The Water-Energy Nexus in the Context of Climate Change:

Investigating Trade-Offs between Water Use Efficiency and Renewable Energy Options for South Africa

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

By: Madhlopa A

Rationale

Water is a major driver of social and economic development for any nation. Nevertheless, access to fresh and adequate water is limited in many parts of the world, particularly in developing countries. As an arid and developing country, South Africa (SA) is faced with water resource challenges, such as issues of water shortage and quality. There is also a mounting pressure on the limited water resources due to economic and population growth, which will be exacerbated by the onset of climate change.

It is perceived that the energy sector is one of the main contributors to water quality and high water use, through the burning of fossil fuels (coal, oil and gas), the discharge of poorly-treated wastewater, and the emission of greenhouse gases that cause climate change. SA has abundant reserves of coal, and coal-fired thermal power plants currently generate most of the electricity. In addition, fossil fuels are getting depleted, thereby decreasing energy security. Moreover, the demand for energy is also increasing. Consequently, there is a need to transform the country's energy mix in order to minimise negative impacts on water resources and mitigate the harmful effects of climate change.

In view of this, SA is making some policy and regulatory shifts, in line with international developments, to address these environmental challenges. Renewable energy is being promoted as one way of achieving sustainable energy provision in the country, with a target of 10 000 GWh of energy to come from various renewable resources by 2013 (DME 2003). The Renewable Energy Feed-in Tariff (REFIT) was introduced in 2009 and later, in 2011, revised to the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) with a competitive bidding process. Under this programme, the power generated by the independent power producers is fed to the national grid through a power purchase agreement (PPA). Nevertheless, some issues require close scrutiny in order to understand the water requirements of renewable energy production in the country. Due to the large gap that exists between water supply and demand, trade-offs in water allocation amongst different users and energy resources are critical.

Aim and objectives

The aim of this study was to investigate trade-offs between water use efficiency and renewable energy in SA. The objectives were to:

a) Investigate renewable energy choices and their water requirements in SA.
b) Investigate the degree to which the SA policy and regulatory instruments enable integrated approaches to long term energy and water resource choices that could stimulate resilience to climate change.
c) Recommend a policy framework that links (or ensures a balance between) efficient water use and energy production under changing climatic conditions.
d) Determine challenges and opportunities which could inform policies and planning towards initiatives that enhance the climate change adaptation capacity of people living in areas under climate related water scarcity by using adequate renewable energy technologies.
e) Map out renewable energy supply sources and overall energy demand over a long term planning horizon that are appropriate.
f) Assess the tradeoffs between resource choices (renewable energy production and the efficiency in water use within parameters of adaptation to climate change).
g) Develop and adapt a scenario framework (or toolbox) designed to reflect various renewable energy sources and water demand to ensure a balanced and efficient water use in SA.

Methodology

A desktop approach was employed to acquire most of the data and information required in this study. This included a thorough review of energy options and their water requirements, energy policy and regulatory instruments, and challenges and opportunities in transitioning to a large share of renewable energy in the country's energy mix. Interviews with a structured questionnaire were used to fill in some data gaps. In addition, workshops were organised to test study findings and to solicit input from different experts working in the water and energy fields.

It was also deemed necessary to apply some analytical tools in the determination of the water intensity of energy technologies, future rainfall and runoff scenarios, and eleven different energy scenarios and their associated water requirements. The considered energy scenarios were obtained from the most recent draft national energy plan, the Draft Integrated Resource Plan 2010-2030 Update Report (DoE 2013c). All computational procedures were performed by using Excel, and the spatial distribution of energy and water resources was determined by using ArcGIS. A conceptual approach was applied to develop a draft policy framework while trade-offs in the energy-water nexus in the context of climate change (mitigation and adaptation) were assessed qualitatively (lose or win from perspectives of energy, water and climate change).

Findings

Renewable energy choices and water requirements in South Africa

In the South African context, there are limited data on all aspects of water usage in the production chain of energy. Wet-cooled power plants driven by conventional fuels (fossil and nuclear) withdraw significant quantities of water over the life-cycle of energy production. The quality of water is also adversely affected in some stages of energy production from these fuels. Hydropower is, by nature, the most water-intensive source of energy in terms of water requirement. Similarly, irrigated biomass is water intensive particularly during the production of biofuel crops. Thus, these two renewable energy sources have a perceived high impact on water resources. On the other hand, solar photovoltaic (PV) and wind energy exhibit the lowest demand for water (although high water use can be observed upstream during the technology manufacturing phase).

Water for energy in the context of climate change

Water quality across the country is poor in the catchments downstream of areas where coal mining and power plants are situated, and these areas often correspond with the areas of high economic activity and human settlements, resulting in competition for water. The current state of water quality suggests that it would benefit most from weighted consideration of the aggregate or cumulative impact of economic activities and choices for the national energy mix.

Energy planning will further need to take into consideration the likely impacts of climate change on water resources in order to mitigate negative impacts of energy resources, both for other users of water resources and for shares of various energy technologies in the energy mix. Energy technologies with low carbon emissions and water demands can be allocated higher shares to achieve sustainability. Recent developments in the energy sector (including the REIPPPP, natural gas pipeline development, shale exploration, potential nuclear build and the National Biofuels Strategy) indicate the potential further impacts of the future energy mix on water resources.

Policy and regulation for the water and energy nexus

It is helpful to examine energy and water policy from the perspective of individual energy sources or technologies as well as at a systemic level – including how energy demand is managed and planned for, the water efficiencies of the energy mix, and the incentives to decision-makers when responding to future national energy needs. The Integrated Resource Plan (IRP) in SA takes water scarcity into account and demonstrates an awareness of the trade-offs. However, beyond that awareness, there is little information indicating the water impacts over the full lifecycle of energy production, and tools are not available for analysis, to assist decision-makers. As a result, the awareness of trade-offs is not efficiently operationalized.

Spatial representation of the trade-offs between water and energy

The demand for water varies with the type of energy technology. However, the spatial distribution of energy resources availability does not coincide with that of water resources. Some areas with suitable renewable energy resources do not have adequate water resources to support the deployment of the relevant energy technologies. So, the water efficiency of specific energy resources should be considered when deciding which energy technology to deploy in a given location.

Scenarios of energy supply and associated water demands

There is a projected general increase in the generation of electricity between 2030 and 2050 under all the eleven investigated scenarios. In spite of this trend, the usage of water decreases for all the scenarios except for the Higher Nuclear Cost scenario. The Big Gas scenario exhibits the lowest demand for water in both time periods. It is also observed the share of renewable energy in the generation of electricity, for all scenarios but the Restrained Learning Rate scenario, also rises between 2030 and 2050. A higher share of renewable energy, especially solar PV and wind, may assist in reducing the demand for water in the energy mix.

Trade-offs between water use efficiency and renewable energy

Second-generation biofuel, solar PV and wind technologies exhibited win-win situations from the perspectives of energy, water and climate change.

Decision support framework for the water-energy nexus

Policy, regulatory and institutional instruments play a vital role in the management of the energy-water nexus. Due to the interdependence of the two resources, it is necessary to plan the exploitation of the energy and water resources in an integrated manner to enhance synergy.

The decision-making environment for the energy-water nexus is influenced by technological, political, regulatory, economic, environmental and social factors at various levels (local or national). In this study, a decision support framework has been proposed. The framework outlines guidelines/considerations for assessing the viability of an energy project from a water perspective. The quantity and quality of available water have been taken into account as a way of averting negative socio-economic and environmental impacts.

Conclusions

Renewable energy choices and water requirements in South Africa

The demand for water varies with the type of energy technology. Conventional fuels (such as nuclear and fossil fuels) withdraw significant quantities of water over the life-cycle of energy production, especially for thermoelectric power plants operated with a wet-cooling system. Some renewable energy technologies are also water-intensive (for example hydro and irrigated biomass). On the other hand, solar photovoltaic (PV) and wind energy technologies demand the lowest amount of water. Hybridization of PV and wind technologies can assist in countering the intermittency nature of solar and wind resources as well as reducing the water demand.

Water for energy in the context of climate change

The quality of water is adversely affected (such as acid mine drainage) in some parts of the country due to the exploitation of coal. Moreover, coal power plants contribute to climate change. Consequently, it is imperative to have an energy mix that assists in minimizing negative impacts on the environment. Increasing the share of renewable energy is one way of mitigating climate change but energy planning needs to take into consideration the constraint of water resources in the country.

Policy and regulation for the water and energy nexus

The IRP in SA takes water scarcity into account and demonstrates an awareness of the trade-offs. Nevertheless, there is limited information indicating the water impacts over the full lifecycle of energy production. Analytical tools are also scarce to assist decision-makers. In this study, a policy framework has been proposed to enhance harmonisation of policies linked to water and energy. The proposed framework takes into account the vertical and horizontal linkages of relevant strategies/policies to promote synergy.

Spatial representation of the trade-offs between water and energy

The type, quality and quantity of the required water resource vary with technology type. Some technologies (such as solar PV, wind and dry-cooled CSP) are more water efficient than others (wet-cooled thermal power plants). It is, therefore, necessary to consider trade-offs that are likely to be made when deciding to deploy a particular technology in a given location.

Scenarios of energy supply and associated water demands

The long-term energy scenarios reported in the IRP are water efficient, except for the Higher Nuclear Cost scenario. Solar PV and wind can assist in reducing the demand for water in the energy mix.

Trade-offs between water use efficiency and renewable energy

Trade-offs between water use efficiency and renewable energy are influenced by the type of energy technology deployed. In this vein, the second generation biofuel, solar PV and wind technologies have the potential to be sustainable from energy, water and climate change standpoints.

Decision support framework for energy and water resource choices

Policy, legal, planning and institutional instruments affect the management of the energy-water nexus. Due to the interdependence of energy and water, it is necessary to plan them in an integrated manner to enhance synergy.

Recommendations

Energy choices and associated water requirements

- There is the need to collect systematic data on water requirements along the energy production chain within the boundary of SA.
- PV, wind and dry-cooled CSP technologies can be considered to be viable renewable options in terms of water withdrawal and consumption.

Water for energy in the context of climate change

- Plans for the energy production chain need to take into consideration a water component to achieve sustainable provision of both energy and water.

Policy and regulation for the water and energy nexus

- There is a need to take on board uncertainties (such as rising fuel costs, the quality and extent of fuel reserves, volatility in commodity prices, rising operational cost and water scarcity) in planning.
- There is a necessity for aligned and/or compatible policies and regulations, as well as cooperation between various governing institutions.

Scenarios of energy supply and associated water demands

- Trade-offs between energy resource choices and their associated water requirements over a long-term horizon need to be analysed in order to give a clearer picture of the balance between to ensure a supply of water for energy generation in the context of water scarcity and climate change.

Decision support framework for energy and water resource choices

- It is necessary to augment information about water impacts, and to develop tools for facilitating the decision-making process to enable achievement of a resilient energy economy.
- In light of the spatial differences in the location of energy and water resources, it is essential to take into consideration the water use and impacts over the entire lifecycle and project lifespan during the energy planning process.

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ACDI	African Climate & Development Initiative
AD	Advanced Decline
AMD	Acid mine drainage
bbl	barrel
BG	Big Gas
CB	Carbon Budget
CCAM	Conformal-Cubic Atmospheric Model
CCGT	Combined Cycle Gas Turbine
CCS	carbon capture and storage
CdTe	cadmium telluride
CE	Constant Emission
CEF	Central Energy Fund
CHDM	Chris Hani District Municipality
CH_4	methane
CMA	Catchment Management Agencies
CO_2	carbon dioxide
CPV	concentrated photovoltaic
CSAG	Climate System Analysis Group
CSIR	Council for Scientific and Industrial Research
CSP	Concentrating Solar Power
CT	Carbon Tax
CTL	Coal to liquid fuel
DBSA	Development Bank of South Africa
DEA	Department of Environmental Affairs
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DoE	Department of Energy
DPE	Department of Public Enterprises
DSM	Demand-side management
DTI	Department of Trade and Industry
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation

EDC	Endocrine Disrupting Compounds
EEA	European Environment Agency
ERC	Energy Research Centre
EU	European Union
fa	fuel acquisition
fp	fuel processing
FBAE	Free Basic Alternative Energy
FBE	Free Basic Electricity
FIB	Friedenheim Irrigation Board
FIT	Feed-In Tariff
FT	Fischer-Tropsch
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GJ	Gigajoule
GW	Gigawatt
GWh	Gigawatt hours
HC	High Coal cost
HN	High Nuclear cost
IBT	Inclined Block Tariff
IEA	International Energy Agency
IEP	Integrated Energy Plan
IEPR	Integrated Energy Policy Report
IGCC	Integrated Gasification Combined Cycle
IPIC	Interdepartmental Project Implementation Committee
IPP	Independent Power Producers
IRP	Integrated Resource Plan
ISRDP	Integrated Sustainable Rural Development Programme
IWUL	Integrated Water Use Licences
K2C	Kruger to Canyons Biosphere
kW	kilowatt
kWh	kilowatt hour
L	litre
LCA	Life cycle analysis
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LTAS	Long Term Adaptation Scenarios

MAP	Mean annual precipitation
MAR	Mean annual runoff
MD	Moderate Decline
ML	Mega litre
MPRDA	Mineral and Petroleum Resources Development Act
MW	Megawatt
MWe	Megawatt electricity
MWh	Megawatt hours
m^3	cubic metre (1 m^3 =1 000 L)
NBI	National Business Initiative
NCCRP	National Climate Change Response Policy
n.d.	not dated
NDP	National Development Plan
NECSA	Nuclear Energy Corporation SOC Limited
NEEAP	National Energy Efficiency Action Plan
NEES	National Energy Efficiency Strategy
NEMA	National Environmental Management Act
NEMWA	National Environmental Management Waste Act
NERSA	National Energy Regulator of South Arica
NGP	New Growth Plan
NPC	National Planning Commission
NPC NDP	National Planning Commission National Development Plan
NWA	National Water Act
NWP	National Water Policy
NWRS	National Water Resources Strategy
NWRS2	National Water Resource Strategy 2
N_2O	Nitrous oxide
OCGT	Open Cycle Gas Turbine
OTEC	Ocean Thermal Energy Conversion
pc	plant construction
pd	plant decommissioning
pg	power generation
PJ	Peta Joules
PPA	Power Purchase Agreement
PS	Pumped Storage
Pt	power transmission

PV	Photovoltaic
R&D	Research and Development
REPPP	Renewable Energy Power Producer Programme
RE	Renewable Energy
REDZ	Renewable Energy Development Zone
REE	Rare Earth Elements
REFIT	Renewable Energy Feed-in Tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RL	Restrained Learning rate
RSA	Republic of South Africa
SA	South Africa
SADC	Southern African Development Community
SANEDI	South African National Energy Development Institute
SAPP	Southern African Power Pool
SEA	Strategic Environmental Assessments
SEI	Stockholm Environment Institute
SIP	Strategic Integrated Projects
SP	Solar Park
TDP	Transmission Development Plan
TJ	Tera Joules
TWh	Tera watt-hours
TWQR	Target Water Quality Range
UNEP	United Nations Environment Programme
UNFCCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VRESAP	Vaal River Eastern Sub-system Augmentation Project
WBCSD	World Business Council for Sustainable Development
WCCS	National Climate Change Strategy for Water Resources
WESSA	Wildlife and Environment Society of South Africa
WGDF	Water for Growth and Development Framework
WMA	Water Management Areas
WWF	World Wide Fund for Nature
WRC	Water Research Commission

1. INTRODUCTION

By: Sparks D, Moorlach M, Madhlopa A, Keen S

1.1. Background

Conventional water use and energy supply are inseparably linked. Energy is needed to pump, treat or transport water. Water is required in fossil fuel extraction and processing, the running of hydroelectric turbines, biofuel production, cooling of thermal power plants and other processes in the entire energy production chain. The mutually dependent nature of the relationship between energy and water means that neither resource should be addressed in isolation, hence the term the water-energy nexus.

Access to secure and reliable water and to energy supplies are essential for sustainable development and for poverty alleviation (United Nations 1998). These priorities are all the more important for South Africa (SA) as a water scarce country, and the Constitution endows each household with the right to 6 000 litres of free water and 50 kWh of electricity per month. While water resources in SA are said to offer opportunities for the economy and much needed employment creation (Odendaal 2013), the country is the thirtieth most water scarce country in the world (Department of Trade and Industry 2013). Limited water supplies mean that commitment to the growth of some economic activities will invariably be at the opportunity cost of others.

SA's National Water Act (Act 36 of 1998) is considered to be highly progressive (Seward 2010), however, much of the electricity production in the country consumes substantial volumes of water. The country has a recent history of energy shortages, electricity blackouts in 2007, 2008 and 2015, petroleum shortages in 2008 and 2011, and gas shortages in 2011 and 2012. Increasing the output of energy using the current production methods will increase the energy demand for water and may involve some opportunity cost to the detriment of other economic activities, communities or watersheds.

To meet the projected energy needs of SA, the Department of Energy has developed plans and strategies which encourage the diversification of the energy supply from the current primary reliance on coal-fired electricity, to an energy mix in which a third is generated from renewable resources (DoE 2011). Furthermore, to meet this goal, the government is currently offering incentives for investment in renewable energy technologies. This will help meet the objectives set out in the National Climate Change Response Strategy, which aim to meet South Africa's international commitment to reduce greenhouse gas emissions by 34% below business as usual by 2030.

Climate change is expected to put added strain on water provision due to projected changes in seasonal and regional temperature patterns of precipitation (Hoekstra *et al.* 2011; Wilson *et al.* 2012). This places additional stress on water and energy planning in that the impacts of climate change are uncertain and variable across the region (DEA 2013). The imperatives of water and energy provision in the context of a growing economy are factors that should be taken into consideration in designing a national energy mix, hence, the motivation for an assessment of the water use and impacts of various energy technologies, and especially renewable energy technologies in support of planning for water and energy. This will help to inform energy and water policy with the vision of facilitating a conducive policy environment.

In light of the planned changes to the energy supply technologies, and with the risk of increased water vulnerability due to climate change, it is important that the country's water and energy policies take cognisance of one another without conflict. This will enhance policy implementation and inform strategic investment in future energy supply. For these reasons, it is necessary to assess the demands that might be placed on the country's water resources in the context of changing energy requirements and water availability.

1.2. Rationale

SA is an arid, water-stressed country with water resources that are increasingly being placed under pressure. The demand for water is rising due to population and industrial growth, with numerous economic activities competing for this limited resource. Consequently, efficient use of water by various economic sectors (including the energy sector) is important to achieve sustainability. It is perceived that the onset of climate change may aggravate the scarcity of water.

Climate change is one of the global challenges of the present century. Previous studies show that anthropogenic activities are generating greenhouse gases (GHGs) and energy consumption is the main contributing factor to this environmental problem (Akhmat *et al*. 2014). The burning of fossil fuels (coal, oil and gas) is contributing to increased levels of the concentration of GHGs in the atmosphere. Most of the electricity in SA is generated by coal-fired thermal power plants (Telsnig *et al*. 2013). Nevertheless, the heavy reliance on this type of fuel is contributing to high carbon emissions. Consequently, the country is making policy and regulatory shifts to mitigate climate change, and renewable energy is being promoted to achieve a sustainable energy supply (DME 2003). Apparently, the demand for water varies with the type of renewable energy technology being deployed. It is, therefore, necessary to consider the impacts of the renewable energy choices on water resources, and several issues need to be examined in order to comprehend the water footprint of energy production in SA. Firstly, due to the large gap that exists between water supply and demand in the country, understanding the trade-offs in water allocation between different users and the policy decisions is critical. Secondly, allocation of additional water for biofuel production will require a shift in the current water allocation policy, with significant implications on other water users.

1.3. Objectives

The main objective of this project was to investigate trade-offs between water use efficiency and renewable energy in SA while the specific objectives were to:

a) Investigate renewable energy choices for SA and their water requirements.
b) Investigate the degree to which the SA policy and regulatory instruments enable integrated approaches to long-term energy and water resource choices that could promote climate resilience.
c) Recommend a policy framework that links efficient water use and energy production under changing climate conditions.
d) Determine challenges and opportunities which could inform policies and planning geared towards initiatives that enhance the climate change adaptation capacity of people living in areas under climate-related water scarcity, by using adequate renewable energy technologies.
e) Map out renewable energy supply sources and overall energy demand over a long term planning horizon that is appropriate.
f) Assess the tradeoffs between resource choices (renewable energy production and the efficiency in water use within parameters of adaptation to climate change).
g) Develop and adapt a scenario framework (or toolbox) designed to reflect various renewable energy sources and water demand to ensure balanced and efficient water use in SA.

1.4. Methodology

While the water-energy nexus is part of the wider water-energy-food nexus (relevant in the context renewable energy technologies for biofuels, and in some cases hydropower), this report focuses on water requirements for energy production, and the associated water impacts. The energy usage associated with water supply and sewerage disposal falls outside the scope of the objectives of this project.

The project had 9 major tasks, as follows:

Task 1: A global literature review, and an investigation into water for generation (and distribution) of energy using different technologies in SA. This task considered renewable energy choices and their water requirements. As a comparison, it also examined the water requirements of conventional energy sources.

Task 2: An overview of current energy policy and regulation in SA, and its consideration or implications for water. In addition, this task included a review of the energy supply chain and the lifecycle of energy production as well as the energy generation technology mix of the national energy system.

Task 3: An overview of the challenges and opportunities to/for adaptation. This task investigated the impacts of current energy choices at a local scale and the development of a more water resilient economy in South Africa. In addition, a review of challenges and opportunities that can inform policies and planning to enhance adaptation to climate change.

Task 4: Development of a Policy Framework. This task aimed at developing a Policy Framework that can enhance harmonisation of policies linked to water and energy. The framework may aid in the development of new policy instruments or the review of existing policy instruments.

Task 5: Preliminary information dissemination through a workshop. The aim of the workshop was providing an opportunity to gather insights into the management of the energy-water nexus from business, national and provincial government, and energy and water practitioners, and researchers.

Task 6: Mapping renewable energy supply and demand, and the associated water requirements. This included determining the spatial trade-offs between resource choices within South Africa in order to give a clearer picture of the balance between the need to increase renewable energy and the need to ensure a supply water for energy generation in the context of water scarcity and climate change impacts.

Task 7: Long term renewable energy mapping and/or scenario building on sources of energy, and the associated water needs, supply and stresses, as well as future climate change impacts. The scenarios that reflect the energy sources and their associated water demand were analysed to ensure balanced and efficient future water use in the country.

Task 8: Developing a decision support tool, and a decision-making framework. This involved developing instrument to enable decision-making for the for the water-energy nexus. This was aimed at allowing some clarity and considerations on the balance between the need to increase renewable energy while ensuring sufficient water supply in the context development and climate change.

Task 9: Further information dissemination through a second workshop. The aim of this workshop was to seek expert input on the instruments developed in Task 8.

2. LITERATURE REVIEW

By: Keen S, Goga S, Laing K, Madhlopa A, Moorlach M, Pegram G, Sauka S and Sparks D

2.1. Introduction

The benefits of efficient management of the water-energy nexus have been understood for some time and many studies contribute to the body of knowledge on the use of water in the energy production chain, from resource extraction and preparation to power generation and beyond. In this assessment, the literature provides useful concepts and approaches to the water-energy nexus are presented. It covers the water intensity of various energy technologies (through reviewing studies on water intensity and use by various energy technologies). Previous findings with respect to policy best practice in the water-energy nexus, and the need to fulfil sustainability requirements, are explored. The current state of water use for energy production in South Africa, and the need for adaptation to climate change are also assessed.

This literature review reveals that there is a lack of research that facilitates comparison of water for energy production in South Africa and that local data is best available only for certain stages of various energy technologies. On the other hand, the research on policy and planning for the energy-water nexus, as well as the impact of climate change on the nexus is emerging.

2.2. Water for energy concepts

2.2.1. Water withdrawal and water consumption

The literature distinguishes between two types of water requirement for energy provision: those of water withdrawal and water consumption. Water withdrawal is the volume of water extracted from the water source that is then unavailable for alternative use. This water may or may not be returned to the source. Water consumed is the volume of water that is permanently removed from the water source or undergoes a change in quality so that it is no longer considered useful as a supply of water. It is not discharged as useful water back into the watershed.

Pegram *et al.* (2011) describes consumed water as equal to "the evaporative loss in a production (i.e. the difference between the water received and the water returned from the facility), any water contained directly in the product (usually a relatively small portion) and water used and made unavailable for future uses (e.g. polluted water) during production". In the context of energy supply, the proportion of water consumed to that withdrawn varies widely depending on energy resource and technology type, as will be described further in the report.

a) Water withdrawal and consumption in different stages of energy technologies

Based on the categories of water use described by Fthenakis and Kim (2010), wherein a given stage (i^{th} stage) of energy production, water is withdrawn, consumed, discharged, and recycled. However, most of the available data in the literature is on water withdrawals and consumption, rather than on water discharged or recycled.

Local (DoE 1983) and international (Gleick 1994; Inhaber 2010; Fthenakis and Kim 2010) studies supplied data for pre-generation and generation water withdrawal and water consumption for coal, nuclear, natural gas, CSP, hydroelectric, PV and wind technologies. Data for transportation biofuel were not readily available.

A review of the international literature (Fthenakis and Kim 2010; Wassung 2010; Inhaber 2004) provided a range of data for water withdrawal and consumption over the lifecycle of coal, nuclear, oil and gas fuelled steam, CSP, hydroelectric, PV, wind and geothermal technologies. Again, data for transportation biofuel was not readily available.

b) Cooling technologies

Thermal power stations use various cooling technologies, each with different water use requirements and water impacts. These cooling technologies can be described as follows;

- During wet cooling, the steam in the turbines is condensed as the water flows through the condensers (Figure 2-1). The warm water is then cooled by evaporation as the water is in direct contact with the air; this results in large amounts of water being lost.
- Indirect dry cooling is a similar process to wet cooling, however, instead of cooling the warm water through exposure to air, the water is cooled through internal cooling elements inside the system. As this is a closed system, no water is lost through evaporation. Steam is channelled directly to heat exchangers, and no cooling towers are required.

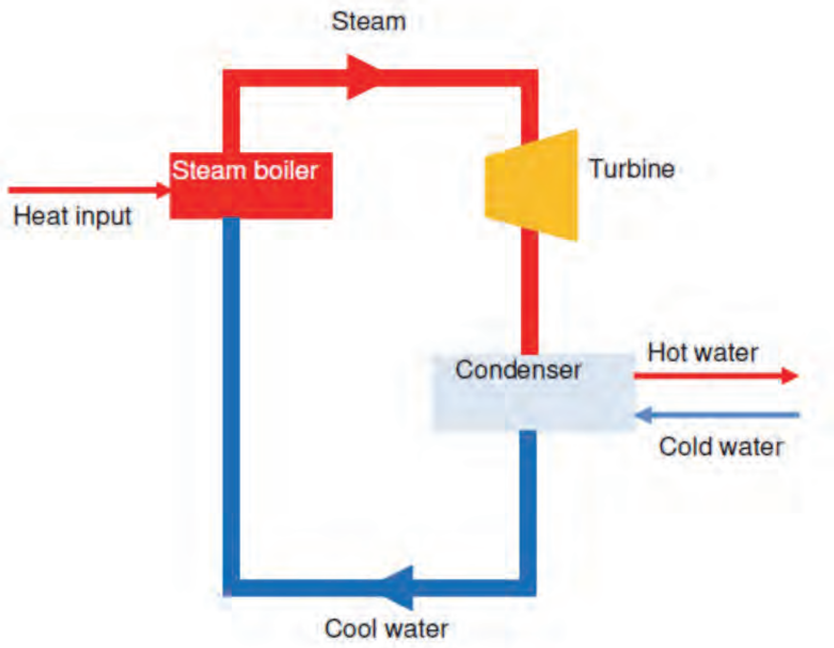


Figure 2-1: Steam power plant with a wet-cooling system.

Pather (2004) reported that dry cooled power stations use approximately 15 times less water than conventional wet cooled power stations. In addition, despite the limitations of dry cooling technology, such as a loss of operational efficiency with an associated loss in revenue, and higher capital and operating costs, this investment is imperative on a national perspective. This is due to the fact that it promotes efficient water use and minimises the impact on water resources through heating and evaporative losses.

2.2.2. Water use in energy production in South Africa

Disaggregated data on water withdrawal and consumption at specific stages of energy production across fuels is scarce. In general, the coal-water nexus has been investigated more extensively than other fuels. Wassung (2010) reported that the energy sector in South Africa uses 2% of the total national water allocation (although the literature provides no methodology as to how this figure is derived). Wassung (2010) also reported that water intensity data (1 534 to 3 326 L/MWh) for coal is comparable to the international consumptive usage (3 460 litres) of water, as reported by Wilson *et al.* (2012).

Data on water usage in renewable energy in South Africa is sparse. Gerbens-Leenes and others (2008) and Stone *et al.* (2010) provide water requirement data for biofuel production. For CSP and PV, data on usage of water in the production of energy in South Africa is scarce. Both technologies are emerging and domestic CSP plants to date are dry-cooled. Olivier (pers. Comm. 2013) reported water consumption for the construction phase of hydroelectric power plants, while G7 Renewable Energies (2013) reported water usage for the construction phase and operation phase for a 120 MW wind power plant, a finding that agrees with Wilson and others (2012) reported water-consumption value of less than 1 L/MWh.

2.3. Tools for analysing water use

Water scarcity and the drive for optimized use have led to various estimations of the amount of water use (withdrawal or consumption) per MWh (or GJ) of energy output. Various approaches have been adopted in this regard. Some of the more common approaches include water footprinting (Hoekstra *et al.* 2011), Life-Cycle Assessment (LCA) and various tools designed to help organizations to understand water use, potential impacts and associated risks.

Various other tools exist for businesses, for example, to understand their water use and impact and associated water risks. These include the World Business Council for Sustainable Development (WBCSD) Global Water Tool, which helps organizations compare their water use, wastewater discharge, and facility information with validated watershed and country-level data. The tool is intended to allow investors and companies from all industry sectors to assess and quantify water-related risks across the globe (WBSCD 2013; WWF-DEG 2011). There are also a number of methods for assessing broader water use impacts relating to scarcity, stress and human health (Boulay 2013).

2.3.1. Life cycle assessment

A life cycle assessment (LCA) framework is a systems analysis tool designed to measure resource use, in order to assess the environmental sustainability of products and services through all components of the value chain (Morrison and Schulte 2010). In terms of water use for energy, it is commonly used to consider ‘cradle to grave’ impacts, and to investigate and evaluate the environmental impacts through all stages of a production cycle.

LCA tools include the ISO 14000 series and the United Nations Environment Programme (UNEP) LCA tool. An LCA is useful for considering the aggregate impact across all stages of the provision of a service or the development of a product. It is not useful to investigate a bounded stage within production, nor impacts within a geographically bounded area.

2.3.2. Virtual water

The concept of virtual water was developed to describe flows of water, not in the conventional fluid water body sense, but as water embedded in traded products, and how this relieves water pressure by, in effect, the import of water (Allan 1997). The concept is useful for discussions of how trade has the equivalent effect of water flowing in or out of an area of water scarcity.

In some of the stages of energy production, water use is bound to a locality (area or region). For example, imported components will, in theory, reduce the need to consume water in manufacturing these components in the country in which they are used. Hoekstra and others (2008) found that the concept of virtual water is especially useful for thinking about the impact of trade on water security, but not for estimating water use within a locality.

2.3.3. Water footprinting

The concept of a water footprint was developed by Hoekstra and Hung (2002), and refined by Hoekstra and Chapagain (2007, 2008) and later by Gerbens-Leens and others (2008). Hoekstra and Hung (2002) describe the three components of a water footprint as green, blue and grey virtual-water. Green water is supplied by precipitation, blue water is abstracted from ground water, surface water or water bodies, and grey water refers to water that has been polluted by human activity, or more specifically as "… the amount of water needed to dilute pollutants emitted to the natural water system during the production process to the extent that the quality of the ambient water remains beyond agreed water quality standards" (Gerbens-Leens *et al.* 2008: 10220).

Gerbens-Leenes and others (2008) utilized this approach in calculations of the water footprint of bio-energy and other primary energy carriers. Water footprinting is a suitable method for measuring the volume of water abstracted and polluted in the provision of goods or services. This tool can be used to increase awareness of water management challenges and to help consumers make informed purchase decisions (Hoekstra *et al.* 2011; Morrison and Schulte 2010).

Fthenakis and Kim (2010) used the water footprinting technique to compare the water withdrawal and consumption across various energy technologies, specifically for the stages of fuel acquisition and preparation, and the stage of generation. They describe water as withdrawn (W_i), consumed (C_i), recycled (R_i), and discharged (D_i) at any given stage of the energy production process (Figure 2-2). They show that water footprinting provides a useful lens to consider water withdrawal versus water consumption, especially as they take into account water impacts along the full supply chain.

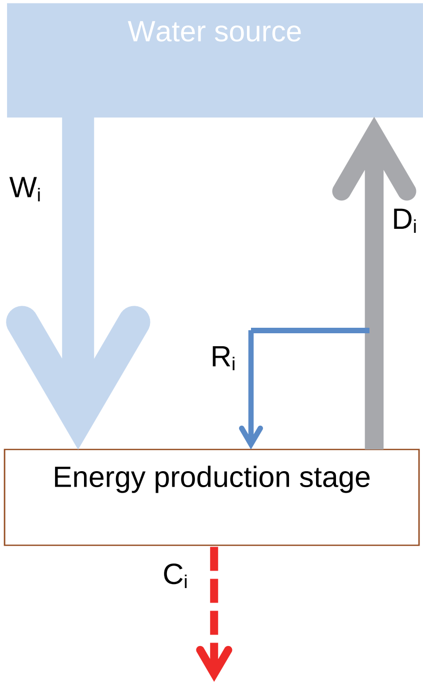


Figure 2-2: The water use in a given stage of the energy production process (Source: Madhlopa *et al*. 2015).

A water footprint is expressed as a ratio of water consumed to a unit of energy produced (i.e. l/MWh). It can, therefore, be used to compare water consumption by the different energy generating technologies as well as water consumption by the same technology across different geographical areas. For these reasons the water footprint method is employed in this study.

2.4. Overview of energy technologies

2.4.1. Coal

Martin and Fischer (2012) found that most of the water consumed for electricity production is associated with coal-fired power stations, which in turn account for 92% of South Africa's electricity generation. The parastatal electricity provider, Eskom, states in its 2013 annual report that it consumes roughly 2% of South Africa's national freshwater resources (334 275 mega litres (ML)) in the seventeen coal-fired power stations that it currently operates (Eskom 2013a; Eskom 2013b). A further two power stations are currently under construction (Medupi in Limpopo, which is partially operational, and Kusile in Mpumalanga).

McCarthy (2011) concluded that the impact of coal (and gold) mining on water is of concern downstream of mining areas. Water is used in many coal mining processes: in the operation of the equipment, in dust suppression, washing and processing the coal as fuel, and rehabilitation of the area once the mine is closed. The volume of water required for washing coal depends partly on the quality of the ore. The sulphur compounds and heavy metals commonly found in coal-bearing rock can contaminate ground or surface water and create a risk of acid mine drainage (AMD), an increasingly serious concern in South Africa.

2.4.2. Carbon capture and storage (CCS)

The CCS technology reduces the emissions of CO_2, methane (CH_4) and nitrous oxide (N_2O) into the atmosphere by capturing emissions from large point sources (e.g. coal power plants). It also, however, decreases the energy capacity and raises water consumption (Wilson *et al.* 2012). A CCS demonstration plant is planned for SA. The cost of this technology is still unattractive to investors and has in some instances been abandoned in other countries (Creamer 2013), putting its future role in SA in doubt.

2.4.3. Conventional oil

EIA (2013) stated that by the end of 2011, SA had proven reserves of 15 million barrels of oil off-shore in the Bredasdorp Basin and off the West Coast of the country, and that the country has the second largest capacity for crude oil refining (484 547 bbl/day) in Africa. There are plans to increase the domestic refining capacity. However, it has not been established whether local reserves are economically viable to extract. Davidson and others (2006) found that a large proportion of the oil consumed in the country is imported from the Middle East and West Africa and is refined locally. The consumption is about 450 000 barrels per day, of which roughly 255 000 barrels are imported. The balance comes from synthetic fuel from coal produced by Sasol, and natural gas from Mossgas.

2.4.4. Natural gas

The EIA (2013) stated that limited reserves of natural gas have been identified in South Africa, but that there is significant potential for shale gas resources (about 137 340 billion litres of technically recoverable shale gas resources in the Karoo Basin, which is in the Western and Central regions of the country). This resource can be extracted through hydraulic fracturing. Nevertheless, Kharak and others (2013) warned that hydraulic fracturing contributes to the contamination of ground water. In this regard, some of the contaminants include methane, benzene and gasoline and the diesel range of organics. Wilson and others (2012) reported that in some cases, well-fed tap water has become flammable due to the presence of these contaminants. Van Wyk (2014) estimated that 20-25 million litres of water may be required to drill one well.

2.4.5. Solar power

a) Concentrated solar power (CSP)

SEA (2009) describes the three technical designs used for CSP: the parabolic trough collector, solar (power) tower and the parabolic dish. CSP designs use mirrors to focus and convert solar radiation into heat, which is transferred to a working fluid. The heat in the fluid is then used to drive the generator and produce electrical power.

a) A parabolic trough collector consists of a linear trough-shaped parabolic collector, which moves around a single axis to follow the sun. Solar radiation is concentrated onto an insulated absorption tube in the centre of the collector and runs the full length of the collector. The collector uses a carrier fluid to transport the collected heat to a storage medium or the turbine.

b) The solar tower uses many mirrors, which all track the sun and move on multiple axes to focus the sun's radiation onto a single receiver point. Like the solar trough, the solar tower uses a working fluid to transport the heat to a storage medium or a turbine.

c) A parabolic dish system consists of one or more parabolic dishes, which concentrate the radiation into a single point. This point can hold a collector, which holds a carrier fluid or a sterling engine, which is in turn coupled to a generator.

IEA-ETSAP and IRENA (2013) reported that CSP plants consume 2 000-3 000 L/MWh. The range within the studies found that CSP plants withdraw 500 to 5 000 L/MWh and consume 300 to 5 000 L/MWh. Volumes are reduced if CSP plants are dry cooled rather than using water to condense steam exiting the turbines. This is, however, less efficient, as compared to wet cooled CSP plants, electricity production is typically reduced by 7% and the capital cost increased by 10% in dry cooled plants (IEA-ETSAP and IRENA 2013). The water impact of CSP plants is relatively low.

b) Concentrated photovoltaic (CPV) and photovoltaic (PV) panels

Photovoltaic (PV) panels convert sunlight directly into electricity by absorbing photons and releasing electrons. These free electrons are captured on an electrode and result in an electric current, which can be used as electricity (SEA 2009). Concentrated photovoltaic technology (CPV) uses (Fresnel) lenses or curved mirrors to focus large amounts of solar radiation onto a small area of a photovoltaic cell to generate electricity more efficiently than traditional PV (Soitec 2013). CPV systems track the position of the sun, which augments the cost of the technology. However, its makers claim that the increased efficiency of CPV offsets the additional cost of cooling and two-axis tracking required to maintain high insolation (Soitec 2013).

Williams (2011) reported that water used in the production of PV can be attributed to two groups of users. The first group comprises the manufacturing plant and its infrastructure, such as water use for HVAC, sanitary use, and landscaping. The second group is the manufacturing process itself where standard and highly purified de-ionized water is used to manufacture PV cells. The water use is associated with removing chemical residues from equipment and rinsing of substrate wafers and panels. Sinha *et al.* (2013) found that half of the life cycle water withdrawal is associated with the manufacturing of the module and the water consumption during the manufacturing of a CdTe PV-cell is a quarter of the water withdrawal. The water consumption is linked to cooling tower evaporation and site irrigation.

Water is also used during the project construction, but no documented values are easily accessible. The water use during generation is linked to the cleaning/washing of the PV-panels, which is aimed at removing dust from the panels to maintain a high level of the transmission of solar radiation. International literature suggests values of 15 L/MWh for CPV and PV (NREL 2002; Fthenakis and Kim 2010). Information is scarce on the frequency of PV-panel cleaning in South Africa. It is likely to depend, in part, on the environment where the system is installed. Frequent cleaning is required in dusty conditions, but the impact of CPV and PV on water is negligible.

2.4.6. Wind power

The generation of electricity by wind energy is through the use of the kinetic energy of the air. A wind turbine extracts energy from moving air and converts it to electrical power. A collection of wind turbines in the same location is a wind farm. Blok (2006) reported that the average annual energy generated on a wind farm typically varies between 0.05 and 0.25 GJ/m^2.

Martin and Fischer (2012) found that a wind power plant with a total capacity of 8.4 MW, requires 1 400 tons of rare earth elements. Every ton of rare earth mineral produced reportedly uses 75 m^3 acidic wastewater and one ton of radioactive waste residue (which contains water) (Hurst 2010).

2.4.7. Hydroelectric power

Globally, hydropower provides approximately 16% of the electricity supply and may be considered a reasonably clean and low-cost renewable source of energy (Hoekstra *et al.* 2011; Mekonnen and Hoekstra 2012). In contrast, hydropower in South Africa accounts for a very small percentage of the total power, at only 2%. Martin and Fischer (2012) note that just under half of this is from run-of-river plants, namely the Gariep (260 MW) and Vanderkloof (240 MW) which are both on the Orange River. Of the remainder, 60% is from pumped storage plants, for example, the Drakensberg (100 MW) and Palmiet (400 MW). Statistics South Africa reports that 4.5% of the country's electricity was imported in 2013 (Statistics SA 2015), a large portion of which will be hydropower imported from the Cahora Bassa Dam in Mozambique, with limited imports from Lesotho and Zambia.

No additional water is used in acquiring or supplying of hydropower. Pegram and others (2011) highlight that despite this, a substantial quantity of water is needed to ensure a constant fuel supply source. Some suggest that no water is used in the process of hydropower generation, since the water used in generation is returned to the water resource and it hence qualifies as in-stream water use. Others argue that evaporation losses associated with the hydropower plant are significant and that hydroelectricity is a significant consumer of water (Hoekstra *et al.* 2011; Mekonnen and Hoekstra 2012). Gleick's (1994) seminal paper on water and energy states that evaporation and seepage are important considerations in hydropower water consumption. He estimated a range of hydropower evaporation values, varying from a minimum of 400 L/MWh, to a maximum of 210 000 L/MWh, with an average of 17 000 L/MWh.

Schulze (2008) reported that in South Africa, evaporation rates vary spatially across the country, to some degree mirroring the geographical annual rainfall distribution. The highest rates are in the North West and Central regions of the country, decreasing eastwards towards the East Coast. Such spatial evaporative losses are important to consider in terms of future planning for hydropower dam placements. Nonetheless, when considering evaporation losses, the size of the reservoir has a larger influence on evaporation than the climate itself, as a deep reservoir with a small surface area will have less evaporative loss than a shallow reservoir with a large surface area.

Pegram *et al.* (2011) argue that it is net evaporation, that is, the difference in evaporation compared with the natural reference condition (e.g. natural vegetation), that needs to be considered, as opposed to total evaporation loss. In New Zealand, Herath and others (2011) found that their values are notably lower than the global averages presented by Gleick (1994) and they highlight the need for taking the local environment into consideration.

Mekonnen and Hoekstra (2012) calculated a blue water footprint loss of $90Gm^3yr^-$, linking this to the evaporation loss associated with the artificial reservoirs created behind hydroelectric dams. They estimated that this is equivalent to 10% of the blue water footprint of global crop production in the year 2000, which they find to be relatively large when compared to other renewable sources of electricity.

Pegram and others (2011) also argue that that hydropower is generally responsible for changing the flow regime, and that this may impact on the environment as well as water availability to users downstream. Conceptually it is also worth noting that a nominal amount of water is used in constructing a hydropower plant (Pegram *et al.* 2011).

2.4.8 Bioenergy

Bioenergy, in the form of wood, agricultural crops, municipal waste and manure, globally contributes 50% of total renewable energy and more than 10% of final global energy consumption. Bioenergy is formed when biomass is directly used as fuel or converted into a secondary energy carrier (solid or liquid fuel or gases) (REN21 2013).

EREN (2000) describes some of the various bioenergy technology applications. Biomass can directly be used as a co-fired energy source during electricity generation. During this process traditional fossil fuels such as coal or natural gas, together with biomass, can be incinerated to generate heat for electricity generation. It can also be traditionally applied by combusting natural biomass in home appliances such as coal or gas stoves. Furthermore, biogas technologies include anaerobic biogas digesters that generate gas for home cooking and heating purposes. The production of ethanol to be used in bio-diesel also goes through various industrial processes, but the final technology application is in vehicles as fuel.

Water use in the production and application of bioenergy varies. Dominguez-Faus and others (2009) estimated that ethanol production from corn requires from 2 270 000 to 8 670 000 L/MWh, whilst soybean-based biodiesel pre-generation and generation utilize between 13 900 000 and 27 900 000 L/MWh compared to the 10 to 40 L/MWh required for petroleum extraction. Closer to home, de Fraiture and others (2008) reported that South Africa uses approximately 416 million litres of water per annum to produce sugarcane for bioethanol production, which is equivalent to 9.8% of total irrigation that is directed at biofuels production. This is a significant amount for a water-stressed country.

The global production of bioethanol from grain and sorghum consumes the highest quantity of water compared to other feedstock. In contrast, sugar cane appears to have the lowest water footprint in ethanol production. Stone and others (2010) explained this wide disparity by arguing that only the grain in the corn is used to produce ethanol, whilst the rest of the crop, that is, the lignocellulose materials (i.e. leaves, stalk and stem) are not utilised in the process. Furthermore, the authors indicate that sugar cane and corn have different photosynthetic processes, which could, in part, explain their dissimilar water requirements (Stone *et al.* 2010). Soybean is considered to be water inefficient in that it requires very high quantities of water for irrigation and even more for the actual production of biodiesel. This is in agreement with Jones' (2008) findings that over 180 000 litres of water would be required to generate sufficient amounts of biodiesel from soybean to power a household for a month.

While authors concur that in some regions, rainfall meets the irrigation requirements of the production of biofuel feedstock, they readily admit that the production of biofuels will continue to compete for limited water stocks in many countries and that this will put additional pressure on limited natural resources for agricultural production (Dominguez-Faus *et al.* 2009; de Fraiture *et al.* 2008; Stone *et al.* 2010). de Fraiture *et al.* (2008) warns that a low carbon economy focused on bioenergy may come at a price to water resources, such as in the case of the USA, where pressure on water resources is exacerbated by the government requirement to produce 57 billion litres of ethanol from corn by 2015 (de Fraiture *et al.* 2008).

2.4.8. Nuclear power

South Africa has one nuclear power plant in operation, namely the Koeberg Nuclear Power Station, in the Western Cape. It was designed and built by a French company, Framatome (now Areva), and commissioned in 1984-85. The Koeberg nuclear plant has a capacity of 1 800 MWe in its two 900 MWe pressurised water reactor technology systems (World Nuclear Association 2013).

A nuclear power plant uses low enriched uranium, as a source of fuel to produce heat during a nuclear reaction process called "fission". Fission is the process of splitting the nuclei of atoms into smaller particles such as protons, electrons and neutrons. The reactor has components for controlling the fission process to avert excessive heat generation. Energy is generated in the reactor and it heats up water, which co-produces steam and drives a turbine. The turbine is connected to a generator, which ultimately produces electricity. The fission process of uranium is used as a source of heat in a nuclear power station in the same way that the burning of fossil fuels (coal, gas or oil) is used as a source of heat in a fossil fuel power plant, only the fission process is far more efficient. The World Nuclear Association, Nuclear Fuel Cycle Overview (2013) estimated that to produce 44 GWh of electricity, it would take one tonne of uranium, or more than 20 000 tonnes of black coal, or 8.5 million cubic metres of gas.

Ocean water cooled nuclear power plants, like Koeberg, consume water by evaporation when the warmed cooling water is discharged to the ocean (Jury and Bain 1989). The elevated temperature of the discharged water may affect the ecosystem at the discharge point.

2.5. The sustainability of water use in energy production in South Africa

The national Department of Water Affairs and Forestry (DWAF), (now known as the Department of Water and Sanitation (DWS)) reported that the country has one of the lowest rates of Mean Annual Precipitation (MAP) to Mean Annual Run-off (MAR) in the world, and that only 9% of rainfall enters the rivers, compared to a global average of 31% (DWAF 1997). This means that a low amount of rainfall is converted to runoff, which can be used by water users, such as the energy sector. This necessitates that all industry, including those in the energy sector, to use water efficiently. Although the sustainability and water use efficiency of thermal power plants, including coal plants, is improved by implementing dry cooling systems, it is at a cost to the energy efficiency of the plant.

The CSIR (2010) reported that fossil fuel processing in South Africa contaminates water and soil, specifically coal, extraction and processing. Botes and others (2010) have highlighted acid mine drainage (AMD), to which coal is a major contributor, as an environmental threat to aquifers. AMD contamination results in low pH and elevated concentrations of heavy metals and other toxic elements.

In contrast, an assessment of the literature revealed some renewable energy technologies (such as solar photovoltaic and wind energy) have low demand for water in terms of withdrawal and consumption. Moreover, the observed water usage in solar photovoltaic technologies is predominantly upstream in the construction of the plant and, or components (Environment Canada 2010). Consequently, the development of the renewable energy sector can provide an opportunity for reduced and efficient use of water within the energy sector.

Most of the energy generation and transmission in South Africa is driven by the electricity parastatal, Eskom, which generates in the region of 90% of the electricity in the country (Bischoff-Niemz 2015). Statistics South Africa analyses in the “Energy Accounts for South Africa” reports indicate that the South African economy and domestic sector depend on energy provided from coal for electricity as a primary fuel, followed by petroleum products and crude oil (Figure 2-3). Other sources of energy are also used, although to a smaller extent; these include gas, hydroelectric power, nuclear power, and other renewable energy sources (which include resources such as biomass, wave, wind and solar power). Winkler (2006) reports that municipality and private auto-generators contribute 0.6% and 3.5% respectively to national electricity supply. Economic growth is perceived to be unsustainable if it demands a lot of energy, generates significant pollutants, and negatively affects public health (Abdallah *et al.* 2013).

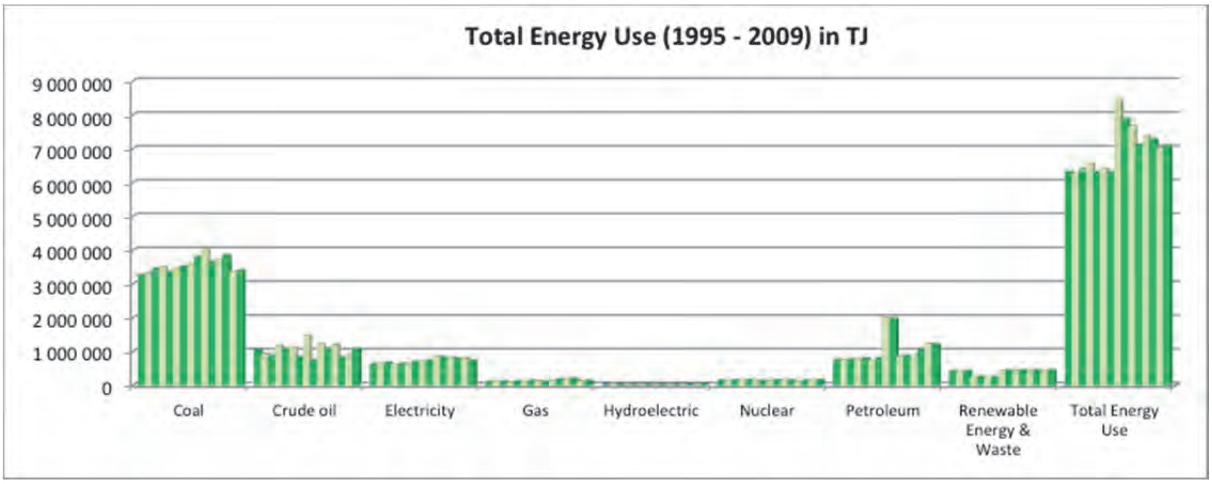


Figure 2-3: Energy resources in South Africa (1995-2009).

The country has enjoyed relatively low electricity prices, however, Winkler (*ibid*) found that these prices do not reflect the true costs of largely coal-based energy generation. This is due to the failure to account for the value of the inputs and the full capital costs, as well as the failure to price the externalities. This creates concerns for long-term financial sustainability.

Further studies (WWF 2010, von Horen 1996) observe that South Africa cannot continue to rely on coal without serious negative impacts on the society, environment and economy. On the other hand, renewable energy has lower carbon emission and can provide an unlimited energy supply.

Other benefits of renewable energy technologies are wide-ranging. Platonova and Leone (2012) reported that renewable energy technologies have the potential to improve water services through solar water heating, small-scale pumping and water purification and treatment in off-grid areas. The DTI (2010) reports that economic and socio-economic opportunities include tax exemptions through the UNFCCC's clean development mechanism (CDM), community benefits from access to energy via renewable energy projects, and long-term employment in renewable energy projects among others.

Ogola and others (2012) found that renewable energy can also contribute to climate change mitigation and adaptation strategies, while Pegels (2010) found that challenges, including financial, technical, policy and other barriers hinder the uptake of renewable energy technology. At a smaller scale, King and others (2011) encourage proposals to enhance local co-benefits from water and energy system technologies, for example in the use of solar water heating to reduce energy costs and, at the same time, enhance water availability and reduce flooding risks by means of a diffuse rainwater harvesting system connected to the solar heaters in urban areas (King *et al.* 2011).

2.5.1. Water-energy policy and planning: sustainability requirements

Studies reviewed by Glassman and others (2011) have highlighted the need for careful forethought to balance trade-offs at both the national and more local level in management of the water-energy nexus. They concur that energy-water planning should occur within an integrated planning environment, and that while water resource planners understand the water demands of electricity generation, there is increasingly a need to account for climate change impacts on water supplies, and also the need to assess the role of climate in changing behaviours in the electricity system.

Many problems that involve energy and water require a tightly coupled understanding of the co-dependency of these systems. Jeffers (2013) proposed that a holistic and integrated approach to water-energy planning facilitates consideration of all criteria within these co-dependent systems, and that this facilitates more economically and environmentally equitable solutions, and that it provides insight for implementation of solutions. The finding that there is the need to integrate water and energy planning and decision-making echoes conclusions in Gleick (1994). Nevertheless, despite the longstanding recognition of these challenges, SEI (2012) found that a lack of suitable tools has hindered efforts to address key questions about the water-energy nexus.

Sustainable economic development in South Africa would need to include water scarcity in planning its energy strategy, across all energy-generating technologies. However, some of the country's richest energy resources are to be found in already water-stressed catchments. For instance, the Northern Cape region and the Karoo are two of the country's driest areas, with the best solar resource suitable for concentrated solar power generation (Pierce *et al.* 2013), and potentially lucrative shale gas reserves respectively.

The importance of integrated planning is well recognized within the policy landscape in South Africa. The National Water Policy Review by the DWA states that 'a close look at the water-energy nexus is critical for South Africa's sustainable development path', and that the 'current policy and legislative provisions on trading of authorised water use do not facilitate the achieving of one of the fundamental principles of the Act, namely equity in allocation' (DWA 2013). It is deemed important that the water and energy policies should take cognisance of one another, or at the very least, not be in conflict with one another.

The main guiding principles for renewable energy development are of equity (inter- and intra-generational), and of consideration of all the social, economic and environmental costs (DME 2003). These principles are complementary to principles for sustainable development, as is the ‘polluter pays’ principle for the environment under the National Environmental Management Act 107 of 1998 (Winkler 2006). Munnick and others (2010) point out that principles guiding energy policy include the principles of supplying energy at the least cost and that of ‘use it or lose it’. These potentially conflict with sustainability principles. Specific critical analysis of the current integrated energy planning process recommends more comprehensive criteria for evaluation of energy scenarios and plans (WWF 2010).

2.5.2. Water for energy in the context of climate change

Due to human activities, excess quantities of greenhouse gases (GHGs) are being emitted into the atmosphere. The primary gas involved is carbon dioxide (CO_2), which is predominantly released during the transformation and combustion of fossil fuels. CO_2, methane (CH_4) and nitrous oxide (NO) all contribute to climate change. Although it is natural to find these gases in the atmosphere, excessive concentrations of them is of concern (Winkler 2005).

The case for anthropogenic climate change is strong, and global efforts have been made to reduce the risks. One of the main global organisations involved in mitigating climate change is the United Nations Framework Convention on Climate Change (UNFCCC), with its primary objective of preventing “dangerous” human interference with the climate system (UNFCCC 2014). Although the efforts of the UNFCCC in mitigating climate change have been in many ways successful, the reality is that climate change will continue, However, the level of impact is still uncertain. Climate change is associated with potential increases in natural disasters, such as extreme droughts and excessive floods. Extreme droughts serve as a reminder that water is a limited commodity that should be closely monitored. In this regard, it is important to take into account the impact of climate change on water resources when planning various economic activities of a country, including the provision of energy.

Previous studies show that anthropogenic activities are generating GHGs and energy consumption is the main contributing factor to this environmental problem (Saikku *et al.* 2008; Akhmat *et al.* 2014). In particular, the burning of fossil fuels is increasing the concentration of GHGs in the atmosphere. This is exacerbated by population and industrial growth which is increasing the demand for energy. Moreover, these resources occur in finite quantities, and so will eventually be depleted.

Energy is the main driver of an economy, and economic growth is perceived to be unsustainable if it demands a lot of energy, generates significant pollutants, and negatively affects public health (Abdallah *et al.* 2013). Energy security is an important factor to consider when planning energy supplies to meet specific demand levels. Properties of energy security include stability, flexibility, adequacy, resilience and robustness (Gracceva and Zeniewski 2014). An energy supply chain needs to have all these properties to be secure. For instance, the fact that there are limited reserves of fossil fuels renders them insecure. Exploitation of renewable energy can, therefore, contribute, not only to the mitigation of climate change, but also energy security. The inclusion of renewable energy in the energy mix requires proper planning in order to achieve the desired outcomes.

Water plays a vital role in the production chain of energy, as shown in Figure 2-4. It is used in fuel acquisition (fa) and processing (fp), plant construction (pc), power generation (pg), power transmission (pt) and plant decommissioning (pd). At each stage of the energy production chain, a volume (W) of water is withdrawn from a reservoir. Part of this quantity of water may be consumed (C), recycled (R) or discharged back into the reservoir (D). For example, water is required during mining, processing and transportation of coal, while thermoelectric power plants need water for steam generation and wet-cooling during electricity generation. So, the demand for water would increase with the amount of energy produced, depending on the energy technology option. Fossil fuels withdraw a large volume of water over the life-cycle of energy production, especially thermoelectric power plants operated with a wet-cooling system (Fthenakis and Kim 2010).

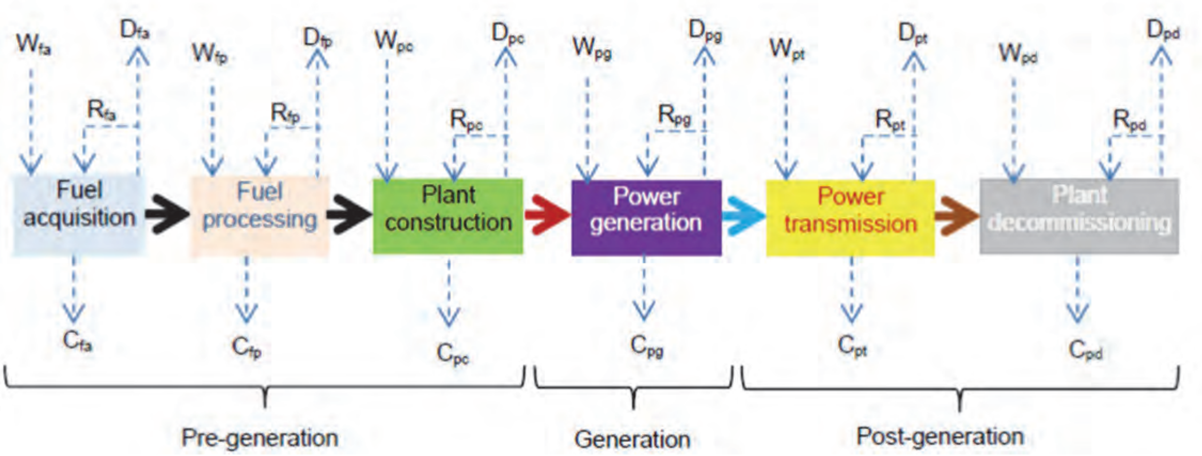


Figure 2-4: Energy production chain.

The concern for water demand in the energy production chain is significant in regions with limited water resources. Moreover, it is reported that climate change will affect water availability, with some areas experiencing a reduction in the water supply (Charlton and

Arnell 2011; Kiem 2013). In view of this, there has been growing interest in assessing water requirements for energy production, and energy scenarios analysis, as discussed in Section 2.6, can play a vital role in this direction. Platonova and Leone (2012) found that while the body of research on climate change and water and the relationship between water availability and renewable energy for development has been growing, not enough has been done to integrate research on climate change, water and energy at the local level. This is particularly true for researchers in developing country institutions. Siddiqi and Anadon (2011) reflected that while the world is facing challenges of climate change, there is also rising demand for water and energy in the context of increasing energy insecurity and water scarcity, and that the intertwined dimensions of the water-energy nexus are drawing attention through new research, policy and public debate.

In Southern Africa, the energy sector is growing, fuelled by coal-based power plants located mainly in South Africa, Zimbabwe and Botswana. These regions are increasingly under stress due to climate change, such as overall temperature increase and projected decline of rainfall. As a result of climate change, East and Southern Africa countries are expected to experience rising temperatures and increased variability of rainfall leading to more severe droughts, floods and heat waves (Platonova and Leone 2012), which will impact the amount of water available and intensify the competition for available water resources. This is coupled with anthropogenic factors, such as land-use changes and growing population pressure, which will place additional pressure on water and energy resources.

2.5.3. Water quality of river basins in South Africa

Ashton (2009) provides an overview of the water quality situation in South Africa and a summary of the water quality of all the major river basins in the country, and the distribution of the different types of natural and human-induced effects on water quality across the country (Ashton 2009). In addition, Maree (2010) described the regions of major sources of pollution in SA. Section 5.4.2 provides an overview of the water quality in South Africa.

2.5.4. Climate change, water and long-term adaptation scenarios

The Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) study was initiated by the national Department of Environmental Affairs (DEA) to develop adaptation scenarios under plausible climate conditions in South Africa found that the impact of climate change on South Africa is likely to be complex, with some areas more affected than others (DEA 2013). In the scenario modelling phase the LTAS identified six climate zones, grouped according to their climate and hydrological characteristics. As discussed in Section 5.4.3, each of these zones is driven by distinct climate systems, ranging from the mid-latitude cyclones interacting with the South Atlantic High in the West, through the tropical temperate troughs interacting with the continental heat low in the central parts, to the South Indian High and tropical cyclones in the East.

2.6. Scenarios analysis

Scenarios are commonly used in studies of uncertain futures. They are theoretical propositions that describe future possible pathways, and are important tools for decision-making that deals with choosing options under specific hypothetical situations. Scenarios aim at: (a) modifying the way of thinking, and creating a common vision; (b) supporting the process of decision-making; (c) managing risk and uncertainty; and (d) learning and understanding (Ravindra and Iyer 2014). It is important to remember that scenarios do not attempt to predict events but provide alternative futures and their connections (Mannermaa 1991; Kahanem 2012).

Scenarios commence by examining the present state and go on to give a final state in the future at a fixed time horizon. In order to have a meaningful comparison, the time scales need be chosen in conformity with the existing future scenarios pertaining to development plans or climate change models (Promper *et al.* 2014). There are many examples in the literature which support the time periods chosen in this study. For example, Saisirirat *et al.* (2013) analysed the penetration rate of electric vehicles in Thailand, using a time period of 2010-2030. de Marco *et al.* (2014) also set a time horizon of 2030 to estimate crown defoliation of twelve tree species in Europe, under three climate and one nitrogen scenarios, while Promper *et al.* (2014) chose three different time periods (2030, 2050 and 2100) to investigate landslide risk scenarios in Austria.

Scenarios analysis finds application in planning energy and other public service systems where several options and situations may exist. Planning of energy needs a proper balance between the supply and demand of energy in a given locality or region. For instance, Raele *et al.* (2014) investigated the scenarios for second-generation ethanol in Brazil. Their work contributed scenarios that can be used in the development of public policy and as a tool for decision-makers working in the energy sector.

Scenarios analysis has been extensively used to map out and understand options for mitigation of climate change. The Long Term Mitigation Analysis study (ERC 2007) developed a scenario framework for long-term mitigation of climate change. It comprised five possible pathways: Growth Without Constraints, Current Development Plans, Can Do, Could Do, and Required by Science (see Figure 2-5), which makes it evident that the Growth

Without Constraints pathway leads to a dramatic rise in carbon emissions, with the Required by Science pathway being the lowest.

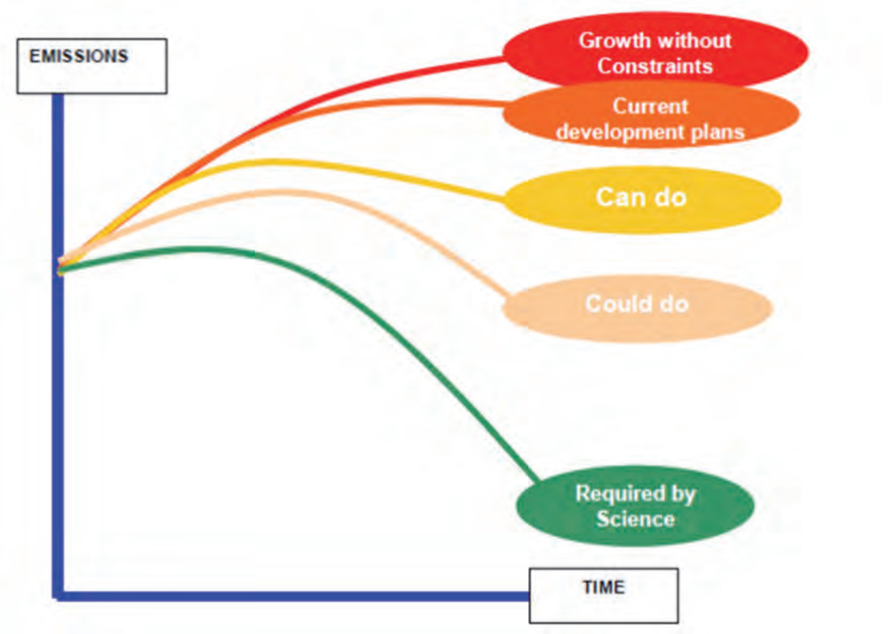


Figure 2-5: Scenarios framework for mitigation of climate change in South Africa. (Source: ERC 2007).

Similarly, Ravindra and Iyer (2014) developed a scenarios framework for identifying and assessing the impact of different decentralised energy options at a community level. They applied the proposed framework to an urban residential community (Vijayanagar, Bangalore in India). They found that liquefied petroleum gas-based and combined heat power micro grid and proactive demand response by the community is the appropriate option that enabled the community to meet its energy needs in a reliable and cost-effective way.

Van Vuuren *et al.* (2014) also developed a new scenario framework for research into climate change. The aim of this framework is to foster collaboration amongst climate change researchers from a wide range of perspectives and spectrum disciplines to develop scenarios that are relevant to policy and decision-making regarding climate change.

2.7. Summary

It is beneficial to manage the water-energy nexus efficiently and this has been understood for some time. Therefore, many studies contribute to the body of technical knowledge on the use of water to supply energy, from the stages of resource extraction and preparation to power generation and beyond. Since Gleick's (1994) full-scale life-cycle analysis of water and energy resources, Hoekstra, Chapagain and others (2008) have performed similar analyses using water footprinting on bioenergy and other primary energy sources. This review collates data from various international and local studies to enumerate the range in data for water intensity of various energy technologies, namely coal with and without CCS, conventional oil, natural gas, solar power, wind power, hydroelectric, transportation biofuels and nuclear technologies. Where available, data are gathered for the pre-generation, the generation and the whole life cycle of these energy technologies. The most water-intense energy technologies are reported to be thermoelectric generation, notably coal and wet-cooled CSP. The energy technology most reported as a threat to water quality is coal, especially with reference to the extraction and processing stages. Studies in SA have focused on individual energy technologies and have provided a wide range of results, no doubt as a result of differing study boundaries, metrics and methodologies. The natural gas and transportation biofuel industries in SA are emerging and there is a dearth of local literature about these technologies.

Literature about best practice for policy in the water-energy nexus focuses on integrated planning and the need to fulfil sustainability requirements, especially in relation to fossil fuels. Studies located in SA tend to focus on coal-fuelled electricity.

It has been shown that scenarios analysis can be applied in planning energy and other public service systems. A proper balance is required between the supply and demand of energy in a given locality or region. The impact of climate change on water-energy nexus in SA has been explored to some extent by the LTAS to investigate national and local adaptation strategies. There is no readily available literature on the potential impact of climate mitigation on the water-energy nexus in the country.

This review of the literature reveals that there is a lack of research that facilitates comparison of water for energy production in SA and that local data is available only for a limited number of stages in the energy production chain for various energy technologies. Therefore, this study utilizes a water footprinting approach to survey international and local literature and to then calculate the water intensity of energy production.

3. METHODOLOGY

By: Madhlopa A, Keen S, Moorlach M, Sauka S and Sparks D

3.1. Introduction

Part of the study was conducted through a literature review. This included a review of different energy options, the water requirements and impacts for different energy generating technologies, various energy policies, regulations, plans and strategies that are prevalent in South Africa, as well as the review of challenges and opportunities towards moving to a renewable energy landscape in the face of a changing climate.

However, in order to meet all the objectives of the project, it was deemed necessary to complement the literature review with an analytical approach. This was implemented for the determination of the water intensity of energy technologies, future rainfall and runoff scenarios, as well as future energy scenarios. A conceptual approach was used to develop a draft policy framework, while trade-offs in the energy-water nexus were assessed by using a qualitative technique. In addition, two workshops were organized to solicit input from experts who are working in the water, energy and related fields. A detailed account of the methodology is given in Sections 3.2-3.5.

3.2. Water intensity of energy technologies

3.2.1. Data Collection

The assessment included a review of the available literature, focussing on SA specific data on water use impacts associated with the various energy types (see Chapter 2). A review of international literature was undertaken to provide comparative data or to be used as proxy data where gaps existed in the SA context. An attempt was made to fill these gaps through engaging with local experts. The engagement with experts involved semi-structured interviews focused on accessing quantitative data to fill gaps. In many cases, the investment in renewable energy generation is still at a very early stage of development and thus, data was not available. Expert judgement was sought on the likely (qualitative) impacts expected in the SA context relative to international contexts and further engagements (through project workshops) yielded more qualitative data as some projects moved into the generation stages of development.

3.2.2. Data Processing

Each fuel undergoes several stages during energy production. In a given stage (i^{th} stage) of energy production, water is withdrawn (W_i), consumed (C_i) discharged (D_i) and recycled (R_i), (Fthenakis and Kim 2010). However, most of the available data in the literature is on water withdrawals and consumption. Consequently, the total water withdrawal (W) and consumption (C) factors over the lifecycle can be computed by using:

$$C = \sum_{i=1}^{i=n} C_i \quad (3.1)$$

$$W = \sum_{i=1}^{i=n} W_i \quad (3.2)$$

where i =1,2, …n, is the number of stages, and $\sum$ is the summation sign.

Some energy production stages involve several processing options. For example, coal transportation can be through batch (for example by train) or continuous (such as slurry by pipeline) means. In such cases, the lowest and highest values were identified using Microsoft Excel. The total withdrawal (W_L) and consumption (C_L) lower-limit factors were calculated from:

$$C_L = \sum_{i=1}^{i=n} C_{i,L} \quad (3.3)$$

$$W_L = \sum_{i=1}^{i=n} W_{i,L} \quad (3.4)$$

where $C_{i,L}$ is the lower limit of water consumption in the i^{th} stage, and $W_{i,L}$ is the lower limit of water withdrawal in the i^{th} stage.

Similarly, upper-limit consumption factors were added to find the upper limit of water usage over the lifecycle of each fuel considered in this study. Bar graphs of these lower and upper values (based on data reported by previous researchers) were plotted for ease of fuel inter-comparison, depending on data availability (see Chapter 4).

3.3. Draft Policy Framework

The information gathered from the general literature, the review of water required for different energy generating technologies, energy policies and regulations, as well as the review of challenges and opportunities for adaptation, were used to develop a policy framework that links efficient water use and energy production under changing climatic conditions.

Existing legislation, strategies, policies and plans were analyzed to establish synergies and disharmonies with respect to efficient use of water, In this regard, the constitution of the Republic of South Africa was placed at the apex of the hierarchy of legislation and policies, followed by all other pieces of legislation which informed sectoral strategies/policies and plans in a descending order (constitution, sectoral pieces of legislation, strategies/policies, plans). At a given level of the hierarchy (e.g. sectoral pieces of legislation), the instruments were then linked horizontally. Thus, each instrument ought to have vertical horizontal linkages. A missing link would indicate a lack of synergy.

3.4. Future water scenarios: rainfall and runoff scenarios

In South Africa, only 9% of that rainfall is converted to runoff. Catchment characteristics such as soil type, vegetation, slope and catchment size influence the rate at which rainfall is converted into runoff. Changes in rainfall characteristics, such as intensity, duration and distribution have a direct impact on the runoff of a particular catchment. As different catchments respond differently to rainfall, an analysis of the relationship between rainfall and runoff is required. This relationship, referred to as the runoff coefficient, is scientifically defined as runoff divided by the corresponding rainfall over the catchment area (mm). Mathematically, this is illustrated by the following equations, where K represents the runoff coefficient:

$$K = Runoff\ [mm] / Rainfall\ [mm] \qquad (3.5)$$

Therefore, Equation (3.6) can be used to estimate runoff.

$$Runoff\ [mm] = K \times Rainfall\ [mm] \qquad (3.6)$$

Data for the rainfall and the runoff coefficient were sourced using the methods described in Sections 3.4.1-3.4.3.

3.4.1. Estimating future rainfall

As part of the Long-Term Adaptation Scenarios (LTAS) projects, future changes in rainfall distribution were predicted through various climate models. Independent climate projections were conducted by the Climate System Analysis Group (CSAG) of the University of Cape Town and by CSIR South Africa in partnership with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) based in Australia using the conformal-cubic atmospheric model (CCAM). Together, the projections provide a far more coherent view of potential climate change trends and scenarios for South Africa, its key sub-regions, and for Southern Africa as a whole. However, it has been shown that CCAM may be used to obtain plausible projections of future climate change, as well as skilful forecasts at the seasonal and short-range time scales, over the southern African region (Engelbrecht *et al.* 2009, Engelbrecht *et al.* 2011; Malherbe *et al.* 2013). It also realistically simulates observed daily climate statistics, such as the number frequency of extreme precipitation events, and the tracks of cut-off lows and tropical cyclones, over the region (Engelbrecht *et al.* 2012;

Malherbe *et al.* 2013). The model has also been applied for simulations of current climatic conditions at spatial scales from global to very small scale at high (1 km) resolution (Engelbrecht *et al.* 2011). Therefore, CCAM projections were used for this study. The figures below provide a spatial representation of climate projections for time periods 2015-2035 for three scenarios, namely the CCAM projections for the A2 emission scenario, the CCAM projections for Representative Concentration Pathway 8.5, and the CCAM projections for the Representative Concentration Pathway 4.5, respectively.

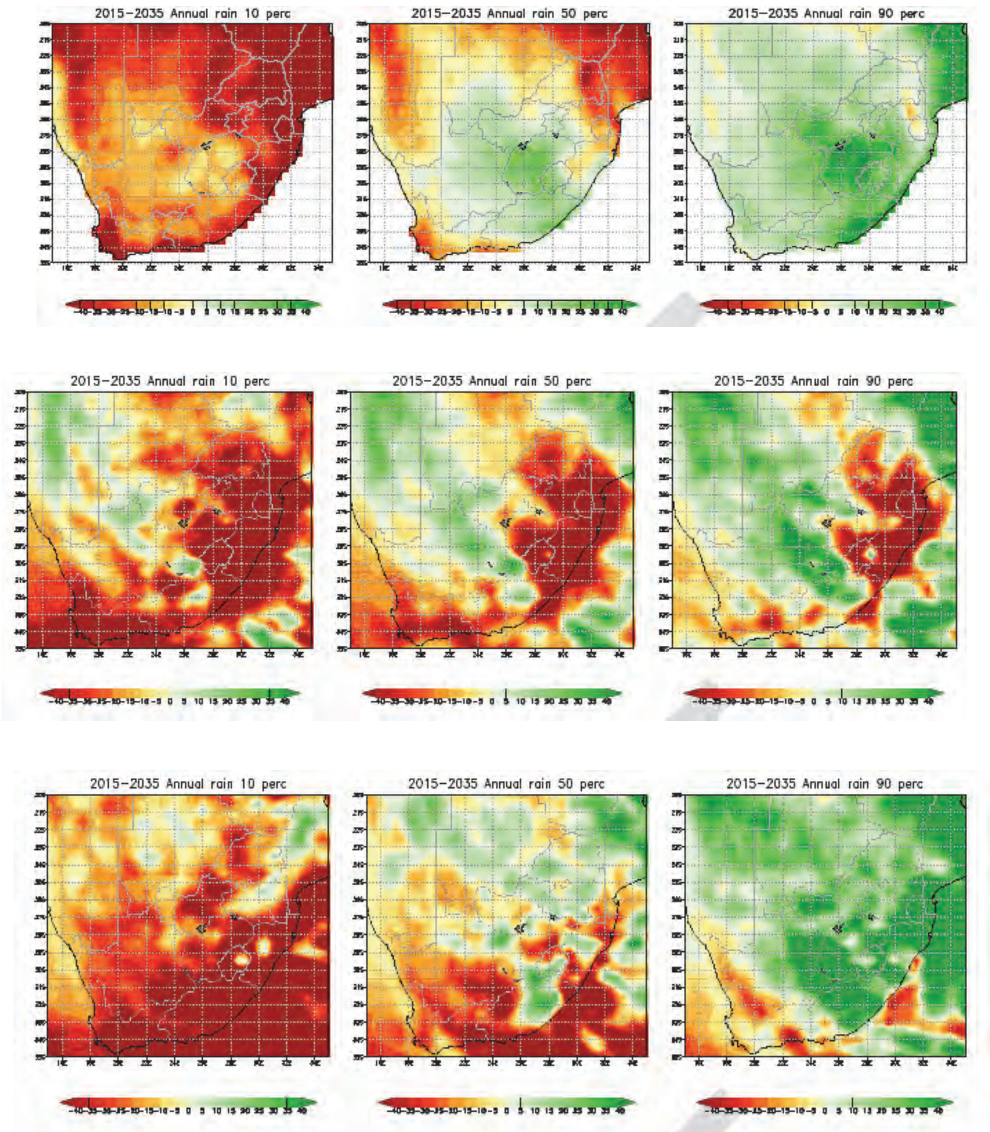


Figure 3-1: Projected change in the average annual rainfall (mm) over South Africa, for the time-periods 2015-2035. The 90th percentile (upper panel), median (middle panel) and 10th percentile (lower panel) are shown for the ensemble of downscaling of three CGCM projections, for each of the time-periods. The downscaling was performed using the regional model CCAM. All the CGCM projections are contributing to CMIP5 and AR5 of the IPCC, and are for RCP4.5. (Source: DEA 2013).

As the NWRS process defined six hydrological zones, as discussed in Section 2.5.4 rainfall projection scenarios were developed for each of the zones based on the climate projection. It is however, evident that future rainfall distribution is uncertain; it will either get wetter or drier. Therefore, it is important to incorporate both water and energy resource in future planning. The estimated changes in rainfall projections for each zone, which represent the extremes of each scenario, are provided in Table 3-1 below. The rainfall projections were then used to estimate runoff.

Table 3-1: Estimate Changes in Rainfall Projections for the Six Climate Zones.

Zones	Wet	Drier
Zone 1	20%	-35%
Zone 2	30%	-35%
Zone 3	20%	-30%
Zone 4	20%	-20%
Zone 5	30%	-20%
Zone 6	5%	-35%

3.4.2. Determining the runoff coefficient

Although the runoff coefficient of a specific catchment is not constant (throughout the catchment lifespan), it is only marginally variable. This is because, as previously mentioned, the runoff coefficient is dependent on the catchment characteristics. Therefore, the catchment characteristics would have to change for the runoff coefficient to also change. For this assessment, it was assumed that the catchment characteristics, and, therefore, the runoff coefficient will be constant until 2035.

To determine the value of the runoff coefficients for each catchment, the Alexander (2002) publication entitled 'The Standard Design Flood' was consulted. The publication provided the runoff coefficient of each catchment (i.e. drainage basin) in South Africa. The study publication also provides useful characteristics for each of the drainage basins identified. These characteristics are provided in Table 3-2, where M represents the average of the annual daily maximum rainfall in millimetres (mm), R represents the average number of days per year on which thunder was heard, C2 represents the runoff coefficients for the 2 year return period, C100 represents the runoff coefficients for the 100 year return period, MAP represents Mean Annual Precipitation in mm, and MAE represents Mean Annual Evaporation in mm. C2 was used for this study. The rainfall coefficient was then used to estimate runoff.

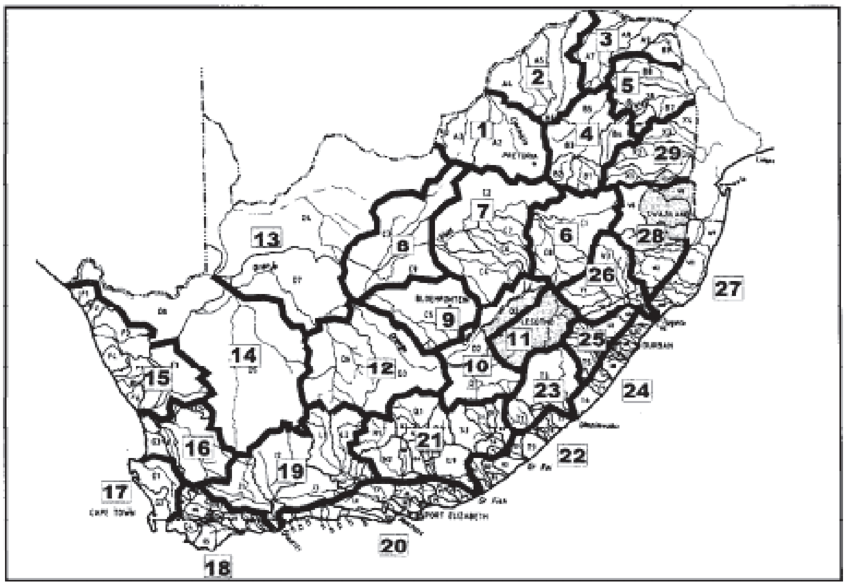


Figure 3-2: Drainage Basins in South Africa (Source: Alexander 2002).

Table 3-2: Information required to calculate SDF (Source: Alexander 2002).

Basin	SAWS station number	SAWS site	M mm	R days	C2 %	C100 %	MAP mm	MAE mm
1	546 204	Struan	56	30	5	40	550	1 800
2	675 125	Autoriteit	62	44	5	30	450	1 900
3	760 324	Siloam	64	28	5	40	470	1 700
4	553 351	Waterval	58	20	10	50	630	1 600
5	680 059	Leydsdorp	78	10	10	50	620	1 700
6	369 030	Siloam	51	54	10	60	670	1 500
7	328 726	Olivine	49	39	10	60	510	1 700
8	322 071	Danielskuil	47	39	5	20	380	2 100
9	258 452	Jacobsdal	43	47	10	40	380	1 800
10	233 049	Wonderboom	54	55	10	50	560	1 600
11	236 521	Mashai	39	66	15	70	430	1 400
12	143 258	Scheurfontein	39	52	5	30	290	2 100
13	284 361	Wilgenhoutsdrif	40	55	2	15	270	2 600
14	110 385	Middelpos	25	13	2	20	140	2 400
15	157 874	Garies	22	11	4	20	130	2 100
16	160 807	Loeriesfontein	28	11	10	40	210	1 900
17	84 059	Redelinghuis	28	1	20	50	260	1 500
18	22 113	La Motte	59	4	20	40	810	1 400
19	69 483	Letjiesbos	34	16	5	30	160	2 200
20	34 762	Uitenhage	53	12	10	50	480	1 600
21	76 884	Albertvale	45	23	10	35	460	1 700
22	80 569	Umzoniana	84	26	15	60	820	1 200
23	180 439	Insizwa	60	45	10	80	890	1 200
24	240 269	Newlands	76	15	15	80	910	1 200
25	239 138	Whitson	55	9	10	80	830	1 200
26	336 283	Nqutu	61	17	10	50	760	1 500
27	339 415	Hill Farm	85	17	15	60	890	1 400
28	483 193	Maliba Ranch	75	54	5	40	740	1 400
29	556 088	Mayfern	66	11	5	40	740	1 600

3.4.3. Estimating the runoff

Equation 2.6 was used to calculate runoff, using rainfall and the runoff coefficient data. Runoff was estimated for both a wetter and drier future. The runoff that was estimated is illustrated spatial in Section 7.2.2. Although DEA (2013) provided an estimate of the runoff in South Africa, these estimates could not be used of this study. This is because the runoff projections, illustrated in Figure 3-3, do not portray the current uncertainty in climate projections.

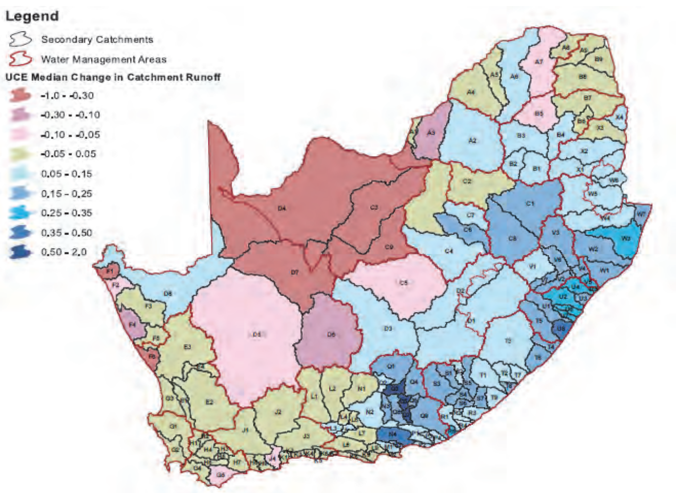


Figure 3-3: Median impact of climate change on the average annual catchment runoff for the period 2040-2050 relative to the base scenario average for 1990-2000 for all secondary catchments in South Africa derived from a Hybrid Frequency Distribution (HFD) analysis of all possible global circulation model (GCM) outputs (+6000 scenarios) for the unconstrained emissions scenario (UCE) (Source: DEA 2013).

The similarities provided between the runoff changes projected by the study, and those illustrated by the DEA (2013) study provided assurance. Importantly, the DEA (2013) projections fell within the wetter and drier runoff extremes developed by this study.

3.5. Energy scenarios and associated water requirements

The updated IRP electricity scenarios provide an important tool for policy and decision-making. It was therefore decided to adopt these scenarios as spanning the likely range of possible outcomes for future electricity generation expansion. To analyse the water demand under these energy scenarios, the following steps were followed:

a) setting a time scale of the scenarios analysis;
b) collecting relevant data; and
c) analysis of the data.

3.5.1. Timescale of analysis

In order to have a meaningful comparison, the timescales need be chosen in conformity with the existing future scenarios pertaining to development plans or climate change models (Promper *et al.* 2014). The long term provides a more flexible time frame with many possibilities. The available scenarios for climate change and energy in South Africa have been documented for time periods 2030 and 2050 (DoE 2013c). These time horizons are within the range reported in literature on scenarios analysis at international level, and were consequently adopted in the present investigation. A summary of the considered scenarios is given in Table 3-3.

Table 3-3: A summary of scenarios analysed in this report.

Scenario symbol	*Scenario description*
CE	Constant Carbon Emissions
MD	Moderate Decline In Carbon Missions
AD	Advanced Decline In Carbon Missions
CT	Carbon Tax
CB	Carbon Budget
PV	Rooftop PV Case
BG	Big Gas
HN	High Nuclear Cost
HC	High Coal Cost
SP	Solar Park
LR	Learning Rate Scenario

3.5.2. Data collection and processing

Data were collected from government reports and other publications, using a desktop approach. These documents were obtained from the internet, library and other sources. The data were predominantly extracted from the updated IRP (DoE 2013c). It should be noted that these data were generated under various appropriate assumptions (not replicated in this report) with robust modelling tools and review processes.

Water requirements of energy technologies vary significantly in terms of their water withdrawal and consumption. Various methods for the estimation of the amount of water used per unit of energy output have been developed. The unit of water intensity used in the IRP is litres per megawatt hour (L/MWh). Consequently, to enable comparisons, the volume of water for energy production was estimated in litres.

When a certain amount of water is withdrawn from a reservoir, part of it is consumed while the remaining portion is discharged into the reservoir. DoE (2013) reports water usage factors (without specifying whether the factors are for water withdrawal or consumption) for different energy technology options, and these factors were used to compute the corresponding amounts of water. Each technology uses a certain amount of water at different stages in the energy production chain. The quantity of water used (W) would depend on the amount of energy (E_{id}) supplied by a given technology. So, the total volume of water used (W) by the various energy technologies deployed was computed from:

$$W = \sum_{i=1}^{i=m} f_i E_{id} \tag{3.7}$$

where f_i is the water usage factor for a given technology (L/MWh) and m is the number of technology options. In practice, water usage factors are constant for a specific energy technology and stage of electricity generation (Fthenakis & Kim 2010). The amount of energy supplied (MWh) was calculated from:

$$E_{id} = N_d N_h k_i P_i \tag{3.8}$$

where k_i is the capacity/load factor of the i^{th} energy technology, N_d is the number of days in a year (365), N_h is the number of hours per day (24), and P_i is the installed capacity of the technology (MW). The various water and capacity factors used in the computation are presented in Table 3-4.

The share of renewable energy (RE) in the scenarios was based on the RE technologies (imported and domestic hydropower, pumped storage, solar PV, CSP and wind) considered in the updated IRP energy scenarios analysis. All the calculations were performed by using an Excel spreadsheet.

Table 3-4: **Water usage and load factors.**

Technology option	Water factor * (L/MWh)	Load factor ** (%)
Existing coal	231	85
New coal	43	85
CCGT	19.2	50
OCGT / Gas Engines	19.8	10
Hydro imports	0	67
Hydro domestic	0	1
Pumped storage (PS)	0	1
Nuclear	0	92
PV	15	19
CSP	310	47
Wind	0.79	30
Other	0	1

*Water factors: All factors from IRP update report (DoE 2013c) except for

1) PV from Fthenakis & Kim (2010).
2) Wind from Madhlopa *et al.* (2013).
3) It should be noted that, for a given technology, there are variations in the water intensities reported in literature (Madhlopa *et al*. 2013). In addition, the IRP update report does not specify whether the reported factors are for water withdrawal or consumption.
4) For nuclear energy, it is assumed that the nuclear power plants will use seawater for cooling, with negligible impact on freshwater resources. Otherwise, the water usage factor for nuclear energy would be greater than zero (Fthenakis & Kim 2010).

**Load factor: All factors from IRP (DoE 2013c) except for:

1) Hydro domestic, PS and Other: estimated.

3.6. Summary

Different energy options and their associated water requirements and impacts on the environment were reviewed at national and international scales. Data was also acquired through interviews, workshops and a semi-structured questionnaire. This information was used to assess the water requirements in the energy production chain in SA. All computational procedures were performed in Excel. For the draft Policy Framework, the information/data was collected from the desktop studies, the review of water required for different energy generating technologies, energy policies and regulations. Existing legislation, strategies, policies and plans were analyzed to establish synergies and disharmonies with respect to efficient use of water. In addition, future water scenarios: rainfall and runoff scenarios were predicted by using climatic models which involved estimation of future rainfall and runoff coefficient. The updated IRP electricity scenarios were used to determine the water demand under long-term energy scenarios using the following steps: a) setting a time scale of the scenarios analysis; b) collecting relevant data; and c) analysis of the data. Trade-offs between water use efficiency and energy were assessed by using a qualitative technique.

4. RENEWABLE ENERGY CHOICES AND WATER REQUIREMENTS IN SOUTH AFRICA

By: Sparks D, Madhlopa A, Keen S and Moorlach M

4.1. Introduction

Water requirements in the energy sector need to be properly examined to establish the overall water benefits of alternative energy technologies in the energy mix. The impact of deploying renewable energy technologies on water resources needs careful consideration. For example, to allocate water for biofuel production will require a shift in the current water allocation policy. Due to the large gap that exists between water supply and demand, trade-offs in water allocation amongst different users and policy makers are critical. This chapter investigates renewable energy choices for SA and their water requirements. It looks at water withdrawals and consumption levels at a given stage of energy production at both international and national levels. Most of the data was collected from secondary sources (literature) and, therefore, the assessment boundaries are not fully comparable. The data include renewable *and* non-renewable energy sources, as the non-renewables provide a very useful means of comparison. A contextual background on each fuel has been presented in the literature review (Chapter 2), to which the reader is referred.

The focus of this report is on South Africa specific water use data associated with the various energy types. Where gaps existed in the South African context, a review of international literature was undertaken to provide comparative data and/or to be used as proxy data. In many cases, the investment in renewable energy generation is still at a very early stage of development and thus, data were not available.

This study found that while there is an abundance of data for some technologies, e.g. coal, there is a lack of local data for others, notably transportation biofuels, wind and solar power. Studies located in South Africa tend to focus on coal-fuelled electricity. There is minimal data for upstream water use beyond resource extraction or capture. A review of the data reported in domestic and international studies shows considerable variation in values. For this reason, value ranges are used throughout this report.

4.2. Findings

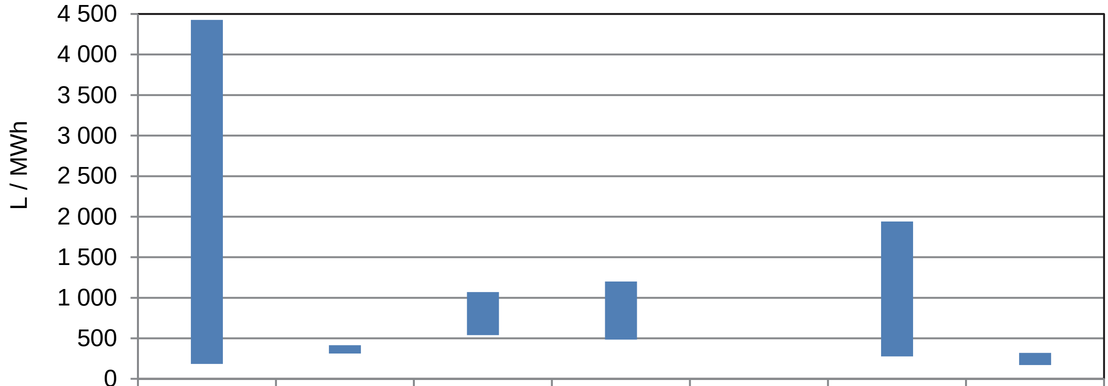
This section examines pre-generation and generation water use, by fuel, using international data. It then considers how water is used over the life cycle of a particular fuel (also in an international data context). This is followed by water use in energy production in an SA context.

4.2.1. Pre-generation water use: international data

4.2.1.1. Water withdrawal (onsite and upstream)

Conventional thermal power plants commonly use coal, nuclear, oil and gas fuels. In these plants, energy production involves various stages including fuel acquisition, processing and transportation. Water is required in coal mining, washing, beneficiation, transportation and power plant construction. Similarly, water use in nuclear power plants is for uranium mining, milling, conversion, enrichment, fuel fabrication, power plant construction and fuel disposal. Extraction, purification, transportation and storage also demand water in the production of energy from natural gas or oil. In this investigation, water usage in the production of energy from renewable energy sources is also considered, and the main renewable energy sources covered are biomass, hydro, solar (PV and CSP) and wind. Biomass can be converted into energy carriers such as biodiesel, methanol, ethanol and hydrogen, with water being required in the cultivation of fuel crops. Upstream water withdrawal for growing fuel crops includes water used in the production of farm inputs such as fertilizer. Corn, jatropha, soybean, maize rape seed, sugar beet and switchgrass fuel crops are covered in this investigation. Upstream data for hydroelectric power plants is scarce (Fthenakis and Kim 2010).

Figure 4-1 shows water withdrawals for conventional and renewable energy sources in the pre-generation phase, based on data reported by the Department of Minerals and Energy Affairs (1983), Gleick (1994), Inhaber (2004) and Fthenakis and Kim (2010). It should be noted that that there are variations in the values reported by different investigators. Hence, value ranges are used throughout this report.



	Coal	Nuclear	Natural gas	CSP	Hydro	PV	wind
Min	184	312	539	485	1	276	170
Max	4 428	415	1 071	1 200	1	1 942	320

Figure 4-1: Water withdrawals during the pre-generation phase for the production of energy from conventional and renewable fuels, excluding biomass.

a) Conventional energy sources

It is observed that coal-fired thermal power plants withdraw the highest range of water from reservoirs. Transportation of coal in the form of slurry draws the highest amount of water (up to 4 528 L/MWh) in the pre-generation phase. On the other hand, transportation of coal by train is more water-efficient (26-38 L/MWh). Water withdrawal during plant construction is relatively low (11-45 L/MWh). Over the whole pre-generation phase, 184-4428 L/MWh are withdrawn for various processes until the coal is ready for use by the power plant. For natural gas, a significant amount of water is withdrawn during extraction. Over the entire pre-generation phase, 539-1 071 L/MWh of water is withdrawn during the production of energy from natural gas. Nuclear power draws the lowest amount of water (amongst conventional fuels) during the pre-generation phase (312-415 L/MWh).

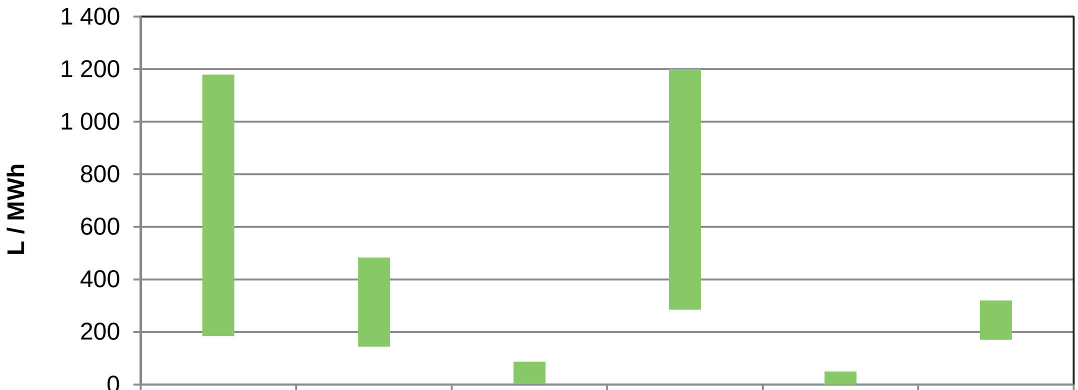
b) Renewable energy sources

Biomass values have been excluded in Figures 4.1-4.6 due to their very high ranges – the reader is referred to the tables in Appendix (F-5) for values related to this fuel source. There is variation in water withdrawals for biomass production depending on the crop and location (weather and other factors). Amongst the crops considered in this investigation, herbaceous perennials exhibit the largest demand for water (435 600 L/MWh), with hybrid poplar (USA) being the most water-efficient fuel crop (up to 187 L/MWh, including onsite and upstream water consumption) in the pre-generation phase. Geothermal is also water-intensive (up to 30 000 L/MWh). The observed water withdrawal levels in PV technology are mostly attributed to material fabrication (upstream) with insignificant water demand onsite. The lowest demand for water in the pre-generation phase is observed in concentrated solar power (CSP). Water withdrawals for wind during pre-generation are mostly attributed to the usage of steel, iron and glass fibre to manufacture wind turbines upstream (Fthenakis and Kim 2010) and to the mining of rare earth minerals. Water withdrawals for hydropower are limited but Inhaber (2004) reported a value of (1.0 L/MWh).

The intermittent nature of some renewable energy sources, such as solar radiation and wind, is a common reason for governments to prioritize investments in dispatchable energy technologies such as coal, nuclear or gas over renewable energy sources. One way of overcoming this limitation is to back up the renewable energy power plant with a conventional source of energy (Cao and Christensen 2000). This affects the total water requirements in the hybrid renewable energy technologies. Inhaber (2004) investigated water withdrawal factors for hybrid solar and wind technologies and found that 100 000 L/MWh was required to back up a solar photovoltaic, solar thermal or wind power plant.

4.2.1.2. Water consumption: international data

Figure 4-2 shows water consumption levels for conventional and renewable energy sources in the pre-generation phase, based on the data reported by the Department of Energy (1983), Gleick (1994), Inhaber (2004) and Fthenakis and Kim (2010).



	Coal	Nuclear	Oil/gas	CSP	PV	wind
Min	184	144	2	285	0	170
Max	1 179	483	87	1 200	50	320

Figure 4-2: Water consumption during the pre-generation phase for the production of energy from conventional and renewable fuels. For wind, estimates of water withdrawals are used for consumption, excluding biomass.

a) *Conventional energy sources*

It is again observed that coal-fired thermal power plants consume the highest range of water. Transportation of coal in the form of slurry draws the highest amount of water (420-870 L/MWh), while surface mining consumes the least quantity of water (420-870 L/MWh) in the pre-generation phase. Over the entire pre-generation phase, 184-1 179 L/MWh is consumed by various processes until the coal is ready for use by the power plant. Nuclear energy production consumes 144-483 L/MWh, with natural gas being most water-efficient (2-87 L/MWh) amongst the conventional fuels considered in the present work.

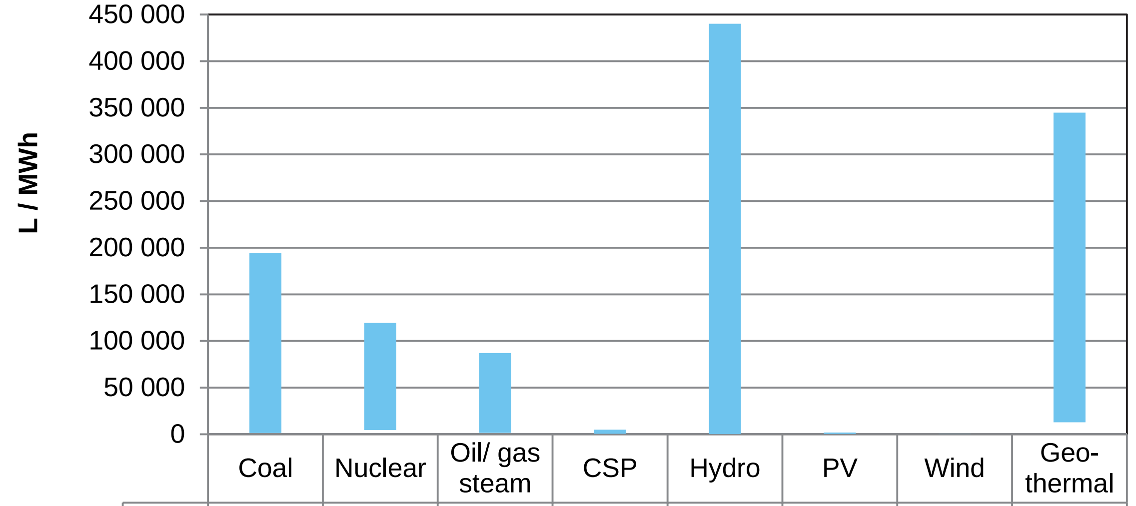
b) *Renewable energy sources*

For renewable energy, sugar beet consumes the largest amount of water (972 000 L/MWh), with hybrid poplar (USA) being the most water-efficient fuel crop (up to 187 L/MWh, including onsite and upstream water consumption) in the pre-generation phase (The reader is referred to the tables in the appendix section). The relatively high levels of water withdrawal observed in wind technology are mostly attributed to upstream processes with insignificant water demand onsite. The lowest consumption of water in the pre-generation phase is observed in solar PV plants with wind energy consuming intermediate levels of water during pre-generation. Data are not available on water consumption in the pre-generation phase of hydropower.

4.2.2. Generation water use: international data

4.2.2.1. Water withdrawal

Water withdrawal levels over the life cycle of conventional and renewable energy sources are presented in Figure 4-3.



