this indicator only encompasses the share of food consumption of the lowest income quintile of a country population" (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WDmBh9V96Uk – *not available in latest update of downloadable data)

		and indigenous status	production, livestock production, fisheries and aquaculture production, and from forestry production. The indicator is computed as annual income (UN Stats, 2018)			harmonized fashion		
66	Food (SDG 2)	Proportion of agricultural area under productive and sustainable agriculture	measure both the extent of land under productive and sustainable agriculture, as well as the extent of land area under agriculture. Focuses on agricultural land, and therefore primarily on land that is used to grow crops and raise livestock (UN Stats, 2018)	Not available	Percentage	None	Yes; indicator 2.4.1	No, no data readily available
67	Food (SDG 2)	Number of plant and animal genetic resources for food and agriculture secured in either medium or long-term conservation facilities	The conservation of plant and animal genetic resources for food and agriculture (GRFA) in medium or long term conservation facilities (ex situ in genebanks) represents the most trusted means of conserving genetic resources worldwide. Plant and animal GRFA conserved in these facilities can be easily used in breeding programmes as well, even directly on-farm (UN Stats, 2018)	Not available yet, although data compilers have been appointed per country. http://www.fao.org/dad-is/sdg-251/en/	No. of species	None	Yes; indicator 2.5.1	No; there is no usable data available yet
68	Food (SDG 2)	Proportion of local breeds classified as being at risk, not-at-risk or at unknown level of risk of extinction	The indicator presents the percentage of livestock breeds classified as being at risk, not at risk or of unknown risk of extinctions at a certain moment in time, as well as the trends for those percentages (UN Stats, 2018)	http://www.fao.org/dad-is/dataexport/en/ Source: FAO	Percentage	Data collection dates are not specified. Data is available for various species per country.	Yes; indicator 2.5.2	No; although data is available per country, it seems like the data was only collected once as no sampling dates are specified
69	Food (SDG 2)	The agriculture orientation index for government expenditures	The Agriculture Orientation Index (AOI) for Government Expenditures is defined as the Agriculture Share of Government Expenditures, divided by the Agriculture Share of GDP, where Agriculture refers to the agriculture, forestry, fishing and hunting sector. The measure in a currency-free index, calculated as the ratio of these two shares. National governments are requested to compile Government Expenditures according to the international Classification of Functions of Government (COFOC), and Agriculture Share of GDP according to the System of National Accounts (SNA) (UN Stats, 2018)	http://www.fao.org/faostat/en/#data/IG/visualize Source: FAOSTAT	Percentage	Data can be calculated using government expenditure and GDP, but data specific for this indicator is not available.	Yes; indicator 2. a.1	No; although there is data per country available, it is fragmented. Further, it is not best practice to incorporate an index as part of another index.
70	Food (SDG 2)	Total official flows (official development assistance plus other official flows) to the agriculture sector	Gross disbursements of total ODA and other official flows from all donors to the agriculture sector (UN Stats, 2018)	Food aid: https://www.oecd-ilibrary.org/development/data/oecd-international-development-statistics/official-and-private-flows_data-00072-en	Million USD	Data is available from 1995-2017 for 35 countries with data missing for some years.	Yes; indicator 2. a.2	No; data is only available for 35 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.
71	Food (SDG 2)	Agricultural export subsidies	Agricultural export subsidies are defined as export subsidies budgetary outlays and quantities as notified by WTO Members in Tables ES:1 and supporting Tables ES:2 (following templates in document G/AG/2 dated 30 June 1995) (UN Stats, 2018)	https://www.wto.org/english/tratop_e/agric_e/transparency_toolkit_e.htm Source: World Trade Organization	Million USD	Data is available from 1995-2014 for 24 countries.	Yes; indicator 2. b.1	No; although it is important to consider financial flows of food export, this level of detail is not yet required in this WEF nexus framework

72	Food (SDG 2)	Indicator of food price anomalies	The indicator of food price anomalies (IFPA) identifies markets prices that are abnormally high. The IFPA relies on a weighted compound growth rate that accounts for both within year and across year price growth. The indicator directly evaluates growth in prices over a particular month over many years, taking into account seasonality in agricultural markets and inflation, allowing to answer the question of whether or not a change in price is abnormal for any particular period (UN Stats, 2018)	http://www.fao.org/giews/food-prices/tool/public/#/dataset/international	-	Data available for 2016 for 57 countries (specifically for rice; data also available for wheat, sorghum, maize, and millet)	Yes; indicator 2. c.1	No; data is difficult to manage as it does not download to an excel format. Further, it is not best practice to incorporate an index as part of another index.
73	Food (SDG 2)	Global food loss index	*No data for this indicator is currently available and its methodology is still under development (UN Stats, 2018)*	Not available yet	-	None	Yes; indicator 12.3.1	No; although this indicator is an SDG indicator it is not best practice to incorporate an index as part of another index.
74	Food (SDG 2)	Average value of food production	The indicator expresses the food net production value (in constant 2004-06 international dollars), as estimated by FAO and published by FAOSTAT, in per capita terms (FAO 2019-03-06)	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.XIix_8t7lhG	I$ per caput	Data available from 1999-2014 for 201 countries.	No, but it is FAO indicator I_1.2	**Yes**; very good data coverage that includes data from 201 countries. The data can be used to infer priorities in terms of resource allocation in the WEF nexus.
75	Food (SDG 2)	Value of food imports over total merchandise exports	Value of food (excl. fish) imports over total merchandise exports (FAO 2019-03-06)	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.XIix_8t7lhG	Percentage	Data available from 1999-2011 for 193 countries	No, but it is FAO indicator I_3.3	No, very good data coverage that includes data from 193 countries. However, there is a low correlation (<0.4) with other key indicators relating to food availability.
76	Food (SDG 2)	Agricultural machinery	Agricultural machinery refers to the number of wheel and crawler tractors (excluding garden tractors) in use in agriculture at the end of the calendar year specified or during the first quarter of the following year. Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded (FAO: 2019-04-29)	https://data.worldbank.org/indicator/AG.LND.TRAC.ZS?view=chart Source: Food and Agriculture Organization, electronic files and web site	Tractors/ 100 km^2 of arable land	Data available from 1961-2009; for only 8 countries in 2009 but for approximately 164 countries in 1965	No	No, this indicator was measured widely up until 2000, and to some degree until 2008, but is no longer recorded.
77	Food (SDG 2)	Percent of arable land equipped for irrigation	Ratio between arable land equipped for irrigation and total arable land. Arable land is defined as the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for arable land are	http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.XIix_8t7lhG Source: FAOSTAT and ESS calculations (11 Sep 2018)	%	Data available from 1999 to-2015 for 178 countries with missing data for some years.	No, but it is FAO indicator I_3.2	No, irrigation is a major user of water worldwide, and a key component of the WEF nexus, despite it having a poor correlation with some of the other indicators in food availability. This indicator has a negative correlation with the other indicators within

			not meant to indicate the amount of land that is potentially cultivable. Total arable land equipped for irrigation is defined as the area equipped to provide water (via irrigation) to the crops. It includes areas equipped for full and partial control irrigation, equipped lowland areas, pastures, and areas equipped for spate irrigation (FAO: 2019-04-29).					the “Access” sub-pillar of the “Food”sub-index, and is therefore excluded.
78	Food (SDG 2)	Agriculture, forestry and fishery, value added	Agriculture corresponds to ISIC divisions 1-5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: This value is not specific to crop production, so care should be taken to ensure proper implementation.(FAO 2019-05-25)	https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS **Source:** Food and Agriculture Organization, AQUASTAT data	% of GDP	Data available from 1966-2017 with many missing data per year. Most recent data are available for 2012 for 171 countries.	No	No, very good data availability and very relevant indicator regarding the value of land and water-based products/food to the economy, but low correlation with most indicators contributing to food availability
79	Food (SDG 2)	Electricity capacity in MW for renewable municipal waste	???	https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies **Source**: Source: IRENA (2019), Renewable capacity statistics 2019; and IRENA (2018), Renewable Energy Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.	MW	Data available from 2000-2018 with many missing data per country. Most recent data are available for 2018 for 41 countries.	No	No; data is only available for 41 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.
80	Food (SDG 2)	Electricity generation in GWh for renewable municipal waste	???	https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies **Source**: Source: IRENA (2019), Renewable capacity statistics 2019; and IRENA (2018), Renewable Energy Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.	GWh	Data available from 2000-2016 with many missing data per country. Most recent data are available for 2016 for 37 countries.	No	No; data is only available for 37 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.
81	Food (SDG 2)	Electricity capacity in MW for solid biofuel		https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies **Source**: Source: IRENA (2019), Renewable capacity statistics 2019; and IRENA (2018), Renewable Energy Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.	MW	Data available from 2000-2018 with many missing data per country. Most recent data are available for 2018 for 108 countries.	No	No, this data is included in the renewable energy consumption and output indicators
82	Food (SDG 2)	Electricity generation in GWh for solid biofuel		https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies **Source**: Source: IRENA (2019), Renewable capacity statistics 2019; and IRENA (2018), Renewable Energy	GWh	Data available from 2000-2016 with many missing data per country. Most recent data are available for	No	No, this data is included in the renewable energy consumption and output indicators

				Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.		2016 for 103 countries.		
83	Food (SDG 2)	Electricity capacity in MW for liquid biofuel		https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies	MW	Data available from 2000-2018 with many missing data per country. Most recent data are available for 2018 for 14 countries.	No	No; data is only available for 14 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.
84	Food (SDG 2)	Electricity generation in GWh for liquid biofuel		**Source**: Source: IRENA (2019), Renewable capacity statistics 2019; and IRENA (2018), Renewable Energy Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.	GWh	Data available from 2000-2016 with many missing data per country. Most recent data are available for 2016 for 17 countries.	No	No; data is only available for 17 countries. The JRC-COIN guideline is that at an indicator level 65% of countries should have valid data.
85	Food (SDG 2)	Alien invasive species	Area of agricultural land that has been encroached by alien invasive species, resulting is less arable land for food production and an increase in water consumption	Not available	Ha/year	None	No	No; there is no usable data available yet however it is important to consider alien invasive plant species as they affect food and water security
86	Food (SDG 2)	Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species	Commitment by countries to relevant multinational agreements, specifically: (1) National adoption of invasive alien species-relevant international policy. (2) Percentage of countries with (a) national strategies for preventing and controlling invasive alien species; and (b) national legislation and policy relevant to invasive alien species. The translation of policy arrangements into action by countries to implement policy and actively prevent and control invasive alien species IAS and the resourcing of this action, specifically: (3) National allocation of resources towards the prevention or control of invasive alien species. (UN Stats, 2018)	Not available	%	None	Yes; indicator 15.8.1	No; there is no usable data available yet
87	Food (SDG 2)	Pests destroying crops [2]	Hectares of crops that are lost per year due to the invasion of pest species (armyworm, corn root worm etc) and diseases caused by fungi and bacteria (potato blight, coffee leaf rust etc)	Not available	Ha/year or kg/ha	None	No	No; there is no usable data available yet however it is important to consider pests as they are seen as the greatest threat to food security, and indirectly affects water security.

ADDENDUM B: UNTREATED INDICATOR DATA

Addendum B: Untreated Indicator Data

Country		ind.01	ind.02	ind.03	ind.04	ind.05	ind.06	ind.07	ind.08	ind.09	ind.10	ind.11	ind.12	ind.13	ind.14	ind.15	ind.16	ind.17	ind.18	ind.19	ind.20	ind.21
		The percentage of people using at least basic drinking water services	Percentage of people using safely managed sanitation services.	Degree of IWRM implementation (1-100)	Annual freshwater withdrawals, total (% of internal resources)	Renewable internal freshwater resources per capita (cubic meters)	Environmental flow requirements (106 m3/annum)	Average precipitation in depth (mm per year)	Access to electricity (% of population)	Renewable energy consumption (% of total final energy consumption)	Renewable electricity output (% of total electricity output)	CO2 emissions (metric tons per capita)	Electric power consumption (kWh per capita)	Energy imports, net (% of energy use)	Prevalence of undernourishment (%)	Percentage of children under 5 years of age affected by wasting (%)	Percentage of children under 5 years of age who are stunted (%)	Prevalence of obesity in the adult population (18 years and older)	Average protein supply (gr/caput/day)	Cereal yield (kg per hectare)	Average Dietary Energy Supply Adequacy (ADESA) (%)	Average value of food production (I$ per caput)
Afghanistan	AFG	63.0	39.2	11.5	43.0	1439	28.3	327.0	84.1	18.4	86.1	0.3	n/a	n/a	30.3	9.5	40.9	4.5	33.0	1981.7	95.0	104.0
Albania	ALB	91.4	97.7	43.1	4.9	9311	13.6	1485.0	100.0	38.6	100.0	2.0	2309	13.8	5.5	9.4	23.1	22.3	104.0	4716.4	129.0	462.0
Algeria	DZA	93.5	87.5	48.2	69.4	288	4.6	89.0	99.4	0.1	0.3	3.7	1356	-177.1	4.7	4.1	11.7	26.6	75.0	1560.7	143.0	220.0
Angola	AGO	41.0	39.4	37.1	0.5	5498	110.7	1010.0	40.5	49.6	53.2	1.3	312	-541.0	23.9	4.9	37.6	6.8	52.0	934.7	108.0	137.0
Argentina	ARG	99.6	94.8	38.2	12.9	6794	515.8	591.0	100.0	10.0	28.1	4.7	3052	13.0	3.8	1.2	8.2	28.5	114.0	5096.5	135.0	1030.0
Armenia	ARM	98.9	91.6	35.9	42.9	2360	2.8	562.0	100.0	15.8	28.3	1.9	1966	71.3	4.3	4.2	9.4	20.9	91.0	3076.1	120.0	426.0
Australia	AUS	100.0	100.0	85.5	3.1	20932	243.3	534.0	100.0	9.2	13.6	15.4	10059	-190.2	1.2	0.8	2.0	30.4	150.0	2074.3	132.0	1009.0
Austria	AUT	100.0	100.0	91.1	6.3	6435	41.5	1110.0	100.0	34.4	76.5	6.9	8356	63.5	1.2	0.8	2.6	21.9	168.0	7245.2	148.0	472.0
Azerbaijan	AZE	84.4	89.3	66.0	147.5	851	12.0	447.0	100.0	2.3	7.0	3.9	2202	-310.4	1.2	3.1	18.0	19.9	58.0	3004.7	130.0	266.0
Bangladesh	BGD	97.3	46.9	50.0	34.2	659	600.3	2666.0	75.9	34.7	1.2	0.5	310	16.8	15.2	14.3	36.1	3.4	29.0	4628.9	109.0	138.0
Barbados	BRB	98.1	96.5	41.7	87.5	282	n/a	1422.0	100.0	2.8	n/a	4.5	n/a	n/a	3.7	6.8	7.7	24.8	88.0	2848.9	121.0	145.0
Belarus	BLR	98.0	94.3	38.1	4.5	3589	27.6	618.0	100.0	6.8	0.8	6.7	3680	86.8	1.2	2.2	4.5	26.6	131.0	3207.5	131.0	573.0
Belgium	BEL	100.0	99.5	77.5	50.0	1071	10.2	847.0	100.0	9.2	20.8	8.3	7709	80.1	1.2	0.8	2.6	24.5	163.0	6984.8	147.0	431.0
Belize	BLZ	97.1	87.2	19.9	0.7	43390	13.7	1705.0	92.2	35.0	45.2	1.4	n/a	n/a	6.5	1.8	15.0	22.4	75.0	3164.6	122.0	453.0
Benin	BEN	67.0	13.9	62.8	1.3	1001	13.1	1039.0	41.4	50.9	5.6	0.6	100	46.6	10.4	4.5	34.0	8.2	49.0	1455.9	123.0	214.0
Bhutan	BTN	97.6	62.9	32.4	0.4	100457	54.1	2200.0	100.0	86.9	100.0	1.3	n/a	n/a	n/a	5.9	33.6	5.8	n/a	3410.4	n/a	257.0
Bolivia	BOL	92.9	52.6	49.4	0.7	28735	396.6	1146.0	93.0	17.5	31.4	1.9	753	-178.0	19.8	2.0	n/a	18.7	52.0	2092.4	105.0	355.0
Bosnia and Herzegovina	BIH	97.7	94.8	60.9	0.9	9955	22.4	1028.0	100.0	40.8	35.5	6.2	3366	22.7	1.2	2.3	8.9	19.4	73.0	5191.7	128.0	252.0
Botswana	BWA	79.2	60.0	41.1	8.1	1107	2.7	416.0	60.7	28.9	0.0	3.2	1749	44.5	28.5	7.2	31.4	16.1	64.0	452.8	98.0	172.0
Brazil	BRA	97.5	86.1	50.7	1.3	27721	6532.0	1761.0	100.0	43.8	74.0	2.6	2601	11.9	1.2	1.6	7.1	22.3	116.0	4180.8	130.0	684.0
Brunei Darussalam	BRN	99.5	96.3	n/a	1.1	20646	5.8	2722.0	100.0	0.0	0.0	22.1	10243	-357.4	2.6	2.9	19.7	14.7	82.0	844.2	124.0	116.0
Bulgaria	BGR	99.3	86.0	60.2	27.2	2907	7.8	608.0	100.0	17.7	18.0	5.9	4709	36.6	3.0	3.2	8.8	27.4	94.0	4817.8	117.0	457.0

Burkina Faso	BFA	53.9	22.5	62.6	6.5	711	3.0	748.0	19.2	74.2	9.4	0.2	n/a	n/a	21.3	7.6	27.3	4.5	61.0	1181.4	122.0	122.0
Cabo Verde	CPV	86.5	65.2	n/a	6.8	570	n/a	228.0	92.6	26.6	20.2	0.9	n/a	n/a	12.3	n/a	n/a	10.6	69.0	178.0	113.0	73.0
Cambodia	KHM	75.0	48.8	45.6	1.8	7897	265.4	1904.0	49.8	64.9	46.4	0.4	271	33.1	18.5	9.6	32.4	3.5	34.0	3459.9	108.0	281.0
Cameroon	CMR	65.3	38.8	33.8	0.4	12275	213.4	1604.0	60.1	76.5	76.1	0.3	281	-28.3	7.3	5.2	31.7	9.5	56.0	1643.7	126.0	244.0
Canada	CAN	98.9	98.5	n/a	1.4	80202	1931.0	537.0	100.0	22.0	63.0	15.1	15546	-72.5	1.2	0.8	2.6	31.3	148.0	3908.8	140.0	746.0
Central African Republic	CAF	54.1	25.1	31.0	0.1	31227	119.4	1343.0	14.0	76.6	99.4	0.1	n/a	n/a	61.8	7.4	40.7	6.3	62.0	879.8	79.0	202.0
Chad	TCD	42.5	9.5	31.8	5.9	1105	25.2	322.0	8.8	89.4	n/a	0.1	n/a	n/a	39.7	13.0	39.9	4.8	47.0	844.7	98.0	154.0
Chile	CHL	100.0	99.9	22.6	4.0	50245	529.3	1522.0	100.0	24.9	43.6	4.7	3912	65.2	3.3	0.3	1.8	28.8	86.0	6858.2	125.0	455.0
China	CHN	n/a	n/a	74.5	21.3	2062	1471.0	645.0	100.0	12.4	23.9	7.5	3927	15.0	8.7	n/a	n/a	6.6	95.0	6029.2	131.0	379.0
Colombia	COL	96.5	84.4	50.4	0.5	44882	1692.0	3240.0	99.0	23.6	68.2	1.8	1290	-274.1	6.5	0.9	12.7	22.1	80.0	4191.8	127.0	282.0
Comoros	COM	83.7	34.2	25.7	0.8	1580	n/a	900.0	77.8	45.3	n/a	0.2	n/a	n/a	n/a	11.1	32.1	6.9	n/a	1355.8	105.0	90.0
Congo, Dem. Rep.	COD	41.8	19.7	31.3	0.1	12208	981.7	1543.0	17.1	95.8	99.8	0.1	109	2.0	n/a	8.1	n/a	5.6	n/a	771.5	n/a	51.0
Congo, Rep.	COG	68.3	15.0	32.0	0.0	45575	664.4	1646.0	56.6	62.4	53.3	0.6	197	-496.6	37.5	8.2	n/a	8.4	46.0	828.2	94.0	87.0
Costa Rica	CRI	99.7	97.1	43.3	2.1	23752	54.4	2926.0	100.0	38.7	99.0	1.6	1958	49.8	4.4	1.0	5.6	25.7	89.0	4027.0	119.0	634.0
Cote d'Ivoire	CIV	73.1	29.9	32.1	2.0	3410	61.3	1348.0	64.3	64.5	16.7	0.5	276	7.1	20.7	6.0	n/a	9.0	58.0	2133.9	119.0	271.0
Croatia	HRV	99.6	97.5	89.8	1.7	8895	60.5	1113.0	100.0	33.1	66.8	4.0	3714	45.9	1.2	0.8	2.6	27.1	112.0	6742.3	123.0	351.0
Cuba	CUB	95.2	90.8	80.4	18.3	3332	9.1	1335.0	100.0	19.3	3.9	3.0	1434	49.8	1.2	2.4	7.0	26.7	66.0	2939.3	147.0	254.0
Cyprus	CYP	100.0	99.4	90.7	28.4	677	0.0	498.0	100.0	9.9	8.8	5.3	3625	94.0	4.6	0.8	2.6	22.6	118.0	2191.0	108.0	269.0
Czech Republic	CZE	99.9	99.1	79.3	12.5	1249	6.6	677.0	100.0	14.8	11.4	9.2	6259	31.6	1.2	4.6	n/a	28.5	135.0	6317.3	128.0	347.0
Denmark	DNK	100.0	99.6	93.0	10.6	1063	2.3	703.0	100.0	33.2	65.5	5.9	5859	1.8	1.2	0.8	2.6	21.3	133.0	6222.0	132.0	1067.0
Djibouti	DJI	76.9	51.4	n/a	6.3	329	n/a	220.0	51.8	15.4	n/a	0.8	n/a	n/a	19.7	21.5	33.5	12.2	59.0	1925.6	108.0	78.0
Dominica	DMA	96.5	77.9	40.0	10.0	2748	n/a	2083.0	100.0	7.8	16.2	1.9	n/a	n/a	5.2	n/a	n/a	28.2	77.0	1696.2	122.0	371.0
Dominican Republic	DOM	94.5	82.7	35.5	30.4	2258	5.5	1410.0	100.0	16.5	11.6	2.1	1578	86.7	10.4	2.4	7.1	26.9	90.0	4761.1	114.0	291.0
Ecuador	ECU	92.6	86.1	41.8	2.2	27818	296.2	2274.0	99.9	13.8	52.8	2.8	1381	-114.7	7.8	1.6	23.9	19.3	93.0	3575.5	115.0	372.0
Egypt	EGY	98.4	93.2	40.3	4100.0	20	2.6	51.0	100.0	5.7	8.3	2.2	1658	-7.4	4.8	9.5	22.3	31.1	64.0	7114.0	152.0	238.0
El Salvador	SLV	93.0	91.1	21.3	13.6	2488	10.2	1784.0	98.6	24.4	57.8	1.0	939	49.2	10.3	2.1	13.6	22.7	59.0	2745.5	116.0	153.0
Estonia	EST	99.6	99.6	80.0	13.5	9669	3.6	626.0	100.0	27.5	14.4	14.8	6732	-2.7	2.8	n/a	2.6	23.8	91.0	2658.4	128.0	432.0
Ethiopia	ETH	39.1	7.1	31.3	6.4	1253	89.3	848.0	42.9	92.2	100.0	0.1	70	5.9	21.4	9.9	38.4	3.6	26.0	2484.0	105.0	114.0
Fiji	FJI	93.7	95.7	n/a	0.3	32231	n/a	2592.0	98.6	31.3	45.0	1.3	n/a	n/a	4.4	6.3	7.5	30.0	93.0	3017.8	124.0	218.0
Finland	FIN	100.0	99.4	74.6	6.1	19592	67.8	536.0	100.0	43.2	44.5	8.7	15250	45.3	1.2	0.8	2.6	24.9	138.0	3574.1	132.0	348.0
France	FRA	100.0	98.7	100.0	14.9	3016	96.8	867.0	100.0	13.5	15.9	4.6	6940	44.1	1.2	0.8	2.6	23.2	159.0	5686.8	140.0	597.0
Gabon	GAB	87.5	40.9	14.4	0.1	87433	138.3	1831.0	91.4	82.0	43.7	2.8	1173	-213.4	9.4	3.4	17.5	13.4	58.0	1604.0	124.0	136.0
Gambia, The	GMB	80.1	41.7	29.8	3.0	1564	3.4	836.0	47.8	51.5	n/a	0.3	n/a	n/a	9.6	11.1	n/a	8.7	72.0	840.7	120.0	68.0
Georgia	GEO	93.3	84.9	35.1	3.1	15597	32.6	1026.0	100.0	28.7	78.0	2.4	2688	68.8	7.4	1.6	11.3	23.3	64.0	2517.2	115.0	163.0
Germany	DEU	100.0	99.2	88.0	30.8	1321	81.0	700.0	100.0	14.2	29.2	8.9	7035	61.4	1.2	1.0	1.3	25.7	143.0	7182.1	137.0	415.0
Ghana	GHA	77.8	14.3	48.6	3.2	1124	33.3	1187.0	79.3	41.4	50.9	0.5	355	-8.2	6.1	4.7	18.8	9.7	46.0	1842.4	135.0	287.0