	Coal	Nuclear	Oil/ gas steam	CSP	Hydro	PV	Wind	Geo-thermal
Min	1 284	4 512	1 489	500	80	276	170	12 800
Max	194 428	119 415	86 971	5 000	440 000	1 957	324	344 700

Figure 4-3: Water withdrawal over the life cycle of energy production from conventional and renewable fuels. Biomass is excluded.

a) Conventional energy sources

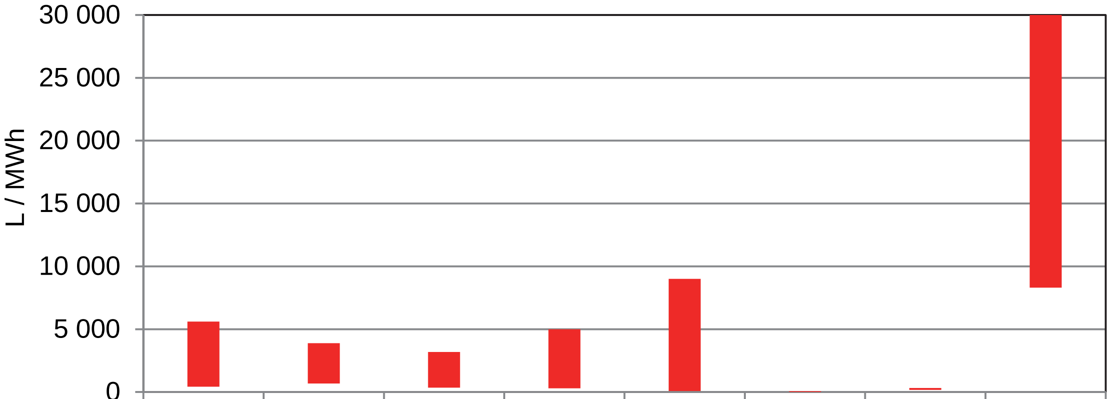
Coal-fired thermal power plants withdraw the highest amount of water (1 284-194 428 L/MWh) from reservoirs. The high water withdrawal is attributed predominantly to cooling during power generation. On the other hand, oil/gas exhibits the lowest range of water intensity (1 489-86 971 L/MWh), with nuclear energy being intermediate.

b) Renewable energy sources

Hydro energy draws the largest amount of water (up to 440 000 L/MWh), with PV and wind being the most water-efficient over the considered stage of the lifecycle. It should be noted that the hydro range is broad, and the high value is reflective of one estimate. Other estimates are considerably lower. These observations are consistent with findings of Fthenakis and Kim (2010) and Wassung (2010).

4.2.2.2. Water consumption

The variation of water consumption across different fuels over the lifecycle is shown in Figure 4-4.



	Coal	Nuclear	Oil/ gas steam	CSP	Hydro	PV	Wind	Geo-thermal
Min	426	674	343	300	80	0	170	8 300
Max	5 609	3 883	3 187	5 000	9 000	65	324	30 000

Figure 4-4: Water consumption over the life cycle of energy production from conventional and renewable fuels. Biomass is excluded.

a) Conventional energy sources

For conventional fuels, coal-fired thermal power plants consume the highest amount of water. Most of the water is consumed during generation, probably through evaporation. Amongst conventional fuels, oil and gas are more favourable from a water perspective.

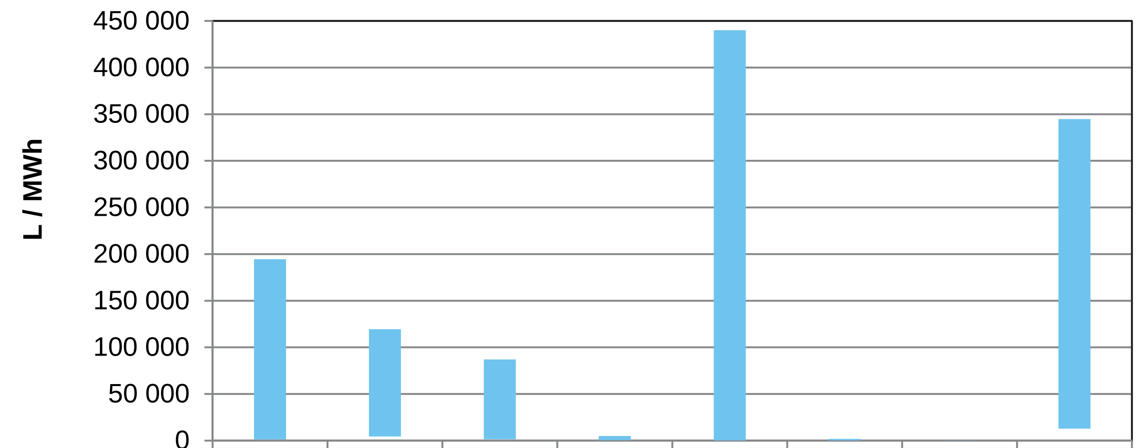
b) Renewable energy sources

For renewable energy, geothermal power consumes the largest amount of water (up to 30 000 L/MWh), attributed to the production of a large volume of wastewater (Inhaber 2004). PV and wind are the most water-efficient over the considered stages of the lifecycle. This observation is consistent with findings of Fthenakis and Kim (2010) and Wassung (2010). It should also be noted that hydropower is relatively less xdwater-efficient compared to conventional fuels due to evaporative water loss. Evaporation takes place at the boundary between the water surface and air layer. So, for a given rate of evaporation (per unit area), the volumetric water loss increases with the exposed surface area of the water. A dam raises the surface area of the water exposed to the ambient environment, thereby augmenting the bulk amount of water that leaves the surface in the form of vapour.

4.2.3. Water use over the lifecycle: international data

4.2.3.1. Water withdrawal

Water withdrawal levels over the life cycle of conventional and renewable energy sources are presented in Figure 4-5.



	Coal	Nuclear	Oil/ gas steam	CSP	Hydro	PV	Wind	Geo-thermal
Min	1 284	4 512	1 489	500	80	276	170	12 800
Max	194 428	119 415	86 971	5 000	440 000	1 957	324	344 700

Figure 4-5: Water withdrawal over the life cycle of energy production from conventional and renewable fuels. Biomass is excluded.

a) Conventional energy sources

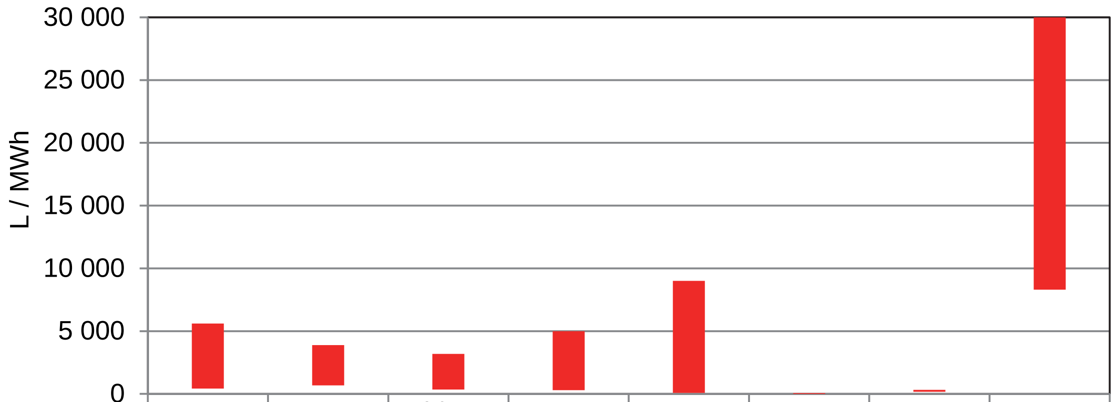
Coal-fired thermal power plants withdraw the highest amount of water (1 284-194 428 L/MWh) from reservoirs. The high water withdrawal is attributed predominantly to cooling during power generation. On the other hand, oil/gas exhibits the lowest range of water intensity (1 489-86 971 L/MWh), with nuclear energy being intermediate.

b) Renewable energy sources

Hydro energy draws the largest amount of water (up to 440 000 L/MWh), with PV and wind being the most water-efficient over the considered stage of the lifecycle. It should be noted that the hydro range is broad, and the high value is reflective of one estimate. Other estimates are considerably lower. These observations are consistent with findings of Fthenakis and Kim (2010) and Wassung (2010).

4.2.3.2. Water consumption

The variation of water consumption across different fuels over the lifecycle is shown in Figure 4-6.



	Coal	Nuclear	Oil/ gas steam	CSP	Hydro	PV	Wind	Geo-thermal
Min	426	674	343	300	80	0	170	8 300
Max	5 609	3 883	3 187	5 000	9 000	65	324	30 000

Figure 4-6: Water consumption over the life cycle of energy production from conventional and renewable fuels. Biomass is excluded.

a) Conventional energy sources

For conventional fuels, coal-fired thermal power plants consume the highest amount of water. Most of the water is consumed during generation, probably through evaporation. Amongst conventional fuels, oil and gas are more favourable from a water perspective.

b) Renewable energy sources

For renewable energy, geothermal power consumes the largest amount of water (up to 30 000 L/MWh), attributed to the production of a large volume of wastewater (Inhaber 2004). PV and wind are the most water-efficient over the considered stages of the lifecycle. This observation is consistent with findings of Fthenakis and Kim (2010) and Wassung (2010). It should also be noted that hydropower is relatively less water-efficient compared to conventional fuels due to evaporative water loss. Evaporation takes place at the boundary between the water surface and air layer. So, for a given rate of evaporation (per unit area), the volumetric water loss increases with the exposed surface area of the water. A dam raises the surface area of the water exposed to the ambient environment, thereby augmenting the bulk amount of water that leaves the surface in the form of vapour.

4.2.4. Water use in energy production in SA

It is reported that the Energy Sector in SA uses 2% of the total national water allocation (Wassung 2010). In addition, coal is currently the main source of electricity in this country. However, disaggregated data on water withdrawal and consumption at specific stages of energy generation is scarce across fuels. In general, the coal-water nexus has been investigated more extensively than other fuels.

a) Conventional energy sources

Some of the reported data for conventional energy is presented in Table 4-1. It is observed that coal uses more water in plant cooling (1 380-1 420 L/MWh). Using pre-generation values from this table, 263-1 646 L/MWh of water is used between the pre-generation and generation stages. The lower limit is the sum of the minimum values of pre-generation (mining and washing, 183 L/MWh) and generation (1 380 L/MWh). For lifecycle usage, Wassung (2010) reported water intensities of 1 534-3 326 L/MWh), which is comparable to the international consumptive usage (3 460 L) of water reported by Wilson *et al.* (2012).

Table 4-1: Water usage in energy production by using thermal electric cycles.

Fuel	Energy production stage	Water use[a] L/MWh	Reference
Coal	Pre-generation, mining & washing	183-226	Martin and Fischer (2012)
	Generation, cooling	1 420	Eskom (2013b)
	Generation, dry cooling	100	Eskom (2013c)
	Generation, indirect dry cooling	80	Martin and Fischer (2012)
	Generation, cooling	1 380	Martin and Fischer (2012)
Nuclear	Generation, cooling	192 539	Eskom (2013a)
Diesel	Generation, dry cooling, water for purging	0.54	Eskom (2009)

[a] Sources of this data report it as water use, without specifying whether withdrawal or consumption.

SA has one nuclear power plant (Koeberg) currently in operation, with an installed capacity of 1 800 MW and a capacity factor of 83.1%. Koeberg uses seawater flowing at 80 000 L/second to cool the condensers (Eskom 2013a). Using these values, the intensity of water use during generation has been estimated as 192 539 L/MWh. Fthenakis and Kim (2010) reported a water withdrawal value of 120 000 L/MWh for a nuclear power plant using the once-through cooling method, which is comparable with the value for the Koeberg power plant. Diesel is also used in backup generators. Water use by dry-cooled generators is relatively low.

b) Renewable energy sources

There is sporadic data on water usage in renewable energy in SA. Table 4-2 shows water requirements for biofuel production.

Table 4-2: Water withdrawal requirements for biomass energy (*Source: Gerbens-Leenes et al. 2008).*

Sugar cane	Heat from biomass	Water use L/MWh
Potato	Heat from biomass	108 000
Sorghum	Heat from biomass	176 400
Sugar Cane	Electricity from biomass	176 400
Maize	Electricity from biomass	151 200
Potato	Electricity from biomass	183 600
Sorghum	Electricity from biomass	295 200
Sugar Cane	Bio-ethanol from biomass	352 800
Maize	Bio-ethanol from biomass	334 800
Potato	Bio-ethanol from biomass	183 600
Sorghum	Bio-ethanol from biomass	684 000

Sorghum requires the highest amount of water (684 000 L/MWh), with potato having the lowest water intensity (108 000 L/MWh). Maize is a food crop, which consequently creates competition between food and fuel for the same resource (here maize is part of the water energy food security nexus). Stone *et al.* (2010) also found that production of bio-ethanol from grain and grain sorghum consumes the highest quantity of water compared to other feedstock (as discussed earlier).

Data on usage of water in the production of energy from CSP and PV is scarce. Olivier (pers. Comm. 2013) reported water consumption of 767 000 L during the construction phase of a 4.5 MW hydropower plant. For wind, a project coordinator reported forecast water usage of 817 000 L in the construction phase of a 120 MW power plant and consumption of 3 650 L during operation phase (G7 Renewable Energies, pers comm 2013). Assuming a capacity factor of 30%, this yields a water intensity of 0.79 L/MWh during operation. Over the lifecycle, Wilson *et al.* (2012) reported a water-consumption value of less than 1 L/MWh.

The analysis below has been categorised by fuel type (i.e. coal, oil/natural gas, solar, wind turbines, hydroelectricity, bioenergy and nuclear). As mentioned in the methodology, conventional fuels have been considered, in addition to renewable fuels, for comparative purposes and in decision-making between renewable and conventional fuel choices. However, the focus of the broader project is on renewable energy and its water footprint. This discussion covers water and water impact for each fuel.

4.3. Analysis

4.3.1. Coal power plants

Results from other countries show that wet-cooled thermal power plants withdraw and consume the highest amounts of water on a lifecycle basis. Most of this water is required during the generation stage, which indicates that more attention needs to be paid to this stage of energy production. However, disaggregated data on water usage (stage-by-stage withdrawal and consumption levels) for SA is scarce. In view of this, water usage patterns from other countries can be used as indicators of the situation in this country. More attention is required to curtail the volume of water withdrawal and consumption in the generation stage.

Coal-fired power has a substantial water impact but new technologies may reduce water consumption and impact. In this respect, Eskom has invested in research to use dry processing to purify coal by removing stone – a major source of the ash, sulphur and abrasive components found in coal. This research focuses on removing these components using dry techniques to reduce the volume of coal to be transported, improve coal combustion rates and lower emissions (Eskom 2013b; de Korte 2010).

Eskom has implemented dry-cooling systems in power plants wherever feasible. This is despite the fact that dry-cooled plants are comparatively less energy-efficient than wet-cooled, leading to higher carbon emissions. Moreover, there are higher capital and operating costs associated with dry cooling. Nevertheless, efforts to invest in dry cooling could also have significant water benefits. According to Eskom (2013b), approximately 85% of the total quantity of water supplied to a power station evaporates through these open cooling towers. In contrast, dry-cooling technology does not rely on open evaporative cooling for the functioning of the main systems. Overall power station water use associated with dry cooling is approximately 15 times lower than a conventional wet-cooled power station. This water conservation effort results in an estimated combined saving of over 200 million litres/day, or in excess of 70 000 million litres/annum (Eskom 2013b).

Matimba Power Station near Lephalale in the Limpopo Province is the largest direct-dry-cooled power plant in the world, with an installed capacity greater than 4 000 MW. It makes use of a closed-circuit cooling system similar to the radiator and fan system used in motor vehicles (Eskom 2013a). Consequently, water withdrawal and consumption at this plant station is significantly associated with upstream operational stages such as coal mining, processing and transportation.

An additional technology option is indirect dry cooling. This entails the cooling of the water through indirect contact with air in a cooling tower, a process during which virtually no water is lost in the transfer of the waste heat. Eskom is undertaking various other water management projects to reduce water requirements in energy production (Eskom 2013a). These local efforts are consistent with the observation (from international data) that most of the water is withdrawn and consumed in the generation stage.

4.3.2. Coal liquefaction

Sasol uses about 4% of the water resources available from the Vaal River System. The water use in operations at Sasol's Synfuels in SA is 12 000 litres per tonne of product (Sasol 2013a). Specific withdrawals are not disclosed by Synfuels operations in SA (only withdrawals associated with global operations are disclosed).

During 2011 Sasol's main operating facilities at Sasolburg and Secunda set voluntary internal water efficiency targets, which took into consideration site-specific constraints and opportunities. With usage in 2010 as a baseline, Sasol Synfuels at Secunda has a target to improve its water use intensity (volume of water used per tonne of product) by 5% by 2015, while, at Sasolburg, Sasol Infrachem is targeting a 15% improvement (Sasol 2013).

According to Sasol's Water Disclosure Report Submission (Sasol 2012), "A study has been conducted to determine the relationship between energy usage (and related carbon emissions) and water usage for alternative cooling technologies for the design of new coal to liquid (CTL) and gas to liquid (GTL) facilities." These results will be used to determine the most appropriate cooling technology selection for new facilities, depending on the availability of water at a specific location.

4.3.3. Carbon capture and storage (CCS)

A power plant with a CCS technology requires more fuel to produce the same amount of energy than a conventional power plant. Water withdrawal and consumption for CCS power plants is estimated to be between seven and fifty times greater than the water required for non-CCS plants (Wilson *et al.* 2012). The water impact of CCS is very high.

4.3.4. Nuclear power

Koeberg Nuclear Power Station has three different water systems, known as the primary, secondary and tertiary circuits. The three water systems are used to cool down the heat produced by the fission energy process. The three systems differ due to their application. The primary water loop is a closed system with pressurized water. It transfers heat from the reactor vessel to the secondary system through a heat exchanger. Cool water is returned to the reactor vessel with no water consumption in this loop. Steam is produced in the secondary loop, and used to drive a turbine which generates electricity. After flowing through the turbine, the steam is condensed and returned to the steam generator unit. The tertiary loop uses seawater to condense the steam (Eskom 2013a).

Water is required at a power plant to cool the system and also to condense the low-pressure steam and finally to recycle it. When the steam in the internal system condenses back to water, the excess heat, which is removed from the system, needs to be recycled and transferred to either the ambient environment or to a heat recovery system.

The Koeberg Nuclear Power Station is built adjacent to an abundant water source (the ocean) and hence uses the once-through cooling method in the tertiary loop to condense the steam after driving the turbine. The cooling water is circulated back into the ocean at an elevated temperature. Water consumption is marginal, with a small proportion of the withdrawn water being consumed. The small amount of water consumed and/or lost refers to the evaporation that occurs when the water circulated back into the ocean and being a few degrees warmer than the ocean temperature (World Nuclear Association 2013). The use of seawater reduces the competition for fresh water. Nevertheless, the elevated temperature of the discharged water may affect the ecosystem at the discharge point.

4.3.5. Oil and natural gas

Extraction of oil by hydraulic fracturing involves pumping a mixture of water, sand and other additives into the ground, thereby creating cracks. The oil is then forced out through these cracks. In addition, water is used in oil or gas-fired thermal electric generators that are wet-cooled. Most of the water used in the production chain of oil/gas-fired thermoelectric power is during generation.

Hydraulic fracturing contributes to the contamination of ground water (Kharak *et al.* 2013). In this regard, some of the contaminants include methane, benzene and gasoline and the diesel range of organics. In some cases, well-fed tap water has become flammable due to the presence of these contaminants (Wilson *et al.* 2012). The high demand of water for wet cooling puts stress on water resources.

For natural gas, there have been environmental concerns about water usage and hydraulic fracturing in the Karoo area. It has been estimated that 20-25 million litres of water may be required to drill one well (van Wyk 2014). However, in light of the fact that the Karoo area is an arid environment, water will have to be sourced from a distance. In addition, water is used in gas-fired thermal electric generators that are wet-cooled. Most of the water used in the production chain of oil/gas-fired thermoelectric power is during generation (up to 5 850 L/MWh) (Wilson *et al.* 2012).

4.3.6. Concentrated solar power and photovoltaic

Concentrated solar power (CSP) plants use water in the resource extraction and the manufacturing of components in the collector. Most of the water used during manufacturing is linked to the heating, ventilation and air-conditioning (HVAC)--system of the manufacturing plant. The parabolic trough, power tower and linear Fresnel technologies can use wet, dry or hybrid cooling systems. The dish Stirling does not require a cooling system (the heated fluid is hydrogen).

CSP plants using steam cycles require cooling to condense the steam exiting the turbines. In this study, it has been found that these plants withdraw 500-5 000 L/MWh and consume 300-5 000 L/MWh, which is in agreement with finding from other studies (2 000-3 000 L/MWh reported by IEA-ETSAP and IRENA (2013).

Dry cooling is an option for areas where water is a constraint, but this method of cooling is less efficient than wet cooling. Compared to wet cooled CSP plants, electricity production is typically reduced by 7% and the capital cost increased by 10% in dry cooled plants (IEA-ETSAP and IRENA 2013). The water impact of CSP plants is very low.

Water is used in the production of PV-cells. The water use can be divided into two groups of users. Firstly the manufacturing plant and its infrastructure, for example, water use for HVAC, sanitary use, and landscaping. The second group is the manufacturing process itself where standard and highly purified de-ionized water is used to manufacture PV cells (Williams 2011). The water use is associated with removing chemical residues from equipment and rinsing of substrate wafers and panels. Sinha and others (2013) found that half of the life cycle water withdrawal is associated with the manufacturing of the module and the water consumption during the manufacturing of a CdTe PV-cell is a quarter of the water withdrawal. The water consumption is linked to cooling tower evaporation and site irrigation.

Water is also used during the project construction, but with no documented figures easily accessible. The water use during generation is linked to the cleaning/washing of the PV-panels, which is aimed at removing dust from the panels to maintain a high level of the transmission of solar radiation. International literature suggests values of 15 L/MWh for CPV and PV (NREL 2002; Fthenakis and Kim 2010). Information is scarce on the frequency of PV-panel cleaning in SA. It is likely to depend, in part, on the environment where the system is installed. Frequent cleaning is required in dusty conditions, but the impact of concentrated photovoltaic (CPV) and photovoltaic (PV) on water is negligible.

4.3.7. Wind power

Wind power does not use water in the acquisition or supply of the fuel per se. It does, however, use water in the acquisition and processing of the rare earth minerals required for the production of the turbines. Rare earth metals are a group of 17 metals that used to be considered a by-product of mining but are now seen as an important component of many “green technologies” such as cell phones, tablets, electric cars, solar panels, and wind turbines. They are not so much rare as mixed up with other rare earth minerals, making them at times uneconomical to mine. The magnets used in wind turbines have an important rare earth component known as neomycin. Presently, neomycin is imported almost entirely from China, although there are rare earth element sources available in the USA, SA, and elsewhere. A large wind turbine (approximately 3.5 MW) generally contains 600 kg of rare earth metals.

Wind energy does not require water for its generation (assuming the land used is still offered for other uses such as agriculture) (Gleick 1994; Martin and Fischer 2012), Water use for the turbine construction phase has been deemed negligible (Gleick 1994). There is also likely negligible water use in the washing of the turbine blades from time to time.

A wind power plant with a total capacity of 8.4 MW requires 1400 tons of rare earth elements (Martin and Fischer 2012). Every ton of rare earth mineral produced uses 75 m^3 acidic wastewater and one ton of radioactive waste residue (which contains water) (Hurst 2010). Wastewater from rare earth mining in China is often discharged without appropriate treatment, impacting on potable water. The water use in the production of rare earth elements, such as neomycin, does not impact on water use in SA, but they do impact on the water footprint globally.

4.3.8. Hydroelectricity

No additional water is used in acquiring or supplying of hydropower. However, a substantial quantity of water is needed to ensure a constant fuel supply source (Pegram *et al.* 2011). Some suggest that no water is used in the process of hydropower generation, since the water used in generation is returned to the water resource and it hence qualifies as in-stream water use. Others argue that evaporation losses associated with the hydropower plant are significant and that hydroelectricity is a significant consumer of water (Hoekstra *et al.* 2011; Mekonnen and Hoekstra 2012).

One of the seminal papers that have considered water and energy, making reference to hydropower water consumption is that of Gleick (1994). Pegram and others (2011) summarise the pertinent points of this paper as relevant to hydropower, to which the reader is referred. Important considerations are evaporation and seepage. Gleick 1994) estimates a range of hydropower evaporation values, varying from a minimum of 40 L/MWh, to a maximum of 210 000 L/MWh, with an average of 17 000 L/MWh.

In SA, evaporation rates vary spatially across the country (see Schulze (2008)) to some degree mirroring the annual rainfall rates spatially too. The highest rates are in the NW and central regions of the country, decreasing eastwards towards the east coast. Such spatial evaporative losses are important to consider in terms of future planning for hydropower dam placements. Nonetheless, when considering evaporation losses, the size of the reservoir (a deep reservoir with a lower surface area will have less evaporative loss) is more important than the climate itself.

Mekonnen and Hoekstra (2012) consider the blue water footprint of hydroelectricity, linking this to the evaporation loss associated with the artificial reservoirs created behind hydroelectric dams. In their study, they calculated the blue water loss through a series of equations and assumptions, and came up with a figure of 90 000 $GLyr^{-1}$. In perspective, this equates to 10% of the blue water footprint of global crop production in 2000, which they find to be relatively large when compared to other renewable sources of electricity (Mekonnen and Hoekstra 2012).

Pegram and others (2011) point out that Mekonnen and Hoekstra (2012) do not consider evapotranspiration of natural vegetation in their interpretation of water consumption. When considering evaporation losses in terms of hydropower. Pegram and others (2011) argue that it is net evaporation loss that needs to be considered, as opposed to total evaporation loss. Net evaporation loss refers to the difference the evaporation deviates from a natural reference condition (e.g. natural vegetation) (Pegram *et al.* 2011). This, they believe will reflect a more accurate picture. Other studies in different environments e.g. in New Zealand (Herath *et al.* 2011) highlight the need for taking the local environment into consideration, since their values are notably lower than the global averages presented by Gleick (1994).

In addition to considering evaporation losses, it is important to remember that hydropower is generally responsible for changing the flow regime (Pegram *et al.* 2011). This, in turn, may impact on the environment as well as water availability to users downstream. Conceptually it is also worth noting that a nominal amount of water is used in constructing a hydropower plant, albeit negligible (Pegram *et al.* 2011).

4.3.9. Bioenergy

Water use in the production and application of bioenergy varies. Dominguez-Faus and others (2009) estimate that ethanol production from corn requires from 2 270 000 to 8 670 000 L/MWh, whilst soybean-based biodiesel pre-generation and generation utilizes between 13 900 000 and 27 900 000 L/MWh compared to the 10-40 L/MWh required for petroleum extraction.

Closer to home, de Fraiture *et al.* (2008) indicate that SA uses approximately 416 million litres of water to produce sugarcane for bioethanol production per annum, which is equivalent to 9.8% of total irrigation that is directed at biofuels production. This is a significant amount for a water-stressed country.

The global production of bioethanol from grain and grain sorghum consumes the highest quantity of water compared to other feedstock. In contrast, sugar cane appears to have the lowest water footprint in ethanol production. Stone and others (2010: 2020) explain this wide disparity by arguing that only the grain in the corn is used to produce ethanol, whilst the rest of the crop, that is, the lignocellulosic materials (i.e. leaves, stalk and stem) are not utilised in the process. Furthermore, the authors indicate that sugar cane and corn have different photosynthetic processes, which could, in part, explain their dissimilar water requirements aside from the obvious fact that they are two different crops (Stone *et al.* 2010). Soybean is also water inefficient in that it requires very high quantities of water for irrigation and even more for the actual production of biodiesel. To further attest to this, some commentators contend that over 180 000 litres of water would be required to generate sufficient amounts of biodiesel from soybean to power a household for a month (Jones 2008).

More disaggregated and recent data is required for water usage in biofuels production in both the global sphere and SA context. For instance, no data could be identified for the processing phase of ethanol production using sugarcane *viz.* cane washing, condenser multi-jet in evaporation and vacuum, fermentation cooling and alcohol condenser cooling, barring an indication that in 1997 all this was estimated to consume 21 m^3/ton and that this has reduced over time to 1.83 m^3/ton in 2004 (Goldemberg *et al.* 2008).

While all the authors concur that in some regions, rainfall meets the irrigation requirements of the production of biofuel feedstock, they readily admit that the production of biofuels is and will continue to compete for limited water stocks in many countries, including the USA. Needless to say, this will put additional pressure on limited natural resources for agricultural production (Dominguez-Faus *et al.* 2009; de Fraiture *et al.* 2008; Stone *et al.* 2010). In the case of the USA, this is exacerbated by the Government requirement to produce 57 billion litres of ethanol from corn by 2015 (de Fraiture *et al.* 2008). All this points to the fact that while a low carbon economy is important, it comes with a significant price tag for water resources – green energy for blue resources as pointed out by de Fraiture and others (2008).

4.4. Summary

Water usage in the production of energy from conventional and renewable fuels has been explored in this study. Data were acquired through a combination of a desktop study and expert interviews. Water withdrawal and consumption levels at a given stage of energy production were investigated. Results show that there are limited data on all aspects of water usage in the production of energy, accounting in part for the significant variations in the values of water intensity reported in the literature (with some approximations). It is vital to take into account all aspects of the energy life cycle to enable isolation of stages where significant amounts of water are used.

Conventional fuels (nuclear and fossil fuels) withdraw significant quantities of water over the life-cycle of energy production, especially for thermoelectric power plants operated with wet-cooling systems. The quality of water is also adversely affected in some stages of energy production from these fuels. Hydro is by nature the most water-intensive source of energy in terms of withdrawal (among all the energy sources covered in this work). However, it is limited in terms of its water consumption. Similarly, biomass is water intensive, but this water would have been used in the production of crops regardless. Thus, these two renewable energy sources have a perceived high impact on water resources. It should be noted, however, that in SA, biofuel generation is currently second rather than first generation only. In this case, the water consumption could be disregarded altogether. Solar photovoltaic (PV) and wind energy exhibit the lowest demand for water, and could perhaps be considered the most viable renewable options in terms of water withdrawal and consumption. Moreover, the observed water usage in these renewable energy technologies is predominantly upstream.

5. WATER FOR ENERGY IN THE CONTEXT OF CLIMATE CHANGE

By: Sauka S, Goga S, Laing K and Pegram G

5.1. Introduction

South Africa (SA) is a relatively water-stressed country and its water resources are under mounting pressure as a result of increasing water-related economic activities, population growth, and the prospect of climate change. Access to energy and water resources is required for economic growth, and is central to the building of an adaptive capacity to climate change.

As a developing country undergoing rapid industrialisation, SA's demand for energy supply is increasing steadily. However, the country is also relatively water-stressed and its water resources are under increasing pressure as a result of increasing water related economic activities, increasing population growth, and climate change. And, although policy and planning have slowly emerged to foster the conjoined savings and management of water and energy resources, a limited collection of water and energy entities have initiated the optimisation of processes that support integrated resource management. There is, therefore, the need to consider the impact of energy choices on South Africa's water resources and the need to understand the trade-offs associated with the social, environmental and economic impacts of these choices for the future.

The energy sector in the SA region is growing, which is largely due to the coal-based power plants that are mainly located in Zimbabwe, Botswana and SA. Regional and national energy technology choices impact SA's water resources beyond the volumes consumed and withdrawn. Other impacts include a requirement to maintain water resource levels for assurance of supply and impacts on water quality. These impacts must be well understood in the context of the status of catchment water quality to facilitate effective management strategies within the water-energy nexus. Climate change projections indicate that the region, together with East Africa, will likely experience increased temperatures and rainfall variability, leading to more severe droughts, floods and heat waves. Although impacts on local water resources and on energy technologies are not fully understood, the projections give guidance in terms of precipitation regimes and temperatures.

The integrated nature of water-energy nexus and development imperatives, for example, access to energy and to water, suggests that water-energy management solutions often have wider socio-economic implications. Case studies may, in the form of lessons learned, offer some insight into factors that have influenced the successful exploration of opportunities and the concession of trade-offs in the water-energy nexus.

5.2. The water-energy nexus: energy supply chain and water impacts

Water and energy are intimately linked – substantial energy is required to move water over long distances for social and economic purposes, while large amounts of water are necessary to produce energy. The interlinking nature of water and energy is demonstrated in the figure below.

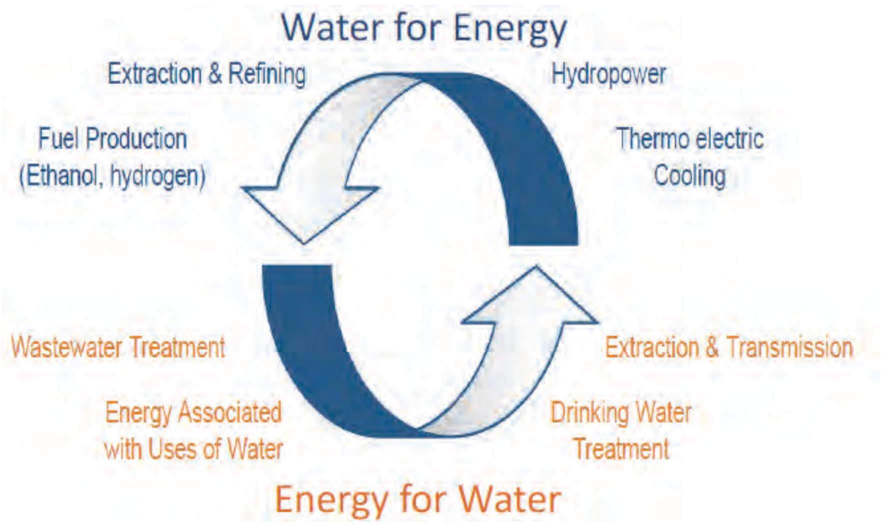


Figure 5-1: The Interlinking nature of water and energy.

As the figure demonstrates, water is required for cooling, extraction and refining, as well as for fuel production. Water is required for a variety of purposes in the energy generation cycle of different energy technologies. For thermal power plants, water is required in the fuel extraction, transportation to the facility, generation and cooling of steam, as well as general maintenance. Nuclear, geothermal, and solar thermal facilities have similar requirements. Hydropower requires a consistent water supply. For some renewable technologies such as wind and photo-voltaic (PV) solar, there are lower direct water requirements but there may be water use implications associated with the land necessary for generation and construction materials.

The following four sections factors capture, in a comprehensive way, where water is required, used, consumed, or impacted by the different technologies associated with energy generation.

5.2.1. Water use associated with storage for assurance of supply

Stored water is needed for energy generation at a high assurance of supply (and to provide static head for hydropower). There are evaporative losses associated with water storage, whether the water is going through hydropower turbines or to cool a thermal plant. Two energy generation technologies, in particular, require a lot of stored water: firstly, thermal plants that use wet cooling technologies have high water supply assurance requirements, and dedicated storage in hydrologically variable environments; and secondly, hydropower generation often requires storage for assured flow and static head.

5.2.2. Water use associated with the fuel supply chain

For technologies that generate fuel, water used in producing the fuel (that is associated with the fuel stock supply chain) can be significant and should be considered as part of the water use required for energy production. Water use in the supply chain should include water lost through evaporation associated with storage. The energy generation technologies requiring large amounts of water in the fuel supply chain are as follows: firstly, first generation biofuel feedstocks need water for cultivation of the biomass, and this water may be sourced from rainfall (green water) and/or irrigation (blue water). In addition, biofuel production requires water for processing of the biomass into fuel. Secondly, for thermal, gas/diesel or nuclear plants, the extraction processing and transport of coal, petrochemical or nuclear material may require large amounts of water.

5.2.3. Water use associated with the generation facility

Water is used directly and indirectly when generating electricity. The quantity of water is dependent upon the technology, the configuration of the facility, the specific generation process within the facility and the efficiency of the plant. The net use of water is important because return flow is available to other users. The following technologies require large amounts of water when generating electricity: firstly, for thermal plants water is required for cooling technology; secondly, hydropower uses water for generation of electricity but returns to the water to the water resources; and thirdly, wet-cooled CSP plants need water for generating electricity and some PV plants need water to clean solar panels in sandy areas.

5.2.4. Downstream water resource impacts

The downstream water resources impacts of energy production facilities or fuel supply chains should also be considered, especially where these affect other water users or the environment. Water quality may be affected in several ways when generating electricity, including during fuel extraction and processing, discharging waste in the water when water is returned from the generation facility, air pollution during energy generation and contamination of the area when generation is taking place. Furthermore, if the flow patterns of water are changed (for example, through the construction of hydropower power dams), this may also affect downstream water users.

The following energy generation technologies have water resource impacts: Firstly, thermal technologies may have a large impact on water quality at the mining sites (coal mining) and may also contribute to salinization of water resources due to emissions or waste discharge when generating electricity. Secondly, nuclear power plants may have a similar impact. In addition, contamination of the electricity generation site and surrounding areas is a real concern, as was seen with recent disaster at the Fukushima nuclear power plant in Japan. Thirdly, hydropower usually the flow of water resources and this can have a large environmental impact and impact on water availability for other users. Fourthly, biofuel production may have water quality impacts when producing the fuel (for example, during fertilization) as well as when generating power. The figure below shows the water use impacts along the energy supply chain.

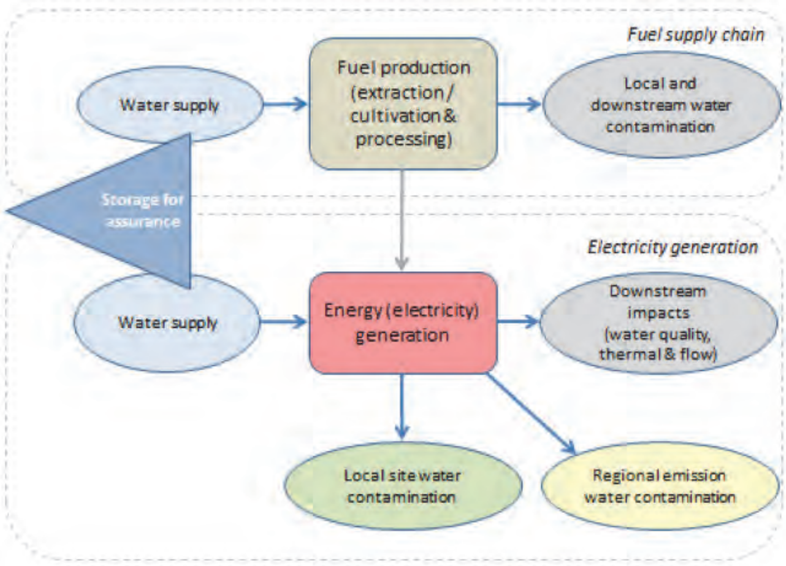


Figure 5-2: Conceptualizing water use and impacts associated with energy generation (Source: Conceptual Framework for Assessing Water Use in Energy Generation, with a focus on Hydropower (Pegasys 2011)).

It is worth noting that water use in the energy supply chain occurs in two almost distinct phases:

- Water associated with fuel supply chain – Water use calculations should consider how water is used in the fuel supply chain, either in terms of water supply or as a result of the water quality impact of the extraction/cultivation of the fuel.

Water associated with generation – Water use from energy generation, including cooling, cleaning, and evaporation, as well as the water impacts of the facility operation.

5.3. Energy choices in South Africa

SA's population and the economy have seen a steady increase in the last 20 years. Sufficient, reliable sources of energy are essential for the continued growth of industrialized nations. As the country increasingly focuses on industrialization as a source of economic growth, and on service provision for the domestic sector (e.g. the mass electrification programme to increase access to electricity), an increase in demand for energy has ensued. In fact, South Africa's energy demand is expected to be twice the current levels by 2030.

Over 85% of the energy used in the world is from non-renewable supplies such as fossil fuels (coal and oil) and nuclear power. SA, like other developing nations, is highly dependent on non-renewable energy sources. However, in the last few years, the energy mix to produce electricity in SA has attracted more renewable energy producers. This has mostly been driven by policy decisions to increase the contribution of renewable energy to the national energy mix, and also by technological advancements and uptake of the technology that makes renewable energy more affordable.

Based on data published by Statistics SA in the Energy Accounts for SA 1995-2001 report, and the subsequent 2002-2009 report, for each energy source and sector, a 15 year trend analysis is visible (i.e. 1995 to 2009). The South African economy and domestic sector depend profoundly on energy resources provided from coal. Figure 5-3 provides a graphic presentation of the total energy use in SA, while Figure 5-4 illustrates the percentage contribution of each sector (in 2009).

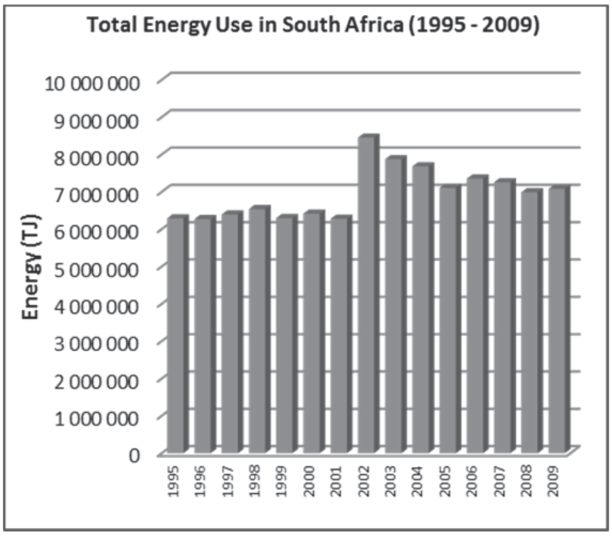


Figure 5-3: Total Energy Use Trend (1995-2009).

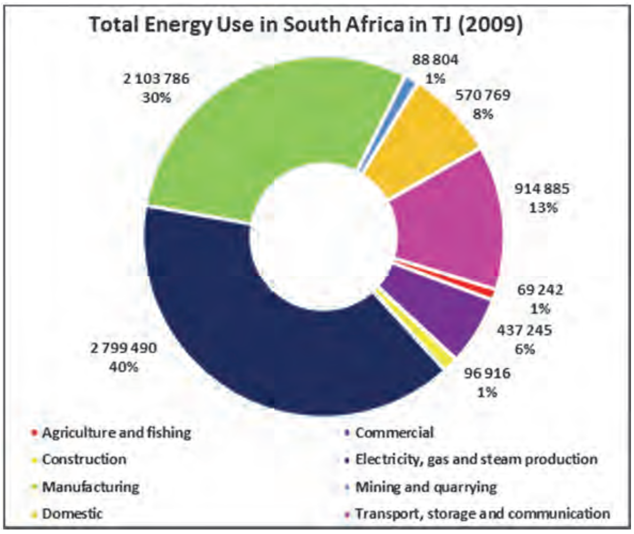


Figure 5-4: Total Energy Use per Sector (2009).

The total energy consumed in SA was 6 292 PetaJoules (PJ) or 6 291 551 teraJoules (TJ) in 1995, and has increased to 7 081 PJ in 2009. This energy use includes the energy that is attributed to the energy used for electricity, gas and steam production, but excludes the energy allocated to exports, losses in distribution, and also the inventory changes in the Energy Accounts. Should these exclusions be incorporated, the total energy consumed in South Africa would be 8 201 PJ in 1995, and 8 958 PJ in 2009. This energy use is mostly attributed to the industrial sector, with the transport sector and the domestic sector consuming the lowest proportion of the total energy. South Africa's primary and secondary energy consumption, as estimated by the International Energy Agency (IEA) for 2009 to 2012, is illustrated in Figure 5-5 below.

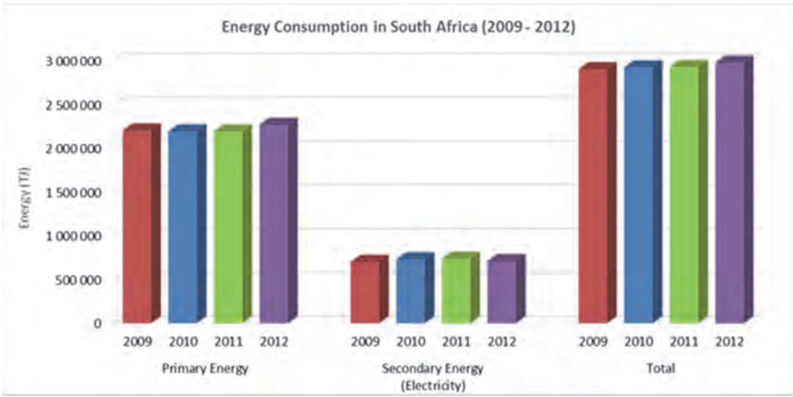


Figure 5-5: Total energy use trend (2009-2012), excluding energy for electricity production, oil refineries, power plants, and other industrial processes.

Figure 5.6 provides a graphic presentation of the energy choices in South Africa. It illustrates the trend in energy sources in the country over the 15 year period.

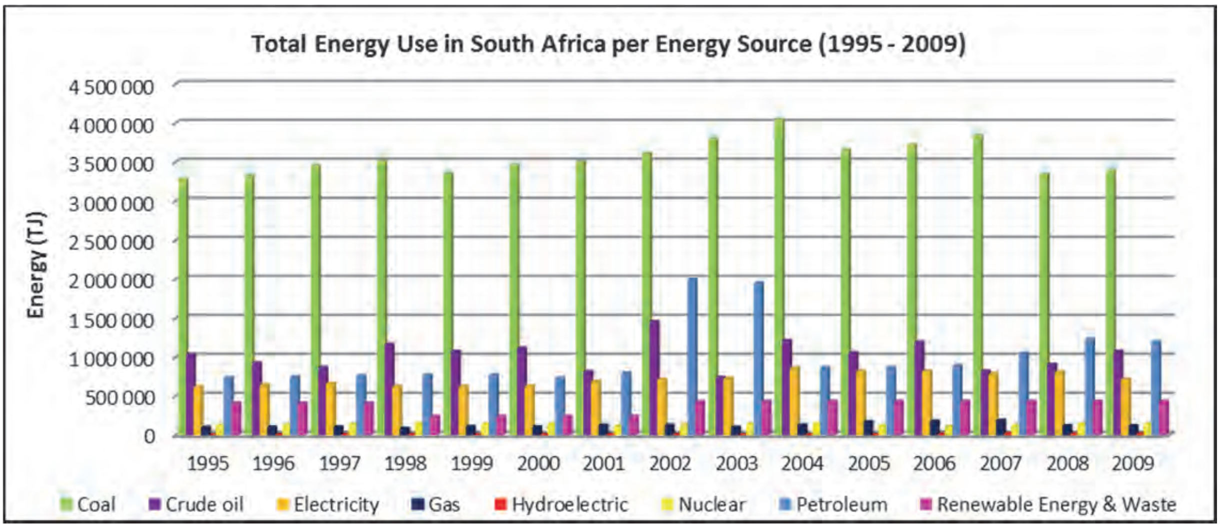


Figure 5-6: Total Energy Use per Energy Source in South Africa (1995-2009).

The source of energy most widely used in South Africa from 1995 to 2009 was electricity, which relies heavily on coal, followed by petroleum products and crude oil. **Electricity** is a secondary energy product that requires primary resources such as coal, crude oil, gas, hydroelectric, nuclear, petroleum and renewable sources as inputs in the production process. Electricity is the most important secondary energy source in South Africa, and the highest user of electricity in the country being the industrial sector. Other sources of energy were also used, although to a smaller extent. These include gas, hydroelectric power, nuclear power, and other renewable energy sources (which include resources such as bioenergy, wave, wind and solar power).

Coal is the most abundant fossil fuel in the world with an estimated reserve of one trillion metric tons. The South African energy sector is dominated by coal, and since approximately 70% of coal used locally is to produce electricity, it is expected to remain the major overall electricity generator for the next few decades. In addition to electricity production, coal is used commercially and for domestic heating and cooking in rural areas. Although South Africa has abundant coal reserves and reliable coal-fired power stations, coal is notorious for its air and water pollution challenges that are prevalent in South Africa.

Crude oil in South Africa is imported from the Middle East and Africa (Saudi Arabia, Iran, Kuwait, Yemen, Qatar, Iraq, Nigeria, Egypt and Angola). Crude oil is a mixture of hydrocarbons that exists in liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities. Crude oil consumed for energy by industry or it is refined to produce a wide array of **petroleum products**, including heating oils, gasoline, petrol, diesel, residual fuel, oil, paraffin, jet fuel, aviation gasoline, liquefied petroleum gas (LPG), refinery gas, lubricants, asphalt, ethane, propane, butane, and many other products used for their energy or chemical content. (The analysis provided in this chapter considers both crude oil and petroleum products – the crude oil that is refined to petroleum products is therefore not accounted for as part of the crude oil energy consumption figures.)

Natural gas production is often a by-product of oil recovery, as the two commonly share underground reservoirs. Limited natural gas reserves exist around the Southern African coast. Even though gas consumption has increased in recent years, the contribution and importance of gas in the South African energy economy is still low compared to other countries. The proposed Mozambique-South Africa gas-transmission pipeline from Maputo to Gauteng would potentially supply many small towns near its route.

South Africa is a relatively dry country and lacks large rivers that are suitable for large-scale **hydro-electricity** generation (most of the large rivers in the Southern African region are north of South Africa's borders). The Eastern Cape and KwaZulu-Natal are endowed with the best potential for developing small (i.e. less than 10 MW) hydro-electricity plants. These plants can either be stand-alone or can exist in a hybrid combination with other renewable energy sources. Advantages can also be derived from the association with other uses of water, for example, water supply, irrigation, flood control, etc. However, the long-term environmental damage of hydro-electric schemes on rivers needs to be investigated. Within the first four REIPPPP bidding windows capacity of 18.3 MW from 3 projects was contracted to the grid (Forder 2015).

In a **nuclear power plant**, the fission of uranium atoms in the reactor provides the heat required to produce steam for generating electricity. Nuclear fission does not emit greenhouse gases and is therefore considered a 'cleaner' fuel than fossil fuels. The Nuclear Energy Policy (DoE 2008) aims to increase the role of nuclear energy as part of the process of diversifying South Africa's primary energy mix. The policy has a vision for the country to become globally competitive in the use of innovative technology for the design, manufacture and deployment of state-of-the-art nuclear energy systems and power reactors, and nuclear fuel-cycle systems.

Renewable energy sources include:

- **Bioenergy** is generated when organic matter is used to produce energy such as providing heat, making liquid fuels, and providing light. The figure below illustrates various feedstock that may be used in the production of bioenergy. The most common source of feedstock is biomass, such as wood and other natural products, which is replenishable as an energy source. Biomass is used commercially in pulp and paper mills and sugar refineries by burning bulk from logs, black liquor and bagasse to produce process heat. Biomass is also used by impoverished South African communities, who rely on wood for cooking food and heating their homes. In some rural areas the supply of wood is not keeping up with demand. As a result, wood collectors have to walk longer distances to meet their daily wood requirements. Another source of bioenergy includes waste that is directly combusted to produce electricity or indirectly through the production of biogas or landfill gas. Biofuels such as ethanol or biodiesel, a liquid based form of bioenergy, can be used for transportation. Within the first four tender bidding windows of the REIPPPP capacity of 78 MW from two biomass projects and 18 MW from a single landfill project was contracted to the grid (Forder 2015).

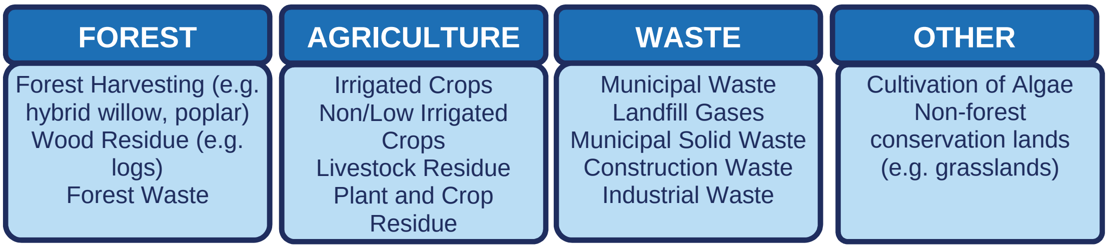


Figure 5-7: Sources of feedstock materials for conversion to bioenergy.

- **Concentrating solar power (CSP)** technologies use mirrors to focus and convert solar radiation into heat, which is transferred to a working fluid. The heat in the fluid is then used to drive the generator and produce power.

- **Photovoltaic (PV)** panels convert sunlight directly into electricity by absorbing photons and releasing electrons. The free electrons are captured on an electrode and result in an electric current, which can be used as electricity (SEA 2009). PV technologies can be used across a range of scale from small-scale individual embedded generators to vast arrays in large scale power plants. CSP technology is used for large scale electricity production. Both technologies can be connected to feed the national grid. The Southern African region is well endowed with sunshine all year round, with a potential for 36 217 GWh solar-thermal power generation per year, which is one of the highest in the world. Grid parity has reportedly been achieved for embedded PV (CSIR 2015) and for commercial PV projects during the roll-out of the REIPPPP (Juwi Renewables 2015). In the first four REIPPPP bidding windows capacity of 700 MW from 8 CSP plants and 2 314.55 MW from PV projects was contracted to the grid (Forder 2015).

- **Wave power (or ocean energy)** could potentially be derived from the various characteristics of the sea. The main reason why this energy resource is not currently being harnessed is that no technology has been proven for South African coastline conditions. Various companies are testing systems internationally to develop viable solutions. Once technical reliability has been proven, cost effectiveness in relation to other solutions will have to be established.

- **Wind energy** technologies have attracted increasing levels of attention in recent years such that the Department of Environmental Affairs commissioned a wind atlas for South Africa as well as strategic environmental assessments to expedite environmental impact assessments for wind (and solar PV) project applications (CSIR 2013). Eskom's Klipheuwel, just north of Cape Town, was the first large wind turbine facility in Sub-Saharan Africa. In the first four rounds of tender bidding in the REIPPPP capacity of some 3 460.6 MW has been contracted to the grid (Forder 2015).

These energy sources drive the industrial sector of the economy, and also provide energy to the transport and domestic sectors. As portrayed above, South Africa's economy is highly energy-intensive. As economies develop and technologies improve, energy intensity naturally tends to decline, and per capita energy consumption tends to increase. In South Africa the contraction of minerals and mining within the economy as a whole has supported such a trend; as a result, in 2006, the country ranked 11th in the world in terms of primary energy intensity. South Africans collectively also have a relatively high per capita energy intensity, despite the fact that about a quarter of the population lack access to modern energy services.

The actual national electricity demand has been lower over the past three years than forecasted in the IRP 2010; in 2012, the forecasted demand was 270 TWh while the actual was 249 TWh. While electricity demand was lower than forecasted, economic activity has been only marginally different from that forecasted. A revised economic and electricity sector outlook has been developed to inform decisions required in the lead-up to a new iteration of the IRP in 2014. The demand in 2030 is now projected to be in the range of 345-416 TWh as opposed to 454 TWh expected in the policy-adjusted IRP. From a peak demand perspective, this means a reduction from 67800 MW to 61 200 MW, with the consequence that at least 6 600 MW less capacity is required (DoE 2013c).

The IRP 2010 policy adjusted scenario suggests that coal-based power generation may absolutely increase by roughly 20%, but that the total contribution of coal would drop from 92% to about 65% in the energy mix as a result of planned new nuclear capacity of 9.6 GW, renewable energy capacity of 17.8 GW, imported hydropower increased by 2.6 GW, and new gas power plants of 6.3 GW. However, other clean energy sources also need to be explored further, such as wave, wind, solar and bioenergy so as to increase the contribution of renewable energy to the national grid.

5.4. Water resources considerations for the water-energy nexus

Climate change is expected to have a major impact on the people, ecosystems and economy of South Africa. It is also widely acknowledged that water resources are one of the primary media through which the impacts of climate change are going to be felt. South Africa is already characterized by low rainfall and high evaporation rates, together with temporal and spatial variability that pose challenges to economic development and livelihoods. Both agriculture and urban-industrial areas in many parts of the country have suffered from both floods and droughts in the past. While South Africa's water infrastructure and water resource management assist the country in adapting and responding to this variable climate, it does impose a social and economic burden to the country.

5.4.1. Water resources in South Africa

The climate in South Africa varies from desert to semi-desert in the west, to sub-humid in the east. The average rainfall in the country is about 450 mm per annum, well below the global average of 860 mm per annum, and is seasonal in winter in the west, summer in the interior and east, and all year on the south coast. The combined flow of all rivers amounts to approximately 49 000 million m^3 per annum, which is less than half of the Zambezi River, the closest large river to South Africa. In the global context, South Africa has scarce and limited water resources. In addition, four of South Africa's main rivers are shared with other countries, and thus supply other nations water needs too; these are the Orange (Senqu), Limpopo, Inkomati, and Pongola (Maputo) Rivers. Together, these four river basins drain about 60% of the South Africa's land area and contribute about 40% of its total surface runoff.

South Africa's water principal water policies are the National Water Act (NWA) (Act 36 of 1998), as well as the 2004 National Water Resources Strategy (NWRS). The NWA was established to ensure that freshwater reserves have been set aside for both human consumption and to ensure the proper functioning of healthy ecosystems (DWAF 1998); the NWRS emphasises the importance of equitable access to reliable water supplies. To facilitate the management of water resources, the NWRS divided the country has been divided into 19 catchment-based water management areas (WMAs). However, after a financial and institutional assessment of the WMAs, the NWRS2 consolidated the 19 previous WMAs into 9 WMAs. Figure 5-8 shows the previous and consolidated WMAs, which consider catchment and aquifer boundaries, financial viability, and equity amongst others.

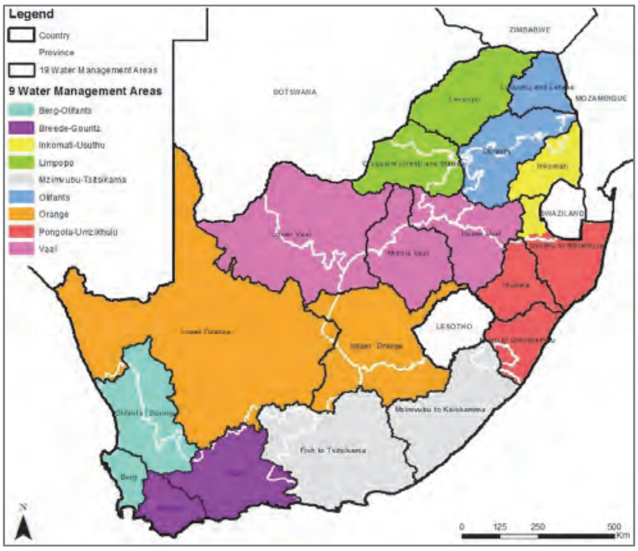


Figure 5-8: Water Management Areas in South Africa.

The NWA provides for the establishment of Catchment Management Agencies (CMA) in each of the nine WMAs to take responsibility for water resources management at a regional or catchment level. The role of CMAs is to ensure that water resources are managed in accordance with national policies, guidelines and standards in their jurisdiction, through the active participation of local communities and other stakeholders.

As the consolidation of the WMAs was confirmed shortly before the NWRS2 was due, the national and WMA water balance tables (for current and projected future water balance) in the NWRS have not been updated. Detailed regional level water resource Reconciliation Strategies have however been developed, which are directed at meeting specific demands as a basis for water management and infrastructure planning for major river basins (NWRS2 2013).

Factors which influence the requirements for water in South Africa include climate, the economic activities (i.e. agriculture, industries), population and the standards of living. Because of the trend towards population growth, urbanisation and the expected economic growth in urban centres, there exists a great uncertainty in the long term user estimates. Apart from the requirements for water in the established user sectors, which can be calculated with numerous scenarios, the quantities of water required for redressing inequities and poverty eradication depends strongly on the specific requirements of local and regional development strategies, and are therefore difficult to project All these factors were taken into consideration when forecasting future water requirements. Eskom's projections of future water requirements for power generation were also added, and provision was made for known and probable future developments in irrigation, mining and bulk use (NWRS2004).

The NWRS states that both the surface and groundwater resources in the country are nearly fully developed and utilised. This is due to concentrated urban areas, industrial zones and the over-exploitation and over-allocation occurring in some localised areas. The reverse applies to the well-watered south-eastern region of the country where there are still significant undeveloped and under-utilised resources. According to the strategy, climate change is likely to lead to more intense and prolonged periods of drought. The eastern coastal areas of the country are projected to become wetter, while in the interior and the western parts of the country it will become drier (NWRS2 2013). A decrease in water availability will also impact on water quality, thereby further limiting the extent to which water may be used and developed.

Chapter 7 provides a detailed spatial overview of the current and projected future water resources in the country. This is supported by a detailed local level assessment, which is contained in Appendix G.

5.4.2. Water quality in South Africa

Water quality refers to the physical, chemical and biological characteristics of water, and describes how suitable the water is for its intended purpose, either in nature or for use by different water users. Different ecosystems and different user groups can have widely variable water quality requirements, which are often referred to as the fitness for use for the relevant water user group. For example, the quality of water to maintain trout streams is different to the quality of water required for irrigation, electricity generation, or human consumption.

The factors that influence the quality of water can result from human activities or natural systems. Natural systems include the geology of formations, the surrounding vegetation, the slope of the land, or the flow rate of the water system. Human activities are more complex and varied, and include land use activities, agricultural practices, human settlements, industrial and mining industries or failure of infrastructure (including water treatment and water resource management interventions such as diversion, storage and inter-catchment transfer systems).

Human impacts on water quality include changes in salinity, eutrophication, micro-pollutants, microbiological pollutants, erosion and, or sedimentation. The occurrence, transport and fate in the aquatic environment of numerous persistent and toxic metals and organic compounds have given cause for serious concern. The effects of polluted water on human health, on the aquatic ecosystem (aquatic biota, and in-stream and riparian habitats) and on various sectors of the economy, including agriculture, industry and recreation, can be disastrous.

The South African Water Quality Guidelines (DWAF 1996) provide a Target Water Quality Range (TWQR) for each of the water use sectors in terms of 'fitness for use', which is based on the acceptable range of concentrations or levels of specific physical, chemical, biological and aesthetic properties of water. In the South African context, the main sources that contribute to poor water quality include:

- Mining and industries, resulting in chemicals, toxins, acidity and increased metal content.
- Urban developments, resulting in increased salinity, nutrients and microbiological activities.
- Agriculture, resulting in increased sediments, nutrients, agro-chemical and salinity; herbicides and pesticides and other metals and manufactured organic components have serious impacts on human and animal health.
- Untreated sewage entering water resources, resulting in microbial contamination arising mainly from a lack of or untreated (due to poorly maintained) sanitation services carrying pathogens that may cause water-borne diseases such as diarrhoea and cholera.

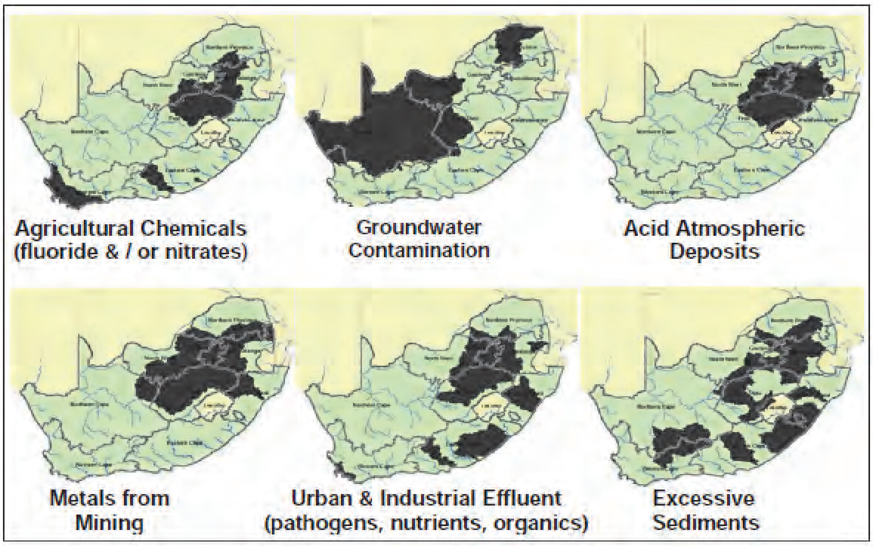


Figure 5-9: Locations of major sources of pollution in South Africa (Source: Maree 2010).

Other sources of pollution include non-point pollution from various land-use activities, acid atmospheric deposits, and erosion caused by excessive soil losses and sedimentation. The distribution of the various sources of pollution that affect surface water resources, aquatic ecosystems, wetlands, estuaries and groundwater resources are illustrated in Figure 5-9.

Contamination of groundwater resources or of sediments deposited in riverbeds, impoundments and estuaries can cause irreversible pollution, sometimes long after the original release to the environment has ceased (Directorate of Water Quality Management nd). It is, therefore, essential that the quality of water resources is managed effectively to ensure the health of the population and ecosystems, and to ensure that industries function in an environmentally sustainable manner. Deteriorating water quality leads to increased treatment costs of potable and industrial process water, and decreased agricultural yields due to increased salinity of irrigation water (*ibid*).

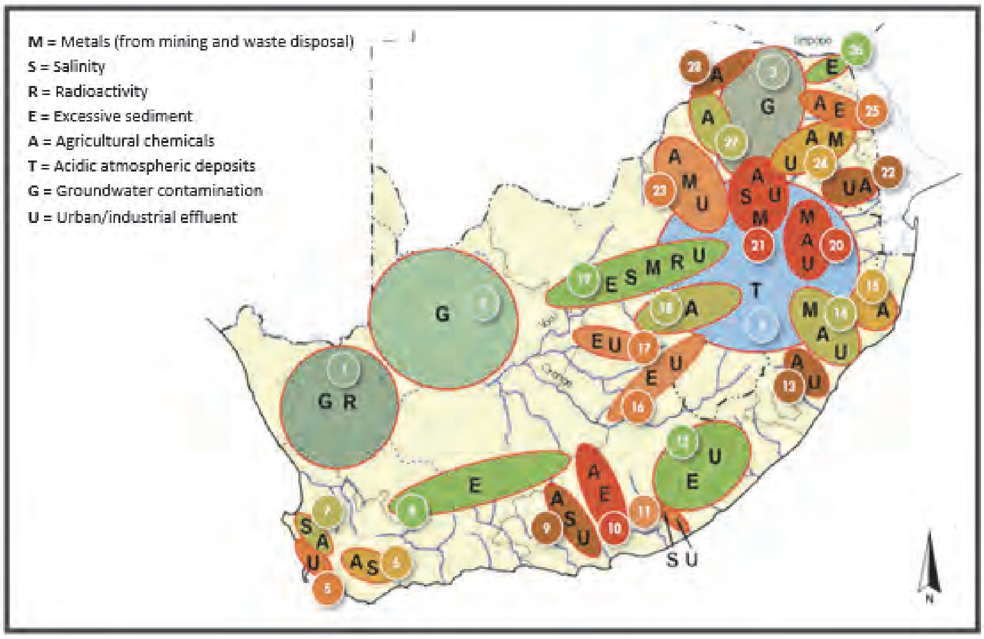


Figure 5-10: Water quality in South Africa (Source: Ashton 2009).

Ashton (2009) provides an overview of the water quality situation in South Africa. In some areas, several different sets of activities combine to exert complex changes in water quality, with the result that the water quality in many areas of the country has been compromised to the extent that it poses serious risks to human health and to the natural environment; the local quality of water resources such as the metallic content and salinity is illustrated in Figure 5-10 (*ibid*).

Ashton (2009) provides the summary below of the water quality of all the major river basins in the country.

- **Limpopo River Basins (3):** There are high concentrations of nitrate and fluoride in the groundwater. Almost all the nitrate is of natural origin with a few small areas showing minor elevations in nitrate concentrations caused by agricultural activities.
- **Central Highveld (4):** The atmospheric depositions from coal-fired power plants and heavy industries contain low concentrations of sulphur and nitrogen oxides and have a

moderately acidic pH. The acidity from the atmospheric deposition is accentuated by the highly acidic seepage (AMD) from operating and abandoned mines.

- **Cape Town Urban Rivers (5):** There are large volumes of contaminated runoff from urban areas and informal settlements; discharges of treated, partially treated and untreated domestic and industrial effluent. The receiving urban rivers contain large numbers of pathogenic organisms and high concentrations of metal ions, nutrients, salts and Endocryne Disrupting Compounds (EDCs).

- **Breede River System (6) and Berg River Basins (7):** The elevated concentrations of dissolved salts from the naturally saline soils and groundwater are aggravated by intensive agricultural land-use. Irrigation return flows contain a variety of agro-chemicals (fertilisers and pesticides). The Berg River system also contains mildly saline groundwater.

- **Karoo River Basin (8):** Easily erodible and vulnerable soils and rock formations. Strong flowing rivers after rainfall events carry high concentrations of suspended silt and clay, posing difficulties to stock farmers in the area and leading to rapid accumulation of sediment in water storage structures.

- **Sundays River Basin (9):** There is a progressive increase in river salinity due to naturally elevated concentrations of dissolved salts, high evaporation rates and high rates of water abstraction for irrigation. Return flows from irrigated agriculture contain elevated concentrations of a variety of pesticides and fertilisers. The water transferred from the Gariep Dam on the Orange River often contains high concentrations of suspended solids. The lower reaches receive urban runoff, as well as inflows of treated, partially treated and untreated domestic and industrial effluent from towns, cities and informal settlements. These effluents contain large numbers of pathogenic organisms and high concentrations of nutrients, salts and EDCs.

- **Great Fish River Basin (10):** There is a progressive increase in river salinity due to naturally elevated concentrations of dissolved salts and high evaporation rates combined with high rates of water abstraction for irrigation. In addition, the rocks and soils forming the catchment are easily erodible and over-grazing by livestock results in high concentrations of suspended sediments.

- **Buffalo River Basin (11):** Saline effluents that are discharged from tanneries cause elevated concentrations of dissolved salts and metal ions in the lower reaches of the river. In addition, the discharge of treated, partially treated and untreated urban and industrial effluent, as well as contaminated runoff from urban centres and informal settlements, results in the river containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and EDCs. As a result, toxic blooms of cyanobacteria occur frequently in the major reservoirs located close to East London.

Due to the nature of the South African economy, the quality of water resources is deteriorating through marked increases in nutrients and microbiological contaminants as a result of various activities, for example, the activities of the mining sector have resulted in serious environmental consequences and acid mine drainage (AMD) incidence and threat, which are prevalent in a number of concentrated mining regions in the north-eastern parts of South Africa.

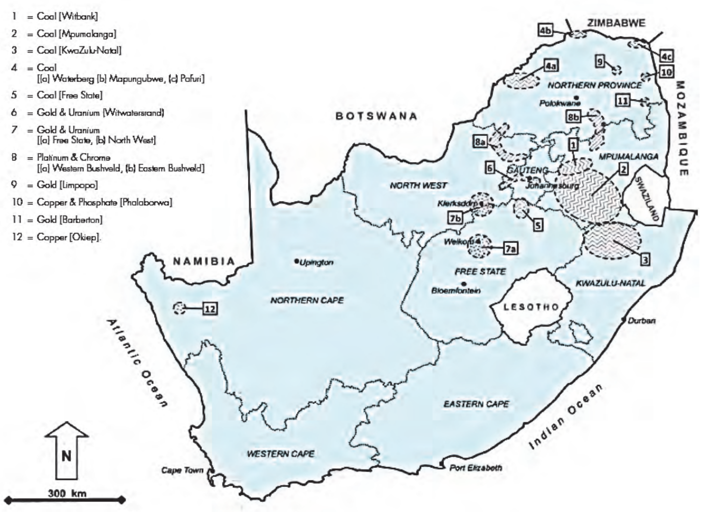


Figure 5-11: Mining areas susceptible to AMD in South Africa (Source: Oelofse and Strydom 2010).

As indicated in Figure 5-11, AMD has been reported at a number of distinct areas within South Africa, including the Witwatersrand Gold Fields, Mpumalanga, KwaZulu-Natal Coal Fields and O'Kiep Copper District. The priority areas that have been flagged by DWA are the Olifants Catchment, the West Rand and Waterberg areas. There is urgency in the need to address the deteriorating water quality as many of the affected watercourses are in close proximity of densely populated urban areas. In addition, the Witwatersrand Goldfields and the Witbank Coalfields are already posing significant water quality problems to the Upper Vaal and Upper Olifants River catchments, respectively. This, in turn, constrains the use of water resources for urban, industrial, power, agriculture, or other water requirements, either due to insufficient supply or inadequate quality.

Mine impacted water and other sources of pollution impact the chemical and physical characteristics of the water resources. The main impact of chemicals in the water relate to salinization (dissolved salts) that may render water unfit or very costly to treat for other uses such as irrigation and human consumption. Eutrophication, which is the enrichment of water with plant nutrients, gives rise to the excessive growth of macrophytes and microscopic plants such as algae and cyanobacteria in rivers and reservoirs. Cyanobacteria, often referred to as blue-green algae, is toxic and may cause the water to be unfit for recreational, irrigation and domestic use (NWRS2004).

Feasible special management techniques may be applied to improve water quality to appropriate standards for particular uses. For example: pollution from wastewater treatment works has become a major concern in South Africa as most wastewater treatment works are overloaded – a strategic approach to minimising the contamination of the resource to which treated effluent is returned has been developed and implemented in a few municipalities, such as Nelson Mandela Bay and the City of Cape Town. This includes the reduction or removal of contaminants through treatment processes, the prevention of contamination during the conveyance of wastewater, and the storage and disposal of sludge. The Green Drop certification, a part of the Wastewater Risk Abatement Plan, has been implemented across all municipalities and private wastewater treatment works, and reflects the state of compliance and assistance that is required by municipalities to decrease their wastewater risk to the environment (NWRS2 2013).

Water quality management forms an integral part of the strategy for water resource management to provide sufficient good quality water, and to ensure environmental sustainability of water resource use. All water resource developments also impact on the functioning of aquatic ecosystems, typically by changing habitat conditions as a result of changed flow and water quality regimes. Environmental considerations are thus also integral to all reconciliation interventions. The impacts on both the social and natural environment need to be taken into account, and assessed together with the technical, economic and other factors.

5.4.3. Climate change impacts of water resources in South Africa

South Africa has high climate and water resource variability. The South African Climate Adaptation Strategy for Water is based on the framework provided by the SADC Climate Change Adaptation Strategy for Water (2011). As with the SADC strategy, the South African strategy prioritises adaptation in dealing with the effects of climate change, rather than mitigation. The strategy starts with the recognition that climate change has already resulted in changing intensity and frequency of extreme weather events, and has thus increased the vulnerability of poor countries and communities to climate change.

The strategy is underpinned by work done as part of defining the status quo on climate change in South Africa. The focus of the strategy is to develop climate change resilience and to reduce vulnerability through integrated water management at a variety of scales, including regional, river basin and local levels. Integrated water resources management is seen as a critical tool in the management of climate change impacts. Therefore, as part of the strategy, six hydro-climatic zones were outlined, which reflect the institutional boundaries defined by WMAs, and also represent similar climate and hydrological characteristics. As indicated by the DWA 2014 report titled “A status quo analysis report for water resources", the zones can be defined as below and as illustrated in Figure 5-12:

- Zone 1: Limpopo, Olifants and Inkomati WMA in the north
- Zone 2: Pongola-Umzimkulu WMA in KwaZulu-Natal in the east
- Zone 3: Vaal WMA in the central interior
- Zone 4: Orange WMA in the western interior
- Zone 5: Mzimvubu-Tsitsikamma in the south-east
- Zone 6: Breede-Gouritz and Berg Olifants WMAs in the south-west

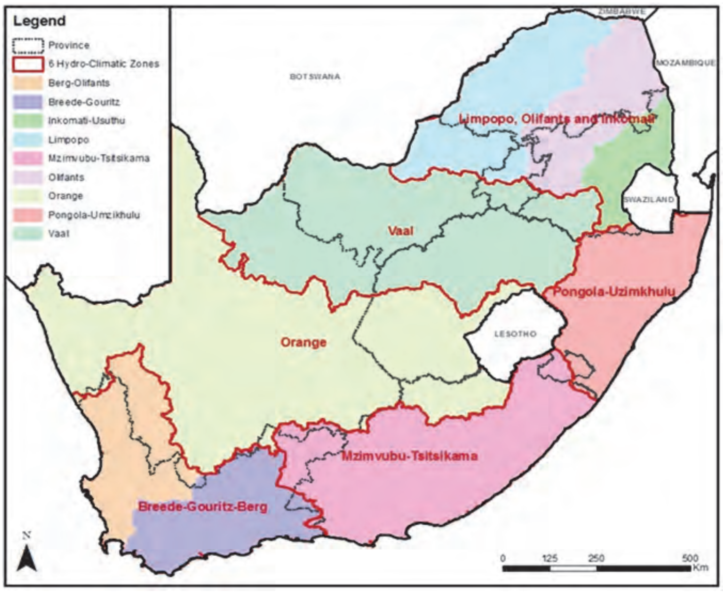


Figure 5-12: Six Hydrological Zones.

A high-level overview of the various hydro-climatic zones in South Africa in provided below, as well as insights into the unique impacts of climate change and in each of the zones.

Zone 1: The Limpopo, Olifants and Inkomati WMA in the northern interior

The northern interior region has a range of economic activities, including mining, agriculture, forestry and the wildlife parks like the Kruger National Park. The region is water scarce. Climate change is projected to impact the region through increased variability in rainfall intensity and distribution; the impact of the variability needs to be better understood, especially considering that this is an area of major economic investment.

The region is a summer rainfall region, although regional rainfall patterns are highly variable and complex in that it is largely driven by similar regional climate dynamics as the central interior, but it is also influenced by the climate dynamics and some complexities of the eastern escarpment. The Highveld areas to the west are fairly dry and experience rainfall in the form of intense convective storm systems that are influenced by moisture from the north. The Lowveld areas to the north east experience more rainfall due to enhanced moisture availability from the Mozambique Channel and interactions with the escarpment topography. Projected climate impacts in this region include: increased variability and likely reduction in overall rainfall, particularly in the summer rainfall period; and significant increases in temperatures, resulting in increased evaporation.

Zone 2: The Pongola-Uzimkulu WMA in KwaZulu-Natal in the east

The economic activities of this water abundant region include mainly the agricultural and urban sectors. The east coast is a summer rainfall region with rainfall produced by large-scale convective systems driven by low pressure troughs. High rainfall events are common, due to more localized convective systems driven by moisture from the adjacent warm Agulhas current. Projected climate impacts in this region include: a likely increase in summer rainfall patterns, with increased large events (storms and floods); and a moderated increase in temperatures due to proximity to the ocean.

Zone 3: The Vaal WMA in the central interior

The central interior is a summer rainfall region with rainfall driven by both local scale and large scale convective systems. Moisture is sourced from the north and north-east and is transported into the region by the combination of the continental heat low as well as the south Indian anti-cyclone. Winter conditions are dry and dominated by the sub-tropical high pressure systems. The economy of the Vaal sits in the urban, mining and agricultural sectors. Projected climate impacts in this region include: highly uncertain future rainfall predictions, with possible wetting or drying during the summer months; a likely increase in storm activity and large rainfall events causing flooding; and a significant increase in temperatures causing increased evaporation.

Zone 4: The Orange WMA in the north-west

The western and north-western interior region is arid with little rainfall throughout the year. Along the coast and towards the south, rainfall occurs during winter and is associated with mid-latitude cyclones passing to the south of the country. Further inland, rainfall shifts to a summer rainfall regime with late summer rain being produced by convective systems driven by the continental heat low and moisture sourced from the north.

The economic activities of the region lie with the agricultural, mining and urban sectors. The Orange River, which is the major source of water in the region, originates in Lesotho with its high summer rainfall pattern, but flows through the arid region into the desert country of Namibia. Projected climate impacts in this region include: uncertainty of rainfall patterns in the eastern parts, but with likely increased storm activity; a likely drying in the arid western and coastal areas; and a significant increase in temperature is expected, resulting in increased evaporation.

Zone 5: The Mzimvubu-Tsitsikamma in the south-east

The region experiences year-round rainfall, although variability is experienced within the region. The mountainous coastal region experiences winter rainfall driven by the mid-latitudes and summer rainfall driven by onshore moisture transport and orographic (or relief) rainfall. Inland of the coastal mountains rainfall is much lower, with a peak in late summer that is driven by convective rainfall. The rainfall pattern feeds the economic activities of the region, which include the forestry, agricultural and urban sectors. Projected climate impacts in this region include: uncertainty in year round rainfall impacts in the area, although likely drying in the west; likely increases in the summer rainfall in the western parts; and moderate temperature increases are also likely.

Zone 6: Breed-Gouritz and Berg Olifants WMAs in the south west

The South Western Cape is a winter rainfall region with a wet season extending largely from April through to August. Extreme events are the result of cut-off low pressure systems that occur several times during each winter season but only occasionally produce very extensive flood events. The summer climate is dominated by the South Atlantic anti-cyclone driving south-easterly winds over the region, which can produce light orographic (or relief) rainfall in the mountains. Inland of the coastal mountains, convective systems occur during summer producing some rainfall. The rainfall pattern drives the economic activities of the region, which include the agricultural and urban sectors. Projected climate impacts in this region include: uncertain climate impacts on winter rainfall, but a likely increase in orographic activity; a possible spread of rainfall beyond the historical winter rainfall period; and moderated temperature increases compared to the rest of the country.

5.5. Impacts of energy choices on water resources in South Africa

SA's promulgated energy supply is the IRP 2010. This plan provides for a possible increase in wave, wind, solar and bioenergy contributions to the national grid. As discussed in Chapter 4, this is important in ensuring the sustainability and health of the country's water resources. Power generation from fossil fuels, nuclear and renewable energy all have varying effects on our natural environment. The impacts of coal mining on groundwater and surface water, and hence on human and wildlife habitats, are severe and manifold and continue long after mines are closed; renewable energy technologies such as solar and wind have little impact on water resources during operations (Martin and Fischer 2012). The remainder of this section discusses the impact of different energy choices on water resources.

5.5.1. Coal and electricity

Coal mining operations use large amounts of fresh water (as discussed in Chapter 4) and pose a contamination threat to water resources in the forms of waterborne effluent and airborne ash. Mine effluent typically consists of hazardous acid generating sulphides (also known as AMD), toxic heavy metals, waste rock impoundments and water, and it is often deposited nearby in large free-draining piles, where it can pollute land and water supplies for decades to come. Detrimental effects on rivers and ground water have been observed many miles downstream from mine sites (WWF-SA 2011). Power-plant produced coal ash contributes to air pollution and water pollution at the disposal sites, contaminating the ground water through slow leakage of toxic elements from these sites. Contaminants include lead, thallium, barium, cadmium, chromium, mercury, nickel, selenium 8 (Gottlieb 2010) and arsenic. These pollutants are dangerously toxic. Arsenic has been shown to cause skin, bladder and lung cancer, and leads to damage of the nervous system. Once mercury enters the aquatic environment, it can be transformed by micro-organisms into the much more toxic form, methyl mercury. This accumulates in fish and subsequently in the people who eat them. A mother passes on the mercury that has accumulated in her body to her developing foetus, which affects the development of its central nervous system. The recycling of coal ash, such as its use in construction materials and as structural fill for buildings and roads, is another pathway for the toxic elements from coal ash to reach human living environments (Martin and Fischer 2012). Effective waste management practices are therefore essential so to minimise the negative impact of coal on the population.

Reduced water availability during longer dry periods as a result of climate change may impact on the operational requirements (such as production and cooling processes) of thermal power plants. This would compound the already negative impacts associated with higher water and ambient air temperatures.

Future capacity and predicted water impacts due to climate change

The coal capacity consists of three components, namely the return to service fleet, the newer plants in the existing fleet (including Medupi and Kusile) and the potential contracting of new coal capacity. New coal capacity might include imports (from Botswana) and, or large power stations located in Lephalale (Limpopo), Majuba (northern KwaZulu-Natal) and in the Bothaville (Free State). Depending on the energy scenario employed, additional electricity supply might be sought in north-western Limpopo.

The identified potential locations for coal power plants fall under Zone 1, 2 and 3. Zones 1 and 3 have industrial economies, particularly mining, while Majuba is located in the northern parts of KwaZulu-Natal, in close proximity to the Vaal and Mpumalanga mining regions in Zone 2. Climate change projections suggest that the north-eastern part of the country is expected to be wetter, however, localised predictions indicate increased variability in rainfall. Decreased rainfall is predicted for Zone 1, while Zone 2 and 3 are expected to have an increase in rainfall and large storms. As mentioned above, temperature increases and longer drier periods are also expected, which may impact operational efficiency.

5.5.2. Crude oil and petroleum products

Refined petroleum products such as petrol, diesel, residual fuel, oil, paraffin, jet fuel, aviation gasoline, liquefied petroleum gas (LPG) and refinery gas are produced by the following methods (Statistics SA 2012):

- Crude oil refining (oil refineries);
- Coal to liquid fuels and gas to liquid fuels (Sasol – South African Coal and Oil); and
- Natural gas to liquid fuels (PetroSA – Petroleum, Oil and Gas Corporation of South Africa)

Oil and petroleum products can be used as or converted to feedstock for electricity generation. From extraction to end use, crude oil and petroleum products impact surface water and groundwater, impairing water quality with hydrocarbons, salts, nutrients, a host of organic compounds, and various heavy metals. In many cases around the world, oil spills and storm-water runoff containing oil derivatives have degraded ecosystems and human water supply (Allen *et al.* n.d.).

Future capacity and predicted water impacts due to climate change

Proven financially viable oil reserves are limited in South Africa and the bulk of crude oil is imported from the Middle East and Africa (Saudi Arabia, Iran, Kuwait, Yemen, Qatar, Iraq, Nigeria, Egypt and Angola). Small oil and gas fields are situated off the south coast of Mossel Bay,

5.5.3. Natural gas

Limited natural gas reserves have been mapped around the South African coast. PetroSA exploits the reserves off the coast of Mossel Bay, where the Mossgas plant converts the gas into liquid fuels (Statistics SA 2012). Sasol produces gas from coal and is researching prospects to import gas from Namibia. Although natural gas is a fossil fuel and is thus non-renewable, it is relatively clean burning compared to gasoline, diesel fuel, oil and coal. Natural gas also has the advantage of having minimal impacts on water resources compared to other fuels, with only solar and wind power consuming less water (DHI Group 2008).

Future capacity and predicted water impacts due to climate change

Potential future gas capacity includes imported gas, combined cycle gas turbine (CCGT) power plants, and open cycle gas turbine (OCGT) power plants. Gas may be imported from both Namibia and Mozambique, crossing the borders in the Oranjemund and Komatipoort areas respectively. The CCGT and OCGT units under consideration would be installed at the five main port areas of Saldanha, Mossel Bay, Port Elizabeth (Coega), Durban and Richards Bay so as to use either imported liquid natural gas (LNG) or as a port to export shale gas should large reserves becomes available.

Natural gas has minimal impact on the environment and minimal water requirements, hence changes in temperature and water availability will result in minimal impact to the energy resources. Similarly, to crude oil, South Africa may be exposed to climate change impacts in the supply chain.

5.5.4. Hydroelectric power

For hydroelectricity, the water impacts largely depend on the type of technology that is used.

- Run-of-river hydropower plants may have an impact on erosion and aquatic ecosystems.
- Pumped storage systems and dams, depending on the size, may have an impact on water temperature, erosion and aquatic ecosystems.

In addition, hydropower schemes have significant effects on surrounding groundwater levels and streams and can change the climatic conditions of a region. Other climate-related adverse effects include changed siltation and sedimentation patterns, – potentially more upstream and less downstream, which impacts on the ecosystems of rivers and river estuaries. Dams can contribute significantly to climate change through emissions of greenhouse gases from decaying plant material in anaerobic conditions in flooded areas. Socio-economic and health impacts of hydroelectric dams include the displacement of communities and a potential increase in water-borne diseases around large dams that are neglected by the authorities.

Besides water loss through evaporation, hydro-power schemes may significantly impact on the environment and human habitats. These impacts may increase in severity as a result of climate change These impacts include:

- Dam safety – dam failures through increased flooding are a potential risk.
- Increased catchment erosion, reservoir sedimentation and the sinking of deltas – As flood magnitudes are expected to increase, erosion and sedimentation of upstream river beds and dams will accelerate, consequently reducing the life expectancy of dams. As dams hold sedimentation back, rivers carry fewer sediments downstream causing river beds and deltas to sink. In conjunction with climate change-induced rises in sea levels, the area of land vulnerable to flooding will increase significantly in the decades ahead.
- Drought and hydro dependency – as flood magnitudes are expected to increase, droughts are likely to increase, too, in both frequency and duration, and hence become more severe as the planet continues to warm. Increases in both flood magnitudes and drought severity reduce the predictability of the hydropower generation capacity of existing and future schemes.
- Rising water temperatures also lead to increasing invasive alien plant infestations, such as water hyacinth and algal blooms. These mats of floating plants can increase evaporation rates by as much as six times when compared with open waters.
- Dams are associated with water-borne diseases, such as malaria, river blindness and others. As water temperatures are expected to increase significantly, the incidences of water-borne diseases are set to rise too (Greeff 2011).

Climate change is expected to increase the magnitude of floods and the occurrence and duration of droughts. These conditions are likely to impact on hydropower supply most directly through higher anticipated evaporation losses. The planned lifetimes of dams are likely to be reduced through increased sedimentation (Martin and Fischer 2012)

Future capacity and predicted water impacts due to climate change

There are numerous existing hydro-electric and pumped storage power stations in South Africa, with an additional pumped storage plant in Ingula (located near Ladysmith) still under construction. The climate change impacts over KwaZulu-Natal include a projected increase in rainfall activity (in the summer), as well as an increase in water temperatures.

Additional hydroelectricity capacity potential lies in imported hydroelectric energy, in imports such as Cahora Bassa and Mpanda Nkua in Mozambique. This means that this supply would be subject to potential climate change impacts in other countries.

5.5.5. Nuclear power

South Africa does not operate any conversion and enrichment for uranium or plutonium, nor do reprocessing facilities for used nuclear fuel rods exist locally. Low- and intermediate-level nuclear waste is deposited at Vaalputs Radioactive Waste Disposal Facility, which is operated by the South African Nuclear Energy Corporation SOC Limited (NECSA 2015).

Uranium extraction and processing impact water resources at the source. The uranium mining process is similar to coal mining, with both open pit and underground mining operations. It produces similar environmental impacts to coal mining, with the added hazard that uranium mine tailings are radioactive. Radon (a radioactive gas) occurs through continuous decay of radioactive substances in uranium mill tailings. Radon escapes from the piles and spreads with the wind and increases the lifetime lung cancer risk of residents living near a tailing pile. The dry, fine sands from radon piles are blown by the wind over adjacent areas and elevated levels of radium can subsequently be found in dust samples in nearby communities. Seepage from tailings is another major hazard and poses a risk of contamination of both ground and surface water, thus contaminating drinking water supplies and fish in the area.

As discussed in Chapter 4, South Africa’s nuclear power plant Koeberg uses sea water for cooling purposes. At peak operation levels, Koeberg uses 80 000 L of sea water per second and about 1 000 L of fresh water (for steam and other purposes) per day. Fresh water is produced on site through desalination. Known impacts on marine life are as a result of the increase in temperature of the water used for cooling (Jury and Bain 1989).

Future capacity and predicted water impacts due to climate change

Further nuclear capacity has been under consideration for construction at Eskom proposed sites along the coast at Thyspunt in the Eastern Cape and Bantamsklip and Duynefontein in the Western Cape. Further sites may be sought, for example in KwaZulu-Natal or the Southern coastal region (Carnie 2015).

The West Coast is predicted to have uncertain climate impacts, but will likely have an increase in rainfall activity and moderate temperature increases. KwaZulu-Natal is also projected to have increased rainfall activity albeit be in the summer (DEA 2013). In addition to the impacts listed above, increase in water temperatures will be a major factor, particularly in KwaZulu-Natal.

5.5.6. Bioenergy

First generation bio-crops can have negative environmental impacts if appropriate practices are not used. Soy and corn-based crops are highly water consumptive and can consume in the region of 1 000 to 3 000 times the amount of water to produce biodiesel that oil might use to produce the same amount of diesel (Glassman *et al.* 2011). Second generation biofuels consume water only in the processing stages. Landfill gas from municipal solid waste is sometimes categorized alongside biofuels as another potential fuel source and is considered to have no water consumption in feedstock production. Alternative biofuels sources in the research and development phase, such as residues, perennial grasses, no or low irrigation crops may in future address water concerns,

Increased demand for agricultural crops to produce energy invariably leads to a series of unresolved discussions regarding food security and the relationship with increased demand for energy crops, and to what extent this drives conversion of forests into agricultural land (Glassman *et al.* 2011).

a) Future capacity and predicted water impacts due to climate change

Further research is required on a number of potential technology options which exist for bioenergy. Advancements in technology need to be directed at reducing biofuels' impact on water quantity and quality and the collateral inputs of fertilizers and pesticides, particularly given the large amounts required for irrigation (Krantzberg and Bassermann 2010). However, these new technologies will take time to develop. This is applicable to what source will be used for the bioenergy, which ultimately impacts water usage and food security, and also the cost of production. The National Biofuel Strategy mandates the blending of petrol and diesel with biofuels as from 1 October 2015 (DME 2007). While bioenergy is mentioned in the IRP2010 Update, no specifics with respect to the site location has been identified.

5.5.7. Solar energy

The impacts of solar technologies vary depending on the scale of the system and the technology used, i.e. PV panels or wet- or dry-cooled CSP. PV panels do not use water for generating electricity and minimal amounts of water are used to manufacture PV components. Dry-cooled CSP plants require minimal water, but wet-cooled CSP like all wet-cooled thermal electric plants, require substantial water supply for cooling (as discussed in Chapter 4); water use, therefore, depends on the plant design and the type of cooling system.

While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement; these emissions are far less than the lifecycle emission rates for natural gas and coal (Union of Concerned Scientists 2013).

a) Future capacity and predicted water impacts due to climate change

CSP plants with capacities of 50 or 100 MW and PV plants of between 5 and 82.5 MW have been contracted to the national grid in the first four tender bidding windows of the REIPPPP; the average capacity of the 45 plants is 51.4 MW. These projects are in the hot interior, mostly to the centre and north-west areas of the country (Forder 2015). These areas are projected to have increased temperatures and in an increase in the number of sunny days; factors that offer greater solar energy potential.

5.5.8. Wind energy

Wind energy has become a more popular technology in South Africa in recent years (Forder 2015), notwithstanding a variety of associated environmental impacts. Concerns include land use, wildlife, noise and visual impacts. There is no water impact associated with the operation of wind turbines. As in all manufacturing processes, some water is used to manufacture steel and cement for wind turbines (Union of Concerned Scientists 2013).

The land use impact of wind power facilities varies substantially depending on the site: wind turbines placed in flat areas typically use more land than those located in hilly areas. However, wind turbines do not occupy all of this land; they must be spaced approximately 5 to 10 rotor diameters apart. Thus, the turbines themselves and the surrounding infrastructure (including roads and transmission lines) occupy a small portion of the total area of a wind facility. The remainder of the land can be used for a variety of other productive purposes, including livestock grazing, agriculture, hiking trails and highways.

Offshore wind facilities require larger amounts of space because the turbines and blades are bigger than their land-based counterparts. Depending on their location, such offshore installations may compete with a variety of other ocean activities, such as fishing, recreational activities, sand and gravel extraction, oil and gas extraction, navigation, and aquaculture. Employing best practices in planning and siting can help minimize potential land use impacts of offshore and land-based wind projects.

The impact of wind turbines on wildlife, most notably on birds and bats, has been widely documented and studied. A recent National Wind Coordinating Committee (NWCC) review of peer-reviewed research found evidence of bird and bat deaths from collisions with wind turbines and due to changes in air pressure caused by the spinning turbines, as well as from habitat disruption. Sound and visual impact are the two main public health and community concerns associated with operating wind turbines.

a) Future capacity and predicted water impacts due to climate change

Onshore wind potential to date has been contracted in the Northern, Western and Eastern Cape (Forder 2015). However, as projected climate change increase in flood and drought events poses the risk of infrastructure damage caused by floods, erosion and, or slope stability. As a result, the topography and geology of potential wind farm sites need to be examined as part of the environmental impact assessment.

5.5.9. Wave or ocean energy

Ocean energy is derived from technologies that utilize seawater as their motive power or harness its chemical or heat potential. It could be used not only to supply electricity but also for direct potable water production or to meet thermal energy service needs. The renewable energy resource in the ocean comes from six distinct sources, each with different origins and requiring different technologies for conversion (i.e. waves, tidal range, tidal currents, ocean currents, ocean thermal energy conversion (OTEC), and salinity gradients). Ocean energy does not directly emit CO_2, however, GHG emissions may arise from different aspects of the lifecycle of ocean energy systems, including raw material extraction, component manufacturing, construction, maintenance and decommissioning.

Besides climate change mitigation, possible positive effects from ocean energy may include avoidance of adverse effects on marine life by virtue of reducing other human activities in the area around the ocean devices, and the strengthening of energy supply and regional economic growth, employment and tourism.

The specific environmental and social impacts of ocean energy technologies will depend in part on the technology in question (Lewis *et al.* 2011). Potential impacts include the alteration of river/ocean bottom habitats during the installation processes (i.e. securing the device to the bottom of the ocean and running power cables to the shoreline). Moving parts (rotors) and mooring systems could affect bottom habitat during operation by striking and entangling fish, diving birds, mammals and other aquatic organisms. In addition, the device may create structural habitat in open waters, and may obstruct the movements/migrations of aquatic animals, and the deployment and operation may disrupt sediments and buried contaminants and increase turbidity. Erosion and scour may also occur around anchors, cables, and other structures, and the movement of the devices may cause an alteration of hydraulics and hydrologic regimes. On a larger scale, extraction of energy from the currents may reduce the ability of streams to transport sediment and debris, cause deposition of suspended sediments and thereby alter bottom habitats (Cada *et al.* 2007).

a) Future capacity and predicted water impacts due to climate change

Wave or ocean energy is considered a high-cost energy source and further research is required on a number of potential technology options that exist for ocean or wave-based energy production. The IRP 2010 Update does not mention wave or ocean energy as part of the country’s future energy mix. However with technology advancements and continuous research currently taking place, this may change in energy planning in the future.

5.6. Implications of energy choices

5.6.1. Energy choices by the formal sector

As already noted, the majority of South Africa’s coal fields and energy generating facilities are located in the northern and north-eastern areas of South Africa. The significant economic activities in these areas have created great pressure on the local water resources. Added to this, climate change is projected to bring about a reduction in overall rainfall for these regions, which will increase the water stress and pose significant challenges for meeting the water demands of the local economy and the local population.

The increasing demand for water by the South African economy, particularly the energy and mining sectors, is of concern primarily because of their impact on water quality (Maree 2010). Insufficient water resources, which are of a poor quality, are unable to support the region’s secondary and tertiary sectors (agriculture, industry, residential, etc.). In addition, as energy generation is seen as a strategic water user in the South African economy, other economic water users will have to bear the brunt of a change in water allocation or water restrictions, which will, in turn, have impacts on the South African economy.

The formal sector's energy choices, the associated energy resource impact on water resources, as well as the relationship between energy and the economy need to be investigated in the South African context. This will be achieved through the use of case studies, through which important learning lessons will be drawn out. This will feed into the water and energy nexus discussion of the challenges and opportunities that exist for the formal sector.

Case Study 1: Impacts of coal mining on the Olifants River Catchment

South Africa's coal mines and coal-fired power stations are mostly located in the north-east of the country. In the Olifants Catchment, the concentration of both coal mining and coal-fired power stations, with their huge demands, air and water pollution, poses severe threats to the human populations, ecosystems and the natural environment. In 2001, mine water use in the catchment amounted to an average 4.6% of total water use, but contributed about 78% of the total sulphate load. Some of the pollution is captured and accumulated in the Witbank and Middelburg Dams, and has impacted downstream users, including people living in the catchment as well as tourists and wildlife of the Kruger National Park.

The quality of water bodies in the mining areas is poor, with acid mine drainage (AMD) contributing the most to water contamination, and polluted water from the coal ash dumps impacts on water bodies, human habitats and river ecosystems. Coal mining directly pollutes surface and groundwater with acid, salts and metals generated during the AMD process. The consequences of AMD polluted waters extend beyond the aquatic habitat into the realms of human and animal health and crop production. Increased salinization, especially through increased sulphate concentrations, disturbs the normal metabolism and nutrient uptake of plants and soil biota. High concentrations of dissolved salts in plants lead to plasmolysis, or cell shrinking and collapse; some crops such as apples, lemons, oranges and potatoes are particularly intolerant.

The most vulnerable and voiceless are the poor who are living in along the river banks and in areas that have no access to clean and safe drinking water. They have to rely on natural water sources (e.g. rivers) for drinking water and would thus be highly vulnerable to the health hazards associated with inadequately treated mine water effluent. Some known health risks associated with exposure to chronic and toxic levels of the pollutants that are commonly associated with mining including respiratory and neurological problems include Alzheimer's disease, neurotoxic effects, bone diseases and diarrhoea.

Most mining and other industrial activities and their associated pollution occur in the upper Olifants catchment in the Witbank and Middelburg areas. To deal with the high levels of pollution, several mines have introduced water treatment technologies, and currently re-use and recycle some of the mine water. The eMalahleni Water Reclamation Plant, which was implemented by Anglo Coal and BHP Billiton, uses reverse osmosis to turn 25 000 m^3 of mining effluent into potable drinking water each day. The eMalahleni Municipality covers its chronic water shortage by using over 70% of the reclaimed water to supply its consumers (WWF-SA 2011).

However, not all industrial sector companies are practicing good water management activities. The mines that supply coal to Eskom's power stations produce significant volumes of wastewater. Eskom performs some wastewater treatment by accepting the water from the mines, treating it, and then using it in the cooling process (Pather 2004). However, this recycling and re-use of water is practiced in only two power stations, Tutuka and Lethabo, with the remaining coal power plants using raw water sourced from freshwater resources. For example, near Witbank, Eskom would rather import clean water from the eastern escarpment than carrying the costs associated with the purification of local water resources.

This case study illustrates that mines and other industrial companies, due to the magnitude of their operations and the high water use and water pollution impacts, have the financial resources required to practice innovative water management approaches. Water management should not only make good business sense (when water pollution levies are properly enforced), but also shows good citizenship.

Case Study 2: Bioenergy at Illovo, a Sugar Manufacturer in KwaZulu-Natal

As the largest sugar producer in Africa, Illovo has a substantial agricultural footprint in its six Southern Africa countries of operation. To realise the high amounts of production, it uses intensive manufacturing processes that consume water, generate solid waste and result in air emissions and water discharges.

The process used at Illovo for manufacturing sugar from sugar cane provides a unique sustainable advantage with minimal environmental impact. This is because the fibrous residue remaining after the extraction of sucrose from sugar cane, known as bagasse, may be used as a bio-renewable energy source in sugar factory boilers to generate electricity. This electricity is capable of not only meeting the power requirements of the sugar factory, but may also be used for operating the irrigation systems used for cane growing, and for supplying company-wide administrative and external users, including domestic users and national grids. The recent completion of one of Illovo's major factory expansion and co-generation project in Swaziland has enabled the company to also export power into Swaziland's national grid.

The unique process of utilising bagasse as an energy source also results in the group having minimal reliance on fossil fuels, such as coal, for its energy requirements. Coal usage within the Illovo group comprises only approximately 4% of total energy usage. During the 2010/11 year, 89% of the energy consumed within Illovo's operations was sourced from renewable resources, replacing fossil fuel alternatives (Illovo Sugar Ltd 2011).

This case study illustrates how a company can decrease the pressure on the national grid by using their financial resources to explore renewable energy options that have minimal impact on water resources to meet their energy needs. This not only decreases the competition for energy on the national grid (thus increasing the energy that is available for the other users), but also the proportion of the industrial sector that is reliant on the water consumptive coal-based energy.

Case Study 3: Friedenheim Hydro Plant, Nelspruit

The Friedenheim hydro plant is located on the Crocodile River in Nelspruit (South Africa). It is privately owned and operated as a commercially profitable and sustainable business venture. It is owned by the members of Friedenheim Irrigation Board (FIB) and operated by MBB, an engineering firm.

Friedenheim hydro is one of the few hydro-electric Independent Power Producers (IPPs) in South Africa. It is an example of a hydro plant that feeds into the electricity grid, providing power to the Mbombela Local Municipality. The plant is equipped with two 1 MW Francis turbines and provides power for water pumping to FIB, but 93% of the power generated is sold to the Nelspruit local authority through a Power Purchase Agreement (PPA) that sets the tariff at 12% below the price at which Nelspruit buys power from Eskom (Klunne 2012).

This case study illustrates how renewable energy can be explored as a business opportunity, and used to not only generate employment opportunities, but to increase the proportion of clean energy in the national energy mix. This increase will ultimately decrease the proportion of water use that is allocated to the energy sector, and will also decrease the water pollution resulting from other energy resource production.

Summary of case studies

The case studies above illustrate that in the formal sector, due to the magnitude of the operations, the choice of energy source potentially has a huge impact on water resources. The formal sector has the added advantage of having the financial ability to explore renewable energy options. Motivation is however often lacking. An improvement in the enforcement of water pollution penalties and charges will serve as a motivation to the formal sector to improve their water management practices. The business advantage of exploring renewable energy options will thus include a lower water pollution penalty burden.

Investment and business opportunities also exist in the renewable energy sector. According to the South African Industrial Policy Action Plan (DTI 2011), the New Growth Plan (NGP) of 2010 acknowledges that the “recovery of economic growth between 1994 and 2008 did not lead to an adequate reduction in unemployment and inequality nor mitigate the emissions intensity of growth”. The IRP 2010 Update considers the aspirational economic growth suggested by the National Development Plan, and aims to shift economic development away from energy intensive industries, by providing growth that is focused on the renewable energy sectors, or industries that use renewable energy. There is thus a huge motivation for the formal sector to be involved in the business of producing renewable energy, and also contributing to employment creation and economic growth.

5.6.2. Impacts of energy choices on rural livelihoods

The National Electrification Programme, which was initiated in the late 1980’s and implemented from 1990, targeted ‘Access to electricity for all’ by the year 2012. (Marquard *et al.* 2007) saw electrification increase from 35% of households in 1990 to 84% in 2011 (StatsSA 2012). Policies that support the provision of energy to indigent households include the Free Basic Electricity (FBE) policy, which allows electrified households up to 50 kWh free of charge and the Free Basic Alternative Energy (FBAE) for non-electrified households, which subsidises alternative sources of energy including paraffin, liquefied petroleum gas, coal, and bio-ethanol gel. In April 2010, the Inclined Block Tariff (IBT) was introduced to give lower-consuming customers the benefit of a lower tariff rate (DoE 2012).

On average, South African households spend 14% of their total monthly household income on energy needs. This is higher than the international benchmark of 10%. Furthermore, close to half of all South African households are energy poor. Studies such as Madubansi and Shackleton (2006) have noted that very poor households continue to depend partially on other energy sources, regardless of being connected to the electricity grid. They do this as they cannot afford to pay high electricity tariffs for all their energy needs. The illegal reconnection of electricity has become a nationwide survivalist tactic for the poor. In addition, the continued dependence on non-commercial energy (such as firewood) has negative potential impacts on health, environmental degradation and energy poverty. Having access to energy is the basic requirement; the environmental and water impact of the energy choice is not part of their consideration. Poor households might well be aware of the disadvantages and health damages of using these energy sources, but their economic choices are very limited.

Case Study 1: Biomass versus electricity usage in Bushbuckridge Local Municipality

Welverdiend and Athol are two rural villages in the communal lands of the Bushbuckridge Local Municipality, which falls in the buffer zone of the Kruger to Canyons Biosphere (K2C) in the Mpumalanga Province. A study was conducted by Matsika *et al.* (2012) to investigate domestic energy security with respect to use patterns of fuel wood and identify differences related to fuel wood scarcity and access to electricity.

Bushbuckridge was identified as part of the Integrated Sustainable Rural Development Programme (ISRDP) by the South African National Government in 2000 and was specially mentioned by the Presidency as needing special development intervention. The ISRDP identified high-poverty priority areas that were underdeveloped but had the potential for economic growth and facilitated conditions to upgrade infrastructure and investment. Most households in the villages have access to electricity, but usually, supplement it with fuel wood, and to a lesser extent gas and paraffin. Due to the socio-economic conditions in the area, residents view access to electricity was seen as a financial burden. The continued use of fuel wood and other sources of energy represents a tangible saving, allowing money to be invested in other household necessities such as education, food and clothing.

The total wood stock in the communal woodlands of both villages has declined and, in Welverdiend there were also changes in the woodland structure and species diversity of the species commonly harvested for fuel wood over this period. The woodlands in Welverdiend have become degraded and no longer produce fuel wood of preferred species and stem size in sufficient quantity or quality. The absence of similar negative impacts in Athol suggests more sustainable harvesting regimes exist there because of the lower human population and lower fuel wood extraction pressure. The Welverdiend community has annexed neighbouring unoccupied private land in a social response to fuel wood scarcity. Athol residents behaved similarly during drought periods. The potential for future conflict with neighbouring conservation areas within the Kruger to Canyons Biosphere is high if current land uses and fuel wood extraction patterns are maintained (Matsika *et al.* 2013).

A study by Tee *et al*. (2009) in Nigeria showed that excessive fuel wood harvesting led to massive soil erosion, decreased water quality and dam siltation. Decreased woodlots and forest stands further increased pressure on remnant lots and decreased forest cover (Tee *et al.* 2009). A project conducted by Working for Wetlands Programme found that the ecosystems in Bushbuckridge were highly deforested and eroded. The project, started in

April 2000, aimed to rehabilitate three wetlands in the water-stressed Sand River catchment area. The project focused on the construction of structures to halt erosion and restore the hydrology of wetlands sites, as many wetlands are degraded by erosion gullies. The wetlands are not only important to the local people living in its immediate vicinity but also play a vital ecological role in feeding clean water into the Sand River, which is the main tributary of the Sabie River and the only river in the Kruger National Park that flows throughout the year. There is a need for proactive response by conservation managers and practitioners to put in place mechanisms to allow local communities to partake in managed and sustainable harvesting practices for fuel wood.

This case study illustrates how access alone to electricity does not necessarily address poverty. Due to the socio-economic conditions in the Bushbuckridge Local Municipality, people cannot afford to spend a lot of money on electricity. The continued use of fuel wood and other sources of energy illustrates that other household necessities such as education, food and clothing might be a higher priority than electricity for poor households.

Case Study 2: Sustainable energy system at Three Crowns Primary School, Lady Frere

Three Crowns Primary School is situated in the Chris Hani District in Khavola serves 178 children and caters from Grade R to Grade 6. The school is part of the Chris Hani District Municipality School Greening Programme started in 2008 in cooperation with Wildlife and Environment Society of South Africa (WESSA) to install renewable electricity.

Although it is connected to the Eskom electricity grid, it also has a sustainable energy system installed. Through the Eskom WESSA Energy and Sustainability Programme, and at the request of the Lady Frere District division of the Department of Basic Education, the Three Crowns Primary School was able to have a sustainable energy system installed at the school.

The sustainable energy technologies that have been installed at the school can be put into two categories, namely renewable electricity (i.e. a solar photovoltaic system) and renewable thermal (i.e. a solar cooker and biogas digester). The electricity is used to power a computer, printer and photocopier as a standalone non-grid tied system, luxuries that many other schools cannot afford in terms of appliances and electricity consumption. The benefits of this system are also shared with the village community when, for example, they need to copy forms for social grants or charge batteries or phones. Information technology can often also be more reliable; during the research for the case study by Gets (2013), a storm was raging and at one point the grid-connected lights went out while the renewable energy system still functioned (Gets 2013). This would also serve as an advantage in the event of load shedding.

Capital and installation costs are often cited as a barrier to sustainable energy system investment. For this project, financial support came from the Development Bank of South Africa (DBSA), with project support for the renewable electrical installation from WESSA. The program has since been expanded into a collection of projects called the Rural Sustainable Villages Programme in the Chris Hani District Municipality (CHDM 2011). These sustainable energy systems not only provide clean energy sources (that have minimal impact on water resources), but also provide the poor opportunities to have access to energy to meet their daily needs.

Summary of case studies

The case studies above show that access to electricity alone does not necessarily address rural poverty. Due to the high tariffs, the use of grid-connected electricity is limited. The poor are often forced to access alternative sources of energy, which are either cheaper or free (such as biomass, paraffin and gas).

Alternatives must be available and affordable if the consumption of energy choices (such as unsustainable bioenergy or coal) that have a negative impact on the natural resources is to be curbed. Degraded natural resources damage ecosystem services and can lead to poor health, both of which are factors that can be detrimental to for sustainable livelihoods. Public and private sector initiatives to finance installation costs can assist to overcome barriers to renewable energy such as solar power provision. Clean and decentralized energy systems that do not harm human and environmental health and do not need a connection to the national grid can offer the co-benefits mentioned above to the socially, economically and geographically marginalised.

5.6.3. Impacts of energy choices for economic growth, social equity and environmental sustainability

For more than a hundred years, SA has relied almost exclusively on coal (and for decades a small share of nuclear power) to grow its economy and meet the country’s industrialisation ambitions. Similar to other developing countries, SA argues that it should not be denied coal to drive and develop its economy seeing that other countries had the benefit of such power to become industrialised themselves. The new coal-fired thermal power stations build programme is, in theory, a response to industrial or productive development needs, but will not touch those without access to the grid or those who are unable to pay a large share of their income on electricity (Gets 2013).

However, economic development using coal and nuclear amounts to regression rather than modernisation, as these have social and economic impacts that negatively cost society, with its poorest members often bearing the brunt of these impacts. The Guardian Online states that Europe has cut emissions while continuing to grow its economy, which is supported by research done by the European Environment Agency (EEA) showing that it was possible to cut emissions while boosting economic growth. Connie Hedegaard, EU commissioner for climate action said: “While our economy grew 48% since 1990, emissions are down 18%”. These figures prove once again that emissions can be cut without sacrificing the economy (Harvey 2012).

According to the South African Industrial Policy Action Plan (DTI 2011), the New Growth Plan (NGP) of 2010 acknowledges that the “recovery of economic growth between 1994 and 2008 did not lead to an adequate reduction in unemployment and inequality, nor mitigate the emissions intensity of growth”. In other words, the current model of utilising fossil fuels for electricity generation, to support economic growth, has not helped curb unemployment and also fails to place the country on a lower emissions trajectory.

The plans to move away from low-job-potential, high-emission centralised power generating technology, illustrated by the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), are limited (only 9% RE expected by 2030). Energy efficiency is also vital for an Energy Revolution; energy must be produced and used efficiently in order to reduce the need for additional capacity. The energy efficiency uptake in South Africa has been slow because of low levels of awareness of its benefits, lack of available technologies and the alternative priorities of companies (Haw and Hughes 2007).

Fossil and nuclear-based energy systems result in an economic development path that has negative social and environmental impacts. These impacts are not always immediately apparent, and are often ignored as being external costs while full cost accounting (where these impacts and costs are included) is a far more robust and accurate approach.

The IRP 2010 Update considers the aspirational economic growth suggested by the National Development Plan in order to reduce unemployment and alleviate poverty in South Africa. This growth rate (an average of 5,4% per year until 2030) is also aligned with a shift in economic development away from energy intensive industries which is assumed to dramatically reduce the electricity intensity of the economy allowing the growth rate to have a less imposing impact on electricity demand to 2030 and beyond (DoE 2013c).

SA has the opportunity to leapfrog fossil-fuelled development by embarking on a world-leading ambitious renewable energy and energy efficiency programme where clean, sustainable, secure, stable, employment-supporting and accessible energy is achieved. This would enable true long-term socio-economic development with reduced emissions. In addition, clean energy options not only create job opportunities, but also have a positive impact on the food, energy and water nexus. This is because clean energy reduces the impact on the environment, especially water resources, and thus increases the amount of clean water that is available for food production. This is particularly true for the rural population that is dependent on river water as the main source of water supply.

This requires commitment from government to decouple development from the current fossil-fuelled and centralised energy system and move towards a clean energy future. Technological and financial barriers as well as political support present challenges to making this change. The REIPPPP suggests promising signs of national commitment to invest in renewable energy projects within the context of the IRP 2010, but there is a very long way to go for South Africa (Gets 2013).

5.7. Summary

SA continues to rely mainly on coal for energy supply, despite the policy-led increase in the supply of renewable energy. The current national mix of energy technologies impacts the water that is available for other economic users in requiring substantial assurance of supply for hydroelectric and wet-cooled thermal power stations. Of the energy technologies, coal-fuelled power stations have the most detrimental effect on water quality, especially in the extraction and processing of coal.

Assessments of water quality across the country indicate that water quality is poor in the catchments downstream of areas where coal mining and power plants are situated, and that these areas correspond with the areas of high economic activity and competition for water. Water management strategies include water quality standards in the form of TWQR. However, the current state of water quality suggests that water quality would benefit from more weighty consideration of the aggregate or cumulative impact of economic activities and choices for the national energy mix.

Energy planning will further need to take into consideration the likely impacts of climate change in order to mitigate negative impacts, both for other users of water resources and for capacity factors (or the efficiency of the installed capacity) of some of these energy choices. The IRP (2010), the Draft IRP (2012) and recent developments across energy technologies, including the REIPPPP, natural gas pipeline development, shale exploration, potential nuclear build and the National Biofuels Strategy inform of further potential impacts of the future energy mix on water resources.

Case studies in the formal sector indicate that opportunities for cost-saving with respect to cleaner energies with low water impacts exist, and that the presence of co-benefits may promote the successful exploration of these opportunities. Case studies of energy technology choices within the informal sector indicate that the provision of safe clean energy is only one of the urgent issues faced by indigent households and that other priorities may lead households to trade energy benefits in order to fulfil other needs.

Planning for energy supply now and in the future necessitates that South Africa's policy makers take into account the water impacts and associated risks of the energy generation technologies available, particularly in areas where there is severe water stress. Both current and future plans for energy generation must aggressively include a water component to maintain supply and also minimise the impact on other sectors of society.

6. POLICY AND REGULATION FOR THE WATER AND ENERGY NEXUS

By: Goga S, Laing K, Sauka S., Pegram G, Madhlopa A, Keen S, Sparks D and Moorlach M

6.1. Introduction

First, this chapter presents a review of the current energy policy and regulatory instruments and discusses policy incentives for the growth of renewable energy technologies in South Africa. A description of the water licencing and allocation processes reveals the level of integration of water resource management and energy planning. The chapter then proceeds to examine the need for greater integrative planning in the water-energy nexus. Finally, it proposes a draft Policy Framework for water and energy management. The draft Policy Framework is complemented by a flow diagram for assessing whether specific policies can be considered to be integrated or not.

6.2. Policy and regulation in South Africa and the consideration of the water-energy nexus

South Africa's energy policy and regulatory instruments must address various challenges in the energy sector – and particularly the electricity sector – which face large pressures from different stakeholders to achieve different, and often competing, objectives. One of government's most pressing post-apartheid challenges has been to grow the economy in order to deal with South Africa's unemployment and poverty issues, and electricity is a critical input to support a growing economy. Electricity supply planning and implementation in South Africa needs to take into account a range of challenges, including assurance of supply, minimization of the cost of energy and curtailment of carbon emissions as well as any negative impacts of the energy mix on the environment and water resources. The interlinked nature of these national imperatives calls for the implementation of integrated policy, and a review of relevant energy policy regime.

6.2.1. Review of current energy policy and regulatory instruments

The White Paper on the Energy Policy of the Republic of South Africa of 1998 was the first policy document relating to energy to be drafted in terms of Section 24 of the Constitution (DME 1998). The energy policy and the process of policy formulation prescribed in the document promote sustainable development by highlighting equity and the sustainable use of natural resources. The major objectives of government policy for the energy sector in the 1998 White Paper on Energy Policy include:

- increasing access to affordable energy services;
- improving energy governance;

- stimulating economic development;
- managing energy-related environmental impacts; and
- securing supply through diversity in energy technologies.

The White Paper on Renewable Energy of 2003 provides an outline of government's vision, policy and strategic objectives for encouraging the use of renewable energies, and to inform the relevant institutions of their role within the process. The paper recognizes climate change as a major environmental threat facing the world, and thus the need for South Africa to reduce the exploitation of its fossil fuels through the deployment of renewable energy technologies. The mid-term (10-year) plan of the Paper was to target a contribution of 10 000 GWh of renewable energy contribution to the final energy consumption by 2013, representing 4% of the projected national demand. The paper recognizes the need to support individual renewable energy technologies in the marketplace because these technologies often require higher investment costs than conventional fossil fuels.

The Integrated Resource Plan 2010 sets a target of 42% of electricity capacity for renewable energy by 2030, thus diversifying South Africa's energy mix. The IRP is to be revised and updated when necessary, as stipulated in the White Paper on Energy of 1998. The Policy-Adjusted IRP 2010-2030, which was promulgated in 2010 and it is now up for revision, forecasts a fall in the reliance on fossil fuels by 2030, with approximately 46% of the total capacity from coal-fired power stations. Nuclear is forecast to increase to 12.7% of the national electricity capacity, and wind to increase to 10.3%. For the IRP 2010-2030 plan to be realised, there will be substantial increases in nuclear, coal-fired, wind and photovoltaic power, and some increase in gas turbine power, hydropower, and concentrating solar power. (See Table 6-1 and Table 6-2).

Table 6-1: Policy-Adjusted IRP (Source: DoE 2013c).

	Committed build											New build options											
	RTS Capacity (coal)	Medupi (coal)	Kusile (coal)	Ingula (pumped storage)	DOE OCGT IPP (diesel)	Co-generation, own build	Wind	CSP	Landfill, hydro	Sere (wind)	Decommissioning	Coal (PF, FBC, Imports)	Gas CCGT (natural gas)	OCGT (diesel)	Import Hydro	Wind	Solar PV	CSP	Nuclear	Total new build	Total system capacity	Peak demand (net sent-out) forecast	Demand Side Management
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW
2010	380	0	0	0	0	260	0	0	0	0	0	0	0	0	0	0	0	0	0	640	44535	38885	252
2011	679	0	0	0	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	809	45344	39956	494
2012	303	0	0	0	0	0	300	0	100	100	0	0	0	0	0	0	300	0	0	1103	46447	40995	809
2013	101	722	0	333	1020	0	400	0	25	0	0	0	0	0	0	0	300	0	0	2901	49348	42416	1310
2014	0	722	0	999	0	0	0	100	0	0	0	500	0	0	0	400	300	0	0	3021	52369	43436	1966
2015	0	1444	0	0	0	0	0	100	0	0	-180	500	0	0	0	400	300	0	0	2564	54933	44865	2594
2016	0	722	0	0	0	0	0	0	0	0	-90	0	0	0	0	400	300	100	0	1432	56365	45786	3007
2017	0	722	1446	0	0	0	0	0	0	0	0	0	0	0	0	400	300	100	0	2968	59333	47870	3420
2018	0	0	723	0	0	0	0	0	0	0	0	0	0	0	0	400	300	100	0	1523	60856	49516	3420
2019	0	0	1446	0	0	0	0	0	0	0	0	250	237	0	0	400	300	100	0	2733	63589	51233	3420
2020	0	0	723	0	0	0	0	0	0	0	0	250	237	0	0	400	300	100	0	2010	65599	52719	3420
2021	0	0	0	0	0	0	0	0	0	0	-75	250	237	0	0	400	300	100	0	1212	66811	54326	3420
2022	0	0	0	0	0	0	0	0	0	0	-1870	250	0	805	1143	400	300	100	0	1128	67939	55734	3420
2023	0	0	0	0	0	0	0	0	0	0	-2280	250	0	805	1183	400	300	100	1600	2358	70297	57097	3420
2024	0	0	0	0	0	0	0	0	0	0	-909	250	0	0	283	800	300	100	1600	2424	72721	58340	3420
2025	0	0	0	0	0	0	0	0	0	0	-1520	250	0	805	0	1600	1000	100	1600	3835	76556	60150	3420
2026	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	400	500	0	1600	3500	80056	61770	3420
2027	0	0	0	0	0	0	0	0	0	0	0	250	0	0	0	1600	500	0	0	2350	82406	63404	3420
2028	0	0	0	0	0	0	0	0	0	0	-2850	1000	474	690	0	0	500	0	1600	1414	83820	64867	3420
2029	0	0	0	0	0	0	0	0	0	0	-1128	250	237	805	0	0	1000	0	1600	2764	86584	66460	3420
2030	0	0	0	0	0	0	0	0	0	0	0	1000	948	0	0	0	1000	0	0	2948	89532	67809	3420
TOTAL	1463	4332	4338	1332	1020	390	700	200	125	100	-10902	6250	2370	3910	2609	8400	8400	1000	9600	45637			

Notes: 1. Committed Generation Capacity Includes Projects Approved Prior to IRP (2010)

Table 6-2: Policy-Adjusted IRP capacity, 2010-2030 (Source: DoE 2013c).

	Total capacity		Capacity added (incl. committed)		New (uncommitted) capacity options	
	MW	%	MW	%	MW	%
Coal	41 071	45.9	16 383	29.0	6 250	14.7
Open cycle gas turbine (OCGT)	7 330	8.2	4 930	8.7	3 910	9.2
Closed cycle gas turbine (CCGT)	2 370	2.6	2 370	4.2	2 370	5.6
Pumped storage	2 912	3.3	1 332	2.4	0	0.0
Nuclear	11 400	12.7	9 600	17.0	9 600	22.6
Hydro	4 759	5.3	2 659	4.7	2 609	6.1
Wind	9 200	10.3	9 200	16.3	8 400	19.7
Concentrating solar power (CSP)	1 200	1.3	1 200	2.1	1 000	2.4
Photovoltaic (PV)	8 400	9.4	8 400	14.9	8 400	19.7
Other	890	1.0	465	0.8	0	0.0
Total	89 532		56 539		42 539	

Historically, renewable energy was perceived to be an important opportunity to increase diversity in the energy supply, primarily with a focus on increased imports of hydro-electricity from within the Southern African Power Pool (SAPP), although this relies on political stability in the host countries (Davidson & Winkler 2003). The IRP 2010/12 currently makes provision for 3 349 MW of imported hydropower.

The IRP 2010-2030 Update Report (2013) (IRP 2010) gives a high-level review to accommodate updated assumptions based on new information and the consideration of additional scenarios without undertaking an entire re-iteration of the plan. The next iteration of the IRP is due after the draft Integrated Energy Plan (IEP) (2013) is finalised. Thus, the IRP 2010 remains the official government plan, while the IRP 2010 Update Report provides critical insight into changes for consideration on key decisions in the interim (DOE 2013c). The IRP 2010 Update Report takes into account:

- the changed landscape in electricity demand and the underlying relationship with economic growth;
- new developments in technology and fuel options (both locally and globally);
- scenarios for carbon mitigation strategies and the impact on electricity supply beyond 2030; and
- the affordability of electricity and its impact on demand and supply beyond 2030 (DoE 2013c).

To illustrate some of the changes in the IRP 2010 Update Report, the differences to the Update Report Base Case (the IRP modelling scenario that tests the least cost plan) are described below. The Update Report 2010 Base Case scenario takes into consideration the following updated information in its modelling assumptions; new Ministerial Determinations, a revised demand forecast, the newly forecasted performance of the Eskom fleet, including the option of life extensions to existing Eskom coal-fired generators and including new generation capacities called for in the Ministerial Determinations that are not yet committed to lapse (DoE 2013c). The Base Case maintains a number of the limitations imposed in the IRP, and in particular, an annual limit of new capacity for wind (1 600 MW) and photovoltaic power (1 000 MW). Table 6-3 provides a snapshot of the changes in capacity between the IRP 2010 and the IRP 2010 Update Report for the Base Case (DOE 2013c).

Table 6-3 Technology Options Arising from IRP 2010 and the Update Base Case in 2030 (Source: DoE 2013c).

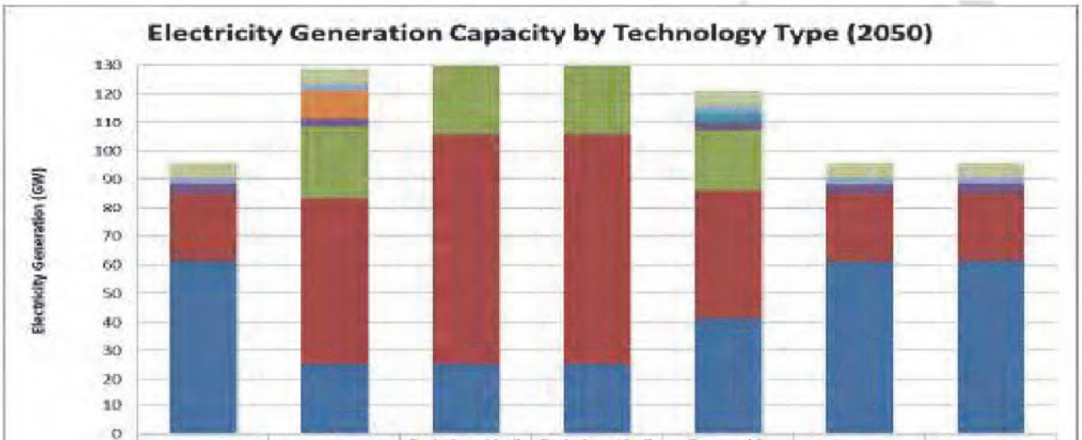
Technology option	IRP 2010 (MW)	Update IRP Base Case (MW)	Change
Existing Coal	34746	36230	Increase
New Coal	6250	2450	Decrease
CCGT	2370	3550	Increase
OCGT/Gas Engines	7330	7680	Increase
Hydro Imports	4109	3000	Decrease
Hydro Domestic	700	690	Decrease
PS (incl Imports)	2912	2900	Decrease
Nuclear	11400	6660	Decrease
PV	8400	9770	Increase
CSP	1200	3300	Increase
Wind	9200	4360	Decrease
Other	915	640	Decrease
Total	**89 532**	**81350**	**Decrease**

Notes:

(1) Demand response options added to IRP 2010 to ensure comparability (previously not considered in IRP).
(2) ''Existing'' coal includes Medupi and Kusile.
(3) Change is based on the IRP 2010 levels.

It is observed from Table 6-3 that there are some corresponding differences between the technology capacities in IRP 2010 and those in the Draft IRP Update Report. This is illustrated by the comparison of the Base Case (the least cost scenario) in each of the IRP 2010 and Update IRP reports (DoE 2013c). The total capacity in Update Base Case capacity is 81 350 MW compared to 89 532 MW in the Policy-adjusted IRP 2010 Base Case (DoE 2010). In the Update IRP Base Case, the life extension of the coal power plants increases the existing coal fleet capacity to 36 230 MW compared to the corresponding capacity in the IRP 2010. However, the New Coal capacity is substantially lower in the Update IRP Base Case compared to the IRP 2010 capacity. Importantly, the nuclear capacity is also much lower in the Update IRP Base Case compared to that in the Policy-adjusted IRP. This includes Koeberg at 1 800 MW and new nuclear capacity of 4 860 MW. CCGT, OCGT/Gas Engines, CSP and PV capacities also increase while the wind capacity decreases significantly.

The main objective of the Draft Integrated Energy Plan 2012 (IEP2012) is to determine the best way to meet current and future energy service needs, while keeping economic costs in mind, serving national imperatives such as job creation and minimizing the impacts of the energy sector on the environment. The Draft IEP 2012 includes a stakeholder engagement process, guided by the IEP Steering Committee, which is an inter-departmental government committee led by the Department of Energy and consisting of the departments of Science and Technology; Environmental Affairs; Water Affairs; National Treasury; Economic Development; Trade and Industry; Human Settlements; Transport; Rural Development and Land Reform; Mineral Resources and the National Planning Commission. The Draft IEP 2012 describes seven energy scenarios for the country for 2050, as shown in Figure 6-1.



	Base Case	Emissions Limit Case	Emissions Limit - No Nuclear Case	Emissions Limit - Natural Gas Case	Renewable Energy Target Case	High Oil Price Case	Low Oil Price Case
Other *	4.9	4.9	4.9	4.9	4.91	4.9	4.9
Gas	0.2	0.2		4	0.237	0.2	0.2
Petroleum	2.4	2.4	2.4	2.4	2.415	2.4	2.4
Nuclear		9.6					
Biomass					3.417120576		
Hydro	3.1	3.1	3.1	3.1	3.109	3.1	3.1
Wind		25	25	25	20.90722329		
Solar	24	58.1	80.1	80.1	44.99309098	24	24
Coal	61.2	25.4	25.4	25.4	41.20415853	61.1	61.2

Figure 6-1: Electricity generation capacity by technology type (2050) (Source: Draft IEPR)

Notes:

1. The 'Emissions Limit' Case has annual emissions limits for power generation and liquid fuel supply as derived from the "Peak Plateau Decline" trajectory, and all supply options are considered.
2. The 'Emissions Limit – No Nuclear' Case requires that the emissions limits of the "Peak Plateau Decline" trajectory are met and 9 600 MW Nuclear Build Programme is specifically excluded.
3. The 'Emissions Limit – Natural Gas' Case requires that the emissions limits of the "Peak Plateau Decline" trajectory must be met. The Nuclear Build Programme is excluded and replaced by natural gas options. Natural gas includes conventional gas, coal bed methane and shale gas.
4. In the 'Renewable Energy Target' Case no emissions limits are set. Renewable energy options are gradually introduced into the energy mix from 2010 to 2030 so that by 2030, 10% of total energy output is from renewable sources. From 2031 onwards, the target of 10% is maintained as a minimum.
5. In the 'High Oil Price' and 'Low Oil Price' Cases, sensitivity analyses are conducted in order to determine the most optimal liquid fuel supply options under each price scenario, while the prices of other commodities such as coal and natural gas are assumed to remain the same as for the Base Case. No emissions limit constraints are set.

6.2.2. Incentives to develop renewable energy

Despite good solar and wind resources the deployment of renewable energy technologies has been initially slow (Edkins *et al*. 2010). Around 90% of South Africa's electricity is derived from coal. The state-owned utility company (Eskom) dominates the production of power with 27 operational coal power stations in South Africa, generating 40.7 GW of the country's capacity and base requirement (Edkins *et al.* 2010). Additional capacity is provided through imports (mainly hydropower) and IPPs to a total capacity of 43.5 GW, in order to supply forecasted peak demand of 36 GW.

Renewable energy for electricity generation in South Africa was initially largely confined to the off-grid sector. Until recently, the transition to renewable energy was considered costly. To promote the uptake of renewable energy and increase diversity in the generation mix, the Department of Minerals and Energy (DME) published a White Paper on Renewable Energy in 2003 with the intention to "bring about integration of renewable energies into the mainstream energy economy". A target of 10 000 GWh of renewable energy by December 2013 was to be produced mainly from biomass, wind, solar and small-scale hydro and to account for approximately 4% (1 667 MW) of the projected electricity demand for 2013 (41 539 MW). The Energy Minister's 2003 budget speech had indicated that renewable energy policy would "lead to the subsidization of Renewable Energy and develop a sustainable market share for clean energy" (Mlambo-Ngcuka 2003).

South Africa's national electricity regulator NERSA approved a Renewable Energy Feed-In Tarrif (REFIT) in 2009. The purpose of the REFIT was to mitigate risk for investors by establishing long-term assurance for their electricity sales at a set tariff to improve access to finance for developers and to give market assurance to drive technology development in the renewable energy sector. The ultimate aim was lower costs of electricity generation from renewable sources. This approach aimed to encourage the development of a number of different technologies and a diversified energy supply base (UNEP 2010). Successful feed-in tariff (FIT) policies have been implemented in more than 40 countries around the world and are cited as the primary reason for the success of the German and Spanish renewable energy markets (Cory, Couture and Kreycik 2009).

However, the REFIT fell foul to policy and regulatory uncertainty, secured no capacity in its two year existence, and was terminated after the announcement of the national competitive bidding Renewable Energy Independent Power Producer Procurement Procurement Program (REIPPPP) by the Department of Energy in 2011 (Eberhard *et al*. 2014). The REIPPPP, run by Treasury staff and housed adjacent to the Department of Energy, has been a relative success in that it has secured 6 589.95 MW of mainly solar and wind power capacity to the national grid by the end of 2015 (Eberhard *et al*. 2014).

The REIPPP has run through 4 tender bidding rounds from 2011 to the end of 2015. A brief description of the process follows. The tenders for different technologies were held simultaneously in each round of bidding. Bidders could bid for more than one project and also for different technologies. Projects had to be larger than 1 MW and there were caps for different technologies, for example, 50 MW for concentrated solar and 140 MW for a wind project. In addition, price caps were set for each of the technologies, and these caps were all much higher than Eskom's average tariff of around 5c per kilowatt hour at the time. Twenty-year local-currency denominated power purchase agreements (PPA) were offered for different technologies (World Bank 2013). The bid evaluations were a two-step process. In the first step, bidders had to satisfy certain minimum threshold requirements in six categories, namely, environment, land, commercial and legal, economic development, financial, and technical. In particular, the economic development criteria were complex, consisting of 17 sets of minimum thresholds and targets. Bid bonds or guarantees had to be posted. Bidders who met the minimum threshold requirements would then be evaluated in step 2 mainly on price (70% weighting), but also in terms of economic development type criteria including job creation, local content, preferential procurement, enterprise development, and socioeconomic development (30% weighting) (World Bank 2013).

For the first round, 53 bids were received and 28 bids qualified, amounting to 1,416 MW of new capacity. Implementation, direct and power purchase agreements were signed between the government, Eskom and each of the 28 successful bidders in November 2012. In the first round, the bidding prices were not particularly competitive and marginally below the caps specified, because the capacity was higher than anticipated (World Bank 2013). In consecutive rounds some of the requirements were revised. The bidding process was more competitive and the bid prices were lower, particularly for wind and photovoltaic technologies, and the range of prices bid was also wider. The transaction costs in terms of advising and financing – which were high in round 1 – fell in round 2 (World Bank 2013) and declined further in subsequent rounds.

a) South Africa’s energy economy

It is useful to consider how incentives in South Africa’s energy economy have influenced the energy mix and whether these incentives are sustainable. As a parastatal, Eskom has historically received significant and widespread support from the government in a number of areas. Support has included low coal prices, utilising power station technologies that maximize economies of scale and exploit the lowest value (and cost) of coal, exemption from taxation and dividends, financing subsidies, and over-capacity, and, for the particular interest of this analysis, priority access to water allocations as the only strategic user. A great deal of attention is paid to the relatively low price of electricity in South Africa. It is important to note that the price of electricity does not reflect the true costs of largely coal-based energy generation in South Africa in that the values of the inputs used to produce electricity are not factored in, the full capital costs are not reflected, and the externalities are not priced (Winkler 2006).

Part of the slow movement towards renewable energy has thus been the structure of the energy economy, uncertainty around the returns for renewable energy, and the incentives under which the primary supplier of energy (Eskom) has been operating. The energy economy has thus strongly favoured coal-powered generation and largely crowded out investment by IPPs in the sector. This uneven financial playing field creates a substantial economic barrier for renewable energy. Thus, even though the high capital cost of renewable energy technologies is often cited as the main barrier to their deployment, the broader energy economy in South Africa also plays a role. The REIPPPP has diversified not only the national electricity supply but also the landscape of actors in the establishment of the IPP unit and the contracting of IPP’s on a project by project basis. Although widely lauded as a success, the REIPPPP faces potential future challenges (Morris and Martin 2015).

6.2.3. Policy and incentives around water supply for energy

At present, the bulk of South Africa’s water (62%) is used by the agricultural sector. Mining operations use approximately 3%, and Eskom’s facilities 2% of the water in South Africa (Groenewald 2012). The state utility does not have discounted rates for its water supply; rather it pays the industrial rate based on the location of operations. However, as noted above the National Water Act defines power supply as a ‘strategic’ water user, meaning that Eskom is given priority allocations of water in a catchment, before all other economic activities.

Coal-powered operations require a very high assurance of water supply because of the need for steam to power the turbines, cool machinery and dilute pollutants. Furthermore, the required water must be of a very high quality. Therefore, this section looks at the current procedure and challenges associated with acquiring a water use licence and water allocation decisions in South Africa. In addition, the costs, risks and impact of energy decisions on South Africa’s water supply are considered. The final part of this section deals specifically with the response of Eskom to water scarcity and the need to reduce its water consumption in its current and planned operations.

The water licencing / water use authorisation process

The water use registration process is different from the water use authorisation process. Registration is the process of officially notifying the Department of Water Affairs of water use. Water use registration occurs for existing lawful uses, general authorisations and licences. Registration is free of charge and a registration certificate is issued once registration forms have been processed. A registration certificate does not authorise one to use water for a particular activity. The Department of Water Affairs informs a water user if there is a need to be licenced. This is a separate procedure to registration; registration is, therefore, the first step in establishing a person as a water user within the Department (DWAF 2007).

Types of water use authorisations

Water may only be used if a person is authorised to do so. According to the External Use Water Application Guideline (DWAF 2007), a person is authorised to use water:

- if water use is permissible in terms of Schedule 1 of the NWA;
- as a continuation of an existing lawful use;
- if authorised in terms of a general authorisation; or
- if licenced to do so in terms of the NWA.

Schedule 1 of the NWA entitles a person to take water for reasonable domestic use, domestic gardening (not for commercial purposes), animals grazing on the land, firefighting or for recreational purposes. Furthermore, it allows the storing and using of run-off water from a roof. It also permits agreed discharge of waste or water containing waste into a conduit controlled by another person who is authorised to accept it and dispose of it. No application for a licence is required for Schedule 1 use (DWAF 2007).

General Authorisations (Section 39 of the NWA) set a cut-off point below which strict regulatory control is not necessary. Thus, water uses below levels specified in the general authorisation constitute the use of water at or below the threshold action level. Water use under a general authorisation (and not described as schedule 1) does not require a licence unless the general authorisation is repealed or lapses (DWAF 2000).

Existing Lawful Water Uses were authorised under the legislation which was in force immediately before the date of commencement of the National Water Act (NWA). Thus, a person may continue an existing lawful water use – a water use that was lawfully exercised in the two years before the commencement of the NWA on 1 October 1998 – subject to the conditions under which it was exercised. Furthermore, the Minister may declare a water use that was not exercised in the qualifying two-year period to be an existing lawful water use.

Licences section (Sections 40 to 52) covers water use which does not fall under schedule 1 water uses or general authorisations or in a manner that is not regarded or declared as an existing lawful use. In this case, a water user would have to apply for a licence. Licences may be issued by the Department of Water Affairs on application, after consideration of the impact of such water use. Licencing includes both stream flow reduction activities as well as transfer of water use entitlements (DWAF 2007). The requirements for a licence for water use may be dispensed by the responsible authority if it is satisfied that the purpose of the NWA will be met by granting of a licence, permit, or other authorisation under any other law (DWAF 2007).

A water use licence can be issued to a person and attaches to the property on which the water is used. The licence includes a description of the licence holder, the properties on which the water may be used, the water uses, the period for which the licence is valid and the conditions of the licence (DWAF 2007). The water use activities shown in Table 6-4 need authorisation, which may include licencing.

Table 6-4: Water uses requiring licences (Source: DWAF 2000).

s21(a):	taking water from a water resource;
s21(b):	storing water;
s21(c):	impeding or diverting the flow of water in a watercourse;
s21(d):	engaging in a stream flow reduction activity (currently only commercial afforestation);
s21(e):	engaging in a controlled activity – activities which impact detrimentally on a water resource (activities identified in s37(1) or declared as such under s38(1)) namely: ▪ irrigation of any land with waste or water containing waste which is generated through an industrial activity or a waterwork; ▪ an activity aimed at the modification of atmospheric precipitation; ▪ a power generation activity which alters the flow regime of a water resource; or ▪ intentional recharge of an aquifer with any waste or water containing waste
s21(f):	discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
s21(g):	disposing of waste or water containing waste in a manner which may detrimentally impact on a water resource;
s21(h):	disposing in any manner of water which contains waste from, or has been heated in, any industrial or power generation process;
s21(i):	altering the bed, banks, course or characteristics of a watercourse;
s21(j):	removing, discharging or disposing of water found underground if it is necessary for the efficient continuation if an activity or for the safety of people; and
S21(k):	using water for recreational purposes

a) The water use licencing process

The potential applicant should consult with DWA to arrange a pre-application consultation. During the pre-application consultation process, information is provided to DWA in order for DWA to:

- align the process with environmental authorisations;
- define the water use and which type of authorisation will be applicable, which will, in turn, dictate the approach to be followed for the water use licence application;
- inform the relevant DWA department to initiate a Reserve determination for the licence assessment where required;
- advise the applicant on the availability of water if necessary;
- advise the applicant on investigation, consultation and information requirements;
- advise the applicant on other legal requirements to be met, for example, environmental and agricultural authorisations; and
- determine and confirm the risk classification of the activity (DWAF 2007).

The pre-application consultation is important for the authorisation process because some of the investigations may require significant periods of time (DWAF 2007).

The application process will follow a distinct approach depending on whether it is a;

- non-waste-discharge related water use (21a, b, c, i, k)
- waste-discharge related water use (21e, f, g, h) (DWAF 2007)

The waste discharge related water uses are subject to a risk-based approach. If the proposed water uses comprise an integrated water use licence application, which combines both non-waste discharge and waste discharge related water uses in a single application, then a risk assessment must be undertaken for all the uses. The risk of the activity is defined by determining the hazard class of the activity, in combination with the sensitivity of the water resource where the water use will take place. The risk-based approach recognises the need for a link between risks posed and the level of control required in managing the sources of pollution (DWAF 2007).

The confirmation of the risk classification determines the extent of the requirement for the licence application. For the risk classification, the activity sector for which the water use is required must be correctly identified before the risk categorisation takes place. The levels of threat are as shown in Table 6-5. The licence application must include management measures to be employed in the catchment with the associated activity risk category and threat level. The risk classification determines the level of detail required in the technical and baseline documentation for the licence application. Public participation is an important part of this process (DWAF 2007).

Table 6-5: Risk categorisation for water licence application (Source: DWAF 2007).

Threat Level	Description
High	High probability of the occurrence of the impact and severe consequences
Medium	An intermediate probability of occurrence with manageable consequences
Low	Low probability of occurrence with negligible consequences

The application must be made on the prescribed forms and must be accompanied by a brief application report, a map, the appropriate supporting documents, and the licence application fee. Once the required information has been gathered and the consultations have been done, the completed application can be submitted at the Regional Office of DWA. The stages in the water licencing process are shown in Figure 6-2.

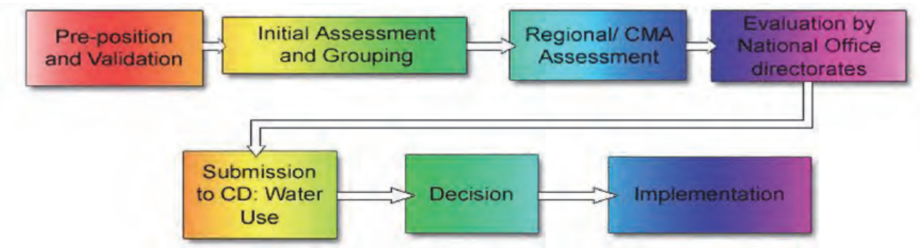


Figure 6-2: The water use licencing process (Source: DWAF Website).

There are generally 6 steps to processing any licence. These steps aim to test the application against the principle of "beneficial use in the public interest", and specifically against Section 27 of the National Water Act.

- Step 1 – Pre-position and validation is done when a licence application is received, and is used to check if everything needed to process the licence is available. The person applying for a licence will be asked to provide missing information, and may get initial feedback before payment of the application fee so they can decide whether to continue.

- Step 2 – Initial assessment and grouping includes a quick assessment of the possible impacts and benefits of the proposed water use. In some cases, a simple set of questions are used to help make this assessment.

- Step 3 – Regional Assessment is done in the regional office where the licence application was made. The regional office gathers all the information required to make a decision on whether to approve the application, and makes a recommendation to the national office.

- Step 4 – Evaluation by the National Office specialist groups who make recommendations on the application. The application is then submitted to the Chief Director: Water Use for a decision.

- Step 5 – Decision by the Chief Director: Water Use: whether to approve the application after considering all the relevant information.

- Step 6 – Implementation by the Regional Office if the application is approved. They will inform the applicant of the outcome of the application, and if approved will issue the licence as well as highlighting any conditions that might be attached to the licence.

The licence can take from 3 to 12 months to process, depending on the complexity of the licence, the benefits to the country, and the possible impacts of the water use. Generally, low impact, high-value licences are processed more quickly. A licence cannot be issued for a period longer than 40 years, but may be issued for shorter periods if necessary. If the applicant is not happy with the decision he, or she can take the decision to the Water Tribunal for appeal. Any other person who has objected to the licence application has a right of appeal to the Water Tribunal (DWAF 2007).

b) Challenges with water licencing

There are many challenges with the water licencing process including the following:

- there are some companies which do not have water use authorisations and continue to illegally abstract water;

- the procedures for licencing are slow;

- the number of applications outstrip DWA's processing capacity;

- the quality of licence applications are sometimes very poor – not all applicable water uses are applied for, incorrect water uses are applied for, there is inadequate participation public participation in the process, applications are technically incomplete and incorrect, and there is poor impact assessment which does not comply with the DWA Guidelines;

- Integrated Water Use Licences (IWUL) are complicated and there is a lack of experienced and qualified people to adjudicate these applications, resulting in compromised decision-making and significant delays. Furthermore, licences are also issued without the inclusion of important recommendations made in the evaluation process. There is also some confusion regarding decision-making with DWA head office overriding regional recommendations;

- compulsory licencing is not implemented; and
- there is a lack of integration between DWA, Department of Environmental Affairs (DEA) and Department of Mineral Resources (DMR) regarding decision-making.

As far as mining, in particular, is concerned, mining activities currently require a mining permit, including an Environmental Management Programme Report (DMR), a water use licence (DWA) and – for listed activities occurring in a mining area – an environmental authorisation and, or waste management licence and/or air emissions licence (DEA). It has been recognised that there is a need to align the processes for requiring a mining licence (Furter 2013), hence the formation of the Interdepartmental Project Implementation Committee (IPIC) on integrating licencing. As part of this process, to ensure that the authorisation processes associated with mining are aligned all four acts (NWA, NEMA and NEMWA and MPRDA) were reviewed for potential amendment. Furthermore, existing environmental impact assessment regulations and listing notices would require amendment to the timeframes agreed on by the three departments. The DEA drafted the amendments for public consultation (Furter 2013).

c) Water allocation decisions

As several catchments in South Africa experience increasing water scarcity and, or increasing economic activity, these catchments will approach full allocation (de Lange 2010). The risk is of dwindling water resources available for exploitation and increasingly expensive water supplies as water managers are put under pressure to accommodate and mediate between the demands of users in a catchment may become a reality. It is not foreseen that existing water rights would be taken away from current users, requiring water managers to make trade-offs between users and between economic sectors (including water allocation reform in order to provide for the needs of emerging black farmers). The agricultural sector, which holds most of South Africa's water rights, does not have the same levels of assurance of supply requirements that Eskom does and individual farmers may be at risk in competing for water supply.

The increasing cost of water associated with the development of new supply sources, constrained water supplies and the potential need to reconsider water allocation policy may result in trade-offs for the South African economy for example in the balancing of food security, domestic water provision, water for energy and the need to redress past historical imbalances to water access. In the absence of clear policy coordination and cooperation between policy makers, the decisions in the energy sector (or implications of the incentives in the energy economy) to situate water intensive energy generation technologies in locations approaching water stress may pose significant challenges for the Department of Water Affairs or other economic activity users to resolve after-the-fact.

d) Costs of water supply to power generation

The upstream impacts of coal mining activities have downstream consequences for coal power generation. This is problematic when, to reduce transmission costs, coal power plants must be located in the same catchment as coal resources.

When there are water quality impacts in the upstream supply chain, the water used must either be treated – which incurs both a financial cost but also an energy cost – or it must be supplied from another river system that has not been polluted. South Africa's coal generation facilities have been forced to transport water over long distances (for example to the Limpopo from the Vaal – and ultimately Lesotho – for Kusile) because local water sources are too polluted and not of sufficient quality for electricity generation.

For example, Kusile's water requirements would have to be fulfilled via the Vaal River Eastern Sub-system Augmentation Project (VRESAP). VRESAP is a project initiated by the Department of Water Affairs aimed at transferring approximately 160 million cubic metres of water from the Vaal River Dam to supply mainly Eskom's and Sasol's growing water requirements. Eskom was assured in the planning phase by the Department of Water Affairs that VRESAP would be able to supply all the water required by the proposed power station.

In addition to the financial cost of transferring water, inter-basin transfers have an associated opportunity cost, as this water could be deployed for other economic uses. Furthermore, water pollution is also an opportunity cost. Finally, cross basin transfers to supply water expands the need for strong water management across two catchments and increases the complexity of the governance and planning requirements, which has transaction cost implications.

e) Water risk to the South African economy

There is a growing water demand from the South African economy. This is compounded by climate change impacts which will result in increasing incidences of drought in the catchment areas which currently support the region's agricultural and industrial outputs. At the same time, extra water will be needed, particularly in the Vaal system, to dilute the heavily salted water from Gauteng's Acid Mine Drainage problem. In short, forecasts for the future are increased water needs for economic development coupled with drought.

As the energy sector is a strategic water user, other sectors will bear the brunt of associated restrictions, which will in turn impact the South African economy. The risk of water scarcity in South Africa is significant for large industrial water consumers (agriculture and domestic water users).

The governance and planning burden is most likely to be concentrated on mitigating the risks of a future water deficit. This will involve curbing illegal water abstraction, and implementing and enforcing water conservation, and practicing water demand management. All of these measures incur costs and mitigate the risk to the South African economy that is posed by water deficits although they do not eliminate such a risk.

f) Eskom's response to water scarcity

Eskom, being a large user of water in the energy sectors, has a reportedly close working relationship with the Department of Water Affairs in order to ensure that current power plants and possible future plants are incorporated into water resource planning. The parastatal's coal-fired power plants are largely situated in the supply area of the Vaal River System and a complex pipeline infrastructure network provides the power stations with water from dams. These consist of dams, pipelines, pumping stations and reservoirs, and are inter-linked. While most of Eskom's power plants are wet-cooled, new power plants under construction are dry-cooled. Dry-cooled power plants are more costly and less energy-efficient, but the water scarcity in South Africa has necessitated a shift towards dry-cooled power plants. Currently, the Vaal River Eastern Sub-system Augmentation Pipeline (VRESAP) is being constructed in order to augment the water supplied from the Vaal Dam to the Eskom power stations as well as Sasol 2 and 3 (DWAF 2009).

In terms of coal reserves, there is potential for building new coal-fired power stations in Waterberg near Lephalale in the Limpopo province, however the quality and extent of the reserves are not yet known. In addition to the Medupi power station, three or four more power stations could be built in the area, though there are water concerns (DWAF 2009). The Mokolo Dam in the area provides water for existing use in the area, but it cannot meet the water demand requirements for the new power stations despite the fact that they will use more efficient dry-cooling technologies (DWAF 2009). Water for the new power stations will thus have to be conveyed from another river system including, for instance, the Crocodile (West) River (DWAF 2009).

Eskom estimates that its water consumption will increase over the next 10 years due to growing demand for electricity, and recognizes that it will have to find ways to limit increases in water consumption, and as such the company launched a ‘long-term water strategy’ (Eskom 2011). Eskom’s annual water use targets (litres of water per unit of electricity, or water intensity) for each of its power stations show a decline in water use from 1.38 L/kWh in 2006 to 1.29 L/kWh in 2011 (Martin & Fischer 2012). This small decrease is attributed to the deployment of a number of technologies in order to reduce water consumption, including dry-cooling, desalination of polluted mine water for use at power stations, and technical improvements on treatment to maximize the use of water.

1) Dry-cooling – Eskom is implementing dry-cooling in its newer power stations. Dry-cooling does not rely on open evaporative cooling as wet-cooling does, and the company reports that the overall water use of dry-cooled power stations is approximately 15 times lower than conventional wet-cooled power stations (Eskom n.d.(a)). The trade-off though is that dry-cooled power stations are less efficient, and require higher capital costs and have higher operating costs. The Matimba power station near Lephalale in Limpopo is the largest direct dry-cooled station in the world; the choice of dry-cooled technology for this power station was largely influenced by the scarcity of water in the area (Eskom n.d.(b)). The water consumption of the station is about 0.1 L/ kWh of electricity, compared to about 1.9 L/kWh on average for the wet-cooled plants. In turn, the Kendal power station near Witbank in Mpumalanga is the largest indirect dry-cooled power station in the world. The water consumption of this station is about 0.08 L/kWh (*ibid*).

2) Desalination – Eskom has endorsed a policy of zero liquid effluent discharge at wet-cooled power stations where the design allows for it (Eskom n.d.(a)). This means that water is cascaded from good to poor quality uses until all pollutants are captured in the ash dams. In terms of this policy, Eskom has introduced desalination plants at the Lethabo and Tutuka power stations, allowing polluted mine-water from the tied collieries to be re-used at the power stations, thus assisting with prevention of negative environmental impacts on surface and ground water (*ibid*).

3) Water metering and monitoring – The Department of Water Affairs measures the supply of water to the power stations at the boundaries of the power station terraces. Together with the Department, Eskom has adopted a metering procedure that measures to a level of accuracy of 0.5% compared to the previous level of 5% (*ibid*). Furthermore, on-going meter verification and upgrades take place on the power station terraces and on-terrace and third party meter readings take place at least once a month. There are also a number of other measures in place including inspections, water balances to verify usage, raw water leak detection, and regular leakage inspections on the pipelines.

4) Demand side management – This is used to reduce the amount of electricity consumed, which in turn reduces the amount of water used in the generation of electricity. Eskom estimates that for every kilowatt hour of electricity that is saved, approximately 1.32 litres of water is also saved on average (*ibid*).

5) International co-operation – As a participant in the Southern Africa Power Pool, which facilitates trading electricity between countries in Southern Africa, Eskom may be able to import hydro-electricity from neighbouring countries thereby reducing both its carbon footprint and water usage.

In addition to the above measures to reduce water consumption, Eskom has contributed to the advancement of the water infrastructure in the country. Over the past 40 years Eskom has been involved in the development of an intensive network of pipelines and dams with the Department of Water Affairs – especially on the Mpumalanga Highveld – through joint involvement in projects, or financial contribution to the infrastructure development. The aim of these projects was primarily to provide a secure water supply to Eskom's power generation facilities, with co-benefits that it has contributed to supplying water to industries and for domestic water use in the area. Eskom is currently a major contributor to the pipeline linking the Vaal Dam to the water supply system in the Mpumalanga Highveld.

6.2.4. Integrated regulatory approaches for the water-energy nexus

Based on the review of RSA policy and regulation instruments, this section provides an assessment of the degree to which these instruments enable integrated approaches to long-term energy and water resource choices which could promote climate resilience.

a) Energy regulatory environment

In line with the Constitution of the Republic of South Africa, the White Paper on Energy Policy of 1998 states that an equitable level of national resources must be invested in renewable technologies. In this vein, the White Paper on Renewable Energy of 2003 identifies sustainable development as one of the essential elements of the national renewable energy policy. It outlines the government's vision, policy and strategic objectives for encouraging the use of renewable energy, and informs relevant institutions of their role within the process. The paper recognizes that renewable energy technologies save on water consumption in comparison to with coal-fired power plants.

The National Energy Act 34 of 2008 framework legislation empowers the Minister to undertake certain measures to ensure energy security including integrated energy planning, energy research and collection of information regarding energy demand, supply and generation. It compels the Minister of Energy to develop and publish an Integrated Energy Plan. The Minister is empowered by the Electricity Regulation Act of 2006 through the Electricity Regulations on New Generation Capacity of 2009 to determine and publish the IRP (DoE 2010).

The objective of the IRP 2010-2030 is to develop a sustainable electricity investment strategy for generation capacity and supporting infrastructure for South Africa. The plan also accounts for implications arising from demand-side management (DSM) and pricing, as well as capacity provided by Eskom and IPPs. The IRP is intended to:

- "improve the long-term reliability of electricity supply through meeting adequacy criteria over and above keeping pace with economic growth and development;
- ascertain South Africa's capacity investment needs for the medium-term business planning environment;
- consider environmental and other externality impacts and the effect of renewable energy technologies; and
- provide the framework for ministerial determination of new generation capacity (inclusive of the required feasibility studies) as envisaged in the new generation capacity regulations".

The development of a National Integrated Energy Plan (IEP) was envisaged in the White Paper on Energy Policy of 1998 and, in terms of the National Energy Act of 2008. The Minister of Energy is, according to the National Energy Act of 2008, mandated to develop and, on an annual basis, review and publish the IEP in the Government Gazette. The purpose of the IEP is to provide a roadmap of the future energy landscape for South Africa. It guides future energy infrastructure investments and policy development, and has a planning horizon of not less than 20 years. The development of the IEP is meant to be a continuous process because it needs to be reviewed periodically to take into account changes in the macro-economic environment, developments in new technologies and changes in national priorities and imperatives, amongst other factors.

b) Water regulatory environment

In South Africa, access to water has historically not been equitable. In addition, there are emerging farmers and poorer communities for whom the impacts of poor quality water are very acute. Responding to the needs of historically disadvantaged individuals is an on-going challenge for South African policy makers, as the impacts of water scarcity and poor water management are often felt by the poor.

In 1997, Cabinet adopted the National Water Policy (NWP) for SA in response the country's new direction as set out by government to increase the access to water The NWP states that "the objective of managing the quantity, quality and reliability of the nation's water resources is to achieve optimum, long-term, environmentally sustainable, social and economic benefit for society from their use". The three main objectives for managing South Africa's resources, as rooted in the Bill of Rights, are:

- to achieve equitable access to water, that is, equity in the access to water services, for the use of water resources, and for the benefits from the use of water resources;
- to achieve sustainable use of water by making progressive adjustments to water use with the objective of striking a balance between water availability and legitimate water requirements, and by implementing measures to protect water resources; and
- to achieve efficient and effective water use for optimum social and economic benefit.

SA's National Water Act (Act 36 of 1998) is considered to be highly progressive (Seward 2010). This Act provides the legal framework for the effective and sustainable management of South Africa's water resources. The Act aims to protect, use, develop, conserve, manage and control water resources as a whole, promoting the integrated management of water resources with the participation of all stakeholders. According to the Act, the priority for water use is providing water resources of sufficient quantity and quality to meet the requirements of the Reserve, and then the meeting of a range of priorities listed below, before water can be allocated in water management areas. The priorities include:

- ensuring water supply to meet international rights and obligations;
- providing for Water use of Strategic Importance (Water use that is considered to be of critical national importance is called water use of strategic importance and is authorised by the Minister. The energy sector is the only strategic user at present);
- facilitating Inter-catchment water transfers; and

- designing a contingency plan to meet projected future water needs.

In order to achieve the purposes of the National Water Act in the context of competing uses of water, the Department of Water Affairs controls water use through registration and through different types of authorisations.

In terms of the Act, the Minister of Water Affairs is responsible for the National Water Resource Strategy (NWRS). The NWRS binds all water institutions and water users, and it must be updated at least every 5 years. This strategy is the most relevant instrument for the energy-water nexus discussion. It sets out the policies, strategies, guidelines and procedures for the management of water in the country.

The first NWRS was adopted in 2004 while the second one was published in 2013 (called NWRS2). The NWRS2 responds to South Africa's key, growth, development, and socio-economic priorities over the next 5 to 10 years. The NWRS2's strategic objectives are to be aligned to both the National Water Act and the National Development Plan (discussed below). NWRS2 recognises that "South Africa's growing economy and social development is giving rise to the growing demands for water. Water plays a central role in most of these national planning initiatives, such as agricultural development, energy security, tourism and recreation, mining, industry and municipal water supply."

With regard to the energy sector, the NWS2 notes that "the energy sector although only using 2% of water, contributes about 15% to the GDP of South Africa and creates jobs for 250 000 (GCIS 2011). It generates about 95% of the electricity in South Africa and also exports it to countries in Africa. The energy sector, including Eskom, is highly dependent on reliable supplies of water for the generation of electricity, and an elaborate and sophisticated network of water transfer and storage schemes has been developed specifically to support this sector and ensures high levels of reliability. The water sector is on the other hand highly dependent on a constant and reliable supply of electricity to "move water" (NWRS2 2013).

Furthermore, it also notes future water challenges to the energy generation sector, and that energy production capacity is expected to increase as the Department of Energy is planning significant investment in new power generation capacity, including building dry-cooled coal-fired power stations (Medupi and Kusile) that will be more water efficient. It notes that these power stations are located in water-scarce areas, and would strain available water resources and the return to service of older power stations, which are wet-cooled, is also burdening available water resources. It recognises that the NDP has proposed the use of renewable energy sources to reduce carbon emissions, but that renewable energy sources may also have water demands.

Regarding coal mining, according to the NWRS2, there are new mines, particularly coal mines located in water scarce areas such as the Lephalale and Steelpoort Valley areas which will put pressure on water resources in these areas. The issue of pollution from mines is also considered to pose a threat to water quality.

In terms of future needs and associated impacts, the NWRS2 recognises that “given the limited water resources available, it is likely that it will not be easy or economically feasible to meet all the demands that may arise. In many parts of the country, the point at which all the economically-exploitable freshwater resources are utilised is approaching fast. New approaches will have to be adopted to balance demand and supply, particularly in the most-stressed inland catchments where much of South Africa’s economic growth and social development are occurring.”

The NWRS2 considers a range of options for balancing supply and demand, which include water conservation and demand management, and the desalination of seawater. Both of these options have energy implications. It is noted that desalination is an energy intensive process. So, a decrease in water consumption would result in a reduction in the energy demand for pumping, treatment and heating of water. The NWRS2 acknowledges that the water-energy connection should receive more attention to ensure that policies that transition to a sustainable, low-carbon South African economy are achieved. This strategy identifies the following challenges:

- The energy sector’s water requirement is about 2%. This may not appear to be a high consumption; however, considering there are only a few power stations, this is a relatively high water-consuming sector and implementing measures that will improve the overall efficiency of water use within the energy sector is critical.

- Most of the power stations were designed with high water usage, wet cooled and wet ashing. Eskom has committed itself to the installation of dry cooled power stations that will drastically reduce the demand for water by these new power stations. The demand for water, however, would be increased due to the choice of air pollution measures selected to combat air pollution, as required by the National Environmental Management Act (NEMA) and there is scope for research and development for alternative, less water intensive technologies to be investigated by the power sector.

- There is scope for continuous improvement at existing power stations; for example, the implementation of hybrid dry and wet cooling systems which might require retrofitting of existing power stations to improve water efficiency. However, measures such as these would require retrofitting or even re-designing and would therefore require careful planning.

The NWRS2 notes the challenges in implementing water allocations and water use authorisations that entrench water conservation and water demand management in the mining, energy and manufacturing sectors. It recognises that the sectors are not homogenous and that universal water use efficiency targets can thus not be set generically across the board. It states that an investigation was conducted by the Water Research Commission in the 1980s to determine water usage by the high water-consuming sectors. This work resulted in the Natsurv series of documents. The DWA and WRC will be collaborating with the relevant sectors to revise these documents, including setting targets per sub-sector as far as is practically possible.

Hydro-power generation, which is mentioned in the NDP and the IRP, receives attention in the NWRS2 as well, which notes that "Hydropower is one of the renewable sources for generating electricity referred to in the Integrated Resource Plan 2010 (IRP 2010) for developing South Africa's electricity generation to meet expected energy demands up to 2030. Development of renewable energy sources, rather than burning fossil fuels such as coal, will contribute to the reduction of carbon emissions, while also ensuring sufficient energy to support growth in the economy." In this regard, the NWRS2 states that the potential for small-scale hydro-electric plants is being considered by DWA, the Department of Environment Affairs, National Treasury, Eskom, the Central Energy Fund and private sector partners, and that the "DWA will work with the Department of Energy, DPE and Eskom to ensure integration of medium and long-term planning for the development of energy and water resources. Particular attention will be paid to the potential for desalination of seawater for supplying coastal towns and cities where there are sufficient sources of electricity to support this." (DWA 2013a).

The draft NWRS2 specifically refers to the water-energy nexus, stating that "a close look at the water-energy nexus is critical for South Africa's sustainable development path." Under the NWRS2 are a number of national thematic plans, including the National Climate Change Strategy for Water Resources (WCCS). The WCCS has been described by the National Climate Change Response White Paper as setting out the short-term response to climate change, while the Water for Growth and Development Framework (WGDF) 2030 is seen as setting out the medium to long-term responses. The strategy recognises that climate change will increase the pressure on already stressed water resources and that the current water resources are insufficient to satisfy the anticipated increase in demand. The framework does however, not speak to a focussed direction that the country needs to take with respect to the effects of climate change on water resources, or the effective management of water quality. There is a crucial requirement for the effective management, use, allocation and re-allocation of available water resources. The strategy does set out particular climate change objectives that are required to be integrated into the short, medium and long-term planning for water resources. These strategies include:

- implementing the best catchment and water management practices to maximise the degree of water security and resource protection under changing climatic conditions;
- reducing the vulnerability and enhancing the resilience to water-related impacts of climate change in communities/sectors at greatest risk;
- providing human, legal, regulatory, institutional, governance and financial resources and capacity to deal with the long-term effects of climate change; and
- undertaking focused monitoring and research in order to ensure the efficacy of water adaptation approaches over the long-term.

Current water management processes need to consider climate change, build adaptive capacity for the future through short and medium term actions and initiatives, and also take a longer term perspective on the considerations and requirements to build a climate, water and development resilient economy and society in South Africa.

c) National imperatives

Internationally the human right to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic use is outlined in the UN General Comment No. 15, which in international law is the legal basis for the right to water and its relationship to other human rights. South Africa's Constitution guarantees everyone the right of access to water.

National Planning Commission (NPC) is tasked with developing the National Development Plan, a long-term development vision for the country. The first National Development Plan (NDP) prepared by the NPC was published in 2012. It is important to note that the NPC does not have direct authority over government departments, although the NDP is being taken as a guiding document for implementation by all government departments. The NDP deals extensively with water and energy issues. On the subject of energy, the NDP refers to the need for improved energy efficiency, including in transport, and an increased use of renewable energy.

At the level of Cabinet, several clusters operate, focused on particular aspects of decision-making. For example, there is a Ministerial cluster dealing with infrastructure, an economic cluster, a social cluster, and various other clusters. These clusters are mirrored at the level of Directors General. The purpose of these clusters is to ensure coordinated decision-making on critical programmes and projects, and among Ministries and Departments.

d) Water-energy framework environment

Water resource management in SA faces various challenges, which may be compounded by its vulnerability to climate change and related stress on water resources. The Department of Water Affairs (DWA) retains responsibility for the country's water sector and oversees the implementation of its policies and regulations by the various water sector institutions. Water sector institutions that take over some specific resource management and service delivery responsibilities from DWA include catchment management agencies, water user associations and water services providers – which are primarily at the municipal level. These institutions are responsible for the regional and local level management, allocation and provision of water resources to all water users (including the energy sector).

As mentioned hitherto, the NWRS2 sets out the policies, strategies, guidelines and procedures for the management of water in the country. The strategy estimates the future demand for water in the power-generation sector, including coal-fired power stations, hydropower schemes, and the mining sector. It further notes that the energy sector in South Africa is highly dependent on reliable supplies of water for the generation of electricity, but it does not quantify or qualify the full burden of the water quality impacts.

What is not sufficiently articulated at a policy level are the impacts of the energy mix on water resources, including the potential need to increase the costs of water, or reallocate water, or the implications of drought on the different sectors. Importantly though, the NWRS2 notes that the DWA and WRC will be collaborating with the relevant sectors to revise documents relating to water use by water-dependent sectors, thus highlighting the concerns around water impacts of the energy and mining sectors.

Energy policy documents recognise that South Africa is classified as a 'water stressed' country. However, water supply is currently not seen as a restriction to future energy supply plans. It is understood that dry cooling technologies for thermal power plants (specifically coal) will reduce the water demand for electricity generation and that most renewable energy technologies have lower water requirements (Madhlopa *et al*. 2013). Mining is considered in the energy plans as a significant user of electricity and hence an important contributor to electricity demand, but there is no mention about the water needs and environment impacts of its energy needs. Coal mining is estimated to have consumed approximately 50 billion litres of water in 2011 in South Africa (Martin & Fischer 2012).

6.3. Proposed Policy Framework for efficient water use in energy production

6.3.1. Introduction

The importance of water in energy supply is recognised in national plans to address energy needs. In this regard, the Integrated Resource Plan (IRP 2010) of South Africa quantifies anticipated water demand and lists water as one of the deciding criteria for energy plans, alongside cost and greenhouse gas emissions. However, the impacts on water over the lifecycle of energy production are not easily quantified. As a result, trade-offs, for example between economic sectors or between dry cooling and generation cost of electricity production, may not be adequately translated into the process of decision-making on the utilisation of water resources in energy supply.

The importance of efficient use of water resources to meet energy demands is emphasised in NWRS2. However, the impact of energy provision on water resources is not sufficiently articulated at a policy level. At the same time, while national energy plans recognise that the limited nature of water resources necessitates water use efficiency, it is not apparent that decisions to invest in potentially long-term interventions for energy supply adequately consider potential changes to water supply in the long term (for instance in the context of climate change).

To ensure sustainable economic development, SA needs to anticipate water scarcity in planning its energy strategy, across all energy technologies. The future energy mix needs to engage more comprehensively with the current and future impacts of water scarcity around SA. To achieve this, it is necessary to scrutinize the use of water in energy production and the impact of different types of energy resources on water resources (Platonova and Leone 2012). A harmonized policy landscape can positively contribute to the efficient use of water in the energy sector. In this vein, this section presents a proposed draft framework that aims to assist in tracing and addressing deficiencies of synergy among the relevant policies.

6.3.2. Guiding principles

Laws, policies and strategies provide the guiding principles for this Policy Framework. The primary guiding principles for water policy in South Africa are equity, sustainability and the efficient use of resources. For the protection of water quality, two principles apply: that of taking a precautionary approach where there is uncertainty of the risk to the environment, and that of 'the polluter pays'. The management of water quality should be done in a holistic manner and should take society and the environment into account; decision-making processes that affect water resources must be transparent and with full disclosure (DWAF 2002).

The right of equitable access to sufficient water is enshrined in the Constitution of the Republic of South Africa (Chapter 2, section 27(b)). This principle is echoed in the National Water Resources Strategy which states that access to water is a basic human need and that there should be equity in access to water services, water resources and benefits from water resource use through social, economic and environmental development and management.

This right applies to the human needs of current and future generations, and requires that water resource use be managed in an environmentally sustainable manner, from which social and economic benefits should be derived for all over the long term (National Water Resources Strategy 2012). This principle is reiterated in the National Planning Commission National Development Plan (NPCNDP), which provides for all people to have access to clean, potable water and for sufficient allocation of water for agriculture and industry, meanwhile recognising the trade-offs in the use of water. The efficient use of water resources is encouraged by the National Planning Commission which targets the reduction in water demand in urban areas to 15% below the business-as-usual scenario by 2030.

Principles guiding energy policy include the principles of supplying energy at least cost and that of 'use it and keep it'. With respect to the environment, guidance is provided by the polluter pays' principle and by the principles under the National Environmental Management Act 107 of 1998 (Winkler 2006).

The main guiding principles of the Renewable Energy White Paper (2003) are equity (inter and intra-generational) and consideration of all the social, economic and environmental costs. The White Paper highlights the need for responsiveness to global and regional issues, to allocate responsibility of function for effectiveness in pursuing its objectives, and the importance of equitable participation by all stakeholders in energy governance (DME 2003).

6.3.3. Key elements and common issues

a) Policy alignment

A Policy Framework promotes the vertical alignment and the horizontal harmonisation of key government and political commitments such as the Millennium Development Goals, the National Development Plan, the Climate Change Response Policy, and the shift to the Green Economy, all of which must be considered within planning for energy supply and water resource management. 'Integrated Energy Planning is therefore not only about ensuring that South Africa's energy needs are met, but rather takes a broader approach in ensuring alignment between cross-sectoral impacts and the National Objectives – where applicable, Regional developments are also considered' (DoE 2013a).

The White Paper on Energy of 1998, the White Paper on Renewable Energy of 2003 and the Energy Act of 2008 provide impetus for planning for sustainable renewable energy, taking water considerations into account. The Integrated Resource Plan 2010-2030 (IRP) and the Integrated Energy Plan (IEP) proposals for a future energy mix speak about and model water-use of different energy-mixes.

So as to encourage the integrated nature of energy planning, the Integrated Energy Planning notes that stakeholder engagement underpins the process of developing the Integrated Energy Plan to ensure that the IEP is understood, its development process is transparent, and that ultimately the necessary stakeholder buy-in is obtained (DoE 2012). At an inter-governmental level, stakeholder engagement is ensured by the IEP Steering Committee, which is an inter-departmental government committee led by the Department of Energy and consisting of the departments of Science and Technology; Environmental Affairs; Water Affairs; National Treasury; Economic Development; Trade and Industry; Human Settlements; Transport; Rural Development and Land Reform; Mineral Resources and the National Planning Commission.

The Draft IEP 2012 promotes the conservation of water as a key objective, however, while water is explicitly given consideration within future energy planning in both the IRP and IEP, and the water impacts of the energy environment are given consideration within the NWRS2, both of these are deficient in detail and have gaps, including accounting for water uses and impacts throughout the energy production cycle, and planning for this. For example, the electricity sector relies on the mining industry for coal, but the impact of coal mining on water resources (in terms of use and impacts) is not given enough consideration within the water planning environment.

In the context of the water-energy nexus the importance of harmonising water and energy governance is highlighted by the NWRS2 which stipulates that the Department of Water Affairs (DWA) should work with the Department of Energy (DoE), Department of Public Enterprises (DPE) and Eskom 'to ensure integration of medium and long-term planning for the development of energy and water resources'. The importance of various institutions working together on water is highlighted by the NWRS2 which mandates the DWA and the Water Research Commission (WRC) to collaborate with appropriate sectors to revise documents pertaining to the use of water by high water-consuming sectors. It highlights concerns related to the effect of energy supply and mining sectors on water resources.

An obstacle to harmonised governance of water resources and energy supply is that the relevant resources are managed at different levels of authority and appear to be working in silos. Under South Africa's water management strategy, as defined under the National Water Resources Strategy, the country is divided into 9 water management areas (WMAs). These WMAs encompass catchments or part thereof. At the more local level, each local authority regulates the abstraction and use of water within its boundaries. At the national scale, large-scale water abstraction and use (e.g. mining) is nationally regulated and licenced by the Department of Water Affairs.

The responsibility for energy planning and permitting rests with the National Government. The National Government is pursuing its plan for electrification to supply 95% of the population with electricity by 2030, with non-grid options available for the rest (NPCNDP 2011). Alongside this commitment the Constitution endows each household with the right to 50 kWh of free electricity, and 6 000 litres of free water, per month. These commitments indicate the need for additional energy (electricity) capacity for new connections and the retiring fleet. The National Development Plan estimates that to meet these commitments about 20 000 MW (of 40 000 MW required new build) should come from renewable energy technologies, and that five million solar water heaters should be installed by 2030 (NPCNDP).

Further work to align energy development and water allocation is however needed, and the National Water Policy Review by the DWA states that 'a close look at the water energy nexus is critical for South Africa's sustainable development path', and that'' the 'current policy and legislative provisions on trading of authorised water use do not facilitate the achieving of one of the fundamental principles of the Act, namely equity in allocation' (DWA 2013). It is deemed important that the water and energy policies should take cognisance of one another, or at the very least, not be in conflict with one another.

b) Energy and water in the context of climate change

To meet the foreseen energy needs of South Africa in the context of a changing climate, the DoE developed an Integrated Resource Plan (IRP). The national strategy of the IRP (DoE 2010) is to meet the growing electricity demand, but at the same time also honouring South Africa's commitment to a greenhouse gas emission reduction of 34% below business as usual by 2030. The National Development Plan (NDP) stipulates a peak, plateau and decline trajectory for greenhouse gas emissions, with the peak being reached around 2025 and that by 2030, an economy-wide carbon price should be entrenched and that the country enforces zero emission building standards by 2030 (NPCNDP). In light of the proposed carbon tax, the carbon intensity of energy sources is an important consideration. It is likely that climate change is expected to put added strain on water provision. This, along with the drive to provide energy for all, will result in an increased demand for water if the current means of energy production are continued.

c) Prospects for change in the water-energy policy nexus

It is important to assess the demands that might be placed on the country's water resources in the context of changing energy requirements and water availability. This can inform strategic investment in future energy supply. Electricity production is considered to be a high-value economic use of water, and electricity producers are considered to be 'priority users', hence this allocation of water takes precedence over most other activities. The DWA has recommended dry-cooling technology at new power plants but it has not recommended a transition to relatively 'water free' renewable energies.

The IRP was developed to meet foreseen energy needs. A part of this strategy is the need to diversify the energy from reliance on coal-fired electricity to an energy mix in which a third is generated from renewable sources. To meet this goal, investment in renewable energy technologies is being incentivised in the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) tender process to supply energy to the national grid.

6.3.4. Structure of the proposed Policy Framework

6.3.4.1. Legislation

Constitution of the Republic of South Africa (1996)

The Constitution is the overarching document that guides all the other legislative and policy instruments adopted by the government. Section 27(b) of Chapter 2 states that everybody has the right of access to sufficient water (RSA 1996). The state is obliged to take reasonable legislative and other measures, within its capacity, to attain the realisation of this right. It is therefore necessary that all sector laws and policies should be properly aligned with the constitution for synergy.

National Water Act 36 of 1998

The National Water Act provides the legal framework for the effective and sustainable management of South Africa's water resources (RSA 1998a). The Act aims to protect, use, develop, conserve, manage and control water resources as a whole. It further promotes the integrated management of water resources with the participation of all stakeholders. The priority is to provide water resources of sufficient quantity and quality to meet the requirements of the reserve (meeting a range of priorities) before water can be allocated in water management areas.

National Energy Act 34 of 2008

The National Energy Act 34 of 2008 empowers the Minister to undertake certain measures to ensure energy security including integrated energy planning, energy research and collection of information regarding energy generation, supply and demand. This regulatory instrument compels the Minister of Energy to develop and publish an Integrated Energy Plan. The IRP for electricity needs to be linked to the outlook for energy because electricity forms a sub-sector of the energy sector. The Minister derives the power to determine and publish the IRP from the Electricity Regulations on New Generation Capacity of 2009, which in turn are promulgated in terms of the Electricity Regulation Act of 2006.

National Energy Regulation Act 40 of 2004

The National Energy Regulator Act 40 of 2004 (RSA 2004) establishes the National Energy Regulator, now commonly referred to as the National Energy Regulator of South Africa. Its duty it is to regulate the piped-gas, petroleum and electricity industries of South Africa.

National Environmental Management Act 107 of 1998

The National Environmental Management Act 107 of 1998 provides a legal framework for 'integrating good environmental management into all development activities' (RSA 1998b). Part 1 of Chapter 7 of this Act provides for the prevention of environmental pollution or degradation. This encompasses the pollution of water resources by various stakeholders, including the energy sector.

6.3.4.2. Strategies

National Water Resource Strategy 2

As discussed in Section 2.7, this Strategy takes on board a range of options for balancing the supply and demand of water (including conservation and demand management, and desalination of sea water). These options have implications for energy demand. It notes the impact of future technology on water resources. Challenges related to how to achieve equity and redistribution, ensuring water security for the future and water availability for economic growth and development are dealt with in this Strategy.

Energy Efficiency Strategy

The Energy Efficiency Strategy is mandated by the White Paper on Energy Policy (DME 2005). This Strategy links the energy sector with other government initiatives, and recognises the potential for improvements in energy efficiency across all economic sectors. It should be noted that the water sector is also an energy user. Energy is used in water abstraction, treatment and conveyance. Thus, implementation of energy efficiency in this sector can contribute to environmental, social and economic sustainability.

6.3.4.3. Policies

a) White Paper on a National Water Policy for South Africa

The White Paper on a National Water Policy for South Africa (1997) is aimed at guiding the management of water in the country. Its objectives are equity in access to water services, water resources and benefits from water resource use (DWAF 1997). The policy highlights the need to focus on efficiency, effectiveness and demand-side management in water utilisation in order to promote water conservation. The policy also covers elements of protecting water resources.

A recent review of water-related policies was conducted (DWA 2013). The review identified unintended oversight and gaps in the present water policies. It outlines critical elements of equitable use of water, as listed below.

a) Provision of adequate supply of safe water to all households to meet their domestic and productive requirements (minimum of 25 litres per person per day provided free of charge to all indigent households).
b) Making sure that the authorisation to use water for productive purposes is aligned with the demographic realities of South Africa and serves to support black economic empowerment.

c) Allocation and use of water supports the reduction of poverty and inequality across the country.
d) Indirect benefits of water from healthy river systems are protected and maintained.

In addition, the document identifies the need to carry out a comprehensive review of the White Paper on Water Supply and Sanitation (1994), White Paper on a National Water Policy for South Africa (1997), White Paper on Basic Household Sanitation (2001) and the Strategic Framework for Water Services (2003) in order to address the observed policy gaps.

b) White Paper on the Energy Policy of South Africa (1998)

The White Paper prescribes energy policy and formulation that promotes sustainable development by highlighting equity and the sustainable use of natural resources. The policy encouraged the introduction of a Renewable Energy Feed-in Tariff. The objectives of this policy are: a) increasing access to affordable energy services; b) improving energy governance; c) stimulating economic development; d) managing energy-related environmental impacts; and e) securing supply through diversity.

c) White Paper on Renewable Energy (2003)

This policy promotes sustainable development as a key element in the national renewable energy policy. It is the most comprehensive policy document pertaining to the government's vision on renewable energy. It informs institutions of roles, encourages the use of renewable energy technologies and stimulates market investment in renewable energy technology. There is a 10-year plan to facilitate the production of 10 000 GWh of energy from renewable energy sources by December 2013 (approximately 4% of projected demand or 1 667 W of projected energy demand for 2013 of 41 539 MW) (mainly from biomass, wind, solar and small-scale hydroelectricity).

d) National Climate Change Response Policy

The National Climate Change Response Policy (NCCRP 2011) focuses on mitigation through the reduction of energy generation and use sector emissions. The NCCRP notes that reduced emissions should come from greater energy efficiency, demand management and moving to a less emission-intensive energy mix. It notes several flagship initiatives including the Renewable Energy Flagship Programme, the Energy Efficiency and Energy Demand Management (EEDSM) Flagship Programme, the Carbon Capture and Sequestration Flagship Programme, the Water Conservation and Demand Management (WCWDM) Programme (to be implemented in the mining, industrial, electricity, agriculture and water service sectors). As part of the EEDSM Programme, government has begun to implement a solar water heating programme primarily aimed at households. For businesses, an energy efficiency savings tax incentive is being proposed; for verifiable energy efficiency savings businesses will be able to make a deduction against taxable income (DNT 2013).

6.3.4.4. Plans

a) Integrated Resource Plan (2010)

The IRP document shows government intent to diversify energy supply. The plan for energy supply includes 3 349 MW of imported hydroelectric power. The draft IRP target for 2013 is 6 000 GWh for renewables. It encourages co-generation (capacity 343 MW in 2010, 518 MW in 2011, 284 MW in 2012, 300 MW in 2013). The objective of the IRP 2010-2030 is to develop a sustainable electricity investment strategy for generation capacity and supporting infrastructure for South Africa over the next 20 years. Specifically, water is recognised as a key constraint and risk in the IRP, and all the scenarios considered deal with the issue of water use in the context of scarce water resources. Clearly, efficient use of water in the energy sector can contribute to sustainable socio-economic development.

b) Integrated Energy Plan

The development of a National IEP was envisaged in the White Paper on Energy Policy of 1998 and, in terms of the National Energy Act of 2008. The purpose of the IEP is to provide a roadmap of the future energy landscape for South Africa which guides future energy infrastructure investments and policy development, and should have a planning horizon of no less than 20 years. The development of the IEP is meant to be a continuous process as it needs to be reviewed periodically to take into account changes in the macro-economic environment, developments in new technologies, and changes in national priorities and imperatives, amongst other factors.

This document lays out a plan to meet current and future energy demands, taking into account the need for job creation and minimising the impact on the environment. It presents models for water use under different energy scenarios going forward. Future scenarios up to 2050, with emissions limits, are covered (DoE 2013c). It shows emissions and water use from different scenarios from the energy mix in the future.

c) National Development Plan

In 2009 South Africa established a National Planning Commission (NPC), tasked with developing the National Development Plan (NDP), a long-term development vision for the country. It is important to note that the NPC does not have direct authority over government departments, although the NDP is being taken as a guiding document for implementation by all the departments (NPC 2011). The NPD has been adopted by both Cabinet and Parliament. It extensively deals with water and energy issues. On the subject of energy, it refers to the need for improved energy efficiency, including in transport, and an increased use of renewable energy. At the level of Cabinet, several clusters operate, focusing on particular aspects of decision-making. For instance, there is a Ministerial cluster for a specific issue, with clusters on infrastructure, economic, a social, and other issues. These clusters are mirrored at the level of Director-General. The purpose of these clusters is to ensure coordinated decision-making on critical programmes and projects among Ministers and departments.

d) Water for Growth and Development Framework

This framework provides the foundation, and creates the necessary pointers, for the development of the National Water Resources Strategy. It recognises that there is a close working relationship with the large water users in the energy sector to make sure that current and future power plants are included in the water resource planning initiatives (DWAF 2009). It is reported that 2% of the available water is allocated to the power generation sector. The document also notes that Eskom is embarking on a number of initiatives to reduce water usage, including the development of dry-cooled power plants. However, it is pointed out that this variety of power plants is less efficient and more costly to operate.

e) Department of Energy Strategic Plan 2011/12-2015/16

This strategic plan outlines the department's strategies to harness all available energy resources in order to meet future demand while achieving government mandates of universal electrification and affordable services. Some of the strategic objectives of this plan are 'Environmental assets and natural resources protected and continually enhanced by cleaner technologies' and 'Mitigation against, and adaptation to, the impacts of climate change' (DoE 2010:20). It is seen that these objectives are consistent with the White Paper on Renewable Energy (2003) and the NCCRP (2011).

This brief discussion shows that the efficient use of water is reflected in the major relevant legislative and policy instruments. Figure 6-3 is a diagrammatic representation of the legislation, strategies, policies and plans, which have been considered in this investigation.

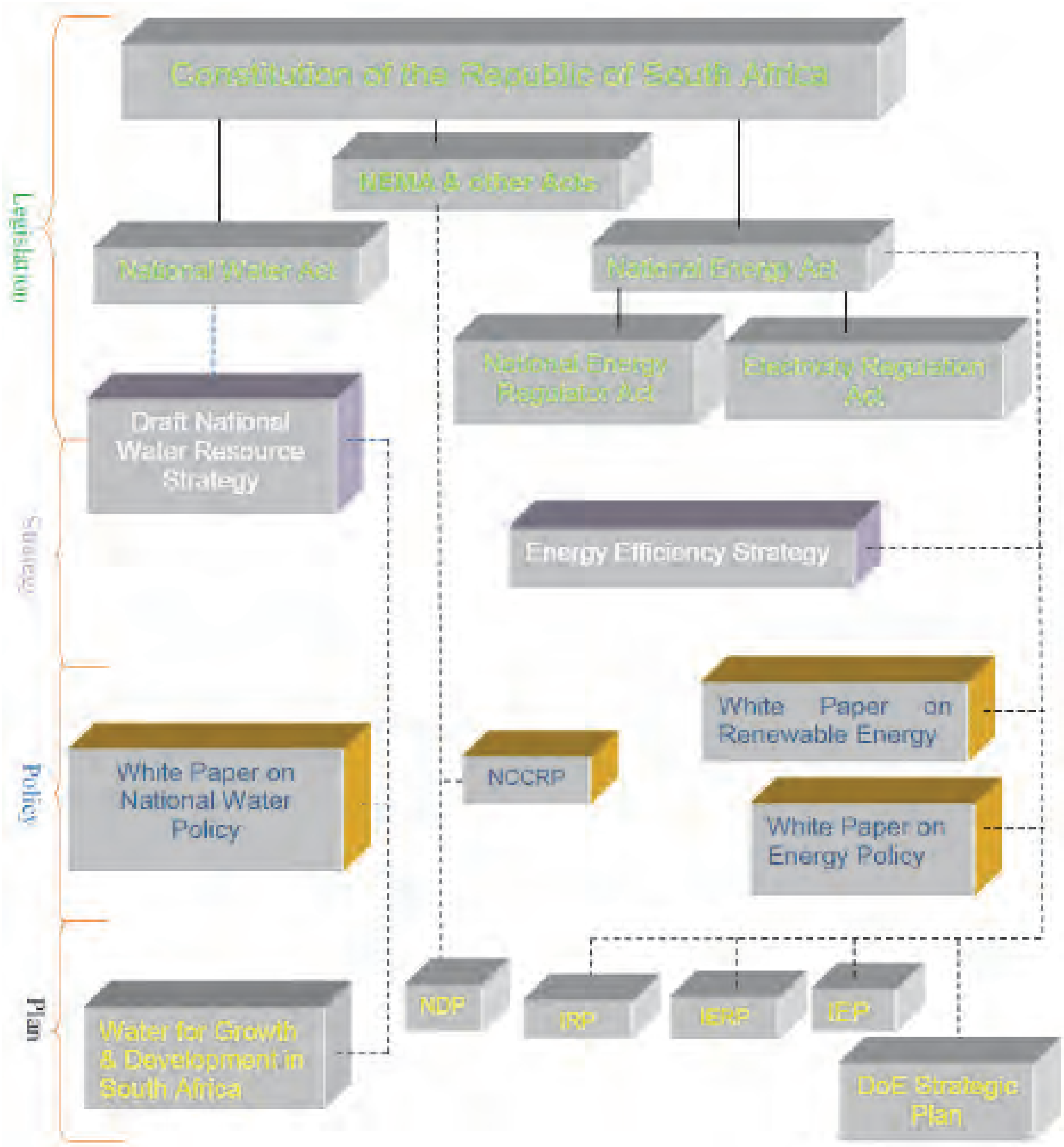


Figure 6-3: Diagrammatic representation of the legislation, strategies, policies and plans considered in this investigation.

6.3.5. Recommended Policy Framework

This section has shown that there exists a network of legislative and policy instruments in SA that directs the management of water and energy resources. Nevertheless, there is an insufficient degree of synergy amongst them with regard to the efficient use of water in the energy sector. There is therefore need for a framework that can assist in tracing policy links in order to achieve sustainability towards effective and efficient resource management and planning.

The constitution of the Republic of South Africa is the supreme piece of legislation (Figure 6-3). This overarching legislative instrument informs the development and implementation of the National Water Act, Energy Act, Environment and other acts. It should be mentioned that domestic legislation is influenced by international agreements, for example under the United Nations Framework Convention on Climate Change. For instance, SA has ratified the Kyoto Protocol. In view of this, the country is making policy and regulatory shifts in line with international law (RSA 1996).

At the level of legislation, it is necessary to ensure that horizontal linkages exist during the design and implementation of the piece of legislation (see diagrammatic representation in Figure 6-4). It is also important that legislation regarding water, energy and other matters should be harmonised with regard to the efficient use of water. In turn, this legislation should influence the vertical development of relevant strategies/policies which are horizontally synergetic. Similarly, national water and energy plans/programmes should emanate from national strategies/policies. These plans should also be comprehensively aligned. There is need to capture elements of water use efficiency at all the levels of policy.

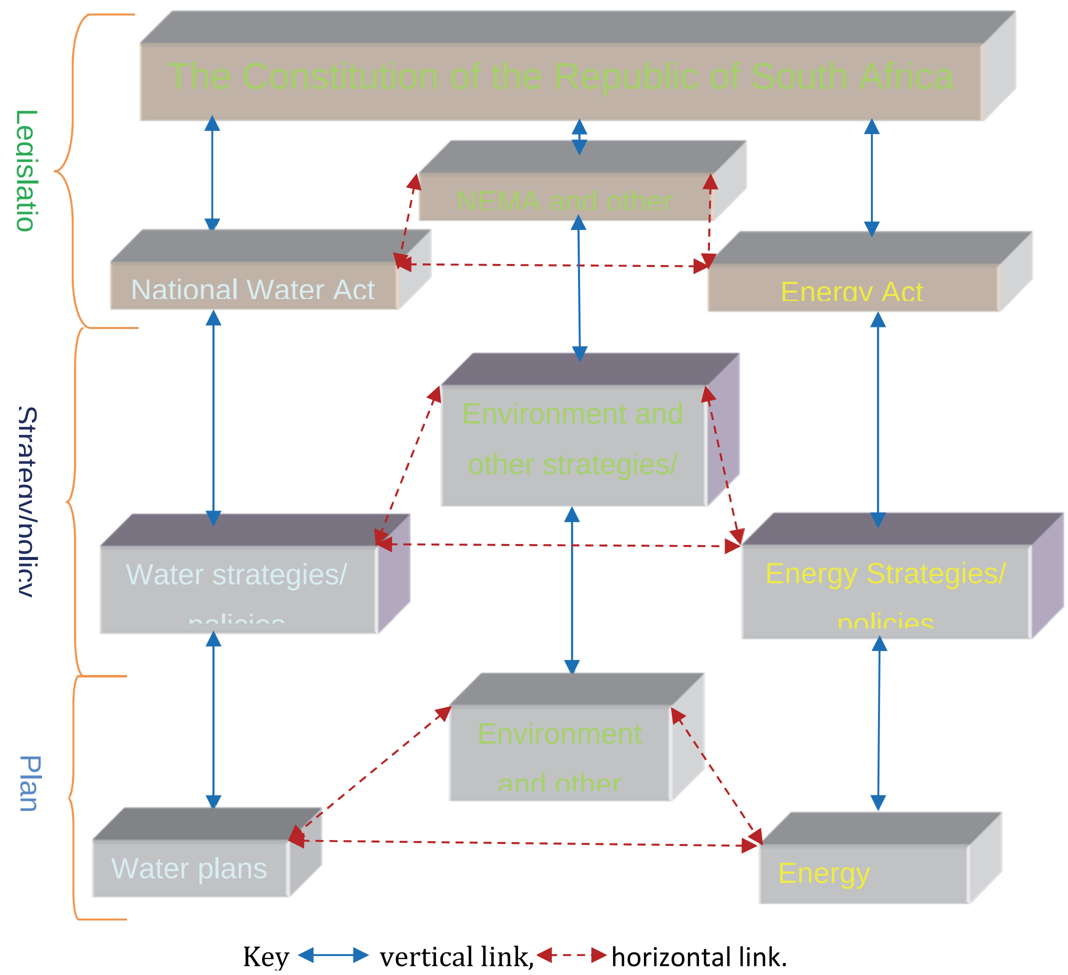


Figure 6-4: Diagrammatic view of the framework for harmonization of legal and policy instruments for water use in the energy sector.

This framework can assist in developing of new policy (legal) instruments or reviewing existing instruments. It should be noted that a given instrument should be linked vertically and horizontally. A missing vertical or horizontal link, where two policies or legal instruments are in conflict or fail to support the primary guiding principles of the other, would indicate that there is need to review the instruments to reflect the efficient use of water.

It is important to establish existence of a policy on the efficient use of water in the energy sector. This may be a stand-alone policy or a section on efficient use of water within a wider energy-related policy. The policy needs to be linked to water, environment and other relevant policies.

Synergy with other policies is also vital for a successful policy instrument. For example, is there some contradiction with other policies? Figure 6-5 shows a suggested flow chart for reviewing or formulating a policy instrument to include efficient use of water in the energy sector.

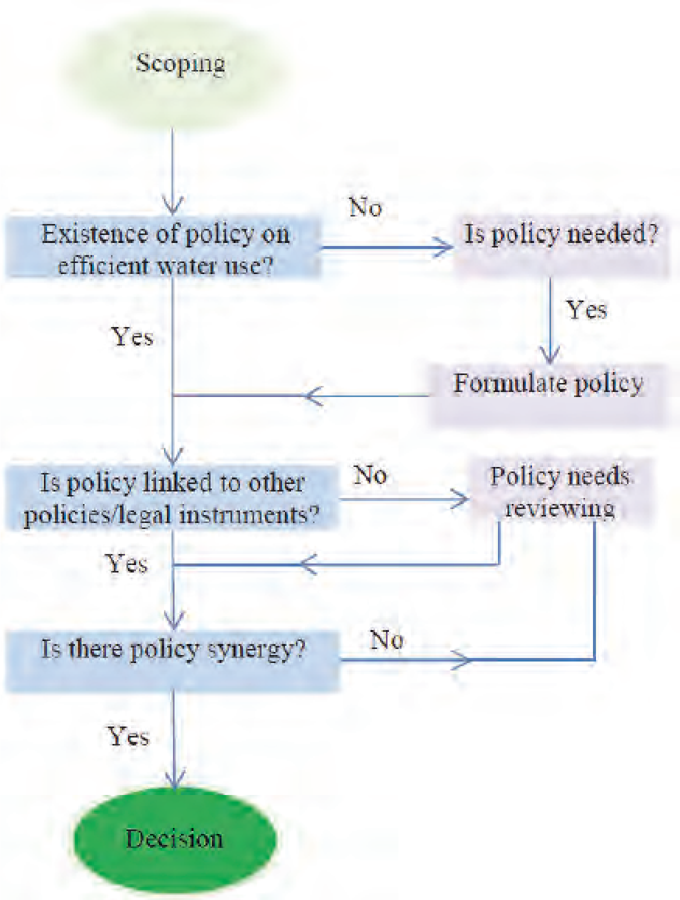


Figure 6-5: Flow diagram for policy review/formulation to incorporate efficient use of water in the energy sector.

6.4. Challenges and opportunities towards adaptation

6.4.1. Policy and planning

South Africa is a relatively water-scarce country and several catchments in the country are already described as fully allocated. In the future, increasing urban and industrial demand, compounded by climate change forecasts indicate a rise in water scarcity in some parts of the country. This will lead to an increase in development and economic pressure, particularly in areas with high water demand and water user competition. In light of the foreseeable water scarcity, a particular challenge will be the allocation of water to the energy sector and the location of energy generation facilities in water-scarce areas.

The future electricity supply in South Africa has been set out by the Department of Energy (DoE) in the Integrated Resource Plan for Electricity 2010-2030, shortened to IRP 2010. According to the IRP 2010, coal-based power generation will absolutely increase by roughly 20%. The total contribution of coal will drop from 92% to about 65% in the energy mix, which is the result of planned new nuclear capacity of 9.6 GW, renewable energy capacity of 17.8 GW, imported hydropower increased by 2.6 GW, and new gas power plants of 6.3 GW. The DoE needs to announce more ambitious targets that could see the electricity sector leading the Energy Revolution resulting in 49% of electricity produced from renewable sources by 2030, increasing to 94% by 2050 (Teske *et al*. 2011).

There is a need for Government commitment to energy decisions to show a clear shift from fossil fuels and there must be synchronization of government policy throughout the various departments addressing energy issues. An Energy Revolution requires inter-departmental coordination including but not limited to the Department of Environmental Affairs Department of Energy and Department of Transport.

The quality of policy and perceived level of government commitment to policy are essential to bolster investor confidence. Given the lack of technical barriers to the drivers of renewable energy investment, financial attractiveness is subordinate to visible and appropriate renewable energy support mechanisms, which rely on political will. The relationship between price and policy requires that barriers be addressed; implying that a decrease in policy barriers will result in a decrease in the cost of renewable energy systems. Legislative reform is essential to facilitate renewable energy uptake particularly on a small to medium scale, i.e. from households to municipal projects (Gets 2013).

Water and energy policies are too often not formulated in an integrated way at a proper scale. Current institutional structures in many developing countries are set up in a way that makes the necessary coordination, integration and horizontal communication (between institutions) very difficult. This presents a source of conflict between different jurisdictions and also between competitive users, e.g. mining, irrigation and hydroelectricity generation. In South Africa, the analysis of national planning in the country shows that the integration of water and energy planning is missing on most levels. It is essential that energy and water planning is considered at a local level, such that local scale water resources are optimised for local scale energy production (which may or may not feed into the national grid).

The misalignment of water and energy policy in South Africa has been recently illustrated through the Shale Gas ‘fracking’ debate in the Karoo. The environmental risks associated with fracking include possible water contamination and a definite decrease in available water resources (due to high water usage in an area that is considered as semi-dessert). However, the high demand for energy and the need for economic development and job creation in the country have increased the pressure on government to proceed with the Shale Gas exploration. The Department of Water Affairs has noted that government “will take every precaution to ensure that the possible impact of fracking on our water resources is carefully managed and minimised” and an interdepartmental task team has been established for unconventional oil and gas exploration and production, and the DWA is a member of this team (DWA 2013). However, with government track record concerning regulatory enforcement and the management of water pollution (by the mining sector), it is yet to be seen whether this will be achieved.

It is essential that energy planning takes water scarcity into account, both in respect to the kinds of energy production mixes and the economic impacts of water use in the catchments where water-intensive energy production facilities are located. The future energy-generation mix needs to engage more comprehensively with the current and future impacts of water scarcity around South Africa. To achieve this, it will be necessary to think about the water used in energy production as well as the impact of different types of energy resources on water resources (Platonova and Leone 2012).

With the risk of increased water vulnerability due to climate change, and in light of the planned changes to the energy supply technologies, it is important that the country’s water and energy policies take cognisance of one another. Water supply is (mostly) fixed by nature (allowing for man-made transfers between water basins and for changes in water availability as a result of climate change), whereas energy supply is by design. It is necessary to assess the demands that might be placed on the country’s water resources in the context of changing energy requirements and water availability. This can inform strategic investment in future energy supply.

Policies should always be designed with energy security and social equity in mind. When energy is produced locally, where it is consumed, and users become at the same time producers and owners of the technology, which has the potential to increase energy equity and security of a community, and to facilitate diffusion via an enhanced sense of ownership. Combining renewable energy and water systems can be appropriate in both urban and rural environments. For example, with a series of strategies ensuring co-benefits such as reducing energy tariffs via solar water heating and, at the same time, enhancing water availability and reducing flooding risks through a diffused rainwater harvest system connected to the solar heaters in urban areas (King *et al.* 2011).

For the industrial sector, the carbon tax should be implemented so that there is a change in behaviour; a shift from polluting energy sources to clean sources. Carbon taxes can be an effective economic tool for tackling climate change, by encouraging countries to reach specific carbon intensity reduction targets. Introducing a carbon tax will help to reflect the true cost of carbon intensive industries by internalising the external (hidden costs) associated with fossil fuels. Hidden costs include health impacts, pollution and water shortages. Revenues generated from such taxation can be used to support energy efficiency technologies, emission reduction projects and further incentivise the development of clean technologies (Gets 2013). It is worth noting that there is a high possibility that the cost of carbon tax might be passed on to the consumer, which may augment energy cost and poverty. Therefore, it is important that the implementation and enforcement of the carbon tax be properly administered.

Policy makers need to become more aware of the issues related to the energy-water-climate change nexus, and research and development will play a vital role in this regard. Political will and enabling framework will be necessary to develop the required policies and strategies, ensure the commitment of participating institutions and the collaborative effort necessary to design, implement and provide long-term follow-up of appropriate strategies and regulations. It is also important to explore the types of partnerships being promoted in the energy-water-climate change domain, and to discern which ones and why they appear to be more effective in promoting policy formulation and implementation in a particular area.

Planning for energy supply now and in the future necessitates that South Africa's policy makers take into account the water impacts and associated risks of the energy generation technologies available, particularly in areas where there is severe water stress. Both current and future plans for energy generation must aggressively plan water strategies to maintain supply, such as to seek options to diversify the energy mix and increase the opportunities to leverage energy generation technologies which have lesser water impacts (Platonova and Leone 2012).

6.4.2. Promoting the Use of Renewable Energy

In the context of increasing climate variability, water scarcity, population growth and development, renewable energy can be useful in ensuring that energy choices do not cause damage to the socio-economic and environmental aspects of society. Renewable energy technologies can also be useful in improving water services, in particular via solar water heating, small-scale pumping and water purification and treatment in off-grid areas (Platonova and Leone 2012). Yet, a number of challenges and opportunities exist that prevent or promote renewable energy technological uptake.

The development of the renewable industry is held back by a lack of ambitious policy that would encourage investment. Further administrative bottlenecks and issues around grid capabilities retard the diffusion of renewable energy technologies. Ultimately, it is the perception of renewable energy capacity that is the barrier and not practical constraints. Committed political will from the South African government is necessary to set processes and policies in place that would eliminate the barriers and foster the right economic conditions to stimulate a competitive renewable energy industry (Gets 2013).

Financial barriers related to the high initial costs of the renewable energy systems and the lack of financing for the rural poor users, who need this technology most, continue to persist. Government funding is limited for the renewable energy and renewable energy-based projects. Funding is often provided by external donors, which can lead to dependency and a lack of long-term sustainability. Adequate financial and economic incentives need to be in place to stimulate local manufacturing of renewable energy technology and to raise the number of investors in the industry. As start-up costs for renewable energy are high, it is essential that there is government backing. This must begin with larger renewable energy investment from the state utility Eskom. The use of state funds must be directed towards investment in renewable energy and not coal or nuclear (Gets 2013).

To improve the uptake of the renewable energy systems, capacity for operation, maintenance and servicing of these technologies needs to be built. Rural communities often lack skilled personnel to maintain and repair systems and have to rely on technicians travelling from the distant urban areas, which delays servicing and increases costs (Prasad *et al.* 2012). One way to remedy it is to build technological capacity in the community so that the community takes care of maintenance and repair. Creation and training of the artisan associations in the project is a good example of ensuring the development of local skills necessary for maintenance and repairs (UNICEF 2010).

In addition, in order to ensure long-term sustainability, and to recover costs, some projects have started to adopt a system where community members are providing financial contributions towards maintenance, or where individuals are provided with incentives for investing in renewable energy, e.g. solar powered hot water geyser. This creates a sense of ownership for the technology, which boosts the incentive to ensure that it is functional for long periods.

Community involvement is, therefore, a key factor in the technology deployment. Research shows that successful projects are those where the community is actively involved in their design and that show a clear economic advantage that can be reached via investments affordable at the community level (Prasad *et al.* 2012). Many renewable energy-based projects in developing countries continue to fail because the needs and preferences of the target communities are not taken into consideration. The exclusion of the rural poor from the decision process is one of the key barriers to the use of renewable energies in some arid and semi-arid areas (Bravo *et al.* 2011).

Cultural and social acceptance of the technologies under study is of great importance. Among other factors, adequate information and education about the benefits of the technology are necessary measures to enhance the acceptance levels by the users (Mallett 2007). Public awareness campaigns emphasizing a wide range of benefits of the systems coupled with other measures discussed earlier assist to increase the utilization levels of the technology (King *et al.* 2011). Technologies need to be affordable and socially and culturally appropriate to the users. When technology development programs are supported by policies favouring knowledge dissemination and financial contribution towards affordability of the technology, and support partnerships between public and non-state actors on capacity building, cultural barriers can be overcome with the showcase of successful pilot examples. In this respect, cultural barriers are often not to be seen as the root causes of the lack of technology dissemination, but as reactions to badly designed programs, lack of information or financial constraints (Platonova and Leone 2012).