Greece	GRC	100.0	99.0	83.2	16.5	5325	19.0	652.0	100.0	17.2	28.7	6.2	5063	64.2	1.2	0.8	2.6	27.4	149.0	4144.8	135.0	592.0
Guatemala	GTM	93.6	67.4	24.9	3.0	6858	70.0	1996.0	91.8	63.7	60.4	1.2	578	32.8	15.8	0.7	46.5	18.8	56.0	2152.3	114.0	302.0
Guinea	GIN	67.4	22.0	24.1	0.2	19144	161.0	1651.0	33.5	76.3	78.8	0.2	n/a	n/a	19.7	8.1	32.4	6.6	61.0	1180.0	115.0	174.0
Guinea-Bissau	GNB	69.2	21.5	n/a	1.1	9271	19.7	1577.0	14.7	86.9	n/a	0.2	n/a	n/a	26.0	6.0	27.6	8.2	63.0	1426.4	102.0	213.0
Guyana	GUY	95.1	86.2	15.6	0.6	315696	227.2	2387.0	84.2	25.3	n/a	2.6	n/a	n/a	7.5	6.4	12.0	19.2	58.0	3516.0	121.0	545.0
Haiti	HTI	64.2	30.5	29.4	11.1	1231	3.2	1440.0	38.7	76.1	8.0	0.3	39	22.0	45.8	5.2	21.9	20.5	49.0	1012.7	96.0	135.0
Honduras	HND	92.2	79.8	20.5	1.8	10291	57.4	1976.0	87.6	51.5	42.3	1.1	630	53.0	15.3	1.4	22.7	19.4	72.0	1748.1	116.0	194.0
Hong Kong SAR, China	HKG	100.0	96.3	n/a	n/a	n/a	n/a	n/a	100.0	0.9	0.3	6.4	6083	98.7	1.2	0.8	n/a	n/a	136.0	2000.0	134.0	5.0
Hungary	HUN	100.0	98.0	73.3	84.2	608	46.1	589.0	100.0	15.6	10.6	4.3	3966	57.7	1.2	0.8	2.6	28.6	135.0	5099.2	120.0	549.0
Iceland	ISL	100.0	98.8	51.9	2.1	519265	96.4	1940.0	100.0	77.0	100.0	6.1	53832	11.6	1.2	n/a	2.6	23.1	148.0	n/a	136.0	344.0
India	IND	87.6	44.2	n/a	44.8	1118	937.1	1083.0	84.5	36.0	15.3	1.7	806	34.3	14.8	21.0	38.4	3.8	52.0	2992.8	108.0	186.0
Indonesia	IDN	89.5	67.9	48.2	5.6	7914	1269.0	2702.0	97.6	36.9	10.7	1.8	812	-103.1	7.7	13.5	36.4	6.9	56.0	5405.5	124.0	243.0
Iran, Islamic Rep.	IRN	94.9	88.3	59.0	72.5	1639	22.7	228.0	100.0	0.9	5.1	8.3	2986	-33.4	4.9	4.0	n/a	25.5	74.0	2166.4	131.0	318.0
Iraq	IRQ	86.1	85.7	25.1	187.5	1006	18.7	216.0	100.0	0.8	3.7	4.8	1306	-229.4	27.7	7.4	22.6	27.4	65.0	3100.6	111.0	53.0
Ireland	IRL	98.9	92.2	80.5	1.5	10520	31.2	1118.0	100.0	9.1	28.0	7.3	5672	85.7	1.2	n/a	2.6	26.9	128.0	8223.3	146.0	976.0
Israel	ISR	100.0	100.0	85.0	189.2	91	0.6	435.0	100.0	3.7	1.9	7.9	6601	65.0	1.2	0.8	2.6	26.7	150.0	4969.5	158.0	342.0
Italy	ITA	100.0	99.3	54.5	29.5	3002	77.8	832.0	100.0	16.5	38.7	5.3	5002	76.4	1.2	0.8	2.6	22.9	156.0	5599.0	142.0	471.0
Jamaica	JAM	92.9	85.4	42.9	7.5	3780	n/a	2051.0	98.2	16.8	10.3	2.6	1056	82.0	8.9	3.6	6.2	24.4	76.0	1090.1	113.0	192.0
Japan	JPN	98.9	100.0	93.9	18.9	3378	212.5	1668.0	100.0	6.3	16.0	9.5	7820	93.0	1.2	2.3	7.1	4.4	87.0	4975.5	113.0	133.0
Jordan	JOR	98.6	96.7	63.4	124.5	77	0.0	111.0	100.0	3.2	1.0	3.0	1888	96.8	13.5	2.4	7.8	33.4	100.0	1530.7	112.0	152.0
Kazakhstan	KAZ	91.1	97.8	30.2	31.0	3722	36.3	250.0	100.0	1.6	8.9	14.4	5600	-116.9	1.2	3.1	8.0	21.3	132.0	1347.7	138.0	430.0
Kenya	KEN	58.5	29.8	52.6	15.5	450	18.6	630.0	56.0	72.7	87.5	0.3	167	17.2	24.2	4.0	26.0	6.0	47.0	1390.7	101.0	149.0
Korea, Dem. People’s Rep.	PRK	99.6	77.1	38.5	12.9	2668	45.9	1054.0	39.2	23.1	72.8	1.6	600	-74.8	43.4	4.0	n/a	7.1	35.0	4083.1	87.0	142.0
Korea, Rep.	KOR	99.6	99.9	67.9	44.8	1278	35.4	1274.0	100.0	2.7	1.9	11.6	10497	81.4	1.2	1.2	n/a	4.9	103.0	6795.2	135.0	202.0
Kuwait	KWT	100.0	100.0	81.5	n/a	3	n/a	121.0	100.0	n/a	n/a	25.2	15213	-391.1	1.2	3.1	4.9	37.0	115.0	13345	141.0	90.0
Lao PDR	LAO	80.4	72.6	n/a	1.8	28952	180.1	1834.0	87.1	59.3	86.4	0.3	n/a	n/a	16.6	6.4	n/a	4.5	37.0	4626.7	106.0	355.0
Latvia	LVA	98.6	92.9	64.3	1.4	8496	18.0	641.0	100.0	38.1	50.2	3.5	3507	45.2	1.2	n/a	2.6	25.7	118.0	3828.4	129.0	471.0
Lebanon	LBN	92.3	95.4	32.2	22.8	857	1.4	661.0	100.0	3.6	2.6	4.3	2893	97.9	10.9	6.6	16.5	31.3	102.0	3013.2	114.0	186.0
Lesotho	LSO	71.6	43.8	32.9	0.8	2437	1.3	788.0	29.7	52.1	100.0	1.2	n/a	n/a	12.8	2.8	33.2	13.5	32.0	508.3	114.0	73.0
Liberia	LBR	69.9	16.9	15.0	0.1	45550	176.8	2391.0	19.8	83.8	n/a	0.2	n/a	n/a	38.8	5.6	32.1	8.6	60.0	1322.3	101.0	74.0
Libya	LBY	96.8	99.7	46.9	822.9	113	n/a	56.0	98.5	2.0	n/a	9.2	1857	-103.0	n/a	6.5	21.0	31.8	n/a	715.0	140.0	181.0
Lithuania	LTU	97.4	93.6	56.6	4.1	5272	10.6	656.0	100.0	29.0	39.4	4.4	3821	75.0	1.2	n/a	2.6	28.4	96.0	3853.0	138.0	675.0
Luxembourg	LUX	100.0	97.6	90.2	4.3	1798	2.3	934.0	100.0	9.0	32.4	17.4	13915	96.3	1.2	0.8	2.6	24.2	139.0	4999.6	138.0	343.0
Macedonia, FYR	MKD	96.8	90.9	n/a	10.2	2599	n/a	619.0	100.0	24.2	35.9	3.6	3497	51.8	4.1	1.8	n/a	23.9	102.0	3858.8	118.0	371.0
Madagascar	MDG	50.6	9.7	36.5	4.0	14286	217.5	1513.0	22.9	70.2	54.6	0.1	n/a	n/a	43.1	15.2	49.2	4.5	24.0	3920.3	89.0	137.0

Malawi	MWI	67.2	43.5	40.3	8.4	946	9.5	1181.0	11.0	83.6	91.3	0.1	n/a	n/a	26.3	2.7	37.1	4.7	39.0	1347.4	104.0	139.0
Malaysia	MYS	96.4	99.6	42.8	1.9	19187	385.0	2875.0	100.0	5.2	10.0	8.0	4596	-5.5	2.9	11.5	20.7	15.3	88.0	3226.5	125.0	470.0
Maldives	MDV	97.9	95.9	35.5	15.7	73	n/a	1972.0	100.0	1.0	1.3	3.3	n/a	n/a	11.0	10.2	20.3	7.9	62.0	2445.9	115.0	18.0
Mali	MLI	74.3	31.3	53.3	8.6	3537	55.2	282.0	35.1	61.5	43.5	0.1	n/a	n/a	6.0	13.5	30.4	7.1	62.0	1607.5	142.0	244.0
Malta	MLT	100.0	100.0	75.3	44.4	116	n/a	560.0	100.0	5.4	7.7	5.4	4925	98.4	1.2	0.8	2.6	31.0	115.0	4744.9	134.0	169.0
Mauritania	MRT	69.6	44.6	45.4	337.0	98	1.2	92.0	41.7	32.2	13.4	0.7	n/a	n/a	11.3	14.8	27.9	11.3	78.0	1221.6	126.0	153.0
Mauritius	MUS	99.9	93.1	64.4	26.4	2182	n/a	2041.0	98.8	11.5	22.7	3.4	2183	84.5	5.8	n/a	n/a	11.5	92.0	3455.0	125.0	190.0
Mexico	MEX	98.3	89.2	49.5	20.0	3293	195.3	758.0	100.0	9.2	15.4	3.9	2090	-4.7	3.8	1.0	12.4	28.4	92.0	3748.8	132.0	293.0
Moldova	MDA	86.7	78.4	n/a	65.7	456	5.5	450.0	100.0	14.3	5.4	1.4	1386	90.0	n/a	1.9	n/a	20.1	85.0	3196.7	105.0	314.0
Mongolia	MNG	83.2	59.2	43.0	1.6	11902	21.2	241.0	81.8	3.4	3.1	7.1	2018	-168.1	18.7	1.0	10.8	19.6	88.0	1279.4	106.0	315.0
Montenegro	MNE	97.6	95.9	34.4	n/a	n/a	n/a	241.0	100.0	43.0	49.7	3.6	4612	27.6	1.2	2.8	9.4	24.9	129.0	3261.7	141.0	156.0
Morocco	MAR	83.0	83.5	63.9	35.7	845	8.2	346.0	100.0	11.3	14.3	1.7	901	90.7	3.9	2.3	14.9	25.6	68.0	936.2	147.0	250.0
Mozambique	MOZ	47.3	23.6	54.6	0.9	3686	133.0	1032.0	24.2	86.4	86.4	0.3	463	-54.6	30.5	6.1	43.1	6.0	41.0	823.8	106.0	97.0
Myanmar	MMR	67.5	64.7	27.3	3.3	19317	595.0	2091.0	57.0	61.5	58.9	0.4	217	-33.0	10.5	7.0	29.2	5.7	70.0	3607.4	118.0	323.0
Namibia	NAM	n/a	n/a	59.1	4.6	2598	7.2	285.0	51.8	26.5	97.8	1.6	1585	74.4	25.4	n/a	n/a	15.0	49.0	453.1	98.0	168.0
Nepal	NPL	87.7	46.1	32.9	4.8	6998	95.9	1500.0	90.7	85.3	100.0	0.3	139	16.7	9.5	9.7	35.8	3.8	53.0	2605.4	118.0	203.0
Netherlands	NLD	100.0	97.7	93.2	97.5	652	38.3	778.0	100.0	5.9	12.4	9.9	6713	35.0	1.2	0.8	2.6	23.1	124.0	7776.9	125.0	810.0
New Zealand	NZL	100.0	100.0	57.6	1.6	72510	204.3	1732.0	100.0	30.8	80.1	7.7	9026	19.5	1.2	0.8	2.6	32.0	117.0	8383.8	123.0	2425.0
Nicaragua	NIC	82.3	76.3	n/a	1.0	25973	107.2	2280.0	81.8	48.2	50.1	0.8	580	40.9	16.2	2.2	17.3	21.8	60.0	1768.0	117.0	238.0
Niger	NER	45.8	12.9	49.7	28.1	183	10.6	151.0	16.2	78.9	0.8	0.1	51	-5.8	14.4	10.3	42.2	4.7	55.0	530.3	123.0	180.0
Nigeria	NGA	67.3	32.6	35.1	5.6	1252	157.2	1150.0	59.3	86.6	18.2	0.5	144	-93.0	11.5	10.8	43.6	7.8	57.0	1443.6	117.0	211.0
Norway	NOR	100.0	98.1	63.4	0.8	74359	261.5	1414.0	100.0	57.8	97.7	9.3	23000	-581.3	1.2	0.8	2.6	25.0	150.0	4607.8	136.0	260.0
Oman	OMN	90.9	99.3	33.2	84.7	353	n/a	125.0	100.0	n/a	n/a	15.4	6554	-206.2	5.4	7.5	14.1	22.9	87.0	5689.9	125.0	114.0
Pakistan	PAK	88.5	58.3	49.8	333.6	296	83.8	494.0	99.1	46.5	31.4	0.9	471	24.1	20.5	10.5	45.0	7.8	74.0	3064.2	108.0	196.0
Panama	PAN	95.0	76.9	36.7	0.8	34990	4.9	2928.0	93.4	21.2	65.3	2.3	2063	80.9	9.2	1.2	19.1	22.5	76.0	2569.7	122.0	238.0
Papua New Guinea	PNG	36.6	18.6	25.0	0.0	103278	504.5	3142.0	22.9	52.5	34.5	0.8	n/a	n/a	n/a	14.3	49.5	19.4	n/a	4737.8	100.0	351.0
Paraguay	PRY	98.9	91.2	31.9	2.1	17856	256.3	1130.0	98.4	61.7	100.0	0.9	1564	-36.9	11.2	1.0	5.6	19.0	92.0	4425.5	111.0	855.0
Peru	PER	89.9	76.8	29.6	0.8	52981	1343.0	1738.0	94.9	25.5	52.7	2.0	1308	-14.9	8.8	1.0	13.1	19.1	50.0	4187.7	117.0	292.0
Philippines	PHL	90.5	75.0	51.0	17.0	4785	151.9	2348.0	91.0	27.5	25.4	1.1	699	45.8	13.7	7.1	33.4	6.0	52.0	3529.0	117.0	196.0
Poland	POL	97.9	98.1	39.5	21.4	1410	31.6	600.0	100.0	11.9	13.8	7.5	3972	28.5	1.2	0.8	2.6	25.6	118.0	3999.9	137.0	491.0
Portugal	PRT	99.9	99.4	74.1	24.1	3653	27.6	854.0	100.0	27.2	47.5	4.3	4663	76.9	1.2	0.8	2.6	23.2	140.0	4422.4	139.0	420.0
Qatar	QAT	100.0	100.0	82.2	387.5	24	n/a	74.0	100.0	n/a	n/a	45.4	15309	-399.0	n/a	0.8	2.6	33.9	n/a	4692.7	n/a	26.0
Romania	ROU	100.0	81.8	72.5	15.1	2129	105.2	637.0	100.0	23.7	39.7	3.5	2584	16.8	1.2	3.5	12.8	24.5	103.0	3971.2	135.0	483.0
Russian Federation	RUS	96.4	88.8	79.0	1.4	29982	2953.0	460.0	100.0	3.3	15.9	11.9	6603	-83.7	1.2	n/a	n/a	25.7	103.0	2650.4	138.0	327.0
Rwanda	RWA	56.7	62.3	34.7	1.6	837	10.3	1212.0	29.4	86.7	56.9	0.1	n/a	n/a	36.1	2.2	37.9	4.8	26.0	1522.5	100.0	209.0
Samoa	WSM	95.5	96.6	69.9	n/a	n/a	n/a	1583.0	100.0	34.3	30.4	1.0	n/a	n/a	3.1	3.7	4.7	45.5	138.0	n/a	129.0	290.0