In South Africa, Eskom is focused only on large centralised grid connected coal-based power generation. Thus, it controls the generation of almost all of the power, as well as the transmission and distribution of that power, resulting in a conflict of interest (McDaid 2008). Improved access to the grid by IPPs is required with grid priority given to renewable energy.

The recent signing of power purchase contracts with independent renewable energy power producers under the REIPPPP is perceived to be the beginning of a move to a smart grid (Gets 2013).

The current energy policy environment promotes large centralised grid connected power generation. However, this does little to meet the energy needs of the approximately 30% of South Africans who neither have access to the grid nor can afford it (Groenewald 2012). A decentralised renewable energy powered dynamic grid, combined with microgrids is a flexible solution to open up power to those who do not have access as yet (Boyle 2010). Developing energy sources at a local and decentralized scale promises to free up financial resources for local development and to enhance national energy security. Decentralizing energy production has other advantages, including:

- It will eliminate barriers caused by the lack of basic infrastructure, such as roads and communications in remote areas.
- It is more resilient to local nodes/links failures that are possible due to climate-related extreme events.
- Individuals and communities will have increased ownership, as decentralized technologies can be managed by the same social networks on which communities rely on in their efforts to adapt to climatic variability and change.
- The increased knowledge and increased awareness of marginalized communities of their rights, as communities will have wider access to resources and opportunities. This will have a positive impact on community vulnerability, food security, health, education and possible business opportunities.
- The mitigation of rural-urban migration and prevent resettlement in informal settlements that are prone to climatic risk.

The opportunities associated with the use of the renewable energy technologies in the context of adaptation to climate change exists. This is would be possible if the capability, quality and reliability of the technology is ensured, and if consideration of the technical limitations related to increasing water scarcity are properly taken into account. This is particularly important as the performance of renewable energy technologies such as wind, hydro and solar is usually tested and assessed under the hypothesis of static climatic conditions and without taking into consideration proper water availability and hydrogeological studies in each implementation site (Platonova and Leone 2012).

Thus, to thrive and deliver its full socio-economic benefits, renewable energy still needs greater political support in the form of fundamentally different market regulations. This can be achieved through increased grid access, smart and modernised power-market design and to some extent a different infrastructure to achieve an energy market that is 100% renewable energy (Get 2013). In order to achieve this, broad institutional support for the dissemination of the technologies through policy, inter-institutional and sectoral coordination is necessary.

6.4.3. Synthesis of challenges and opportunities

A synthesis of the various challenges and opportunities towards adaptation for the water-energy nexus is briefly described in this section. It is observed that the national energy system has a heavy reliance on coal-based energy production. Nevertheless, there is an opportunity for more ambitious targets that could see the electricity sector leading the Energy Revolution – e.g. 49% of electricity produced from renewable sources by 2030, increasing to 94% by 2050 (Teske *et al.* 2011). In this regard, it is necessary to understand the implications of this transition on water resources.

Water and energy policies are neither commonly formulated in an integrated way nor at a scale that affords complementary implementation. Energy planning in SA needs to take local water scarcity into account, both with respect to the energy production mix as well as the economic impacts of water use in the catchments where water-intensive energy production facilities are located.

The level of carbon tax for electricity producers is anticipated by some critics to be high, which might lead to the cost being passed on to the consumer; this would increase the cost of energy, thus increasing energy poverty. Conversely a low carbon tax would be ineffective and negate the intention for a carbon tax to reflect the true cost of carbon intensive industries by internalising the external costs associated with fossil fuels. Revenues generated from such taxation could be used to support energy efficiency technologies, emission reduction projects and further incentivise the development of clean technologies.

Strategies to address problems of a lack of energy security and social equity are often not aligned. Opportunities exist for embedded generation, and for energy producers to export electricity, which has the potential to increase energy equity and security of communities that invest in embedded generation. It also allows users to avoid purchasing electricity from the grid, which may be too expensive for them.

There are many uncertainties in the energy-water-climate change nexus. Research and development on the issues related to the nexus, and also technological advances need to be promoted, particularly technology options that are relevant to the South African environment.

Renewable energy technologies are becoming more attractive for investors as they approach grid parity. Financial barriers related to the high initial costs of renewable energy systems and storage still exist. As start-up costs for renewable energy are high, it is essential that there be government-promoted support and incentives. Adequate financial and economic incentives need to be in place to allow for stimulating local manufacturing of renewable energy technology and to increase the number of investors in the industry. However, government funding is limited for the renewable energy, and renewable energy-based projects. The use of state funds for investment in energy technologies must reflect policy to employ the most sustainable and cost-effective options.

There is a lack of capacity for the operation, maintenance and servicing of renewable technologies in community owned embedded generation projects. It is important to build technological capacity in the community so that the communities are owners of the technologies, and so that they maintain and service the technologies.

Lack of community involvement in inception and planning of social or community renewable energy projects excludes the rural poor from the decision process, which is likely to hinder cultural and social acceptance of projects. Successful projects are those where the community is actively involved in their design as the needs and preferences of the target communities are taken into account. Technologies need to be affordable, as well as socially and culturally appropriate to the beneficiaries.

Eskom distribution plans focus on large centralised grid connected coal-based power generation. It generates, transmits and distributes most of the national electrical power. So, this organization is an interested party in the electricity market in South Africa. An independent transmission operator could assist in resolving any conflict of interest. A decentralised renewable energy dynamic grid, combined with microgrids is a flexible solution that could make electricity more accessible. Developing energy sources at both local and national, but decentralized, scales could redirect financial resources for local development and enhancement of the national energy security.

6.5. Summary

Planning requires coordination amongst government institutions and policy makers. Although water is acknowledged and reported within the planning process, water impacts (particularly impacts pertaining to the location of the energy source) are often not properly accounted for. The Draft IEPR 2012 models water use for different energy scenarios going forward but water is not properly considered in the context of full supply chain and quality impacts. Importantly though, the NWRS2 notes that the DWA and WRC will be collaborating with the relevant sectors to revise documents relating to water usage by high water-consuming sectors, thus highlighting the concerns around water impacts of the energy and mining sectors.

There is an existing network of legislative and policy instruments in SA that directs the management of water and energy resources. Nevertheless, there is an insufficient degree of synergy amongst them with regard to the efficient exploitation of the water resource in the energy sector. Therefore, there is a need for a framework that can assist in tracing policy links in order to achieve sustainability towards effective and efficient resource management and planning. It is necessary to ensure that horizontal linkages exist during the design and implementation of the piece of legislation. Legislation pertaining to water, energy and other matters should be harmonised with respect to the efficient use of water.

The draft Policy Framework proposed in this study can assist in the development of new policy (legal) instruments or reviewing existing instruments. A given instrument should be linked vertically and horizontally. A missing vertical or horizontal link, where two policies or legal instruments are in conflict or fail to support the primary guiding principles of the other, would indicate a need to review the instruments in order to reflect the efficient use of water.

While it is clear that there are several benefits to increasing renewables in the South African energy mix in order to achieve sustainability, it is also helpful to keep an awareness of the other trade-offs and incentives influencing the energy economy. Eskom, as South Africa’s primary energy producer, has a keen awareness of the risks of water scarcity and the potential impacts on their operations and costs. This is, however, room for improvement in terms of efficient water use and minimising water impacts. As discussed in this chapter, moving towards, a more renewable-based energy mix will be difficult, and will require a balancing act between water and energy resource planning and management.

7. SPATIAL REPRESENTATION OF THE WATER-ENERGY NEXUS

By: Sauka S and Pegram G

7.1. Background

While South Africa's water infrastructure and management capacity assist the country in adapting and responding to variable climate, water quality and shortages impose a social and economic burden to the country. The increasing water demand due to economic and population growth results in the growing water and energy demands. Effective management of water resources is thus imperative to ensure good water quality and the access to water for all water users. In addition, the access to adequate and clean energy for all users should also be pursued. Therefore, the planning and management for both water and energy resources should be at the core of all development planning initiatives in the country.

7.2. Water resources

South Africa (SA) is characterised by low rainfall and high evaporation rates, together with temporal variability and spatial unevenness. This poses major challenges to economic development and livelihoods. In order to cope with climatic and physical challenges, South Africa has developed sophisticated and extensive surface water storage and transfer schemes, including inter-basin transfer schemes, and most catchments are linked to a degree that is unusual elsewhere (as shown in Figure 7-1).

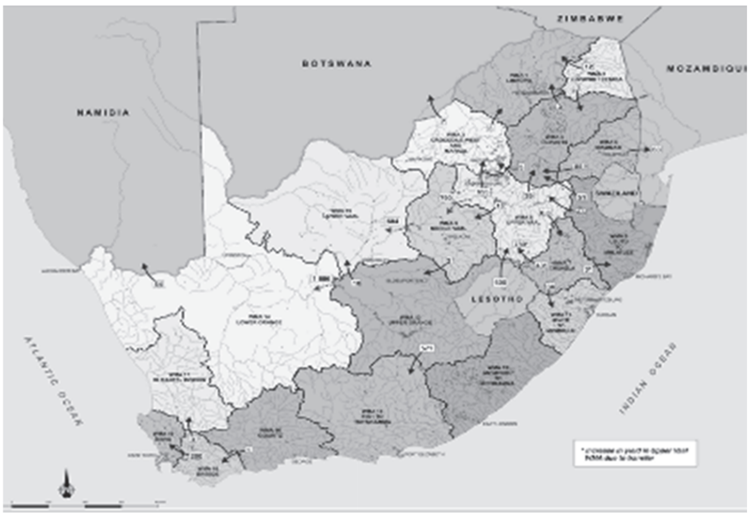


Figure 7-1: Inter-water management area transfers (Source: NWRS2004).

However, SA is approaching full utilisation of available surface water yields, and is running out of cost effective and physically appropriate sites for new dams. Aside from the water demands of the energy, agriculture and mining sectors, increasing urbanisation and industrialisation continue to place enormous pressure on scarce water resources in terms of water allocation and the impact on water resources. This is exacerbated by ineffective governance and water management practices.

The roles of the country's water management institutions, strategies and policies are to ensure that water security is ensured for current and future generations. This is important because the water resources in SA are highly stressed, and this may be compounded by the county's vulnerability to climate change and its associated impacts. Climate change is expected to have a major impact on the population, ecosystems and economy of SA. It is also widely acknowledged that water resources are the primary medium through which the impact of climate change is going to be felt (DEA 2013).

7.2.1. Current water resources demand and availability

SA is characterised by a semi-arid climate which varies from sub-humid along the east to arid in the west. In addition, the large variation in topography, together with the uneven distribution of rainfall results in an uneven distribution of water resources. The seasonal and inter-seasonal variation of rainfall also results in variable surface runoff and groundwater discharge throughout the year. The country has an average rainfall of approximately 450 mm per annum (mm/a), which is approximately half of the world average of 860 mm/a. The eastern and south-western regions experience high rainfall, with the annual average in excess of 1000 mm per annum, while the western regions are dry and experience less than 100 mm per annum (as illustrated in Figure 7-2).

In global terms, SA is classified as a dry country, with a total flow of 49 000 million cubic metres per year (m^3/a) being approximately half of the Zambezi River. The country has also international river basins (such as the Limpopo and Orange Rivers), each with their own transboundary water requirements and quality commitments.

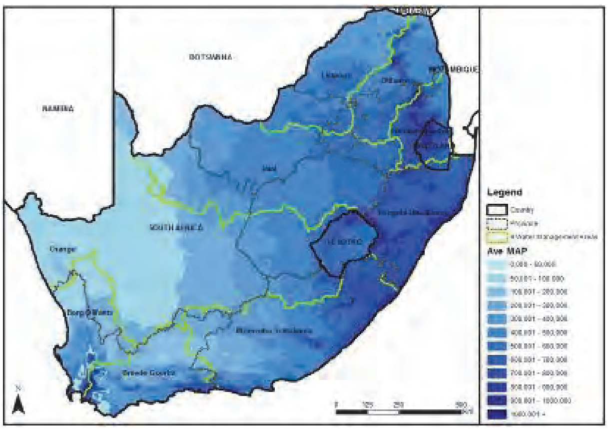


Figure 7-2: Current Rainfall Distribution (Data Sourced from WRC2005 2011).

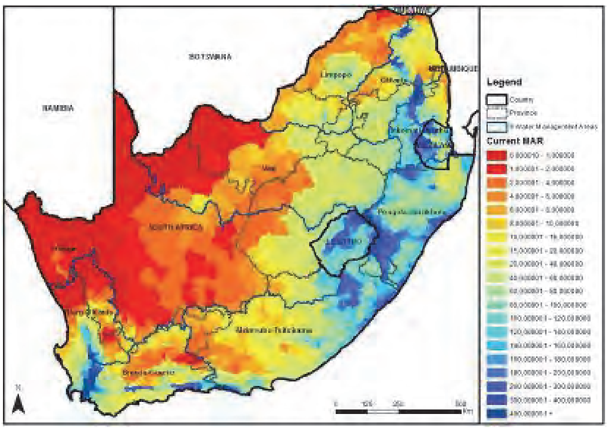


Figure 7-3: Mean Annual Runoff (MAR) (Data Sourced from WRC2005 2011).

SA depends mainly on surface water resources for its urban, industrial and agricultural requirements. In general, surface water resources are highly developed over most of the country. The total MAR under natural (undeveloped) conditions, as illustrated in Figure 7-3, is estimated at a little over 49 000 million m³/a. This includes about 4 800 million m³/a originating from Lesotho and 700 million m³/a originating from Swaziland, which naturally drains into SA (DWA 2004). About 320 major dams, each with a full supply capacity exceeding 1 million m^3, have a total capacity of more than 32 400 million $metres^3$, equivalent to 66% of the total mean annual runoff (MAR).

A major challenge to water resource planning is that water resource availability is not aligned with settlement distribution. Settlement distribution patterns are in response to the economic landscape, due to, for example, mining industries that are established remotely due to mineral niches. As a result, the water demand in certain catchments is not always aligned with water availability, often even exceeding local water availability. Figure 7-4 and Figure 7-5 illustrate the water demand and availability, respectively, for various sub-catchments in the country. Water availability is represented as the yield incorporating inter-basin transfers.

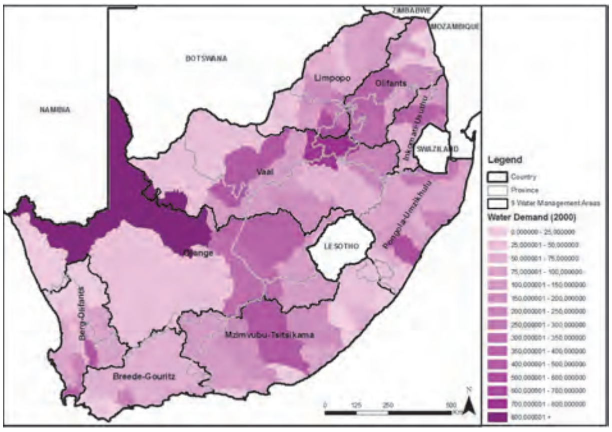


Figure 7-4: Water Demand (2000) (Data Sourced from NWRS1 2004).

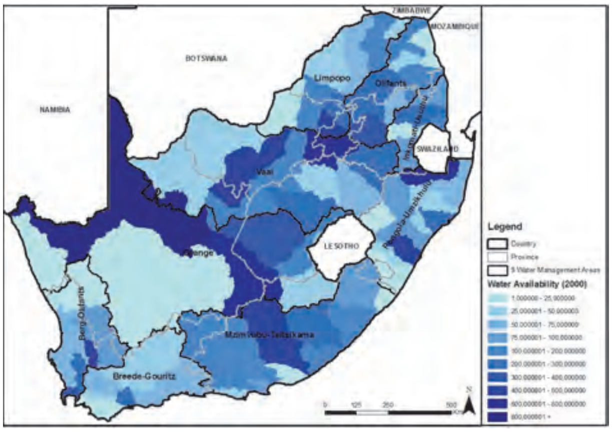


Figure 7-5: Water Availability (2000) (Data Sourced from NWRS1 2004).

As is evident from Figure 7-4, the catchments with high water demand are associated with metropolitan areas. On the other hand, with the exception of the Orange River Catchment, Figure 7-5 illustrates that the water availability tends to be higher in the eastern part of the country than in the west. This is largely due to the mountainous topography and moderate climate (with high rainfall) in the eastern region compared to the low-lying, dry and hot western region.

Water demand and availability are therefore not always aligned, resulting in catchments that are either water abundant or in deficit. Figure 7-6 illustrates that most of the catchments associated with urban areas are in deficit, while those that are sparsely populated are in balance. The exceptions to this are the northern and south-western parts of the country; these areas are characteristically dry areas with low rainfall.

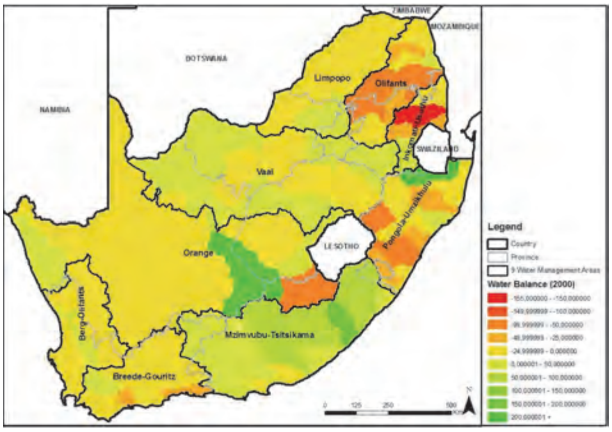


Figure 7-6: Water Balance (2000) (Data Sourced from NWRS1 2004).

7.2.2. Future water resource demand and availability

As part of the Long-Term Adaptation Scenarios (LTAS) project, future changes in rainfall distribution were predicted. As indicated in Section 3.4, the two independent climate projections provided a coherent view of potential climate change trends and scenarios for SA, its key sub-regions, and for SA as a whole. From the LTAS study, four climatic futures (up to the year 2050) were created, and can be described as:

1. **Warmer (<3°C above 1961-2000) and wetter**, with a greater frequency of extreme rainfall events.
2. **Warmer (<3°C above 1961-2000) and drier**, with an increase in the frequency of drought events and somewhat greater frequency of extreme rainfall events.
3. **Hotter (>3°C above 1961-2000) and wetter**, with a substantially greater frequency of extreme rainfall events.
4. **Hotter (>3°C above 1961-2000) and drier**, with a substantial increase in the frequency of drought events and greater frequency of extreme rainfall events.

The scenarios above are associated with the rainfall projections illustrated in Table 7-1. It is evident that future rainfall distribution is uncertain; it will either get wetter or drier. Therefore, it is important to incorporate both futures in water resource planning.

Table 7-1: Rainfall projections for the six hydrological zones (DEA 2013).

Scenario	Limpopo/ Olifants/ Inkomati	Pongola-Umzimkulu	Vaal	Orange	Mzimvubu-Tsitsikamma	Breede-Gouritz/ Berg
1: warmer/ wetter	↑ spring and summer	↑ spring	↑ spring and summer	↑ in all seasons	↑ in all seasons	↓ autumn, ↑ winter and spring
2: warmer/drier	↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ in all seasons, strongly ↓ summer and autumn	↓ in all seasons, strongly ↓ in the west
3: hotter/wetter	Strongly ↑ spring and summer	Strongly ↑ spring	↑ spring and summer	↑ in all seasons	Strongly ↑ in all seasons	↓ autumn, ↑ winter and spring
4: hotter/ drier	Strongly ↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ all seasons, strongly ↓ in summer and autumn	↓ all seasons, strongly ↓ in the west

Rainfall projections under a wetter scenario are illustrated in Figure 7-7, while projections under a drier scenario are illustrated in Figure 7-8.

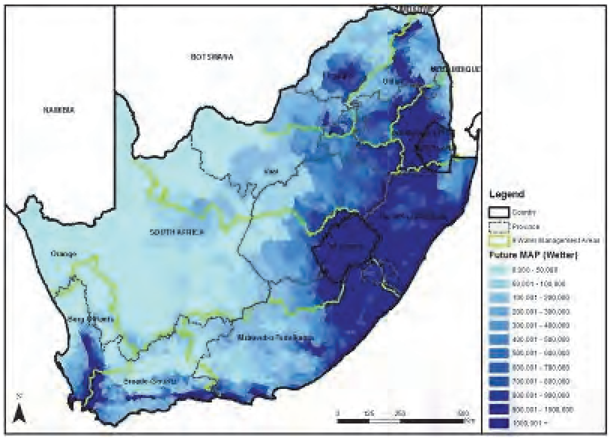


Figure 7-7: Future rainfall distribution – Wetter Scenario.

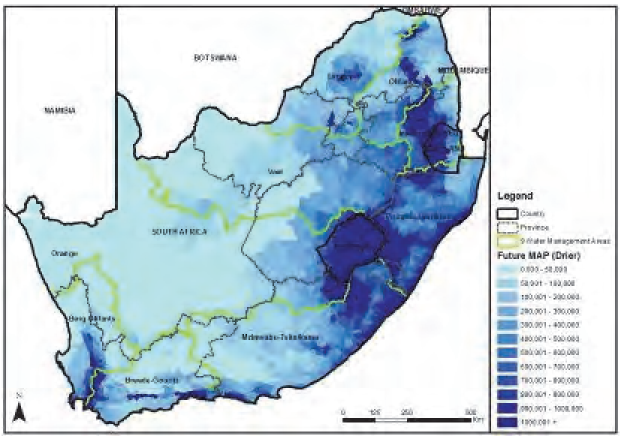


Figure 7-8: Future rainfall distribution – Drier Scenario.

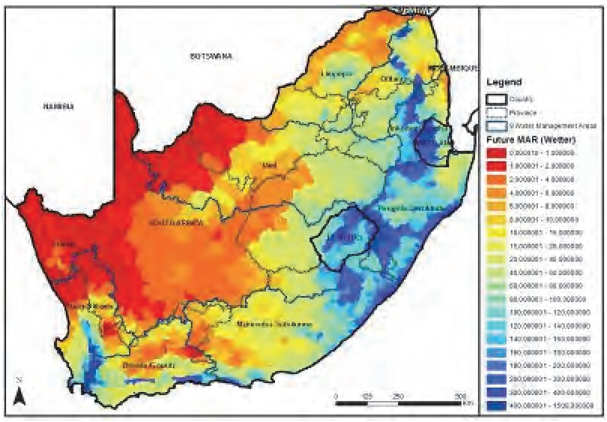


Figure 7-9: Future mean annual runoff (MAR) – Wetter Scenario.

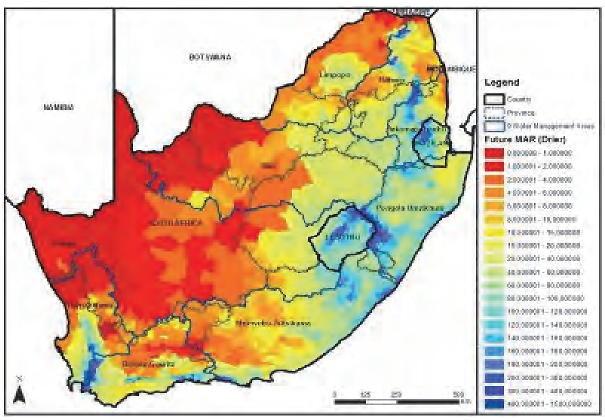


Figure 7-10: Future mean annual runoff (MAR) – Drier Scenario.

LTAS states that the changes in rainfall and runoff will vary significantly across the country, with positive changes in the eastern and central region, and negative changes in the western region. Areas showing the highest probability of extreme rainfall related events include Kwazulu-Natal, parts of Southern Mpumalanga and the Eastern Cape. Other areas show neutral to reduced changes in rainfall, with the exception of the central and lower Orange River region. Specific areas of high risk where cumulative negative climate change impacts are likely to occur (including increased evaporation, decreased rainfall and decreased runoff) include the southwest of the country, the central-western parts and, to some extent, the extreme north.

There is however far more uncertainty relating to rainfall projections in the summer rainfall regions of SA, while the winter rainfall region will show a high likelihood of drying projections by mid to end century. Climate projections show a far higher probability of increased rainfall over the summer periods in the eastern regions of SA. A rise in temperature across the country will lead to most of the catchments experiencing increased evaporation, leading to catchments being in deficit.

While hydrology directly affects aquatic environmental conditions, the configuration of water use and supply systems has a significant impact on the availability of water to meeting demands.

Figure 7-11 graphically illustrates future water availability under the wetter and drier scenarios, while Figure 7-12 and Figure 7-13 illustrate future yield under the scenarios. A high variability is evident between the drier and wetter scenarios.

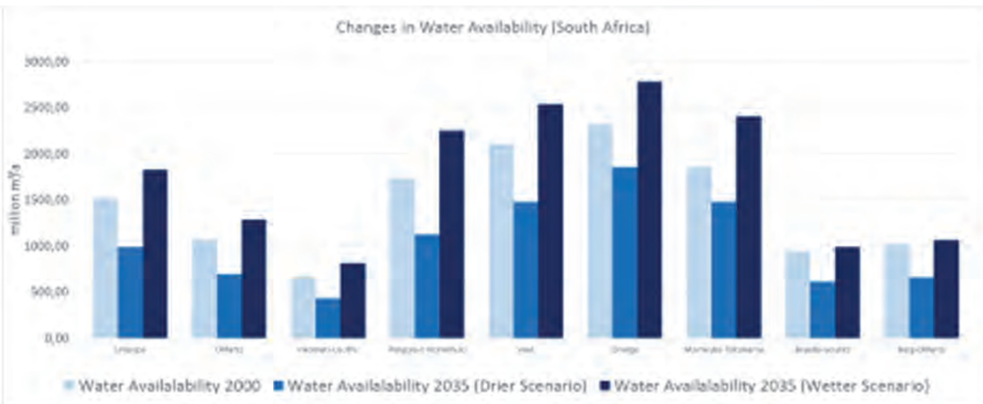


Figure 7-11: Changes in water availability under the different climate scenarios.

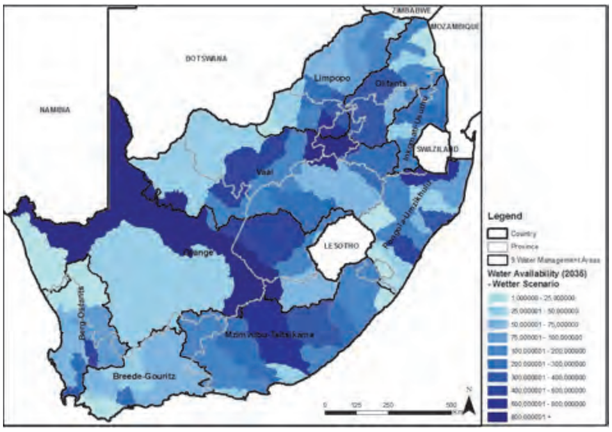


Figure 7-12: Future yield – Wetter Scenario.

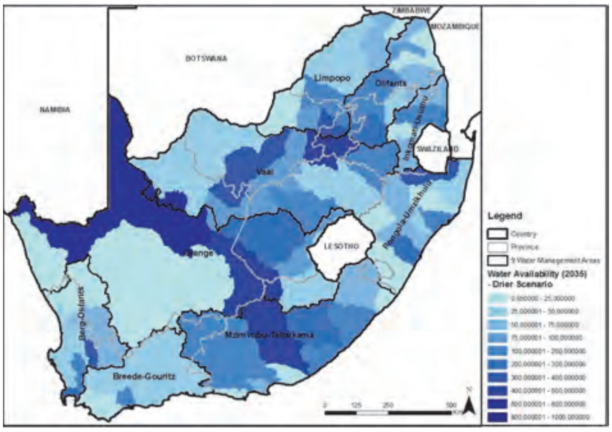


Figure 7-12: Future yield – Wetter Scenario. **Figure 7-13: Future yield – Drier Scenario.**

The rate at which water demand is likely to change is not predictable. As part of the NWRS, estimates for water demand that are based on development trajectories were conducted. This included an upper scenario of average real growth in GDP of over 4% per year for the period up to 2025, and a less favourable low growth scenario of roughly 1.5% per year. These estimates, illustrated in **Figure 7.14**, consider population growth, changes in standards of living as well as changes in the local and regional economic activities, with the assumption that the growth will continue to 2035 as projected.

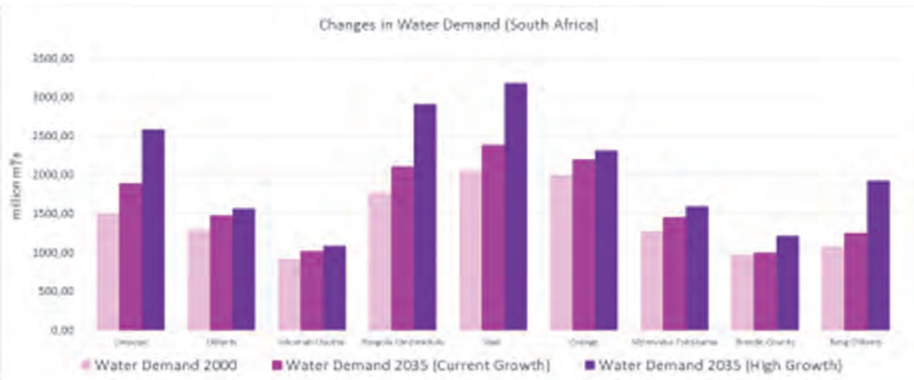


Figure 7-14: Changes in water demand under the different growth scenarios.

Under each of the two climate scenarios (i.e. the drier and wetter scenarios), either of the growth trends is possible. The water balance for each of the possible growth rates, under the wetter and drier scenarios are shown in Figure 7-15 to Figure 7-18.

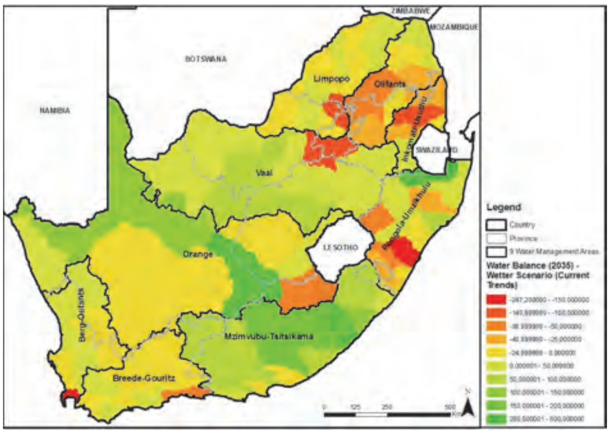


Figure 7-15: Future water balance (Current Growth Trends) – Wetter Scenario.

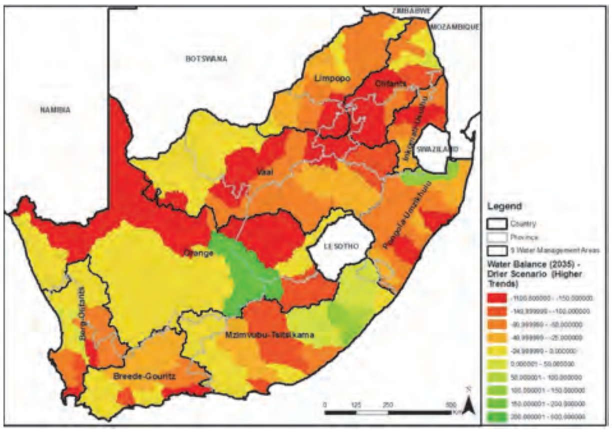


Figure 7-16: Future water balance (Current Growth Trends) – Drier Scenario

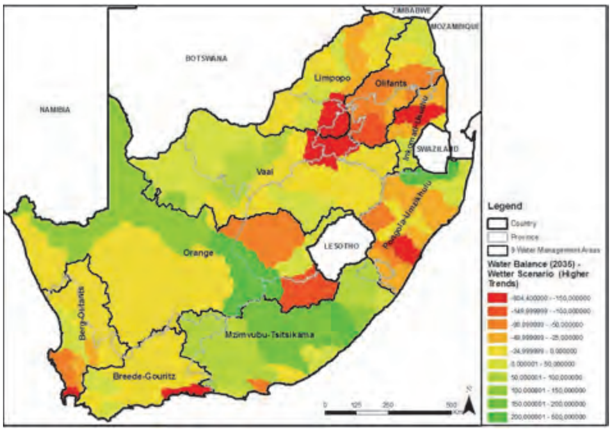


Figure 7-17: Future water balance (High Growth Trends) – Wetter Scenario.

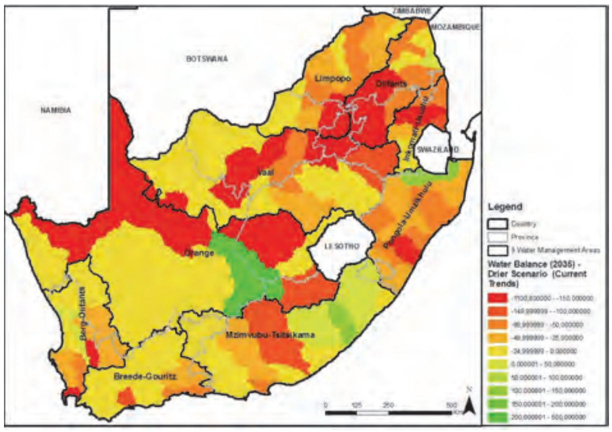


Figure 7-18: Future water balance (High Growth Trends) – Drier Scenario.

From Figure 7-15 to Figure 7-18 it is evident that under both the wetter and drier scenarios, high growth trends will result in a high number of catchments being in deficit. This is further illustrated in **Figure 7-19**, which shows that under both growth rates, only the Orange and Mzimvubu-Tsitsikamma WMAs will be in balance under the wetter scenarios and the Mzimvubu-Tsitsikamma WMA possibly also being in balance under a drier scenario. On the other hand, under low growth rates the Pongolo-Umzimkhulu and Vaal WMAs will possibly be in balance under a wetter scenario.

Therefore, a future increase in population, urbanisation and a growing economy will likely create considerable pressure on SA's water resources. To meet the growing water demands, an increase in inter-basin transfers will most likely be the option. Ensuring water resource optimisation will require more efficient solutions to water use.

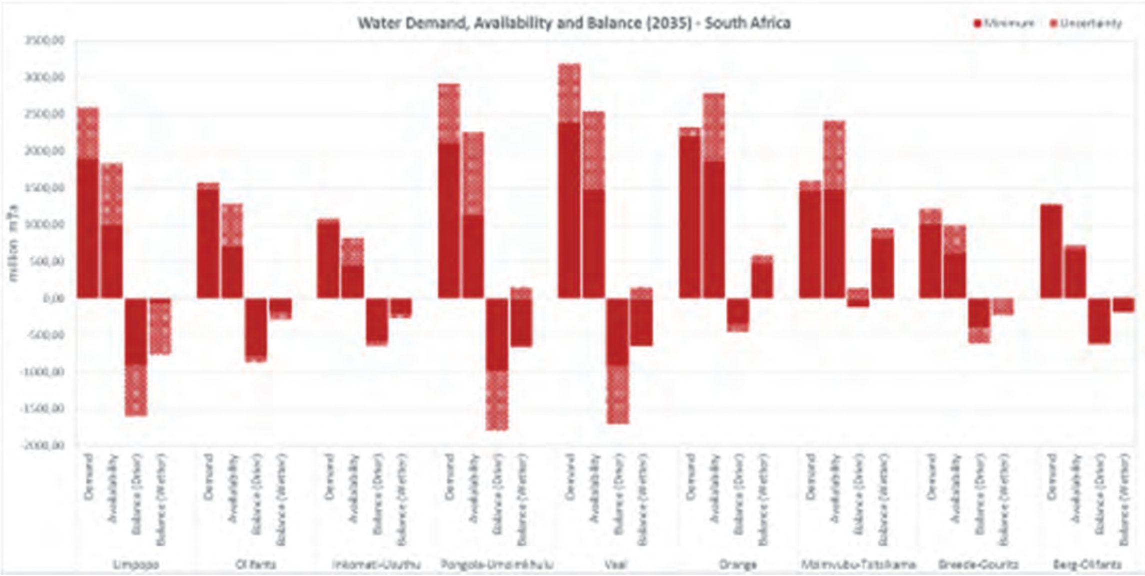


Figure 7-19: Future water demand, water availability and water balance.

7.2.3. Local status of water resources

Appendix B contains a detailed assessment of the local status of water resources. In summary:

- **Limpopo WMA**: the water balance is negative for all of the areas in the WMA under a drier future, and positive in Lephalale, Nzhelele/ Nwanedzi, Elands and Lower Crocodile (West) under a wetter future. However, low growth could potentially also result in a positive water balance in the Sand area under a wetter future.

- **Olifants WMA**: the water balance is negative for most of the areas in the WMA under a drier and wetter future. Minimal amounts of water are available in Luvuvhu/Mutale, Shingwedzi and Lower Letaba under a wetter future.

- **Inkomati-Usuthu WMA**: the water balance is negative for all the areas in the WMA under a drier future, and is positive in Upper Usuthu in a wetter future. Even through a period of low growth, the water demand will exceed the water availability in most of the catchment under both futures.

- **Pongola-Umzimkhulu WMA**: the water balance is positive for the Pongola area in the WMA under a drier future, and in Pongola and Mkuze under a wetter future. However, low growth could potentially result in a positive water balance in Mkuze, Mhlatuze, Mooi/Sundays and Buffalo under a wetter future.

- **Vaal WMA**: the water balance is negative for all the areas in the WMA under a drier future, and is positive in Sand-Vet, Harts and Molopo under a wetter future. However, low growth could potentially also result in a positive water balance in Wilge, Vaal Dam – upstream, Rhenoster-Vals and Middle Vaal under a wetter future.

- **Orange WMA**: the water balance is positive for the Senqu (Lesotho) and Vanderkloof areas in the WMA under a drier future, and in Senqu (Lesotho) and, Vanderkloof and Orange under a wetter future. However, low growth could potentially also result in a positive water balance in Caledon RSA and Orange Coastal under a wetter future.

- **Mzimvubu-Tsitsikama WMA**: the water balance is positive for the Mzimvubu, Mtata, Mbashe and Kei areas in the WMA under a drier future, and in Mzimvubu, Mtata, Mbashe, Kei, Amatola, Wild Coast, Fish, Sunday, Gamtoos and Tsitsikamma under a wetter future.

- **Breede-Gouritz WMA**: the water balance is positive for the Lower Breede area in the WMA under a drier future, and in Riviersonderend and Lower Breede under a wetter future. However, low growth could potentially also result in a positive water balance in Overberg East under a drier future, and in Gouritz, Upper Breede and Overberg East under a wetter future.

- **Berg-Olifants WMA**: the water balance is negative for all areas in the WMA under a drier future, and is positive in Knersvlakte under a wetter future. However, low growth could potentially also result in a positive water balance in Koue Bokkeveld and Upper Berg under a wetter future.

The water availability scenarios for local water resources provided in this section are useful for planning water usage in the long term. As previously indicated, water demand is influenced by multiple factors, such as population growth, economic growth and GDP. Therefore, future water availability may be allocated to different sectors, including the energy sector.

7.3. Energy resources

Energy demand in SA is broadly categorised into base and peak loads. The **base load** is the minimum amount of energy that is consistently required. Numerous power stations are relied upon for this consistent supply. Base power stations are designed to operate consistently, and are shut down only for scheduled maintenance and emergency repairs. In the South African context, coal and nuclear power plants supply the base load, with hydroelectric power growing in areas with abundant water resources.

The **peak load** is the demand placed on the system in addition to the base load. Due to domestic energy needs, peak energy demand periods occur in the early morning and early evenings, and vary between warm and cold seasons (depending on heating and cooling requirements). Peak power stations therefore provide energy in periods of high energy demand, and are aimed at supplementing base load power stations.

SA's base load is largely coal-fired because of the relatively abundant and cheap low-grade coal reserves. In addition, hydroelectric, hydro-pumped storage and gas turbine stations exist and are growing in number. It is often argued that renewable energy technology cannot provide base load capacity to the electricity network and thus a power system based on coal and nuclear is assumed to be essential. While this is debatable, it is true that the balance required by grid operators to follow the peaks is difficult when only coal or nuclear stations are available. It is therefore useful to determine an appropriate energy mix which enables operators to follow demand fluctuations and provide a reliable power supply system (Pegasys 2013).

The volume and type of energy demanded depends on various factors, including climate, size of dwellings, number of people per dwelling, floor area of service sector buildings per unit of service sector output, share of energy-intensive products in manufacturing output, ton-km of transported goods per GDP, average distance travelled per capita, and the share of different modes of transport activities, amongst other factors (IEA 2012). While these elements influence the demand for energy, the supply of energy is largely influenced by climate and weather patterns, available infrastructure and local natural resources (such as coal, water, uranium, and solar radiation or wind velocity).

7.3.1. Current energy resource demand and supply

The Draft 2012 Integrated Energy Planning Report (2013) indicates that primary energy supply in South Africa is dominated by coal (67%), followed by crude oil (20%). Nuclear, natural gas and renewable energy (including hydro and biomass) play a smaller role in the total energy mix, collectively contributing the remaining 13%. When considering electricity specifically, 90% is generated from coal, followed by around 5% from nuclear and around 4.5% from hydropower. Other sources of electricity, including petroleum products (diesel), natural gas and other renewable energy sources (i.e. solar, wind, biomass, bagasse, and landfill gas) collectively contribute less than 0.5% towards the total installed capacity for electricity generation. In addition, SA imports hydroelectricity from the Cahora Bassa Dam in Mozambique, and other smaller coal, co-generation and pumped storage plants (DoE 2013a).

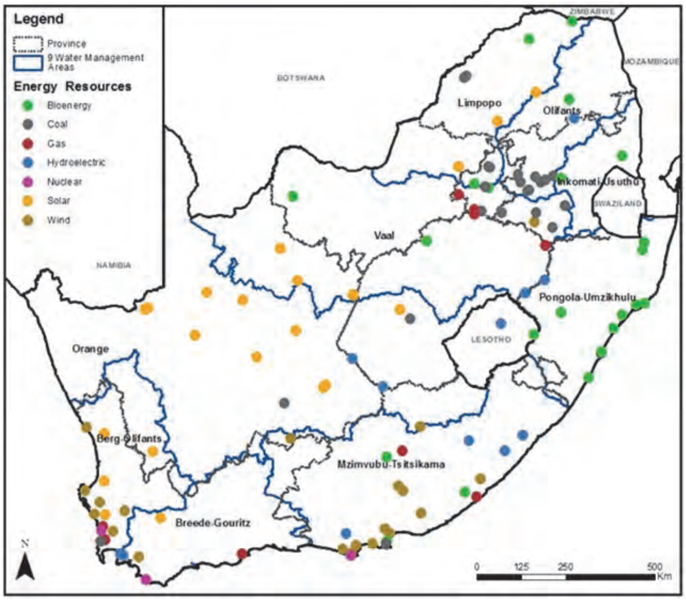


Figure 7-20: Location of energy resources in South Africa.

The past few years have seen a growing recognition of the need to diversify primary energy sources and to reduce over-reliance on fossil fuels for energy supply. Figure 7-20 illustrates various existing and future energy sources (i.e. energy resources that are currently under construction or have been committed).

Distributed generation is an off-grid solution using small wind, solar and micro-hydro generators of between 5 kW to 10 MW near the end-user to provide electricity. Many renewable energy solutions lend themselves to distributed generation. Small-scale generation has already been implemented in various provinces: Over 2 000 clinics and 16,800 schools obtain their electricity from solar photovoltaic (PV) systems (DoE 2013a).

The reliability of supply to end customers is dependent on the performance of the overall generation, transmission and distribution systems. Efforts to improve the performance of the distribution network (Figure 7-21) are critical in ensuring reliable electricity supply to all customer end user segments (Brown 2008). Problems have arisen because of the belief that 'electricity for all' means grid electricity for all. The government is presently supporting off-grid energy resources by allocating concessions, subsidising up to 70% of the capital cost and about 80% of the maintenance costs (Afrane-Okese and Muller 2003). The success of initiatives implemented by government is mixed, mainly due to high cost of implementation.

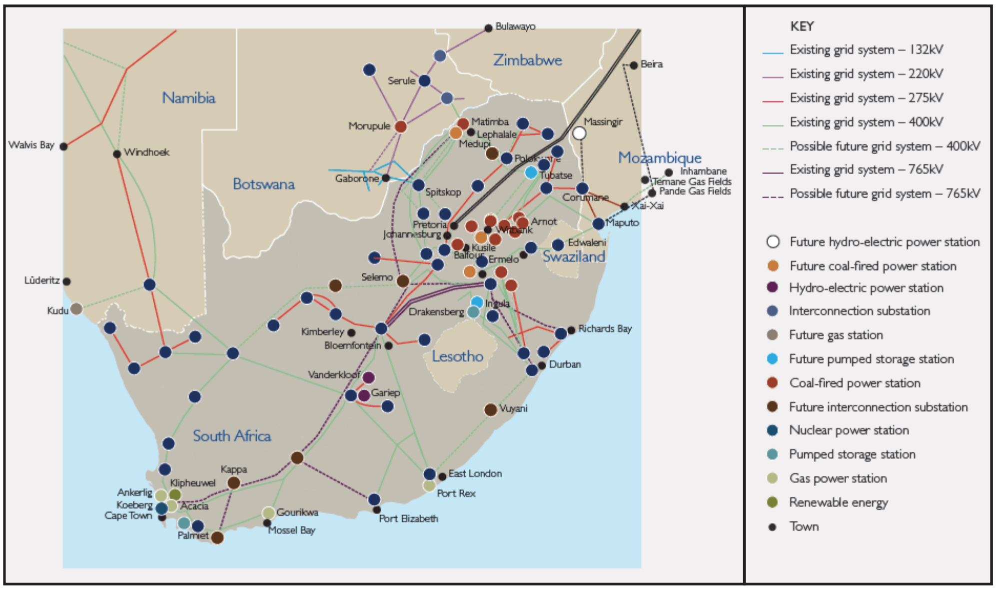


Figure 7-21: South Africa's electricity distribution network (Eskom 2010).

Generally, the overall macro-economic environment will determine the extent of electrification required for the remaining un-electrified households in urban and rural areas. Eskom (2002) has shown that the cost of new connections is declining, but it is nevertheless clear that the cost of connecting the remaining urban and rural residents will be very high. Supplying grid electricity to some rural areas is difficult because of their remoteness and low population density, thus cost becomes prohibitive; a weak rural economy makes cost recovery even more difficult. However, policy approaches based on 'taking electricity to the people' or 'bringing the people to electricity' should be explored (Winkler 2006).

There is potential to increase the supply of energy to households through increased investment in decentralised renewable energy resource projects. This will not only ensure that capital investment is efficiently distributed depending local needs, but will also allow for the optimisation of local natural resources (such as solar, wind and water resources).

7.3.2. Future energy resource demand and supply

As indicated in the Integrated Resource Plan (IRP) Update (2013), the actual energy demand has been lower over the past three years than projected in the IRP 2010. The new trends indicate a lower growth in electricity demand relative to previous projections (as shown in Figure 7-22).

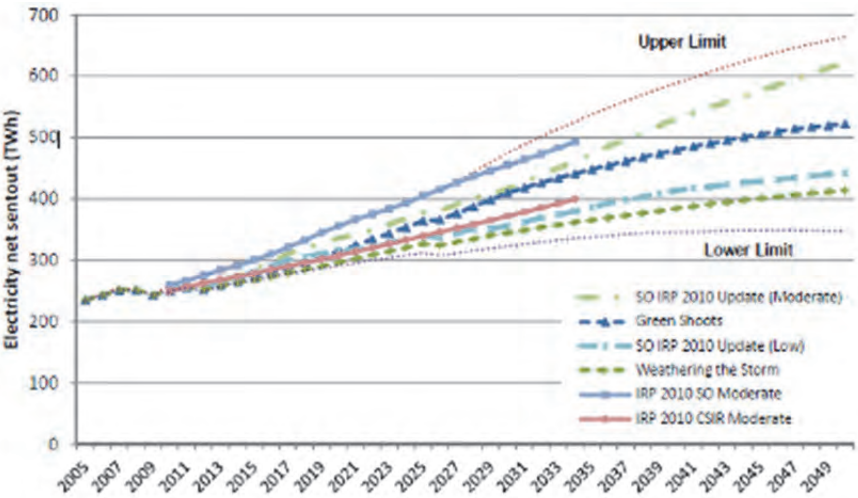


Figure 7-22: Electricity demand projections to 2050 (DoE 2013c).

Whilst electricity demand was lower than forecasted, economic activity has been only marginally different from forecasted activity. Total GDP growth for each year was 2.9%, 3.4% and 2.4% for 2010, 2011 and 2012 respectively. This is comparable to the prediction of 2.4%, 3.7% and 4% (in the moderate growth scenario). The 2012 lower growth departs from the forecast and has a high impact on the resulting electricity demand. A number of updated demand forecasts were developed during 2012 based on the latest economic indicators and measured electricity demand (DoE 2013c).

A default assumption in many scenario-modelling exercises is that energy demand grows with economic output (GDP). Overall historic consumption, as recorded by total sales of electricity in GWh, has grown fairly consistently in line with GDP growth over the past 50 years. Although economic growth is an important driver for energy demand, GDP as a measure fails to account adequately for natural resources and external costs. Its focus by definition is on overall growth, which diverts attention from the structure of the economy. The emphasis on economic and industrial strategy, depending on how it falls between the primary, secondary and tertiary economic sectors, has major implications for future energy demand (Winkler 2006).

In addition, other factors that influence energy demand apart from economic growth include demographic trends and basic service provision, as well as the rate of technological change as it provides the opportunity to explore new energy resources. Due to projected changes in the factors listed above, the spatial distribution of the country's projected energy demand for 2040 is illustrated in Figure 7-23 and Figure 7-24.

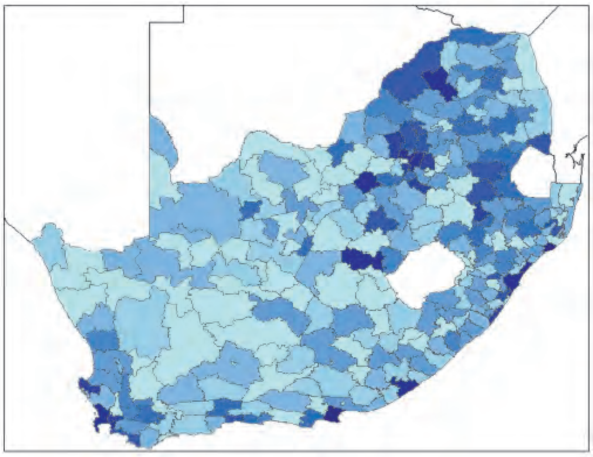


Figure 7-23: Projected electricity demand for 2040 (DoE 2013c).

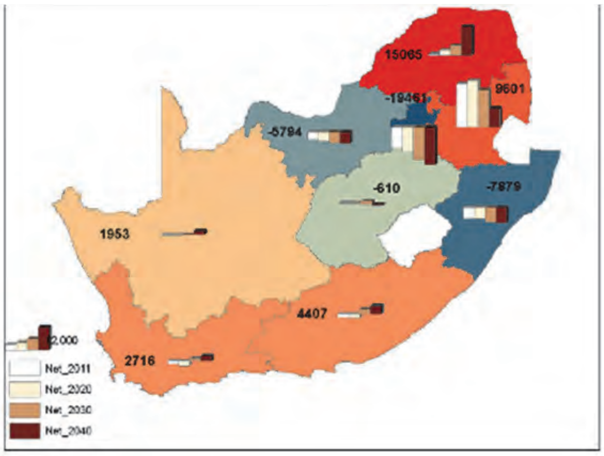


Figure 7-24: Projected provincial demand balance for 2040 (DoE 2013c)

The major load centres are indicated as dark blue areas and mostly represent district (metropolitan) municipalities that are projected to experience population and economy growth. When comparing the projected energy demand with the projected energy supply, it is possible to obtain a demand balance of the district municipalities. A negative demand balance illustrates areas where demand is projected to be more than supply, while a positive demand balance illustrates areas projected to have energy surplus. The provincial demand balance is illustrated in Figure 7-24.

Figure 7-23 shows that new sources of energy will be required to supply the projected energy demand. As a result, the IRP 2013 has proposed numerous transmission power corridors when new energy resources will be located across the country. To support the IRP scenarios, numerous scenarios have been proposed and are discussed in Chapter 8. The main difference between the scenarios is the physical amount of each type of energy resource technology that will come online. The location of each type of the energy resource is based on the optimal utilisation of available local natural resources in the context of climate change, by promoting the efficient use of water resources and fulfilling local and national energy demand.

At a smaller scale, however, the location of energy resources only has to take into account local water resource availability. Therefore, for example, solar energy can be located across the country, as long as there are sufficient natural resources. This is, however, only applicable for distributed energy projects (solar, wind, micro-hydro and irrigated bioenergy) and rain-fed bioenergy, as these energy resources are dependent on the local yield (i.e. runoff) and local rainfall.

Despite these proposed energy scenarios, it is anticipated that major bottlenecks will still occur, requiring significant developments of the transmission infrastructure. Effort should be undertaken to either identify alternative sites or undertake the transportation of the resource itself to reduce the transmission infrastructure requirements. Serious consideration should be given to managing the skewed distribution of future generation in order to leverage transmission capacity against minimum transmission investment (DoE 2013c).

7.4. Summary

SA has the opportunity to leapfrog fossil-fuelled development by embarking on ambitious renewable energy and efficiency programmes where clean, sustainable, secure, stable, employment-supporting and accessible energy can be achieved. This would enable long-term socio-economic development with reduced emissions. Renewable energy also presents various natural resource advantages that are lacking in traditional coal-based energy resources.

It is noted that SA is a water scarce country which also suffers from high unemployment and poverty. The choice of energy resources is, therefore, important, particularly in light of water resource scarcity. Different energy resources require different water inputs in terms of type and quantity. The availability of the required water resource type, the water use quantity and quality requirements, and the water efficiency of the specific energy resources should be considered when deciding which energy resources to exploit.

In order to initiate this process, the Department of Environmental Affairs (DEA) has identified Renewable Energy Development Zones (REDZs), which are illustrated in Figure 7-25. The Strategic Environmental Assessments (SEAs) for wind and solar photovoltaic (PV) aim to facilitate the implementation of sustainable green energy initiatives.

The SEA identifies areas where large-scale wind and solar PV energy facilities can be developed in terms of Strategic Integrated Projects (SIPs) 8 and in a manner that limits significant negative impacts on the environment, while yielding the highest possible socio-economic benefits to the country (CSIR 2014). The location of the proposed REDZs falls into the identified WMAs for solar and wind energy (as discussed in Appendix G), and therefore also incorporate the trade-offs between water and energy resources.

Figure 7-25: 8 Proposed Renewable Energy Development Zones (REDZs) for wind and solar PV energy (Source: CSIR 2014).

This will ensure that short-term planning approaches not only consider the availability of natural resources, but also consider water resource availability. As water and energy needs are also shaped by population growth, climate change, and changes in energy resource availability and technology type, the planning for water and energy needs to be considered in an integrated manner. This will ensure the sustainability of energy projects while also ensuring environmental sustainability.

8. SCENARIOS OF ENERGY SUPPLY AND ASSOCIATED WATER DEMANDS

By: Madhlopa A, Moorlach M, Sparks D and Keen S

8.1. Introduction

The concept of scenarios analysis was introduced in Section 2.6. It was shown (in the said section) that this analytical technique can be applied in planning energy and other public service systems. Thus, it can be employed to investigate multiple public service systems (such as energy and water). In this chapter, the implications of various energy scenarios on water resources in South Africa are investigated. Different future scenarios are examined in order to get a deeper understanding of energy demand and supply, and the associated water requirements over the time horizon to 2050. The chapter starts by presenting the South African context, followed by a discussion on findings, and ends with a summary.

8.2. The South African context

The major source of energy in South Africa is coal, but the country cannot continue to rely heavily on coal without serious negative impacts on the society, environment, health and economy. South Africa is diversifying the sources of energy to promote sustainable development. In this vein, the government formulated an integrated resource plan (IRP) to develop a sustainable electricity investment strategy for generation capacity and supporting infrastructure for South Africa over the next 20 years (DoE 2013c). The plan developed scenarios characterised by combinations of assumptions and constraints, for instance, varying GDP growth, primary resource availability and price and limits on CO_2 emissions, which resulted in contrasting cost optimal capacities of existing generation technologies. The generation technology options that were considered in the scenarios analysis included existing coal, new coal, combined cycle gas turbine (CCGT), open cycle gas turbine (OCGT)/gas turbine, hydro imports, hydro domestic, pumped storage (PS), nuclear, photovoltaic (PV), concentrated solar power (CSP), wind and other. The following scenarios were developed within the IRP:

1. ***Technology options arising from the three emission options in 2030 and 2050 considered under the following three scenarios:***

    a) Constant Emissions (CE): In this scenario, carbon emissions would be made at a constant rate of 275 million tons per annum (DoE 2013c). This scenario does not meet the requirements of the DoE of Peak-Plateau-Decline in the levels of emissions but it acts as an assumption over the Base Case.

b) Moderate Decline (MD): In this scenario, carbon emissions start to decline from the established 275 million tons per annum at a moderate rate in 2037 before reaching a target of 210 million tons per annum in 2050.

c) Advanced Decline (AD): This scenario is aimed at achieving an early reduction in carbon emissions from the IRP 2010 limit of 275 million tons per annum in 2030 before declining at an increasing rate to 140 million tons per annum in 2050.

2. ***Technology options arising from the carbon tax (CT)***

   To evaluate the impact of the carbon tax on the electricity sector in the updated IRP (DoE 2013c), it was assumed that the electricity industry was granted a 60% exemption on the full carbon tax until 2019 after which this tax-free allowance is annually reduced by 10% until it is eliminated in 2025. This effectively translates to a carbon tax of R40/ton in 2015 increasing gradually to R47/ton in 2019 before the more rapid escalation to R117/ton in 2025. Under this scenario, there is insignificant reduction in carbon emissions

3. ***Technology options arising from the updated IRP's carbon budget scenario (CB)***

   In this scenario, the total emissions allowance for the electricity industry is fixed over a specific period and is imposed as a constraint.

4. ***Technology options arising from IRP Rooftop PV case (PV)***

   As the cost of photovoltaic (PV) decreases, it is highly likely that the generation of electricity from PV will increase. The realisation of PV electricity generation can take place in the commercial and residential sectors, and to some extent in the industrial sector.

   Many forms of embedded generation exist (wind, biogas and biomass), but for the purposes of this scenario, the updated IRP report considered only the roll-out of residential PV as a proxy for commercial and industrial PV.. This is based on the assumption of 50% of households of LSM7 and above investing in 5 kWp of capacity each by 2020 (DoE 2013c).

5. ***Technology options arising from the Big Gas scenario***

   There is great potential for exploitation of offshore and shale gas in South Africa. This scenario considers large-scale exploitation of shale gas, which can result in a decrease of gas price, and a switch from coal and nuclear to gas.

6. ***Technology options arising from the Higher Nuclear Cost scenario (HN)***
   Nuclear power is attractive due to environmental policies that support low-carbon economic pathways, and strategic considerations that relate to the curtailment of the dependence on fossil fuels (Mari 2014). Nevertheless, there is some uncertainty about the cost of nuclear technology, with a range of $3 800/kW to $7 000/kW (DoE 2013c). This scenario considers energy supply with a higher cost of nuclear energy ($7 000/kW).

7. ***Technology options arising from the Higher Coal Cost scenario (HC)***
   South Africa is endowed with abundant coal resources, which translates into lower costs for coal-fired technologies relative to other power-generating technologies if externalities or cost of carbon are not considered. The base case of the updated IRP assumes R350 per ton for new coal-fired generation. For the Higher Coal Cost scenario, R500 per ton is assumed for new coal-fired generation, but the price for discarded coal as used by fluidised bed combustion technology (FBC) remains at R150 per ton. The lower discarded coal price results in slightly higher coal-fired capacity for the Higher Coal Cost scenario in 2030 relative to the Moderate Decline scenario because the model needs capacity earlier and can build FBC. FBC capacity is likely capped in the updated IRP model and therefore the Higher Coal Price scenario results in less coal-fired capacity by 2050 and more gas-fired capacity.

8. ***Technology options arising from the Solar Park test case.(SP)***
   South Africa possesses one of the most abundant solar resources in the world (Donev *et al.* 2012), especially in the Northern Cape, which can support the exploitation of concentrated solar power (CSP) in the solar corridor. The Moderate Decline scenario delays the construction of CSP until 2030 but the idea of a Solar Park test forces construction to take place earlier, allowing for 1000 MW of CSP construction each year from 2018 to 2022. This results in the delay of the construction of a nuclear power plant in the Moderate Decline scenario from 2025 to 2030.

9. ***Technology options arising from the learning rate scenario (RL)***
   The cost of manufacturing a technology tends to decrease with increasing experience. It is common to accumulate more knowledge and skills about a given technology as time passes by. In the case of energy technologies, the learning rate plays a vital role in the mitigation of climate change (McDonald and Schrattenholzer 2001). Cheaper energy technologies are more attractive to invest in than expensive ones. In this regard, energy technologies with a high carbon footprint easily attract funding as long as the cost is low. Consequently, technology learning is an important factor in the analysis of scenarios for

future energy supply systems. Technology learning rates are a function of global installed cumulative capacity, and have been studied for South Africa (Winkler *et al.* 2009) and are integrated in ERC's energy modelling (ERC 2013a).

The Base Case of the IRP assumed aggressive learning rates for all technologies except coal, including modest learning for nuclear and aggressive learning for PV and for CSP (DoE 2013c). A Restrained Learning Rate scenario was developed for the IRP update for comparison to the Base Case. In the Restrained scenario no learning was assumed for nuclear, biomass, IGCC and wind, with more restrained learning for CSP and PV until 2020 after which learning was assumed to cease.

8.3. Findings and discussion

8.3.1. Climate change and mitigation scenarios

The following scenarios from the IRP were compared: 1) Constant Emissions, Moderate Decline and Advanced Decline scenarios, 2) Moderate Decline and Carbon Tax scenarios, 3) Advanced Decline and Carbon Budget scenarios.

Figure 8-1 shows water usage under the Constant Emissions, Moderate Decline and Advanced Decline scenarios for the two time periods considered (viz. 2030 and 2050). There is no distinct difference in water requirements amongst the three scenarios in 2030. This is attributed to the fact that all the three scenarios have almost the same corresponding capacity for all the technology options (except OCGT/gas engines, PV and wind). However, there is a decline in water requirement for all the scenarios (30, 30 and 33% for the Constant Emissions, Moderate Decline and Advanced Decline scenarios respectively) between the two time periods. The Advanced Decline scenario exhibits the lowest water demand in 2050, which is a positive trend, and is explained by the increase in nuclear energy (about 40% of the annual energy is generated by nuclear power plants), which predominantly uses seawater with insignificant impacts on the fresh water resources.

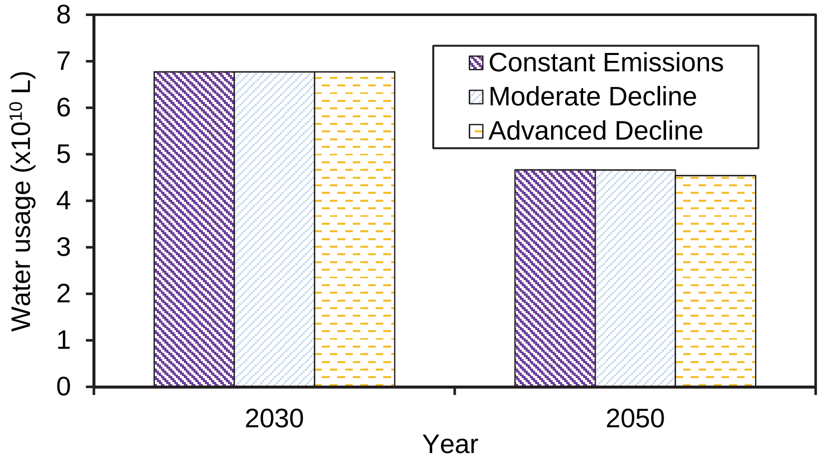


Figure 8-1: Annual water usage in energy production under Constant Emissions, Moderate Decline and Advanced Decline scenarios.

Figure 8-2 shows water usage under the Constant Emissions and Carbon Tax scenarios for the two time periods considered (viz. 2030 and 2050). A marked difference is observed in water usage amongst the two scenarios in each time period. The water usage for the Carbon Tax scenario is consistently lower than that for the Constant Emissions scenario. In addition, the demand for water decreases for each scenario (35% for the Carbon Tax) between the two time periods. Once again, this is an encouraging result: declination in water usage within the energy sector.

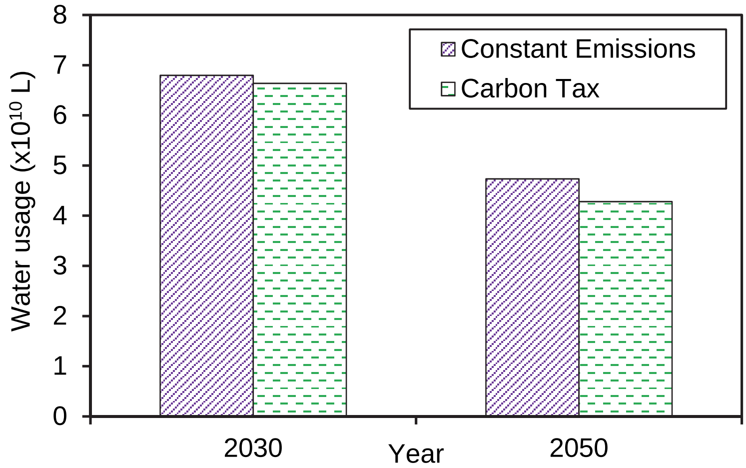


Figure 8-2: Annual water usage in energy production under Constant Emissions and Carbon Tax scenarios.

Figure 8-3 shows water usage under the Advanced Decline and Carbon Budget scenarios for the two time periods considered (viz., 2030 and 2050). A minor difference is observed in water usage between the two scenarios in each time period. The water usage in the

Advanced Decline scenario is lower than that in the Carbon Budget scenario in both time periods. In addition, the demand for water for each scenario decreases (32% decrease for the Carbon Budget) between the two time periods. From a water perspective, this shows that the Advanced Decline scenario would be more preferred than the Carbon Budget.

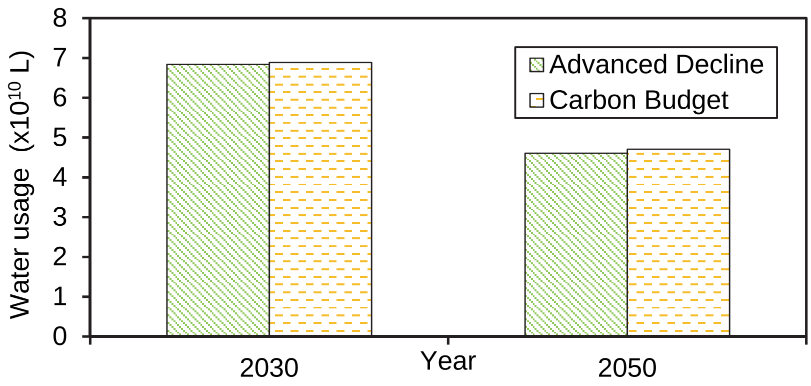


Figure 8-3: Annual water usage in energy production under Advanced Decline and Carbon Budget scenarios.

8.3.2. Technology-specific scenarios compared to Moderate Decline

The following scenarios were compared, 1) Rooftop PV and moderate decline 2) big gas and moderate decline, 3) higher nuclear cost and moderate decline, 4) higher coal cost and moderate decline, 5) solar park and moderate decline.

The water usage under the Moderate Decline and Rooftop scenarios is presented in Figure 8-4. The Rooftop PV scenario displays lower usage of water than the Moderate Decline, with a general decrease in water usage between the two time periods. It is interesting to note that the Rooftop scenario requires less water than the Moderate Decline Scenario. This is expected because the water intensity for the PV technology is relatively low.

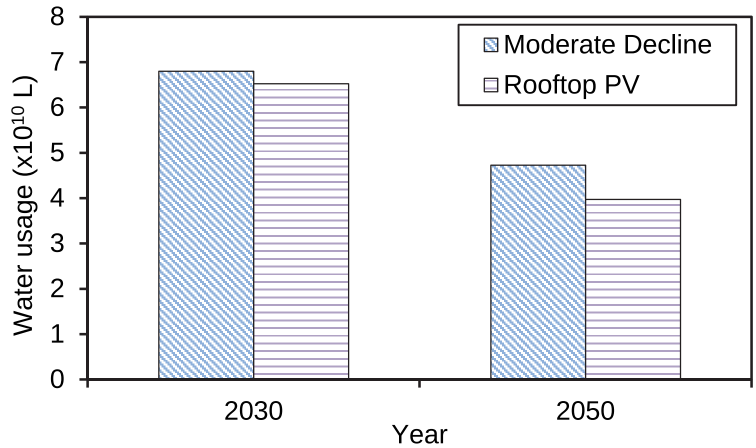


Figure 8-4: Annual water usage in energy production under Moderate Decline and Rooftop PV scenarios.

The result of replacing nuclear with shale gas is presented in Figure 8-5. It is observed that the Big Gas scenario is more water-efficient than the Moderate Decline scenario in both time periods. In addition, the total annual water usage in generating electricity declines for both scenarios. This observation is attributed to the relatively lower water intensity for CCGT and OCGT/Gas engine energy technologies (DoE 2013c). Increasing the share of gas allows more electricity to be produced by these technologies. It should be noted that fracking requires some water and contributes to contamination of water resources (Kharak *et al.* 2013). In addition, Wilson *et al.* (2012) report that most of the water used in the production chain of gas-fired thermoelectric power is during generation (for wet-cooled power plants). Based on the water intensities assumed in the IRP update, CCGT and OCGT/Gas engines have relatively lower demands for water than coal (DoE 2013c). Consequently, increasing the share of gas would tend to reduce the total annual water demand.

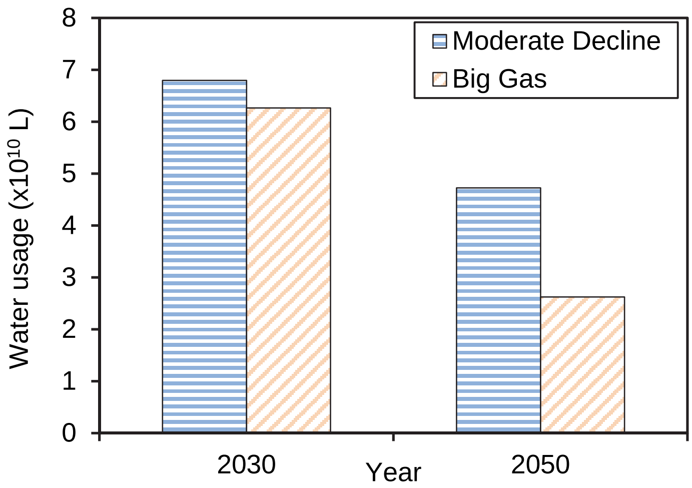


Figure 8-5: Annual water usage in energy production under Moderate Decline and Big Gas scenarios.

Figure 8-6 shows the total water usage in generating electricity under the Higher Nuclear Cost scenario. This figure demonstrates that the Higher Nuclear Cost scenario is slightly more water-efficient than the Moderate Decline scenario in 2030 and 2050. The Moderate Decline scenario exhibits a reduction in water demand between the two time horizons, with a reversed trend for the Higher Nuclear Decline. This observation is probably due to the fact that increasing the cost of nuclear energy allows CSP, wind and CCGT gas to make up for the shortfall (DoE 2013c). It should be noted that CSP technology, which has relatively high water intensity, contributes the largest proportion (about 27%) of the total annual electricity in 2050.

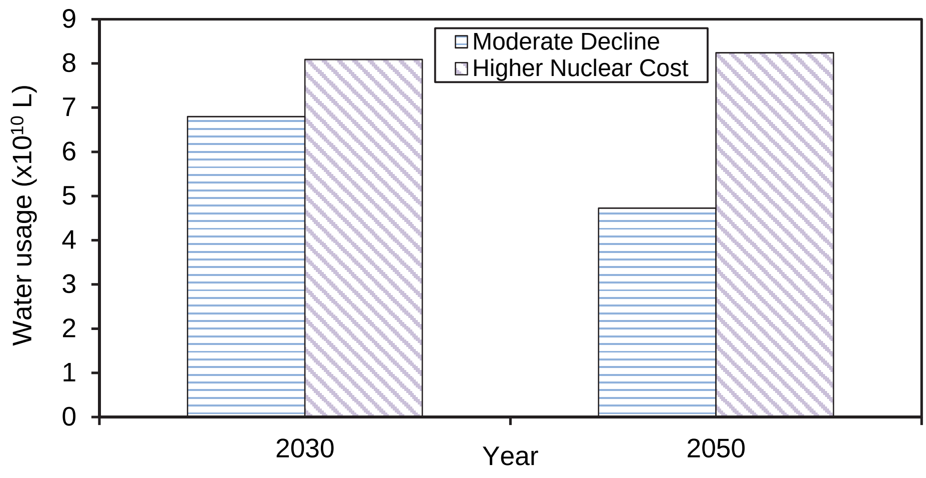


Figure 8-6: Total annual water usage under the Moderate Decline and High Nuclear Cost scenarios.

Figure 8-7 shows the total water usage in generating electricity under the Higher Coal Cost scenario. It is observed that the total annual water usage for the two scenarios is comparable in 2030 but significantly different in 2050, with the Higher Coal Cost scenario being more favourable. This is attributed to the fact that increasing the cost of coal permits the gas technology, which has a low water intensity, to be competitive.

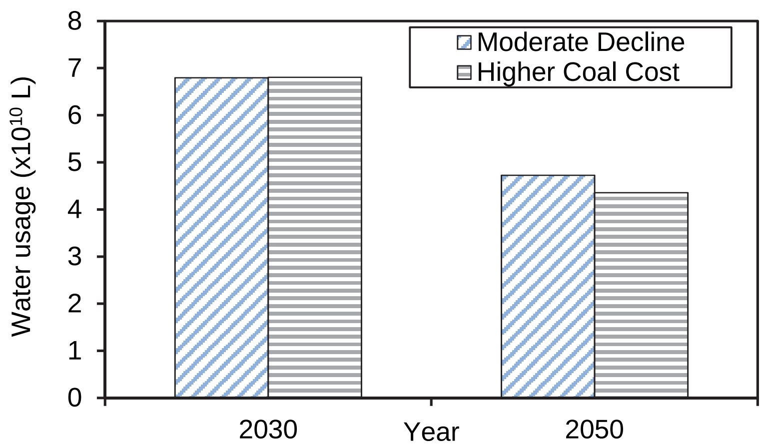


Figure 8-7: Total annual water withdrawal arising from the High Coal Cost scenario.

The total water usage in generating electricity under the Solar Park scenario is provided in Figure 8-8. This figure demonstrates that the Moderate Decline scenario is more water-efficient than the Solar Park scenario in 2030, probably due to the higher energy production from nuclear energy, PV and wind with less energy production from wet-cooled CSP under this scenario than energy production from the corresponding technologies the Solar Park Scenario. In 2050, the Moderate Decline scenario uses less water than the Solar Park scenario, which may be attributed to the higher energy production from the CSP technology under the former scenario than the latter. Nuclear power plants (using seawater), PV and wind have low water intensities while CSP has a higher water usage factor. Thus, increasing the shares of PV and wind would tend to reduce the annual demand for water while raising the share of CSP would produce an opposite effect on the water demand. The total annual water demand declined for both scenarios, with the Solar Park scenario being more preferred from a water perspective.

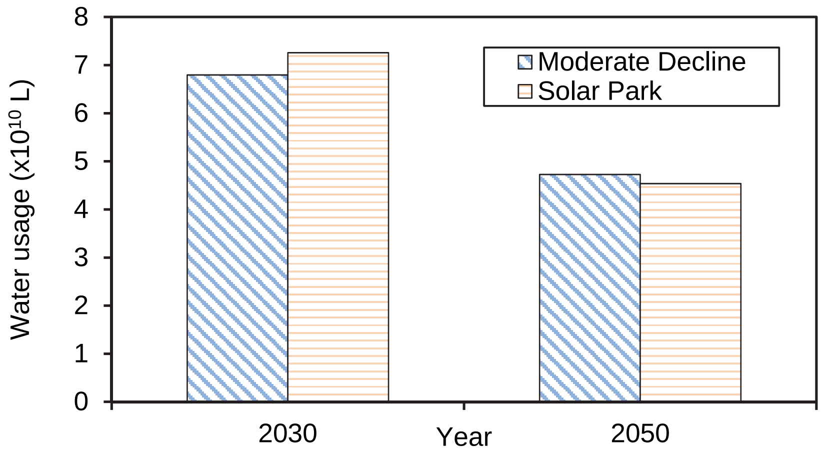


Figure 8-8: Total annual water consumption arising from the Solar Park scenario.

8.3.3. Inter-comparison of water requirements for various scenarios

In Figure 8-9 it is shown that the Big Gas (BG) scenario has the lowest share of renewables in 2030, with the Restrained Learning Rate (LR) exhibiting the lowest share in 2050, which shows that that RE is not as competitive under these scenarios in this time period. On the other hand, a Higher Nuclear Cost (HN) allows the largest proportion of energy production from the renewable energy technologies (considered in this analysis) in both time periods, with a significant proportion generated by CSP.

Results also indicate an increase in the share of RE between the two time horizons for each scenario, except for the Restrained Learning Rate scenario (RL). It is pleasing to note that all scenarios pertaining to climate change exhibit increasing shares of electricity generation from RE resources. This observation is encouraging, considering the fact that RE is one of the pillars of sustainable energy production.

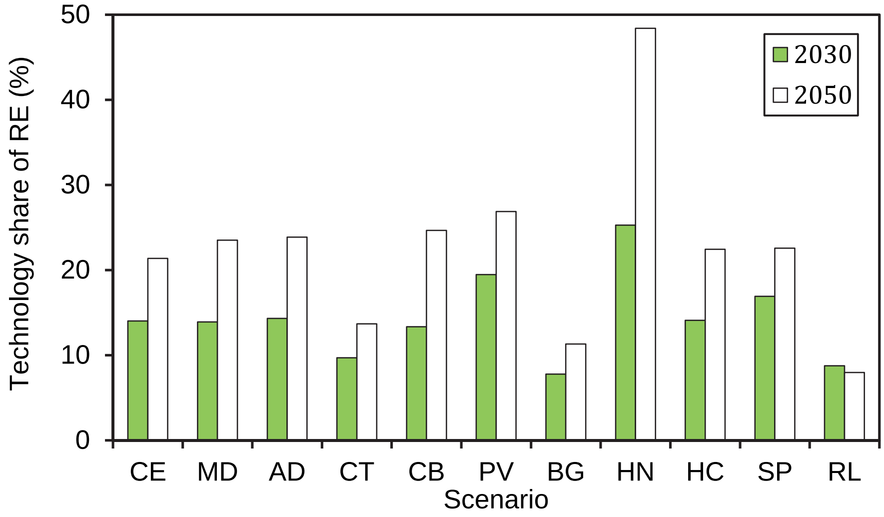


Figure 8-9: Share of renewable energy (RE) in electricity generation in South Africa for 2030 and 2050.

A summary of the annual water usage for all considered scenarios is provided in Figure 8-10. The Big Gas scenario (BG) exhibits the lowest demand for water while the High Nuclear Cost (HN) requires the highest amount of water in both time horizons. When the cost of nuclear energy is high, no new nuclear units are built and this shortfall in capacity is taken up by CSP, wind and CCGT gas (DoE 2013c). It should be noted that the water intensity for wet-cooled CSP plants is relatively high. Consequently, an increase in the share of CSP would tend to augment the water demand for energy production. From a water perspective, results indicate that the Big Gas scenario is most favourable. For gas, the largest proportion of the water is used in the generation stage (Wilson *et al.* 2012).

One of the objectives the IRP is to reduce water consumption in the energy sector (DoE 2013c). It can be observed from Figure 8-10 that the demand for water decreases (except for the Higher Nuclear Cost, HN) between the two time horizons, in spite of the increasing electricity production. This is probably due to the rise in the shares of electricity generation by using energy technologies (such as solar PV and wind) with low water intensities. The Higher Nuclear Cost allows more energy to be produced from renewables. It should be noted, however, that increasing the share of wet-cooled CSP in the generation of electricity augments water usage in energy sector.

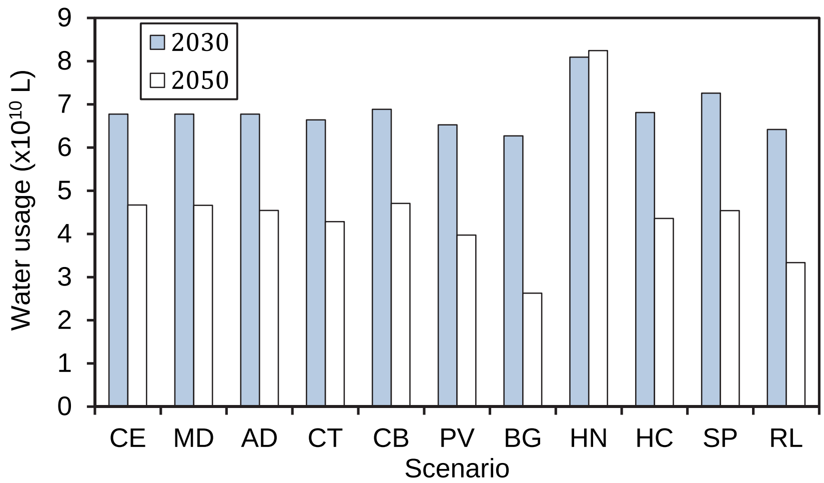


Figure 8-10: Annual water usage for energy production for all scenarios in 2030 and 2050.

8.4. Summary

The water use for generating electricity was investigated for different Scenarios for South Africa using data from the IRP update (DoE 2013c). Eleven different scenarios were investigated, These were; Constant Emissions, Moderate Decline, Advanced Decline, Carbon Tax, Carbon Budget, Rooftop PV, Big Gas, Higher Nuclear Cost, Higher Coal Cost, Solar Park and Restrained Learning Rate. Two time periods were considered (2030 and 2050) by using existing national data on energy scenarios. These data, together with the data collected in chapter 4 (renewable energy choices and water requirements in South Africa), were used to calculate the water consumption during production stage of electricity generation for each of the described scenario's.

Results show that there is a general increase in the electricity production from 2030 to 2050 under all considered scenarios. Despite the increased electricity production, the water usage tends to decrease for all scenarios except high nuclear Cost. The Big Gas scenario sees to use the least amount of water in both the analysed time frames (2030 and 2050). For all scenarios, except restricted learning Rate the percentage of renewable energy does increase between 2030 and 2050. A higher share of renewable energy in the energy mix can assist in reducing the water demand for the energy production.

9. DECISION SUPPORT FRAMEWORK FOR THE WATER-ENERGY NEXUS

By: Madhlopa A, Pegram G, Sauka S, Sparks D, Keen S and Moorlach M

9.1. Background

South Africa (SA) has experienced electricity shortages (such as the electricity blackouts in 2007 and 2008 and those more recently in 2014 and 2015). In addition, as part of its development agenda, the country has committed itself to providing access to energy for all. In so doing, the increase in energy supply required to meet the demand will result in an increase in water use and impacts associated with energy resources, unless different energy technologies are deployed. This places increased pressure on freshwater resources, which will be exacerbated by a changing climate. To minimise climate change vulnerability, a future SA will need to diversify its energy mix, with a greater portion of this being derived from renewable energy resources. This can only be achieved through an energy planning environment that considers water resources integrally in its planning processes.

9.2. Integrated water-energy resource planning

Historically, energy and water systems have been developed, managed, and regulated independently. However, as these systems are tightly intertwined, recent developments have focused national attention on the connections between energy and water infrastructure. Thus, effective energy and water resource planning calls for the integration of multiple approaches. An approach that integrates the inherent complexity provided by both resources does not only give an insight into the interconnected nature of energy and water but also improves the acceptance of planning approaches among a diverse set of users. Societies must find an appropriate balance among trade-offs, at both the national and local levels, taking into consideration both water availability and energy needs (Glassman *et al.* 2011).

The White Paper on Renewable Energy states that integrated resource planning decisions around the world now consider not only maintaining security of supply, but give full consideration of the economic, environmental and social impacts of all alternatives, such as demand-side management and energy efficiency programmes. This 'levelling of the playing fields' between conventional supply options and more environmentally benign alternatives (such as renewable energy) encourages a shift towards a more sustainable approach (DoE 2003).

There are various distinct aspects to augment the integration of energy and water resource planning. A common approach for electricity and water resources' planning is depicted in

Figure 9-1a. Energy planners currently project future energy supply and demand, but often fail to consider climate-related impacts of water supply, which will directly affect the energy supply (e.g. hydropower). Conversely, water resource planners understand the water demands of electricity generation, and are increasingly accounting for climate change impacts on water supplies, but do not necessarily assess the role of climate in changing behaviours in the electricity system (Jeffers 2013). Therefore, energy-water planning should strive for an integrated planning environment, as illustrated in **Figure 9-1**b.

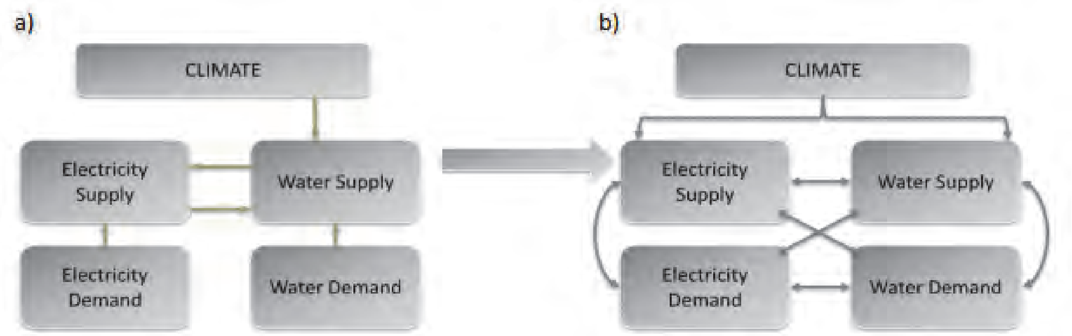


Figure 9-1: a) Current coupling in energy and water resource planning; b) coupling required for integrated water and energy resource planning (Source: Jeffers 2013).

9.3. Integrated planning landscape

Integrated energy planning is undertaken to determine the best way to meet current and future energy service needs in the most efficient and socially beneficial way. As an emerging economy, SA needs to balance the competing demands for continued economic growth with its social needs and the protection of the natural environment. The country needs to grow its energy supply to support economic expansion and, in so doing, alleviate supply bottlenecks and supply-demand deficits. In addition, it is essential that all citizens are provided with clean and modern forms of energy at an affordable price (DoE 2012).

Several current trends, such as population growth, climate change, technology developments, research and development (R&D) and policies are further increasing the need to address the energy-water nexus in an integrated and proactive way. In this regard, the White Paper on Energy Policy identifies integrated energy planning as the most suitable process for planning purposes. However, the White Paper on Energy Policy states that integrated energy planning suffers from the same drawbacks as other ideal models; it requires a great deal of data and analysis to implement, something that is rather scarce in SA. Therefore, enhancing and integrating data and models will better assist researchers, decision-makers, and the public when performing integrated energy-water planning. To promote this, SA has several plans, strategies and policies that have been developed to encourage integrated planning (as discussed in Chapter 6).

9.4. Integrated planning for the water-energy nexus

Water availability will affect the future of the energy-water nexus. While there is significant uncertainty regarding the magnitude of effects, water availability and predictability may be altered by changing temperatures, shifting precipitation patterns, increasing variability, and more extreme weather (USA DoE 2014). This will have a net impact on the energy needs. For instance, while on the one hand an increase in ambient air temperature increases the demand for household cooling, a decrease in the ambient temperature increases the heating needs. Therefore, variations in climate will lead to changes in energy demand, which will also increase water demand for the energy production chain. These changes and variations pose challenges for maintaining resilient energy infrastructure and ensuring energy supply in the context of a changing climate. This is of concern due to the spatial misalignment of energy resources and water resource in the country, especially in the context of climate change.

For future energy needs, the location of each type of the energy resource should be based on current and future local natural resource availability. Planning should aim for an optimal utilisation of available local natural resources, by promoting the efficient and sustainable use of water resources while also meeting and fulfilling local and national energy demand. Figure 9-2 illustrates the envisaged location of various energy resources based on current and future availability of energy and water resources.

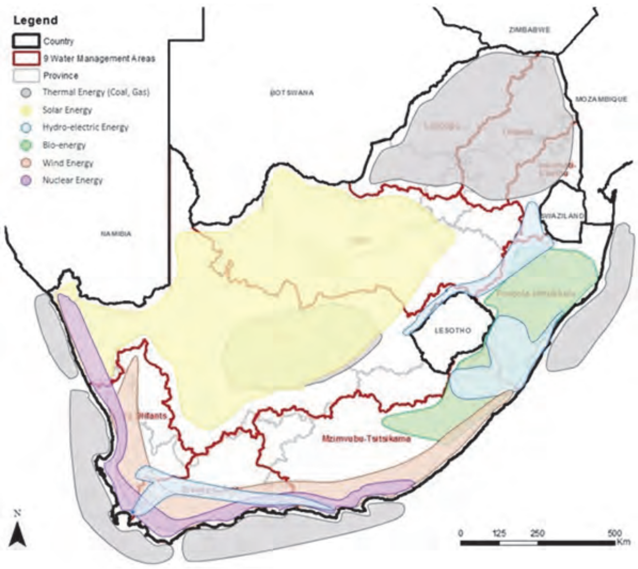


Figure 9-2: The location of energy resources.

For renewable energy options, these are inherently aligned with the required water resources; thermal energy, on the other hand, requires large amounts of water resources for its life cycle processes. Therefore, it is essential that the energy resources are spatially aligned with the available water resources because the demand for water varies with the energy technology option. For example:

- Thermal energy and large hydro plants require large amounts of water, and are dependent on regional yield (i.e. runoff). The magnitude of the water requirements needs consideration of the broader catchment and region, and should, therefore, be located in areas with sufficient runoff.
- Distributed energy projects (solar PV, wind, micro-hydro and irrigated bioenergy) are dependent on local yield (i.e. runoff), and require significantly less quantity than thermal and large hydro plants. These projects therefore only require the consideration of water resources at a local level.
- Rain-fed bioenergy is dependent on rainfall, and should, therefore, be located in regions with sufficient rainfall.
- Other types of energy technologies:
    - Nuclear power plants utilise seawater, and are thus located in coastal areas. The environmental risk associated with nuclear energy, such as explosions or waste contamination, require careful consideration of the proximity to human population and environmentally sensitive habitats.
    - Alternative bioenergy, such as feedstock produced from solid waste, algae or manure, has varying water needs depending on the feedstock. This is likely to compete with local water users as water is often sourced from a municipal water supply.

Different approaches can be taken in order to meet these planning needs, all of which include a consideration of the trade-offs between water and energy resources. This includes taking into account the water availability and demand, as well as the water requirements and impacts associated with exploitation of the energy resources. It is, therefore, envisaged that different approaches (or a combination thereof) can be applied to achieve integrated water-energy planning:

- **Centralised energy** planning approach: the national grid is expanded and all electricity consumers are connected to the national grid. Large-scale energy resources (such as coal or gas), as well as renewable energy resources (such as large hydro) feed into this grid.

- **Decentralised energy** planning approach: an energy resource is exploited to meet local energy needs and is not connected to the national grid. However, excess energy may be used to feed into the national grid if the transmission infrastructure exists. This approach enables local natural resources (such as solar or hydro) to be optimised.

- An approach which promotes **separation of the life-cycle processes**, which can be practised when local natural resources are not sufficient to meet local energy requirements, or when there is a mismatch between water availability and the water requirements of the energy resource. This can allow for life-cycle processes to optimise water availability, particularly in instances where policies aim for upscaling technology production. In this approach, for example, SA could manufacture solar and wind technologies in water abundant areas, and then install the plants in water scarce areas, using innovative water management processes, where the energy resources are required. At a large scale, nuclear energy is also an example of this approach, where uranium is transported to coastal areas to enable energy production processes that use desalination.

9.5. Decision Support Framework

Nations around the world are evaluating their energy options and developing policies that apply appropriate financial incentives to various technologies to encourage sustainable energy production, including socio-economic, environmental and energy security considerations. Water needs to be part of this debate, particularly how communities will manage the trade-offs between water and energy at the local, national, and cross-border levels. These decisions impact businesses, investors, security, environment, justice, development, and sustainability (Glassman 2011).

The energy-water decision landscape is starting to attract attention and gain awareness as a result of the increasing importance of water in energy production, rising uncertainty of water supply, and similar trends at the global scale. SA needs to learn lessons from other water-scarce countries (including studies that have identified barriers to integrated policy designs) with regard to the integration of energy and water issues in policy making, to maximise water and energy productivity. Successful integrated watershed and basin management experiences should be studied for potential wider application (USA DoE 2014).

The decision-making landscape for the energy-water nexus is shaped by political, regulatory, economic, environmental, and social factors, and available technologies. This landscape is fragmented, complex, and changing. The incentive structures are overlapping but not necessarily consistent. Water management is inherently multi-jurisdictional and primarily a state and local issue. Energy for water is also the subject of policy activity at multiple scales. Consequently, a more integrated approach to the interconnected energy and water challenges could stimulate the development and deployment of solutions that address objectives in both domains. The energy-water decision landscape is, however, highly fragmented. It comprises a diverse set of actors and interests, overlapping but not necessarily consistent incentive structures, and inherent regional variation in energy and water availability (USA DoE 2014). These include:

- decision-makers, which include state, provincial and/or local level regulating institutions;
- catchment-based water resources managers and water service providers;
- energy resource project developers; and
- Civil society (water and energy users).

While these diverse stakeholders often act independently and have competing goals, the impacts of their individual decisions are interconnected. Therefore, the collaboration between the national government, local government, private sector and civil society is essential. In addition, there is also an opportunity for the harmonisation of energy and water policies, and for the integration of the planning environment. This can be achieved by having a two-part planning environment: a) national level planning that focuses on large scale energy resources such as coal power stations or large hydropower plants; and b) catchment based planning that concentrates on projects (for smaller scale energy projects such as small hydro plants, wind or solar projects) and decision-making at catchment level.

The White Paper on Energy Policy (1998) states that the energy regulators should ensure that an integrated resource planning approach is adopted for investment decisions by energy suppliers and service providers, in terms of which comprehensive evaluations of the economic, social and environmental implications of all feasible supply and demand side investments will have to be undertaken. This is an effective means of ensuring that the natural preference of utilities for large supply-side investments is compared on an equal footing with all feasible alternatives, and that their environmental costs are integrated into an economic and social analysis.

9.5.1. National level energy-water resource planning

The White Paper on Energy Policy of 1998 identifies integrated energy planning as the most suitable decision support framework for overall national energy sector guidance and macro-planning. The integrated energy planning considers not only maintaining security of supply, (taking into consideration all fuel types and energy carriers) but also the economic, environmental and social impacts of all alternatives, such as demand-side management and energy efficiency programmes so as to promote a sustainable approach to energy planning. As such, the IEP provides the roadmap of the future energy landscape for SA, guiding both investment in energy infrastructure and informing policy formulation implementation. The purpose of the IEP is to: a) identify which energy resources to exploit; b) inform investment in energy infrastructure; and c) propose alternative energy strategies to meet optimal levels of energy production and consumption.

The Energy Act (Act No. 34 of 2008) mandates the Minister of Energy to develop and review the IEP on an annual basis, as the primary energy planning process. This process of reviewing is designed to take into account the changes in the macro-economy, technology development, and national imperatives. To maintain the relevance, the Energy Act requires the IEP to have a planning horizon of not less than 20 years. The White Paper promotes a role for both national and local planning for the energy system. 'For instance planning, standards and collective bargaining are best addressed at the national level, whilst local planning and customer service complaints are better addressed at a local level' (DME 1998: 44). As previously mentioned, the use of integrated energy planning is considered ideal because it includes the 'systematic analysis of all the factors that influence the evolution of energy systems. It facilitates problem solving and makes it possible to explore linkages, evaluate trade-offs and compare consequences, thereby helping countries to develop an effective energy strategy that supports national sustainable development goals' (DoE 2013c: 37).

The IEP engages in a technical and stakeholder process. It uses data on the current energy requirements, and calculates the likely future energy requirements of consumers (demand). It then formulates and assesses scenarios to describe the optimal mix of energy sources and technologies (supply), to meet those energy needs in the most cost-effective, efficient, socially beneficial and environmentally responsible manner.

The modelling of the energy supply and demand system requires a great deal of data to quantify resources and impacts of the multiple processes energy undergoes from extraction of the resource, through conversion to a secondary energy carrier, electricity, heat or liquid fuels, through transmission and distribution for use in energy technologies to meet the end-use energy demand. The latest draft of the IEP (2012) incorporates climate change mitigation objectives by explicitly modelling the effects of GHG emissions constraints following the upper bound of the 'peak-plateau-decline' trajectory defined in the National Climate Change Response Policy, as well as the effects of the proposed carbon tax.

However, this pre-requisite for reliable and relevant data presents a challenge, and the lack of adequate data has been raised as an ongoing obstacle to effective energy planning (White Paper 1998; NEF 2014). Not only is the IEP data-intensive, but it also requires accurate and up-to-date information, for example on latest technologies and associated costs; hence the iterative nature of both report processes. Nevertheless, the frequency of publishing the IEP (and the IRP) is longer than envisaged by the White Paper (the most recent Cabinet approval of the IEP was in 2003 and the IRP in 2011).

a) The landscape of national energy-water planning

Many other energy plans draw on the IEP as the primary energy planning process in South Africa. These include the sub-sector roadmaps, for example, the Integrated Resource Plan (IRP) for electricity and the Transmission Development Plan (TDP). Figure 3 depicts the landscape of the other energy plans in relation to it. Policies that impact the attainment of IEP objectives are described in the Draft 2012 IEP as 'high-impact' policies (DoE 2013a). Examples of these include the National Climate Change Response Strategy and the IRP, and of course, the National Development Plan that serves as a reference point for all South Africa's policy to support economic growth and to meet social needs.

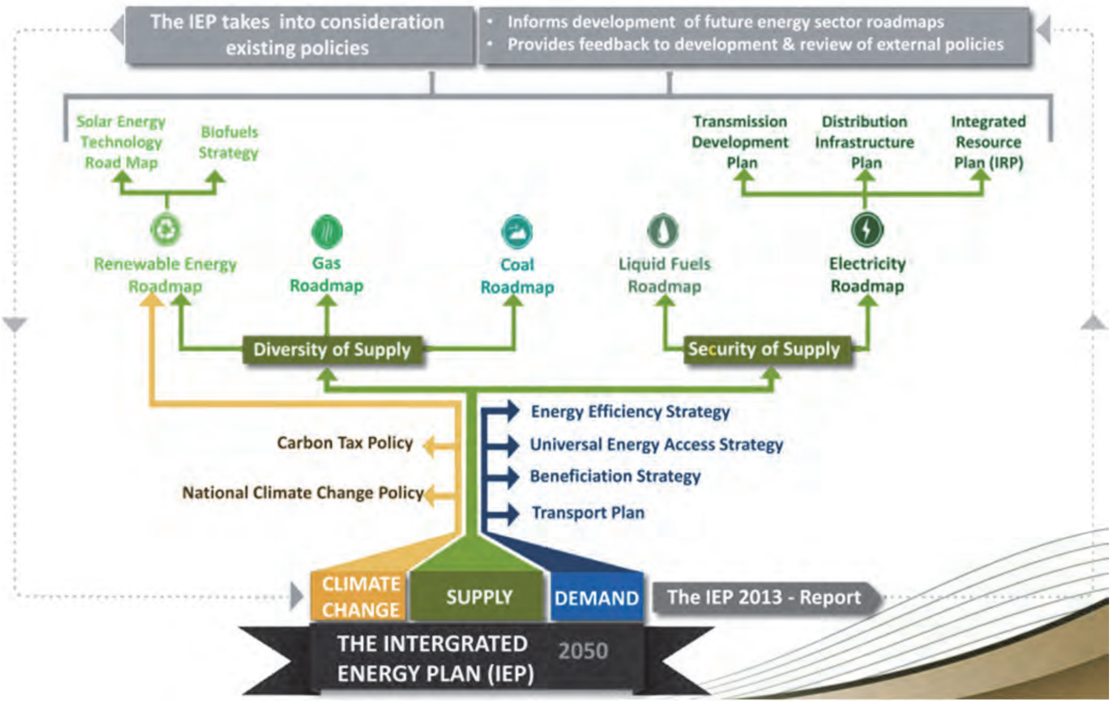


Figure 9-3: The energy sector policy landscape (Source: Maserumule 2014).

Perhaps, the most commonly referred to plan is the IRP (IRP 2010), published as a notice under the Electricity Regulation Act (No. 4 of 2006), and which is a planning framework for managing electricity demand and supply, currently for 2010 to 2030. The IRP 2010 process also assesses a range of potential scenarios, in this case to deliver the country's future electricity demand, taking into consideration the need for an adequate reserve margin as well as the decommissioning of old power plants (the IRP is currently based on assumed average economic growth of 4.6% for the period, and estimated electricity demand by 2030 requiring an increase in generation capacity to 52 248 MW).

The other national planning instrument that covers all energy carriers is the National Energy Efficiency Action Plan (NEEAP) which summarises the actions to support the National Energy Efficiency Strategy (NEES), the first strategy to focus explicitly on energy efficiency. The NEES sets voluntary national and sectoral energy efficiency targets. This provides guidance to all stakeholders and incentives to business energy users to achieve energy efficiency objectives. The NEEAP draws on international best practice and to accelerate the implementation of the National Energy Efficiency Strategy. The NEEAP is intended to be monitored on an annual basis and updated no less than every three years. Key objectives of the integrated energy plan for SA are presented in Table 9-1.

Table 9-1: Key objectives of the Integrated Energy Plan.

Key objectives of the Integrated Energy Plan for South Africa
• To ensure security of supply (with a reserve margin of no less than 19% (as recommended by the Energy Security Master Plan – Electricity of 2007 (DoE 2012)). • To keep low the cost of energy. • To provide universal access to energy. • To diversify supply sources. • To promote energy efficiency. • To promote localization and technology transfer. • To minimize emissions.

b) The IEP process

The process of the IEP identifies and then assesses various energy technology options, it devises scenarios of energy demand and supply, and then evaluates the scenarios for comparison. Stakeholders in the public and intra-governmental forums inform the scenarios and review assumptions made in the IEP process (for example of costs and technology learning rates, and of socio-economic issues and macroeconomic development). Water availability is considered as an important constraint to energy production (especially for synfuel and coal power technologies (DoE 2013c). So, water is included as an integral part of this IEP and estimated water volumes for each of the technology alternatives are included in the scenarios of energy and supply.

The overarching aim of the IEP is described as 'to promote sustainability, for society, the economy and the environment'. The draft IEP states that *'integrated energy planning is undertaken to determine the best way to meet current and future energy service needs in the most efficient and socially beneficial manner. As a fast emerging economy, South Africa needs to balance the competing need for continued economic growth with its social needs and the protection of the natural environment. South Africa needs to grow its energy supply to support economic expansion and in so doing, alleviate supply bottlenecks and supply demand deficits. In addition, it is essential that all citizens are provided with clean and modern forms of energy at an affordable price (DoE 2013a).'*

In essence, this translates to sustainable development, while meeting the eight key objectives of the IEP. The process of the IEP is first the definition of criteria by which to assess scenarios of energy futures for the country, then the modelling of the scenarios, and finally the evaluation of the scenarios for recommendation to Cabinet in the IEP Report.

The IEP process invites stakeholders from government, business and civil society to participate in defining the set of criteria for meeting the IEP's key objectives. Some of the objectives are easily quantified for example the volume of water consumed, or the cost of energy production while others can be quantified against a target, such as attainment of energy access for all (as a percentage). Some criteria are qualitative in nature, like the promotion of localization and technology transfer. These criteria are assessed using a multi-criteria decision analysis approach and then weighted according to their relative importance.

The approach is considered rigorous in integrating social, economic and environmental objectives, but as with any such approach, it suffers some shortcomings. Admittedly, even with its technical approach, it is impossible to remove all subjectivity. The selection of objectives introduces bias even before they are prioritised. For example, of the key objectives, four describe ideals for the energy supply (security, low cost, universal access, diversity of supply), and one is for energy demand, albeit less tangibly (to promote energy efficiency). In the remaining three key objectives the socio-economic and technology objectives are combined as one.

A shortfall of the approach is that externalities and costs beyond the planning horizon of twenty years are not included in the optimisation model. Externalities would include both the cost of reparation of environmental damage (such as that caused by acid mine drainage), and of impacts, for example of the cost to individuals and the economy of poor health as a result of energy provision, or lack thereof. Assessment of costs carries a degree of uncertainty, more so when the costs are based on incomplete data. However, it is important to acknowledge the potential costs especially where they present potentially high or likely risk, for instance by lock-in to declining technologies. More comprehensive criteria for evaluation of energy scenarios and plans has been proposed in a recent WWF report (WWF 50% by 2030) and used in Figure 9-4.