Sao Tome and Principe	STP	79.7	40.1	22.8	0.3	11398	n/a	3200.0	65.4	41.1	10.5	0.6	n/a	n/a	10.2	4.0	17.2	10.6	76.0	2098.4	113.0	147.0
Saudi Arabia	SAU	100.0	100.0	56.7	943.3	78	n/a	59.0	100.0	0.0	0.0	19.5	9444	-191.5	5.5	11.8	9.3	35.0	103.0	5243.3	135.0	103.0
Senegal	SEN	75.2	48.4	53.3	8.6	1774	20.2	686.0	64.5	42.7	10.4	0.6	223	52.7	11.3	7.2	17.0	7.4	72.0	1349.0	111.0	103.0
Serbia	SRB	91.2	94.6	29.9	49.4	1179	73.5	686.0	100.0	21.2	26.9	5.3	4272	28.8	5.6	3.9	6.0	23.5	78.0	6173.5	110.0	392.0
Sierra Leone	SLE	58.1	14.5	18.6	0.1	22602	117.2	2526.0	20.3	77.7	61.0	0.2	n/a	n/a	25.5	9.4	37.9	7.5	57.0	1889.1	109.0	177.0
Singapore	SGP	100.0	100.0	100.0	31.7	110	n/a	2497.0	100.0	0.7	1.8	10.3	8845	97.7	n/a	3.6	4.4	6.6	n/a	n/a	n/a	5.0
Slovak Republic	SVK	97.9	98.9	65.8	4.4	2325	26.9	824.0	100.0	13.4	22.7	5.7	5137	60.7	2.7	0.8	n/a	22.4	112.0	6430.4	119.0	284.0
Slovenia	SVN	99.5	99.1	57.9	6.2	9054	17.1	1162.0	100.0	20.9	29.4	6.2	6728	48.5	1.2	0.8	2.6	22.5	119.0	6464.4	127.0	313.0
Solomon Islands	SLB	64.0	31.3	25.8	n/a	77671	n/a	3028.0	47.9	63.3	2.3	0.4	n/a	n/a	12.3	7.9	31.6	20.5	48.0	1657.0	113.0	202.0
South Africa	ZAF	84.7	73.1	65.5	34.6	821	20.1	495.0	84.2	17.2	2.3	9.0	4198	-14.5	6.1	2.5	27.4	27.0	83.0	3809.5	123.0	229.0
South Sudan	SSD	50.4	10.4	38.3	2.5	2255	33.9	900.0	8.9	39.1	0.6	0.1	40	-1058	n/a	22.7	31.1	n/a	n/a	1511.8	n/a	146.0
Spain	ESP	99.9	99.9	82.5	33.0	2392	38.2	636.0	100.0	16.3	34.9	5.0	5356	71.4	1.2	0.8	2.6	n/a	n/a	3430.3	n/a	657.0
Sri Lanka	LKA	92.3	94.2	25.3	24.5	2542	38.5	1712.0	95.6	52.9	48.5	0.9	531	50.3	10.9	15.1	17.3	5.4	48.0	3897.4	112.0	121.0
Sudan	SDN	58.9	34.6	39.9	673.3	102	15.1	250.0	38.5	61.6	64.5	0.3	190	-9.0	25.2	16.3	38.2	7.4	69.0	684.8	106.0	163.0
Suriname	SUR	94.7	79.2	15.1	0.6	180681	83.4	2331.0	87.2	24.9	60.1	3.6	3632	-43.8	7.6	5.0	8.8	26.5	80.0	4433.0	117.0	248.0
Eswatini	SWZ	67.6	58.0	52.6	39.5	2038	3.1	788.0	65.8	66.1	46.6	0.9	n/a	n/a	20.7	2.0	n/a	13.5	44.0	1138.1	103.0	237.0
Sweden	SWE	100.0	99.3	88.5	1.6	17636	104.7	624.0	100.0	53.2	63.3	4.5	13480	24.7	1.2	0.8	2.6	22.1	132.0	5438.2	126.0	290.0
Switzerland	CHE	100.0	99.9	81.4	5.0	4934	27.3	1537.0	100.0	25.3	62.2	4.3	7520	50.1	1.2	0.8	2.6	21.2	154.0	5132.6	131.0	306.0
Syrian Arab Republic	SYR	96.7	92.9	n/a	198.3	371	5.6	252.0	100.0	0.5	2.3	1.6	950	47.8	n/a	11.5	27.5	25.8	n/a	1614.7	134.0	255.0
Tajikistan	TJK	74.1	95.5	n/a	17.6	7588	6.8	691.0	100.0	44.7	98.5	0.6	1480	36.2	n/a	9.9	26.8	12.6	59.0	3348.7	97.0	142.0
Tanzania	TZA	50.1	23.5	n/a	6.2	1608	56.3	1071.0	32.8	85.7	34.2	0.2	99	10.7	32.0	4.5	n/a	4.1	46.0	1540.7	106.0	193.0
Thailand	THA	98.2	95.0	n/a	25.5	3281	189.6	1622.0	100.0	22.9	8.5	4.6	2540	41.6	9.0	5.4	10.5	10.8	59.0	3031.8	114.0	386.0
Timor-Leste	TLS	70.2	44.0	14.1	14.3	6774	4.1	1500.0	63.4	18.2	n/a	0.4	n/a	n/a	27.2	11.0	50.2	2.9	48.0	2454.4	102.0	96.0
Togo	TGO	62.8	13.9	31.9	1.5	1591	8.1	1168.0	46.9	71.3	75.3	0.4	153	20.0	16.2	6.7	27.5	7.1	49.0	1131.4	114.0	122.0
Trinidad and Tobago	TTO	96.9	92.1	25.0	8.8	2835	2.2	2200.0	100.0	0.3	n/a	34.2	7134	-102.7	4.9	6.3	11.0	19.7	89.0	1480.9	129.0	103.0
Tunisia	TUN	94.2	93.1	54.5	76.7	376	0.7	207.0	100.0	12.6	2.8	2.6	1444	36.2	4.9	2.8	10.1	27.3	90.0	1541.7	142.0	358.0
Turkey	TUR	98.9	96.4	69.5	18.5	2947	77.0	593.0	100.0	13.4	32.0	4.5	2855	75.2	1.2	1.7	9.5	32.2	120.0	3105.4	158.0	484.0
Turkmenistan	TKM	94.5	96.6	n/a	1983.6	257	5.4	161.0	100.0	0.0	n/a	12.5	2679	-191.5	5.5	4.2	11.5	17.5	83.0	1075.6	121.0	325.0
Uganda	UGA	38.9	19.2	58.7	1.6	1004	49.2	1180.0	26.7	89.1	93.0	0.1	n/a	n/a	41.4	3.6	28.9	7.1	47.0	1906.2	95.0	120.0
Ukraine	UKR	97.7	95.9	38.9	27.0	1217	98.1	565.0	100.0	4.1	4.4	5.0	3419	27.2	3.3	8.2	22.9	26.1	91.0	4652.4	119.0	589.0
United Arab Emirates	ARE	99.6	100.0	74.9	1866.7	17	n/a	78.0	100.0	0.1	0.2	23.3	11264	-183.8	1.2	0.8	2.6	29.9	88.0	21487	126.0	66.0
United Kingdom	GBR	100.0	99.1	76.7	5.5	2244	88.4	1220.0	100.0	8.7	24.8	6.5	5130	34.6	1.2	0.8	2.6	29.5	138.0	7022.6	138.0	259.0
United States of America	USA	99.2	100.0	n/a	14.9	8844	1491.0	715.0	100.0	8.7	13.2	16.5	12984	7.3	1.2	0.5	2.1	37.3	161.0	8142.9	147.0	704.0
Uruguay	URY	99.2	95.7	n/a	4.0	26963	134.8	1300.0	100.0	58.0	88.6	2.0	3068	44.4	1.2	1.3	10.7	28.9	103.0	4940.5	133.0	1152.0
Uzbekistan	UZB	91.5	100.0	45.2	300.9	531	14.0	206.0	100.0	3.0	20.7	3.4	1645	-26.2	7.4	4.5	19.6	15.3	72.0	4613.1	115.0	321.0
Vanuatu	VUT	90.5	53.5	38.9	n/a	38632	n/a	206.0	57.8	36.1	21.3	0.6	n/a	n/a	7.1	4.4	28.5	23.5	104.0	612.5	128.0	279.0

Venezuela, RB	VEN	97.4	94.9	n/a	2.8	26189	1025.0	2044.0	99.6	12.8	63.7	6.0	2658	-178.8	11.7	4.1	n/a	25.2	84.0	3426.9	105.0	201.0
Vietnam	VNM	91.2	78.2	37.7	22.8	3884	432.6	1821.0	100.0	35.0	36.7	1.8	1411	-15.1	10.8	6.4	n/a	2.1	71.0	5448.0	123.0	300.0
Yemen, Rep.	YEM	70.4	59.7	n/a	168.6	80	n/a	167.0	71.6	2.3	n/a	0.9	216	-120.6	34.4	16.3	n/a	14.1	45.0	995.3	95.0	65.0
Zambia	ZMB	61.2	31.1	46.1	2.0	5134	49.4	1020.0	27.2	88.0	97.0	0.3	707	8.3	44.5	6.3	40.0	6.5	41.0	2418.0	93.0	118.0
Zimbabwe	ZWE	66.6	38.6	61.0	29.1	796	9.3	657.0	38.1	81.8	52.7	0.8	537	15.3	46.6	3.2	26.8	12.3	58.0	580.0	87.0	75.0

ADDENDUM C: CONCEPTUAL FRAMEWORK, DATA TREATMENT, NORMALISATION, WEIGHTING AND AGGREGATION

Addendum C: Conceptual Framework of WEF Nexus Index composition

Item	Dimension/indicator	Supra-dimension	Weight	Aggregation	Direction	Name of dimension/indicator
Index	Index		1	Arithmetic	1	Water-Energy-Food Nexus Index
Pillars	p.01	si.01	0.333	Arithmetic	1	Water sub-index
	p.02	si.01	0.333	Arithmetic	1	Energy sub-index
	p.03	si.01	0.333	Arithmetic	1	Food sub-index
Sub-pillars	sp.01	p.01	0.5	Arithmetic	1	Access
	sp.02	p.01	0.5	Arithmetic	1	Availability
	sp.03	p.02	0.5	Arithmetic	1	Access
	sp.04	p.02	0.5	Arithmetic	1	Availability
	sp.05	p.03	0.5	Arithmetic	1	Access
	sp.06	p.03	0.5	Arithmetic	1	Availability
Indicators	ind.01	sp.01	0.333	Arithmetic	1	The percentage of people using at least basic drinking water services
	ind.02	sp.01	0.333	Arithmetic	1	Percentage of people using safely managed sanitation services.
	ind.03	sp.01	0.333	Arithmetic	1	Degree of IWRM implementation (1-100)
	ind.04	sp.02	0.25	Arithmetic	-1	Annual freshwater withdrawals, total (% of internal resources)
	ind.05	sp.02	0.25	Arithmetic	1	Renewable internal freshwater resources per capita (cubic meters)
	ind.06	sp.02	0.25	Arithmetic	1	Environmental flow requirements (106 m3/annum)
	ind.07	sp.02	0.25	Arithmetic	1	Average precipitation in depth (mm per year)
	ind.08	sp.03	0.5	Arithmetic	1	Access to electricity (% of population)
	ind.09	sp.03	0.167	Arithmetic	1	Renewable energy consumption (% of total final energy consumption)
	ind.10	sp.03	0.167	Arithmetic	1	Renewable electricity output (% of total electricity output)
	ind.11	sp.03	0.167	Arithmetic	-1	CO2 emissions (metric tons per capita)
	ind.12	sp.04	0.5	Arithmetic	1	Electric power consumption (kWh per capita)
	ind.13	sp.04	0.5	Arithmetic	-1	Energy imports, net (% of energy use)
	ind.14	sp.05	0.333	Arithmetic	-1	Prevalence of undernourishment (%)
	ind.15	sp.05	0.167	Arithmetic	-1	Percentage of children under 5 years of age affected by wasting (%)
	ind.16	sp.05	0.167	Arithmetic	-1	Percentage of children under 5 years of age who are stunted (%)
	ind.17	sp.05	0.333	Arithmetic	-1	Prevalence of obesity in the adult population (18 years and older)
	ind.18	sp.06	0.25	Arithmetic	1	Average protein supply (gr/caput/day)
	ind.19	sp.06	0.25	Arithmetic	1	Cereal yield (kg per hectare)
	ind.20	sp.06	0.25	Arithmetic	1	Average Dietary Energy Supply Adequacy (ADESA) (%)
	ind.21	sp.06	0.25	Arithmetic	1	Average value of food production (I$ per caput)

Appendix C: Data treatment, Normalisation, Weighting and Aggregation

Data Treatment

Some countries do not measure certain indicators because of the low occurrence of what is being measured in that country. For example, in high-income countries, the proportion of children under five years of age who are affected by wasting is typically very low. UNICEF report an average prevalence of wasting in high-income countries of 0.75% (Sachs et al. 2018). This value was imputed to treat data for high-income countries with missing data for this indicator in the calculation of the WEF Nexus Index. Similarly, the prevalence of stunting in children under five years of age in high-income countries has been taken to be 2.58% while the prevalence of undernourishment (% of the population) has been taken to be 1.2% for high-income countries with missing data (ibid.).

The negative values for *Energy imports, net (% of energy use)* and the *Cereal import dependency ratio* were removed such that these indicators excluded the export component that they measure. Due to a low correlation with the other indicators in the food sub-pillars (both with and without the export component of its indicator) the *Cereal import dependency ratio* was subsequently removed from the list of indicators that constitute the WEF Nexus Index. The indicator, *Annual freshwater withdrawals,* has been truncated at 100 in order to reduce the absolute values of the skewness and kurtosis within the generally accepted range, i.e. |<2| and |<3.5| respectively, since this coincided with the conceptual framing of this indicator in development of the WEF Nexus Index.

For some indicators, values are not available for the latest year in the database's record, and the latest value for each country had to be utilised. Examples of indicators for which this had to be done included *Energy imports, net (% of energy use)*, *Energy use (kg of oil equivalent per capita)*, *Firms experiencing electrical outages (% of firms)*, *Percentage of children under 5 years of age affected by wasting*, and *The share of food expenditure of the poor*.

It was necessary to standardise the names of countries in the different databases, e.g. in the World Bank and FAO databases. This is because, for example, one may refer to "Viet Nam" while another refers to "Vietnam". Other examples are "Ivory Coast" as opposed to "Cote d'Ivoire", "Republic of Korea" verses "Korea, Rep." and "Swaziland" instead of "Eswatini".

Within the COIN Excel Tool,[1] various statistical properties of each indicator are determined. These include the missing values (%), missing values (#), minimum, maximum, mean, standard deviation, skewness and kurtosis. By analysing the simultaneous 'anomalous' values of skewness and kurtosis (Saisana et al. 2018) it was ascertained that six indicators have outliers that require 'treatment', either by means of Winsorisation or the Box-cox transformation. The reason for treating outliers is that in developing a composite indicator one is interested in descriptive statistics such as the mean, standard deviation and correlation coefficient, which are often spoiled by outliers (ibid.). Not treating outliers may cause misinterpretations of composite indicators. Winsorisation is the JRC-COIN's preferred method of treating data if there are a low number of outliers, i.e. less than five, while the Box-cox transformation is the preferred method of treatment if there are more than five outliers. The number of outliers for the six indicators require treatment are presented in Table 1**.**

[1] Revision: CT2019-07-30, developed by JRC-COIN.

Normalisation, Weighting and Aggregation

Since many of the indicators are measured in different units and have differing ranges, some form of normalisation of the data is necessary before it can be weighted and subsequently aggregated. Normalisation transforms indicators to a common scale, which renders the variables comparable. Various methods of normalisation exist, such as Ranking, Standardisation (or z-scores), Min-max, Distance to a reference (OECD 2008), etc. The method of normalisation utilised in the development of the WEF Nexus Index is the Min-max method. This method normalises the indicators to all have an identical range (0;100) by subtracting the minimum value and dividing by the range of the indicator values.

Table 1: Indicators with outliers and the method of data treatment employed

Indicator	Ind. No.	No. of outliers	Treatment of outliers
Renewable internal freshwater	ind.05	18	Box-cox
Environmental flow requirements	ind.06	17	Box-cox
CO_2 emissions per capita	ind.11	4	Winsorisation
Electric power consumption	ind.12	3	Winsorisation
Cereal yield	ind.19	2	Winsorisation
Average value of food production	ind.21	2	Winsorisation

The WEF Nexus Index is made up of pillars, sub-pillars and indicators, as shown in Table 6-1. The final weight that each indicator and aggregation level have in the overall index is also presented in this table. For example, each indicator is weighted by its indicator weight, but also the weight of its sub-pillar, pillar and sub-index. These are combined to give the overall indicator weight at the index level. The same methodology is used for sub-pillars, pillars and sub-indexes.

These elements are repeated in Table 6-1, which presents the composition of the framework for the calculation of the WEF Nexus Index. The relationship between each dimension and supra-dimension within the WEF Nexus Index is presented in this table, together with the weighting and aggregation of each element within the composite indicator. The following is highlighted in terms of the direction column in the table:

> "A value of 1 means that higher values of the indicator are associated with higher values of the index/concept (e.g. higher values of the indicator "income" indicate higher values of index "quality of life"). A value of -1 means that higher values of the indicator are associated with lower values of the index/concept (e.g. higher values of indicator "deforestation" are associated with lower values of index "environmental performance")" (JRC-COIN 2015).

The weighting of the pillars, i.e. the water, energy and food 'sub-indices', must be equal, since this is the essential philosophy of the WEF nexus. Where previous integrated resource methods, such as IWRM, were water-centric, the attraction of the WEF nexus has been that it is multi-centric, with each sector being treated with equal importance (Allouche et al. 2015). Because the WEF nexus is multi-centric there is a greater chance of it being accepted by a broader set of stakeholders, especially those in the energy and agricultural sectors (Cai et al. 2018). By providing equal weighting across the three pillars it is implied that SDGs 2, 6 and 7 are equally important.

Generally, either the geometric or arithmetic means are utilised to aggregate multiple indicators into a composite index. The OECD (2008) state that “an undesirable feature of additive aggregations is the implied full compensability, such that poor performance in some indicators can be compensated for by sufficiently high values in other indicators.” In developing the SDG Index, Sachs et al. (2016) provide two reasons why the arithmetic mean was selected, namely that (i) each SDG generally describes complementary policy priorities with a reasonable degree of substitutability; and that (ii) the arithmetic mean is relatively easy to communicate.

ADDENDUM D: WEF NEXUS INDEX DASHBOARD

Addendum D: WEF Nexus Index Dashboard

				Water Sub-index							Energy Sub-index						Food sub-index							
			WEF Nexus Index	The percentage of people using at least basic drinking water services	Percentage of people using safely managed sanitation services.	Degree of IWRM implementation (1-100)	Annual freshwater withdrawals, total (% of internal resources)	Renewable internal freshwater resources per capita (cubic meters)	Environmental flow requirements (10^6 m^3/annum)	Average precipitation in depth (mm per year)	Access to electricity (% of population)	Renewable energy consumption (% of total final energy consumption)	Renewable electricity output (% of total electricity output)	CO_2 emissions (metric tons per capita)	Electric power consumption (kWh per capita)	Energy imports, net (% of energy use)	Prevalence of undernourishment (%)	Percentage of children under 5 years of age affected by wasting (%)	Percentage of children under 5 years of age who are stunted (%)	Prevalence of obesity in the adult population (18 years and older)	Average protein supply (gr/caput/day)	Cereal yield (kg per hectare)	Average Dietary Energy Supply Adequacy (ADESA) (%)	Average value of food production (I$ per caput)
Rank	**Country**		**Index**	ind.01	ind.02	ind.03	ind.04	ind.05	ind.06	ind.07	ind.08	ind.09	ind.10	ind.11	ind.12	ind.13	ind.14	ind.15	ind.16	ind.17	ind.18	ind.19	ind.20	ind.21
1	Norway	NOR																						
2	New Zealand	NZL																						
3	Sweden	SWE																						
4	Iceland	ISL																						
5	Canada	CAN																						
6	Denmark	DNK																						
7	Australia	AUS																						
8	Austria	AUT																						
9	Finland	FIN																						
10	Brazil	BRA																						
11	United States of America	USA																						
12	France	FRA																						
13	Switzerland	CHE																						
14	Colombia	COL																						
15	Paraguay	PRY																						
16	Croatia	HRV																						
17	United Kingdom	GBR																						
18	Malaysia	MYS																						
19	Argentina	ARG																						
20	Uruguay	URY																						
21	Germany	DEU																						
22	Costa Rica	CRI																						
23	Slovenia	SVN																						
24	Netherlands	NLD																						
25	Luxembourg	LUX																						
26	Albania	ALB																						
27	Ecuador	ECU																						
28	Bosnia and Herzegovina	BIH																						

29	Ireland	IRL
30	Greece	GRC
31	Romania	ROU
32	Belgium	BEL
33	Portugal	PRT
34	Italy	ITA
35	Japan	JPN
36	Russian Federation	RUS
37	Estonia	EST
38	Chile	CHL
39	Peru	PER
40	Indonesia	IDN
41	Suriname	SUR
42	Vietnam	VNM
43	Brunei Darussalam	BRN
44	Czech Republic	CZE
45	Mexico	MEX
46	Poland	POL
47	Kuwait	KWT
48	Latvia	LVA
49	Korea, Rep.	KOR
50	Kazakhstan	KAZ
51	Venezuela, RB	VEN
52	Turkey	TUR
53	Slovak Republic	SVK
54	United Arab Emirates	ARE
55	Bulgaria	BGR
56	Hungary	HUN
57	Trinidad and Tobago	TTO
58	Cuba	CUB
59	Israel	ISR
60	Gabon	GAB
61	Serbia	SRB
62	Ukraine	UKR
63	Nepal	NPL
64	Lithuania	LTU
65	Myanmar	MMR
66	Thailand	THA
67	Belarus	BLR
68	Philippines	PHL
69	Georgia	GEO
70	Bolivia	BOL
71	Panama	PAN
72	South Africa	ZAF

73	Uzbekistan	UZB
74	Azerbaijan	AZE
75	Guatemala	GTM
76	Saudi Arabia	SAU
77	Sri Lanka	LKA
78	Cameroon	CMR
79	Spain	ESP
80	Montenegro	MNE
81	Ghana	GHA
82	El Salvador	SLV
83	Cyprus	CYP
84	Iran, Islamic Rep.	IRN
85	Oman	OMN
86	Honduras	HND
87	Malta	MLT
88	Bangladesh	BGD
89	Nicaragua	NIC
90	Algeria	DZA
91	Egypt	EGY
92	Armenia	ARM
93	Macedonia, FYR	MKD
94	Belize	BLZ
95	Guyana	GUY
96	Mongolia	MNG
97	China	CHN
98	Tunisia	TUN
99	Fiji	FJI
100	Mauritius	MUS
101	Dominican Republic	DOM
102	Cambodia	KHM
103	Turkmenistan	TKM
104	Jamaica	JAM
105	Qatar	QAT
106	Lao PDR	LAO
107	Nigeria	NGA
108	Cote d'Ivoire	CIV
109	Pakistan	PAK
110	Korea, Dem. People's Rep.	PRK
111	Morocco	MAR
112	Bhutan	BTN
113	Tajikistan	TJK
114	Singapore	SGP
115	India	IND
116	Senegal	SEN

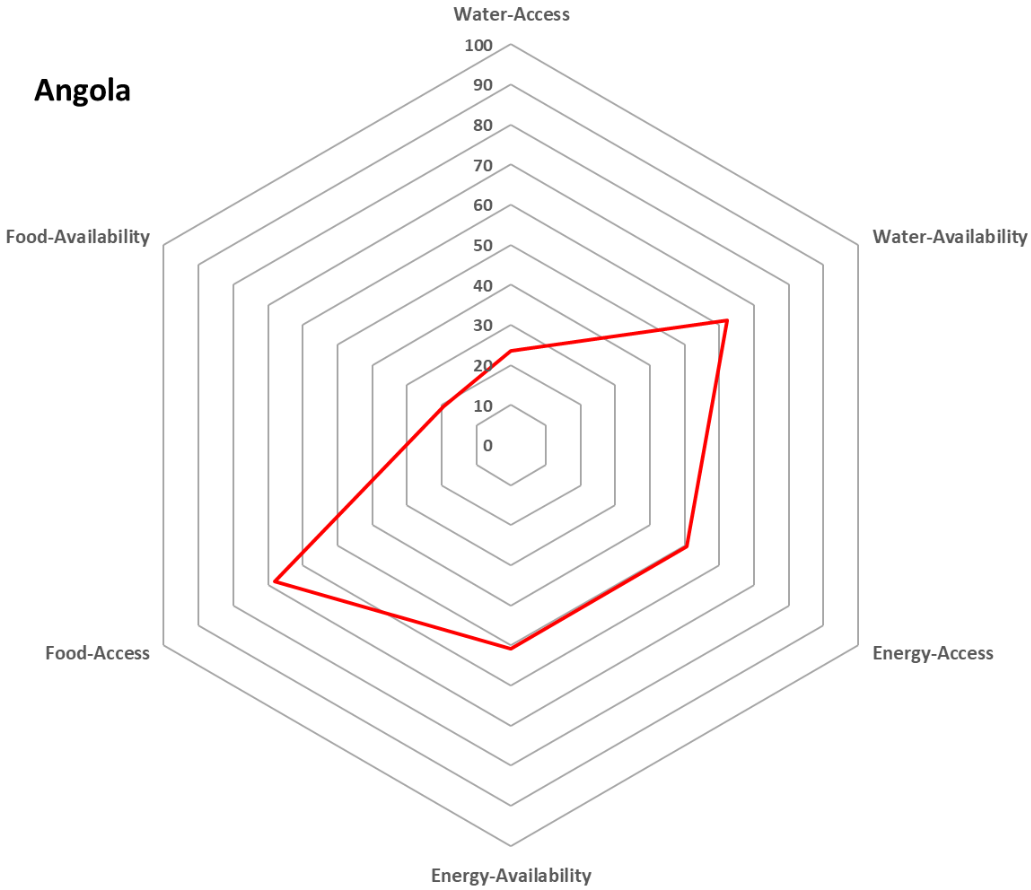
117	Maldives	MDV
118	Kenya	KEN
119	Lebanon	LBN
120	Congo, Rep.	COG
121	Iraq	IRQ
122	Samoa	WSM
123	Togo	TGO
124	Angola	AGO
125	Barbados	BRB
126	Mozambique	MOZ
127	Zambia	ZMB
128	Sao Tome and Principe	STP
129	Dominica	DMA
130	Ethiopia	ETH
131	Benin	BEN
132	Jordan	JOR
133	Libya	LBY
134	Mali	MLI
135	Zimbabwe	ZWE
136	Botswana	BWA
137	Guinea	GIN
138	Tanzania	TZA
139	Hong Kong SAR, China	HKG
140	Eswatini	SWZ
141	Congo, Dem. Rep.	COD
142	Niger	NER
143	Sudan	SDN
144	Vanuatu	VUT
145	Syrian Arab Republic	SYR
146	Haiti	HTI
147	Moldova	MDA
148	Gambia, The	GMB
149	Cabo Verde	CPV
150	Sierra Leone	SLE
151	Lesotho	LSO
152	Malawi	MWI
153	Rwanda	RWA
154	Uganda	UGA
155	Afghanistan	AFG
156	Timor-Leste	TLS
157	Liberia	LBR
158	Burkina Faso	BFA
159	Guinea-Bissau	GNB
160	Solomon Islands	SLB