Further recommended criteria include greater weighting for scenarios and technologies that address climate change mitigation and adaptation, by increasing climate resilience; and for support to local communities (perhaps by passing on reduced costs of distribution). Costs might include opportunity cost in the consideration of alternative use of resources, as well as the costs of fuel and equipment maintenance. Added to the consideration of future costs are the likely trend in costs of a given resource, the likelihood of changing technology in the future, and the cost that this would entail. Benefits like the return on technology investment could be considered over the expected lifetime of the capital. Climate change may result in changes to resource availability; notably water, and also to wind and possibly insolation.

Watershed transfers to augment energy supply processes may impact climate resilience in the affected catchments.

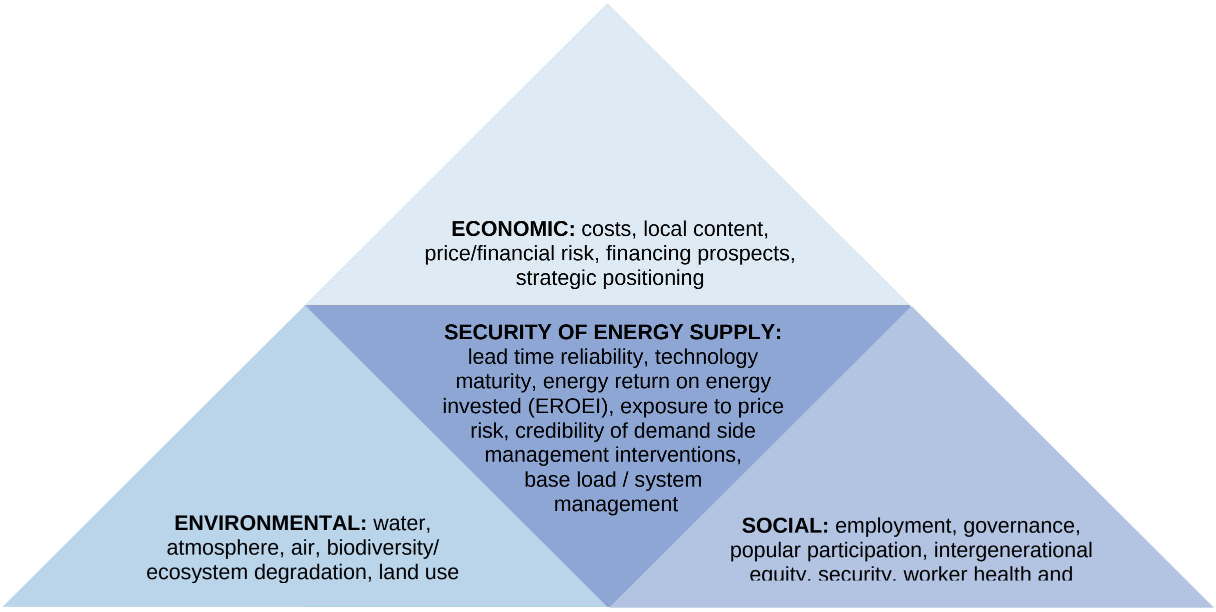


Figure 9-4: Criteria for assessment of energy plans and policies as recommended by WWF; depicted within the framework of the (traditional) three pillars of sustainable development.

In summary, the IEP modelling team devises feasible scenarios of energy supply in order to meet projected demand. The scenarios are compared according to the quantitative and qualitative assessments of the criteria to meet the objectives. It is highly improbable that any scenario could be optimal for all the objectives and there are inevitably trade-offs to be considered for each of the scenarios as a guide to the national energy plan. Other limitations of the optimization modelling approach include uncertainties in the data, for example of future costs, and in omission of hidden costs for example of externalities and opportunity cost.

c) The trade-offs

The sustainability of resource utilisation relies on seeking synergies and minimising the impact of trade-offs. Mapping the trade-offs between objectives, it becomes apparent that for some technologies, there can be overriding synergies (of course this is for only the objectives as per headings in Table 9-2. The assessment of these trade-offs and synergies may well be changing with climate change, and the relative valuation of resources, carbon and ecosystem services.

Table 9-2: Mapping trade-offs between energy technologies and water use efficiencies.

Energy technology	Energy	Water	Climate mitigation	Climate adaptation (vulnerability)
Hydro	Win	Win	Win	Lose
Wind	Win	Win	Win	Win
Nuclear – fossil fuel powered desalination	Lose	Win	Win	Win
Nuclear – renewable powered desalination	Win	Win	Win	Win
Solar PV	Win	Win	Win	Win
Coal Wet cooling Dry cooling CTL CCS	Win Win Lose Lose Lose	Lose Lose Win Lose Lose	Lose Win Lose Lose Win	Lose Lose Lose Lose Lose
Off-shore gas GTL CCS	Win Lose Lose	Win Lose Lose	Win Win Win	Win Lose Lose
Fracked gas GTL CCS	Win Win Lose	Lose Lose Lose	Lose Win Win	Lose Lose Lose
Biofuel, first generation	Win	Lose	Win	Lose
Biofuel, second generation	Win	Win	Win	Win
Inter-basin water augmentation for energy	Win	Lose	Lose[1]	Lose
Energy efficiency and demand management	Win	Win	Win	Win
Water efficiency and demand management	Win	Win	Win	Win

Objectives related to water and ecosystem services are likely to become more important in future. The recent Carbon Disclosure Project South Africa Water Report 2014 makes reference to the current work on water-pricing, so as to incorporate the costs of maintaining the integrity of the water supply. This would be a valuable input to the energy-water planning.

The analysis of trade-offs may differ at the national and local or watershed level. For example, water augmentation might not increase costs compared to benefits at the national aggregate. The trade-offs between hydropower and the alternative of altering a hydrological course might be limited to a watershed, while the benefits are experienced on a national scale. Hence, the significant economic, social or environmental costs may be at the watershed level. The appropriate scale for the analysis of the trade-offs of these objectives is thus important. This suggests that national energy-water planning should ideally be integrated for natural resources (energy and water sources, air) with consideration of socio-economic impacts, and that this would ideally also be integrated at the national and water

[1] Inter-basin augmentation invariably means a loss of ecosystem services from the drawn down basin. This can negatively impact climate resilience and hence adaptiveness.

catchment scales. Admittedly, this introduces problems of assessing a vast number of alternatives for energy and water provision. Nevertheless, it is essential that the shared needs of water resource management and energy provision are targeted efficiently.

Analysis of the trade-offs in energy-water planning highlights some challenges in truly integrating energy-water planning:

- Adherence to overarching objectives of sustainable development, for example of economic efficiency, social equity and waste minimisation provide synergies between strategies and thus for planning.

- In the face of climate change, vulnerability reduction measures are important for all planning, especially for resource utilisation and investment in infrastructure.

- Resource planning is increasingly important and a silo style approach creates costly trade-offs and risks for sustainable development. An approach that incorporates integrated nexus assessment (of trade-offs and synergies) can better inform nexus planning.

Areas of research that suggest potential for working towards better integration of national energy-water planning are as follows:

- Further work to assess the ‘real’ costs of resources, notably for water and for including externalities for example of effluent and other forms of pollution. Perhaps promoting water efficiency with a corresponding, complementary and aligned strategy and plan for water efficiency.

- The promotion of local energy provision to relieve some of the pressure and impact of large energy networks, potentially to consider integrating a basin and national approach to energy planning.

- The use of GIS-based decision-making tools with constraints for water, impacts and implications for resilience (and/or vulnerability). Allow for ‘no go’ assessment in cases where the tradeoffs present high vulnerability but balanced by no-go or increased vulnerability (of ecosystems or of infrastructure in a climate changed world).

- Promote water and energy planning at the same stage of the resource process.

- Promote consideration of the geographical location of the energy technologies, as these are essential when considering the availability of water. Consider the potential costs in the light of climate change.

- Centralised energy: The national grid is expanded and electricity consumers are connected to the national grid. In this approach, localised large-scale energy resources (such as coal or gas) as well as renewable energy resources will feed into the national grid.

- Decentralised energy: Renewable energy is sufficient to meet local energy needs. In this approach, local natural resources (such as solar or hydro) are optimised. Excess energy may be used to feed in to the national grid if the transmission infrastructure exists.

- The separation of the life-cycle processes can be practiced when local natural resources are not sufficient to meet energy requirements, or when there is a mismatch between water availability and the water requirements of the energy resource. For example, for solar and wind energy, the manufacturing of the required equipment can be done off-site in areas with sufficient water resources; then, the actual energy production which has low water requirements can be done on-site, using innovative water management processes. This will allow for life-cycle processes to optimise water availability.

9.5.2. Catchment-based energy-water resource planning

Both energy and water systems play a vital role in the socio-economic development of any nation. Many problems that involve energy and water require tightly coupled understanding of co-dependency of these systems. Therefore, a holistic and integrated approach can examine all criteria for these problems at once, resulting in more equitable solutions and providing insights to those that have the ability to enact these solutions (Jeffers 2013).

At a local level, efforts to address climate change have heightened awareness of the 'water-energy nexus', and of the need to integrate water and energy planning and decision-making. A great deal of this has to do with water scarcity: in many places, with some conflicts arising amongst water demands for energy production, urban use, agricultural irrigation, and supporting environmental systems. At the same time, energy demand from the water sector (especially for irrigation, but also for desalination and water and sewage treatment) has emerged as a real concern; not only can it strain already overtaxed energy systems, but it also adds significantly to the greenhouse gas emissions. Yet even as recognition of these issues has grown, a lack of suitable tools has hindered efforts to address key questions about the water-energy nexus (SEI 2012).

This framework therefore aims to provide a tool where water resource planners and managers, as well as project developers are equipped to assess the state of the water resources (at the appropriate scale), to assess the potential water quantity requirements and quality impacts, and to ascertain the suitability of a specific energy resource for the intended catchment. This is particularly important because there are a large number of potential impacts to surface and groundwater associated with certain energy projects. This framework can therefore assist planners and project developers to explore how individual water or energy management choices are likely to influence either system, and thus enables the consideration of the key issues and impacts on water resources within the specific context of the proposed development, as well as an understanding of trade-offs that might not be apparent when looking at either system alone.

The framework includes a critical consideration, which is absent from the current water-use licensing approach, of how climate change will influence water in the catchment, and how future changes in the planning approaches due to climate change and other associated catchment wide characteristics will affect the viability of a certain energy resource in a particular catchment.

a) Considerations for catchment-based decision-making

There are several factors that need to be included in the catchment-based decision-making process. A three-step process, one that should be followed to ensure that all the important aspects and information have been taken into account, is illustrated in Figure 9-5. This will facilitate the completion of the decision-making process.

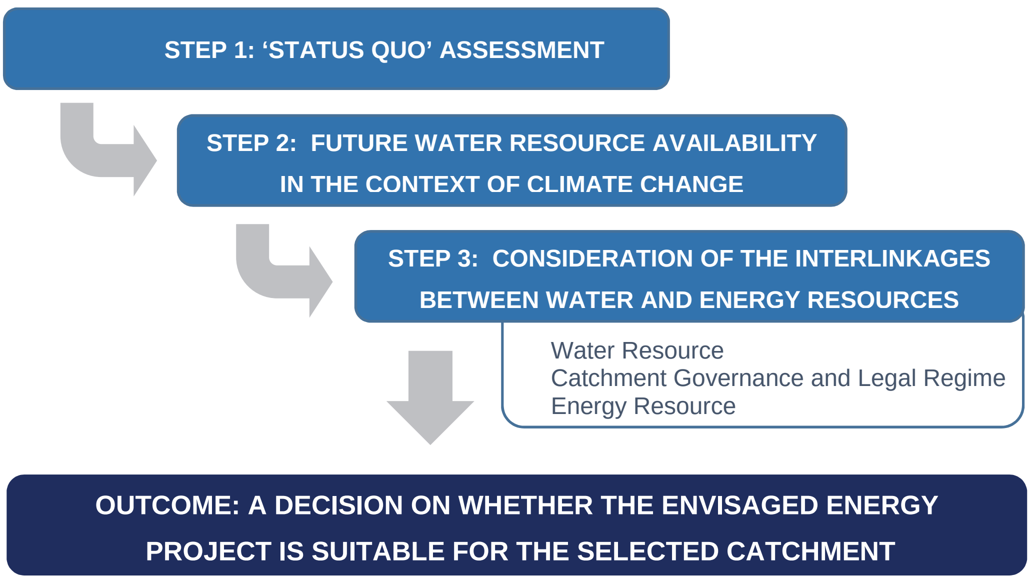


Figure 9-5: 3 Step Process for Catchment-Based Decision-Making.

Step 1: 'Status quo' assessment

It is essential that a reliable 'status quo' assessment is conducted. This entails a 'snapshot' of the current state of water resources at the proposed location. The scope of the assessment should depend on the nature of the required water resources (at the required scale) and on how the catchment boundaries are defined where the proposed development will be located. In addition, the significance of the envisaged downstream impact of the energy resource should also influence the boundaries. In addition to facilitating the identification and rating of the significance of the expected impacts, the assessment will also enable planners and project developers to determine whether the project is likely to have an impact on water resources during the life-cycle (RSB 2011), and which catchment characteristics will be impacted.

Step 2: Future water resource availability in the context of climate change

The biophysical properties of water resources need to be evaluated, particularly in the context of a changing climate. This entails estimates of future water resource availability that are associated with climate projections. However, for this to be possible, climate and water resource data at the appropriate scale is required; which is not always available. Therefore, it may be necessary for the data to be collected and for local climate projections to be applied before beginning this step of the decision-making process.

Step 3: Consideration of the interlinkages between energy and water resources

There are various cross-cutting parameters that need to be considered, and proper comprehension of these parameters is required prior to the completion of this decision-making process. These parameters are associated with water resources, the catchment governance, and the energy resource being considered for the project. An overview of these considerations is provided in Table 9-3. It is, however, worth noting that depending on the local context and the type of energy resource, several of these parameters may be regarded as non-applicable or negligible.

Table 9-3: Considerations for water-energy resource planning.

Considerations	Important Parameters
Water Resource	**Current:** • State of water resources in the catchment, focusing on water quality and quantity • Water demand in the catchment **Future:** • Climate projects and projected changes in quality and quantity • Projected water demand in the catchment
Catchment Governance and Legal Regime	**Current:** • Water licence requirements • Energy licence requirements • Water allocation and competition for water • Socio-economic characteristics, and likely impact on water allocation and licences • Institutional and regulatory environment **Future:** • Possible changes in water planning and institutional environment • Possible changes in energy and/or water regulatory environment • Development and socio-economic changes in region and projected impact on water allocation and licences
Energy Resource	**Input:** • Water quantity requirements • Water quality requirements • Water impacts **Output:** • Waste-water quality • Water impacts

Table 9-3 provides three overarching considerations, namely water resources, catchment legal regime and energy resources. These considerations are elaborated as follows:

b) Water resources

The current and future status of the proposed catchment needs to be properly evaluated. This entails an assessment of whether the catchment is in deficit, is stressed or is water-abundant.

- A catchment that is in deficit is a catchment where water demand exceeds water availability. In this case, all the available water has been allocated and all available water development options have been exhausted. In such a case, only the options of buying a water allocation or bringing in a water allocation from another catchment exist as possibilities for finding water for the project. Often, in this context, water is being used for economic purposes to the detriment of the environmental health of water resources, sometimes with the result that watercourses dry up for part of their length, or in particular seasons. This does not constitute sustainable water use (RSB 2011).

- A stressed catchment is one where water availability is highly constrained due to high water demand, i.e. water demand is only marginally less than water availability. Water stress can also occur when the quality of freshwater deteriorates to the extent of restricting its use. While some institutions formally declare stressed catchments as such, it is important to note that not all cases of water scarcity will be formally recorded or recognised, particularly where water management institutions are weak or absent (RSB 2011).

A water-abundant catchment is a catchment where water availability far exceeds water demand. Therefore, competition for water and conflicts in water allocation is likely to be minimal. However, it is important to consider the possibility of future climate impacts on the water resources, which may lead to flooding or droughts. In addition, possible water transfers can be implemented to supplement catchments that are in deficit.

Figure 9-6 illustrates the differences between the three states. It is observed that a catchment can be defined differently depending on the water that is available for future use. However, it is important to consider the impacts of climate change on the water availability in the catchment. In a wetter future, for instance, the increase in water resources may result in a status change from water deficit to abundance (provided the water demand increases within envisaged limits). On the other hand, in a drier future, the decrease in water resources can result in the status of a catchment area changing from water abundance to deficit. Hence, knowledge of future water availability in the context of climate change will allow for effective planning for long-term water use.

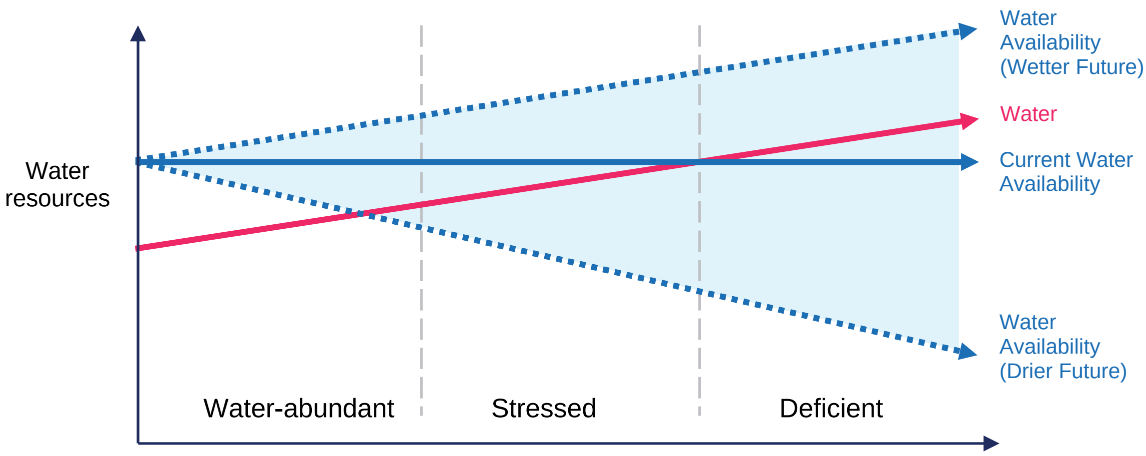


Figure 9-6: Water availability and demand in a water-abundant, stressed and deficient.

In addition, decision-makers and developers need to consider that changes in the catchment management and planning environment can impact water resource availability in the future. This includes the construction of a dam upstream, which does not only impact the amount of water that is available, but also the flow regime of the catchment. In addition, the implementation of water management instruments (such as water transfers) affects the water availability and hence the water allocation in the catchment.

Catchments can be defined at different scales, e.g. primary catchment or sub-catchment. Therefore, while a primary catchment may appear stressed or water-abundant at one scale, a different picture may become visible at a sub-catchment scale. Thus, within a stressed primary catchment, it is still possible to have sub-catchment that is water abundant. A good example of this is the Orange Catchment, where the Upper Orange is considered as water abundant while the entire catchment is in deficit. As there is a possibility that planning may be considered at the primary scale and not the sub-catchment scale, for example, it is essential that all relevant scales are considered. To enable the assessment of the current and future state of water resources, the questions that should guide the decision on whether the proposed catchment is suitable are presented in Figure 9-7.

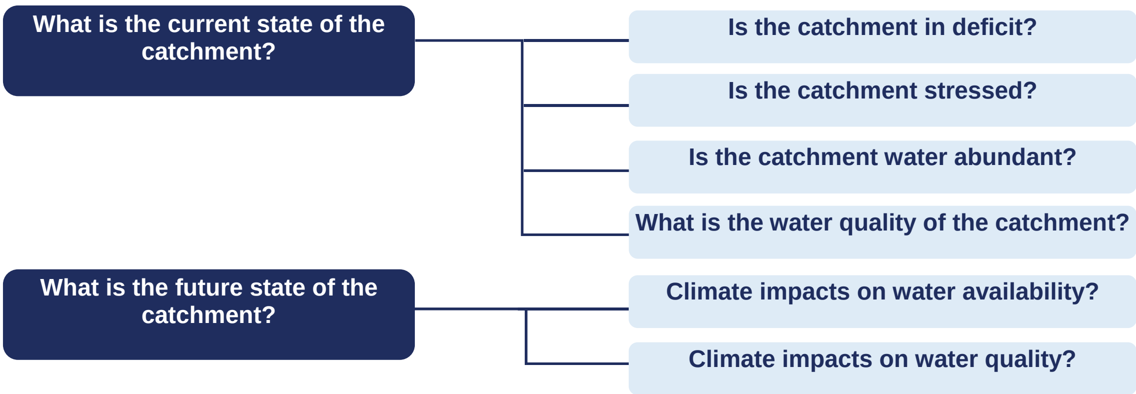


Figure 9-7: Water resource considerations.

c) Catchment governance and legal regime

The catchment governance and legal regime are associated with how the catchment is managed and how plans are made for water and energy resources. This includes not only the institutional and regulatory environment, but also the catchment characteristics.

Energy projects may require water and/or energy licences; these may include energy operator licences, water use authorisations and also water abstraction licences. The catchment management institutions are therefore responsible for water allocation and granting licences to energy project developers. The process and considerations employed by the catchment institutions for allocating water and granting licences needs to be investigated. Changes in the institutional, planning and/or regulatory environment, as well as changes in the catchment characteristics, such as population growth or economic development, may affect the allocation of water and the granting of licences. It is therefore essential that the catchment institution is not only sustainable in the long term, but also considers long-term catchment characteristics and is consistent in the approach it employs to grant licences and to allocate water.

Water is also required to ensure environmental sustainability. In South Africa, environmental flow is incorporated during water planning, and it is essential that the environmental flow is not sacrificed through the over-allocation of water resources. This does not only ensure sustainable water resources, but also ensures that ecosystems and human livelihoods are sustained. To enable the assessment of the current and future catchment governance and legal regime, the questions that can guide the consideration of a catchment as a suitable location for a specific energy project are provided in
Figure 9-8.

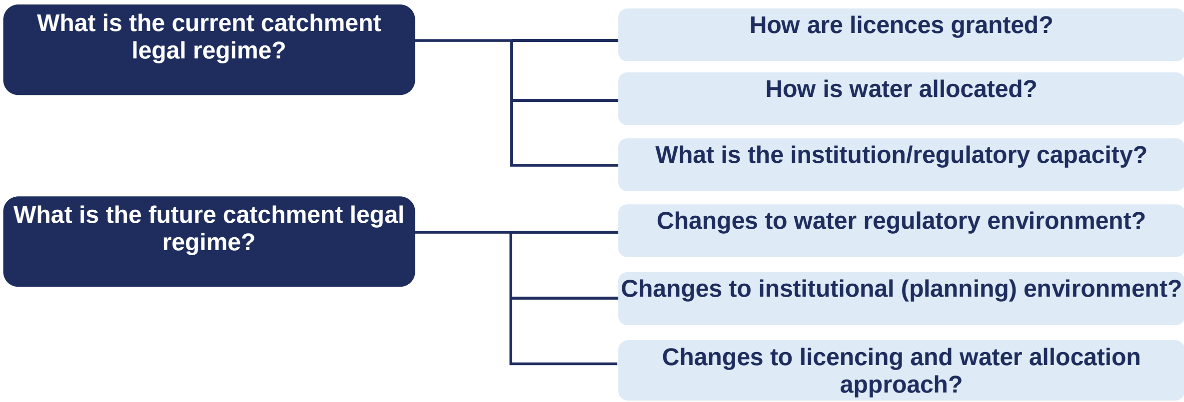


Figure 9-8: Catchment governance and legal regime considerations.

d) Energy resources

The location of the energy resource and the water resources that it will utilise should be identified. This includes an understanding of the water requirements and water impacts over the life cycle of the energy project. To enable this, the questions that should guide the decision of whether the proposed catchment is suitable are given in **Figure 9-9**.

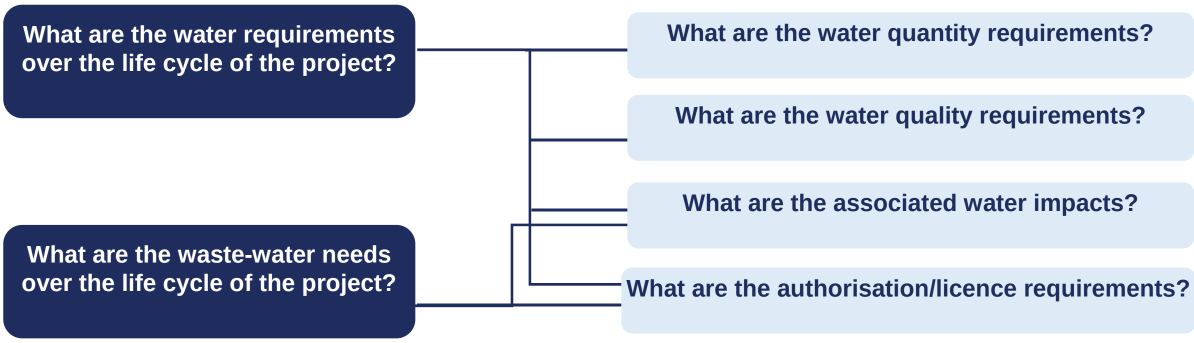


Figure 9-9: Energy resource considerations.

9.5.3. Catchment-based decision-making framework

Each energy technology has different water requirements and impacts; this not only includes the water quantity and quality input and output, but also the authorisation and/or licensing requirements. It is essential that the water considerations are for the entire life-cycle of the energy resource. Table 9-4 provides the decision-making process for energy projects. Although only one table is provided for all the different energy resources, the questions will not be applicable to all.[2] Therefore, depending on the type of energy resource, several of these questions may be regarded as non-applicable or negligible. It should also be noted that this project is only suitable for the catchment scale, and can therefore not be applied on large-scale energy projects such as thermal power stations and large hydro projects.

This framework is aimed at providing a decision-making tool for energy resource projects. The questions described above should be used to assess whether a proposed catchment is suitable for an energy resource. The framework was tested at a workshop using two case studies (provided in Appendix B). It was found that the framework provides a useful tool for determining whether a catchment is suitable for a specific energy project.

[2] The provision of only one decision-making framework is due to the commonalities associated with the different energy resources; only a few of the questions are not applicable to all energy resources, which therefore did not validate creating tables for each energy resource.

Table 9-4: Catchment-based decision-making framework for energy projects.

Questions		Resources
Catchment Governance and Legal Regime		
1.	Does the project require authorisation?	Project plans; catchment management institution/ plans; Licensing departments; water services provider strategic plans; development plans
2.	Does the project require any water and/or energy licences?	
3.	Is the water allocation approach by the water planning authority consistent?	
4.	Is the granting of licences stable and consistent?	
5.	Is there a high competition for water in the catchment that might influence allocation?	
6.	Are there projected changes in institutional (planning) environment (in the project timeframe)?	
7.	Are there projected changes in water and/or energy regulatory environment (in the project timeframe)?	
8.	Is future water allocation and licencing secured (for the project timeframe)?	
Water Quantity		
1.	Is the water quantity sufficient to meet requirements, including the flow if necessary?	Project plans; catchment management institution/ plans; local government and water services provider strategic plans; water management plans;
2.	If not, is it possible to source alternate water (e.g. through treating waste-water)?	
3.	If the project requires water stored in dams, is it sufficient to meet requirements?	
4.	Is the rainfall sufficient and consistent to meet requirements?	
5.	Will climate change cause an increase in water quantity (in the project timeframe)?	
6.	Is water demand likely to increase in future, thus impacting the water allocation (in the project timeframe)?	
7.	Will future water quantity be sufficient to meet requirements (in the project timeframe)?	
Water Quality Resources Requirements		
1.	Is the water quality sufficient to meet current requirements?	Project plans; catchment management institution/ plans; local government and water services provider strategic plans; water management plans;
2.	If not, is it possible to treat available water?	
3.	Will future allocation (i.e. water users) impact water quality (in the project timeframe)?	
4.	If yes, are there future plans to treat water to meet requirements?	
5.	Will climate change result in a decrease in water quality (in the project timeframe)?	
6.	Will future water quality be sufficient to meet requirements (in the project timeframe)?	
7.	If required in future, will you be able to treat water to meet your requirements?	
Energy Resources Impacts		
1.	Will the project result in changes in the hydrology of the catchment?	Project plans; EIAs; local municipality; catchment management institution/ plans; natural resource strategies and plans
2.	Does the energy project have waste-water discharge requirements?	
3.	Will waste-water discharge (including runoff) have a negative impact on the catchment?	
4.	Will the project result in increased erosion?	
5.	Will the project result in changes to local land-use, vegetation and other natural characteristics?	
6.	Will the project result in impacts on the aquatic ecosystem?	
7.	Will the project result in increased evaporation?	

9.5.4. Trade-offs at a catchment scale

Visualising energy and water as interconnected systems to be managed as an integrated whole both illuminates opportunities that might not otherwise be apparent and exposes hard trade-offs. The challenges lie in identifying and developing specific economically and environmentally preferable solutions (Jeffers 2013). Appendix I provides a detailed assessment of the trade-offs between water and energy resources at a catchment scale. A summary of this assessment is provided below.

Wind energy is associated with low water use during the energy production process. However, the components of wind energy technologies require the mining of rare earth elements (REE), which are used for permanent magnets in generators. REE mining has similar water impacts as those associated with uranium mining. Water impacts therefore include the water quality concerns during the mining phase, as well as during the construction phase (such as erosion during rainfall events, which may have an impact on local water resources). Although these elements are currently mainly found in China, South Africa is investing in at least two REE-mines, in Zandkopsdrift (Northern Cape) and Steenkampskraal (Western Cape). Therefore, although there are minimal trade-offs between energy and water resources during the energy production process, the mining of components required for the wind technology has water implications. These include the possible impact of water resources, which may influence the fitness of use for other water users, as well as the allocation of water to the mining companies, which affects the water availability for other water users.

South Africa is also endowed with abundant levels of solar radiation. In this vein, there are two main kinds of solar energy**,** namely solar photovoltaic (PV), which directly converts solar energy into electricity using a PV cell made of a semi-conductor material, and concentrating solar power (CSP), which concentrate energy from the sun's rays to heat and transfer it into mechanical energy (by turbines or other engines) and then into electricity. The water quality impacts of solar energy are low, particularly for small decentralised solar plants. There may however be water quality concerns during the construction phase, as a result of erosion during rainfall event, which may have an impact on local water resources. However, it is worth noting that water use largely depends on the type of technology used. PV has low water use and water quality impacts. It requires the mining of quartz sand, but this is not a major water concern. Nevertheless, processing the sand into electronic or solar grade silicon comes with a significant environmental and climate impact if not managed properly. On the other hand, CSP is comparable to any other thermal energy process, as it requires cooling, although dry cooling may be used as a way to minimise water use in dry areas, such as the Karoo. At present, CSP plants being implemented in South Africa are dry-cooled.

Therefore, similarly to wind energy, there are minimal trade-offs between energy and water resources during the energy production process for PV, although the mining of components required for the solar technologies has water implications. These include the possible impact of water resources, which may influence the fitness of use for other water users, as well as the allocation of water to the mining companies, which influences the water availability for other water users. Wet-cooled CSP on the other hand uses large amounts of water and has water quality implications, and may thus have influence, as the water availability and the fitness of use for other water users.

For hydropower, water requirements and impacts depend largely on the size and type of technology used. The variation in sizes gives the additional ability to meet large centralized urban energy needs as well as decentralised rural needs. Run-of-river technologies involve the channelling of a portion of a river through a canal or penstock. Depending on the size, run-of-river hydro-electric energy may have an impact on the flow regime, aquatic ecosystems and may cause erosion. Dam technology typically includes a large hydropower system, where a dam is used to store river water in a reservoir and the water is released either to meet changing electricity needs or to maintain a constant reservoir level. Depending on the size, dam hydro-electric energy may have an impact on water temperature and aquatic ecosystems, and may also result in erosion. Pumped storage technology works like a battery, pumping water uphill to a reservoir at a higher elevation from a second reservoir at a lower elevation; when the demand for electricity is low, and during periods of high electrical demand, the water is released back to the lower reservoir and turns a turbine, generating electricity. Depending on the size, pumped storage hydro-electric energy may have an impact on water temperature and aquatic ecosystems, and may also result in erosion. The water and energy trade-offs for this energy resource are therefore associated with changes in the water resources, with possible impacts on the use of the water.

Bioenergy has varying water requirements and water impacts depending on the 'type' of water resources that is used to grow the feedstock. For rain-fed agriculture, water impacts include erosion due to runoff and possible interception. There are therefore minimal trade-offs between water and energy resources for rain-fed feedstock, as the use of rainfall does not result in competition for water, except for when interception impacts the vegetation and natural resources, or when the erosion in water that is not fit for use by other water users. For irrigated feedstock, water impacts include high water usage, which could lead to an increase in the competition for water. Alternative feedstock, such as algae and grasslands, do not consume high amounts of water, and are not expected to compete with food for land and water (Rösch *et al.* 2009; Trivedi *et al.* 2015). Waste generated biofuels on the other can use high amounts of water, and can also rely on municipal water resources; this will increase the competition for water at a local level. Therefore, depending on the local water resource availability and the local waste-water management approaches, bioenergy can result in trade-offs between water and energy resources through water availability for other water users.

Large-scale energy resources such as thermal power plants (including gas and coal), large hydroelectric plants and nuclear power plants, are large-scale energy providers and use large amounts of water. Therefore, these types of energy technologies should be considered at a national scale and not on a catchment basis, and as a consequence have not been included in this assessment.

9.6. Summary

SA is facing a growing energy demand with an increase in industrial and socio-economic development, exacerbated by climate change. Consequently, the country has made provisions to diversify its energy mix and augment the share of renewable energy technologies in order to sustainably meet the growing electricity demand. Moreover, the country has limited water resources to support various economic activities including the various stages of the energy production chain. So, the impacts of deploying renewable energy technologies on water resources need proper understanding. Policy, legal, planning and institutional instruments play a vital role in the management of the energy-water nexus. Due to the interdependence of energy and water, it is necessary to plan them in an integrated manner to enhance synergy.

The decision-making environment for the energy-water nexus is influenced by technological political, regulatory, economic, environmental, and social factors at various levels. It is necessary to plan energy and water resources in an integrated way at both national and local levels. In this study, a decision support framework has been proposed. The framework outlines guidelines/considerations for assessing the viability of an energy project from a water perspective. The quantity and quality of available water have been taken into account as a way of averting negative socio-economic and environmental impacts.

10. CONCLUSIONS AND RECOMMENDATIONS

By: Madhlopa A

10.1. Conclusions

10.1.1. Energy choices and associated water requirements

Water usage in the production of energy from conventional and renewable fuels was explored. Findings show that there are limited data on all aspects of water usage in the production of energy, accounting in part for the significant variations in the values of water intensity reported in the literature. It is vital to take into account all aspects of the energy life cycle to enable isolation of stages where significant amounts of water are used.

Conventional fuels (such as nuclear and fossil fuels) withdraw significant quantities of water over the life-cycle of energy production, especially for thermoelectric power plants operated with a wet-cooling system. The quality of water is also adversely affected in some stages of energy production from these fuels. Hydro is by nature the most water-intensive source of energy in terms of withdrawal (among all the energy sources covered in this work). However, it is limited in terms of its water consumption. Similarly, biomass is water intensive, but this water would have been used in the production of crops regardless. So, these two renewable energy sources have a perceived high impact on water resources. Solar photovoltaic (PV) and wind energy exhibit the lowest demand for water, and could perhaps be considered the most viable renewable options in terms of water withdrawal and consumption. Moreover, the observed water usage in these renewable energy technologies is predominantly upstream.

10.1.2. Energy policy and regulation and its implications for water

It is helpful to examine energy and water policy from the perspective of individual energy sources or technologies but also at a systemic level – including how energy demand is managed and planned for, the water efficiencies of the energy mix, and the incentives to decision-makers when responding to future national energy needs.

The integrated resource planning carried out in South Africa (SA) takes water scarcity into account and demonstrates an awareness of the trade-offs. However, beyond that awareness, there is too little information available indicating the water impacts over the full lifecycle of energy production, and there are no tools for analysis available, in order to assist decision-makers. As a result, the awareness of trade-offs is not efficiently translated into decision-making practice.

While it is clear that there are several benefits to increasing renewables in the South African energy mix in order to achieve sustainability, it is also helpful to keep an awareness of the other trade-offs and incentives influencing the energy economy. Eskom, as SA's primary energy producer, has a keen awareness of the risks of water scarcity and the potential impacts on their operations and costs. Moving towards more renewable-based energy will be difficult for several reasons and the energy generation mix is a complex balancing act.

However, while in the longer term, energy decision-makers in SA need to take into account several uncertainties which will include rising fuel costs, volatility in commodity prices, rising operational cost as well as water scarcity in their planning. Increasing the information available about water impacts and generating tools to assist with better decision-making will be an important input for a resilient energy economy in future.

10.1.3. Impacts of current energy choices, and challenges and opportunities towards adaptation

Water impacts vary in the energy generation cycle of different energy technologies. Coal power plants may have a large impact on water quality at the mining sites (coal mining) and may also contribute to salinization of water resources due to emissions or waste discharge when generating electricity. Nuclear power plants may have a similar impact. In addition, contamination of the electricity generation site and surrounding areas is another concern. Hydropower relies on the continuous flow of water resources and this can have a large environmental impact and impact on water availability for other users. Biofuel production may have water quality impacts when producing the fuel as well as when generating power (especially if wet cooling is used).

Planning for energy supply now and in the future necessitates that SA's policy makers take into account the water impacts and associated risks of the energy generation technologies available, particularly in areas where there is severe water stress. Both current and future plans for energy generation must aggressively plan water strategies to maintain supply, such as to diversify the energy mix and increase the opportunities to leverage energy generation technologies which have lesser water impacts.

10.1.4. Policy Framework for efficient water use in energy production

A Policy Framework is proposed to enhance harmonisation of policies linked to water and energy. It is important that legislation regarding water, energy and other matters should be harmonised with regard to the efficient use of water. In turn, this legislation could influence the vertical development of relevant strategies/policies which are horizontally synergetic.

Similarly, national water and energy plans/programmes should emanate from national strategies/policies. These plans should also be comprehensively aligned. There is need to capture elements of water use efficiency at all the levels of policy.

10.1.5. Spatial representation of the trade-offs between water and energy

SA is a water-scarce country which also suffers from high unemployment and poverty. Energy is often viewed as a necessary vehicle to drive growth and development and is thus a key input into the economy and a basis for the provision of access to basic services.

The choice of energy resources is important, particularly in light of water resource scarcity. Different energy resources require different water inputs in terms of type and quantities. The availability of the required water resource type, the water use quantity and quality requirements, and the water efficiency of the specific energy resources should be considered when deciding which energy resources to develop. Second generation biofuel, solar PV and wind technologies exhibit win-win situations with respect to energy, water and climate change considerations.

10.1.6. Scenarios of energy supply and associated water demands

Water usage in the generation of electricity, under different scenarios for SA, has been investigated using data from the IRP update (D0E 2013). Eleven energy scenarios were analysed: Constant Emissions, Moderate Decline, Advanced Decline, Carbon Tax, Carbon Budget, Rooftop PV, Big Gas, Higher Nuclear Cost, Higher Coal Cost, Solar Park and Restrained Learning Rate. Two time periods were established (2030 and 2050) by using the existing national data on energy scenarios. These data were used to calculate the annual volume of water under each scenario.

Results show that there is a general increase in the generation of electricity between 2030 and 2050 under all the considered scenarios. In spite of this trend, the usage of water decreases for all the scenarios except for the Higher Nuclear Cost. It is also found that the Big Gas scenario exhibits the lowest demand for water in both time periods. The share of renewables in the generation of electricity, for all scenarios but the Restrained Learning Rate, also rises between 2030 and 2050. A higher share of renewable energy, especially solar PV and wind, can assist in reducing the demand for water in the energy mix.

10.1.7. Decision support framework for energy and water resource choices

Policy, legal, planning and institutional instruments play a vital role in the management of the energy-water nexus. Due to the interdependence of energy and water, it is necessary to plan them in an integrated manner to enhance synergy.

The decision-making environment for the energy-water nexus is influenced by technological political, regulatory, economic, environmental, and social factors at various levels. It is necessary to plan energy and water resources in an integrated way at both national and local levels. In this study, a decision support framework has been proposed. The framework outlines guidelines/considerations for assessing the viability of an energy project from a water perspective. The quantity and quality of available water have been taken into account as a way of averting negative social, economic and environmental impacts.

10.2. Recommendations

10.2.1. Energy choices and associated water requirements

- Comprehensive data covering the different stages of the energy production chain should be collected within the boundary of SA.
- Second generation biofuel, solar PV and wind technologies are less water-intensive, consequently they could be considered for promotion of water use efficiency in the energy sector.

10.2.2. Water for energy in the context of climate change

- Plans for the energy production chain need to take into consideration a water component to achieve sustainable provision of both energy and water.

10.2.3. Policy and regulation for the water and energy nexus

- There is a need to take on board uncertainties (such as rising fuel costs, volatility in commodity prices, the quality and extent of fossil fuel reserves, rising operational cost, and water scarcity) in planning.
- Synergy of policies/regulations and cooperation amongst the various governing institutions are necessary to effectively achieve water use efficiency.

10.2.4. Scenarios of energy supply and associated water demands

- Trade-offs between energy resource choices and their associated water requirements over a long-term horizon need to be analysed in order to give a clearer picture of the balance between to ensure a supply of water for energy generation in the context of water scarcity and climate change.

10.2.5. Spatial representation of the trade-offs between water and energy and the Decision support framework for energy and water resource choices

- It is necessary to augment information about water impacts, and to develop tools for facilitating the decision-making process to enable achievement of a resilient energy economy.
- In light of the spatial differences in the location of energy and water resource, it is essential to consider the use of water over the entire lifecycle of energy production.

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APPENDIX A WORKSHOP 1 REPORT

A 1. Introduction

A.1.1 Water-energy nexus, climate change and renewable energy technology

Water plays a vital role in the socio-economic development of any nation. It is exploited in different economic sectors, including the energy sector. Water and energy are inextricably related, and this relationship is usually referred to as the water-energy nexus. Water is used for energy production in the abstraction, growth and preparation of some fuels as well as in some power plants. It is also used in the raw materials for plant infrastructure, manufacturing of plant components, and the construction of power generating infrastructure. The volume of water used in the raw materials will vary widely, not only with the technology, but also the material type and plant design. Furthermore, these materials can be imported from any location and the associated water use is not limited to any water catchment, water management area or local authority.

The production of electricity may demand a significant quantity of water, and growth in the energy supply poses a challenge in regions where water is scarce. Consequently, there is a need to exploit water resources sustainably. Already, most of the catchment areas in South Africa use more water than is available on an annual basis (Figure A-1).

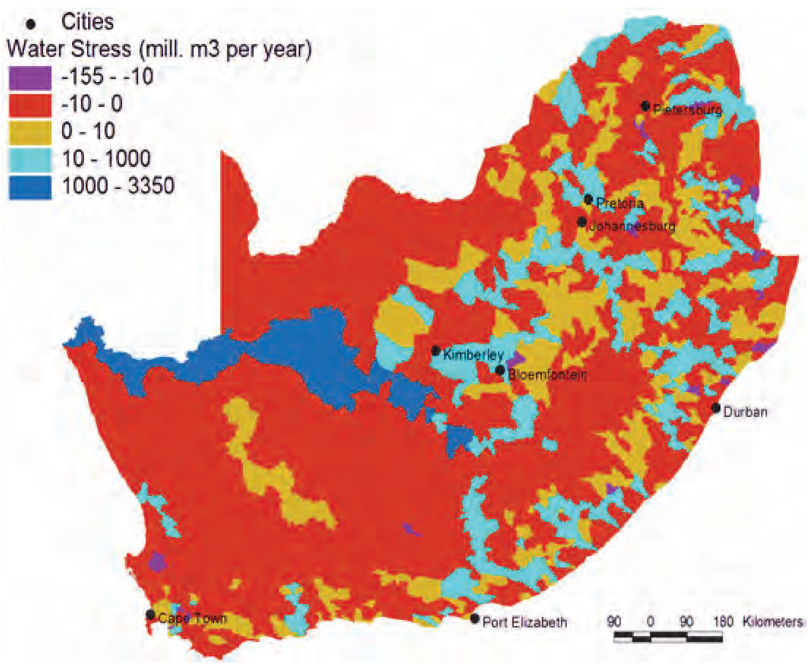

Figure A-1: 2005 annual water balance in South African catchments Based on data from the Department of Water and Forestry (Colvin *et al.* 2009).

South Africa is divided into nine water management areas: Limpopo, Olifants, Inkomati-Usuthu, Pongola-Mzimkulu, Vaal; Orange, Mzimvubu-Tsitsikamma, Breede-Gouritz and Berg-Olifants (see Figure A-2). Each local authority is allowed to regulate the abstraction and use of water within its boundaries. Large-scale water abstraction and use, for example by mining and some industry, is regulated and licensed by the national government. Water resource management in this country faces various challenges, which may be compounded by its vulnerability to climate change and consequent increased stress on water resources. The impact of climate change is complicated, with some areas likely expected to be more affected than others. In this regard, six climatic zones were identified in South Africa as part of the Water Sector Climate Adaptation Strategy process, reflecting institutional boundaries defined by Water Management Areas (Figure A-3). These zones are grouped based on their climatic and hydrological variables.

Figure A-2: Water management areas *Source: DWA (2013).*

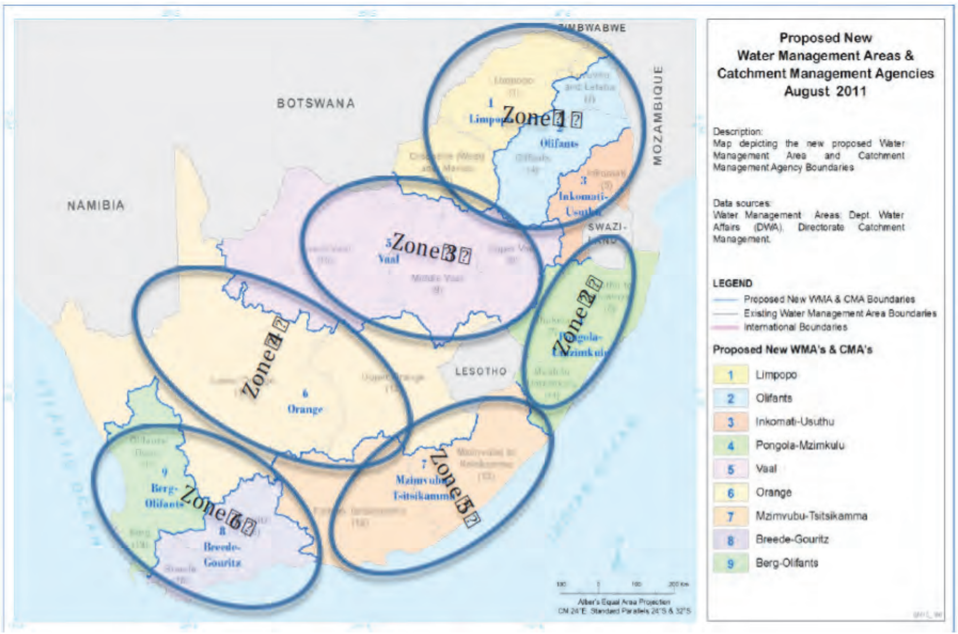

Figure A-3: Climate water zones in South Africa ***Source: DWA (2013).***

On the other hand, energy is needed to pump, treat or distribute water. At present, the main source of primary energy in South Africa is coal, and overreliance on this energy resource is significantly contributing to climate change. The advent of climate change may result in a decrease in the amount of rainfall. Moreover, the growing economy and social development are increasing demand for water (DWAF 2013), so that it is likely that most areas will require more energy for the provision of water services. Water conveyance and treatment to meet stringent drinking regulations require energy from often distant locations. There are growing concerns about the increase in greenhouse gas (GHG) emissions as a result of the intense use of fossil fuels (including coal and petroleum) for energy supply, and applying renewable energy technologies can assist in the mitigation of climate change as well as increase the security of the country's energy supply.

Climate change is expected to augment the strain on water provision due to projected changes to seasonal and regional temperature and patterns of precipitation (Hoekstra *et al.* 2011; Wilson *et al.* 2012). In the light of this, the Department of Energy (DoE) developed an Integrated Resource Plan (IRP) (DoE 2010), embodying a national strategy to meet both the growing electricity demand and international commitment to reduce GHG emissions by 34% below business-as-usual by 2030. The IRP strategy diversifies the energy mix from the current primary reliance on coal-fired electricity to an energy mix in which a third is generated from renewable sources (DoE 2010). To meet this goal, the government is currently offering incentives for investment in renewable energy technologies under the Renewable Energy Independent Power Procurement Programme (REIPPP), with a bidding process. So far, three rounds of bidding have been successfully implemented. However, the impact of deploying renewable energy technologies on water resources needs to be considered properly and this study contributes towards efforts in this direction.

A.1.2 The water-energy nexus project

The Water Research Commission (WRC) commissioned a project on the water-energy nexus in South Africa in 2013. The aim of this project is to investigate trade-offs between water use efficiency and renewable energy in South Africa, and it comprises a series of nine tasks.

A.1.3 Completed tasks

a) Task 1

The first task focussed on renewable energy choices and water requirements. Research results show that there are limited data on all aspects of water usage in the production of energy. There is a need to take into account all aspects of the energy life cycle to enable isolation of stages where significant amounts of water are used. Conventional fuels (nuclear and fossil fuels) withdraw significant quantities of water over the life-cycle of energy production, especially for thermoelectric power plants operated with a wet-cooling system. The quality of water is also adversely affected in some stages of energy production from these fuels. This investigation has also shown that solar photovoltaic and wind energy exhibit the lowest demand for water, and could perhaps be considered the most viable renewable options in terms of water withdrawal and consumption.

b) Task 2

Energy policy and regulation in South Africa and its consideration or implications for water were investigated in the second task. Findings show that it is helpful to examine energy and water policy from the perspective of individual energy sources or technologies but also at a systemic level – including how energy demand is managed and planned for, the water efficiencies of the energy mix, and the incentives to decision-makers when responding to future national energy needs. The IRP takes water scarcity into account and demonstrates an awareness of the trade-offs but, beyond that awareness, there is little information indicating the water impacts over the full lifecycle of energy production, and there are no tools available for analysis, in order to assist decision-makers. As a result, the awareness of trade-offs is not efficiently translated into decision-making practice.

c) Task 3

Impacts of current energy choices, and the challenges and opportunities involved in adapting to climate change were investigated in the third task. It was found that water impacts vary in the energy generation cycles of different energy technologies. Planning for energy supply now and in the future necessitates that South Africa's policy makers take into account the water impacts and associated risks of the energy generation technologies available, particularly in areas where there is severe water stress.

d) Task 4

The aim of the fourth task was to develop a policy framework that can enhance harmonisation of policies linked to water and energy. The formulation of this framework took into consideration the following key points:

- South Africa faces concomitant imperatives to secure a supply of clean water, protect water resources, and provide a secure supply of energy.
- It is important to use water resources efficiently in the energy production chain.
- Legal and policy instruments developed direct the management of water, energy and other sectors.
- Harmonisation of policies is required for effective management of the water-energy nexus.

This framework can help in the development of new policy (legal) instruments or review existing instruments.

A.1.4 Present task

The aim of this task was to evaluate methods for prioritising renewable energy technologies and water catchments in South Africa. To this end, a workshop was organised and took place on 13 May 2014 at the Stone Cottages, Kirstenbosch in the City of Cape Town. It was perceived that sharing insights of practitioners in the energy-water nexus can assist in tackling the water-energy challenge.

A.1.5 Workshop objectives

The workshop was aimed at providing an opportunity to gather insights into managing the water-energy nexus from business, national and provincial government, and water and energy practitioners and researchers. It was also an invaluable opportunity for networking between various groups interested in the water-energy nexus. The focus of this forum was on water use (withdrawal and consumption) for renewable energy technology, especially in areas already perceived to be water stressed. The three objectives of the workshop were to:

- discuss and evaluate means of prioritising water concerns in energy planning / proposals / projects;
- evaluate methods to prioritise technologies and catchment areas for case study; and
- elicit feedback on the Policy Framework for water for energy that was drafted in an earlier task of the project, for the purpose of refining the Framework.

The workshop also gave the opportunity to test the hypothesis that water requirements are not well integrated into decision-making that requires a selection between renewable energy technologies. The workshop activities were planned with assumptions that:

- project developers select one of two or more appropriate renewable energy technologies;
- the process of developing renewable energy projects may be initiated with a site already in mind or with an already selected renewable energy technology; and that
- there may be means to prioritise the consideration of water resources in the selection of renewable energy technologies.

A 2. Approach

A.2.1 Stakeholder representation

Stakeholders were invited from different groups of organisations: civil society/non-governmental organisations), South African National Energy Development Institute (SANEDI), REIPPPP, the business sector, DoE, Department of Water Affairs (DWA), Department of Environmental Affairs (DEA), other government departments and academia. Due to other official commitments, there was unfortunately no representation from the DWA, DEA and the WRC. A list of attendees is presented in Appendix B of this report.

A.2.2 Workshop process

Participants were welcomed to the workshop by ERC and a facilitator, and the aims and anticipated outcomes of the workshop were explained. Self-introductions were conducted to provide a perspective of the stakeholder representation and expertise. An overview of the day’s programme was also outlined (see Appendix C).

PowerPoint presentations were made on the renewable energy and water resource maps (see Appendix D), and methods for decision-making. The presentation on renewable energy and water resources was aimed at providing insights into the spatial distribution of these resources. Various methods of decision-making were presented to give a starting point for the discussion. After the prelude, participants were divided into three random groups and requested to discuss, evaluate and select appropriate methods for prioritising renewable energy (RE) technologies. The objectives set out by WRC pertaining to the water-energy nexus were clarified. In this regard, the discussion was to focus on project-level considerations. The workshop participants could contribute by drawing from their experience and exposure to look at how this could be done (methodologies/approaches). To start the discussion, three methods for selecting energy technologies were suggested:

- multiple criteria;
- decision tree; and
- incorporating strategic assessments in current guidelines for energy projects.

Groups examined the methods in detail and recorded their points on paper. After group discussions, participants re-convened in a plenary session to consolidate ideas. A representative from each group presented their findings by putting up their points and explaining them (see Figure A-4).

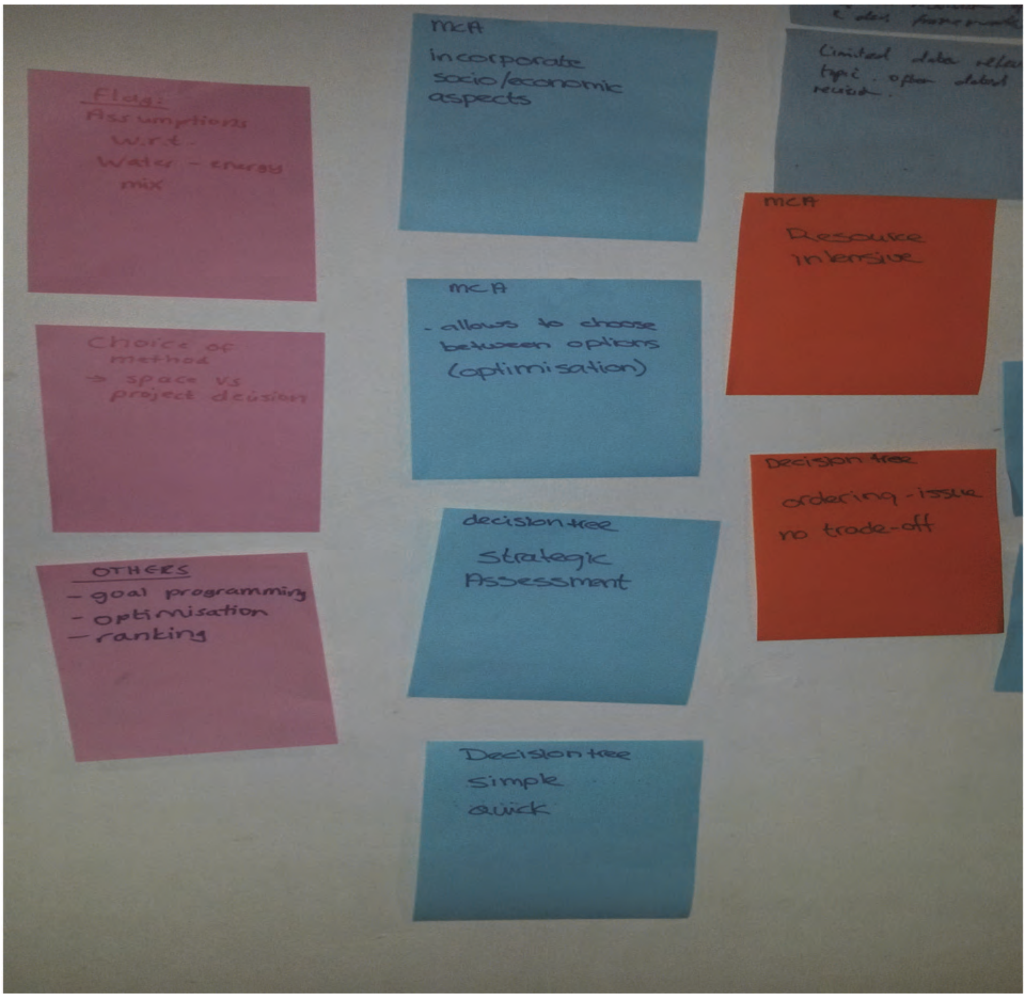

Figure A-4: A record of some points on methods for prioritising energy technology.

A 3. Key issues and findings

A.3.1 Distribution of renewable energy and water resources

- South Africa is endowed with various renewable energy resources (solar, wind and other resources).
- Water is scarce in some areas with good renewable energy resources. For instance, there is abundant solar radiation in the Northern Cape (Figure A-5) but water is scarce in this region (Figure A-1).
- Choices of energy technologies and where to exploit them need to take into account local water scarcity.

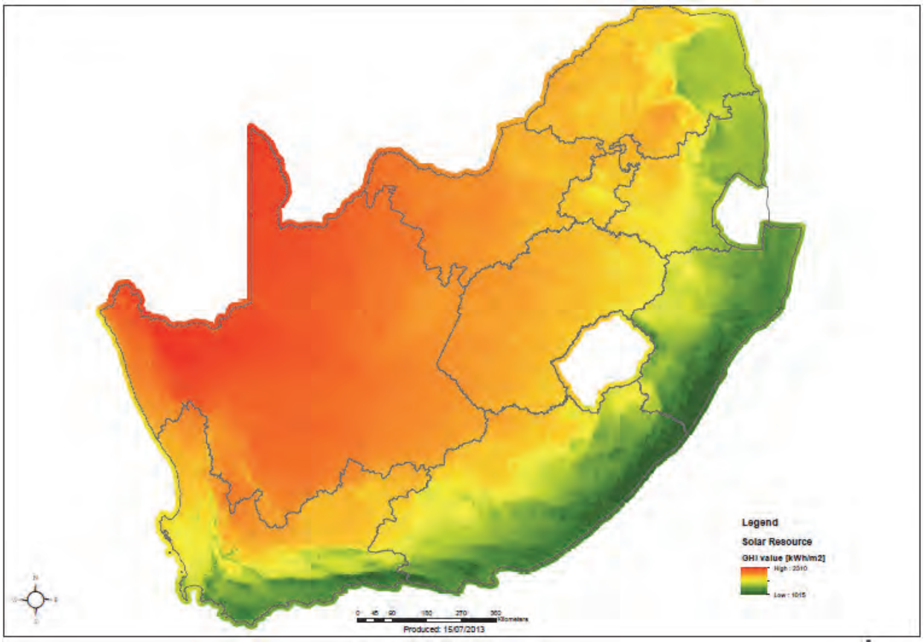

Figure A-5 : Global horizontal solar radiation distribution in South Africa.

A.3.2 Methods for prioritising energy technologies

- There are risks associated with each criterion for prioritising energy technologies. These should be modelled through sensitivity studies to determine thresholds.
- Participants noted that it is important to look at existing prioritisation frameworks. A lot of work has previously been done for prioritising water, so there is not much need for developing new methods. Instead, the importance of the water resource in energy decision-making processes should be augmented.

- Financial modelling precedes all renewable energy projects. In view of this, it was suggested that relevant information that would affect all projects be made freely available. This information would include updated assessments of water availability and analysis on the likely future price of water, taking into consideration competing demands on water, likely changes to water availability and quality (as a result of water use and climate change). The benefit of this approach is that assessments of project sustainability would be made on the basis of the best available and most recent information.

- It was suggested that the setting of benchmarks as guidelines (e.g. an amount of water consumption per unit of energy production) could be used for more 'fair' allocation of water amongst different types of energy projects.

- The spatial and temporal disconnection regarding water was mentioned as a key constraint in quantifying the amount of water used. In this vein, the workshop participants shared the concern that there is a lack of coordination between project licencing by the various relevant departments. Projects are required to apply to the DWA, DEA, and DoE for various permissions and licences. However, there is a time lag in this process and there would be a risk that any department's assessment of an application might not have full information as to the other permissions granted or the aggregate impact on water resources of recently-given permissions. Workshop participants felt there is a lack of transparency on how changes are made to water allocations and that this might be a complicated process. Some participants felt that, in their experience, allocations were not always done centrally and the methods for prioritising licences were not always clear.

- A country could choose to focus on a specific technology and create incentives to make it work. However, the incentives should be considered along with the costs of employing one technology rather than another. So, the costs related to the water demand would be weighed against the incentive. If, for example the cooling system being considered for electricity generation is water-intense or energy-inefficient, then the benefit of the incentive might be nullified.

- On the localisation policy (jobs, water trade-offs), it was observed that local production provides jobs but places a water burden within the country.

A.3.3 Proposed criteria

The list of criteria drawn up and discussed by participants included:

- costs of water (including the opportunity cost of alternative uses);
- water availability, current and future;
- water quality;
- seasonal and spatial water variability;
- intensity of water use;
- incentives / taxes;
- socio-economic factors (benefits and costs to society and the local community);
- climate change resilience;
- knowledge capital (commonly available data and analysis around water resources);
- infrastructure;
- location;
- technology;
- environmental concerns;
- type of user (strategic or priority);
- local / regional / international content of production;
- non-equivalence of technologies (base and peak load);
- prospects for onsite water storage or recycling facilities;
- seasonality of precipitation;
- compatible technologies, i.e. smart grids;
- risk and uncertainty.

It was acknowledged that some of these criteria are difficult to quantify – for example, knowledge capital, socio-economic factors and climate resilience. However, qualitative analysis can also be used to make a decision. The localisation criterion was held to present a trade-off in water scarce areas between providing jobs and placing a burden on water resources.

A.3.4 Suggested case study catchments to evaluate methods and criteria to prioritise renewable energy technologies

Workshop participants agreed that the recently published Strategic Environmental Assessment (SEA) for the rollout of wind and solar PV energy in South Africa (CSIR 2013) provides ideal potential case studies for the WRC project. The report highlights eight wind and solar PV SEA focus areas, among which water concerns vary; two of the focus areas are in the Western Cape (where the workshop was held).

A.3.5 Draft Policy Framework

- Specific suggestions for inclusion in the Policy Framework (see Appendix D) were to include Strategic Infrastructure Projects (SIPs), the New Growth Plan, the Green Economy Accord, and Industrial Action Plans.
- The draft Policy Framework should be circulated to participants for comprehensive feedback.

A 4. Concluding remarks and recommendations

A.4.1 Concluding remarks

- Choices of energy technologies should take into account water scarcity in South Africa.
- Different methods already exist for prioritising energy technologies. These methods have associated risks.
- Water requirements are not well integrated into decision-making processes that require a selection of energy technologies.
- Existing methods should be modified to include variables for efficient use of water in the energy sector.
- Some criteria have been proposed for prioritising energy technologies.
- It appears that financial modelling can play an important role in prioritisation of energy technologies.

A.4.2 Recommendations

a) The interdisciplinary nature and complexity of the water-energy nexus requires further consideration with respect to what has already been done, and how this can be used in order to achieve the set objectives. So, there is a need to build on the 'knowledge capital' surrounding energy and water use by making information available to practitioners, researchers, developers and project managers.

b) Workshop participants recommended that further study make reference to the following in order to map trade-offs and to draft scenarios in further tasks within this project:

- IRP scenarios (IRP 2010 and the draft IRP 2013);
- Strategic Environmental Assessment (SEA) for the rollout of wind and solar PV energy in South Africa (available at www.csir.co.za/nationalwindsolarsea);
- Industrial Policy Action Plan;
- Strategic Infrastructure Projects;
- New Growth Path / National Development Plan;
- DWA Climate Change Adaptation and Mitigation Plan; and
- DWA climate change adaptation and mitigation plan.

c) Participants recommended the following as potential resources in further research inquiries:

- Developers of renewable energy projects.
- Respected stakeholders in industry with relevant expertise.
- Look at the locations suggested by the DEA for different RE technologies and consider using those as case studies.
    - o Contact project developers to get a sense of what they are thinking about, what challenges they face and how they plan to overcome them (for example: Martin Ginster, Sasol, Nanda Govender, Eskom, Musi Chonco, SABMiller).
- Look at Eden Project, co-founded by Sanlam; this may be useful for modelling logic – incorporating water into the financial model.
- The University of KwaZulu-Natal and Eskom study on climate change and water use in Waterberg.
- The South African National Biodiversity Institute Long Term Adaptation Scenarios Flagship Research Programme for South Africa.
- The DEA LTAS water studies.

- Council for Scientific and Industrial Research water projects and Integrated Assessment Modelling.
- DWA outputs.
- The National Water Resources Strategy.

A 5. References

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HOEKSTRA, A.Y. *ET AL.*, 2011. The water footprint assessment manual, London: Earthscan.

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A 6. Supporting documents

A.6.1 Workshop invitation

The UCT Energy Research Centre invites you to participate in a workshop:

Evaluation of methods for prioritization of renewable energy technologies and water catchments in South Africa

13 May 2014 | **Stone Cottages, Kirstenbosch, CT** | **09:30-15:00**

Rationale

This aim of the workshop is to consult a range of expert stakeholders and decision-makers who will assist the team to propose, evaluate and select method(s) that will enable governing bodies at different levels to select the most appropriate RET for a particular site or prospective sites for RET installation, in terms of least water demand/pollution, and also to assist in selecting sites in which the selected method(s) can be tested.

Travel Costs

This project is funded by the Water Research Commission (WRC). Travel costs to this workshop will be met by the Energy Research Centre for participants who live outside Cape Town. Lunch and refreshments will be provided to all participants.

Background

ERC and Pegasys are working on a project that proposes methods for selecting renewable energy technologies (RETs) that take into consideration the water requirements and associated water impacts of the technology, the water availability and resilience of the area, and other important criteria. Given the increasing scarcity of water in South Africa, and the threat that climate change may further stress water supply, heightened by South Africa's targets of having 3 725 MW of renewable energy online by 2016, it is imperative to factor water demand and impacts into future plans for renewable energy generation.

Please RSVP to wrcworkshop2014@gmail.com by 25 April 2014

ERC ENERGY RESEARCH CENTRE University of Cape Town

For further information, please contact:
Mr Pieter Krog, Ms Mascha Moorlach or Dr Debbie Sparks
e-mail: wrcworkshop2014@gmail.com
tel: 0216503230.

WRC WATER RESEARCH COMMISSION

A.6.2 Participant list

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A.6.3 Workshop agenda

Programme for workshop on the evaluation of methods for prioritization of renewable energy technologies and water catchments in South Africa

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Date: **13 May 2014**
Venue: **Stone Cottages, Kirstenbosch**

09.30-10.00:	Tea/coffee and registration
10.00-10.15:	Welcome, aims of the workshop, questions
10.15-10-30:	Introductions
10.30 -10.40:	Process overview
10.40-11.15:	Small group activity on categories and criteria for designing a decision-making method
11.15-11.45:	Report back and sorting exercise
11.45 -12.00:	Presention of decision making tools and decide on "commissions"
12.00-13.00:	Work in "commisions" groups
13.00-13.45:	LUNCH
13.45-14.30:	Presentations and discussion in plenary
14.30.15.00:	Site selection for method testing and case studies
15.00 –	Closure and farewell

A.6.4 Proposed Policy Framework

It is important that Water, Energy and other Acts should be harmonised with regard to the efficient use of water. In turn, these Acts should influence the vertical development of relevant strategies/policies which are horizontally synergetic. Similarly, national water and energy plans/programmes should emanate from national strategies/policies. These plans should also be aligned. There is need to capture elements of water use efficiency at all the levels of this framework.

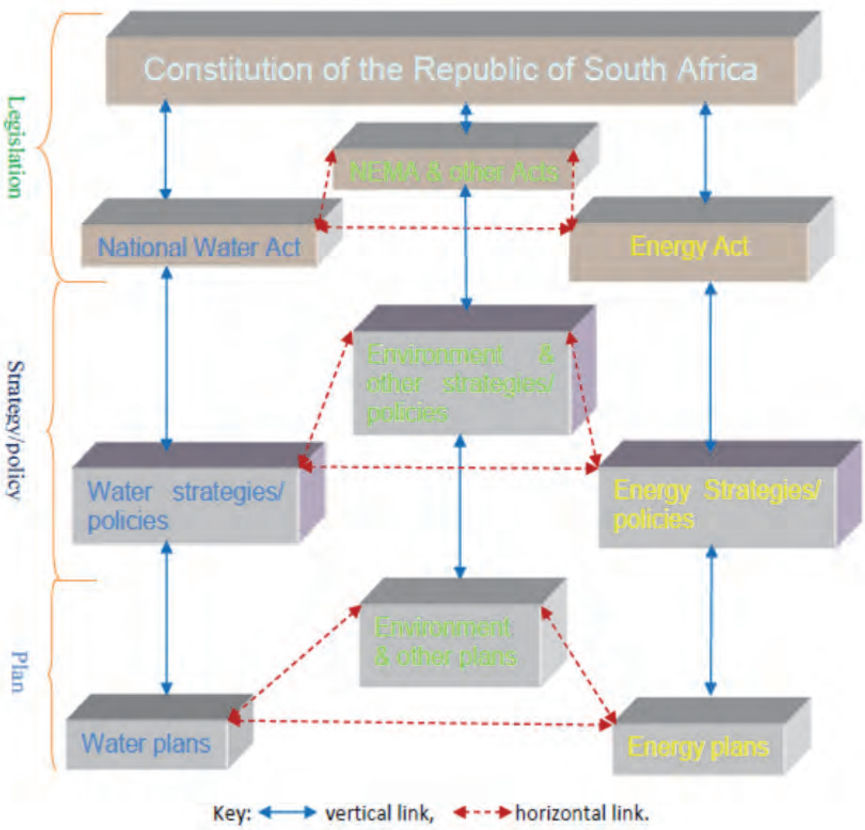

Figure A-6 : Diagrammatic view of the framework for harmonising legal and policy instruments for water use in the energy sector.

A.6.5 Maps of renewable energy resources

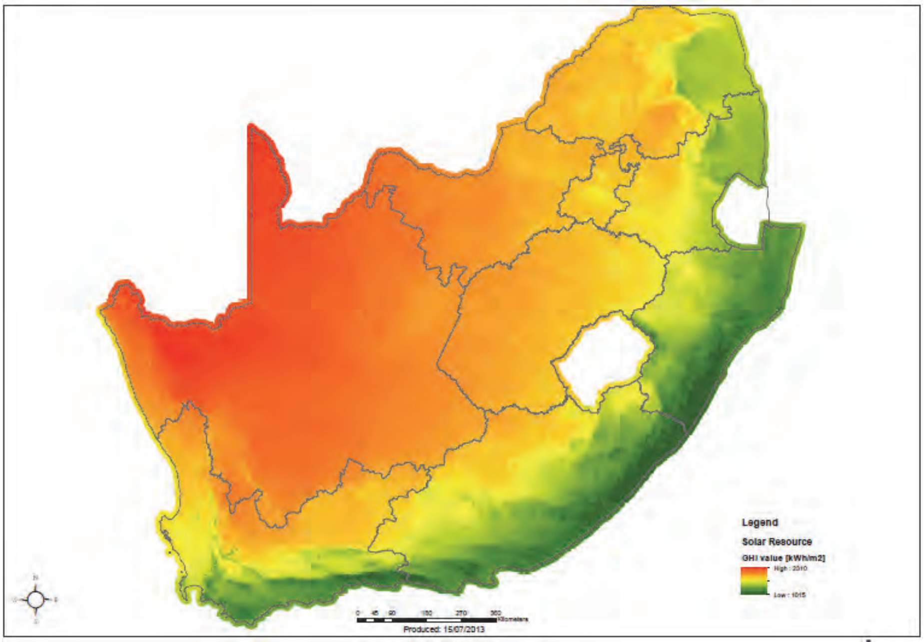

Figure A-7 : Global horizontal solar radiation.

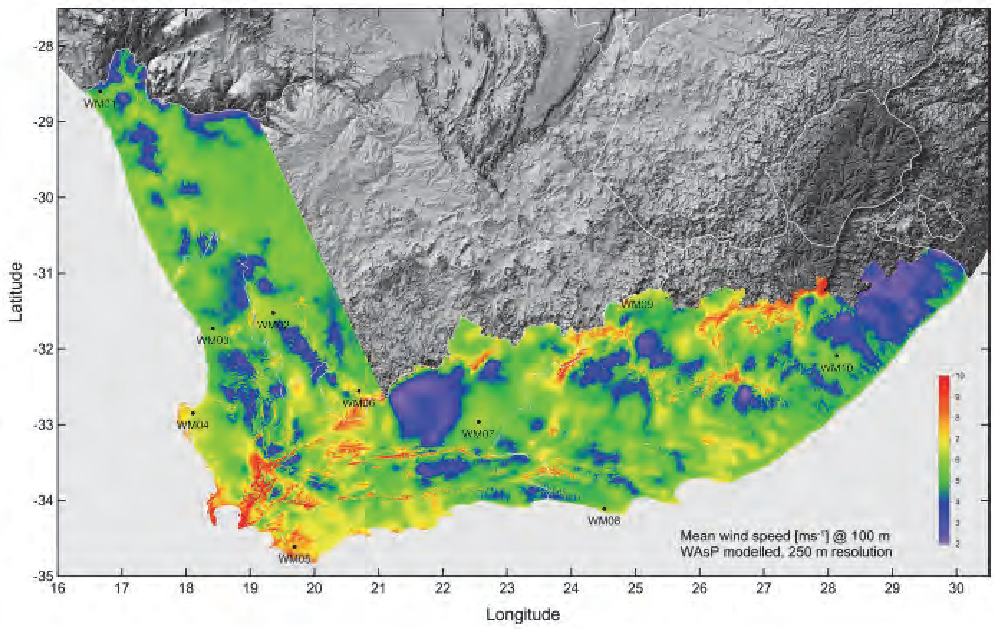

Figure A-8 : Wind resource.

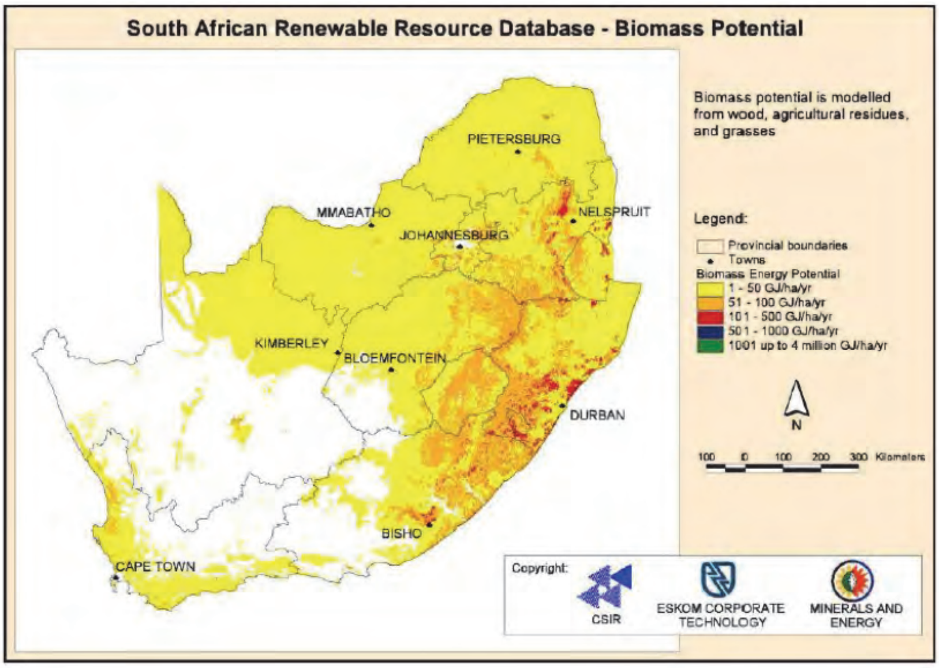

Figure A-9 : Biomass resource.

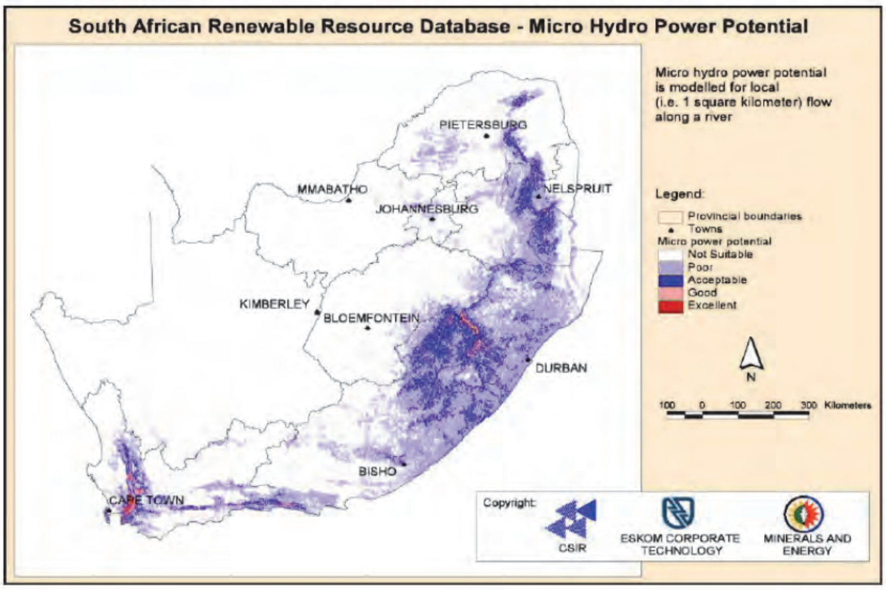

Figure A-10 : Small hydro resource.

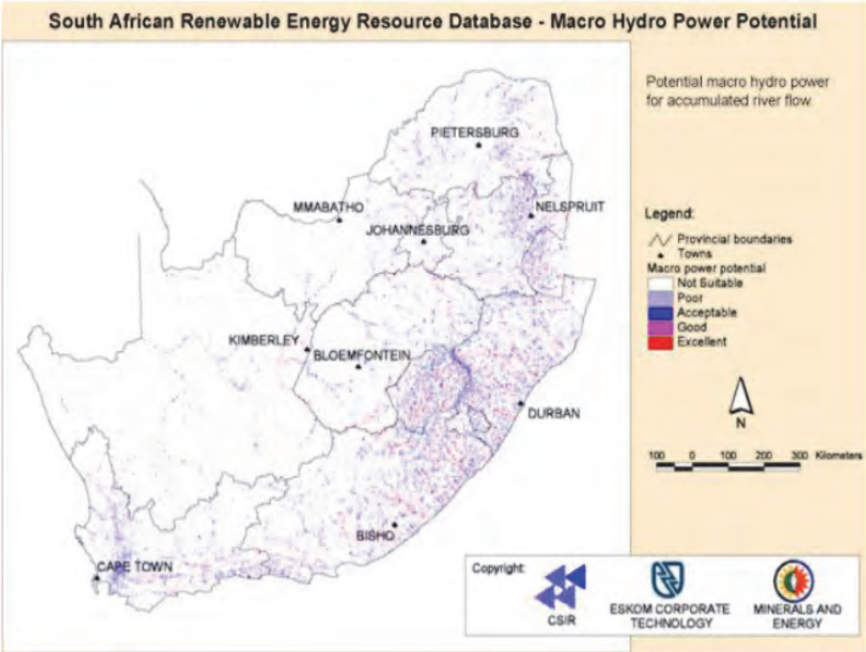

Figure A-11 : **Large hydro resource.**

APPENDIX B Workshop 2: A Workshop on the Decision Support Framework for the Water-Energy Nexus

B 1. Background: The Water-Energy Nexus

South Africa is a water scarce country, with water availability mostly concentrated in the Eastern and South-Eastern parts of the country. The current and future water availability, which is likely to change due to climate change, will impact the water users in the country. These water users not only include the population of the country, but also the other sectors such the industry, commercial and energy.

Therefore, water availability will affect the future of the energy-water nexus. While there is significant uncertainty regarding the magnitude of effects, water availability and predictability may be altered by changing temperatures, shifting precipitation patterns, increasing variability, and more extreme weather (USA DoE 2014). There is therefore a need to consider water resources availability when considering energy resources.

However, as there are various renewable energy options, each with different natural resource requirements, the location of each renewable energy project should be aligned will natural resource availability, such as solar, hydro or wind. Therefore, based on the current resource availability in South Africa, the concentration of energy resources is likely to imitate the spatial distribution illustrated Figure B-1

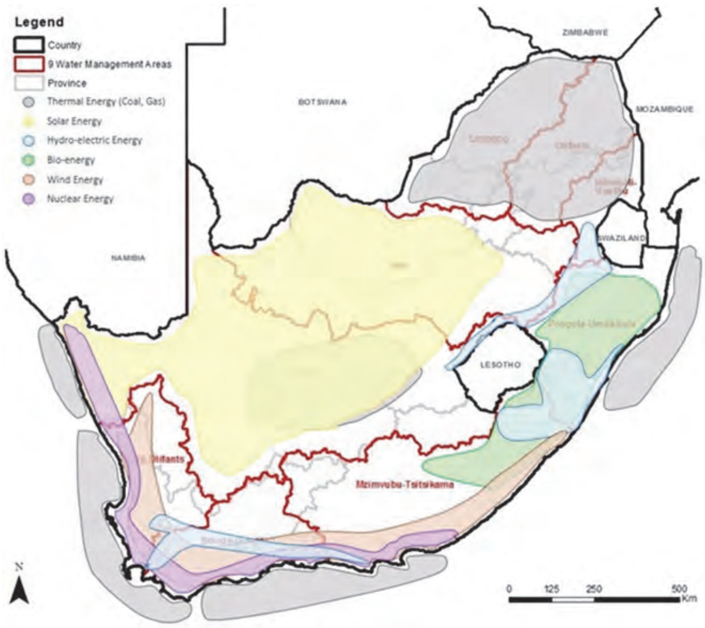

Figure B-1: Recommended location of energy resources in South Africa.

Each of the energy resources depicted in Figure B-1 has different water requirements. Therefore, the magnitude of the energy resource project should be aligned with the water requirements versus the water availability (including the water quality). A planning approach that allows the consideration of the required aspects is therefore required.

As water and energy needs are also shaped by population growth, climate change, and changes in energy resource availability and technology type, the planning for water and energy needs to be considered in an integrated manner. In addition, it is essential that the energy resources are spatially aligned with the available water resources because the demand for water varies with the energy technology option. For example:

- Thermal energy and large hydro plants are dependent on local yield (i.e. runoff), and should therefore be located in areas with sufficient runoff. The magnitude of the water requirements needs consideration of the broader catchment and region.

- Distributed energy projects (solar, wind, micro-hydro and irrigated bioenergy) are also dependent on local yield (i.e. runoff), and should therefore be located in areas with sufficient runoff. However, these plants require significantly less water than thermal and large hydro plants, and therefore require the consideration of water resources at a local level.

- Rain-fed first generation bioenergy is dependent on rainfall, and therefore needs to be located in regions with sufficient rainfall.

- For other types of energy technologies:

    - Nuclear power plants can use seawater, and in these instances would be located in coastal areas.
    - Alternative bioenergy, such as feedstock produced from solid waste, algae or manure, has varying water needs depending on the feedstock. This is likely to compete with local water users because the water used is often sourced from a municipal water supply. (ERC and Pegasys 2015)

Therefore, planning approaches that enable sustainable exploitation of water and energy resources should be considered, which include consideration of the trade-offs between water and energy resources. This includes taking into account the water availability and demand, as well as the water requirements and impacts associated with exploitation of the energy resources.

Context: The Decision Support Framework

The White Paper on Energy Policy (1998) states that the energy regulators should ensure that an integrated resource planning approach is adopted for investment decisions by energy suppliers and service providers, in terms of which comprehensive evaluations of the economic, social and environmental implications of all feasible supply and demand side investments will have to be undertaken. This is an intended to ensure that the feasible alternatives for supply-side investments are compared on an equal footing and that their environmental costs are integrated into an economic and social analysis (ERC and Pegasys 2015).

The decision-making landscape for the energy-water nexus is shaped by political, regulatory, economic, environmental, and social factors, and available technologies. This landscape is fragmented, complex, and changing. The incentive structures are overlapping but not necessarily consistent. Water management is inherently multi-jurisdictional and primarily a state and local issue. Energy for water is also the subject of policy activity at multiple scales. Consequently, a more integrated approach to the interconnected energy and water challenges could stimulate the development and deployment of solutions that address objectives in both domains. The energy-water decision landscape is, however, highly fragmented. It comprises a diverse set of actors and interests, overlapping but not necessarily consistent incentive structures, and inherent regional variation in energy and water availability (USA DoE 2014).

In South Africa, the decision-makers and actors in the water and energy planning landscape include:

- Regulating institutions at the national, provincial and/or local level;
- Water service providers and catchment level water resources managers;
- Energy resource project developers; and
- Water and energy users.

While these diverse stakeholders often act independently and have competing goals, the impacts of their individual decisions are interconnected. Therefore, the collaboration between the national government, local government, private sector and civil society is essential. In addition, there is also an opportunity for the harmonisation of energy and water policies, and for the integration of the planning environment. As indicated in the decision-making framework, this can be achieved through a two-part planning process:

1. National level planning that focuses on large scale electricity power plants, such as some of the coal power stations or large hydropower plants; and
2. Catchment-based planning that concentrates on projects (for smaller scale energy projects such as small hydro plants, wind or solar projects) and decision-making at catchment level (ERC and Pegasys 2015).

The decision-making framework developed as part of project provides a tool that allows water resource planners, managers and developers to assess the state of water resources, potential water quantity and quality related issues, (as a means of averting negative socio-economic and environmental impacts) and to determine the appropriateness of a specific energy resource for the catchment area under question. Importantly, it also considers how climate change influences water availability in catchments, which, until now, has been excluded from the water use licensing approach. A number of questions were formulated to ease the decision-making process for energy resource projects (ERC and Pegasys 2015).

Scope and objectives of this workshop

Investigating the water-energy nexus in the context of climate change is the ultimate aim of this project. By considering growing water scarcity, lack of access to clean energy and vulnerability to climate change, this project provides an important building block in advancing research for policy influence in the emerging area of energy-water-climate change nexus in South Africa, and the necessary tools to inform policy decisions in the context of an appropriate energy mix, and efficient water use planning.

This workshop was the ninth and pen-ultimate task of this project. The objective of this workshop was to present the decision support framework and tool to stakeholders. The workshop not only provided background context of the framework, but also evaluated the usefulness of the framework and sought feedback from stakeholders. In addition, the usability and appropriateness of the tool was assessed through the use of case studies.

B 2. Workshop approach

The participants were welcomed to the workshop by the facilitator, and a brief overview of the agenda was provided below. The participants were invited to introduce themselves in order to determine who was in the room and which organisations were represented. In addition, the objectives of the workshop were laid out, as stipulated in Section B.1, and a broad overview of the entire project was provided.

Agenda for the Workshop on a:

Decision Support Framework for the Water-Energy Nexus

7 May 2015

09:30 - 09:45	**Registration and Tea**
09:45 - 10:00	Welcome and Introductions
10:00 - 10:10	The Project and Objectives of this Workshop
10:10 - 10:45	The Water-Energy Nexus in the Context of a Changing Climate
10:45 - 11:05	The Decision-Support Framework for the Water-Energy Nexus (Part A)
11:05 - 11:20	Discussion
11:20 - 11:45	The Decision-Support Framework for the Water-Energy Nexus (Part B)
11:45 - 12:00	Discussion
12:00 - 13:00	**Lunch**
13:00 - 14:30	Case Studies
14:30 - 14:45	Comments and Recommendations
14:45 - 15:00	Closure and Way Forward

Following the overview of the project and objective of the workshop, the workshop commenced. As shown in the agenda, the workshop was divided into 3 broad phases, namely:

1. An overview of the water-energy nexus in the context of a changing climate
2. An overview of the decision support framework
3. Case studies to test out the decision support framework (at the catchment-level)

A brief overview of how each of the phases below was approached is provided below.

Phase 1: An overview of the water-energy nexus in the context of a changing climate

The aim of this phase was to provide an overview of the entire project to date. PowerPoint presentations were done on the water-energy nexus, focused on the outcomes of the previous deliverables. Importantly, it was highlighted that because of the differences in spatial distribution of natural resources and water resources, effective and innovative energy and water planning decisions need to be made. This will minimise the pollution of water resources caused by energy projects, and thus increase water that is useable by other users in the country.

The floor was opened up for discussions, and the stakeholders were offered the opportunity to ask questions. Recommendations for this phase are laid out in Section B.6.

Phase 2: An overview of the decision support framework

The aim of this phase was to provide an overview of how integrated planning can be used to ensure that the trade-offs between water and energy resources are considered during the planning phase. It was emphasised that water and energy planning approaches need to address the spatial disparity between water and energy resources. This can be achieved by aligning energy resource with the availability of the 'type' of water resources. For example:

- Thermal energy and large hydro plants are dependent on local yield (i.e. runoff), and should therefore be located in areas with sufficient runoff. The magnitude of the water requirements needs consideration of the broader catchment and region.

- Distributed energy projects (solar, wind, micro-hydro and irrigated bioenergy) are also dependent on local yield (i.e. runoff), and should therefore be located in areas with sufficient runoff. However, these plants require significantly less water than thermal and large hydro plants, and therefore require the consideration of water resources at a local level.

- Rain-fed bioenergy is dependent on rainfall, and therefore needs to be located in regions with sufficient rainfall.

- Other types of energy technologies are:
    - In South Africa, nuclear power plants use seawater for cooling, and are thus located in coastal areas.

- o Alternative bioenergy, such as feedstock produced from solid waste, algae or manure, has varying water needs depending on the feedstock, which may be sourced from a municipal water supply if required.

As stipulated in the decision support framework, It is therefore envisaged that different approaches (or a combination thereof), aimed at optimal use of available local resources, as well as technology and cost requirements, can be applied to achieve this.

- In the centralised energy planning approach, the national grid is expanded and all electricity consumers are connected to the national grid. Large-scale energy generation (such as coal) or gas (for peaking power supply) as well as renewable energy resources (such as large hydro) feed into this grid.

- In the decentralised energy planning approach, energy is exploited to meet local energy needs and is not connected to the national grid. Local natural resources (such as solar or hydro) are optimised, and excess energy may be used to feed in to the national grid if the transmission infrastructure exists.

- The separation of the life-cycle processes can be practiced when local natural resources are not sufficient to meet local energy requirements, or when there is a mismatch between water availability and the water requirements of the energy resource. For example, for solar and wind energy, the water-intensive manufacturing of the required equipment can be done off-site in areas with sufficient water resources; then, the actual energy production which has low water requirements can be done on-site, using innovative water management processes. This can allow for life-cycle processes to optimise water availability, particularly in instances where policies aim for upscaling technology production.

However, as discussed in Section B.1, there are numerous decision-makers and actors in the South African water and energy landscape (such as national-level planning and regulating institutions, catchment based water resources managers and water service providers, energy resource project developers and water users). Therefore an approach that integrates both resources, while also incorporating the considerations required by all the different decision-makers and actors is required.

Section B.1 provided an overview of the proposed approach, and states that planning for the water and energy nexus can be achieved at two levels, namely at national level and at the catchment level. The proposed approach was presented to the participants in three parts, namely an introduction of the framework, an overview of the National level planning framework, and an overview of the catchment based planning approach). The floor was then opened up for discussions, and the stakeholders were offered the opportunity to ask questions. Recommendations for this phase are laid out in Section B.6.

Phase 3: Case studies to test out the decision support framework (at the catchment-level)

The aim of this phase was to test usability of the tool. Two case studies were used to determine the effectiveness and appropriateness of the tool. A description of the case studies in provided in Section B.4. Although the tool has to be updated, it was deemed as a useful starting point when considering the location of water resources.

The floor was opened up for discussions, and the stakeholders were offered the opportunity to ask questions. Recommendations for this phase are laid out in Section B.6.

B 3. Stakeholder representation

As the water-energy nexus in the context of climate change requires valued insight from stakeholders in the water, energy and climate change sectors, representatives from each of these sectors were invited. In addition, as previously indicated, there are various decision-makers in water and energy planning landscape. Therefore, representatives from the public and private sector were invited, from project development, project approval, civil society and research levels. The workshop invitation is provided on the following page.

However, due to other commitments, several representatives could not attend. As can be seen in the table below, representatives from the South African National Energy Development Institute (SANEDI), GreenCape, the World Wildlife Fund (WWF), the Western Cape Department of Environmental Affairs and Development Planning (DEAP), Watergy, the Renewable Energy and Energy Efficiency Partnership (REEEP) and the University of Cape Town attended the workshop. The list of workshop participants is provided below.

No.	Name	Organization	Email address
1	Dr Karen Surridge-Talbot	Sanedi	karenst@sanedi.org.za
2	Michael Rabe	Watergy	mike@re-solve.co.za
3	Jason Schäffler	Sanedi-REEEP	jason@reeep.org; jason@nano.co.za
4	Sarah Birch	WC-DEAP	Sarah.Birch@westerncape.gov.za
5	Annelie Roux	GreenCape	annelie@green-cape.co.za
6	Klaudia Schachtschneider	WWF	KSchacht@wwf.org.za
7	Valentina Russo	UCT	v.russo@uct.ac.za
8	Amos Madhlopa	ERC	amos.madhlopa@uct.ac.za
9	Debbie Sparks	ERC	debbie.sparks@uct.ac.za
10	Samantha Keen	ERC	samantha.keen@uct.ac.za
11	Mascha Moorlach	ERC	mascha.moorlach@uct.ac.za
12	Guy Pegram	Pegasys	guy@pegasys.co.za
13	Siyasanga Sauka	Pegasys	siyasanga@pegasys.co.za
14	Hannah Baleta	Pegasys	hannah@pegasys.co.za

Pegasys invites you to participate in a workshop on the:

Decision Support Framework for the Water-Energy Nexus

Date: 7 May 2015	Venue: Pegasys, Cape Town CBD	Time: 09:30 -15:00

BACKGROUND: Water and energy systems have historically been treated as separate realms, with little consideration of one in the planning of the other, and little discussion of interactions between the two. Yet in reality, they are closely interlinked. Water is needed in the vast majority of global energy production systems, for fuel extraction and processing, in hydropower production, and for power-plant cooling, among other uses. On the other hand energy is essential for pumping, treating and distributing water.

Due to the inter-linkages between the two resources, many challenges that involve energy and water require tightly coupled understanding of these systems' co-dependencies. For example, changes in climate may spark increased demand for water resources and energy resources, leading to a higher demand for hydropower but lower hydropower availability. Therefore, a holistic and integrated approach can examine all criteria for these resource challenges at once, resulting in more equitable solutions and providing insight to those that have the ability to enact these solutions. In addition, it is essential that water and energy resource availability, planning and management is considered at the appropriate scale.

This Decision Support Framework therefore aims to aid water resource planners and managers, as well as project developers to assess the state of the water resources (at the appropriate scale), to assess potential water quantity requirements and quality impacts, and to ascertain the suitability of a specific energy resource for the intended catchment, particularly in the context of a changing climate. This framework provides a tool where planners and project developers can explore how individual water or energy management choices are likely to influence either system, and thus enables the consideration of the key issues and impacts to water resources within the specific context of the proposed development, as well as an understanding of trade-offs that might not be apparent when looking at either system alone.

OBJECTIVE: The workshop aims to present a draft of the decision support framework to stakeholders in a facilitated discussion on its application, flexibility and appropriateness. Your participation will thus be greatly appreciated. Please confirm your attendance before Friday the 24th of April 2015.

WORKSHOP DETAILS: This project is funded by the Water Research Commission (WRC). Travel costs to this workshop will be met by Pegasys for participants who live outside Cape Town. Lunch and refreshments will be provided to all participants. Directions to the venue will follow.

ADDITIONAL INFO: For further information, please contact: Miss Siyasanga Sauka from Pegasys at 021 461 5476 or siyasanga@pegasys.co.za.

B 4. Testing the Decision Support Framework and Tool

Two case studies were used to portray the advantages of having a decision support framework that is used for catchment based water and energy planning. These case studies are presented in Section 5.5, where they were used to illustrate how the choices made by the various energy sectors in the country have an impact on local water resources.

Case Study 1: Friedenheim Hydro Plant, Nelspruit

Background

The Friedenheim hydro plant is located on the Crocodile River in Nelspruit (South Africa). It is privately owned and operated as a commercially profitable and sustainable business venture. It is owned by the members of Friedenheim Irrigation Board (FIB) and operated by MBB, an engineering firm.

Friedenheim hydro utilises run-of-river technology and is one of the few hydro-electric Independent Power Producers (IPP) in South Africa. It is an example of a hydro plant that feeds into the electricity grid, providing power to the Mbombela Local Municipality. The plant is equipped with two 1 MW Francis turbines and provides power for water pumping to FIB, but 93% of the power generated is sold to the Nelspruit local authority through a Power Purchase Agreement (PPA) that sets the tariff at 12% below the price at which Nelspruit buys power from Eskom (Klunne 2012).

Run-of-river hydro

For hydropower, water requirements and impacts depend largely on the size and type of technology used. The variation in sizes gives the additional ability to meet large centralized urban energy needs as well as decentralised rural needs.

Run-of-the-River power is considered a project that has little or no capacity for energy storage and hence can't co-ordinate the output of electricity generation to match consumer demand. It thus generates much more power during times when seasonal river flows are high (i.e., spring freshet), and depending on location, much less during drier summer months or frozen winter months. The potential power at a site is a result of the head and flow of water. By damming a river, the head is available to generate power at the face of the dam. Where a dam may create a reservoir hundreds of kilometres long, in run of the river the head is usually delivered by a canal, pipe or tunnel constructed upstream of the power house. Due to the cost of upstream construction, a steep drop in the river is desirable.

Run-of-river technologies involve the channelling of a portion of a river through a canal or penstock. Small, well-sited run-of-river projects can be developed with minimal environmental impacts. Therefore, depending on the size, run-of-river hydro-electric energy may have an impact on the flow regime, aquatic ecosystems and may cause erosion.

Catchment characteristics

Nelspruit is located in the Crocodile Catchment in the Inkomati-Usuthu WMA (as shown below).

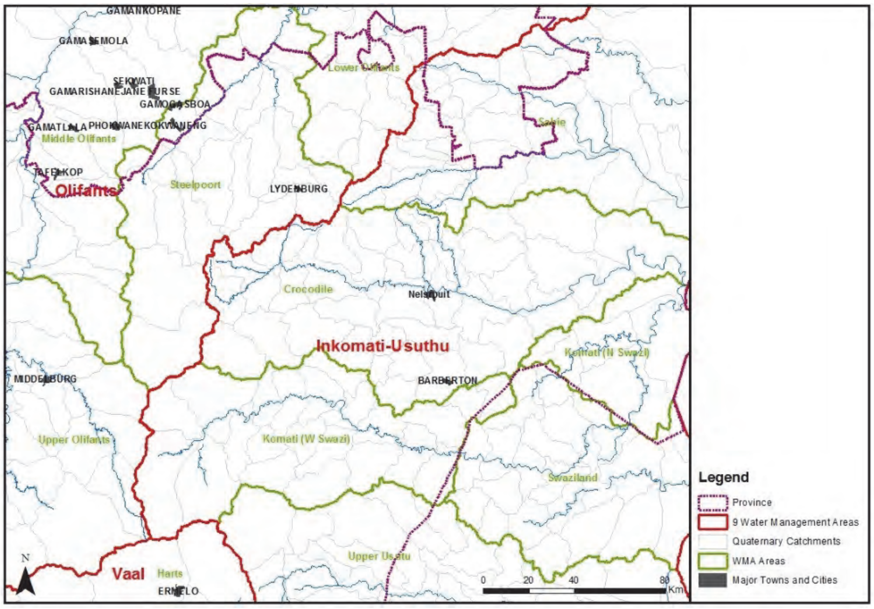

Figure B-2: Location of Nelspruit in the Crocodile Catchment.

The water demand, availability and balance for the catchment are illustrated in the table below. These figures not only include the current state of water resources, but the future projection. In addition, as the catchment fall under the previous Inkomati WMA, the water quality concerns for that catchment, as illustrated in the NWRS 1 have been provided. The table shows that there are no major concerns in the catchment.

Table B-1: Water resources in the Crocodile Catchment in the Inkomati-Usuthu WMA (million m^3/a).

Catchment	Water Demand	Water Availability	Water Balance	Water Balance (Drier Scenario)		Water Balance (Wetter Scenario		Water Demand		Water Availability	
	2000	2000	2000	2035 (Current Growth)	2035 (High Growth)	2035 (Current Growth)	2035 (High Growth)	2035 (Current Growth)	2035 (High Growth)	2035 (Drier Scenario)	2035 (Wetter Scenario)
Crocodile	364,00	209,00	-155,00	-251,95	-310,75	-137,00	-195,80	387,8	446,6	135,85	250,8

Table B-2: Physio-chemical water quality issues in various WMAs (NWRS1).

Water management area		Domestic use								Irrigation use				Recreational Use
		F	TDS	Ca	Mg	SO_4	Cl	Na	K	SAR	EC	pH	Cl	
5	Inkomati													

Key:

Domestic use: X indicates that the water quality indicator is outside the ideal range for domestic use at some locations in the WMA. F = Fluoride; TDS = Total dissolved salts; Ca = Calcium; Mg = Magnesium; SO_4 - Sulphate; Cl = Chloride; Na = Sodium; K = Potassium.

Irrigation use: A symbol indicates that the water quality indicator is outside the target water quality range for irrigation use at some locations in the WMA, where L, M and H means Low, Medium or High risk, (+) = alkaline and (-) = acidic.

SAR = Sodium Adsorption Ratio; EC = Electrical Conductivity; pH = a measure of acidity/alkalinity; Cl = Chloride; b = Boron.

Recreational Use: X indicates that the water quality indicator is occasionally outside the acceptable levels for recreational use at some locations because toxic cyanobacteria have been found.

The figures below illustrate the current and projected future rainfall and MAR distribution in the catchment. The future distribution is shown for a wetter and drier climate future.

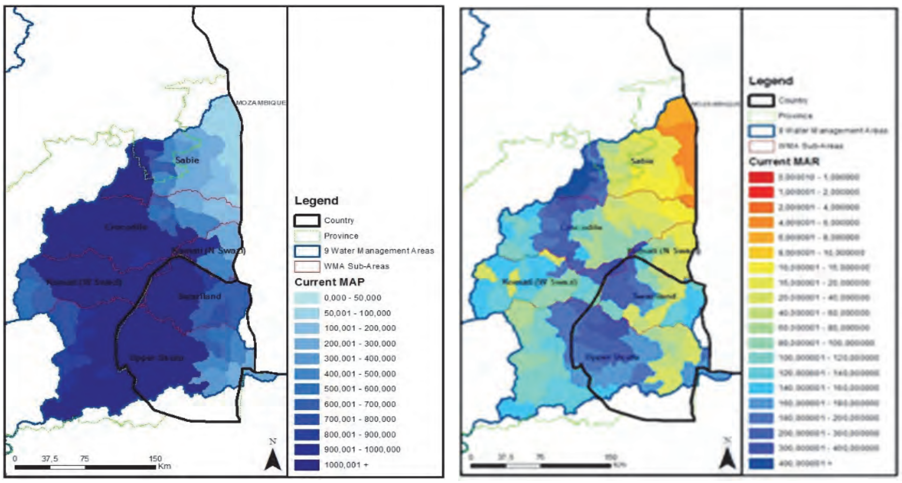

Figure B-1: Current (A) rainfall distribution and (B) mean annual runoff (MAR) for Inkomati-Usuthu WMA.