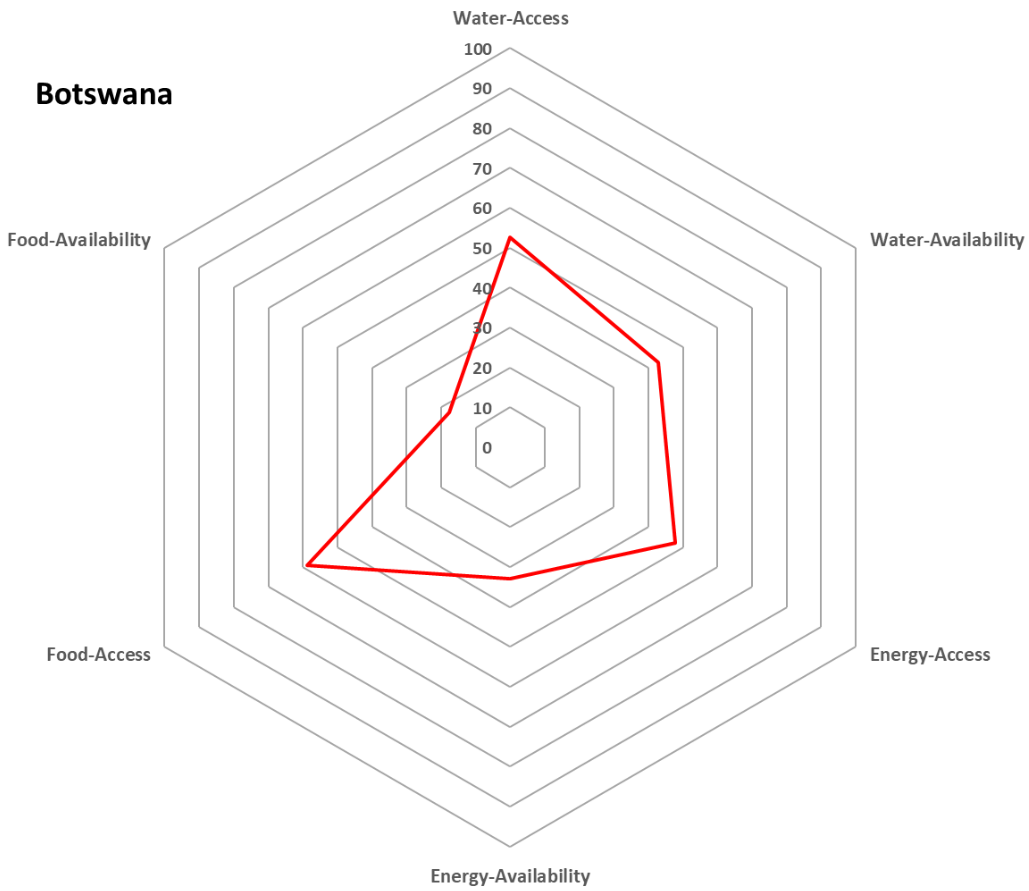
161	Comoros	COM
162	Yemen, Rep.	YEM
163	Namibia	NAM
164	Central African Republic	CAF
165	Madagascar	MDG
166	Mauritania	MRT
167	Djibouti	DJI
168	Papua New Guinea	PNG
169	South Sudan	SSD
170	Chad	TCD

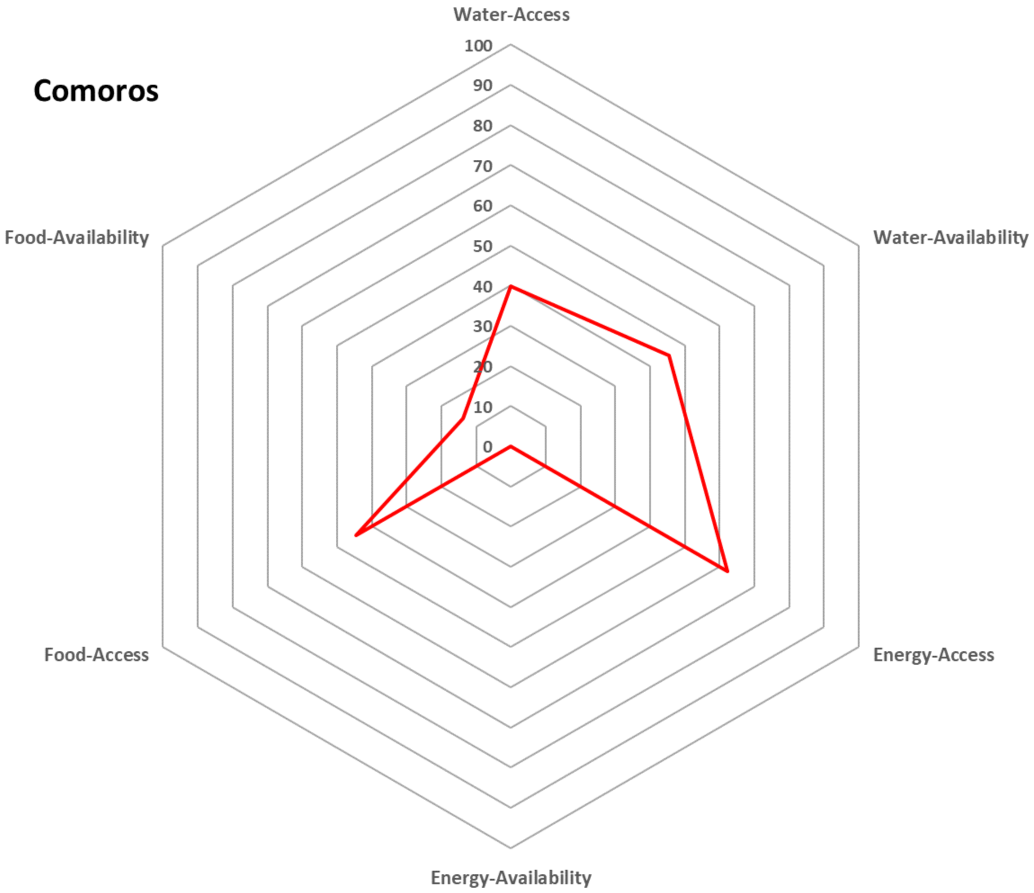
Legend: Quartiles

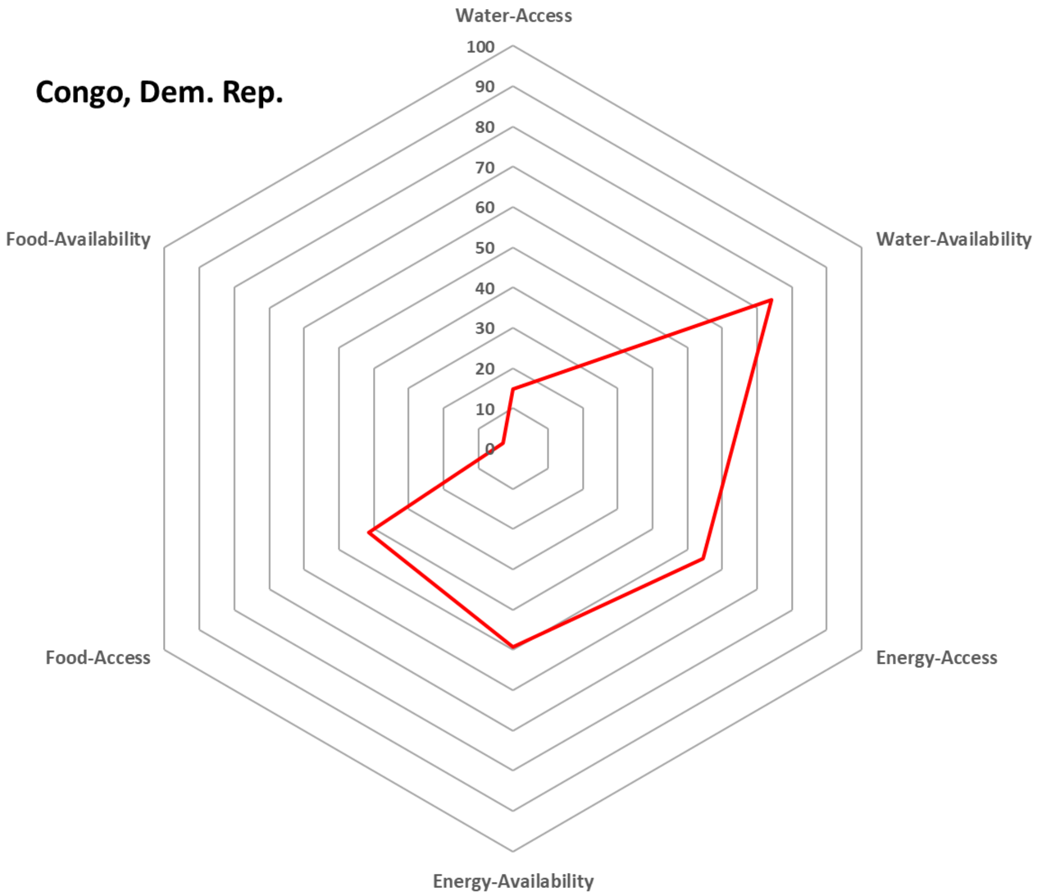
	: values between 0 and 25
	: values between 25 and 50
	: values between 50 and 75
	: values between 75 and 100 to 25
	: insufficient data

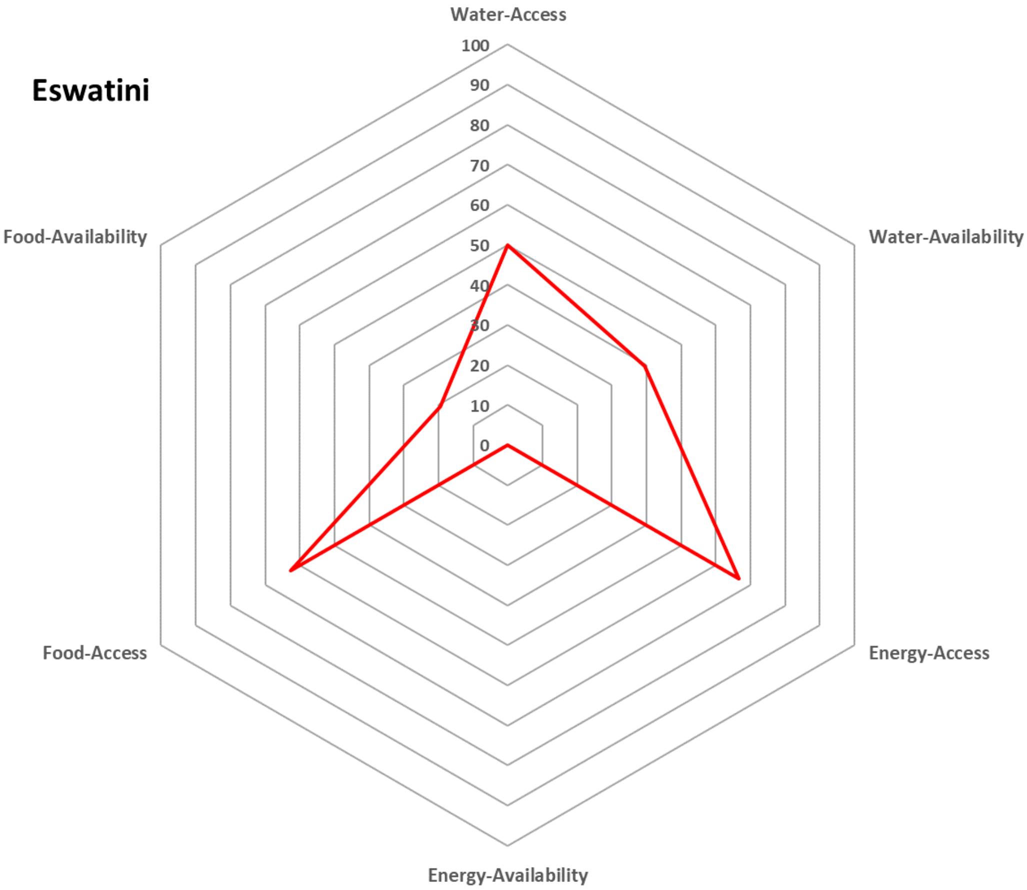
ADDENDUM E: RADAR CHARTS OF THE WEF NEXUS INDEX SUB-PILLARS FOR SADC COUNTRIES

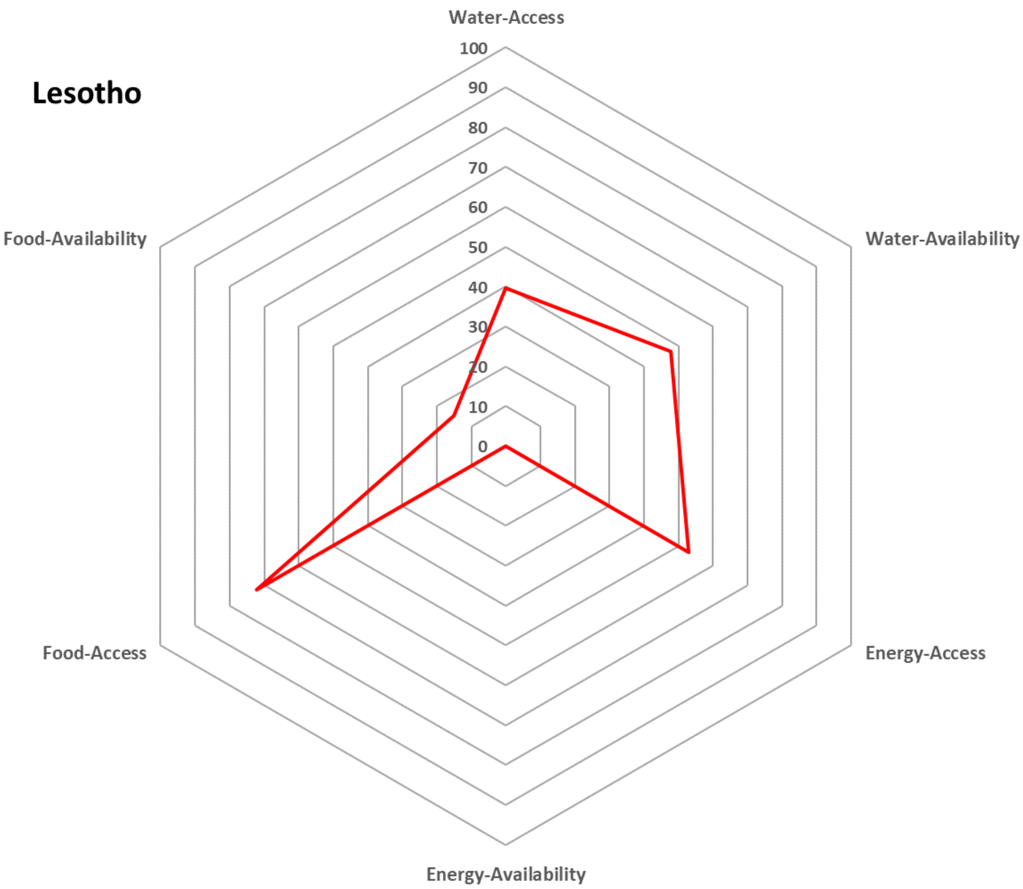

Angola
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0

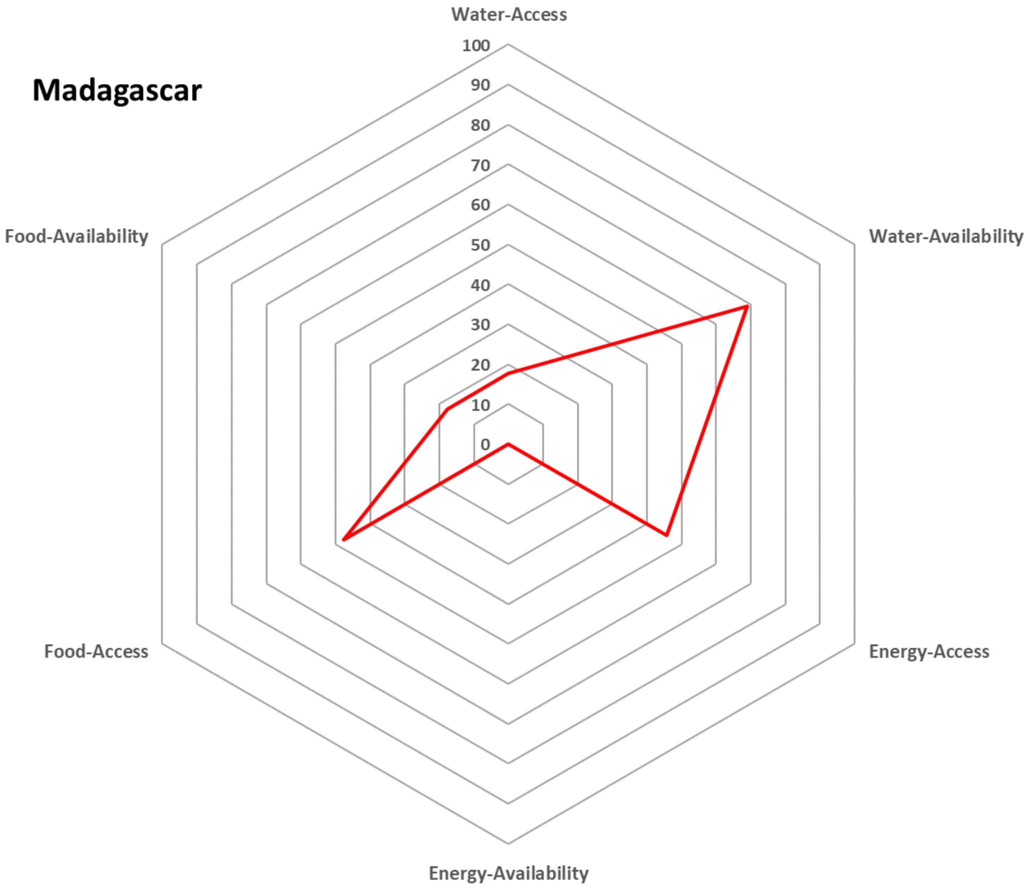

Botswana
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0

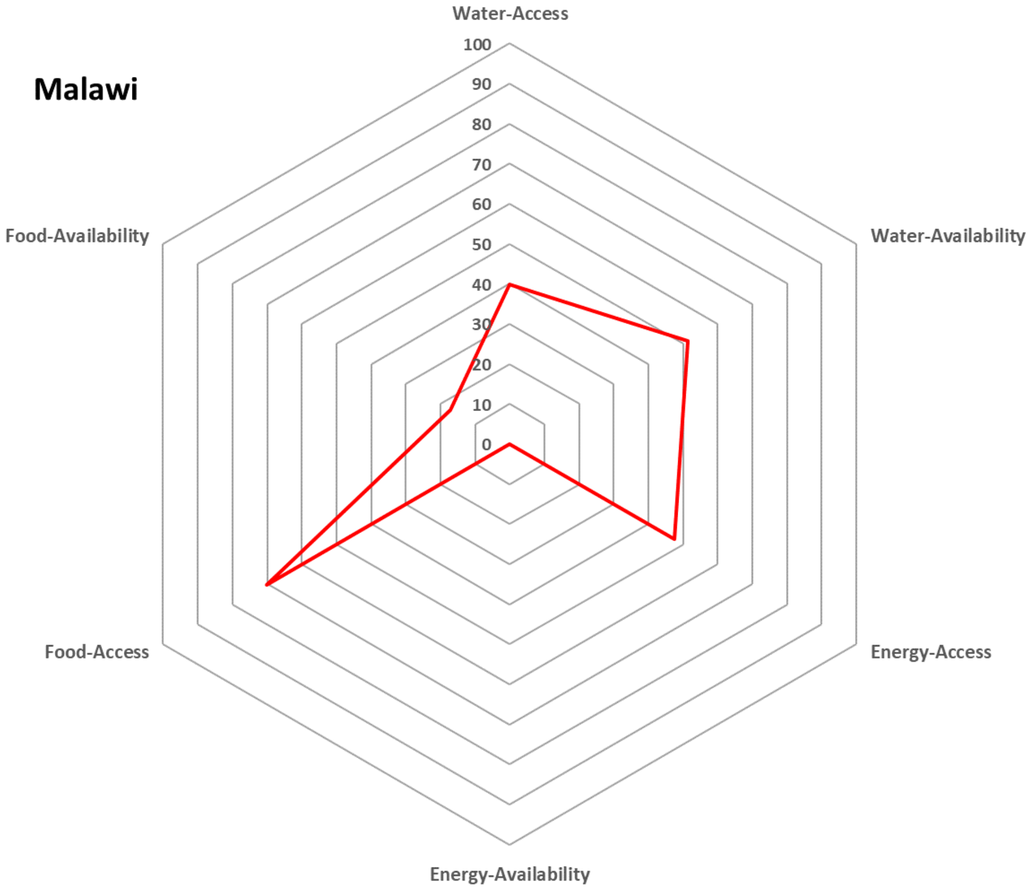

Comoros
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0

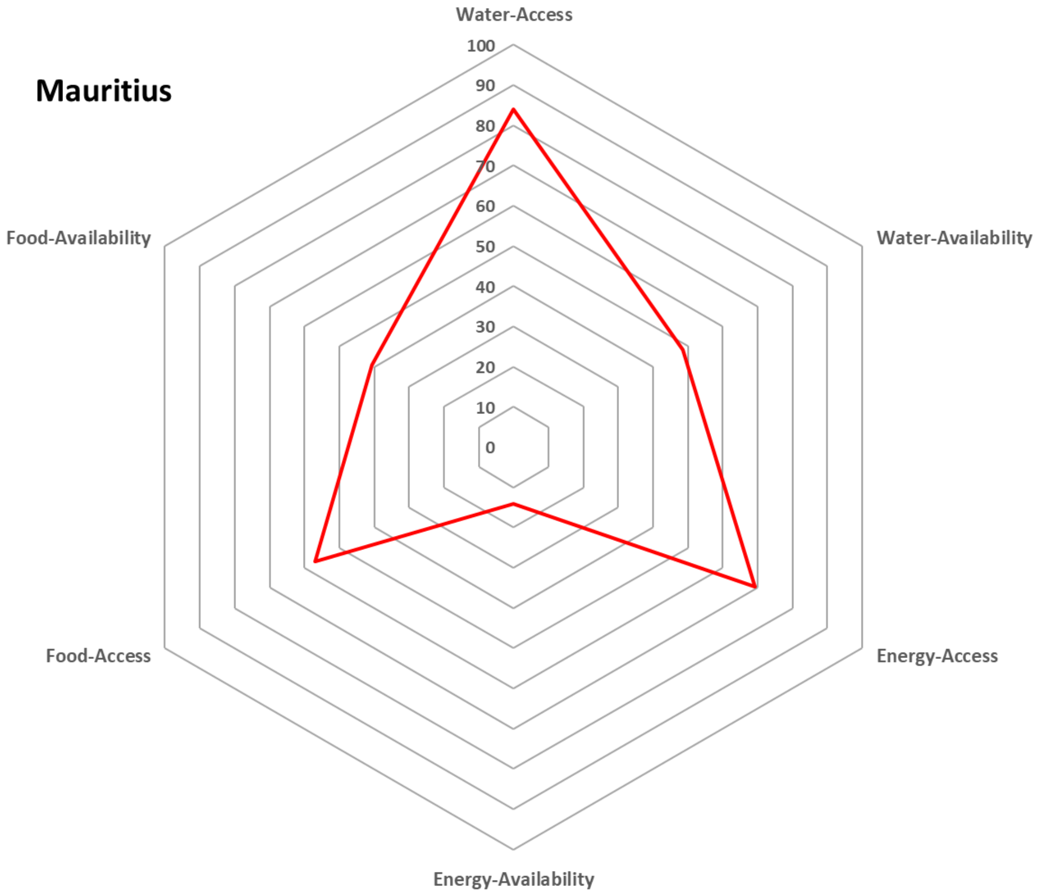

Congo, Dem. Rep.
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0

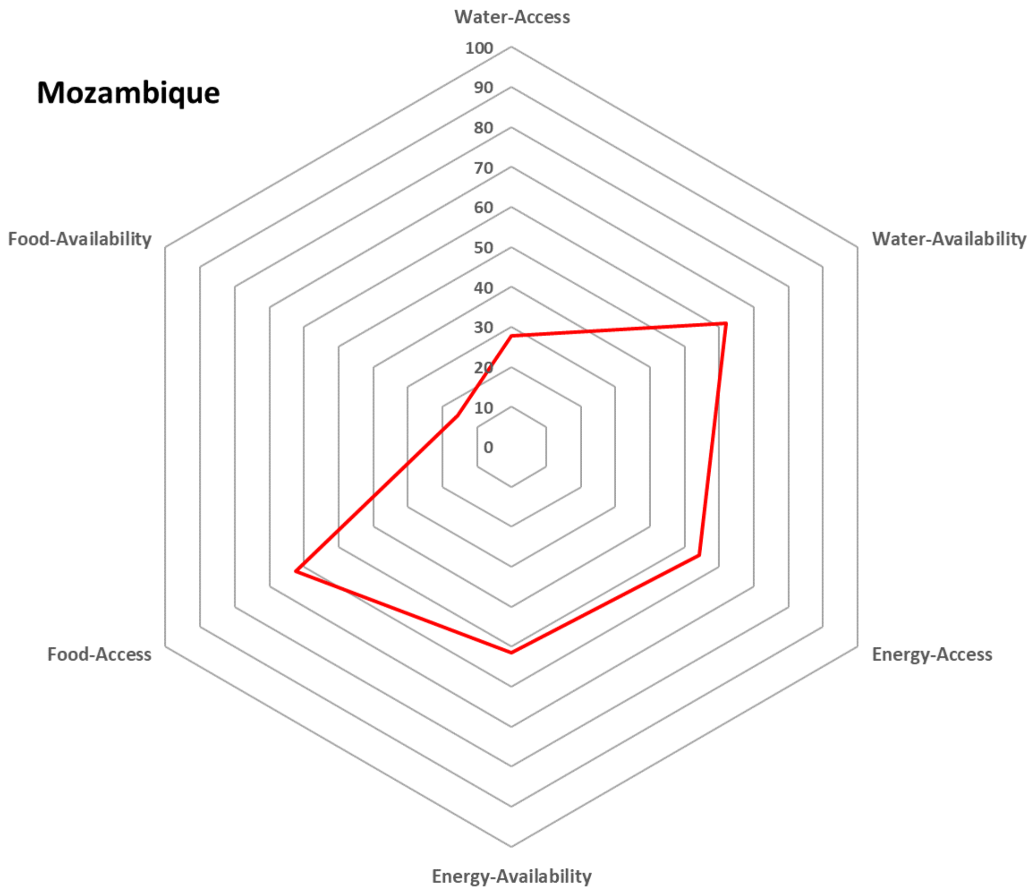

Eswatini
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0

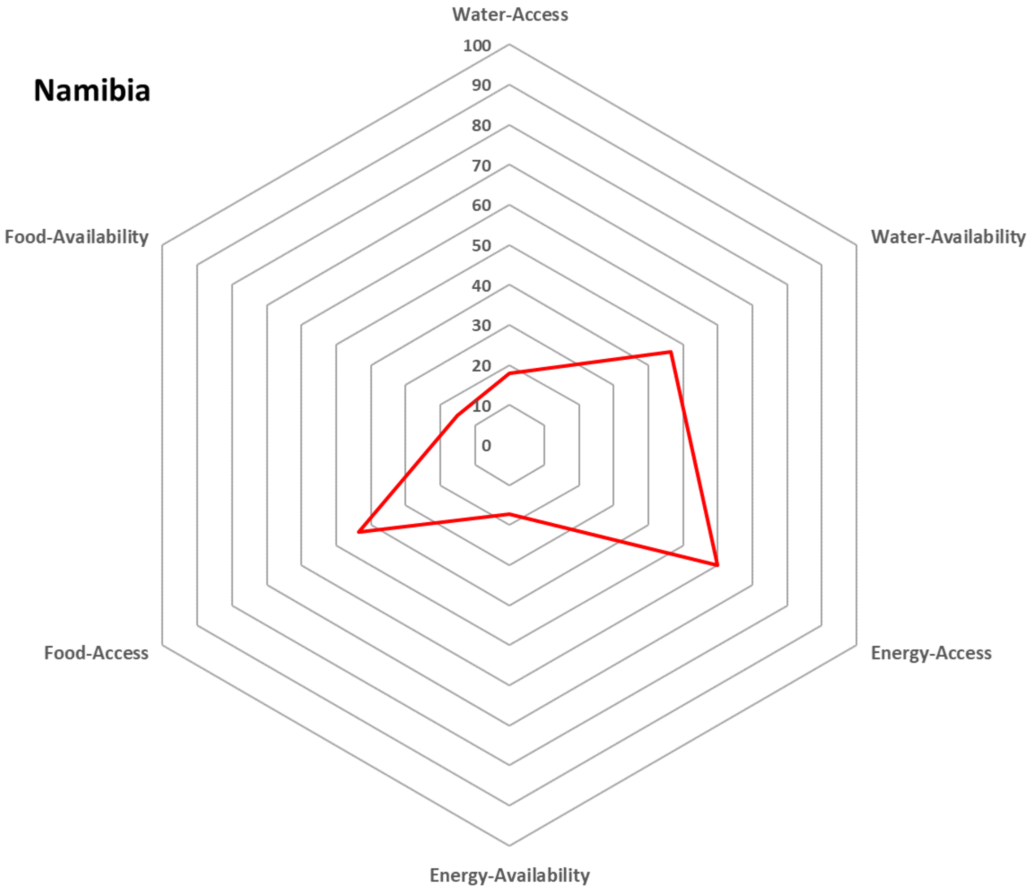

Lesotho
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0

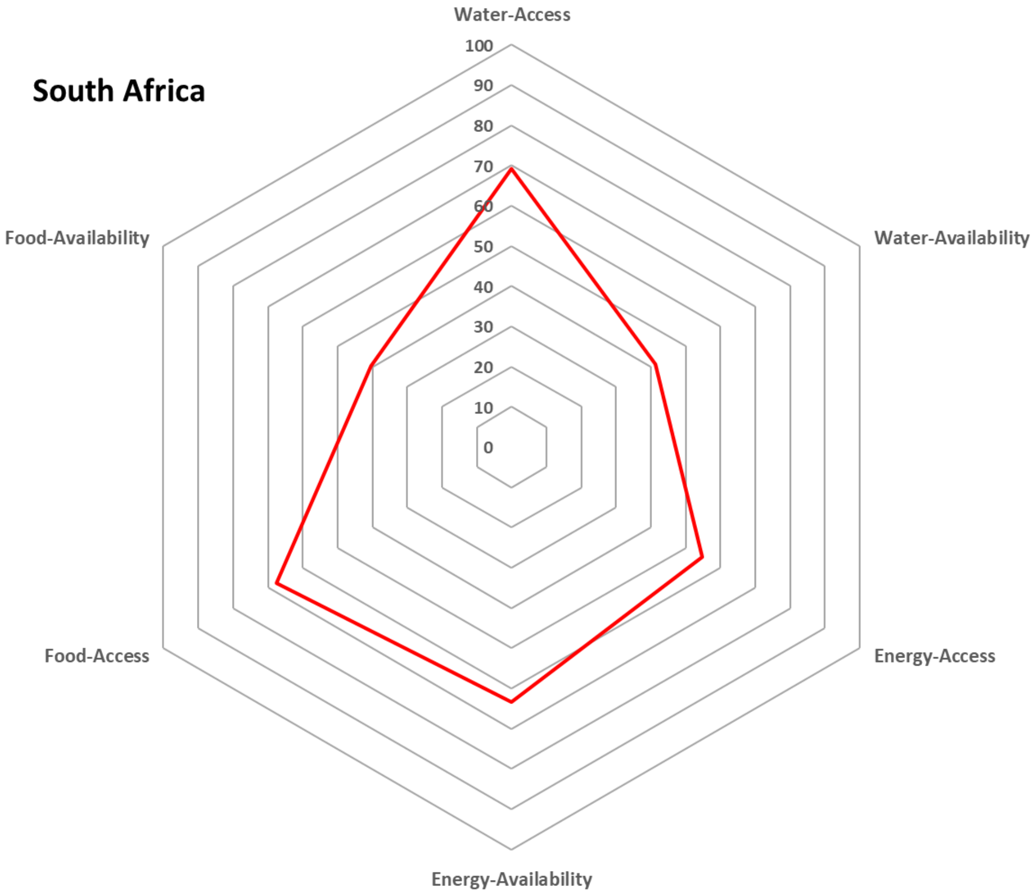

Madagascar
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0

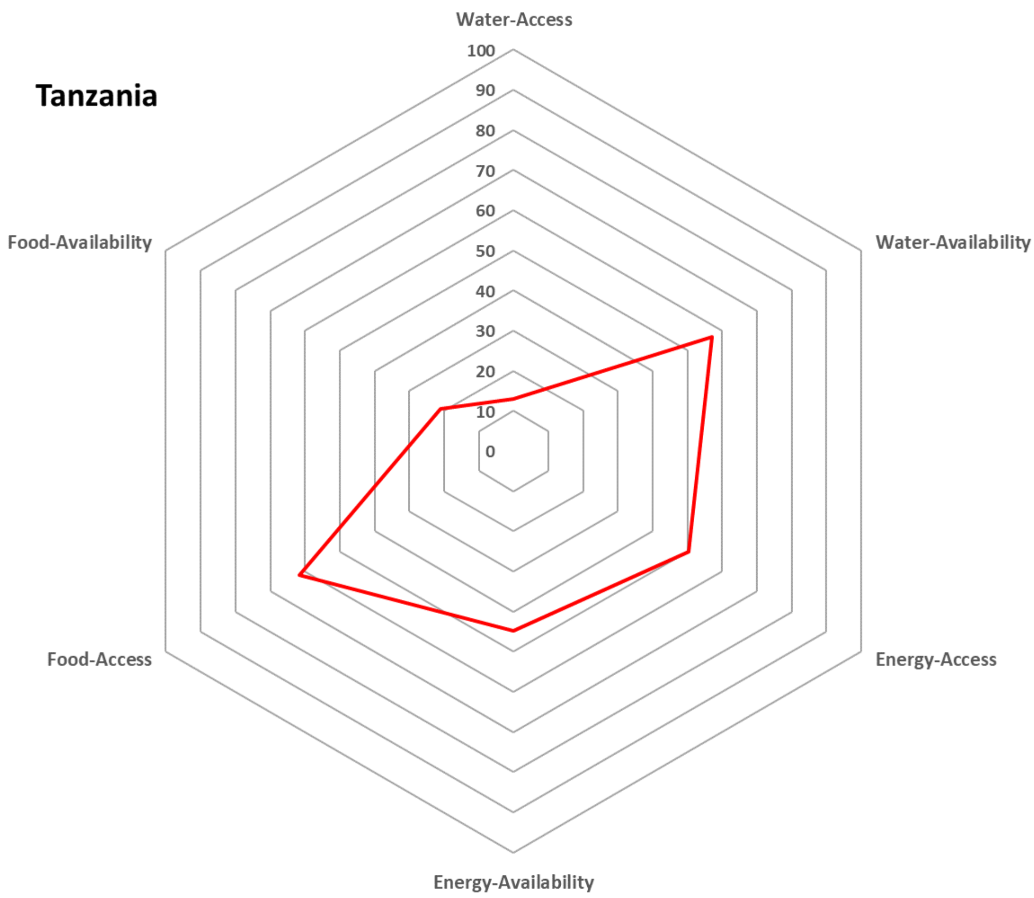

Malawi
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0