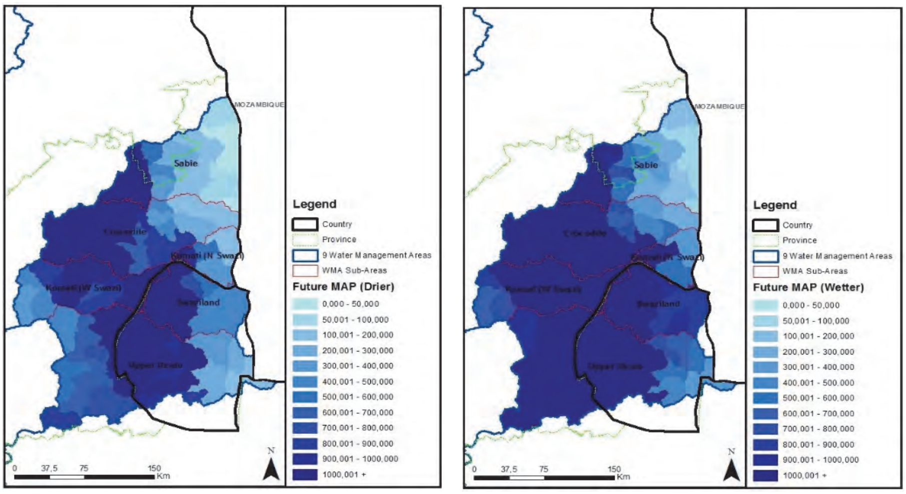

Figure B-2: Future rainfall distribution for the Inkomati-Usuthu under a (A) Drier Scenario and (B) Wetter Scenario.

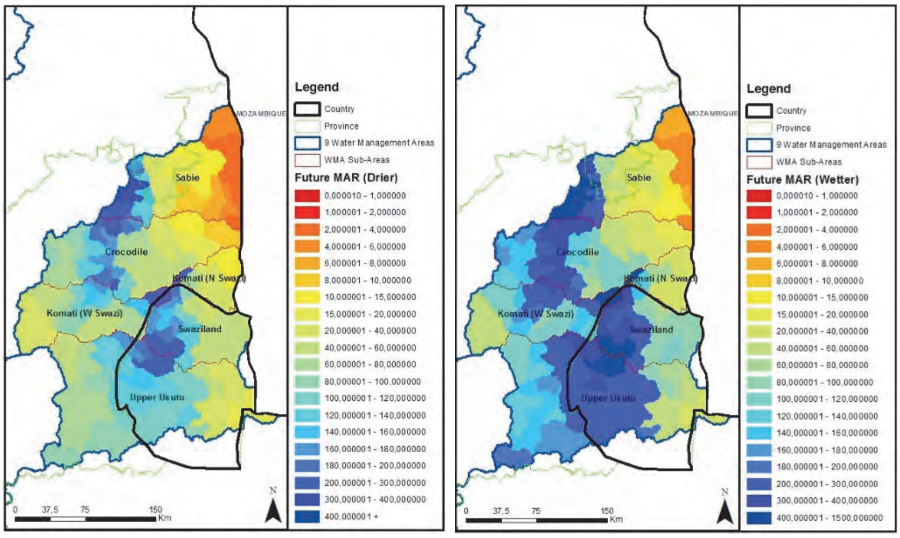

Figure B-3: Future mean annual runoff (MAR) for the Inkomati-Usuthu under a (A) Drier Scenario and (B) Wetter Scenario.

Catchment governance and legal characteristics

The following catchment governance and legal characteristics related factors should be considered for the case study:

- The governance and legal regimes of the catchment/region operate on a five-year basis. Therefore, every 5 years, a new political party (may) be elected to run the municipality, or the current party may continue their reign, but under different management. Therefore, after every 5 years there is a possibility that the catchment governance and legal regime may alter. This may therefore not only impact the water allocation approach in the catchment, but also the licencing, regulation, institutional environment and also catchment/regional/provincial develop plans and spatial planning approaches.
- The catchment/region is a water scarce region, with a high competition for water. This is mainly due to the economic activities in the region (mostly upstream).

Exercise related considerations (this data has been tailored for this exercise, and should not to be used externally)

The following project related factors should be considered for the case study:

- The project has authorisation and water licence requirements.
- The projected life-span of the energy resource is 30 years (until 2028).
- The water quantity (flow) is sufficient to meet requirements. However, a drier future will result in a decrease in the water quantity in the catchment, resulting in concerns about the sufficiency of the water quantity. In addition, a decrease in overall water quantity will

result in an increase in competition for water in the catchment, resulting in possible changes in water allocation and a possible decrease in water flow.

- As the project is not dependent on incoming water quality, the quality of the catchment is not a concern. This is also not expected to change in the future.
- The project is however projected to make changes to the hydrology of the catchment. However, due to the size of the project, this is expected to be relatively low.
- Although the project will not have waste-water discharge requirements, it is expected to have an impact on the water quality of the project. This can be related to the aquatic ecosystems and may cause erosion. The erosion may lead to an alteration of the natural characteristics (vegetation along the river basin).

Outcome of exercise

The outcome of the tool is illustrated below. The tool indicates that the hydro project is not ideal for the Crocodile Catchment. In light of the seasonal variability of the flow, as well as the climate projections in the area, water availability is not certain. In addition, as a long-term project that requires licencing, changes in the governance regime and potential changes in the water demand and allocation also pose long-term concerns for water availability for the project.

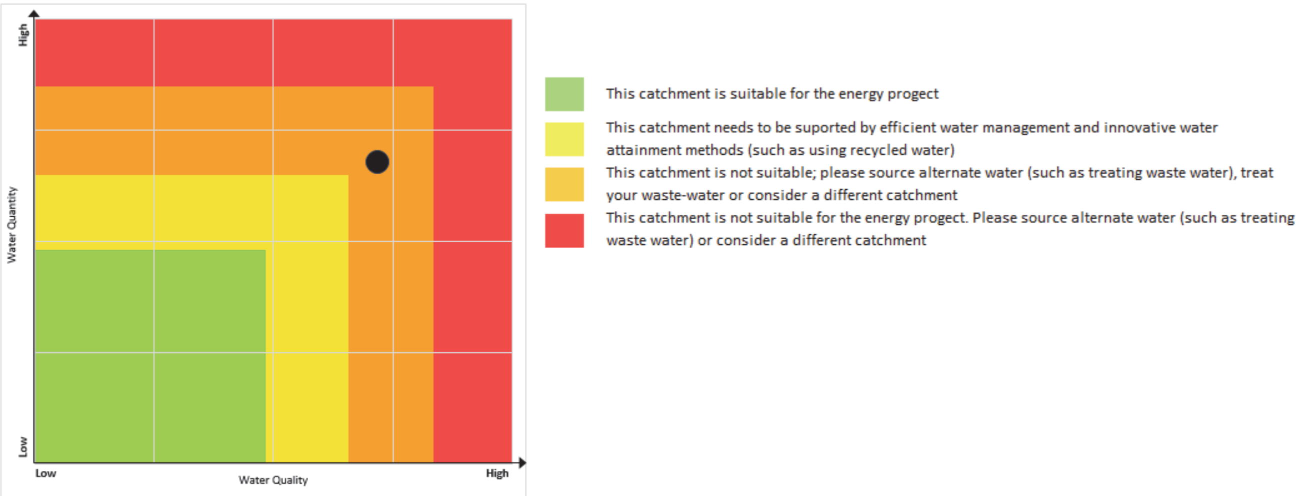

Figure B-4: Outcome of the tool for Case Study 1.

Case Study 2: Sustainable energy system at Three Crowns Primary School, Lady Frere

Background

Three Crowns Primary School is situated in the Chris Hani District in Khavola village near Lady Frere, about 220km from East London in the Eastern Cape. It currently serves 178 children and caters from Grade R to Grade 6. The school is part of the Chris Hani District Municipality School Greening Programme started in 2008 in cooperation with Wildlife and Environment Society of South Africa (WESSA) to install renewable electricity. Although it is connected to the Eskom electricity grid, it also has a sustainable energy system installed. Through the Eskom WESSA Energy and Sustainability Programme, and at the request of the Lady Frere District division of the Department of Basic Education, the Three Crowns Primary School was able to have a sustainable energy system installed at the school.

The sustainable energy technologies that have been installed at the school can be put into two categories, namely renewable electricity (i.e. a solar photovoltaic system) and renewable thermal (i.e. a solar cooker and biogas digester). The electricity is used to power a computer, printer and photocopier as a standalone non-grid tied system, luxuries that many other schools cannot afford in terms of appliances and electricity consumption. The benefits of this system are also shared with the village community when, for example, they need to copy forms for social grants or charge batteries or phones. Information technology can often also be more reliable; during the research for the case study by Gets (2013), a storm was raging and at one point the grid connected lights went out while the renewable energy system still functioned (Gets 2013). This would also serve as an advantage in the event of load shedding.

Sustainable energy systems are usually not supported because of the high installation costs. For this project, financial support came from the Development Bank of South Africa (DBSA), with project support for the renewable electrical installation from WESSA. The program has since been expanded into a collection of projects called the Rural Sustainable Villages Programme in the Chris Hani District Municipality (CHDM 2011). These sustainable energy systems not only provide clean energy sources (that have minimal impact on water resources), but also provide the poor opportunities to have access to energy to meet their daily needs.

This case study will focus on the solar photovoltaic (PV) system.

Solar Photovoltaic (PV) System

Solar photovoltaic (PV) directly converts solar energy into electricity using a PV cell made of a semi-conductor material. The water quality impacts of solar energy are low, particularly for small decentralised solar plants. PV has low water use and water quality impacts.

There may therefore be water quality concerns during the construction phase, as a result of erosion during rainfall event, which may have an impact on local water resources. Larger utility-scale solar facilities can raise concerns about land degradation and habitat loss; however, land impacts from utility-scale solar systems can be minimized by locating them at lower-quality locations such as brownfields, abandoned mining land, or existing transportation and transmission corridors.

While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement; these emissions are far less than the lifecycle emission rates for natural gas and coal (Union of Concerned Scientists 2013). Solar requires the mining of quartz sand, but this is not a major water concern. Nevertheless, processing the sand into electronic or solar grade silicon comes with a significant environmental and climate impact if not managed properly.

Therefore there are minimal trade-offs between energy and water resources during the energy production process for PV, although the mining of components required for the solar technologies has water implications. These include the possible impact of water resources, which may influence the fitness of use for other water users, as well as the allocation of water to the mining companies, which influences the water availability for other water users.

Catchment characteristics

Lady Frere is located in the Kei Catchment in the Mzimvubu-Tsitsikama WMA (as shown below).

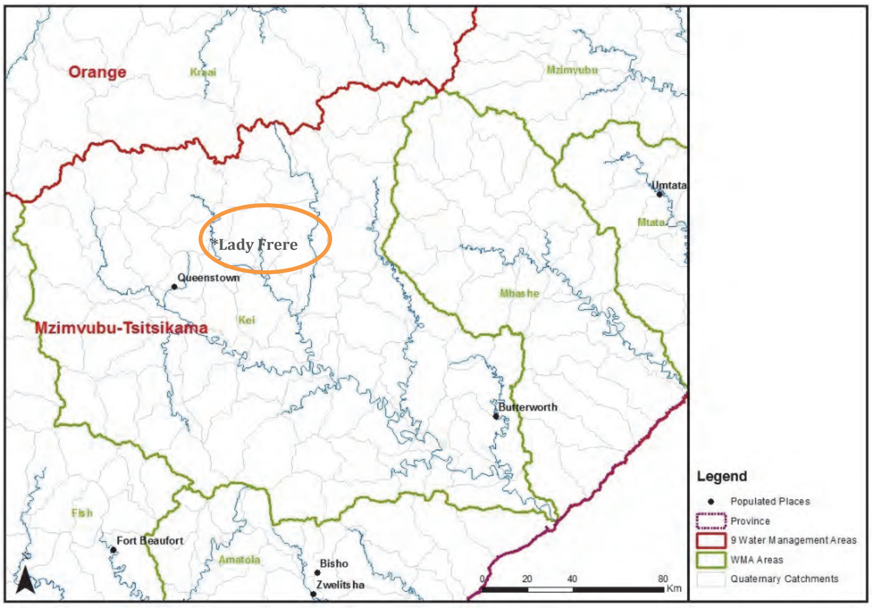

Figure B-5: Location of Lady Frere in the Kei Catchment.

The water demand, availability and balance for the catchment are illustrated in the table below. These figures not only include the current state of water resources, but the future projection. In addition, as the catchment fall under the previous Mzimvubu to Keiskamma WMA, the water quality concerns for that catchment, as illustrated in the NWRS 1 have been provided. The table shows that an alkaline pH is a concern in the catchment, particularly for Irrigation purposes. Water is often also not fit for use by the recreational sector.

Table B-3: Water resources in the Kei Catchment in the Mzimvubu-Tsitsikama WMA (million m^3/a).

Catchment	Water Demand	Water Availability	Water Balance	Water Balance (Drier Scenario)		Water Balance (Wetter Scenario		Water Demand		Water Availability	
	2000	2000	2000	2035 (Current Growth)	2035 (High Growth)	2035 (Current Growth)	2035 (High Growth)	2035 (Current Growth)	2035 (High Growth)	2035 (Drier Scenario)	2035 (Wetter Scenario)
Kei	174,00	274,00	100,00	38,20	29,80	175,20	166,80	181	189,4	219,2	356,2

Table B-4: Physio-chemical water quality issues in various WMAs (NWRS1).

Water management area		Domestic use								Irrigation use				Recreational Use
		F	TDS	Ca	Mg	SO_4	Cl	Na	K	SAR	EC	pH	Cl	
12	Mzimvubu to Keiskamma											(+)		X

Key

Domestic use: X indicates that the water quality indicator is outside the ideal range for domestic use at some locations in the WMA.

F = Fluoride; TDS = Total dissolved salts; Ca = Calcium; Mg = Magnesium; SO_4 - Sulphate; Cl = Chloride; Na = Sodium; K = Potassium.

Irrigation use: A symbol indicates that the water quality indicator is outside the target water quality range for irrigation use at some locations in the WMA, where L, M and H means Low, Medium or High risk, (+) = alkaline and (-) = acidic.

SAR = Sodium Adsorption Ratio; EC = Electrical Conductivity; pH = a measure of acidity/alkalinity; Cl = Chloride; b = Boron.

Recreational Use: X indicates that the water quality indicator is occasionally outside the acceptable levels for recreational use at some locations because toxic cyanobacteria have been found.

Figure B-5 illustrates the current and projected future rainfall and MAR distribution in the catchment. The future distribution is shown for a wetter and drier climate future.

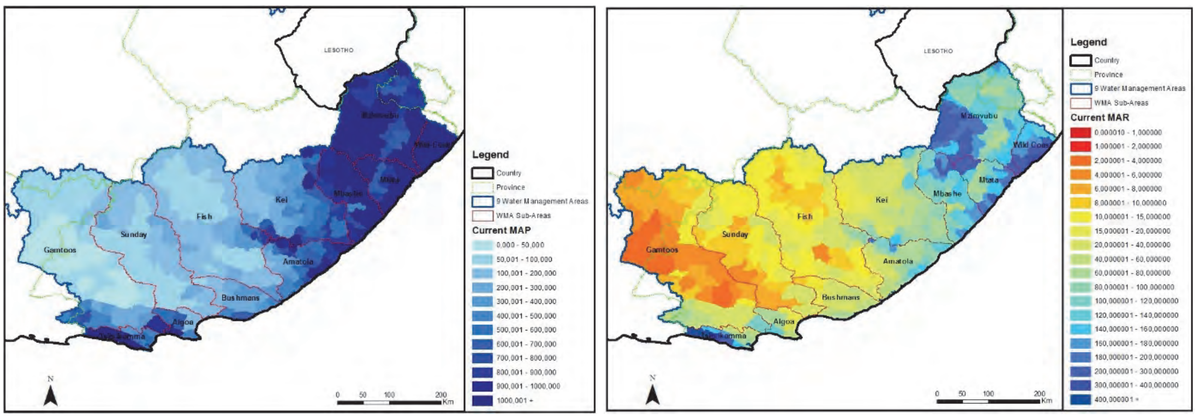

Figure B-6: Current (A) rainfall distribution and (B) mean annual runoff (MAR) for the Mzimvubu-Tsitsikama WMA.

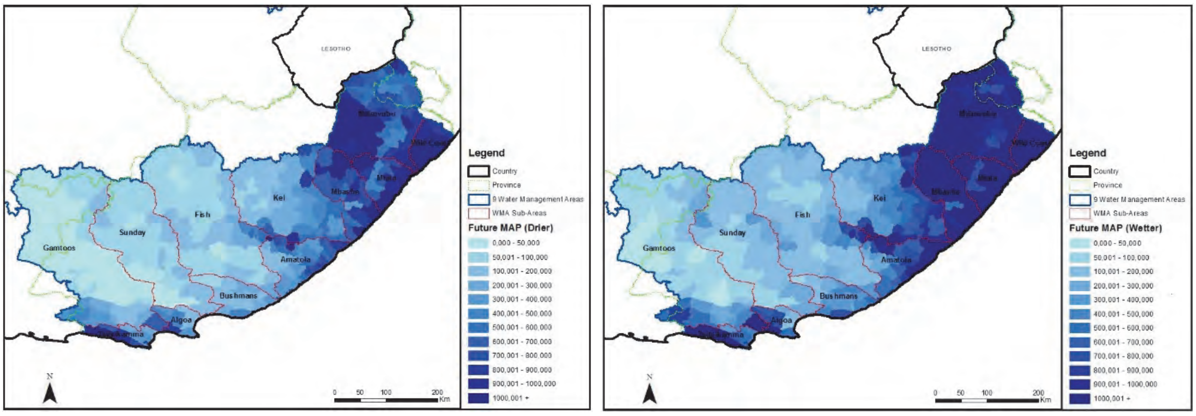

Figure B-7: Future rainfall distribution for the Mzimvubu-Tsitsikama WMA under a (A) Drier Scenario and (B) Wetter Scenario.

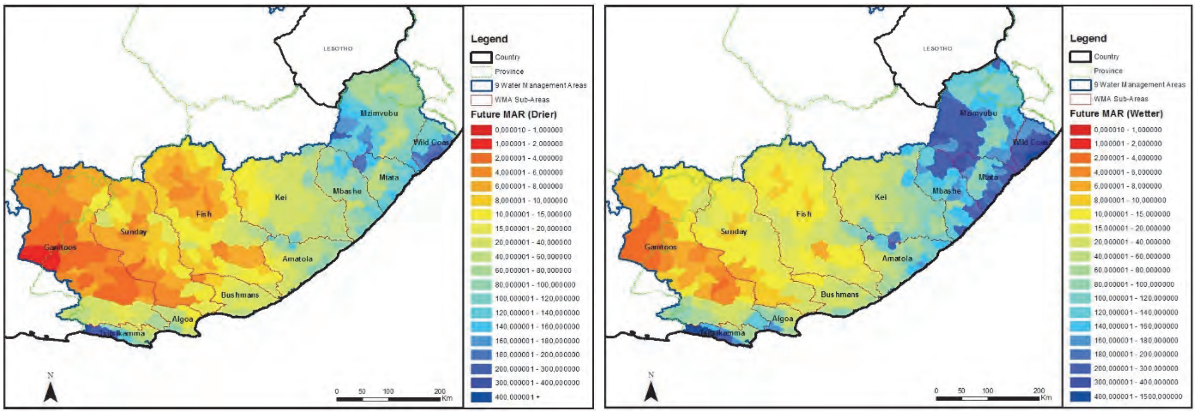

Figure B-8: Future mean annual runoff (MAR) for the Mzimvubu-Tsitsikama WMA under a (A) Drier Scenario and (B) Wetter Scenario.

Catchment governance and legal characteristics

The following catchment governance and legal characteristics related factors should be considered for the case study:

- Similarly to the Crocodile Catchment (region) – and other regions in SA, the governance and legal regimes of the catchment/region operate on a five-year basis. Therefore, every 5 years, a new political party (may) be elected to run the municipality, or the current party may continue their reign, but under different management. Therefore, after every 5 years there is a possibility that the catchment governance and legal regime may alter. This may therefore not only impact the water allocation approach in the catchment, but also the licencing, regulation, institutional environment and also catchment/regional/provincial develop plans and spatial planning approaches.
- The catchment/region is a water scarce region. However, there is relatively low competition for water in the region.

Exercise Related Considerations (this data has been tailored for this exercise, and should not to be used externally)

The following project related factors should be considered for the case study:

- The solar technologies will not be built on-site, therefore water is only required for the energy production stages.
- The project has no authorisation and water licence requirements.
- The projected life-span of the energy resource is 5 years.
- As the project has very low water quantity requirements, the water quantity is sufficient to meet the requirements. This is also not expected to change in the future.
- As the project is not dependent on incoming water quality, the quality of the catchment is not a concern. This is also not expected to change in the future.
- The project is not projected to make changes to the hydrology of the catchment, and does not have waste-water discharge requirements. There is therefore no projected impacts on the water quality from the project.

Outcome of Exercise

The outcome of the tool is illustrated below. The tool indicates that the solar project is ideal for an area with limited water resources and a high competition for water.

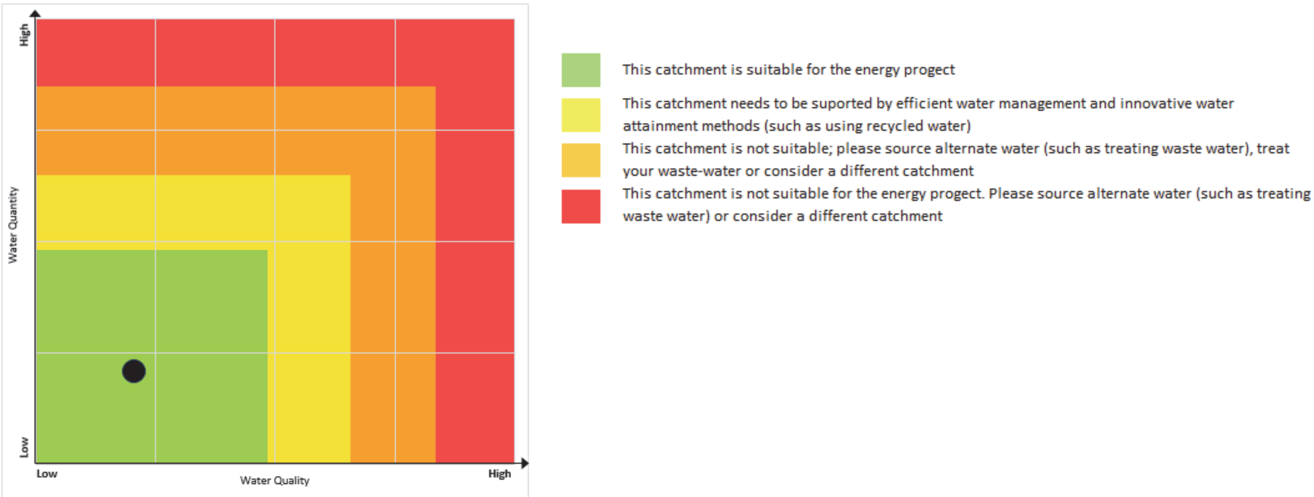

Figure B-9:Outcome of the tool for Case Study 2.

B 5. Key issues and findings

This section highlights key issues and findings that were highlighted by the participants during the workshop. These issues and findings address both the current water and energy nexus landscape in the country, as well as the considerations for the project.

The Water-Energy Nexus in the context of a changing climate

- There is currently an underestimation of water use in the country. In addition, water use calculations are often outdated and therefore do not enable planning that is applicable for the required time period. For water use by the energy sector, the 2% is a gross understatement as it does not represent water required for the production of electricity, especially coal based electricity.

- In South Africa, agriculture is considered as one of the largest users of water. As there is a direct linkage between water quality, water availability and food, as well as energy required for food productions, there is a need to also include the food-water-energy nexus. Although for this project it was deemed as not useful to dwell on this complexity, it was deemed necessary to note the considerations of the nexus. This is particularly important as at a national level, communication is not happening between the different departments.

- Energy demand projections are often based on the assumption that energy use increases with an increase in economic growth, however many other factors impact energy demand. Examples of these factors include population growth, increased access to services, and energy efficiency improvements.

- Although the interaction between water and energy planners is deemed as existent at the national level (for large scale energy projects), it was observed that the entire energy mix is lacking the consideration of the most suitable water (i.e. water quality) relative to other users.

- There is sufficient evidence that Lesotho is likely to get wetter in future, which should increase the potential for hydro-electricity. However, the risks posed by climate change also includes increased flooding (which may damage infrastructure). The ability of Lesotho to adapt to these challenges will determine their ability to continue providing energy to South Africa. This poses a risk to future energy supply to the country through imports.

Scenarios and the mapping of water and energy resources

- Participants noted that the time frame for the energy options was not well defined. There was deemed to be a need to not only focus on the long-term, but to have energy options for the short-term (i.e. 5 years), particularly in light of the current energy crisis.
- The energy options were based on the IRP national scenarios. It was discussed that there was deemed to be a need to think outside of the IRP box, and to develop energy

option that have not been proposed. There is currently a gap in the current scenarios, as they do not represent the most optimal water-energy option. Therefore, two additional scenarios were proposed by the participants:

  - Demand management scenario, which is focused on energy efficient technologies and on decreasing energy demand. This is due to the fact that a decrease in energy demand results in a decrease in energy generation, and ultimately a decrease in water used and water impacted by energy resources.
  - Water supply scenario, which is focused on water-efficient and low impact technologies that still provide the required energy output (base and peak load). This scenario provides an optimised water-energy mix.

- Energy options also need to address technology that is out of the box. As technology is constantly being updated, there is a need for new technologies to be highlight. These include options such as floating solar panels, which not only generate electricity, but also reduce water evaporation in dams. These options should be highlighted in the report. There is a need to think outside of engineering terms when considering energy resource option. Issues such as social and ecological impacts should also be considered.

- The Department of Environmental Affairs (DEA) and the Council of Scientific and Industrial Research (CSIR) developed a project that defines development zones for the country. The Renewable Energy Development Zones (REDZs) are aimed at supporting the strategic planning and future development of wind and solar PV projects in the medium to long term in the country.

The Decision Support Framework and Tool

- The framework was deemed as useful.
  - The national level scenario needs to expand on how water can be included in the energy planning process. This will ultimately lead to the objectives of this framework, which is to promote integrated planning as defined by the IEP. Therefore, a new (never seen before) framework needs to be developed.
  - Although deemed useful, it was found that the questions were vague and therefore needed to be updated. It was suggested that considerations for food and social aspects also need to be incorporated.

B 6. Recommendations

Recommendations from Participants

The workshop provided a brief overview of the various components of the project. Therefore, stakeholders had an opportunity of commenting on the outcomes of the various tasks. In addition, the responsibility of addressing these recommendations is also provided.

Recommendations on Scenarios (to be addressed by the ERC):

a) More aggressive scenarios are required, and there is a need for short term (5-10yrs) energy options. These should move beyond the IRP scenarios, and should represent that best available options.

b) Two suggested scenarios, i.e. the demand management scenario and the water supply. Detailed descriptions of these are provided in Section B.5.

Recommendations on mapping (to be addressed by Pegasys):

a) Participants recommended that DEA's REDZ mapping be looked at, and the water impacts of the recommended zones be assessed.

Recommendations on National Planning Framework (to be addressed by the ERC):

a) Participants recommended that there is a need to expand on quick-wins – what factors are considered in a 'win' or 'lose' criteria, and how would national level decision-makers determine which energy option is a win.

b) There is a need to include how the 'wins' can be incorporated into scenarios and future energy planning.

c) Provide recommendations on technologies that could be explored at a larger scale to minimise water use and water impacts ('losses'), such as floating solar on hydro dam.

d) Add short section on national lens on trade-offs between social impacts (especially food) and energy – rural development. (This section should also highlight how energy choices result in trade-offs on agriculture/food, and how intensive agriculture limits/impacts energy choices.)

Recommendations on Catchment Planning Framework (to be addressed by Pegasys):

a) The questions should be updated and the tool should be finalised.

b) Possibly ask 2 project developers to test tool and functionality.

Considerations for recommendations

The ability of the project team to address the above the recommendations will depend on numerous aspects, such as:

- The availability of required data and required mechanisms to build the required scenarios. As building scenarios (from scratch) for integrated resource planning requires extensive data and consultations with a wide spectrum of stakeholders, it is a project in its own right. In order to have meaningful comparison, the timescales need be chosen in conformity with the existing future scenarios pertaining to development plans or climate change models (Promper *et al.* 2014). In the present work, consideration was given to meaningful time horizons for which national data would be available in South Africa (SA). The use of 5 years would only be acceptable if other existing developmental national plans cover this period.
- Demand is driven by the type and rate of growth of the economy rather than being a variable in the energy mix. Energy efficiency is addressed in the first phase of the IRP process.
- In future IRP Update scenarios water requirements for electricity might be optimized (along with supply and cost) rather than treating water consumption as a constraint.
- The limitations of the scope and budget of the project.

The project team agreed that the recommendations should be addressed before the end of June 2015.

APPENDIX C Capacity building

Student research

Two postgraduate students (Ms Letsiwe Dlamini and Mr Pieter Krog) were awarded bursaries (R60 000 each) toward their studies for a master's degree at the University of Cape Town (UCT). They both completed their coursework (80 credits) and embarked on their research projects in 2014. In order to qualify for the award of master's degree, candidates had to complete a dissertation worth 120 credits. Consequently, research projects played a significant role in this training programme.

Ms Dlamini successfully completed her research project, and graduated in June 2015. She investigated 'Alternative funding sources for community equity ownership in renewable energy projects in South Africa'. Out of this research, one article has been drafted and submitted for possible publication in a journal. She is the first author of this article which is currently under review. Mr Krog submitted his dissertation, tilted 'To what extent can subsidised housing contribute to climate mitigation?', on 17 February 2015. He is expected to graduate in December 2015. Abstracts of the dissertations are given in Appendix D.

Internship

Ms Dlamini and Mr Krog have also been involved in the main WRC project as interns to enable them gain practical experience in research. They have been assigned specific tasks to contribute to a given deliverable from time to time. These tasks included: Data collection and analysis, and writing up some sections of draft reports. They also contributed, as co-authors, to drafting two manuscripts which have since been published in the Journal of Energy in Southern Africa and the International Journal of Renewable and Sustainable Energy Reviews. Other students were also involved as interns in this project.

APPENDIX D Abstracts of Student theses

The potential Greenhouse Gas emissions reduction when energy service interventions are applied to the current subsidised housing demand

Submitted by: Petrus Jacobus Krog

To the University of Cape Town, Energy Research Centre

A thesis presented in partial fulfilment of the requirements for the degree of Master of Philosophy in Development Studies

2015

Abstract

This dissertation examines the role of subsidised housing in reducing Greenhouse Gas emissions in South Africa. Climate change is an occurring event and is largely caused by human activities, such as the production of energy from fossil fuels (NRC 2010). Buildings are seen as one of the highest consuming sectors of energy and therefore present many potential climate change mitigation opportunities. The South African subsidised housing sector is expanding significantly and can potentially reduce up to 3% of the total current CO_2 emissions from the residential sector. It can also potentially reduce up to 0.06% of South Africa's total annual CO_2 emissions.

University of Cape Town

Investigating alternative funding sources for community equity ownership in renewable energy projects in South Africa

A dissertation submitted to the Faculty of Engineering and the Built Environment in partial fulfilment for the award of the degree of
Master of Philosophy in Energy and Development Studies

By

Letsiwe Thulisile Sibongile Dlamini

Student Number: DLMTHU009

Energy Research Centre

University of Cape Town

Cape Town, South Africa

2015

Abstract

The combined effect of a number of factors has forced the Government of South Africa to launch and seek to expand the renewable energy sector through the Renewable Energy Independent Power Producer Procurement Programme (REI4P). Such elements include environmental issues, especially climate change; the need to diversify energy sources in order for the country to be energy secure; and the developmental potential that investment in a new industry, in this instance the renewable energy industry, can bring in terms of job creation, economic growth and the exploitation of abundant natural resources. In addition to the REI4P, the Government has also been compelled to seek to expand energy supply in the country, in general, due to the energy crisis, which in turn, is closely associated with a population that is growing at a pace that is much faster than the rate at which energy can be readily supplied.

Community Equity Ownership (CEO) or local community ownership is a unique feature of the REI4P that has recently come under close scrutiny due to its requirement for project companies to offer a minimum of between 2.5% to 5% shares of their companies to local communities residing within 50km of their renewable energy plants, in an effort to contribute toward their socio-economic development; the challenges presented by community trusts; and the subsequent resistance towards the notion of local community ownership by REI4P project companies. It is the subject of this research because it is still a critical and integral component of the REI4P and challenges associated with its financing have, in the past, jeopardised the accomplishment of the very goals for which it was instituted.

The value of Social License to Operate (SLO) is that it can lay the foundation for positive relations to prevail between communities and Independent Power Producers (IPPs) in the pursuit of a viable renewable energy industry and increased energy supply in South Africa. To this end, the study demonstrates that whilst CEO is mandatory in the REI4P, it also constitutes SLO because if communities own shares in REI4P projects, they are more likely to cooperate with them. Thus, the CEO, Socio-Economic Development (SED) and Enterprise Development (ED) requirements of the REI4P essentially represent the SLO ‘building blocks’ for the Programme.

Development Finance Institutions (DFIs) have been at the forefront of funding local community ownership, although other financial institutions, including commercial banks have started financing it as well, while requiring guarantees and security from communities, which can offer neither. The continued implementation of the REI4P, as well as the launch of the

Baseload IPP Programme and the Medium Term Risk Mitigation Project, will ultimately increase the total number of IPP Programmes in the country and will likely intensify the demand for finances to fund CEO, should it be sustained. In view of this, where will the funding for this key aspect of the current and proposed IPP Programmes come from? This study sought to identify alternative funding options for CEO in order to support its continued implementation in both the REI4P and the proposed IPP Programmes.

An exploratory research design was pursued for the study in view of data limitations arising from the infancy of the renewable energy sector in South Africa. Moreover, a questionnaire survey was undertaken and a purposive sampling technique was used to interrogate a select group of financial institutions and REI4P Independent Power Producers (IPPs), with a view to determine what their experiences have been in relation to funding CEO, as well as to identify alternative funding options for it, going forward. In this regard, a sample size of 15 was taken out of a combined total of 72 financial institutions and IPPs. Thematic content analysis was subsequently performed to process the data.

The main risk associated with financing CEO that was identified by stakeholders has to do with a lack of security in lending to disadvantaged communities because they often have no collateral and can offer no guarantees that demonstrate their capacity to repay debts. Furthermore, the establishment of a Grant Scheme for funding CEO, on the one hand, and a Guarantee and Incentive Programme, on the other, wherein Government stands in as guarantor for communities as they borrow funds to facilitate CEO; were found to be potentially instrumental in widening the pool of funding for CEO. Increased vendor support and more 'preferential' loan terms and 'softer' loans from DFIs were also identified as critical in the endeavour to increase the funding sources for CEO. Although the use of the Government Pension Fund to warehouse shares on behalf of communities and utilising communal land as equity both hold some promise; they require further research. It is, therefore, concluded that there is potential for alternative funding options for community equity ownership in the REI4P. The study also found that, based on the experiences of survey respondents, there are inadequate sources of finance for CEO, in light of the increasing pressure on available financial opportunities. To this end, the delineation between the potential for funding local community shareholding in REI4P projects and actual access to funding is fundamental.

APPENDIX E : Publications

Accredited journals

MADHLOPA A, SPARKS D, KEEN S, KROG P and DLAMINI T (2015) Optimization of a PV-wind hybrid system under limited water resources. *Renewable and Sustainable Energy Reviews* **47** 324-331.

SPARKS D, MADHLOPA A, KEEN S, MOORLACH M, DANE A, KROG P, DLAMINI T (2014) Renewable energy choices and their water requirements in South Africa. *Journal of Energy in Southern Africa* **25**(4) 80-92.

Conference paper

The abstract below was accepted for publication and presentation at the 4th YWP-ZA Biennial and the 1st African YWP Conference. However, only the presentation was done at the conference (provided in the following page). The publication will be submitted to WISA or WaterSA before the end of 2016. The WRC will be acknowledged as required.

A FRAMEWORK FOR CATCHMENT BASED WATER-ENERGY RESOURCE PLANNING

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Water and energy systems have historically been treated as separate realms, with little consideration of one in the planning of the other, and little discussion of interactions between the two. Yet in reality, they are closely interlinked. Water is needed in the vast majority of global energy production systems, for fuel extraction and processing, in hydropower production, and for power-plant cooling, among other uses. And energy is essential for pumping, treating and distributing water.

Due to the inter-linkages between the two resources, many challenges that involve energy and water require tightly coupled understanding of these systems' co-dependencies. For example, changes in climate may spark increased demand for water resources and energy resources, leading to a higher demand for hydropower but lower hydropower availability. Therefore, a holistic and integrated approach can examine all criteria for these problems at once, resulting in more equitable solutions and providing insight to those that have the ability

to enact these solutions. In addition, it is essential that water and energy resource availability, planning and management are considered at the appropriate scale.

This framework therefore aims to aid water resource planners and managers, as well as project developers to assess the state of the water resources (at the appropriate scale), to assess potential water quantity requirements and quality impacts, and to ascertain the suitability of a specific energy resource for the intended catchment, particularly in the context of a changing climate. This framework therefore provides a tool where planners and project developers can explore how individual water or energy management choices are likely to influence either system, and thus enables the consideration of the key issues and impacts to water resources within the specific context of the proposed development, as well as an understanding of trade-offs that might not be apparent when looking at either system alone.

Keywords: Climate Change, Energy Resources, Framework, Integrated Planning, Water Resources, Water-Energy Nexus

Topic: Environmental water, and water resources OR Water governance, management and society

Stop Talking, Start Doing

A Framework for Catchment-Based Planning for the Water-Energy Nexus

4th YWP-ZA Biennial and 1st African YWP Conference

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Introduction

Water and energy systems have historically been treated as separate realms, with little consideration of one in the planning of the other, and little discussion of interactions between the two. Yet in reality, they are closely interlinked. Water is needed in the vast majority of global energy production systems, for fuel extraction and processing, in hydropower production, and for power-plant cooling, among other uses. And energy is essential for pumping, treating and distributing water.

Therefore, a holistic and integrated approach can examine all criteria for these problems at once, resulting in more equitable solutions and providing insight to those that have the ability to enact these solutions. In addition, it is essential that water and energy resource availability, planning and management is considered at the appropriate scale.

Considerations for Decision Making

There are several factors that need to be included in the catchment-based decision making process. A 3-step process, should be followed to ensure that all the important aspects and information have been taken into account

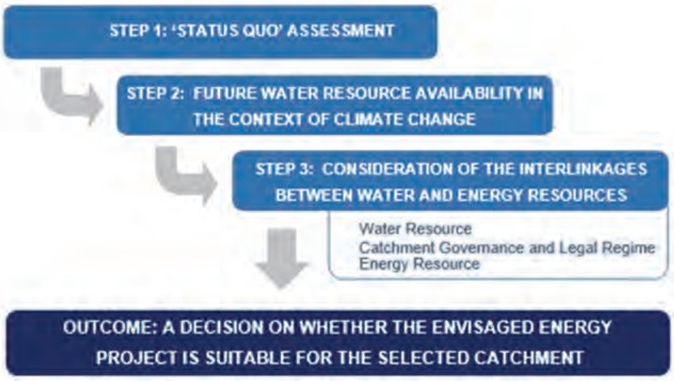


Figure 1: Three Step Process for Catchment-Based Decision Making

Step 1: 'Status quo' assessment. This entails a 'snapshot' of the current state of water resources at the proposed location.

Step 2: Future water resource availability in the context of climate change. This entails estimates of future water resource availability that are associated with climate projections.

Step 3: Consideration of the interlinkages between energy and water resources. There are various cross-cutting parameters that need to be considered, and proper comprehension of these parameters is required prior to the completion of this decision-making process. These parameters are associated with *water resources*, the *catchment governance*, and the *energy resource* being considered for the project.

a) **Water resources.** The current and future status of the proposed catchment needs to be properly evaluated. This entails an assessment of whether the catchment is in deficit, is stressed or is water-abundant. To enable the assessment of the current and future state of water resources, the questions that should guide the decision on whether the proposed catchment is suitable are presented in Figure 2.

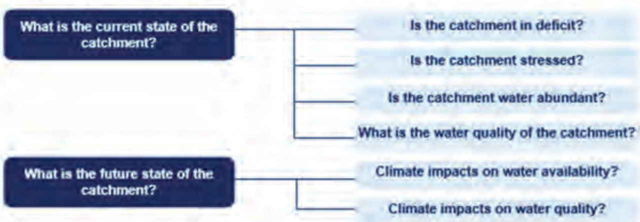


Figure 2: Water resource considerations

b) **Catchment governance and legal regime.** The regime is associated with how the catchment is managed and how plans are made for water and energy resources. This includes not only the institutional and regulatory environment, but also the catchment characteristics. To enable this assessment, the questions that can guide the considerations for an energy project are provided in Figure 3.

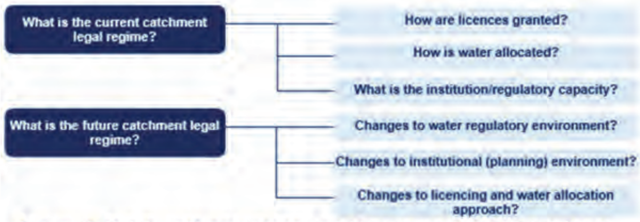


Figure 3: Catchment governance and legal regime considerations

c) **Energy resources.** The location of the energy resource and the water resources that it will utilise should be identified. This includes an understanding of the water requirements and water impacts over the life cycle of the energy project. To enable this assessment, the questions that can guide the considerations for an energy project are provided in Figure 4.

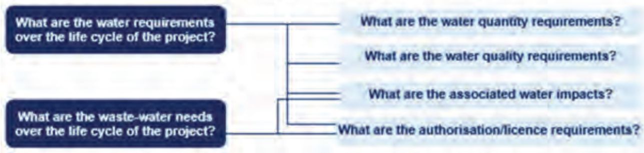


Figure 4: Energy resource considerations

It is essential that the water considerations are for the entire life-cycle of the energy resource. An excel based tool was developed to enable the implementation of the framework. It is aimed at assessing whether a proposed catchment is suitable for an energy resource project.

Case Study: Sustainable Energy System at Three Crowns Primary School, Lady Frere

Three Crowns Primary School is situated in the Chris Hani District in Khavola Village near Lady Frere, about 220km from East London in the Eastern Cape. It currently serves 178 children and caters from Grade R to Grade 6. In 2008, through the Eskom WESSA Energy and Sustainability Programme, and at the request of the Lady Frere District division of the Department of Basic Education, the Three Crowns Primary School was able to have a sustainable energy system installed at the school. The sustainable energy technologies that have been installed at the school can be put into two categories, a solar photovoltaic system) and renewable thermal (i.e. a solar cooker and biogas digester).

This case study will focus on the solar photovoltaic (PV) system. Due to the fact that Solar PV uses low amounts of water, and has minimal water impacts, the outcome of the tool was that the Kei Catchment is suitable for the energy project.

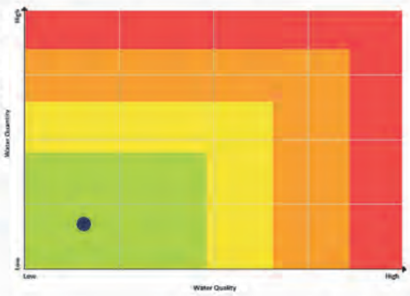


Figure 5: Outcome of the tool

Conclusions

This framework aims to aid water resource planners and managers, as well as project developers to assess the state of the water resources (at the appropriate scale), to assess potential water quantity requirements and quality impacts, and to ascertain the suitability of a specific energy resource for the intended catchment, particularly in the context of a changing climate. It provides a tool where planners and project developers can explore how individual water or energy management choices are likely to influence either system. It thus enables the consideration of the key issues and impacts to water resources within the specific context of the proposed development, as well as an understanding of trade-offs that might not be apparent when looking at either system alone.

APPENDIX F : DATA ON INTERNATIONAL WATER USAGE IN ENERGY PRODUCTION

Table F-1: Pre-generation water withdrawals for thermoelectric fuel cycles.

Fuel	Energy production stage	On-site L/MWh	Upstream L/MWh	Country	Reference
Coal	Eastern underground mining and washing	190	507	USA	DOE 1983, Fthenakis and Kim 2010
	Eastern surface mining (0.9 seam thickness)	38[a]	148	USA	DOE 1983, Fthenakis and Kim 2010
	Western surface mining (0.7 m seam thickness)	NA	11	USA	DOE 1983, Fthenakis and Kim 2010
	US coal mining	106	53	USA	Gleick 1993 Fthenakis and Kim 2010
	Beneficiation (Material fractionation)	>45	53	USA	Fthenakis and Kim 2010
	Transportation (train)	NA	26-38	USA	Fthenakis and Kim 2010
	Transportation (slurry pipeline)	450	3 100	USA	Fthenakis and Kim 2010
	Construction – coal-power plant	NA	11-45	USA	Fthenakis and Kim 2010
Nuclear	Uranium mining	38	15	USA	Fthenakis and Kim 2010
	Milling	19	68	USA	Fthenakis and Kim 2010
	Conversion	15	8	USA	DOE 1983, Fthenakis and Kim 2010
	Enrichment (diffusion)	79	115	USA	Fthenakis and Kim 2010
	Enrichment (centrifuge)	8	102	USA	DOE 1983, Fthenakis and Kim 2010
	Fuel fabrication	0.3	0.4	USA	DOE 1983, Fthenakis and Kim (2010)
	Power plant construction (PWR)	NA	19	USA	DOE 1983, Fthenakis and Kim 2010
	Power plant construction (BWR)	NA	38	USA	DOE (1983), Fthenakis and Kim (2010)
	Spent fuel disposal	NA	19	USA	Kim and Fthenakis 2005 Fthenakis and Kim 2010
Natural gas	Extraction (onshore)	130	300	USA	DOE 1983, Fthenakis and Kim 2010
	Extraction (offshore)	0.8	0.4	USA	DOE 1983, Fthenakis and Kim 2010
	Purification	64	NA	USA	DOE 1983, Fthenakis and Kim 2010
	Pipeline transportation	1.5	38	USA	DOE 1983, Fthenakis and Kim 2010
	Storage (underground)	NA	15	USA	DOE 1983, Fthenakis and Kim 2010
	Power plant environmental control	NA	89	USA	Fthenakis and Kim 2010

[a] Washing only.

BWR – Boiling water reactor, NA – Not applicable, PWR – Pressurized water reactor.

Table F-2: Pre-generation water consumption for thermoelectric fuel cycles in the United States (Upstream water consumption not included).

Fuel type	Energy production stage	Consumption L/MWh	Country	Reference
Coal	Surface mining	11-53	USA	Fthenakis and Kim 2010
	Underground mining	30-200	USA	Fthenakis and Kim 2010
	Washing	30-64	USA	NETL 2006, Fthenakis and Kim 2010
	Beneficiation	42-45	USA	Fthenakis and Kim 2010
	Transportation – slurry pipeline	420-870	USA	DOE 1983, Fthenakis and Kim 2010
Nuclear	Surface uranium mining	200	USA	DOE 1983, Fthenakis and Kim 2010
	Underground uranium mining	4	USA	Fthenakis and Kim 2010
	Milling	83-100	USA	Fthenakis and Kim 2010
	Conversion	42	USA	DOE 1983, Fthenakis and Kim 2010
	Enrichment (diffusion)	45-130	USA	Fthenakis and Kim 2010
	Enrichment (centrifuge)	4-19	USA	Fthenakis and Kim 2010
	Fabrication	11	USA	Fthenakis and Kim 2010
Natural gas	Extraction (onshore)	NG	USA	Gleick 1993. Fthenakis and Kim 2010
	Extraction (offshore)	NG	USA	Gleick 1993, Fthenakis and Kim 2010
	Purification	57	USA	Gleick 1993, Fthenakis and Kim 2010
	Pipeline transportation	30	USA	Gleick 1993 Fthenakis and Kim 2010

Table F-3: Pre-generation water withdrawal factors of PV and wind technologies for manufacturing the devices and constructing the power plants.

Technology/ fuel	Type	On-site L/MWh	Upstream L/MWh	Reference
PV	Multi-Si	200	1 470	Fthenakis and Kim 2010
	Mono-Si	190	1 530	Fthenakis and Kim 2010
	Frame	NA	64	Fthenakis and Kim 2010
	CdTe	0.8	575	Fthenakis and Kim 2010
	BOS	1.5	210	Fthenakis and Kim 2010
Solar thermal			4-5	Inhaber 2010
Wind	Off shore, Denmark (CF=29%)		230	Schleisner 2000 Fthenakis and Kim 2010
	Off shore, Denmark (CF=46%)		170	Schleisner L.2000, Fthenakis and Kim 2010
	On land, Denmark (CF=25%)		170	Fthenakis and Kim 2010
	Onshore, Denmark (CF=32%)		320	Fthenakis and Kim 2010
	On land, Italy (CF=19%)		250	Fthenakis and Kim 2010
	On shore, Spain (CF=23%)		210	Fthenakis and Kim 2010

CF –capacity factor, BOS – balance of systems

Table F-4: Pre-generation water withdrawal factors for biomass/bioenergy production.

Biomass	Energy type	On-site L/MWh	Upstream L/MWh	Reference
Hybrid Poplar, USA	Electricity	0	187	Mann and Spath 1997
Herbaceous perennials, Southwestern USA, irrigation	Electricity	435 600	1,116	Klass 1998, Fthenakis and Kim 2010
Corn, USA	Ethanol	1 260-43 560	NA	Wu *et al.* 2009
Switchgrass, USA	Ethanol	180-936	NA	Wu *et al.* 2009
Corn, Illinois	Ethanol	1 818	NA	Mubako and Lant 2008
Corn, Iowa	Ethanol	612	NA	Mubako and Lant 2008
Corn, Nebraska	Ethanol	67 320	NA	Mubako and Lant 2008

Table F-5: Pre-generation water consumption factors for biomass/bioenergy production.

Biomass	Energy type	On-site L/MWh	Upstream L/MWh	Reference
Hybrid Poplar, USA	Electricity	0	187	Mann and Spath 1997
Maize, global average	Electricity	72 000	NA	Gerbens-Leenes *et al.* 2009
Sugar beet, global average	Electricity	972 000	NA	Gerbens-Leenes *et al.* 2009
Soybean, global average	Electricity	342 000	NA	Gerbens-Leenes *et al.* 2009
Jatropha, global average	Electricity	831 600	NA	Gerbens-Leenes *et al.* 2009
Corn, USA	Ethanol	972-30 960	NA	Wu *et al.* 2009
Corn, USA	Ethanol	648-204 480	NA	Chiu *et al.* 2009
Switchgrass, USA	Ethanol	180-936	NA	Wu *et al.* 2009
Sugar beet, global average	Ethanol	126 000	NA	Gerbens-Leenes *et al.* 2009
Soybean, global average	Biodiesel	781 200	NA	Gerbens-Leenes *et al.* 2009
Rapeseed, global average	Biodiesel	882 000	NA	Gerbens-Leenes *et al.* 2009

Table F-6: Generation water withdrawal and consumption for thermoelectric fuel cycles.

Power plant	Energy production stage	Withdrawal L/MWh	Consumption L/MWh	Country	Reference
Coal	Once-through, subcritical	103 000	530	USA	NETL 2009, Fthenakis and Kim 2010
	Once-through, supercritical	85 600	450	USA	NETL 2009, Fthenakis and Kim 2010
	Once-through	76 000 -190 000	1 140	USA	Najjar *et al.* 1979, Fthenakis and Kim 2010
	Once-through	NA	1 210	USA	Gleick 1993, Fthenakis and Kim 2010
	Once-through (fluidized-bed)	NA	950	USA	Gleick 1993, Fthenakis and Kim 2010
	Cooling pond, subcritical	67 800	3 030	USA	NETL 2009, Fthenakis and Kim 2010
	Cooling pond, supercritical	57 200	242	USA	NETL 2009, Fthenakis and Kim 2010
	Cooling pond	1 100-2 300	1 000-1 900	USA	Najjar *et al.* 1979, Fthenakis and Kim 2010
	Wet tower, subcritical	2 010	1 740	USA	NETL 2009, Fthenakis and Kim 2010
	Wet tower, subcritical	2 590	2 560	USA	NETL 2007, Fthenakis and Kim 2010
	Wet tower, subcritical	4 430	4 430	USA	Fthenakis and Kim 2010
	Wet tower, supercritical	2 500	1 970	USA	NETL 2009, Fthenakis and Kim 2010
	Wet tower, supercritical	3 940	3 940	USA	Fthenakis and Kim 2010
	Wet tower,	2 270	2 240	USA	NETL 2007, Fthenakis

Power plant	Energy production stage	Withdrawal L/MWh	Consumption L/MWh	Country	Reference
	supercritical				and Kim 2010
	Wet tower	1 900-2 300	1 700-1 900	USA	Najjar *et al.* 1979, Fthenakis and Kim 2010
	Wet tower	NA	3 100	USA	Gleick 1993, Fthenakis and Kim 2010
	Wet tower, eastern	NA	2 800	USA	DOE 1983, Fthenakis and Kim 2010
	Wet tower, western	NA	1900	USA	DOE 1983, Fthenakis and Kim 2010
Nuclear	Once-through	119 000	530	USA	NETL 2009, Fthenakis and Kim 2010
	Once-through	95 000-230 000	1500	USA	Najjar *et al.* 1979, Fthenakis and Kim 2010
	Cooling pond	1 900-4 200	1 700-3 400	USA	Najjar *et al.* 1979, Fthenakis and Kim 2010
	Wet tower	4 200	2 300	USA	NETL 2009, Fthenakis and Kim 2010
	Wet tower	3 000-4 200	2 800-3 400	USA	Najjar *et al.* 1979, Fthenakis and Kim 2010
	Wet tower (LWR)	NA	3 200	USA	Gleick 1993, Fthenakis and Kim 2010
	Wet tower (HTGR)	NA	2 200	USA	Gleick 1993, Fthenakis and Kim 2010
Nuclear	Wet tower (PWR)	NA	3 100	USA	Fthenakis and Kim 2010
	Wet tower (BWR)	NA	3 400	USA	DOE 1983, Fthenakis and Kim 2010
Oil/ gas steam	Once-through	85 900	341	USA	NETL 2009, Fthenakis and Kim 2010
	Once-through	NA	1 100	USA	Gleick 1993, Fthenakis and Kim 2010
	Once-through	NA	950	USA	DOE 1983, Fthenakis and Kim 2010
	Cooling pond	29 900	420	USA	NETL 2009, Fthenakis and Kim 2010
	Wet tower	950	610	USA	NETL 2009, Fthenakis and Kim 2010
	Wet tower	NA	3 100	USA	DOE 1983, Fthenakis and Kim 2010
	Wet tower (oil)	NA	1 100	USA	DOE 1983, Fthenakis and Kim 2010
NGCC	Once-through	34 100	76	USA	NETL 2009, Fthenakis and Kim 2010
	Once-through	28 000-76 000	380	USA	Gleick 1993, Fthenakis and Kim 2010
	Cooling pond	22 500	910	USA	NETL 2009, Fthenakis and Kim 2010
	Wet tower	568	490	USA	NETL 2009, Fthenakis and Kim 2010
	Wet tower	1 030	1 020	USA	NETL 2007, Fthenakis and Kim 2010

Power plant	Energy production stage	Withdrawal L/MWh	Consumption L/MWh	Country	Reference
	Wet tower	1 900	1 900	USA	Fthenakis and Kim 2010
	Wet tower	870	680	USA	Gleick 1993, Fthenakis and Kim 2010
	Dry cooling	15	15	USA	NETL 2009, Fthenakis and Kim 2010
IGCC	Wet tower	855	655	USA	NETL 2009, Fthenakis and Kim 2010
	Wet tower	1 420-1 760	1 360-1 420	USA	NETL 2007, Fthenakis and Kim 2010
	Wet tower	2 600-3 100	2 570-3 140	USA	Fthenakis and Kim 2010
	Wet tower	950	680	USA	Gleick 1993, Fthenakis and Kim 2010

NGCC – natural gas combined cycle, IGCC – integrated gasification combined cycle, LWR – light water reactor, HTGR – high temperature gas-cooled reactor, PWR – pressurized water reactor, BWR – boiling water reactor.

Table F-7: Water use in renewable power plants.

Power plant	Type	Withdrawal L/MWh	Consumption L/MWh	Country	Reference
Biomass	Steam plant	1 800	1 800	USA	Berndes 2002
	Biogas-steam, wet cooling	2 100	1 700	USA	Berndes 2002
	Biogas-steam, dry cooling	150	0	USA	Berndes 2002
CPV	CPV	0	0	USA	Fthenakis and Kim 2010
	CPV, cleaning	15	15	USA	NREL 2002, Fthenakis and Kim 2010
CSP	Tower	2 900	2 900	USA	NREL 2002, Fthenakis and Kim 2010
	Tower	3 200	3 200	USA	NREL1997, Fthenakis and Kim 2010
	Tower, wet cooling	3 100	3 100	USA	NREL 2003, Fthenakis and Kim 2010
	Parabolic trough, wet cooling	3,700	3,700	USA	NREL 2006, Fthenakis and Kim 2010
	Parabolic trough, dry cooling	300	300	USA	NREL 2006, Fthenakis and Kim 2010
	Parabolic trough, wet cooling	3 100	3 100	USA	NREL 2003, Fthenakis and Kim 2010
	Parabolic trough, wet cooling	3 100-3 800	3 100-3 800	USA	Cohen *et al.* 1999, Fthenakis and Kim 2010
	Trough	2 100	2 100	USA	NREL1997, Fthenakis and Kim 2010
	Stirling dish, cleaning	15	15	USA	NREL 2002, Fthenakis and Kim 2010
Geothermal	Dry system	7 570	5 300	USA	DOE 2006, Fthenakis and Kim 2010
	Dry system	6 800	6 800	USA	Gleick 1993, Fthenakis and Kim 2010
	Hot water system	15 000	15 000	USA	Gleick 1993, Fthenakis and Kim 2010
	Hot water system	44 700	2 300-6 800	USA	EPRI 1997, Fthenakis and Kim 2010
Hydro		0	17 000	USA	DOE 1983, Fthenakis and Kim 2010
		0	38-210 000	USA	Fthenakis and Kim

Power plant	Type	Withdrawal L/MWh	Consumption L/MWh	Country	Reference
					2010
			5 300	USA	Fthenakis and Kim 2010
		791 677	20 000	Spain	Carrilo and Frei 2009
PV	PV	0	0	USA	Fthenakis and Kim 2010
	PV, cleaning	15	15	USA	NREL 2002, Fthenakis and Kim 2010
			1-5		Macknick *et al.* 2012
Wind		0	0	USA	DOE 2006, Fthenakis and Kim 2010
		4	4	USA	Fthenakis and Kim 2010

Table F-8: Water withdrawals and consumption over lifecycle of fuels in USA and China.

Fuel type	Withdrawal L/MWh	Consumption L/MWh	Reference
Coal, re-circulating	2 500		Fthenakis and Kim 2010
Coal, once-through	98 400		Fthenakis and Kim 2010
Coal, cooling pond	65 300		Fthenakis and Kim 2010
Coal	16 052	692	Wilson *et al.* 2012
Geothermal	700	700	Wilson *et al.* 2012
Nuclear, re-circulating	5 000		Fthenakis and Kim 2010
Nuclear, once-through	120 000		Fthenakis and Kim 2010
Nuclear, cooling pond	3 900		Fthenakis and Kim 2010
Nuclear	14 811	572	Wilson *et al.* 2012
Oil/gas re-circulating	2 300		Fthenakis and Kim 2010
Oil/gas, once-through	85 900		Fthenakis and Kim 2010
Oil/gas, cooling pond	29 900		Fthenakis and Kim 2010
Natural gas	6 484	172	Wilson *et al.* 2012
PV, multi-Si	1 900		Fthenakis and Kim 2010
PV, CdTe	800		Fthenakis and Kim 2010
PV	231	2	Wilson *et al.* 2012
Solar thermal	800	800	Wilson *et al.* 2012
Wind	<61	<1	Wilson *et al.* 2012
Wind	640		Li *et al.* 2012
Hydro	80		Fthenakis and Kim 2010
Hydro	440 000	9 000	Wilson *et al.* 2012
Biomass, South west	438 000		Fthenakis and Kim 2010
Biomass, Midwest	2 000		Fthenakis and Kim 2010

APPENDIX G : LOCAL WATER RESOURCE ASSESSMENT

Chapter 7 contains a national level assessment of water resources. However, in order to be able to identify areas where renewable energy resources may be located, it was deemed necessary to also conduct a water resource assessment at the WMA level. This appendix mainly contains a graphical assessment; the methodology employed is the same as that used in Chapter 7, and has therefore not been repeated. The data used for this analysis is contained in Appendix G.

G 1. Limpopo WMA

The Limpopo WMA is located in the north-western corner of the country. It is an amalgamation of the previous Limpopo and Crocodile West-Marico WMAs. Figure G-1 below illustrates the location of the Limpopo WMA.

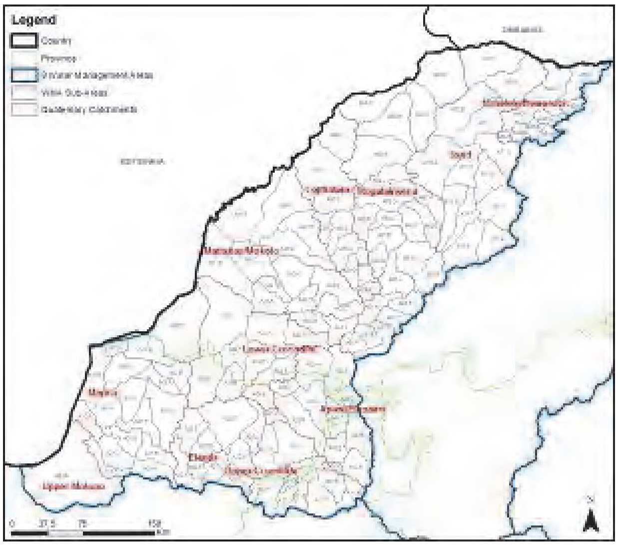


Figure G-1: The Limpopo WMA.

Its main rivers, the Crocodile and Marico, give rise to the Limpopo River at their confluence. The water management area borders on Botswana and Zimbabwe, where the Limpopo River demarcates the entire length of the international boundaries before flowing into Mozambique. The region is semi-arid and the mean annual rainfall ranges from 300 mm to 800 mm over most of the WMA (NWRS, 2004).

G 1.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Limpopo WMA. This includes: water demand (Figure G-3), water availability (Figure G-4), water balance (Figure G-4), rainfall distribution (Figure G-5) as well as the mean annual runoff (Figure G-6).

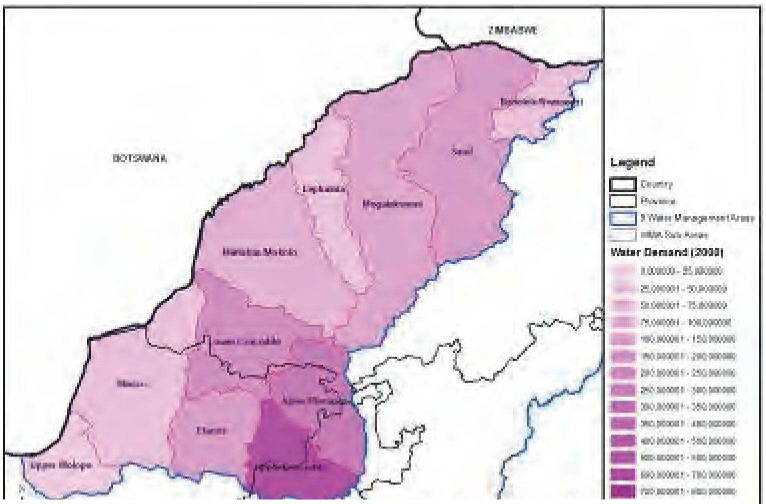


Figure G-2: Current Water Demand of the Limpopo WMA (2000).

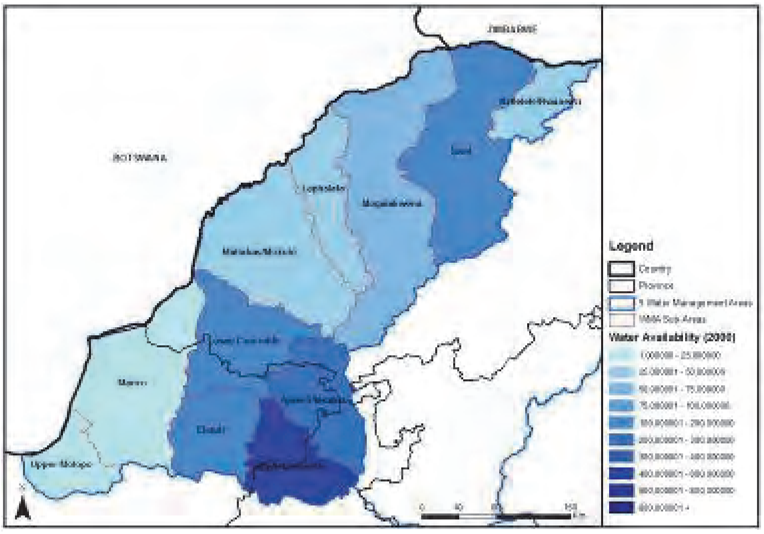


Figure G-3: Current Water Availability (Yield) of the Limpopo WMA (2000).

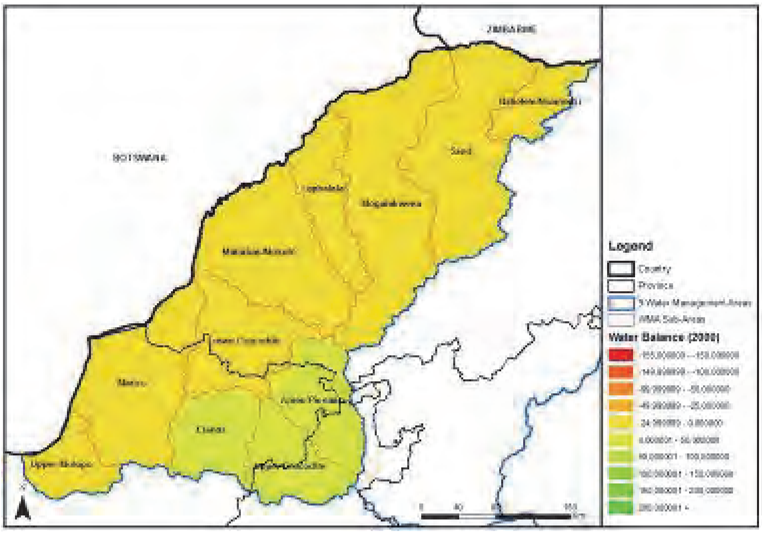


Figure G-4: Current Water Balance of the Limpopo WMA (2000).

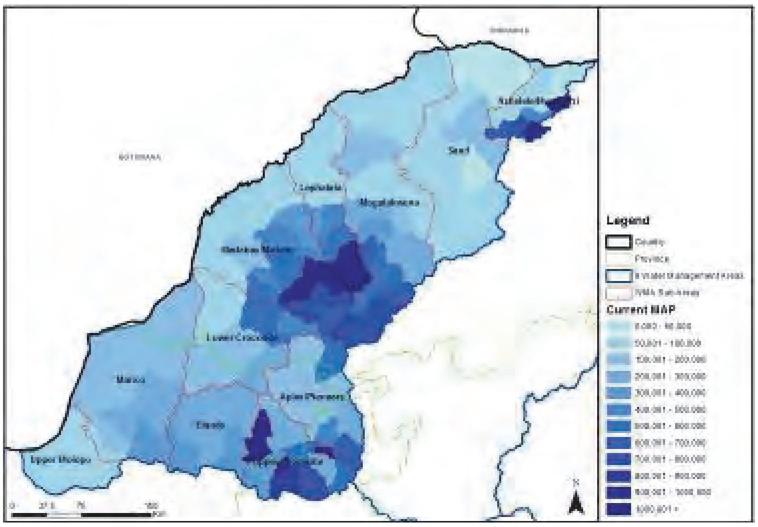


Figure G-5: Current Rainfall Distribution for the Limpopo WMA.

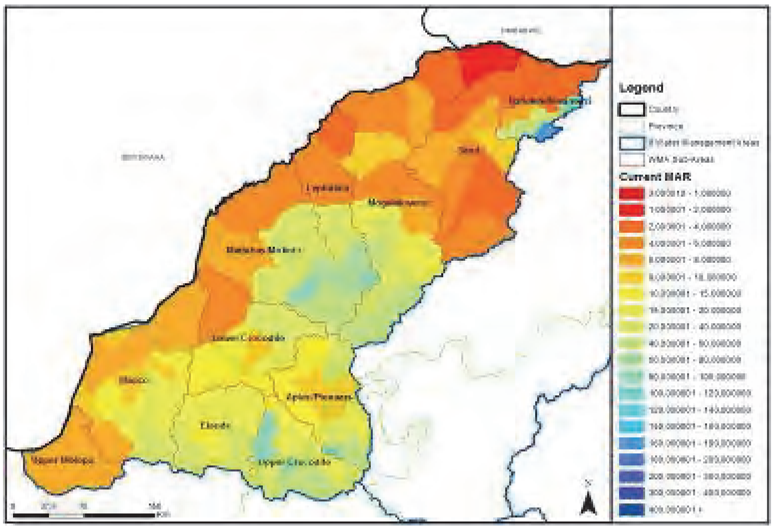


Figure G-6: Current Mean Annual Runoff (MAR) for the Limpopo WMA.

G 1.2. Future status of water resources

This section provides a spatial overview of the future status of water resources for the Limpopo WMA, under different scenarios. This includes: water demand (Figure G-7), water availability (Figure G-8), water balance (Figure G-9), rainfall distribution (Figure G-10) as well as the mean annual runoff (Figure G-11). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-12.

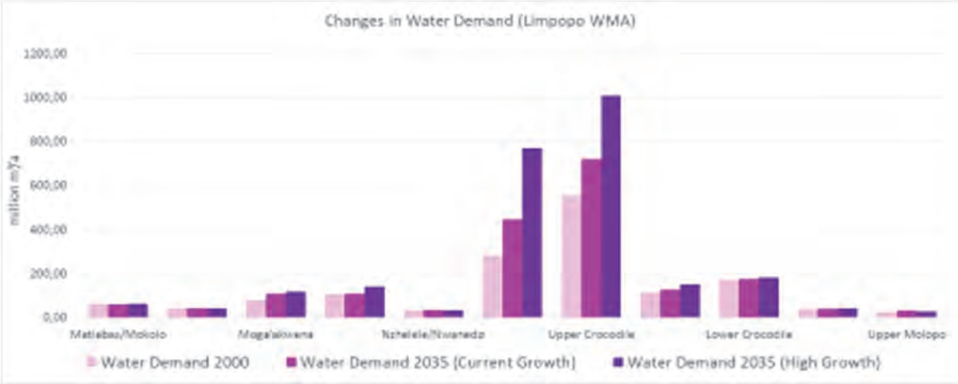


Figure G-7a: Changes in Water Demand under the Different Growth Scenarios for the Limpopo WMA.

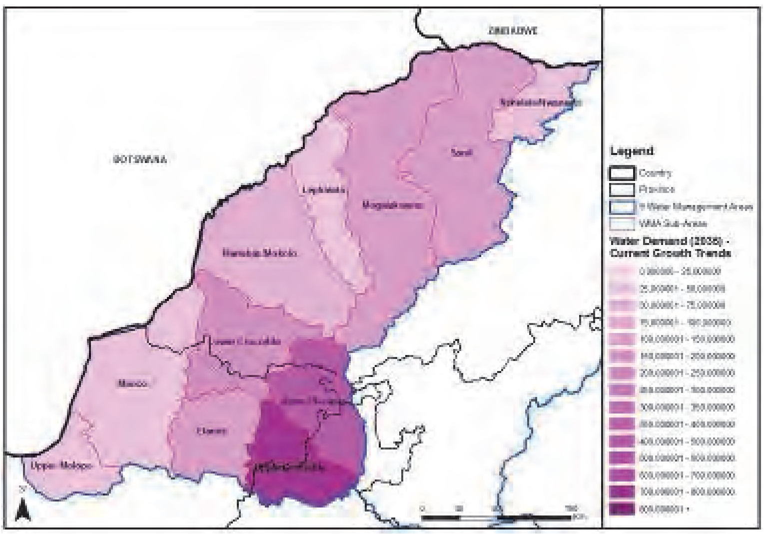


Figure G-7b: Water Demand for Current Growth Trends for the Limpopo WMA.

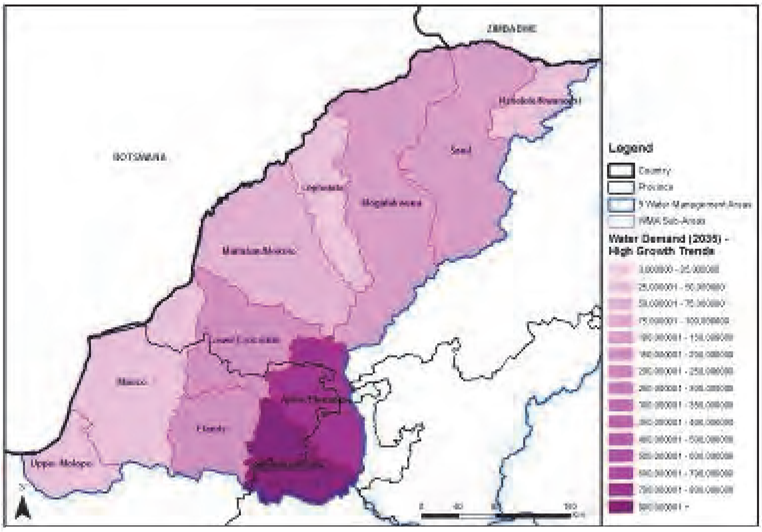


Figure G-7c: Water Demand for High Growth Trends for the Limpopo WMA.

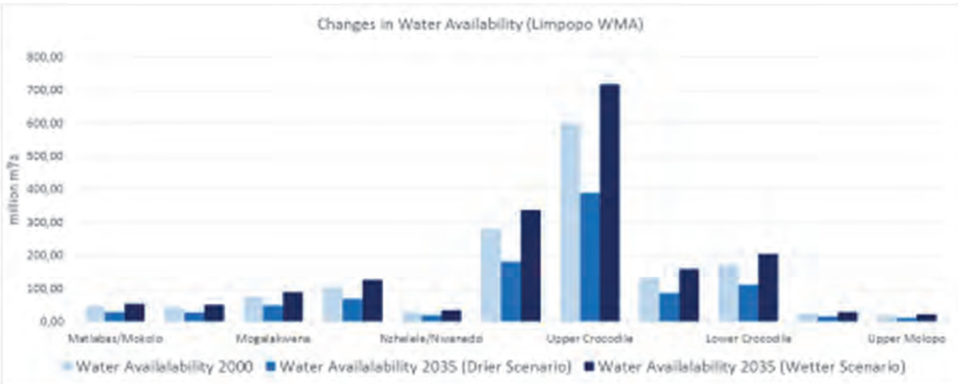


Figure G-8a: Changes in Water Availability under the Different Climate Scenarios.

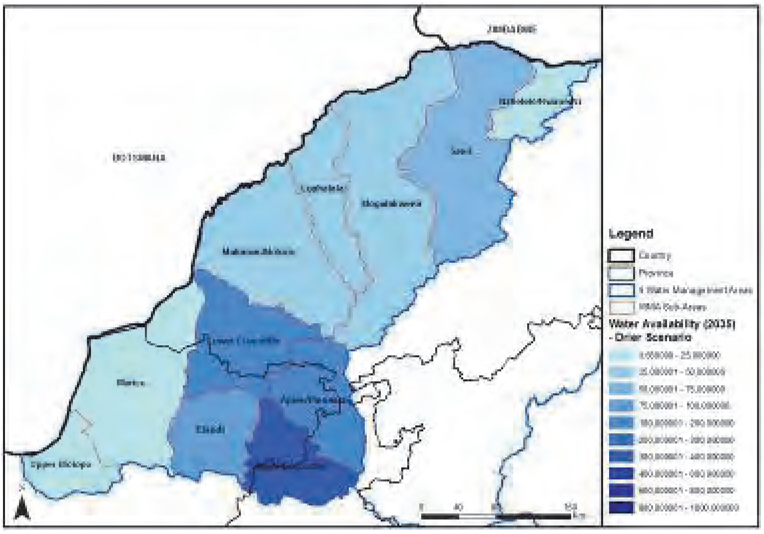


Figure G-8b: Water Availability under a Drier Scenario for the Limpopo WMA.

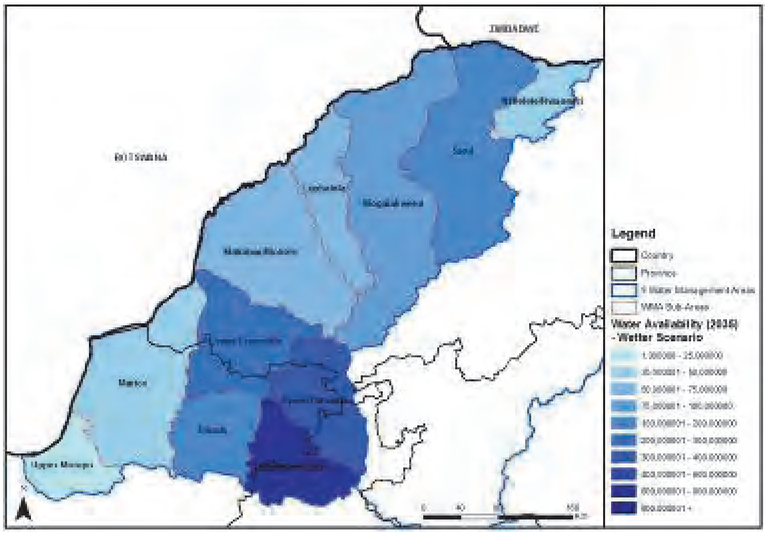


Figure G-8c: Water Availability under a Wetter Scenario for the Limpopo WMA.

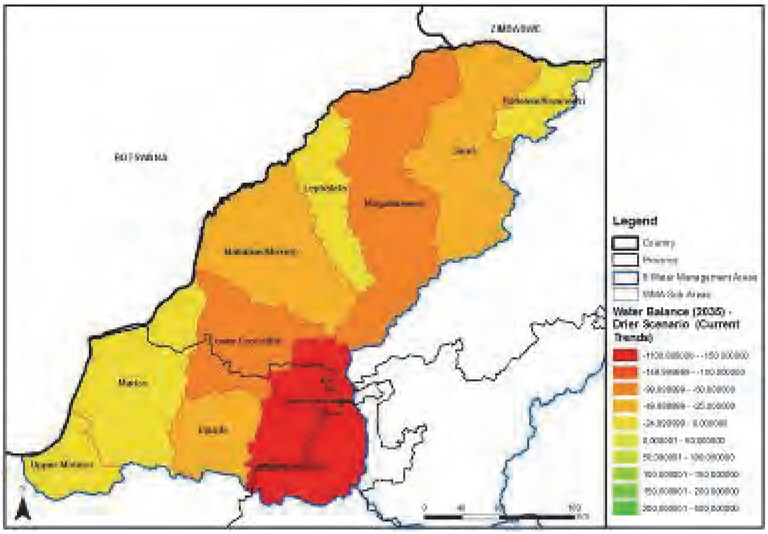


Figure G-9a: Future Water Balance of the Limpopo WMA under a Drier Scenario (Current Growth).

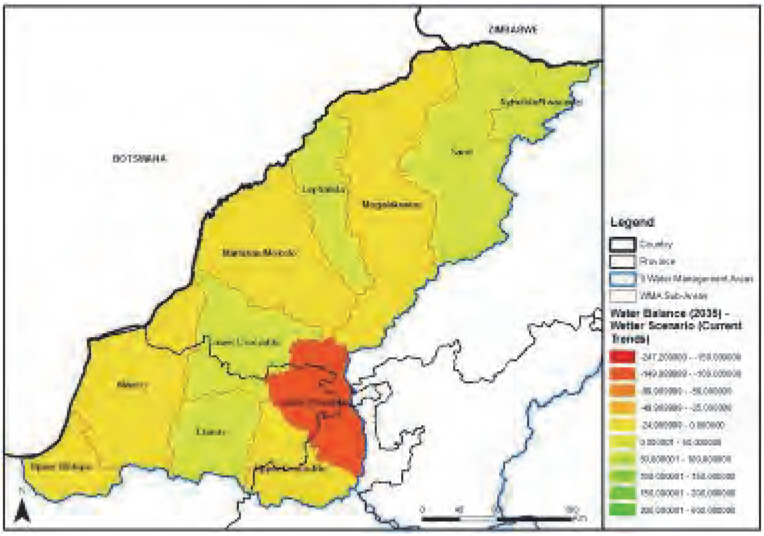


Figure G-9b: Future Water Balance of the Limpopo WMA under a Wetter Scenario (Current Growth).

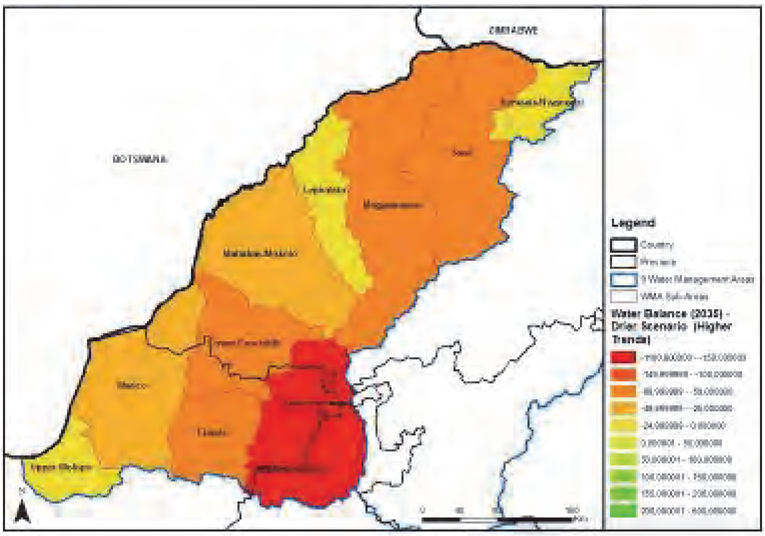


Figure G-9c: Future Water Balance of the Limpopo WMA under a Drier Scenario (High Growth).

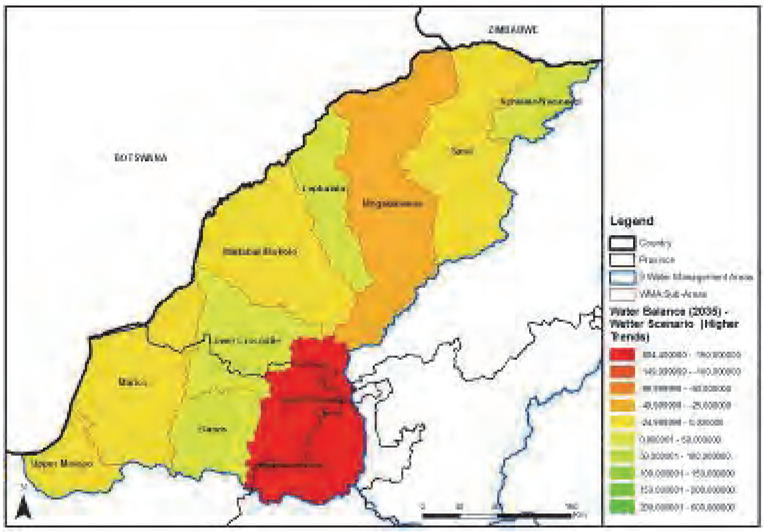


Figure G-9d: Future Water Balance of the Limpopo WMA under a Wetter Scenario (High Growth).

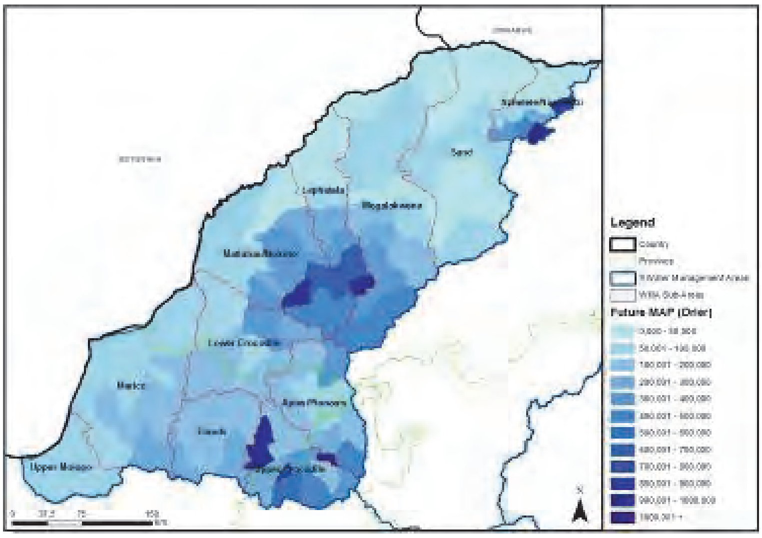


Figure G-10a: Future Rainfall Distribution and for the Limpopo WMA under a Drier Scenario.

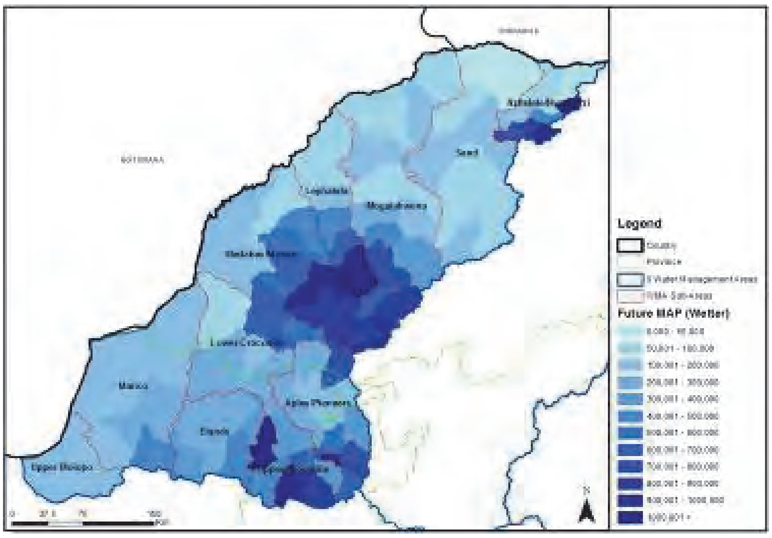


Figure G-10b: Future Rainfall Distribution for the Limpopo WMA under a Wetter Scenario.

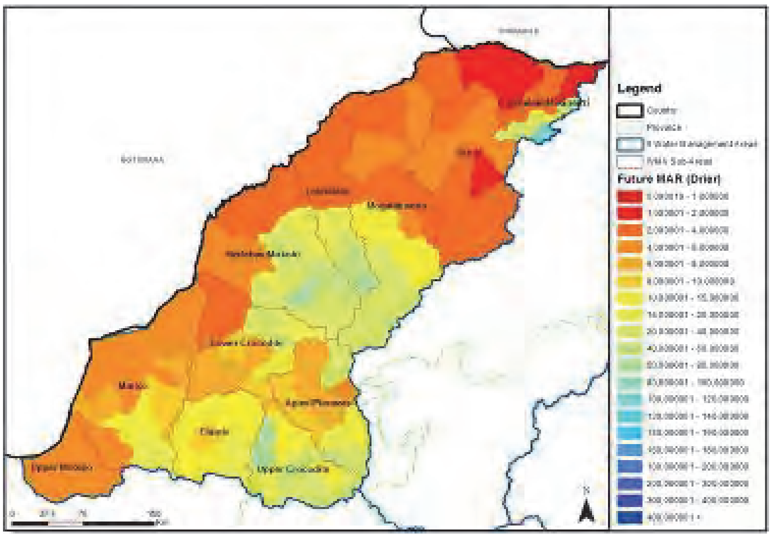


Figure G-11a: Future Mean Annual Runoff (MAR) for the Limpopo WMA under a Drier Scenario.

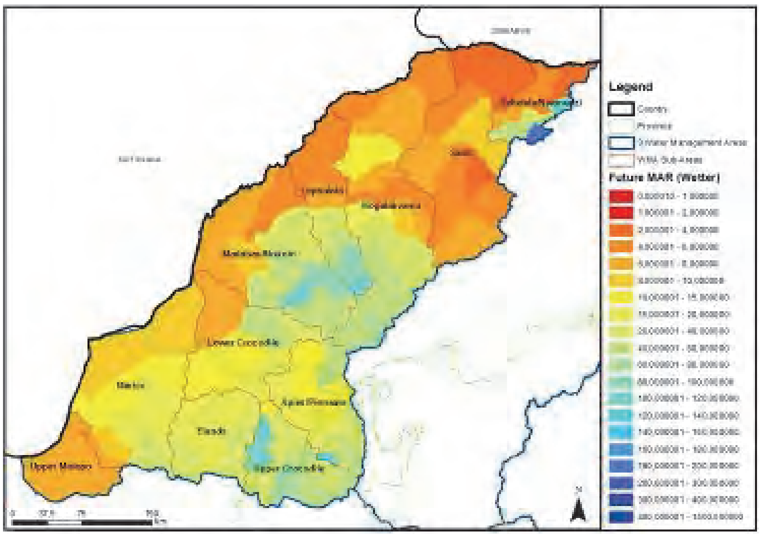


Figure G-11b: Future Mean Annual Runoff (MAR) for the Limpopo WMA under a Wetter Scenario.

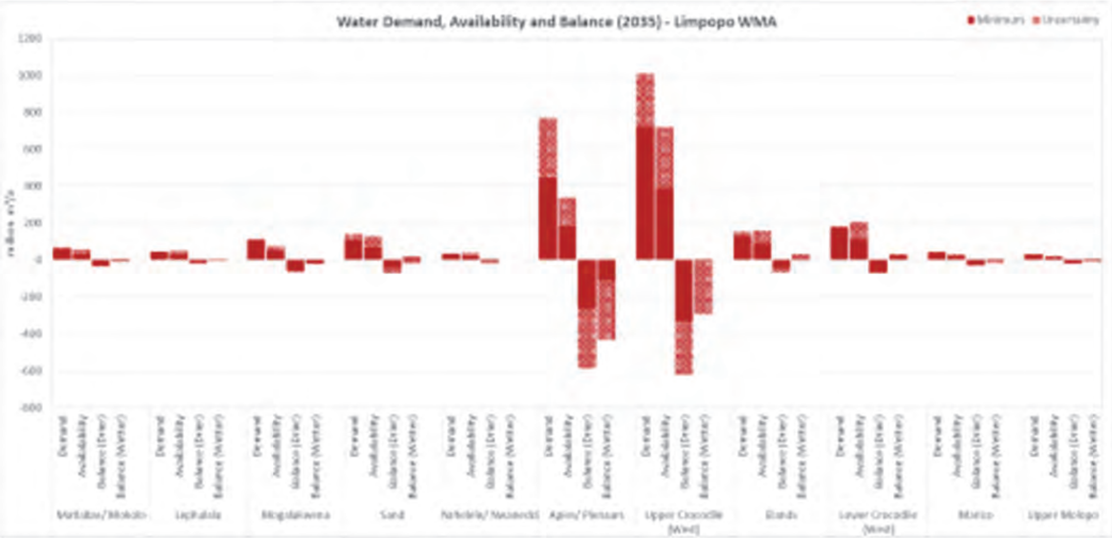


Figure G-12: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is negative for all of the areas in the WMA under a drier future, and positive in Lephalale, Nzhelele / Nwanedzi, Elands and Lower Crocodile (West) under a wetter future. However, low growth could potentially also result in a positive water balance in the Sand area under a wetter future. Therefore, the location of energy resources should be aligned with the water availability.

G 2. Olifants WMA

The Olifants WMA is located in the north-eastern corner of the country. It is an amalgamation of the previous Olifants and Luvuvhu-Letaba WMAs. Figure G-13 below illustrates the location of the Olifants WMA.

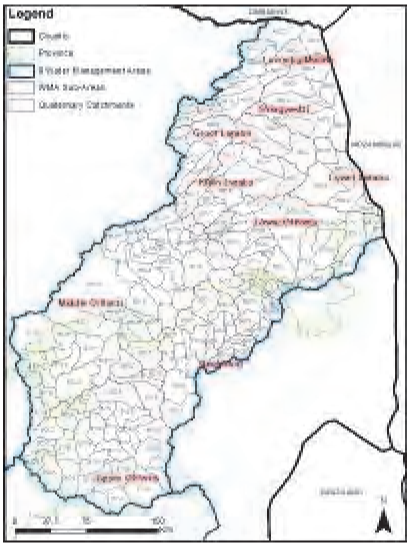


Figure G-13: The Olifants WMA.

The Olifants WMA corresponds with the South African portion of the Olifants River catchment, which is a tributary to the Limpopo Basin shared by South Africa, Botswana, Zimbabwe and Mozambique. The Olifants River originates to the east of Johannesburg and initially flows northwards before gently curving eastwards towards the Kruger National Park (KNP), where it is joined by the Letaba River before flowing into Mozambique. A unique feature of this water management area is the Kruger National Park along its eastern boundary, through which all the main rivers flow into Mozambique. Due to the topography, rainfall varies from well over 1 000 mm/a to less than 300 mm/a. Distinct differences in climate occur; from cool Highveld in the south to subtropical east of the escarpment (NWRS, 2004).

G 2.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Olifants WMA. This includes: water demand (Figure G-14), water availability (Figure G-15), water balance (Figure G-16), rainfall distribution (Figure G-17) as well as the mean annual runoff (Figure G-18).

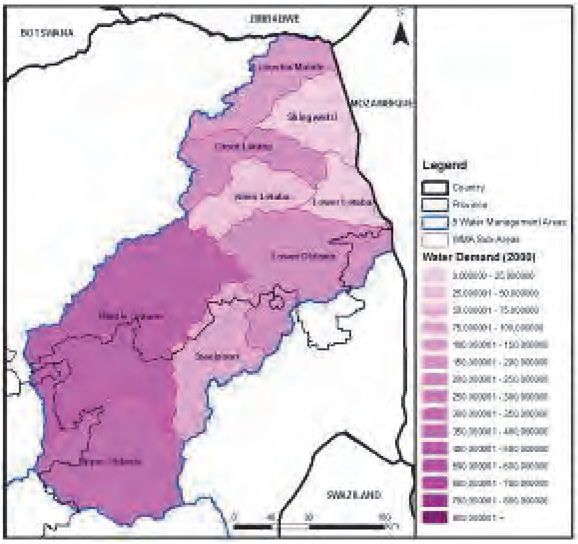


Figure G-14: Current Water Demand of the Olifants WMA (2000).

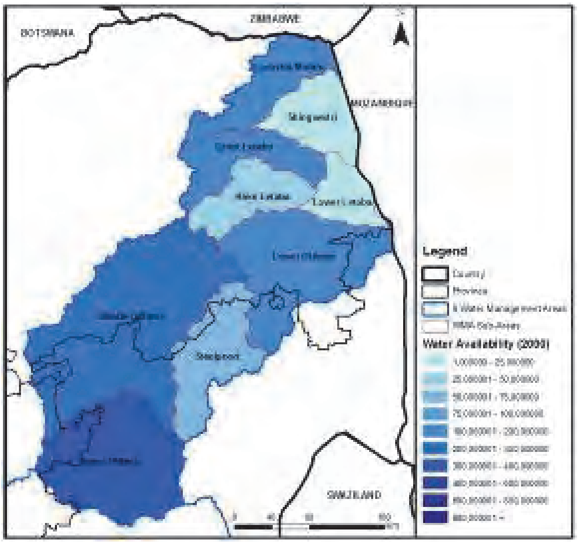


Figure G-15: Current Water Availability (Yield) of the Olifants WMA (2000).

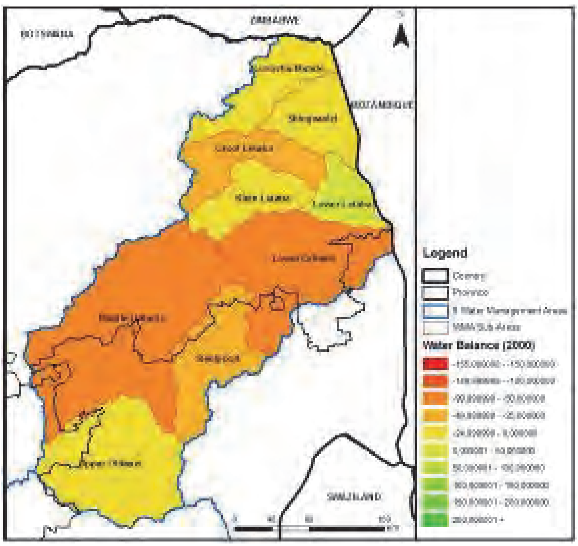


Figure G-16: Current Water Balance of the Olifants WMA (2000).

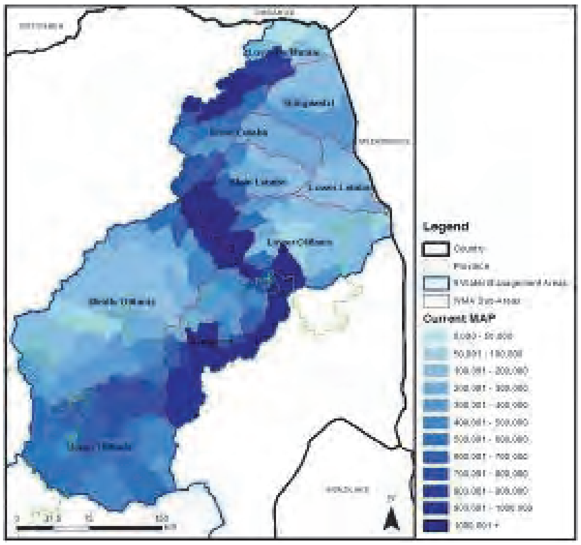


Figure G-17: Current Rainfall Distribution for the Olifants WMA.

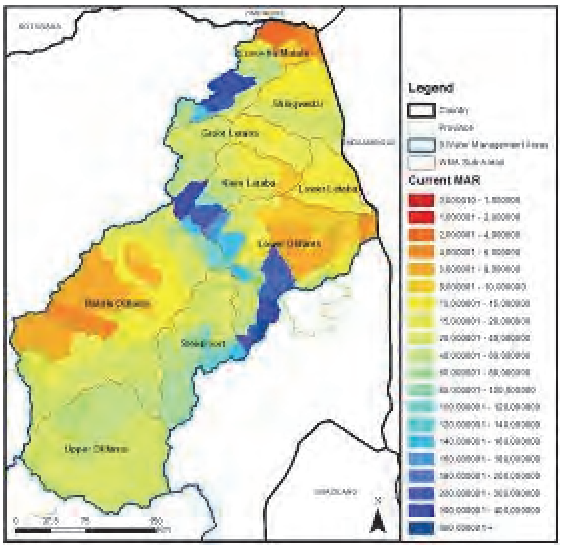


Figure G-18: Current Mean Annual Runoff (MAR) for the Olifants WMA.

G 2.2. Future status of water resources

This section provides a spatial overview of the future status of water resources for the Limpopo WMA, under different scenarios. This includes: water demand (Figure G-19), water availability (Figure G-20), water balance (Figure G-21), rainfall distribution (Figure G-22) as well as the mean annual runoff (Figure G-23). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-24.

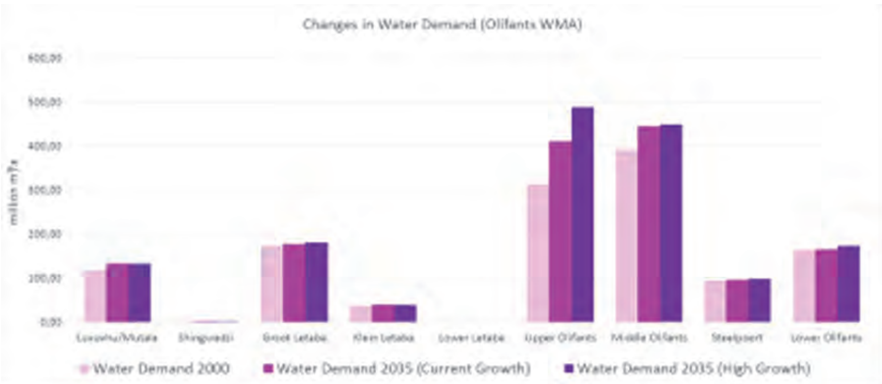
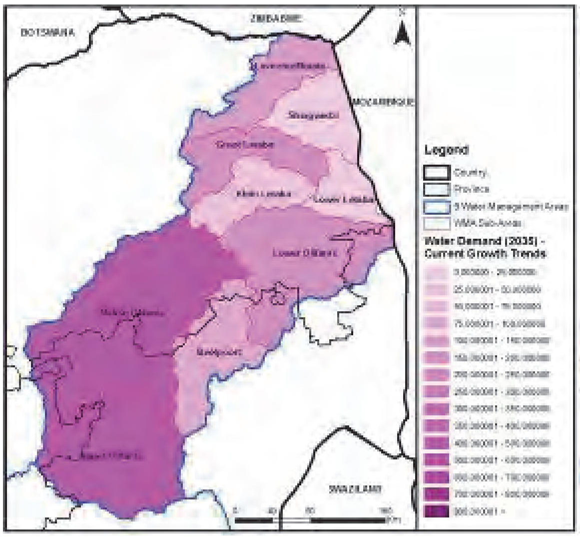


Figure G-19a: Changes in Water Demand under the Different Growth Scenarios for the Olifants WMA.



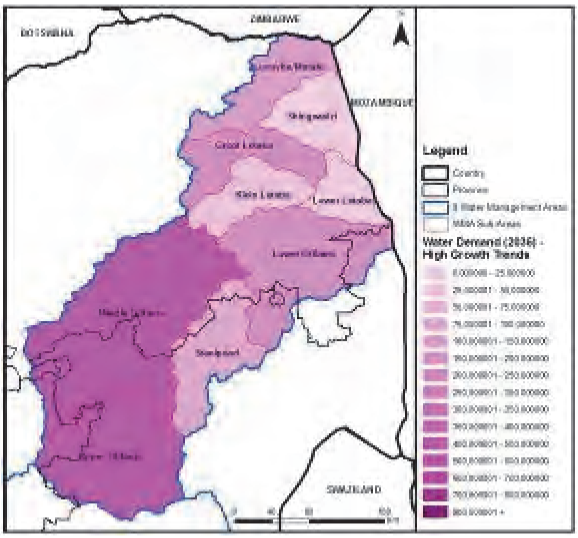


Figure G-19b: Water Demand for Current Growth Trends for the Olifants WMA.

Figure G-19c: Water Demand for High Growth Trends for the Olifants WMA.

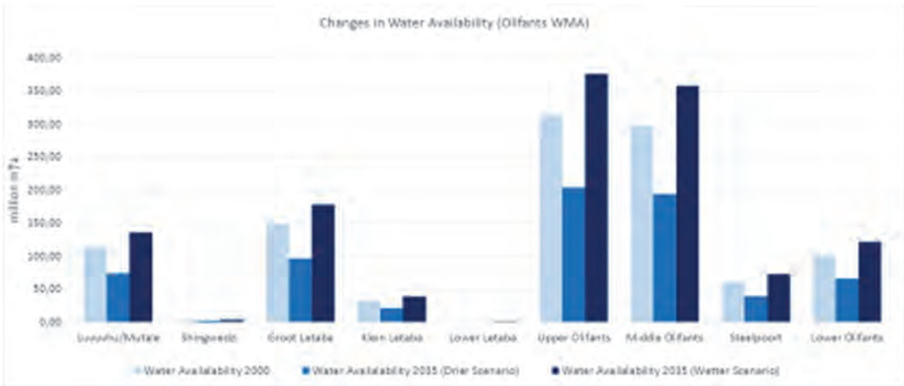
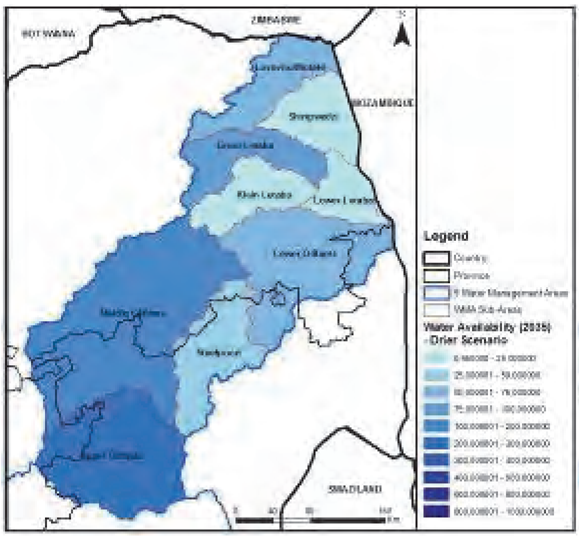


Figure G-20a: Changes in Water Availability under the Different Climate Scenarios for the Olifants WMA.



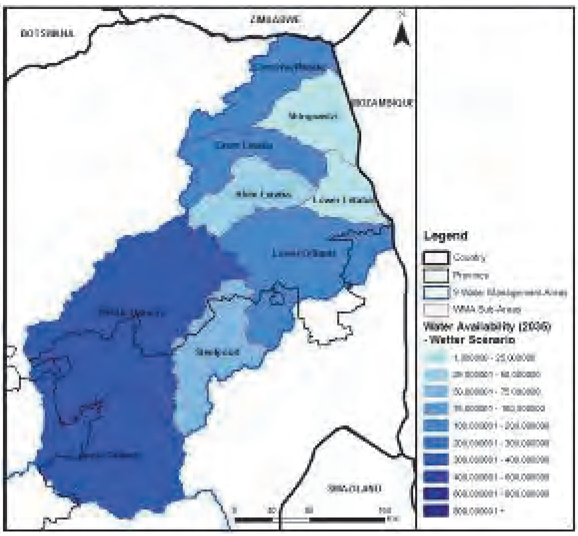


Figure G-20b: Water Availability under a Drier Scenario for the Olifants WMA.

Figure G-20c: Water Availability under a Wetter Scenario for the Olifants WMA.

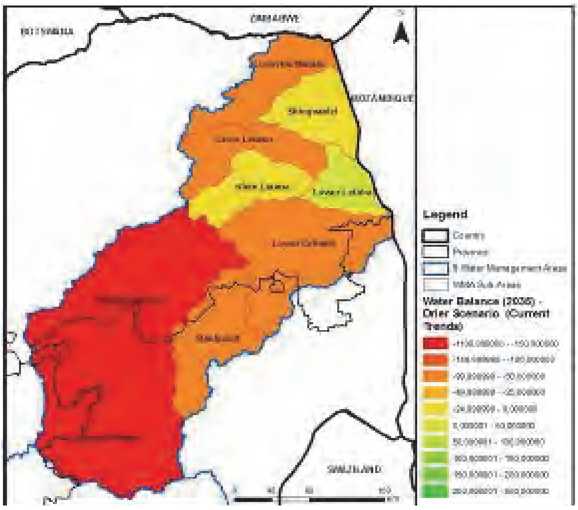


Figure G-21a: Future Water Balance of the Olifants WMA under a Drier Scenario (Current Growth)

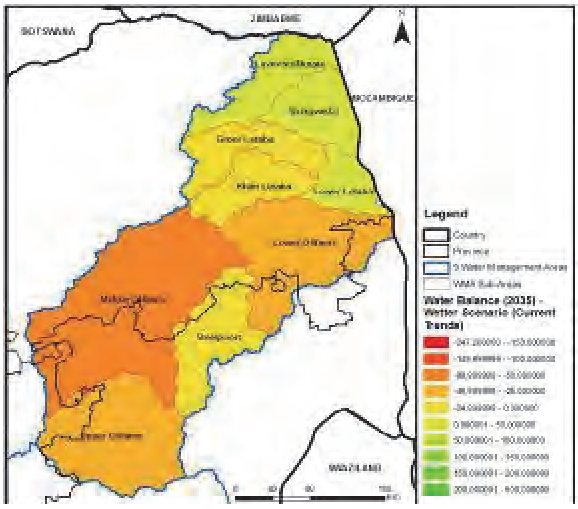


Figure G-21b: Future Water Balance of the Olifants WMA under a Wetter Scenario (Current Growth)

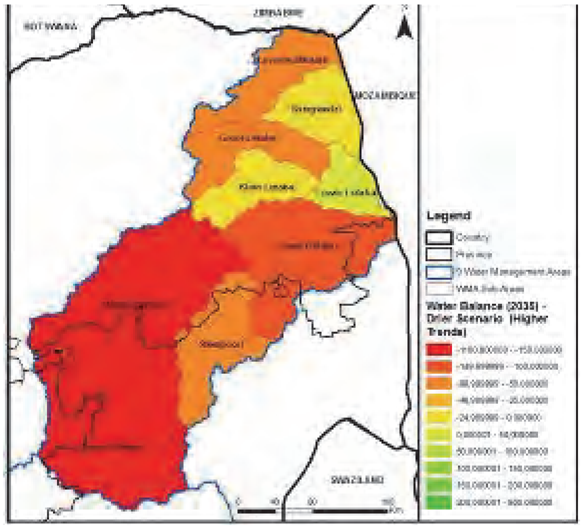


Figure G-21c: Future Water Balance of the Olifants WMA under a Drier Scenario (High Growth).

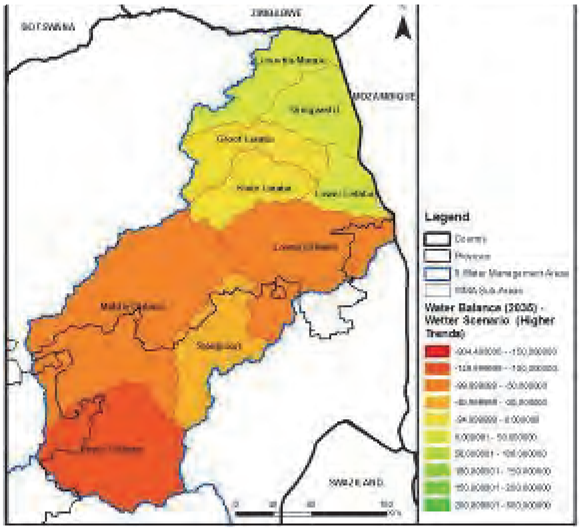


Figure G-21d: Future Water Balance of the Olifants WMA under a Wetter Scenario (High Growth).

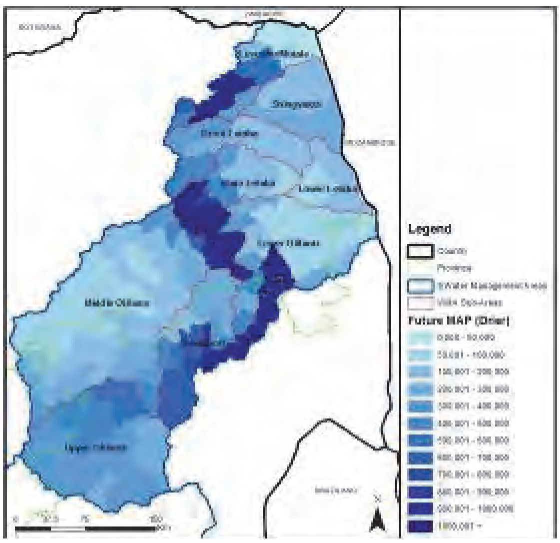


Figure G-22a: Future Rainfall Distribution for the Olifants WMA under a Drier Scenario.

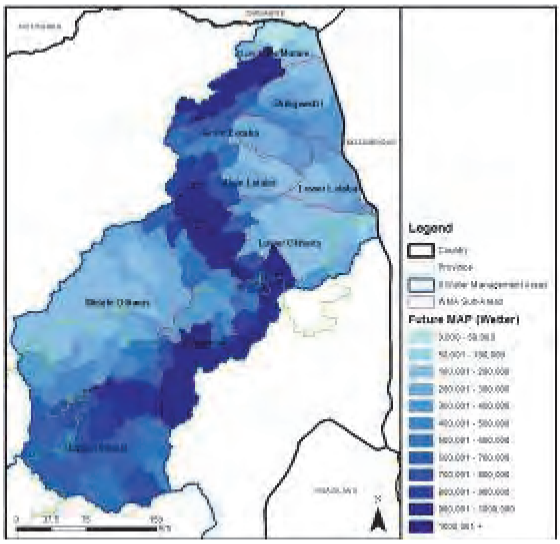


Figure G-22b: Future Rainfall Distribution for the Olifants WMA under a Wetter Scenario.

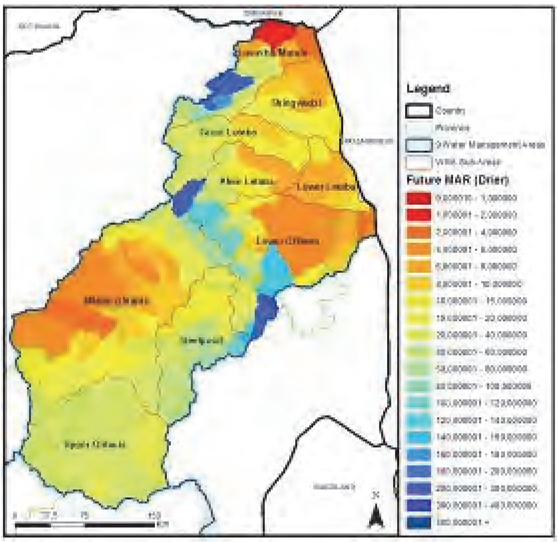


Figure G-23a: Future Mean Annual Runoff (MAR) for the Olifants WMA under a Drier Scenario.

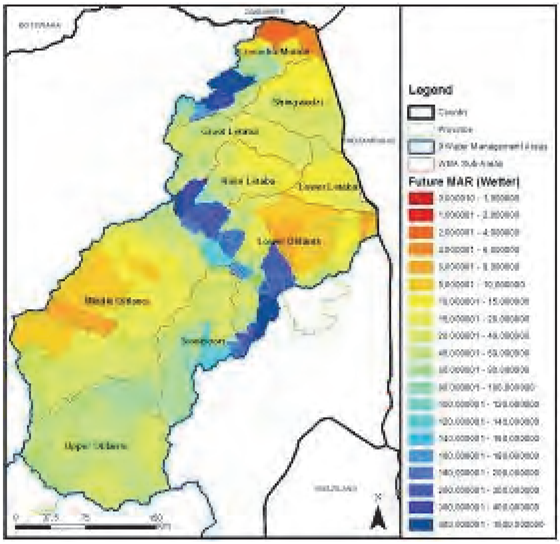


Figure G-23b: Future Mean Annual Runoff (MAR) for the Olifants under a Wetter Scenario.

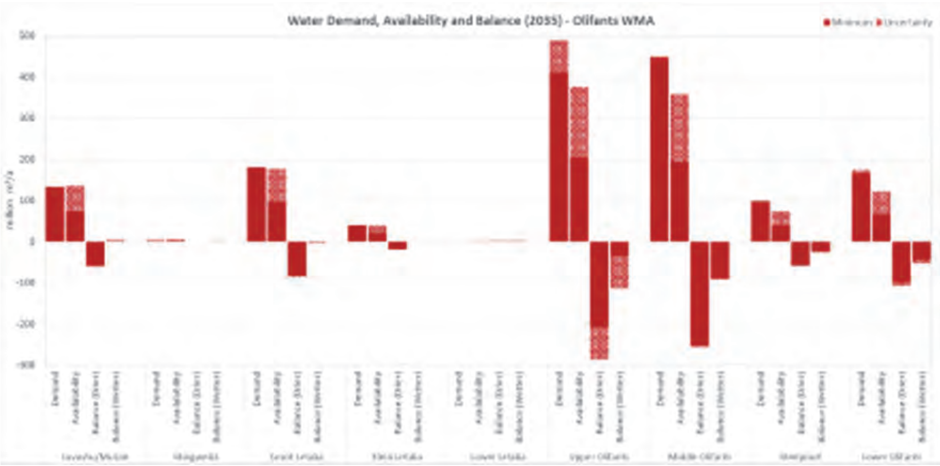


Figure G-24: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is negative for most of the areas in the WMA under a drier and wetter future. Minimal amounts of water are available in Luvuvhu/Mutale, Shingwedzi and Lower Letaba under a wetter future. Therefore, the location of energy resources should be aligned with the water availability.

G 3. Inkomati-Usuthu WMA

The Inkomati-Usuthu WMA is an amalgamation of the previous Inkomati WMA and the Usuthu Catchment of the Luvuvhu-Letaba WMA. Figure G-25 below illustrates the location of the Inkomati-Usuthu WMA.

The WMA is situated in the north-eastern part of South Africa and borders on Mozambique and Swaziland. All the rivers from this area flow through Mozambique to the Indian Ocean. The Komati River flows into Swaziland and re-enters South Africa before flowing into Mozambique. The Usutu River has its headwaters in South Africa and flows into Swaziland. Topographically the WMA is divided by the escarpment into a plateau in the west and a subtropical Lowveld in the east. Annual rainfall varies from close to 1 500 mm in the mountains to 400 mm in the lower-lying areas (NWRS, 2004).

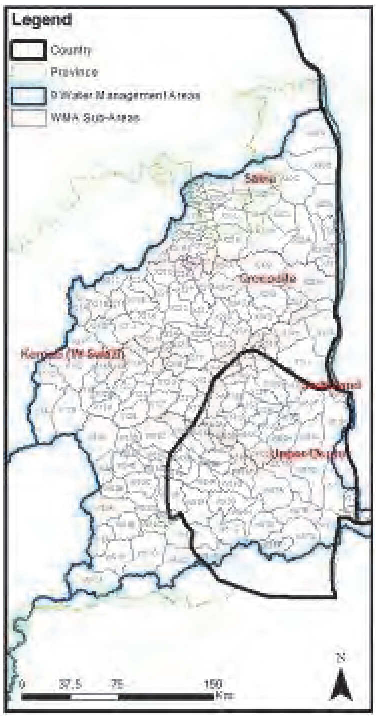


Figure G-25: The Inkomati-Usuthu WMA.

G 3.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Inkomati-Usuthu WMA. This includes: water demand (Figure G-26), water availability (Figure G-27), water balance (Figure G-28), rainfall distribution (Figure G-29) as well as the mean annual runoff (Figure G-30).

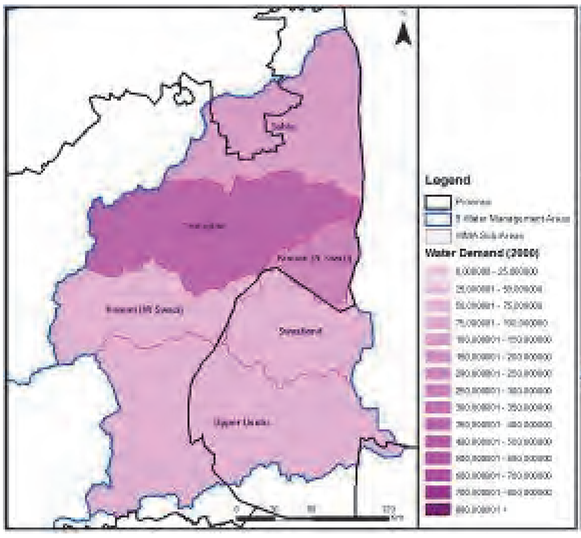


Figure G-26: Current Water Demand of the Inkomati-Usuthu WMA (2000).

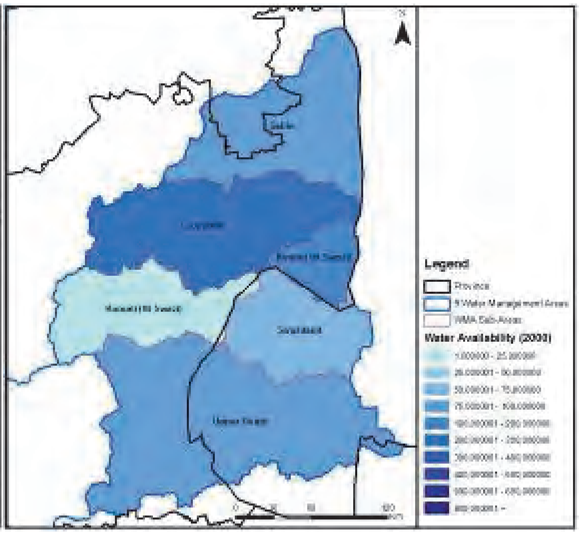


Figure G-27: Current Water Availability (Yield) of the Inkomati-Usuthu WMA (2000).

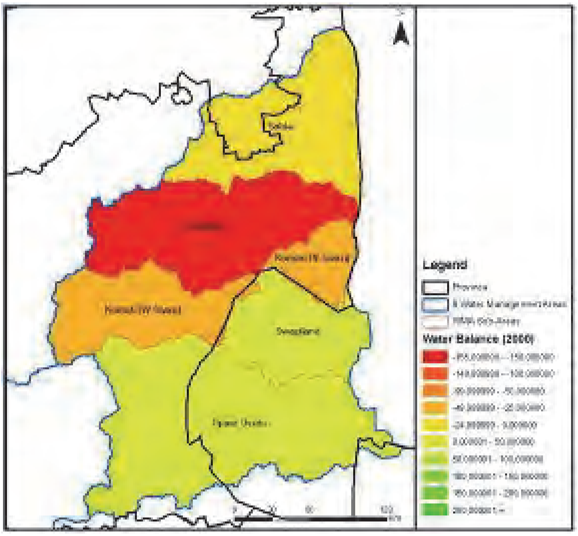


Figure G-28: Current Water Balance of the Inkomati-Usuthu WMA (2000).

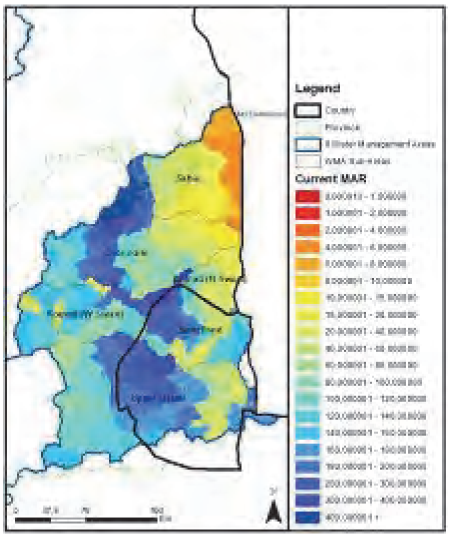


Figure G-29: Current Rainfall Distribution for the Inkomati-Usuthu WMA.

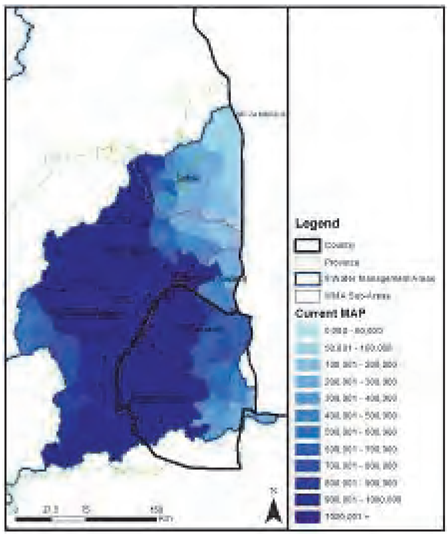


Figure G-30: Current Mean Annual Runoff (MAR) for the Inkomati-Usuthu WMA.

G 3.2. Future Status of Water Resources

This section provides a spatial overview of the future status of water resources for the Inkomati-Usuthu WMA, under different scenarios. This includes: water demand (Figure G-31), water availability (Figure G-32), water balance (Figure G-33), rainfall distribution (Figure G-34) as well as the mean annual runoff (Figure G-35). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-36.

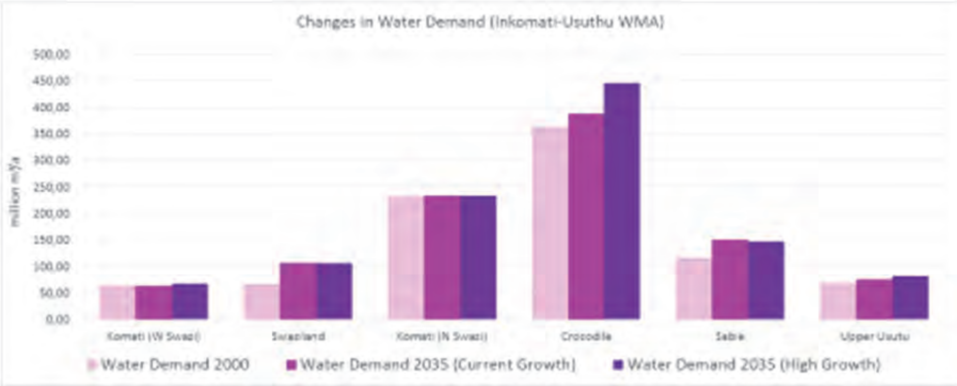


Figure G-31a: Changes in Water Demand under the Different Growth Scenarios for the Inkomati-Usuthu WMA.

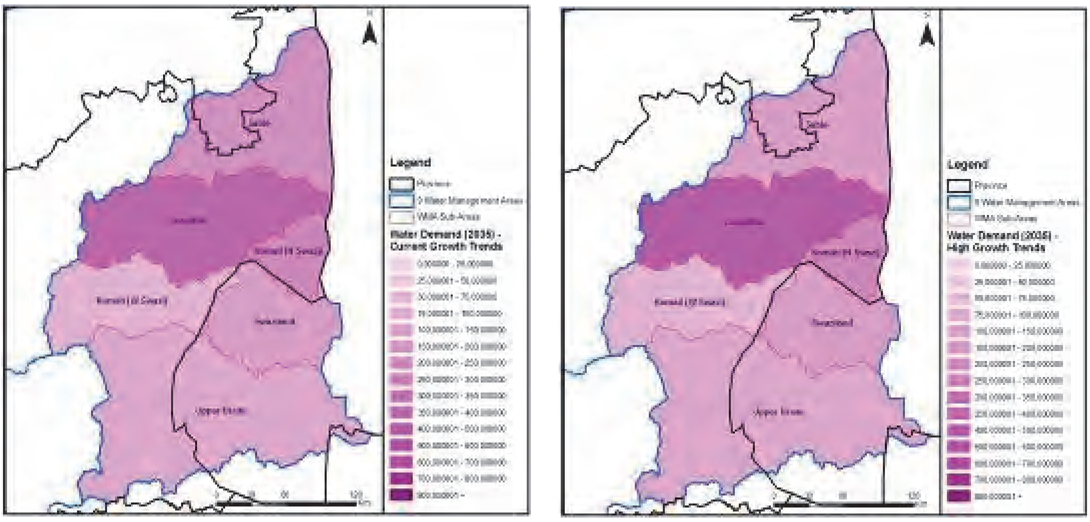


Figure G-31b: Water Demand for Different Growth Trends for the Inkomati-Usuthu WMA ((1) Current Growth Trends; (2) High Growth Trends).

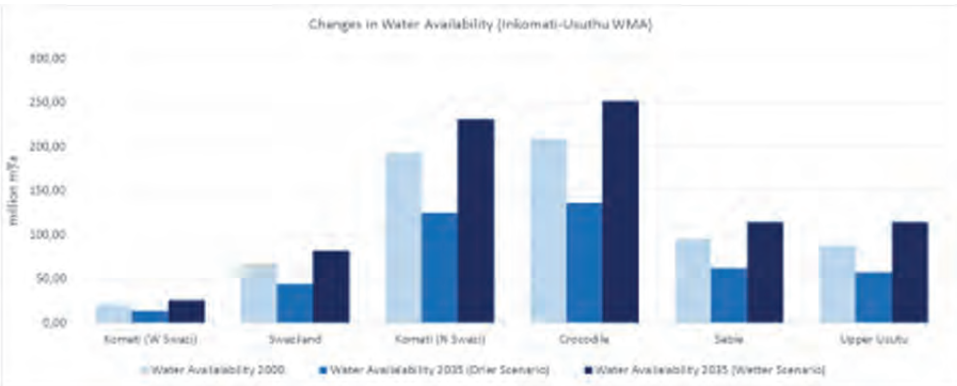


Figure G-32a: Changes in Water Availability under the Different Climate Scenarios for the Inkomati-Usuthu WMA.

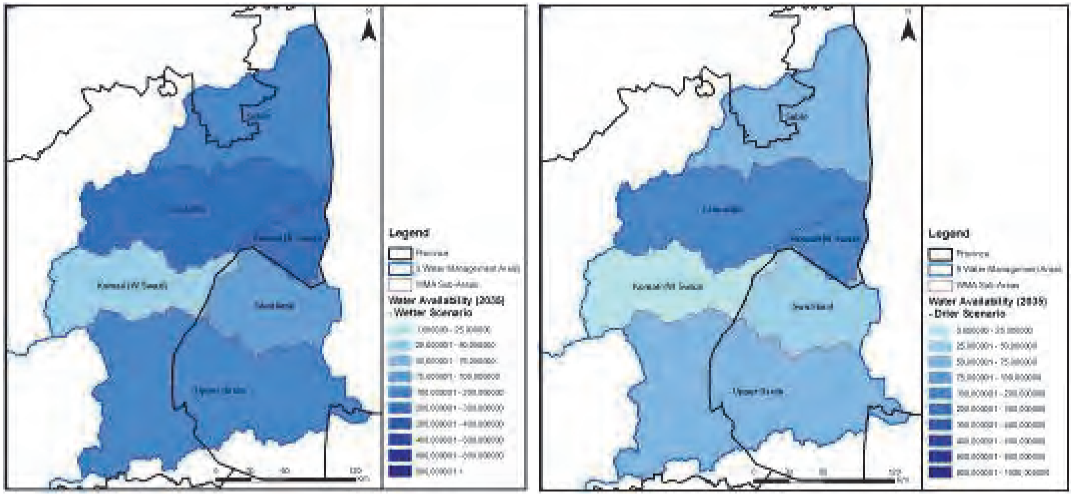


Figure G-32b: Water Availability under the Different Climate Scenarios for the Inkomati-Usuthu WMA ((1) Drier Scenario; (2) Wetter Scenario).

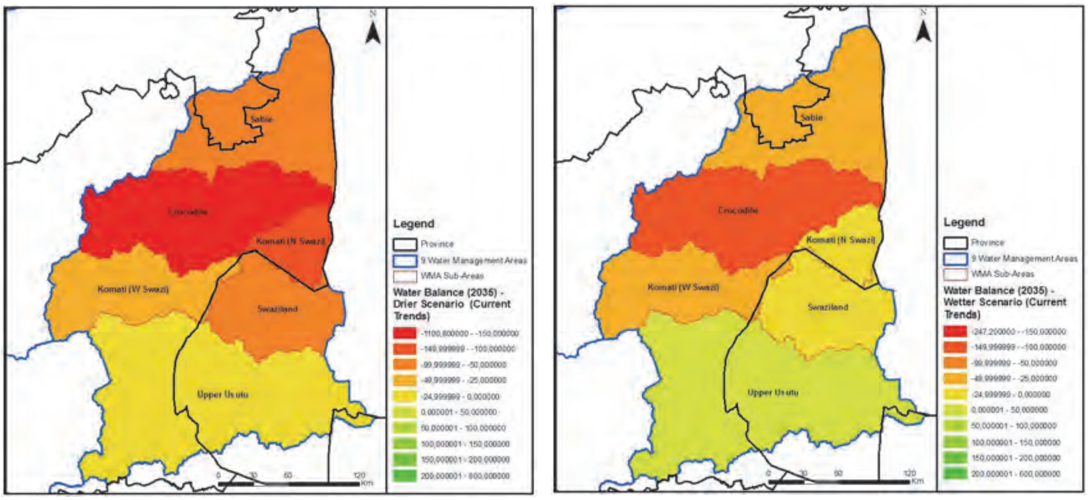


Figure G-33a: Future Water Balance of the Inkomati-Usuthu WMA under Current Growth Trends ((1) Drier Scenario; (2) Wetter Scenario).

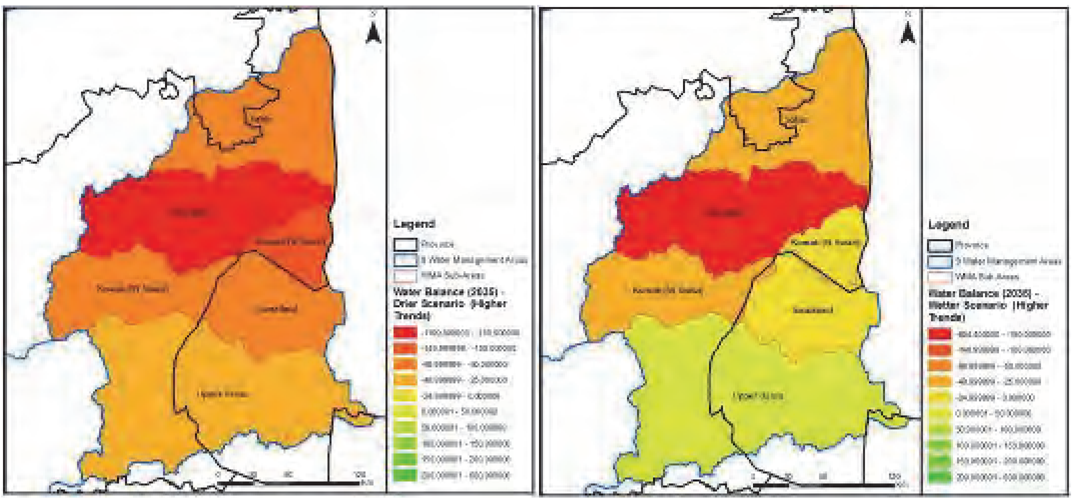


Figure G-33b: Future Water Balance of the Inkomati-Usuthu WMA under High Growth Trends ((1) Drier Scenario; (2) Wetter Scenario).

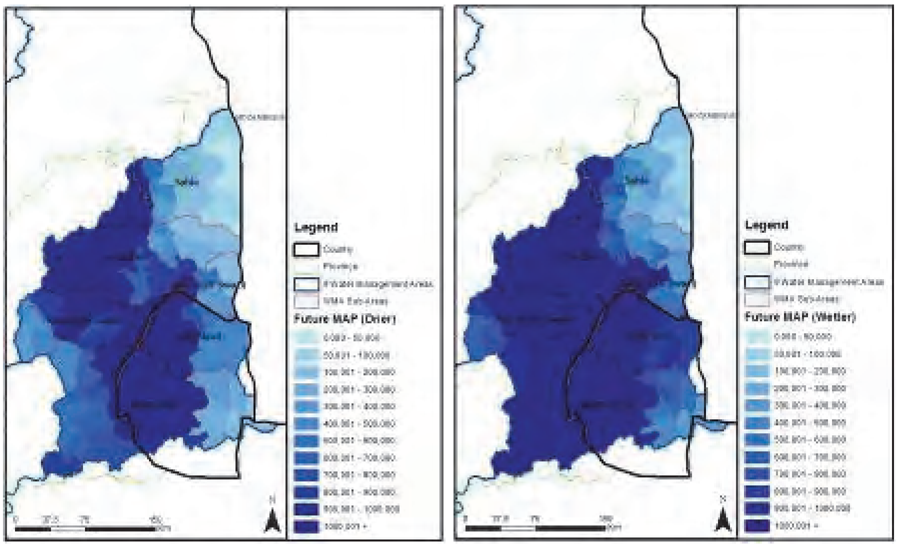


Figure G-34: Future Rainfall Distribution for the Inkomati-Usuthu WMA ((1) Drier Scenario; (2) Wetter Scenario).

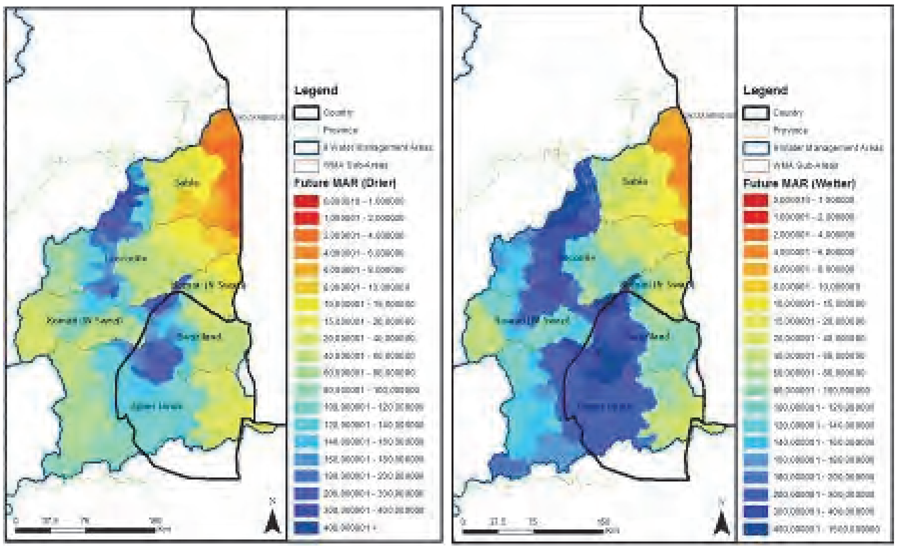


Figure G-35: Future Mean Annual Runoff (MAR) for the Inkomati-Usuthu WMA ((1) Drier Scenario; (2) Wetter Scenario).

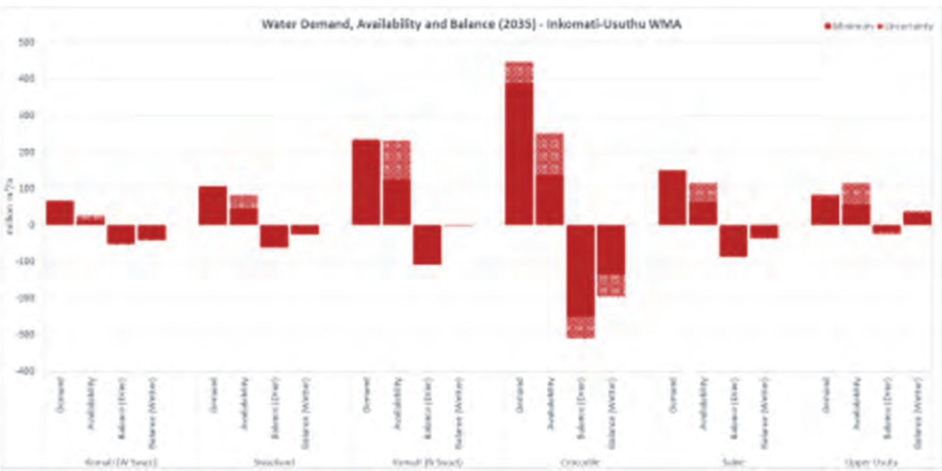


Figure G-36: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is negative for all the areas in the WMA under a drier future, and is positive in Upper Usuthu in a wetter future. Even through a period of low growth, the water demand will exceed the water availability in most of the catchment under both futures. Therefore, the location of energy resources should be aligned with the water availability.

G 4. Pongola-Umzimkhulu WMA

The Pongola-Umzimkhulu WMA is located in the eastern border of the country. It is an amalgamation of the previous Usutu to Mhlatuze (excluding the Usuthu Catchment), Thukela and Mvoti-Umzimkulu WMAs. Figure G-37 below illustrates the location of the Pongola-Umzimkhulu WMA.

Figure G-37: The Pongola-Umzimkhulu WMA.

The WMA falls predominantly within KwaZulu-Natal, bordering on Swaziland and Mozambique. The Pongola River catchment lies partly in Swaziland, while the Thukela River is a funnel-shaped catchment, with several tributaries draining from the Drakensberg escarpment towards the Indian Ocean. Parts of the Thukela enjoy a high ecological status. It is characterised by mountain streams in the upper reaches, where several parks and conservation areas are located, as well as a number of important wetlands and veils. Several parallel rivers drain the WMA to the south, two of which originate in the Drakensberg Mountains at the border with Lesotho. Climate in the region can be described as sub-humid to humid, but varies considerably. Mean annual rainfall ranges between 600 mm and 1 500 mm. The terrain is rolling, with the Drakensberg escarpment as the main topographic feature (NWRS, 2004).

G 4.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Pongola-Umzimkhulu WMA. This includes: water demand (Figure G-38), water availability (Figure G-39), water balance (Figure G-40), rainfall distribution (Figure G-41) as well as the mean annual runoff (Figure G-42).

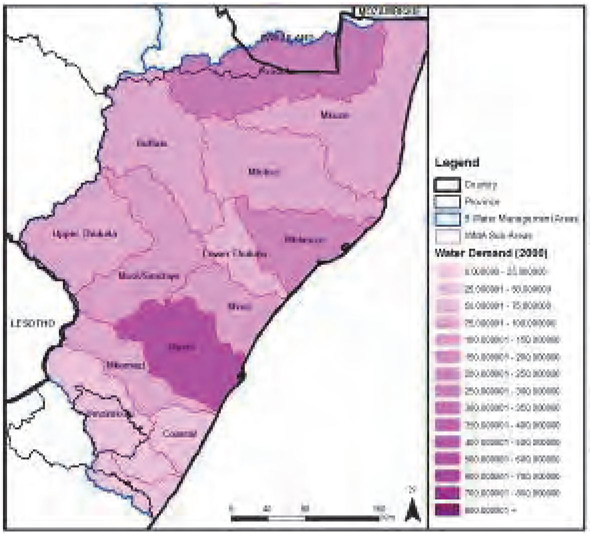


Figure G-38: Current Water Demand of the Pongola-Umzimkhulu WMA (2000).

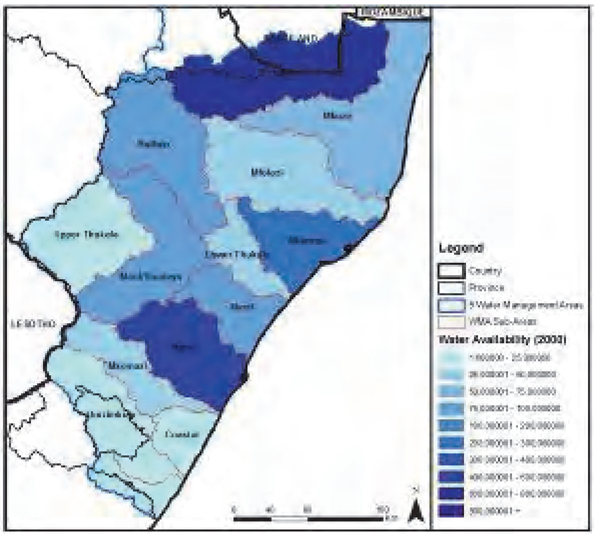


Figure G-39: Current Water Availability (Yield) of the Pongola-Umzimkhulu WMA (2000).

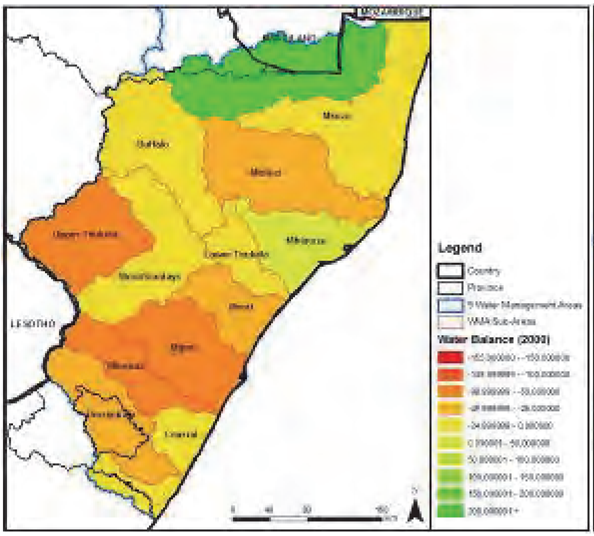


Figure G-40: Current Water Balance of the Pongola-Umzimkhulu WMA (2000).

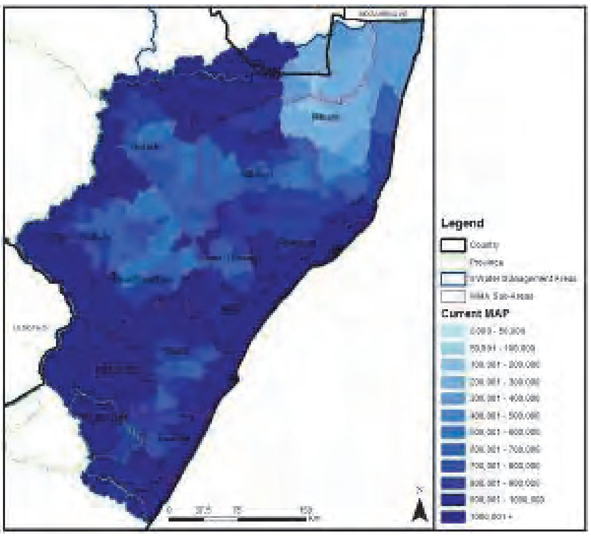


Figure G-41: Current Rainfall Distribution for the Pongola-Umzimkhulu WMA.

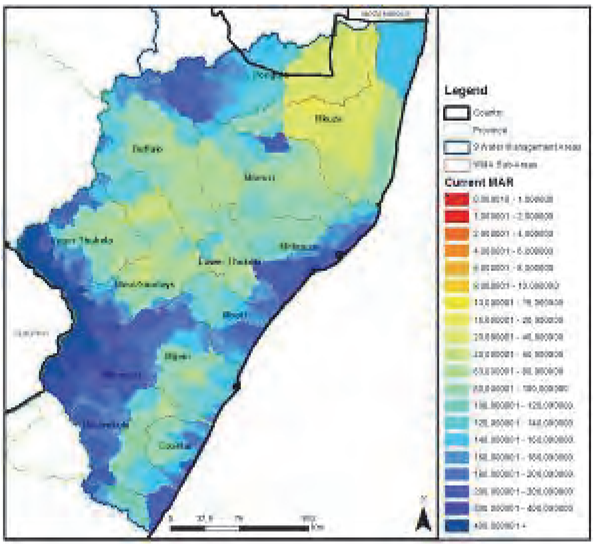


Figure G-42: Current Mean Annual Runoff (MAR) for the Pongola-Umzimkhulu WMA.

G 4.2. Future status of water resources

This section provides a spatial overview of the future status of water resources for the Pongola-Umzimkhulu WMA, under different scenarios. This includes: water demand (Figure G-43), water availability (Figure G-44), water balance (Figure G-45), rainfall distribution (Figure G-46) as well as the mean annual runoff (Figure G-47). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-48.

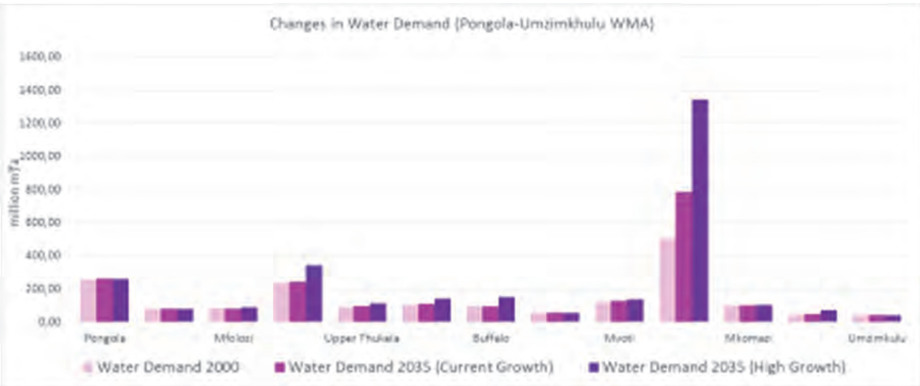


Figure G-43a: Changes in Water Demand under the Different Growth Scenarios for the Pongola-Umzimkhulu WMA.

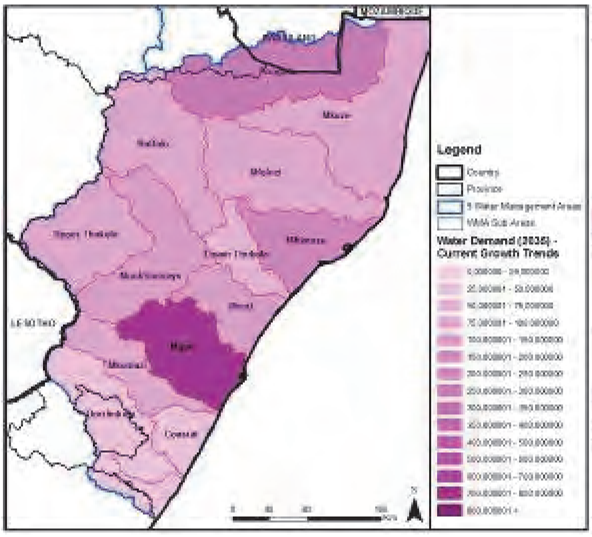


Figure G-43b: Water Demand for Current Growth Trends for the Pongola-Umzimkhulu. WMA

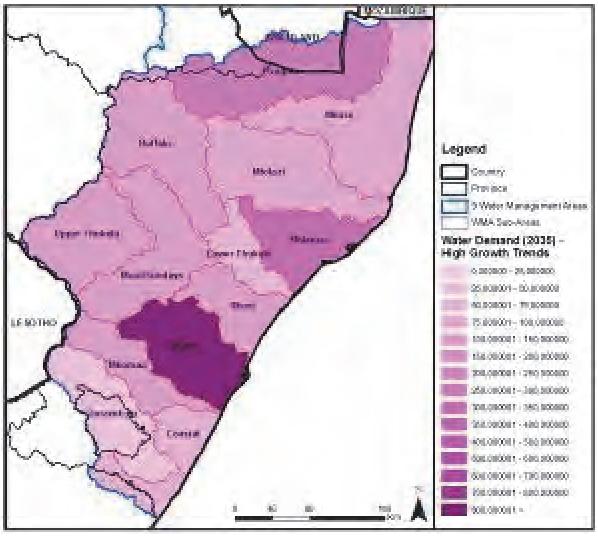


Figure G-43c: Water Demand for High Growth Trends for the Pongola-Umzimkhulu WMA.

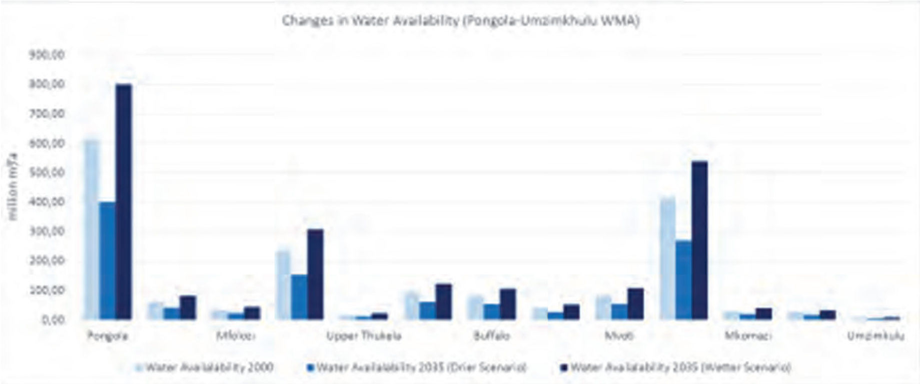


Figure G-44a: Changes in Water Availability under the Different Climate Scenarios for the Pongola-Umzimkhulu WMA.

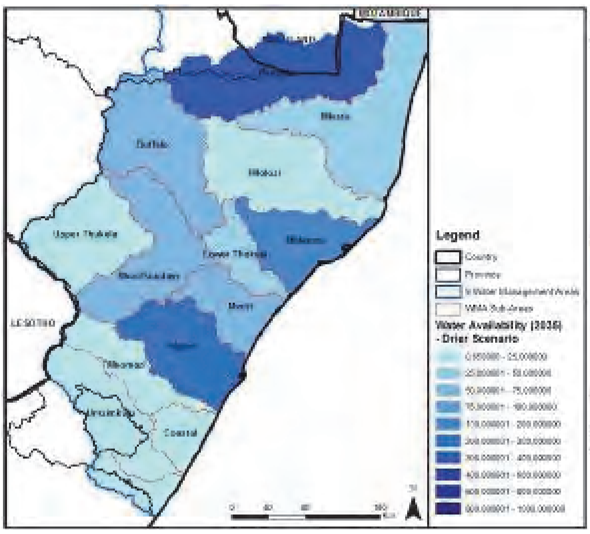


Figure G-44b: Water Availability under a Drier Scenario for the Pongola-Umzimkhulu WMA.

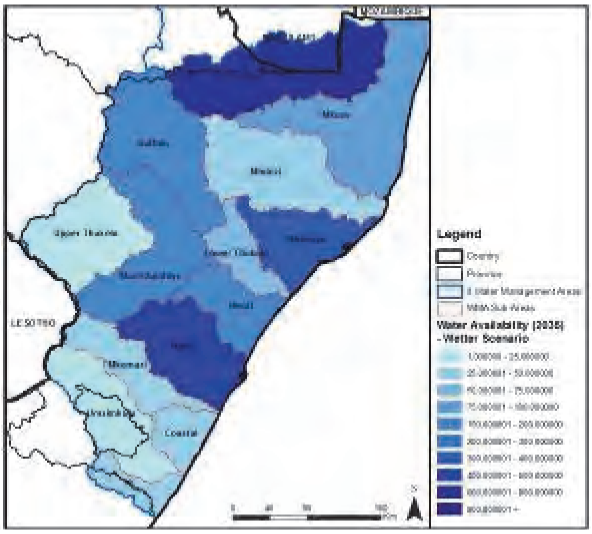


Figure G-44c: Water Availability under the a Wetter Scenario for the Pongola-Umzimkhulu. WMA

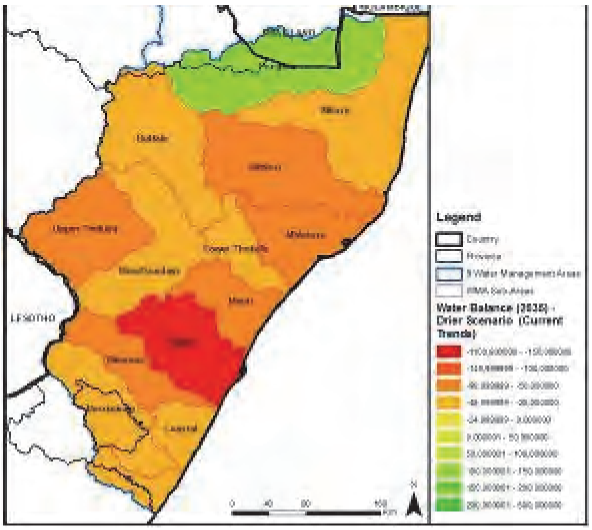


Figure G-45a: Future Water Balance of the Pongola-Umzimkhulu WMA under a Drier Scenario (Current Growth).

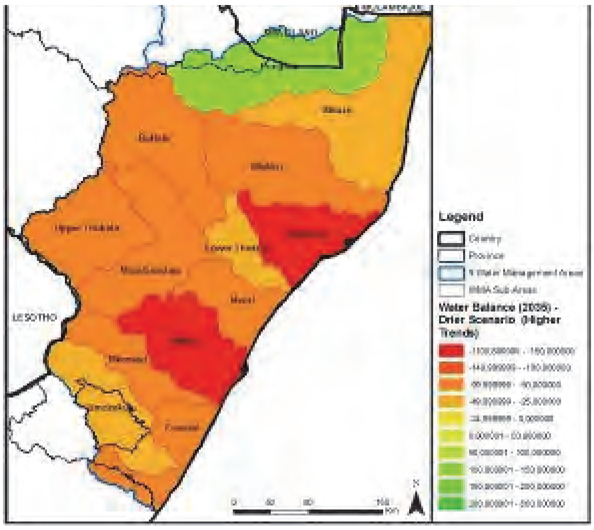


Figure G-45b: Future Water Balance of the Pongola-Umzimkhulu WMA under a Wetter Scenario (Current Growth).

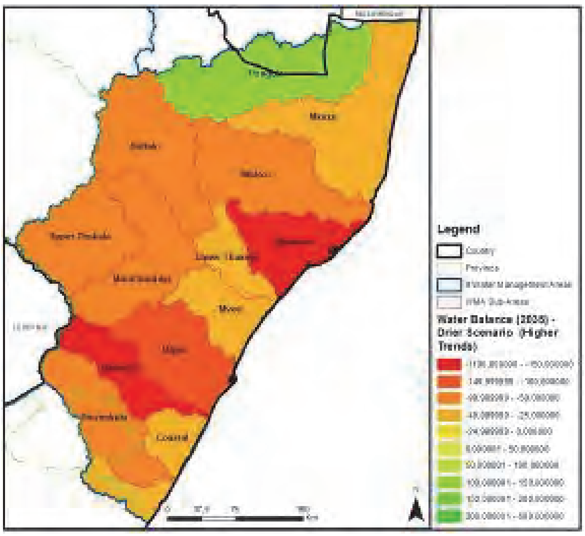


Figure G-45c: Future Water Balance of the Pongola-Umzimkhulu WMA under a Drier Scenario (High Growth).

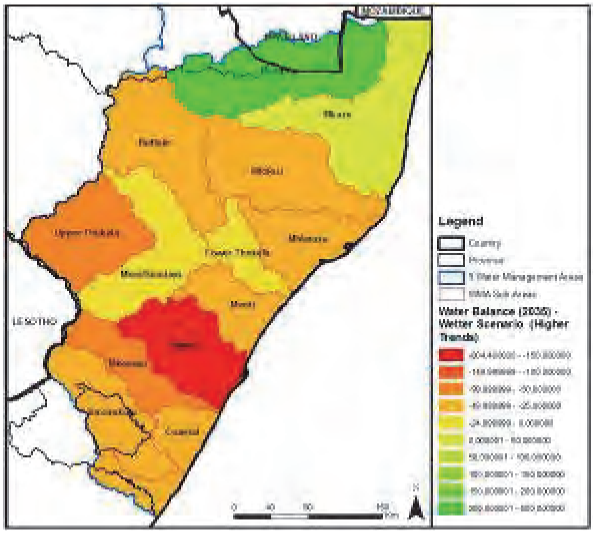


Figure G-45d: Future Water Balance of the Pongola-Umzimkhulu WMA under a Wetter Scenario (High Growth).

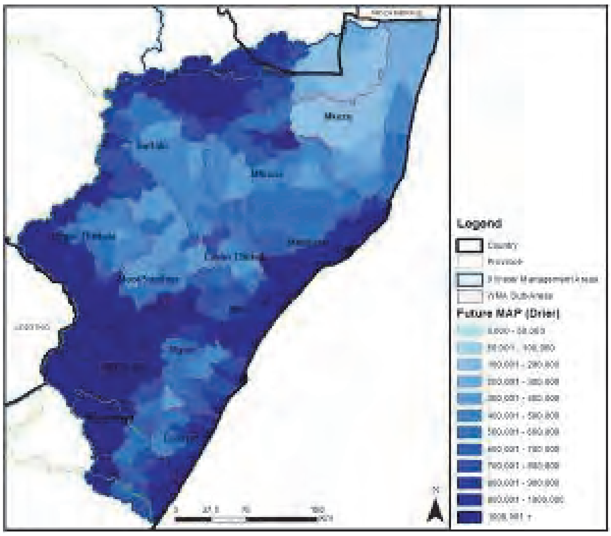


Figure G-46a: Future Rainfall Distribution for the Pongola-Umzimkhulu WMA under a Drier Scenario.

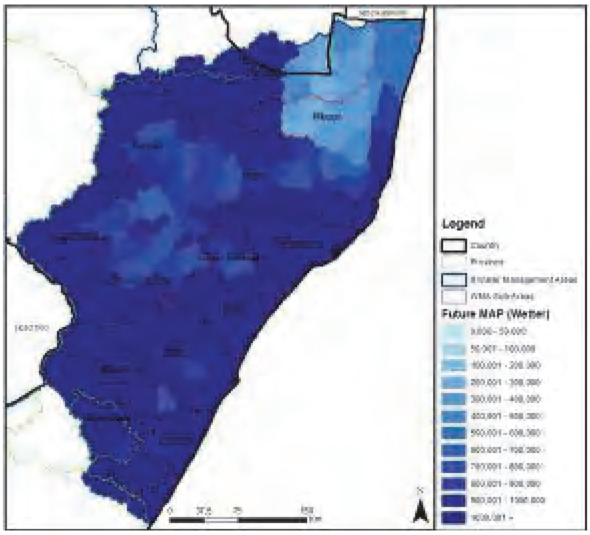


Figure G-46b: Future Rainfall Distribution for the Pongola-Umzimkhulu WMA under a Wetter Scenario.

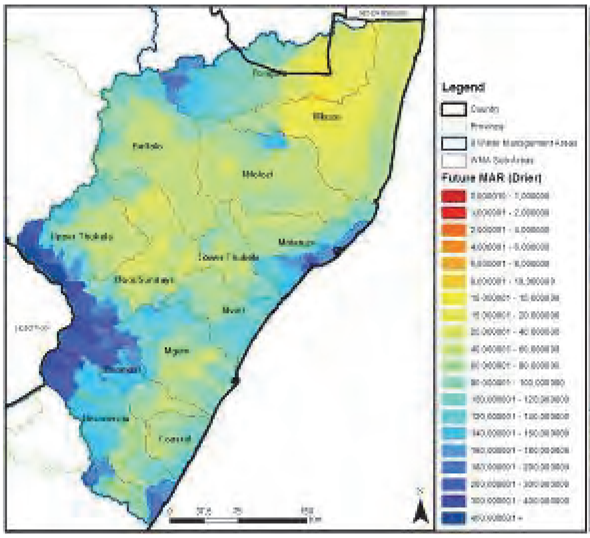


Figure G-47a: Future Mean Annual Runoff (MAR) for the Pongola-Umzimkhulu WMA under a Drier Scenario.

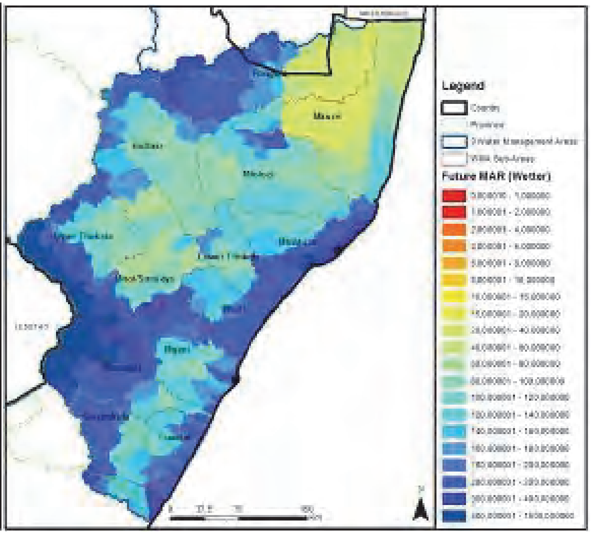


Figure G-47b: Future Mean Annual Runoff (MAR) for the Pongola-Umzimkhulu WMA under a Wetter Scenario.

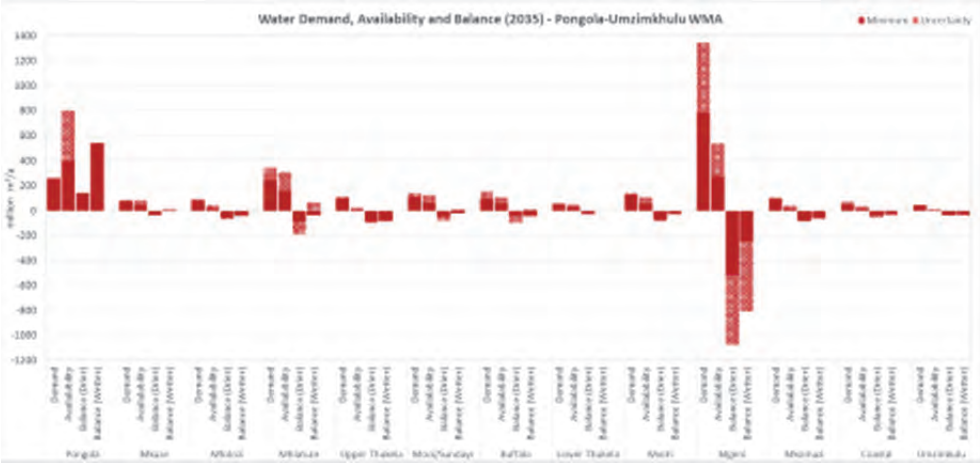


Figure G-48: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is positive for the Pongola area in the WMA under a drier future, and in Pongola and Mkuze under a wetter future. However, low growth could potentially result in a positive water balance in Mkuze, Mhlatuze, Mooi/Sundays and Buffalo under a wetter future. Therefore, the location of energy resources should be aligned with the water availability, in whichever future.

G 5. Vaal WMA

The Vaal WMA is an amalgamation of the previous Upper Vaal, Middle Vaal and Lower Vaal WMAs. It lies in the eastern interior of South Africa, and borders on Botswana in the north. From a water resources management perspective it is a pivotal WMA in the country. Large quantities of water are transferred into the area from two neighbouring areas, as well as water sourced from the Upper Orange River via Lesotho. Similarly, large quantities of water are transferred out to other WMAs, which are dependent on water from the Vaal WMA to meet much of their requirements. Climate in the region is semi-arid to arid, with rainfall ranging from 800 mm to as low as 100 mm per year and evaporation reaching 2 800 mm per year towards the west and as high as 1 900 mm per year in the central Vaal (NWRS, 2004). Figure G-49 below illustrates the location of the Vaal WMA.

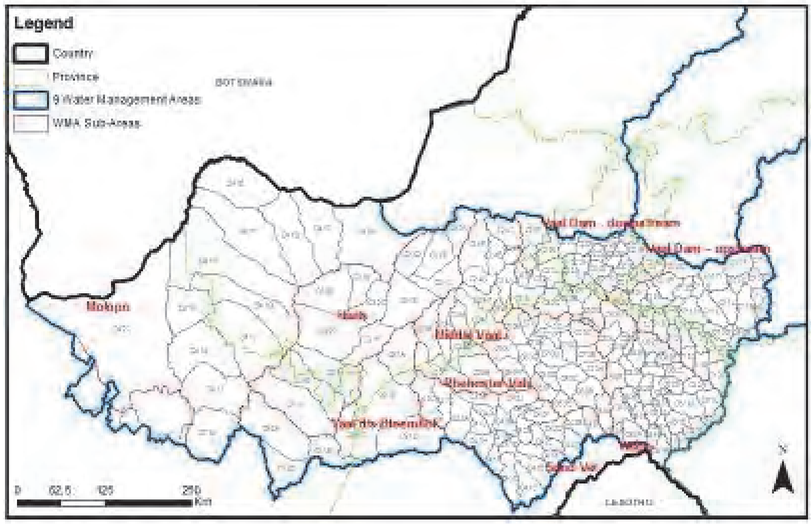


Figure G-49: The Vaal WMA.

G 5.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Vaal WMA. This includes: water demand (Figure G-50), water availability (Figure G-51), water balance (Figure G-52), rainfall distribution (Figure G-53) as well as the mean annual runoff (Figure G-54).

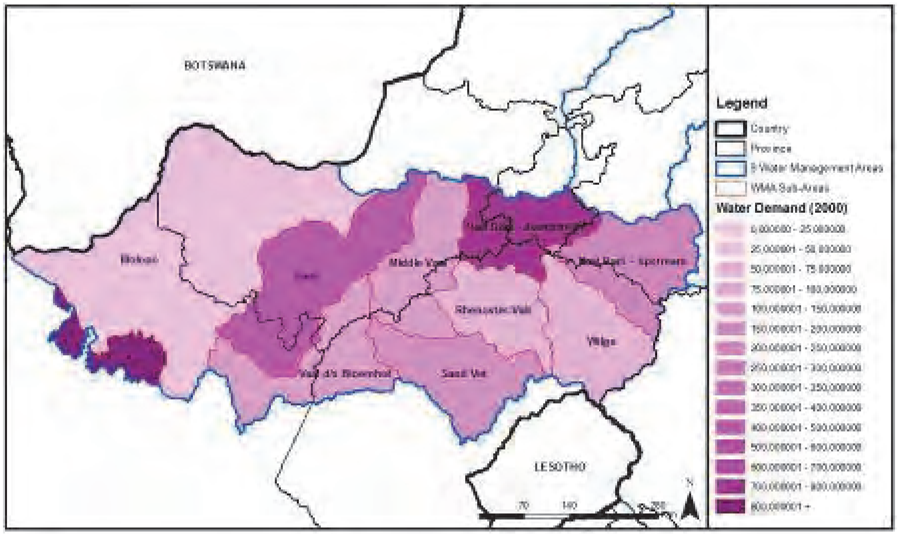


Figure G-50: Current Water Demand of the Vaal WMA (2000).

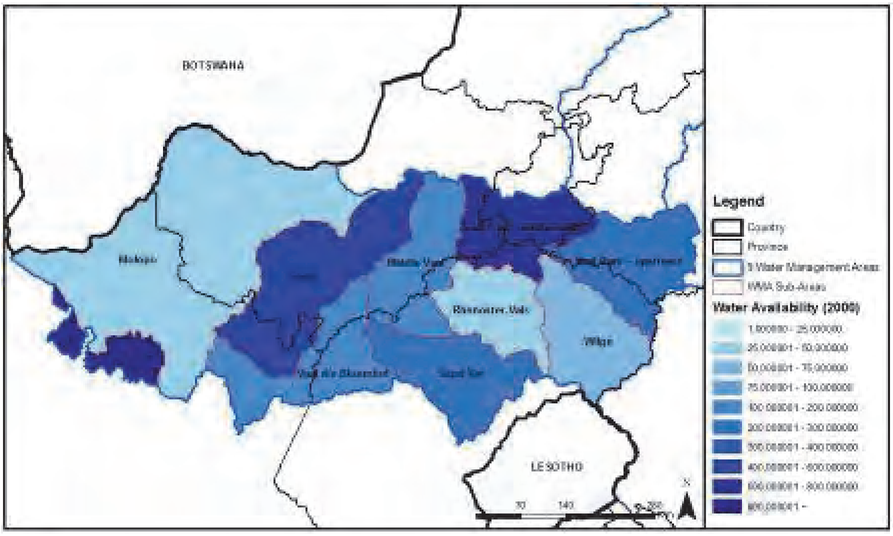


Figure G-51: Current Water Availability (Yield) of the Vaal WMA (2000).

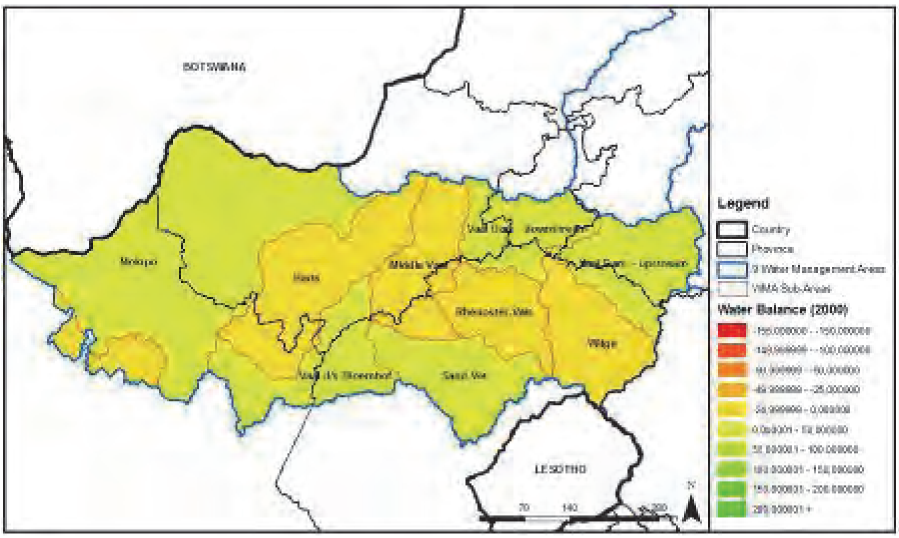


Figure G-52: Current Water Balance of the Vaal WMA (2000).

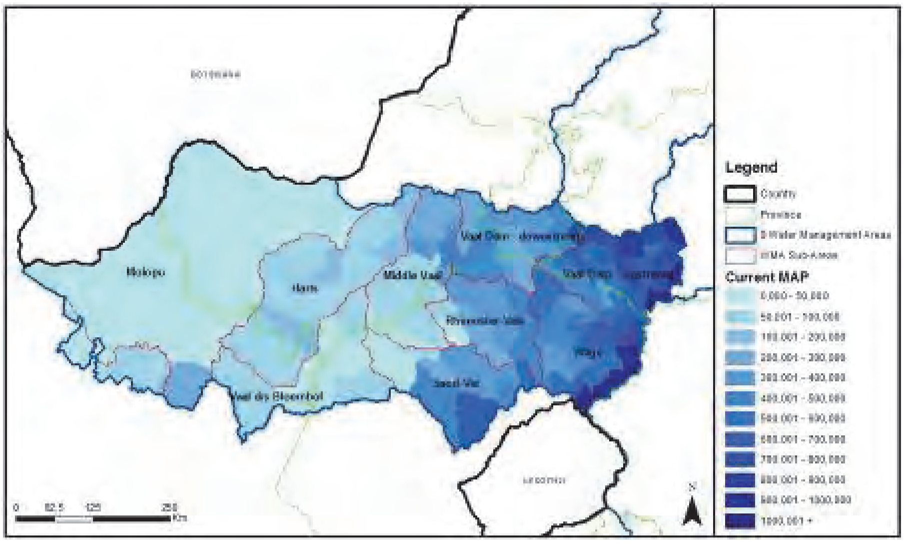


Figure G-53: Current Rainfall Distribution for the Vaal WMA.

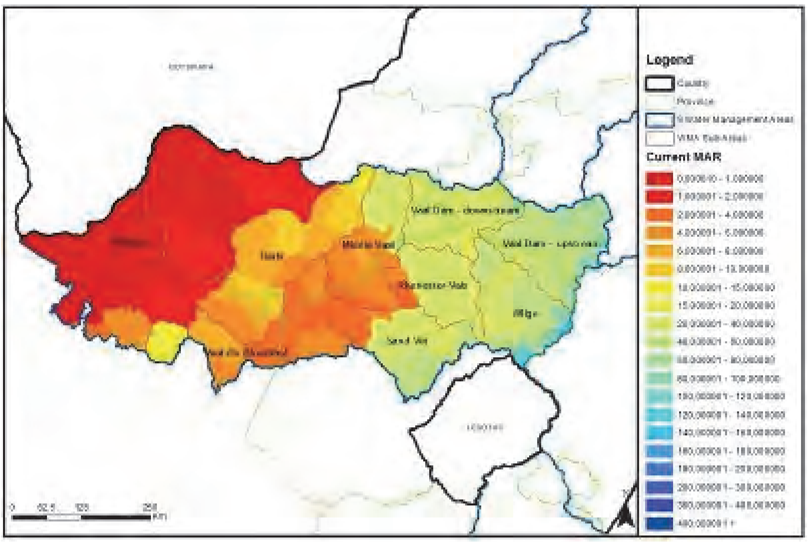


Figure G-54: Current Mean Annual Runoff (MAR) for the Vaal WMA.

G 5.2. Future status of water resources

This section provides a spatial overview of the future status of water resources for the Vaal WMA, under different scenarios. This includes: water demand (Figure G-55), water availability (Figure G-56), water balance (Figure G-57), rainfall distribution (Figure G-58) as well as the mean annual runoff (Figure G-59). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-60.

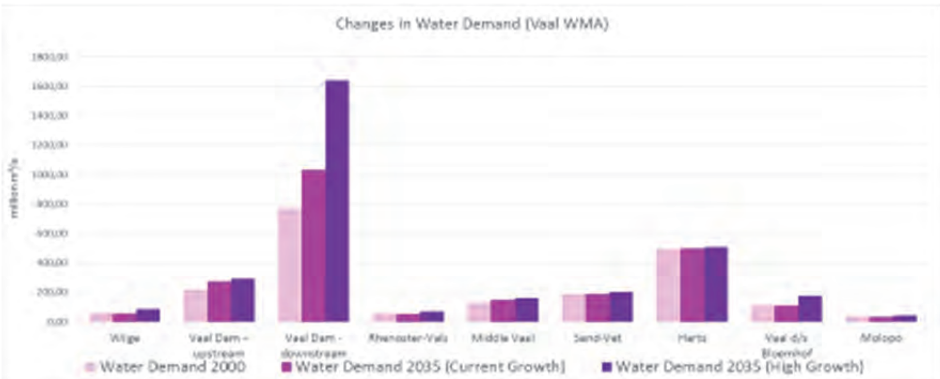


Figure G-55a: Changes in Water Demand under the Different Growth Scenarios for the Vaal WMA.

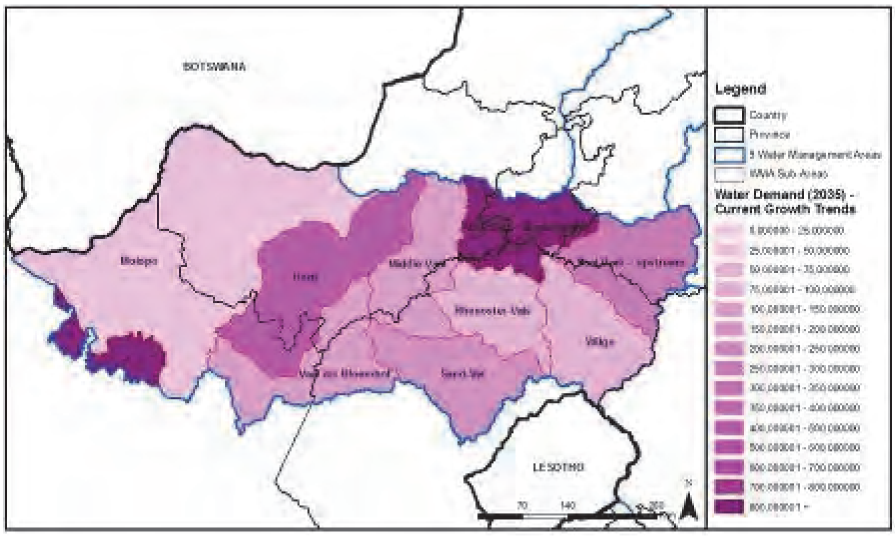


Figure G-55b: Water Demand for Current Growth Trends for the Vaal WMA.

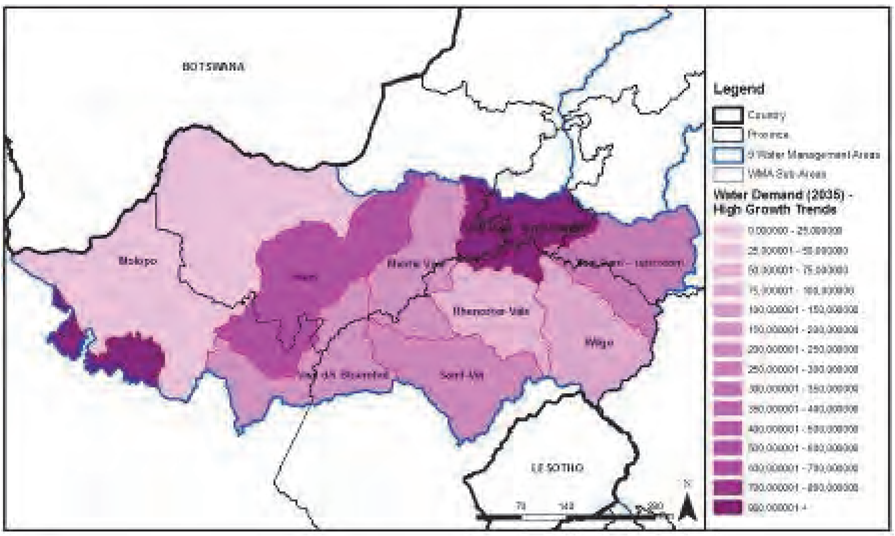


Figure G-55c: Water Demand for High Growth Trends for the Vaal WMA.

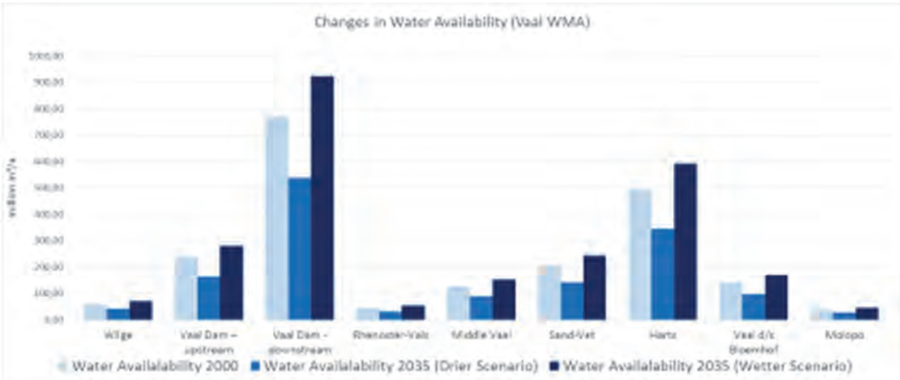


Figure G-56a: Changes in Water Availability under the Different Climate Scenarios for the Vaal WMA.

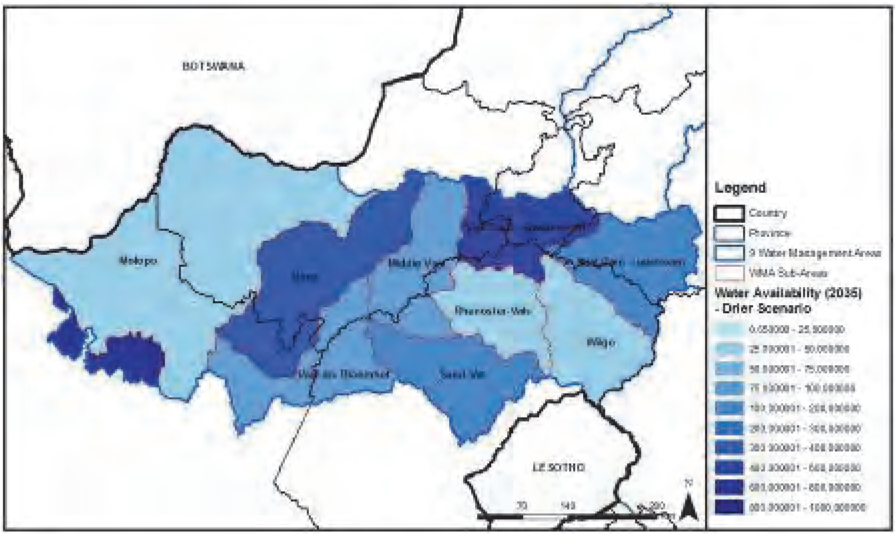


Figure G-56b: Water Availability under a Drier Scenario for the Vaal WMA.

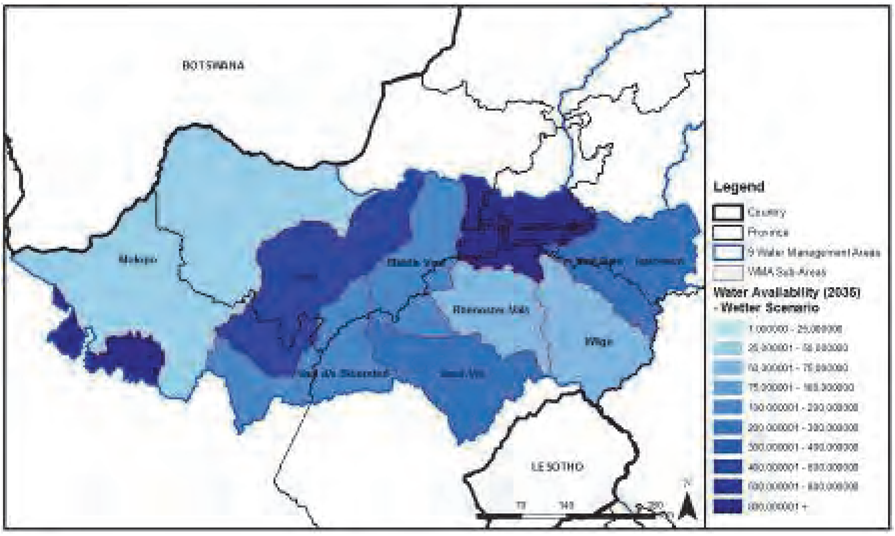


Figure G-56c: Water Availability under a Wetter Scenario for the Vaal WMA.

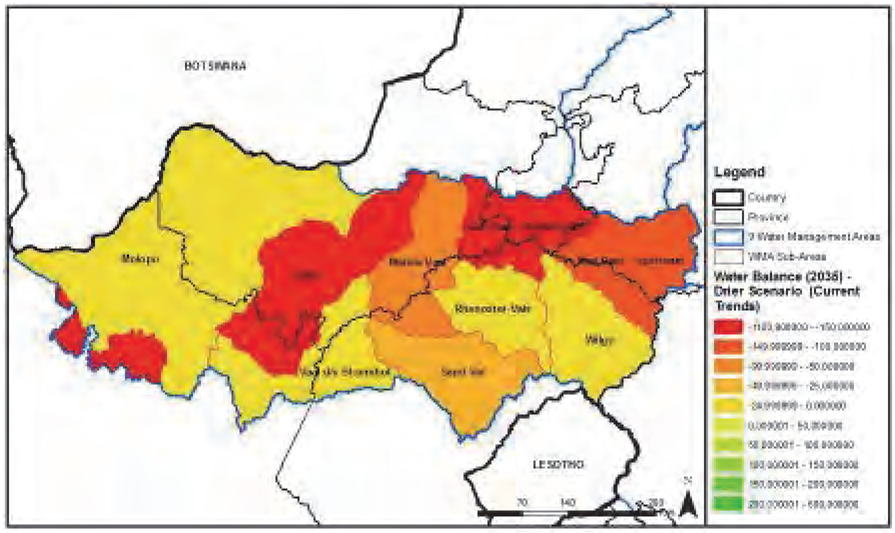


Figure G-57a: Future Water Balance of the Vaal WMA under a Drier Scenario (Current Growth).

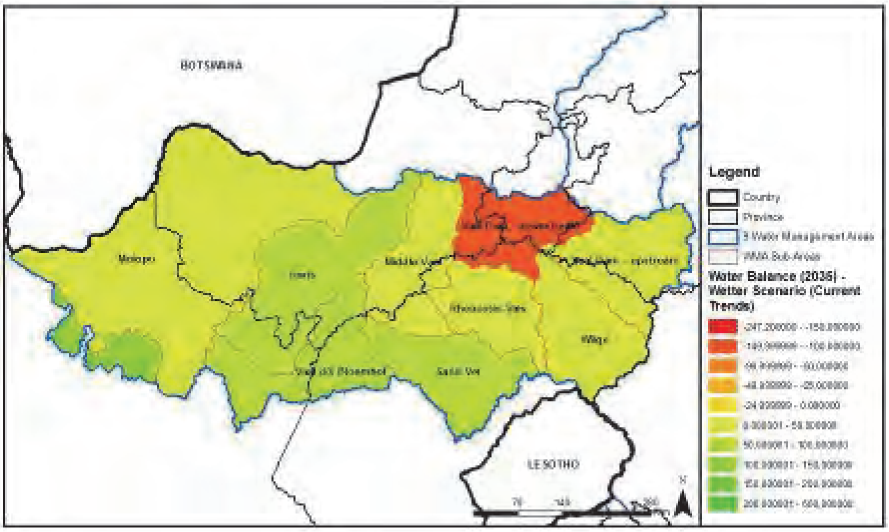


Figure G-57b: Future Water Balance of the Vaal WMA under a Wetter Scenario (Current Growth).

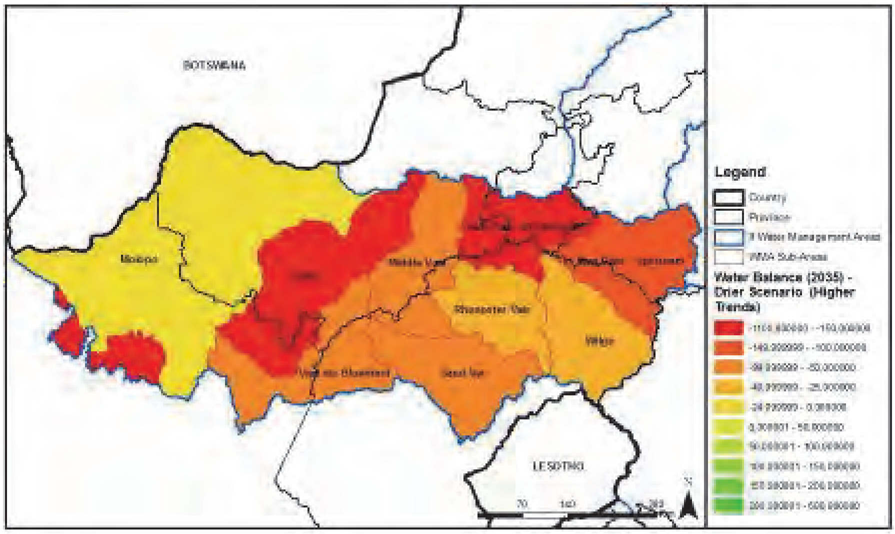


Figure G-57c: Future Water Balance of the Vaal WMA under a Drier Scenario (High Growth).

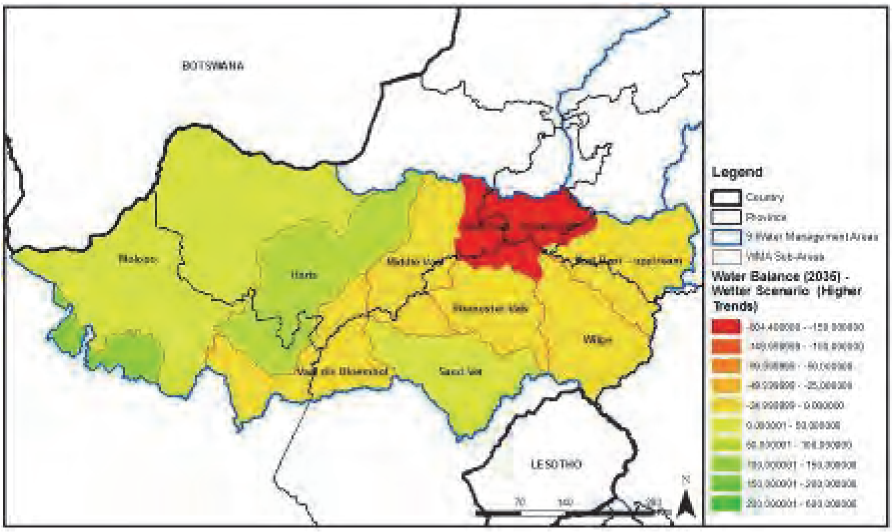


Figure G-57d: Future Water Balance of the Vaal WMA under a Wetter Scenario (High Growth).

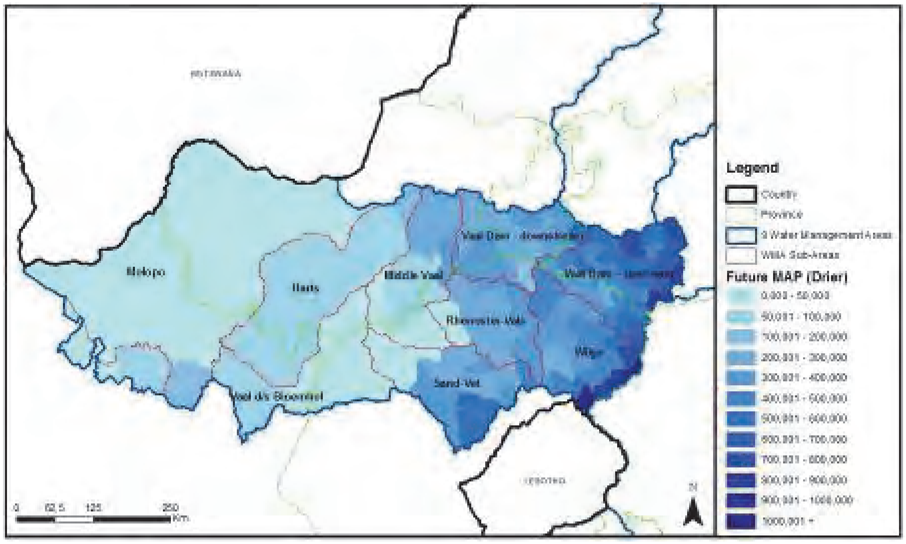


Figure G-58a: Future Rainfall Distribution for the Vaal WMA under a Drier Scenario.

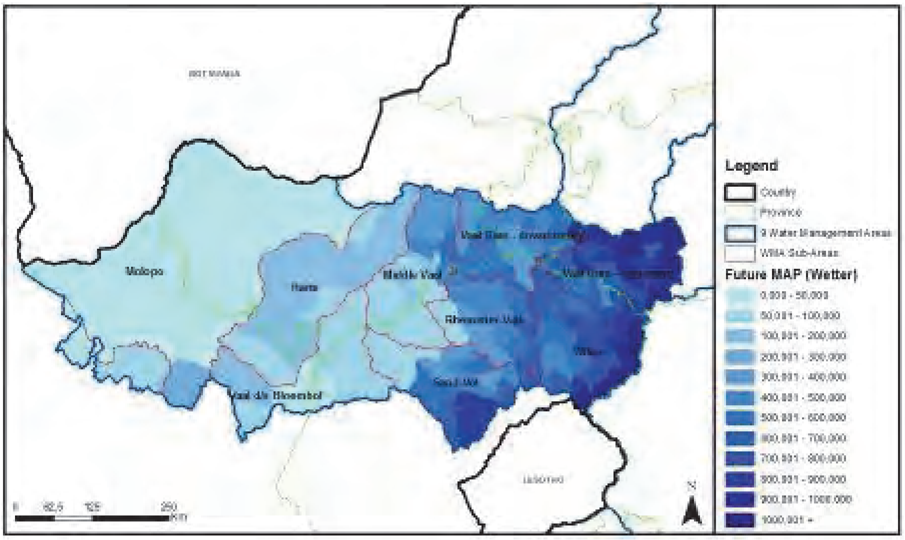


Figure G-58b: Future Rainfall Distribution for the Vaal WMA under a Wetter Scenario.

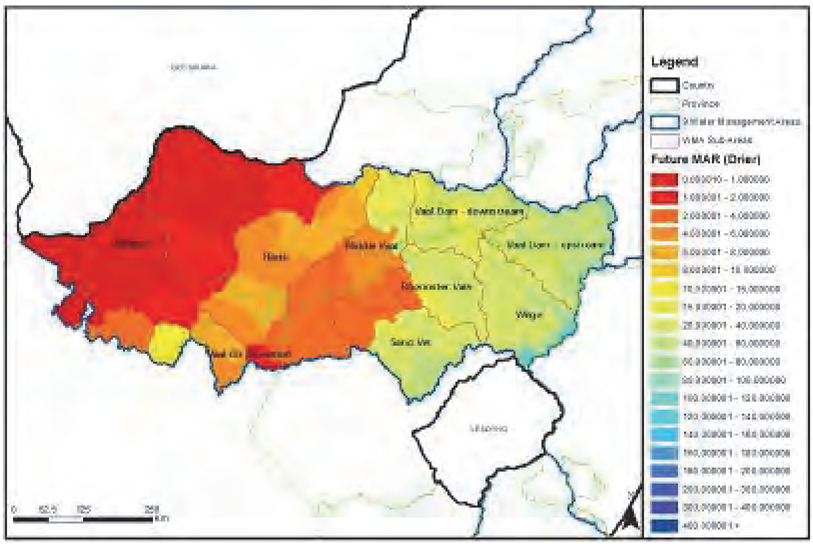


Figure G-59a: Future Mean Annual Runoff (MAR) for the Vaal WMA under a Drier Scenario.

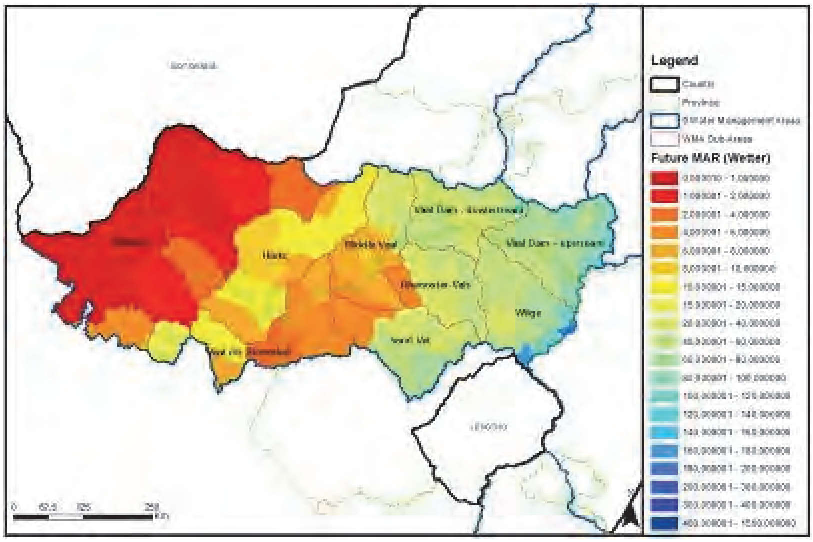


Figure G-59b: Future Mean Annual Runoff (MAR) for the Vaal WMA under a Wetter Scenario.

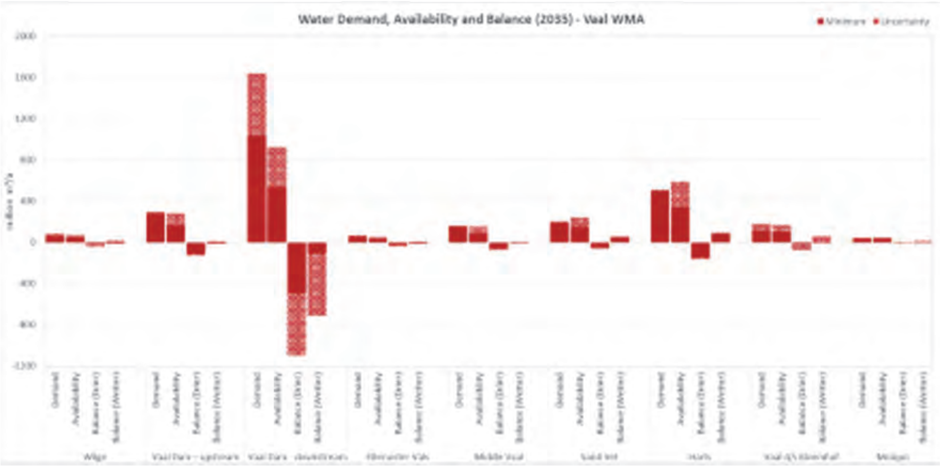


Figure G-60: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is negative for all the areas in the WMA under a drier future, and is positive in Sand-Vet, Harts and Molopo under a wetter future. However, low growth could potentially also result in a positive water balance in Wilge, Vaal Dam – upstream, Rhenoster-Vals and Middle Vaal under a wetter future. Therefore, the location of energy resources should be aligned with the water availability.

G 6. Orange WMA

The Orange WMA is located in the north-eastern corner of the country. It is an amalgamation of the previous Upper Orange and Lower Orange WMAs. It is situated in the western extremity of South Africa and borders on Botswana, Namibia and the Atlantic Ocean. It also borders on Lesotho to the east, where the Orange River originates as the Senqu River in Lesotho. Draining the Highlands of Lesotho, the Senqu River contributes close to 60 per cent of the surface water associated with the Upper Orange water management area. The climate varies considerably over the region and rainfall ranges from over 1 000 mm/a in the foothills of the mountains to as little as 20 mm/a in the west (which is characterised by prolonged droughts) (NWRS, 2004). Figure G-61 below illustrates the location of the Orange WMA.

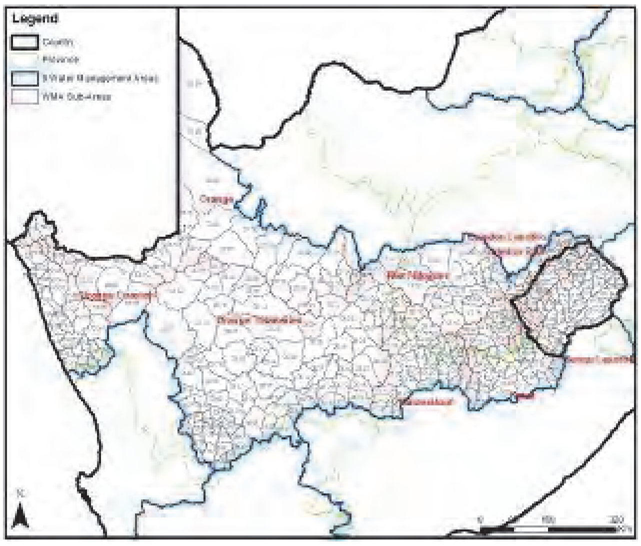


Figure G-61: The Orange WMA.

G 6.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Orange WMA. This includes: water demand (Figure G-62), water availability (Figure G-63), water balance (Figure G-64), rainfall distribution (Figure G-65) as well as the mean annual runoff (Figure G-66).

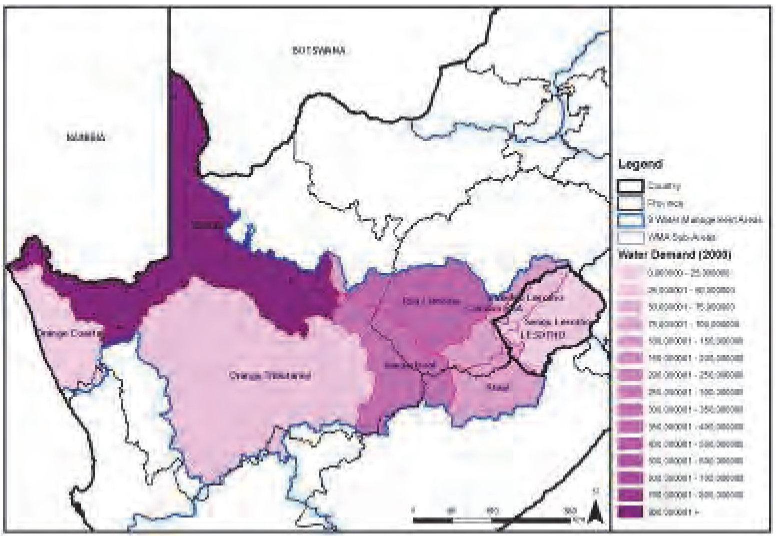


Figure G-62: Current Water Demand of the Orange WMA (2000).

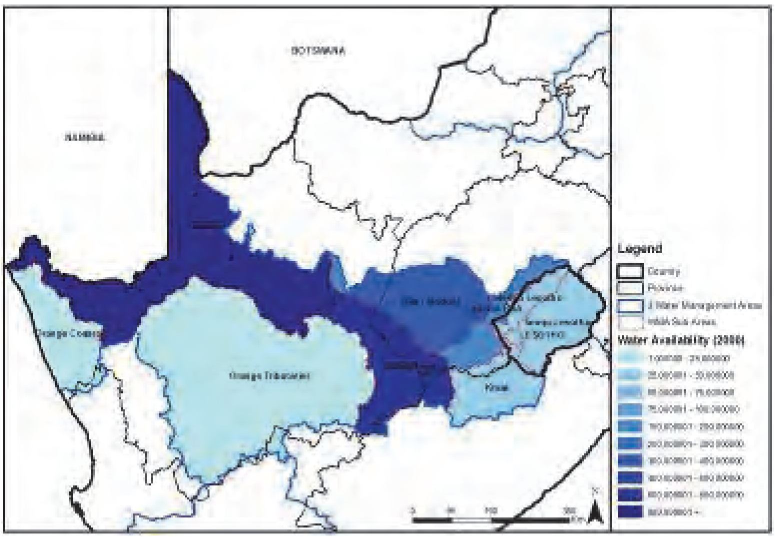


Figure G-63: Current Water Availability (Yield) of the Orange WMA (2000).

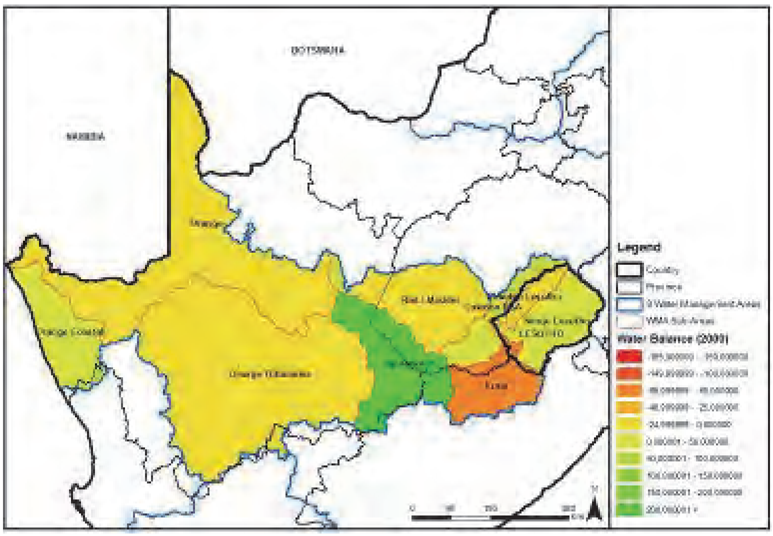


Figure G-64: Current Water Balance of the Orange WMA (2000).

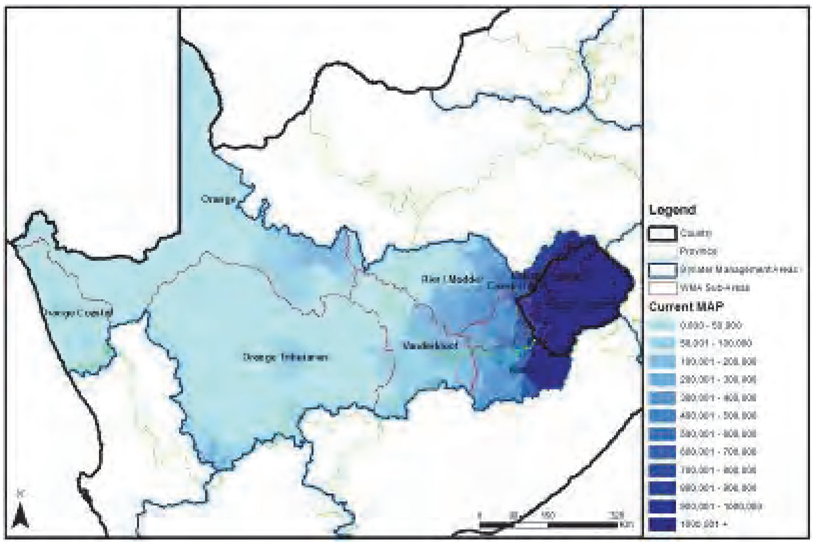


Figure G-65: Current Rainfall Distribution for the Orange WMA.

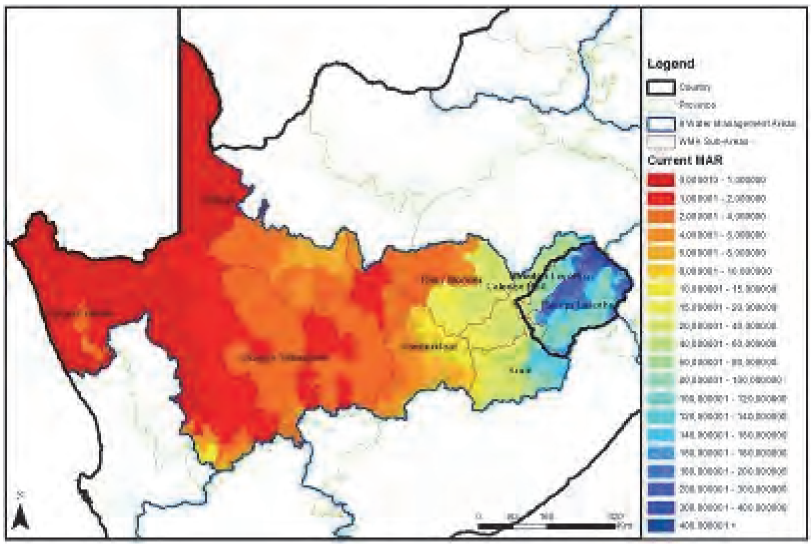


Figure G-66: Current Mean Annual Runoff (MAR) for the Orange WMA.

G 6.2. Future status of water resources

This section provides a spatial overview of the future status of water resources for the Orange WMA, under different scenarios. This includes: water demand (Figure G-68), water availability (Figure G-69), water balance (Figure G-70), rainfall distribution (Figure G-71) as well as the mean annual runoff (Figure G-72). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-72.

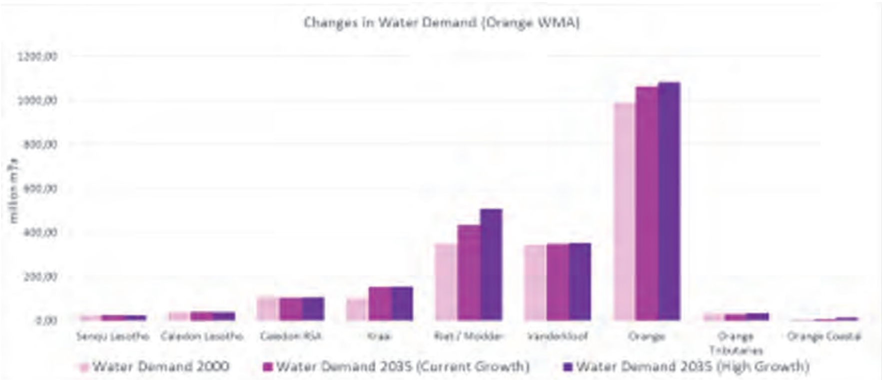


Figure G-67a: Changes in Water Demand under the Different Growth Scenarios for the Orange WMA.