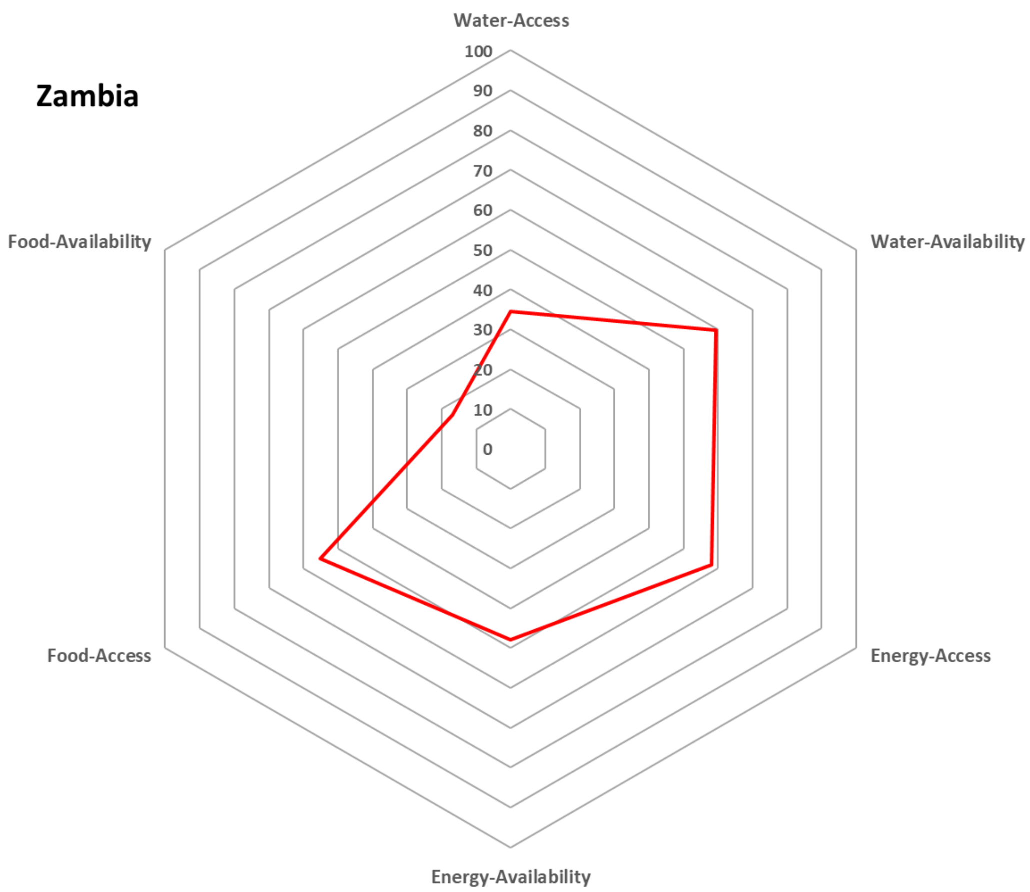

Mauritius
Water-Access
100
90
80
70
60
50
40
30
20
10
0
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability

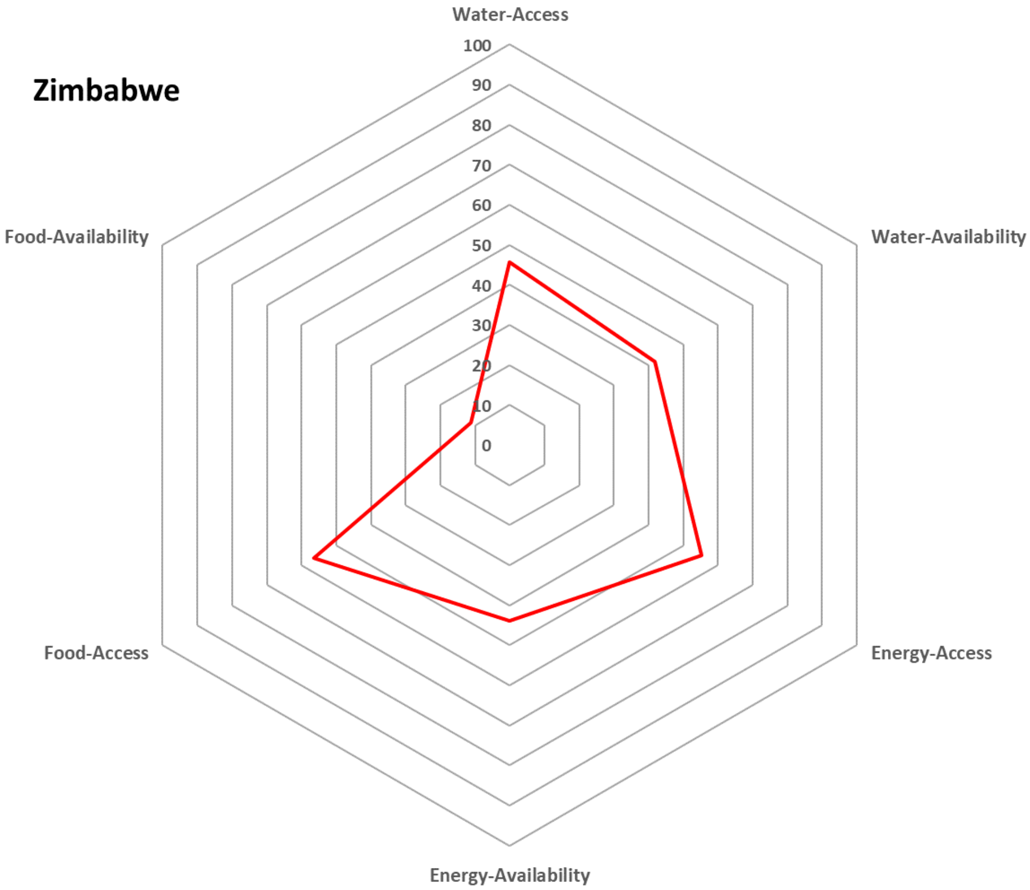

Mozambique
Water-Access
100
90
80
70
60
50
40
30
20
10
0
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability


Namibia
Water-Access
100
90
80
70
60
50
40
30
20
10
0
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability


South Africa
Water-Access
100
90
80
70
60
50
40
30
20
10
0
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability


Tanzania
Water-Access
100
90
80
70
60
50
40
30
20
10
0
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability


Zambia
Water-Access
100
90
80
70
60
50
40
30
20
10
0
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability


Zimbabwe
Water-Access
Water-Availability
Energy-Access
Energy-Availability
Food-Access
Food-Availability
100
90
80
70
60
50
40
30
20
10
0