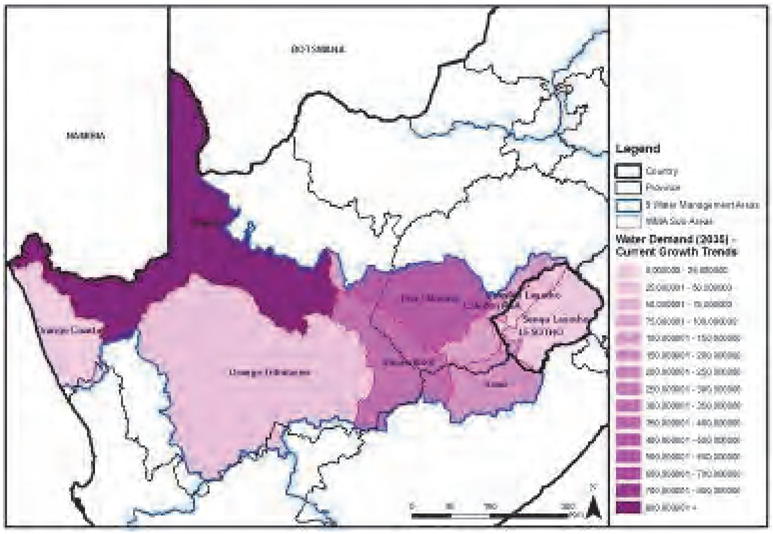


Figure G-67b: Water Demand for Current Growth Trends for the Orange WMA.

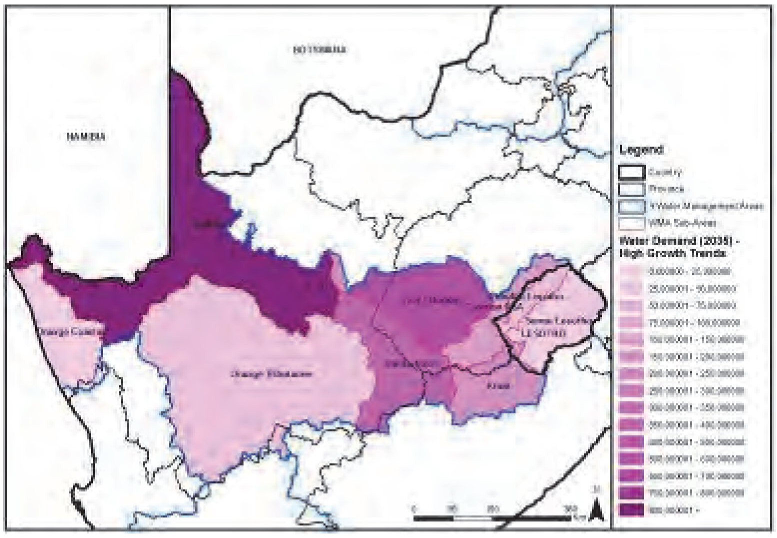


Figure G-67c: Water Demand for High Growth Trends for the Orange WMA.

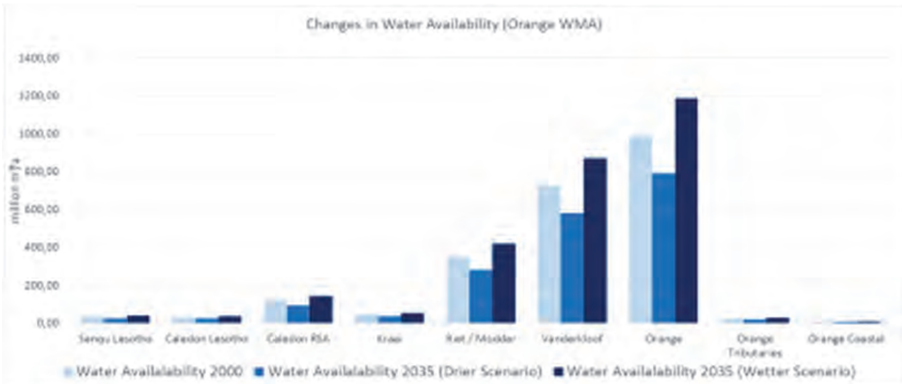


Figure G-68a: Changes in Water Availability under the Different Climate Scenarios for the Orange WMA.

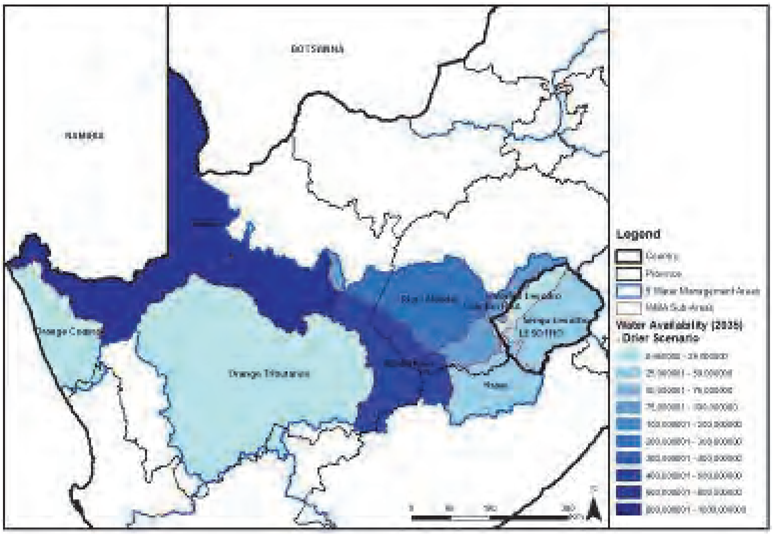


Figure G-68b: Water Availability under a Drier Scenario for the Orange WMA.

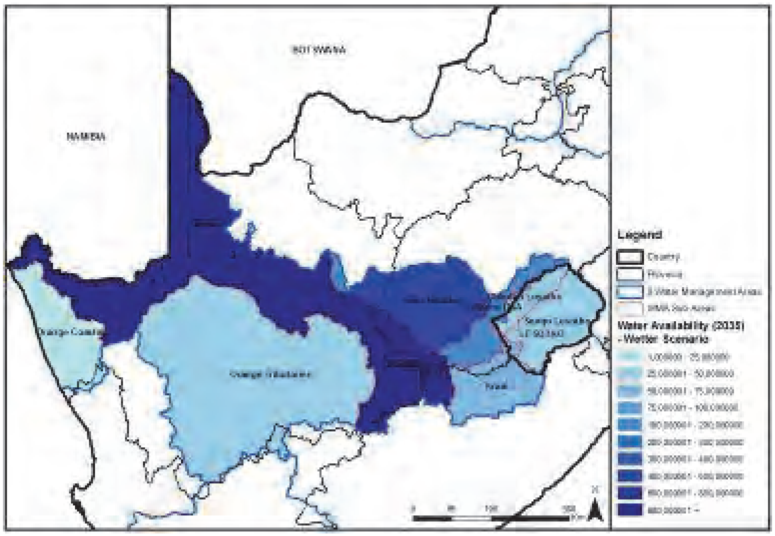


Figure G-68c: Water Availability under a Wetter Scenario for the Orange WMA.

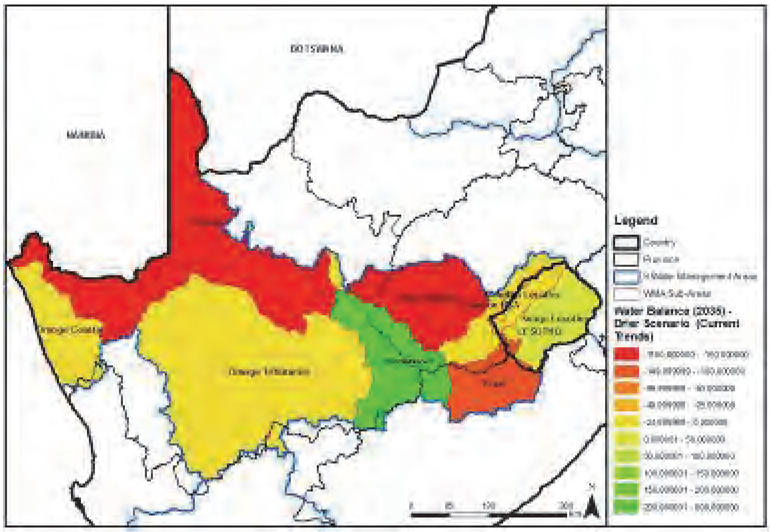


Figure G-69a: Future Water Balance of the Olifants WMA under a Drier Scenario (Current Growth).

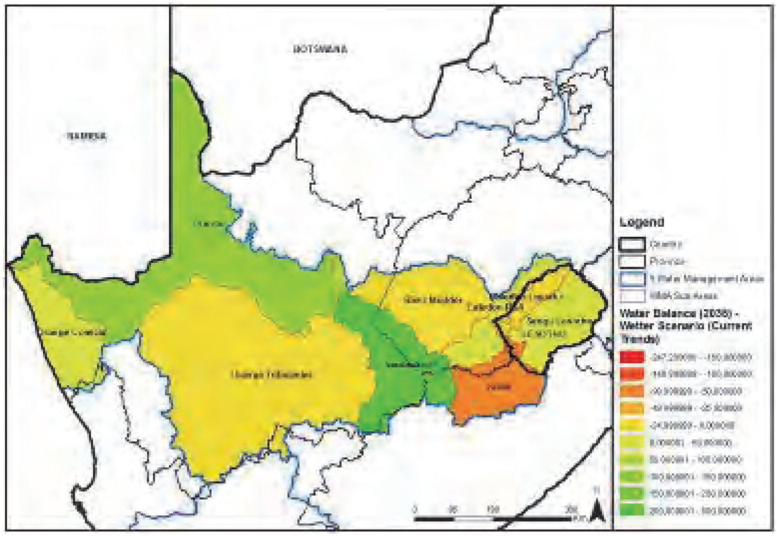


Figure G-69b: Future Water Balance of the Olifants WMA under a Wetter Scenario (Current Growth).

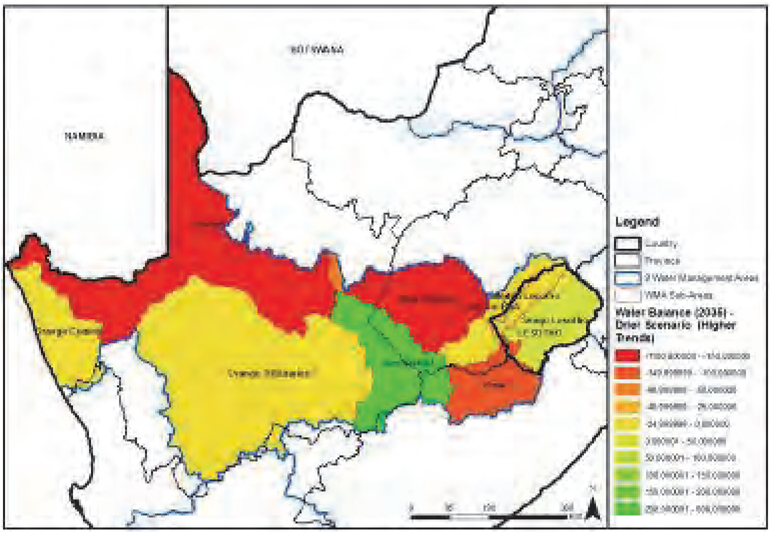


Figure G-69c: Future Water Balance of the Olifants WMA under a Drier Scenario (High Growth).

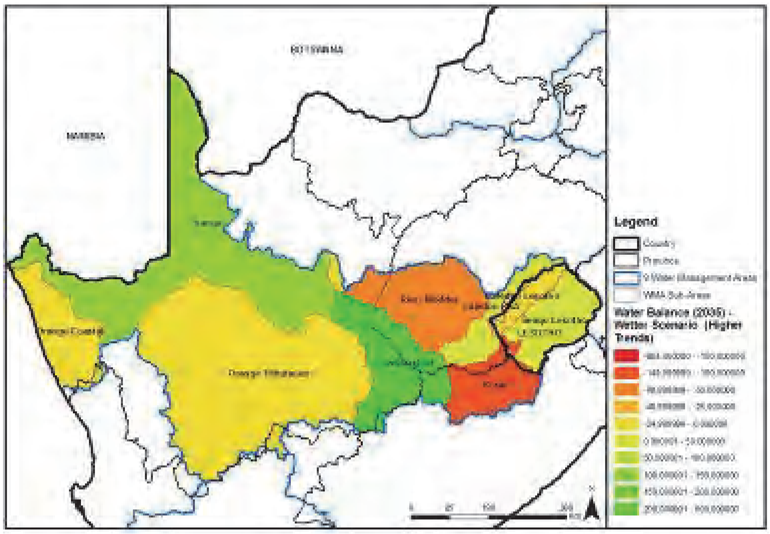


Figure G-69d: Future Water Balance of the Olifants WMA under a Wetter Scenario (High Growth).

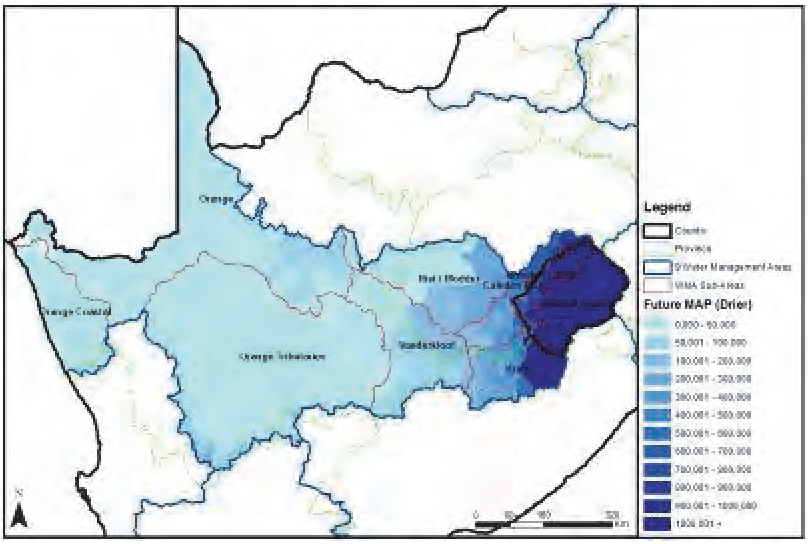


Figure G-70a: Future Rainfall Distribution for the Orange WMA under a Drier Scenario.

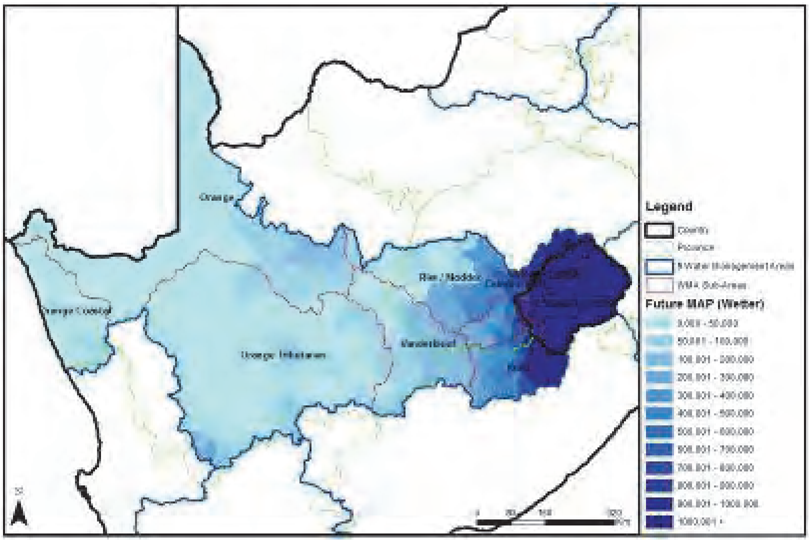


Figure G-70b: Future Rainfall Distribution for the Orange WMA under a Wetter Scenario.

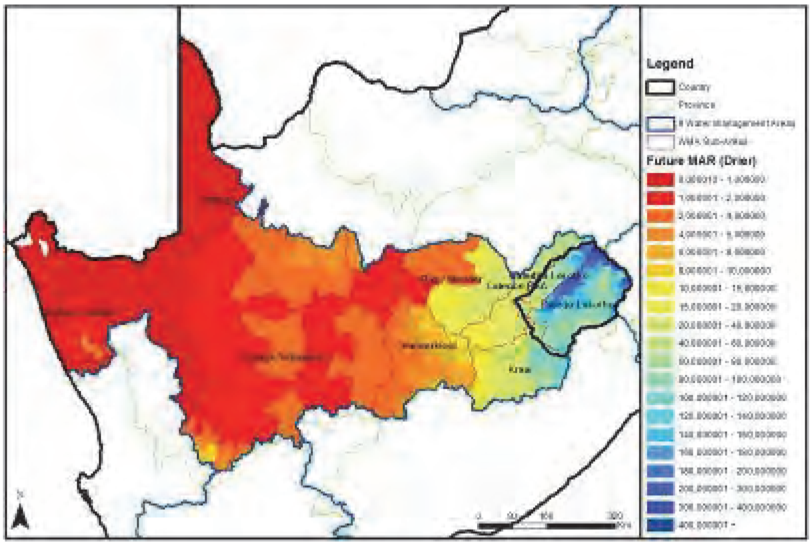


Figure G-71a: Future Mean Annual Runoff (MAR) for the Orange WMA under a Drier Scenario.

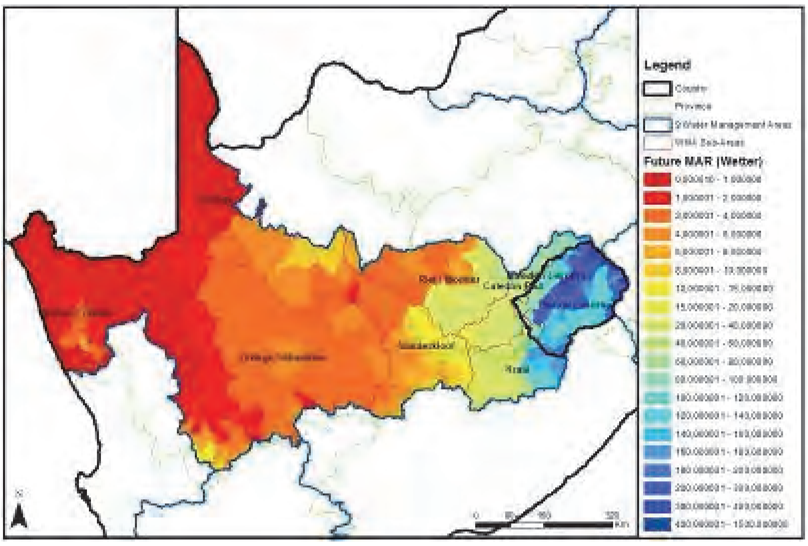


Figure G-71b: Future Mean Annual Runoff (MAR) for the Orange WMA under a Wetter Scenario.

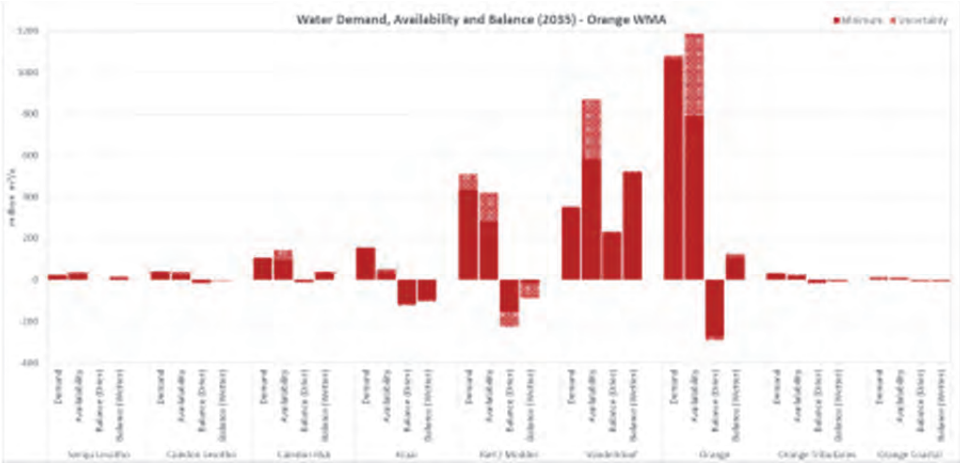


Figure G-72: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is positive for the Senqu Lesotho and Vanderkloof areas in the WMA under a drier future, and in Senqu Lesotho, Vanderkloof and Orange under a wetter future. However, low growth could potentially also result in a positive water balance in Caledon RSA and Orange Coastal under a wetter future. Therefore, the location of energy resources should be aligned with the water availability, in whichever future.

G 7. Mzimvubu-Tsitsikama WMA

The Mzimvubu-Tsitsikama WMA is located in the south-eastern corner of the country. It is an amalgamation of the previous Mzimvubu-Keiskamma and Fish-Tsitsikamma WMAs. The WMA is situated area lies predominantly within the Eastern Cape Province and borders on Lesotho to the north. The south-western part of the area is characterised by several mountain ranges lying parallel to the coast, with undulating terrain and localised massive inland and the highest points on the border with Lesotho, which also forms the division with the Orange River catchment. Several national parks and conservation areas are found in the water management area. Many of the estuaries are still in a relatively natural state. The Mzimvubu River is the largest undeveloped river in South Africa. Climate over the water management area is strongly influenced by its location and topography. Typical arid Karoo climate prevails over most of the interior, where annual rainfall ranges from 200 mm to 600 mm, while areas along the coast and eastern parts experience rainfall in the range from 700 mm to 1 500 mm/a (NWRS, 2004). Figure G-73 below illustrates the location of the Mzimvubu-Tsitsikama WMA.

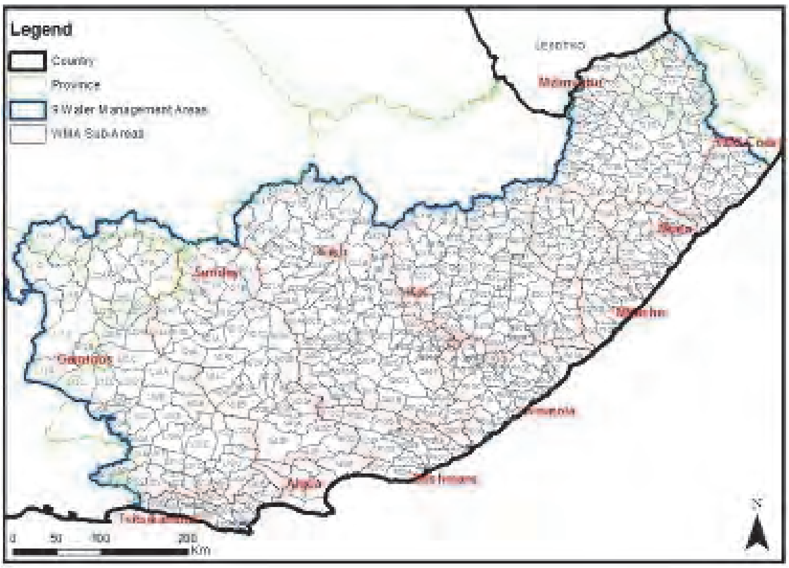


Figure G-73: The Mzimvubu-Tsitsikama WMA. Increase font size, edit font colour

G 7.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Mzimvubu-Tsitsikama WMA. This includes: water demand (Figure G-74), water availability (Figure G-75), water balance (Figure G-76), rainfall distribution (Figure G-77) as well as the mean annual runoff (Figure G-78).

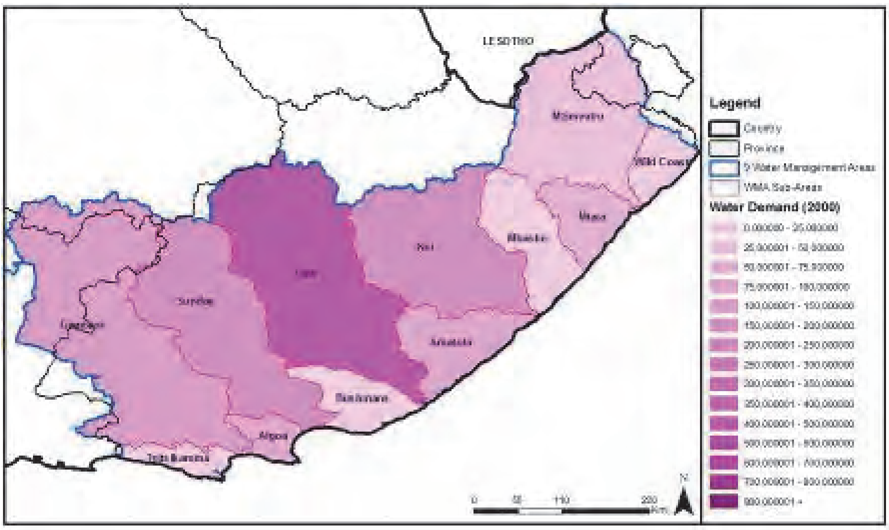


Figure G-74: Current Water Demand of the Mzimvubu-Tsitsikama WMA (2000).

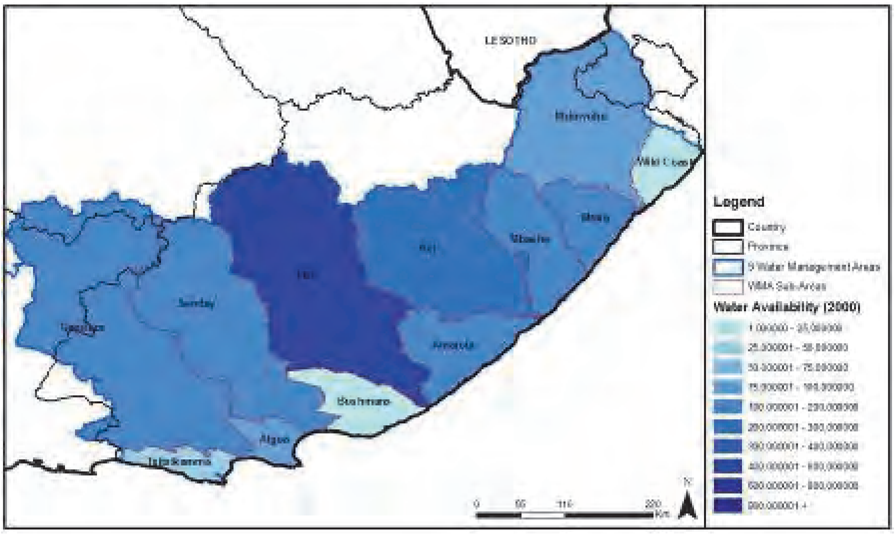


Figure G-75: Current Water Availability (Yield) of the Mzimvubu-Tsitsikama WMA (2000).

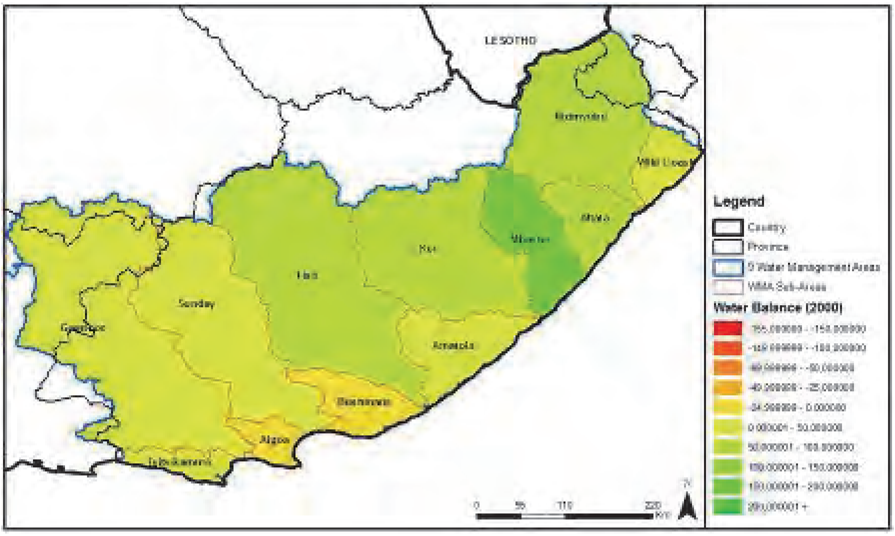


Figure G-76: Current Water Balance of the Mzimvubu-Tsitsikama WMA (2000).

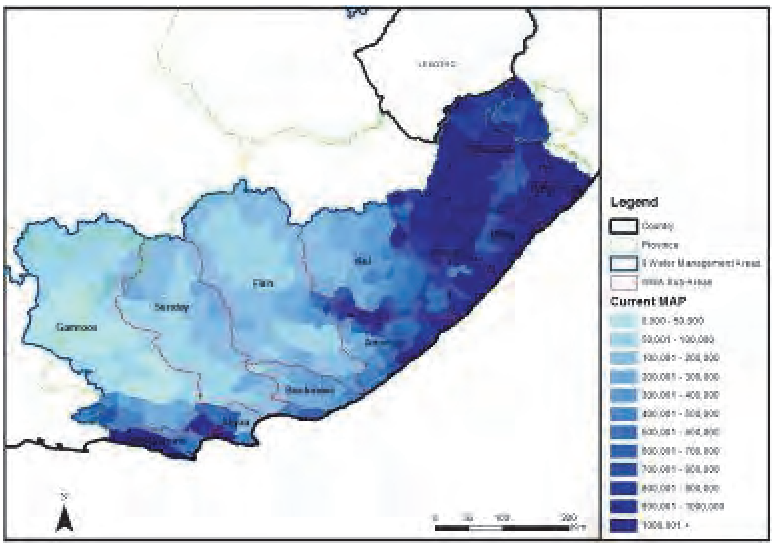


Figure G-77: Current Rainfall Distribution for the Mzimvubu-Tsitsikama WMA.

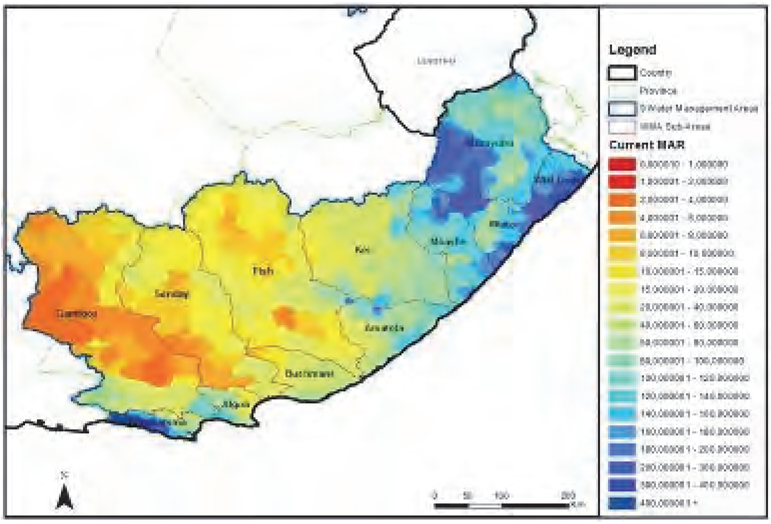


Figure G-78: Current Mean Annual Runoff (MAR) for the Mzimvubu-Tsitsikama WMA.

G 7.2. Future status of water resources

This section provides a spatial overview of the future status of water resources for the Mzimvubu-Tsitsikama WMA, under different scenarios. This includes: water demand (Figure G-79), water availability (Figure G-80), water balance (Figure G-81), rainfall distribution (Figure G-82) as well as the mean annual runoff (Figure G-83). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-84.

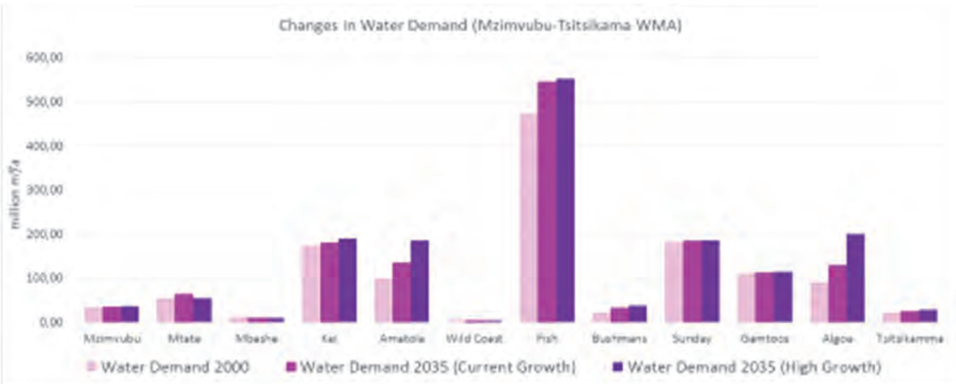


Figure G-79a: Changes in Water Demand under the Different Growth Scenarios for the Mzimvubu-Tsitsikama WMA.

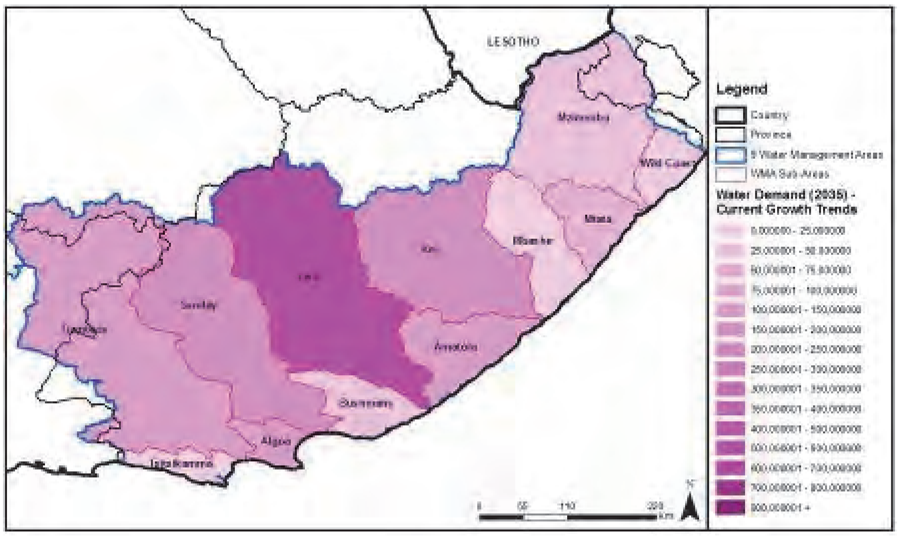


Figure G-79b: Water Demand for Current Growth Trends for the Mzimvubu-Tsitsikama WMA.

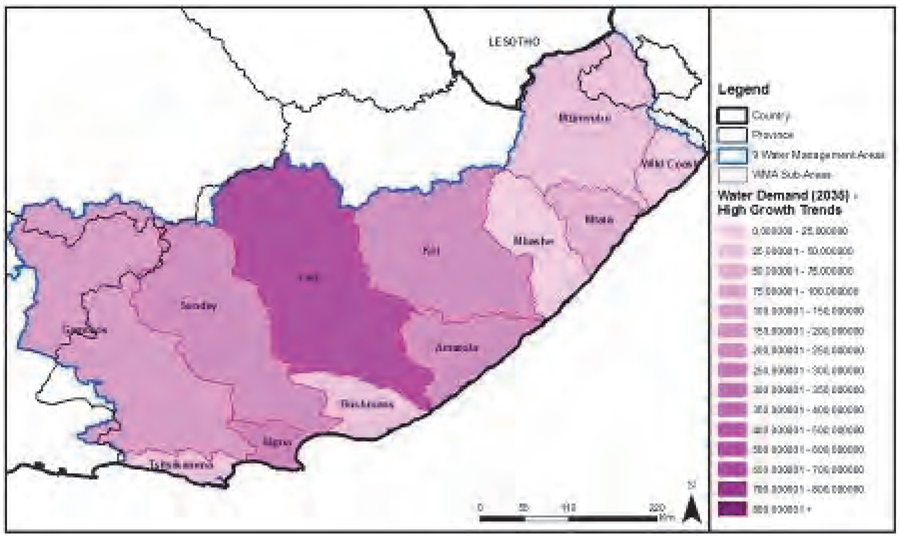


Figure G-79c: Water Demand for High Growth Trends for the Mzimvubu-Tsitsikama WMA.

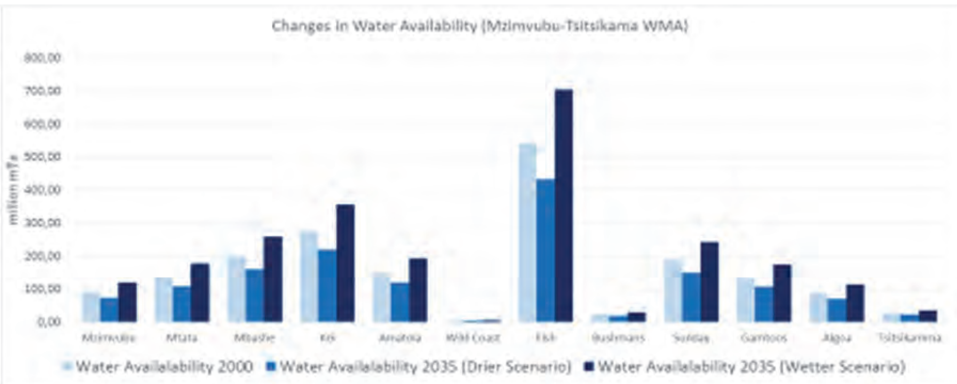


Figure G-80a: Changes in Water Availability under the Different Climate Scenarios for the Mzimvubu-Tsitsikama WMA.

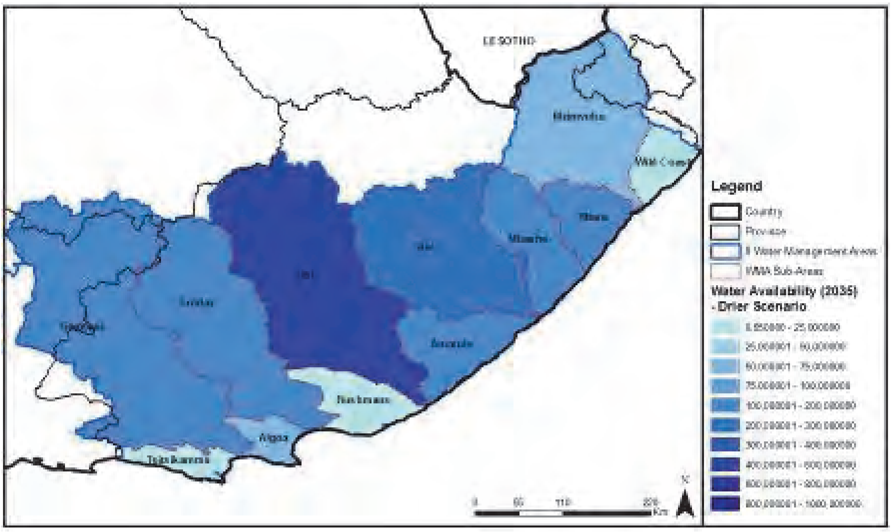


Figure G-80b: Water Availability under a Drier Scenario for the Mzimvubu-Tsitsikama WMA.

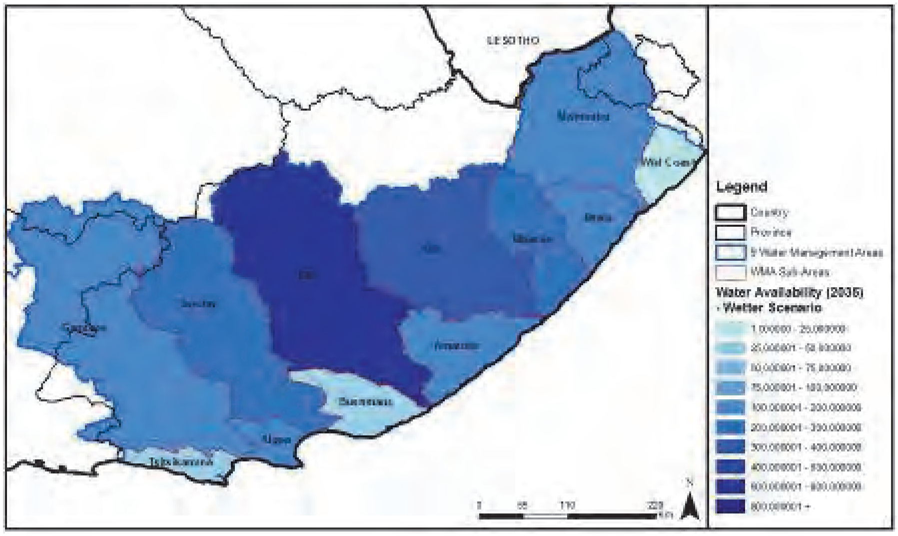


Figure G-80c: Water Availability under a Wetter Scenario for the Mzimvubu-Tsitsikama WMA.

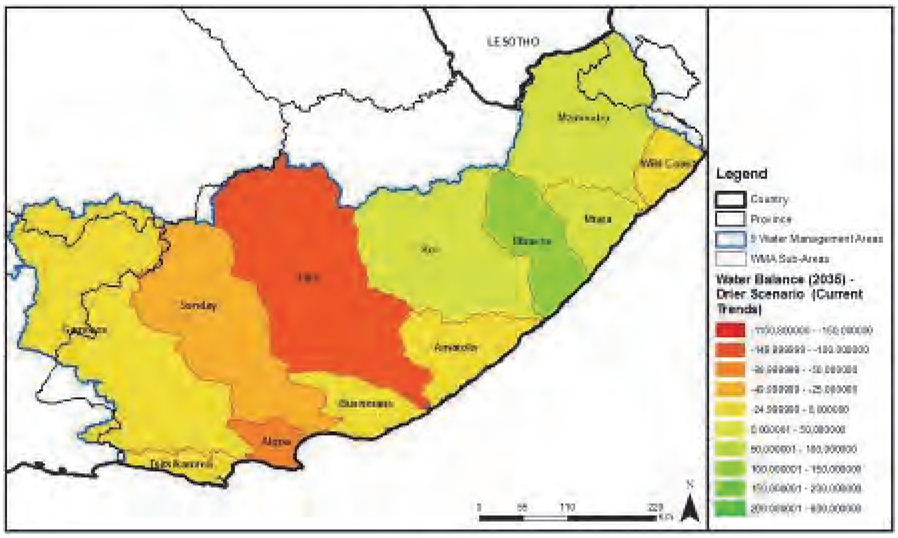


Figure G-81a: Future Water Balance of the Mzimvubu-Tsitsikama WMA under a Drier Scenario (Current Growth).

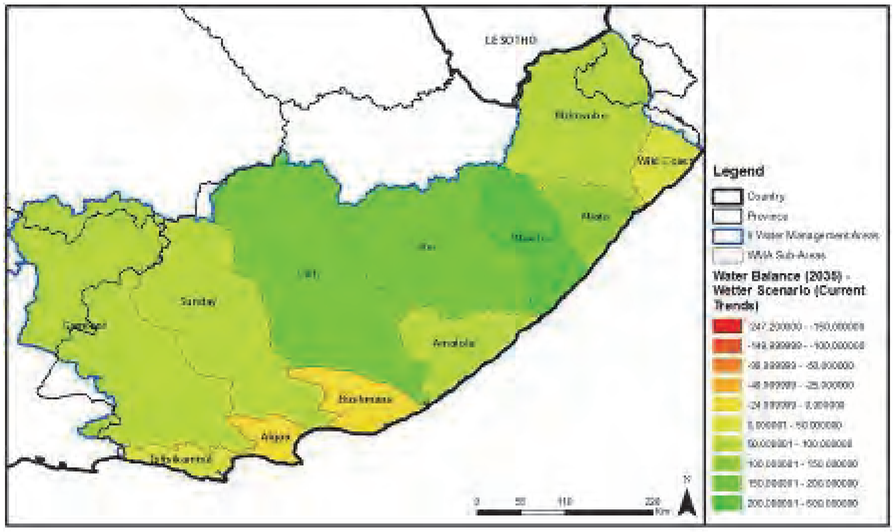


Figure G-81b: Future Water Balance of the Mzimvubu-Tsitsikama WMA under a Wetter Scenario (Current Growth).

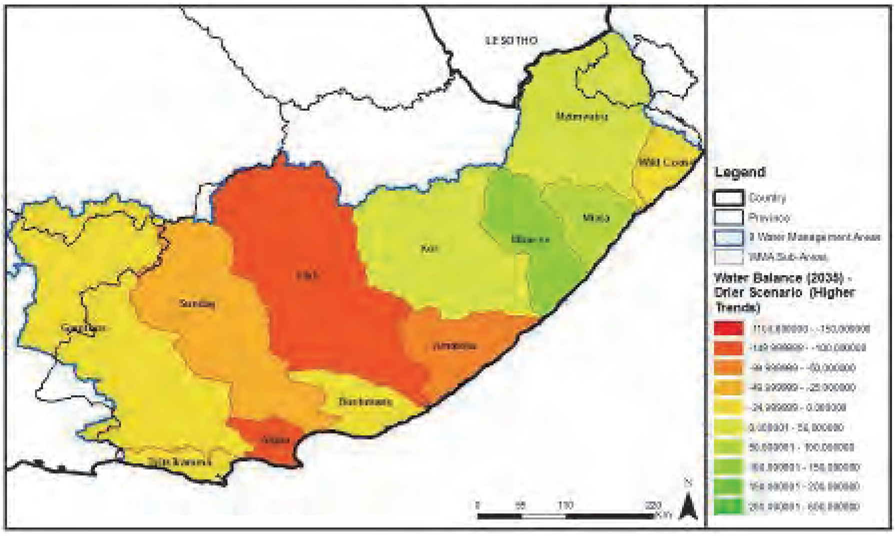


Figure G-81c: Future Water Balance of the Mzimvubu-Tsitsikama WMA under a Drier Scenario (High Growth).

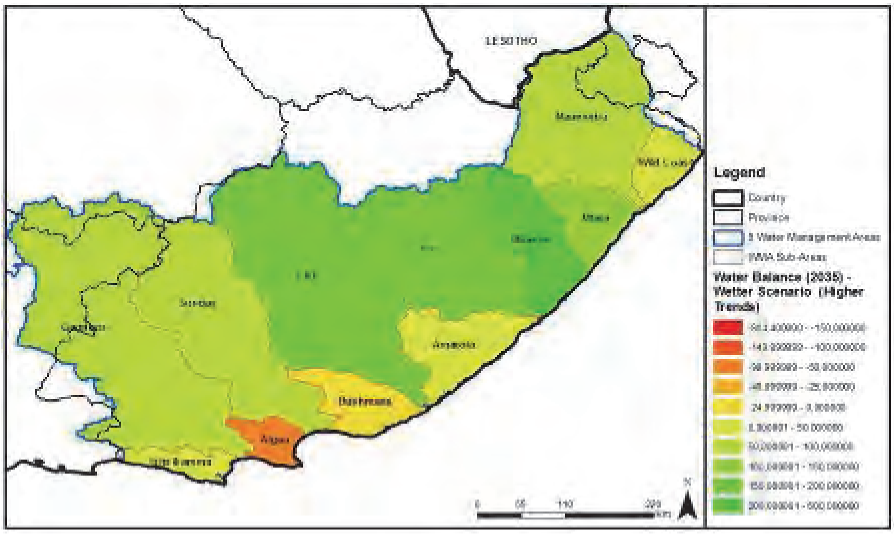


Figure G-81d: Future Water Balance of the Mzimvubu-Tsitsikama WMA under a Wetter Scenario (High Growth).

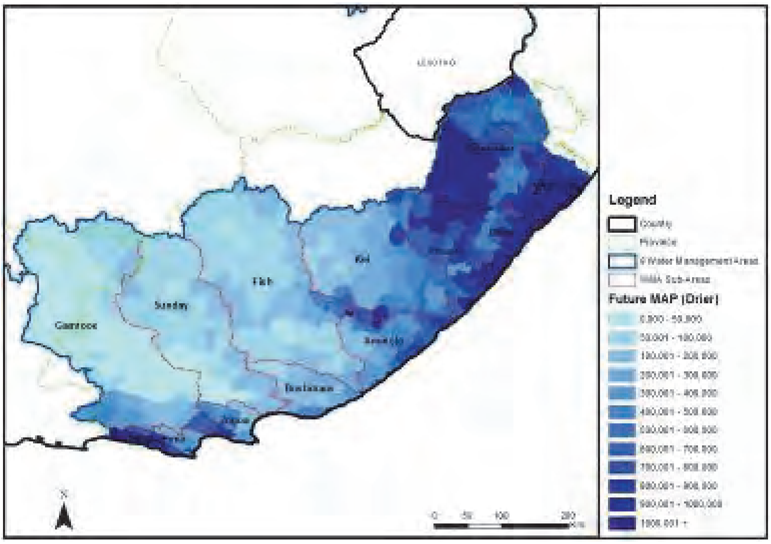


Figure G-82a: Future Rainfall Distribution for the Mzimvubu-Tsitsikama WMA under a Drier Scenario.

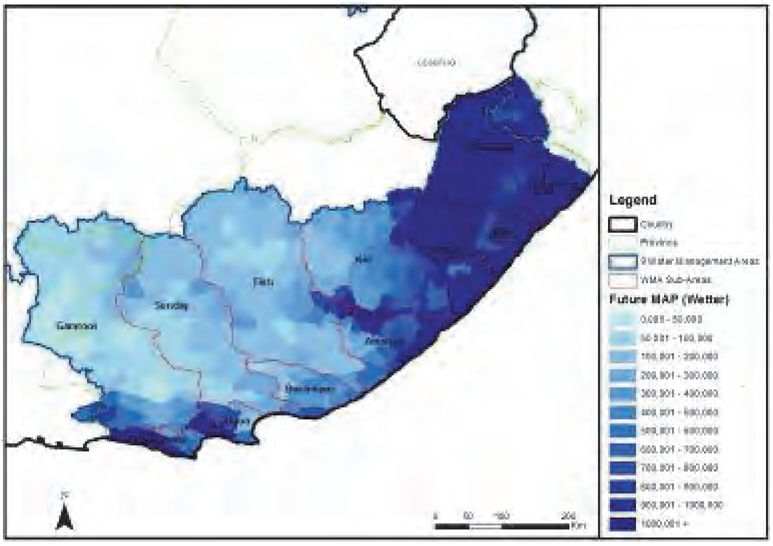


Figure G-82b: Future Rainfall Distribution for the Mzimvubu-Tsitsikama WMA under a Wetter Scenario

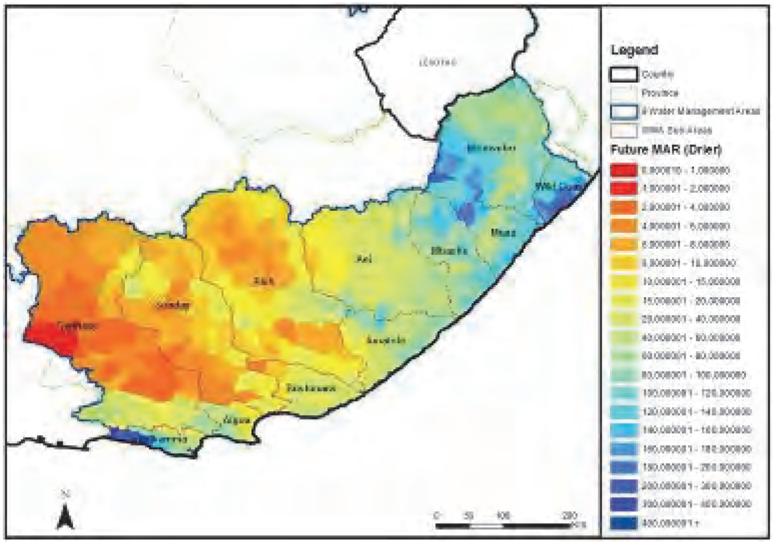


Figure G-83a: Future Mean Annual Runoff (MAR) for the Mzimvubu-Tsitsikama WMA under a Drier Scenario.

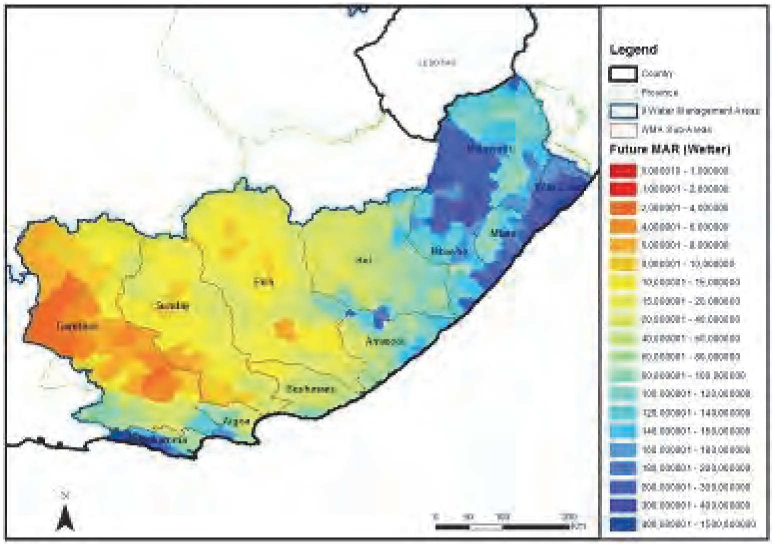


Figure G-83b: Future Mean Annual Runoff (MAR) for the Mzimvubu-Tsitsikama WMA under a Wetter Scenario.

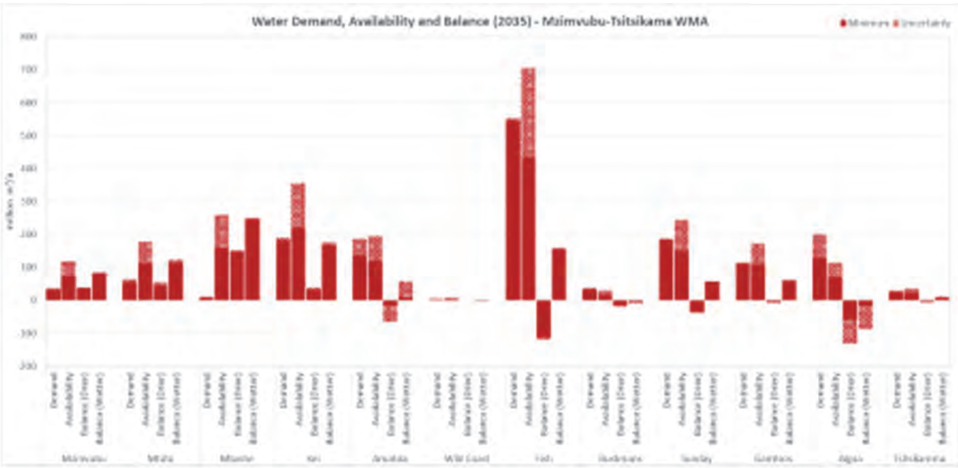


Figure G-84: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is positive for the Mzimvubu, Mtata, Mbashe and Kei areas in the WMA under a drier future, and in Mzimvubu, Mtata, Mbashe, Kei, Amatola, Wild Coast, Fish, Sunday, Gamtoos and Tsitsikamma under a wetter future. Therefore, the location of energy resources should be aligned with the water availability, in whichever future.

G 8. Breede-Gouritz WMA

The Breede-Gouritz WMA is located in the south-western corner of the country. It is an amalgamation of the previous Breede and Gouritz WMAs. The WMA is the southern-most water management area in South Africa and predominately in the Western Cape Province, extending inland across the Little Karoo and into the Great Karoo. Rainfall occurs during the winter. The climate in the area varies considerably. In the western mountainous regions rainfall can exceed 1 500 mm/a, while in the lower eastern parts of the area the rainfall decreases to about 200 mm/a. Indigenous forests, wetlands and estuaries of high conservation status are found in the humid areas. The water in the arid areas is naturally of high salinity as a result of the geology and climate (NWRS, 2004). Figure G-85 below illustrates the location of the Breede-Gouritz WMA.

Figure G-85: The Breede-Gouritz WMA. Increase font size, edit font colour

G 8.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Breede-Gouritz WMA. This includes: water demand (Figure G-86), water availability (Figure G-87), water balance (Figure G-88), rainfall distribution (Figure G-89) as well as the mean annual runoff (Figure G-90).

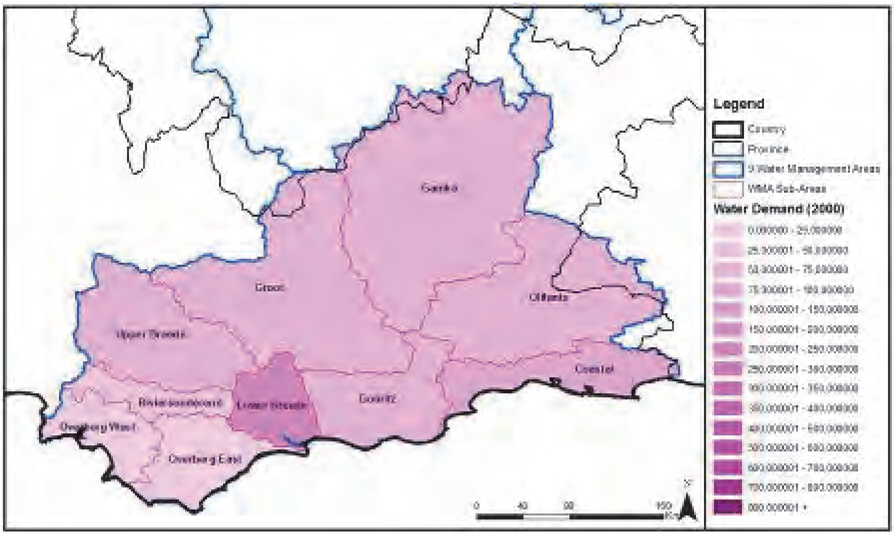


Figure G-86: Current Water Demand of the Breede-Gouritz WMA (2000).

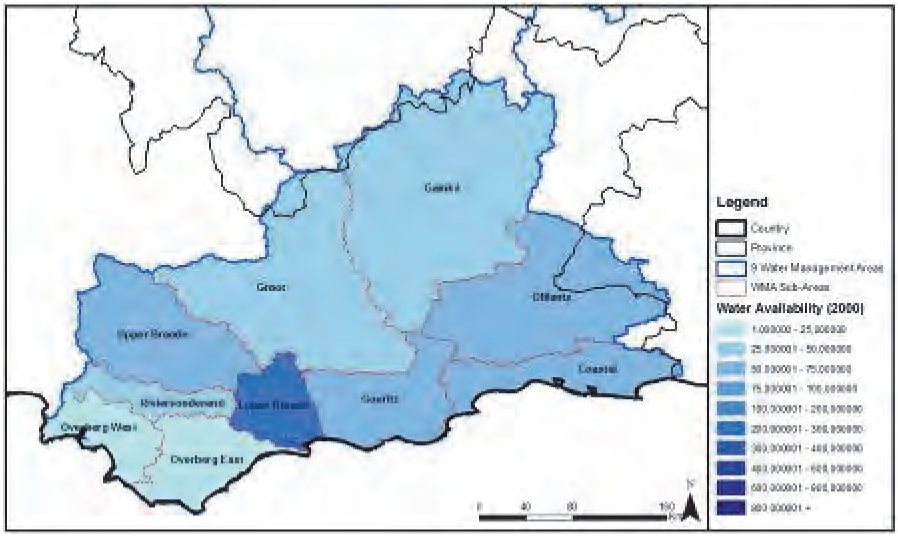


Figure G-87: Current Water Availability (Yield) of the Breede-Gouritz WMA (2000).

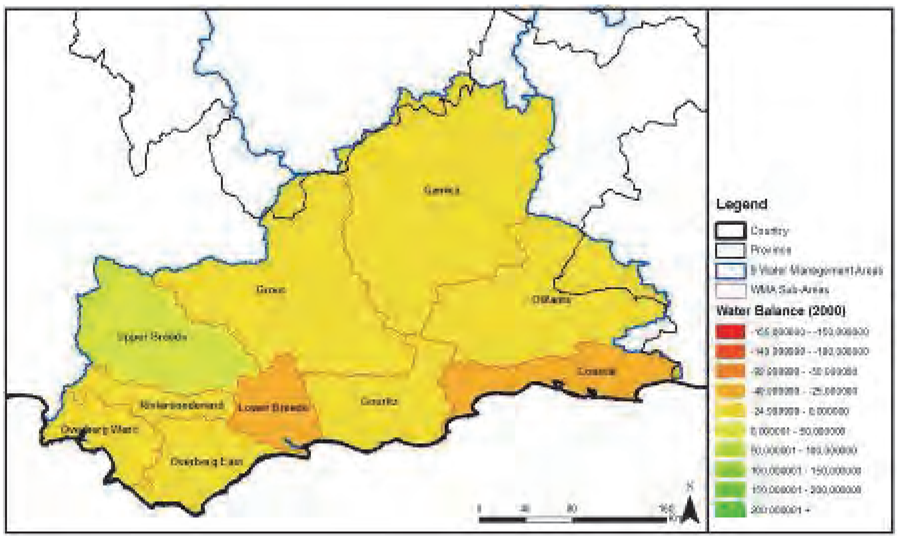


Figure G-88: Current Water Balance of the Breede-Gouritz WMA (2000).

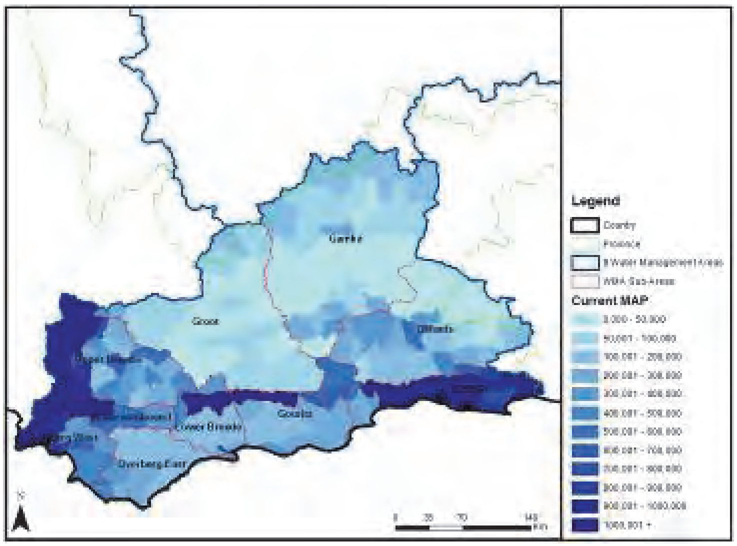


Figure G-89: Current Rainfall Distribution for the Breede-Gouritz WMA.

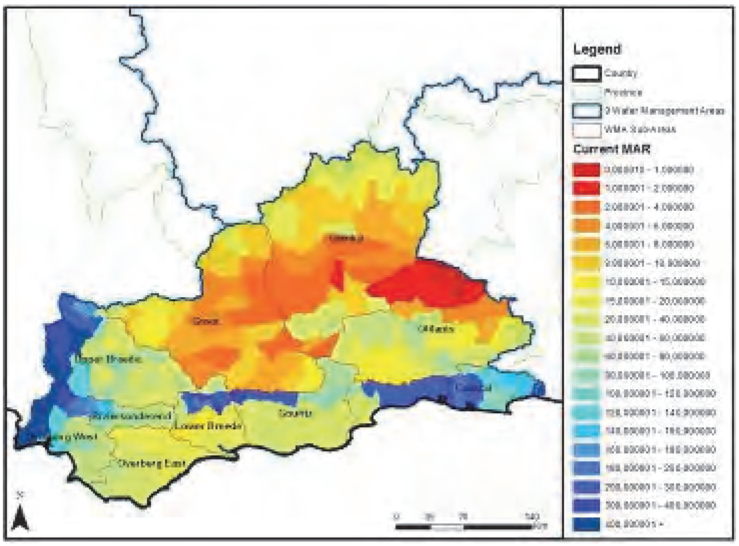


Figure G-90: Current Mean Annual Runoff (MAR) for the Breede-Gouritz WMA.

G 8.2. Future Status of Water Resources

This section provides a spatial overview of the future status of water resources for the Breede-Gouritz WMA, under different scenarios. This includes: water demand (Figure G-91), water availability (Figure G-92), water balance (Figure G-93), rainfall distribution (Figure G-94) as well as the mean annual runoff (Figure G-95). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-96.

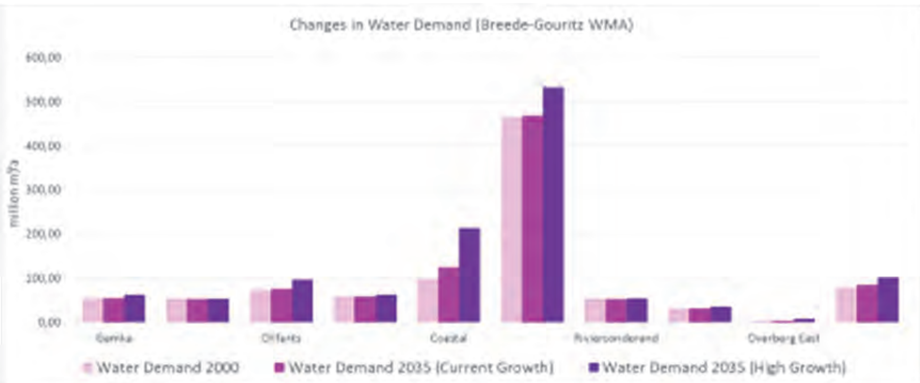


Figure G-91a: Changes in Water Demand under the Different Growth Scenarios for the Breede-Gouritz WMA.

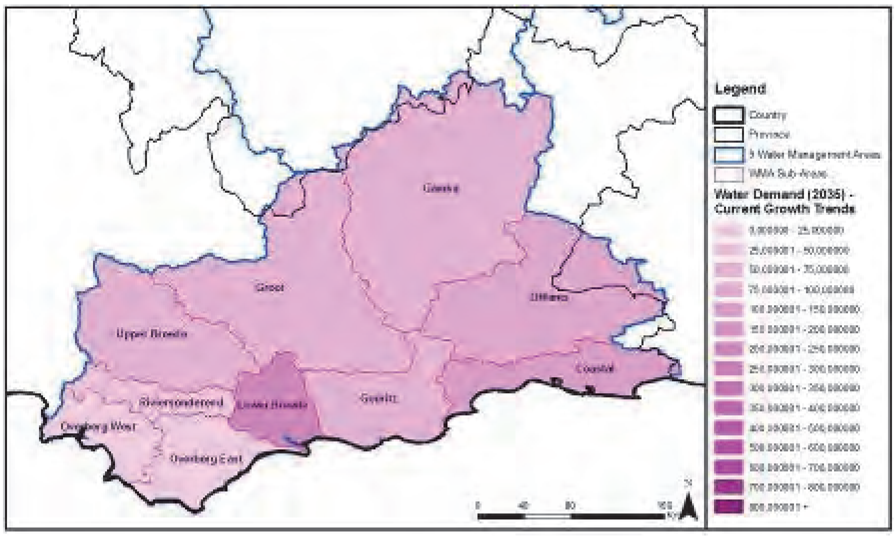


Figure G-91b: Water Demand for Current Growth Trends for the Breede-Gouritz WMA.

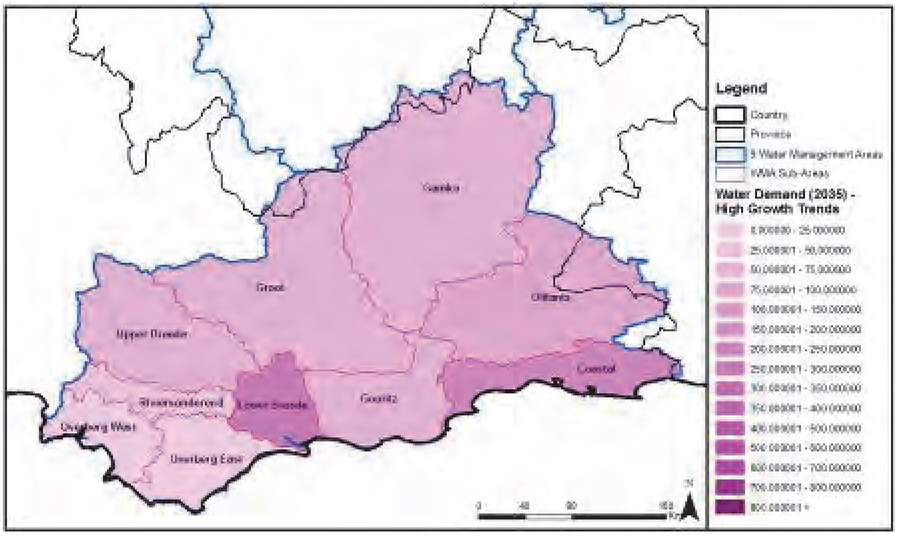


Figure G-91c: Water Demand for High Growth Trends for the Breede-Gouritz WMA.

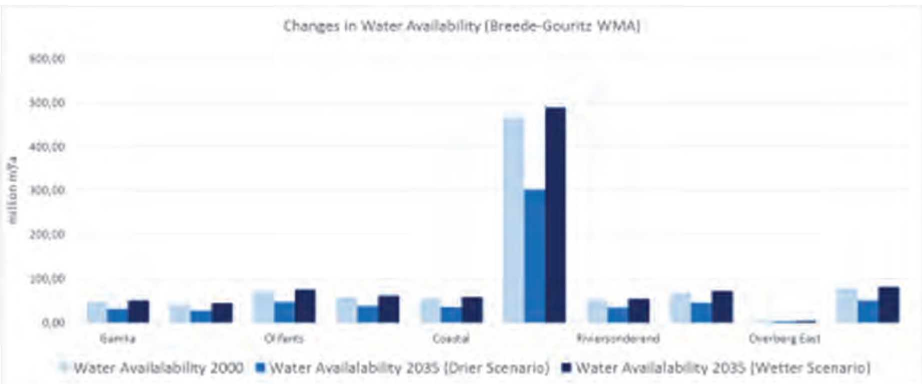


Figure G-92a: Changes in Water Availability under the Different Climate Scenarios for the Breede-Gouritz WMA.

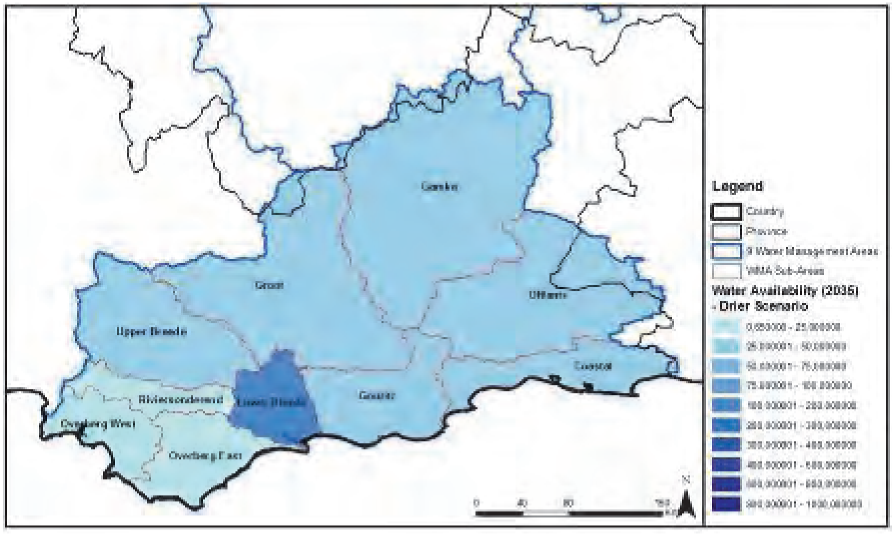


Figure G-92b: Water Availability under a Drier Scenario for the Breede-Gouritz WMA.

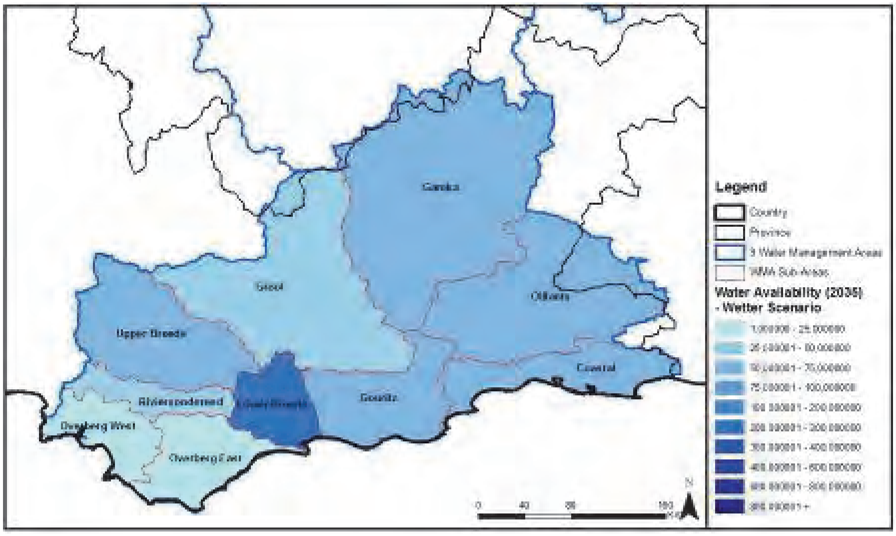


Figure G-92c: Water Availability under a Wetter Scenario for the Breede-Gouritz WMA.

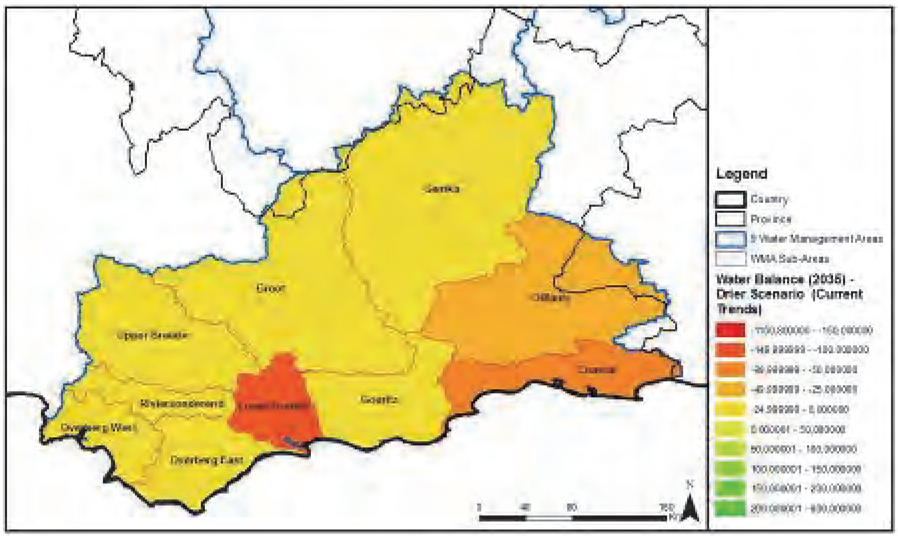


Figure G-93a: Future Water Balance of the Breede-Gouritz WMA under a Drier Scenario (Current Growth).

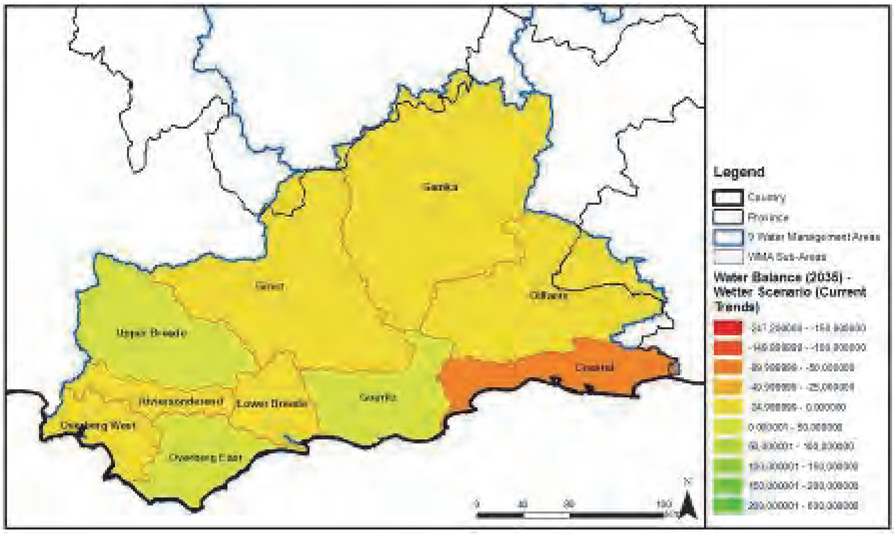


Figure G-93b: Future Water Balance of the Breede-Gouritz WMA under a Wetter Scenario (Current Growth).

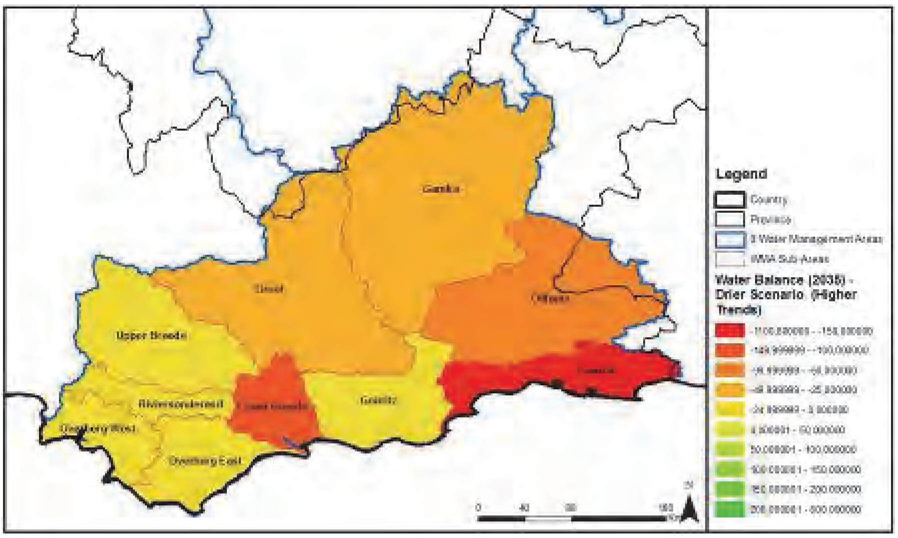


Figure G-93c: Future Water Balance of the Breede-Gouritz WMA under a Drier Scenario (High Growth).

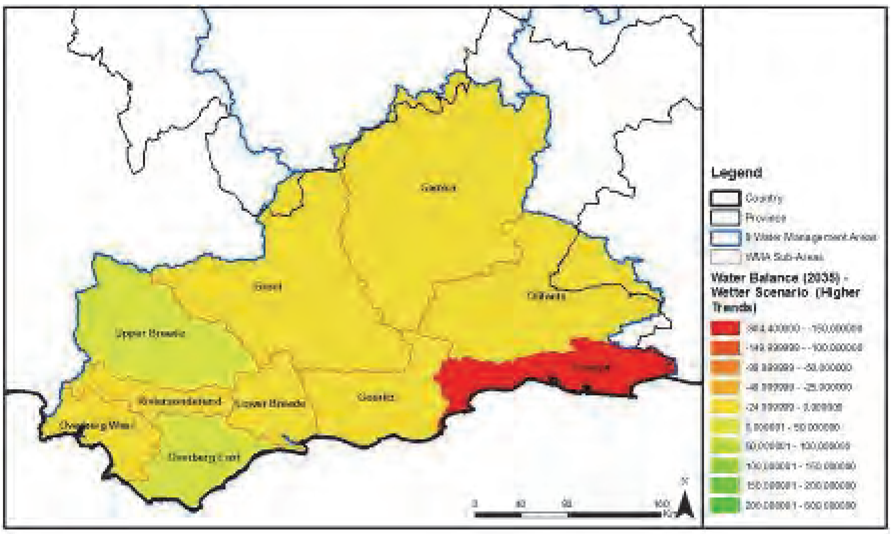


Figure G-93d: Future Water Balance of the Breede-Gouritz WMA under a Wetter Scenario (High Growth).

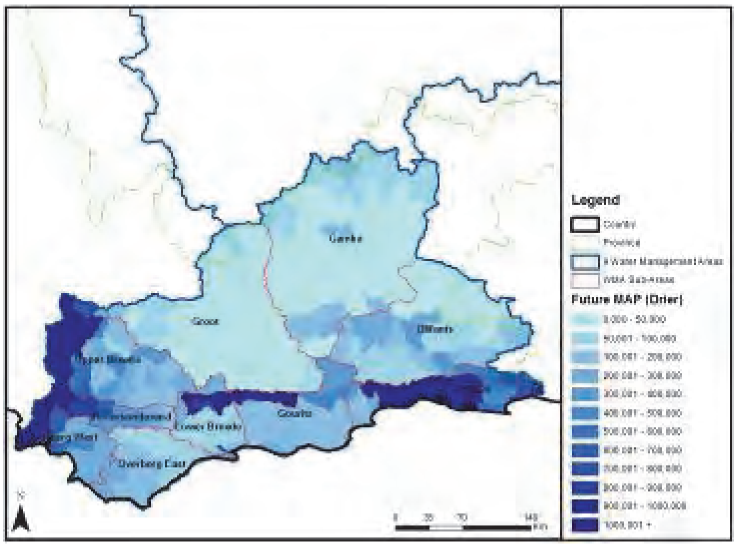


Figure G-94a: Future Rainfall Distribution for the Breede-Gouritz WMA.

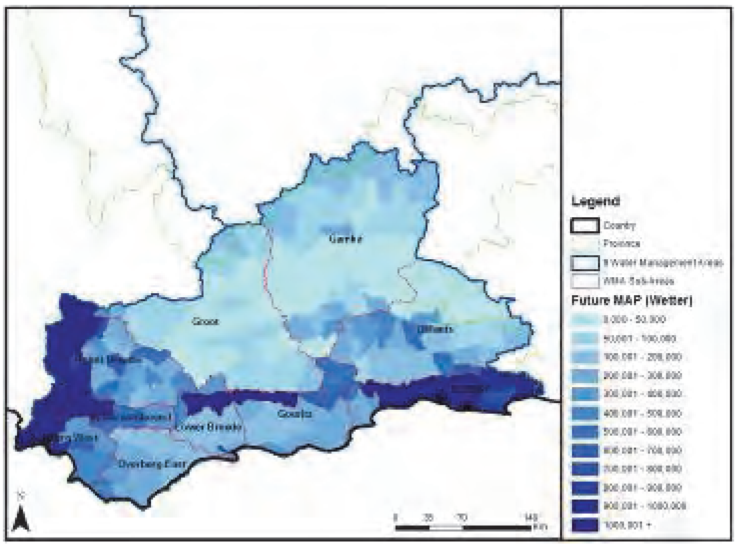


Figure G-94b: Future Rainfall Distribution for the Breede-Gouritz WMA.

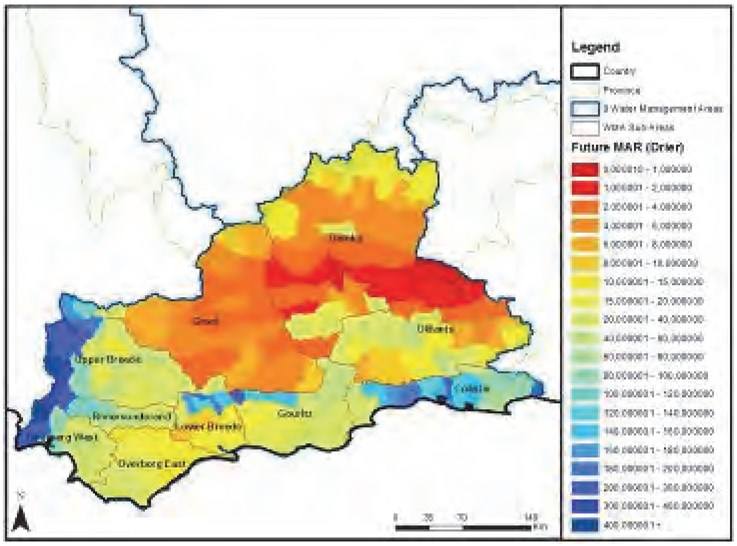


Figure G-95a: Future Mean Annual Runoff (MAR) for the Breede-Gouritz WMA.

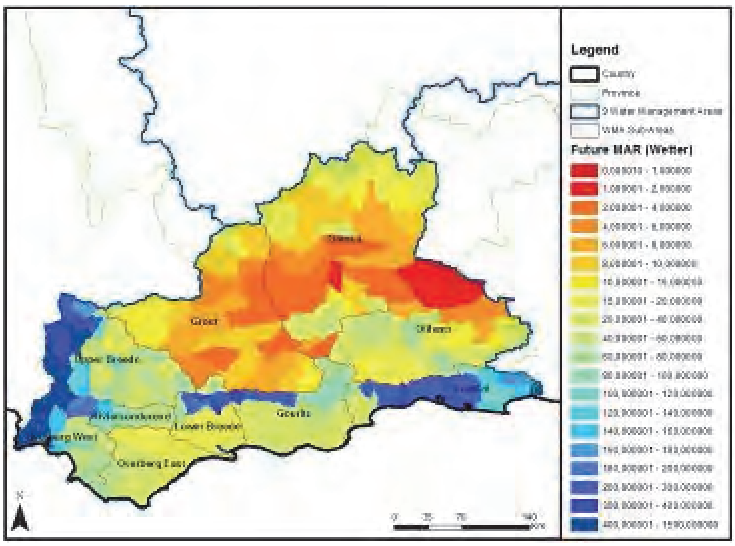


Figure G-95b: Future Mean Annual Runoff (MAR) for the Breede-Gouritz WMA.

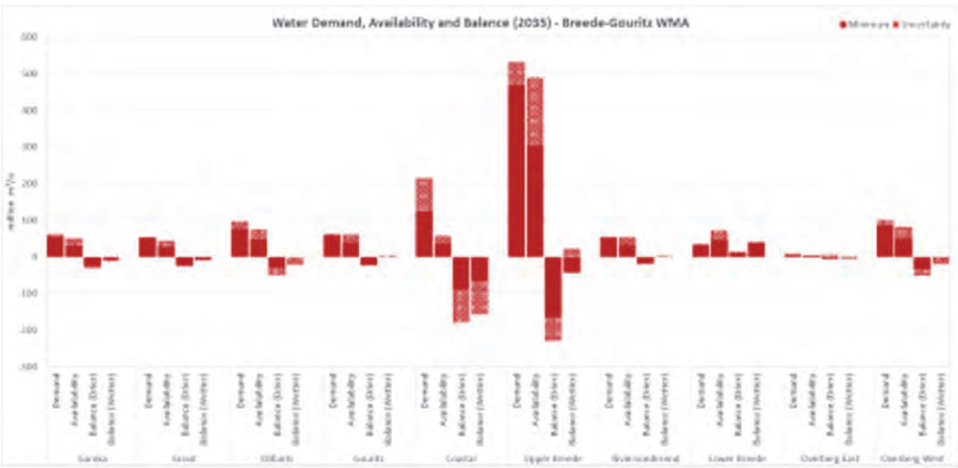


Figure G-96: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is positive for the Lower Breede area in the WMA under a drier future, and in Riviersonderend and Lower Breede under a wetter future. However, low growth could potentially also result in a positive water balance in Overberg East under a drier future, and in Gouritz, Upper Breede and Overberg East under a wetter future. Therefore, the location of energy resources should be aligned with the water availability, in whichever future.

G 9. Berg-Olifants WMA

The Berg-Olifants is located in the south-western corner of the country. It is an amalgamation of the previous Berg and Olifants/Doring WMAs. The WMA lies on the west coast of South Africa along the Atlantic Ocean and is shared by the Western Cape and Northern Cape provinces. It is one of the most diverse WMAs in the country with respect to its natural characteristics and water resources. Prominent topographic features are the Cederberg range and the narrow Olifants River valley, as well as Table Mountain to the east and the Cape Peninsula mountains in the south-west. Sandy lowlands, with minimal runoff, extend across the central and western part of the WMA. Figure G-97 below illustrates the location of the Berg-Olifants WMA.

Figure G-97: The Berg-Olifants WMA.

Rainfall varies from over 1 000 mm/a in the extreme south to less than 100 mm/a in the north; in winter rainfall is highly varied, ranging from a high of over 3 000 mm/a in the mountains to less than 300 mm/a in the north-west. The Cape Fynbos represents a unique floral kingdom of World Heritage status (NWRS, 2004).

G 9.1. Current status of water resources

This section provides a spatial overview of the current status of water resources for the Berg-Olifants WMA. This includes: water demand (Figure G-98), water availability (Figure G-99), water balance (Figure G-100), rainfall distribution (Figure G-101) as well as the mean annual runoff (Figure G-102).

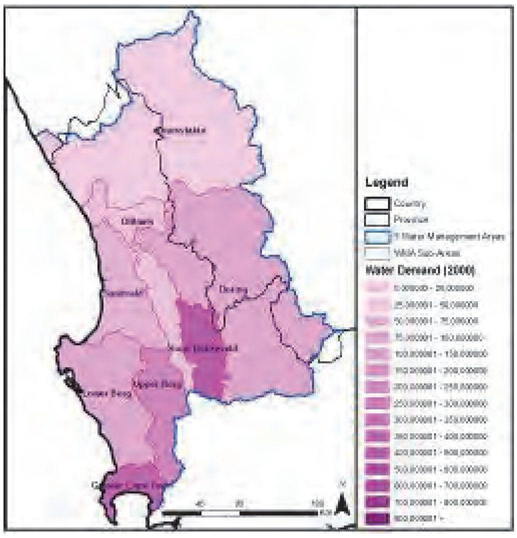


Figure G-98: Current Water Demand of the Berg-Olifants WMA (2000).

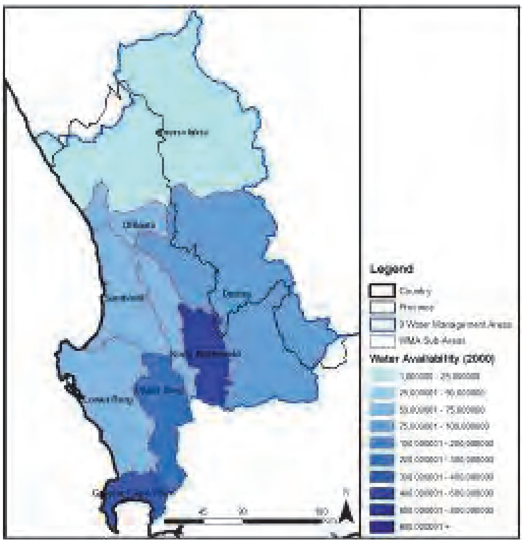


Figure G-99: Current Water Availability (Yield) of the Berg-Olifants WMA (2000)

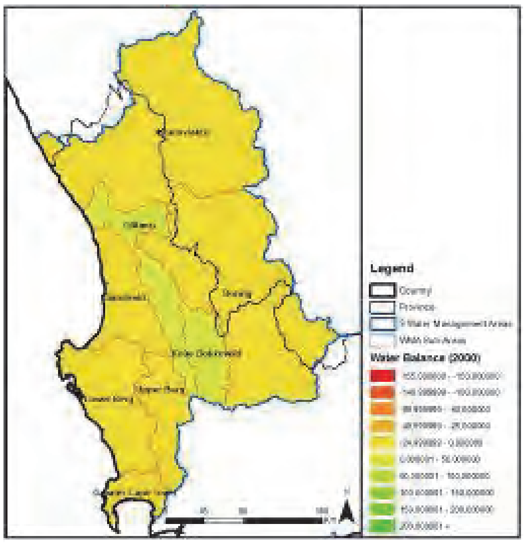


Figure G-100: Current Water Balance of the Berg-Olifants WMA (2000).

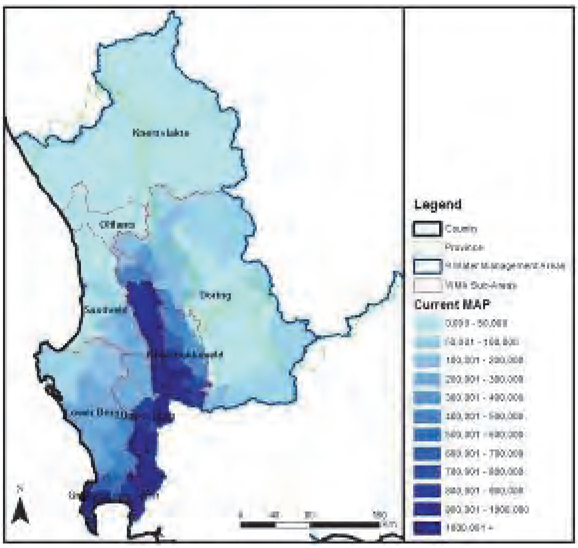


Figure G-101: Current Rainfall Distribution for the Berg-Olifants WMA.

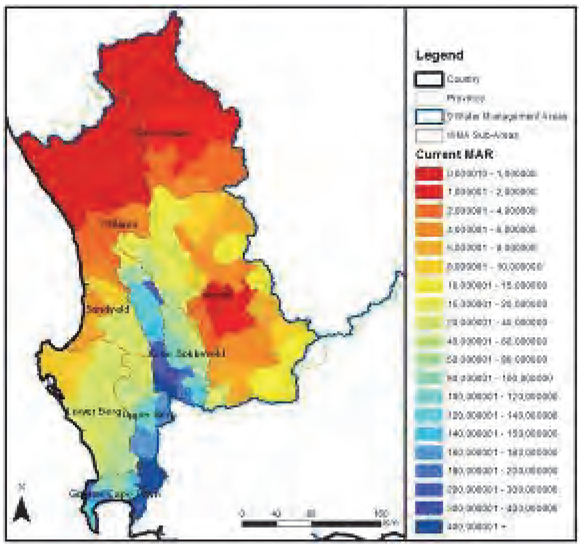


Figure G-102: Current Mean Annual Runoff (MAR) for the Berg-Olifants WMA.

G 9.2. Future status of water resources

This section provides a spatial overview of the future status of water resources for the Berg-Olifants WMA, under different scenarios. This includes: water demand (Figure G-103), water availability (Figure G-104), water balance (Figure G-105), rainfall distribution (Figure G-106) as well as the mean annual runoff (Figure G-107). In addition, a comparison of the future water demand, water availability and water balance is provided in Figure G-108.

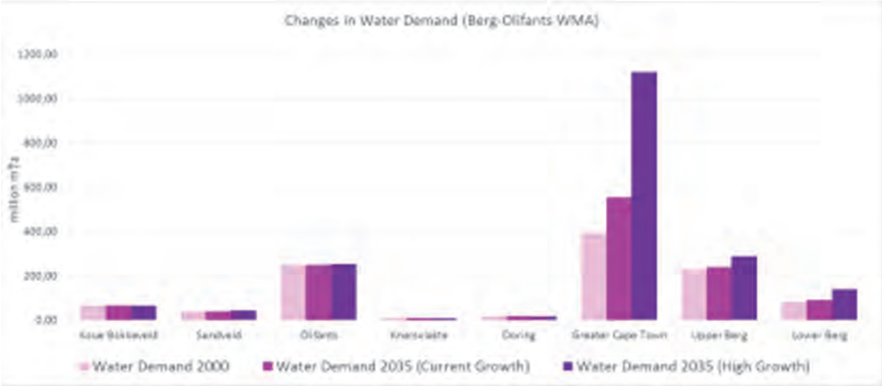


Figure G-103a: Changes in Water Demand under the Different Growth Scenarios for the Berg-Olifants WMA.

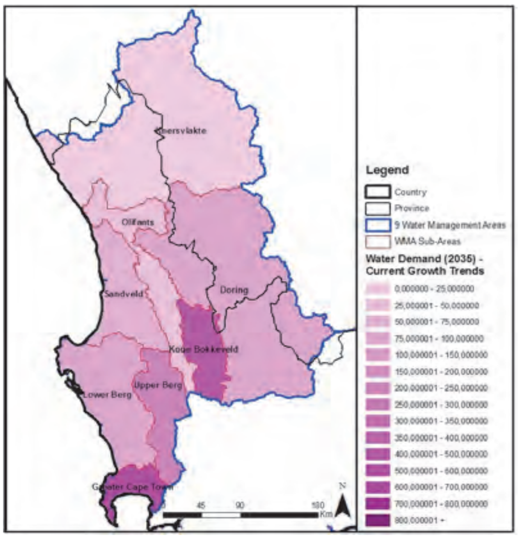


Figure G-103b: Water Demand for Current Growth Trends for the Berg-Olifants WMA.

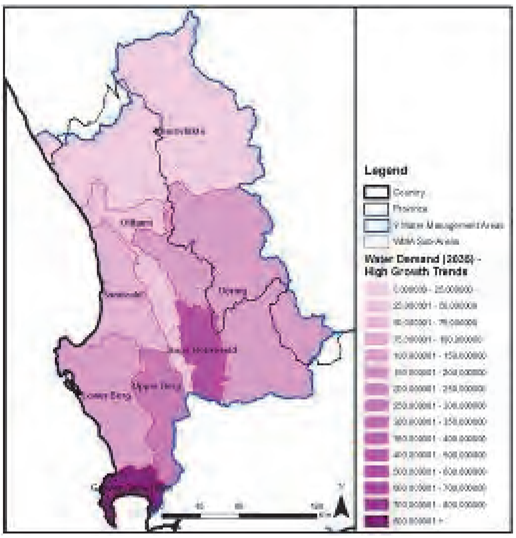


Figure G-103c: Water Demand for High Growth Trends for the Berg-Olifants WMA.

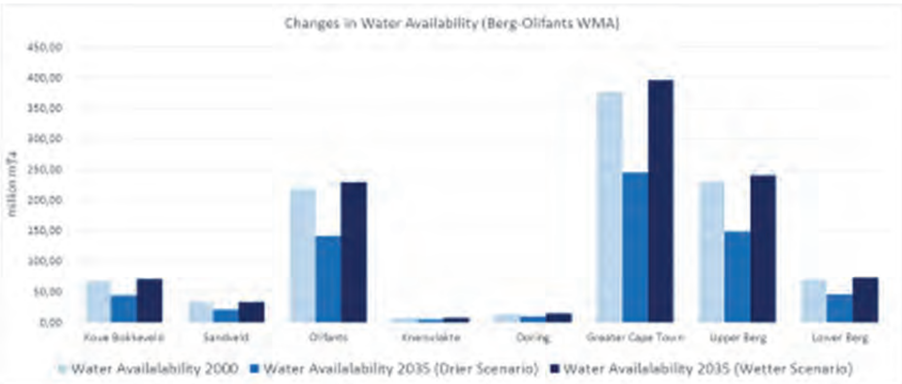


Figure G-104a: Changes in Water Availability under the Different Climate Scenarios for the Berg-Olifants WMA.

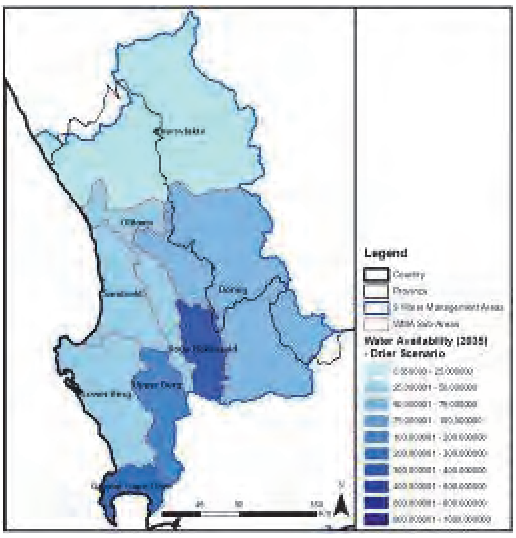


Figure G-104b: Water Availability under a Drier Scenario for the Berg-Olifants. WMA

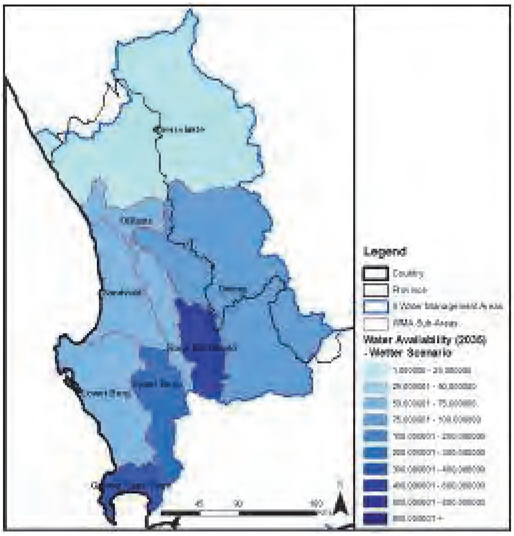


Figure G-104c: Water Availability under a Wetter Scenario for the Berg-Olifants WMA.

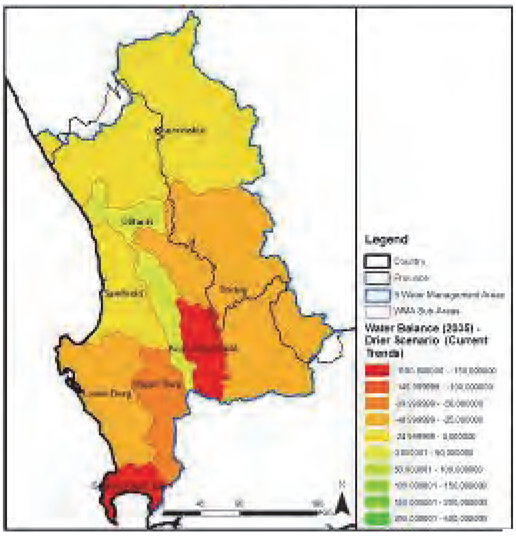


Figure G-105a: Future Water Balance of the Berg-Olifants WMA under a Drier Scenario (Current Growth).

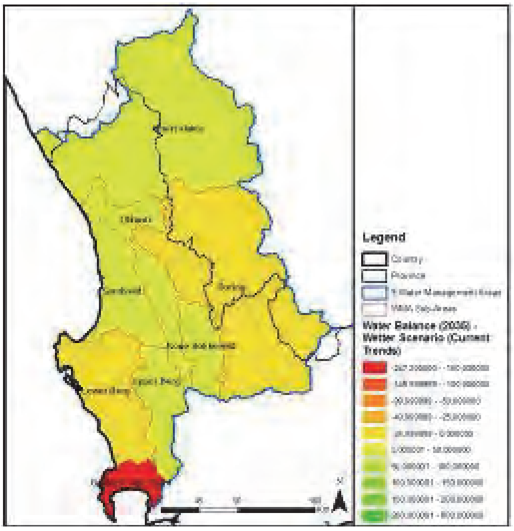


Figure G-105b: Future Water Balance of the Berg-Olifants WMA under a Wetter Scenario (Current Growth).

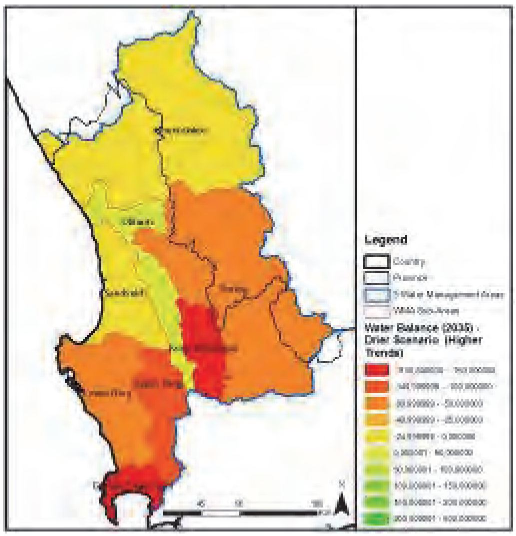


Figure G-105c: Future Water Balance of the Berg-Olifants WMA under a Drier Scenario (High Growth).

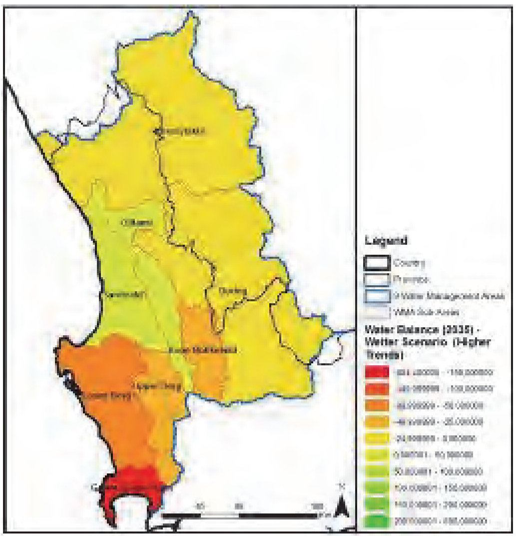


Figure G-105d: Future Water Balance of the Berg-Olifants WMA under a Wetter Scenario (High Growth).

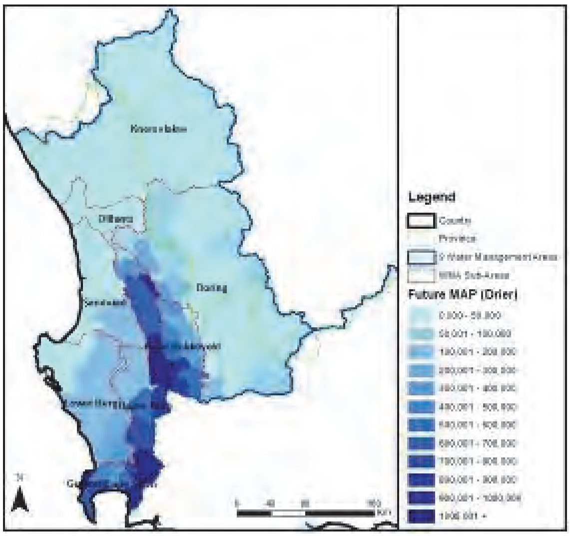


Figure G-106a: Future Rainfall Distribution for the Berg-Olifants WMA under a Drier Scenario.

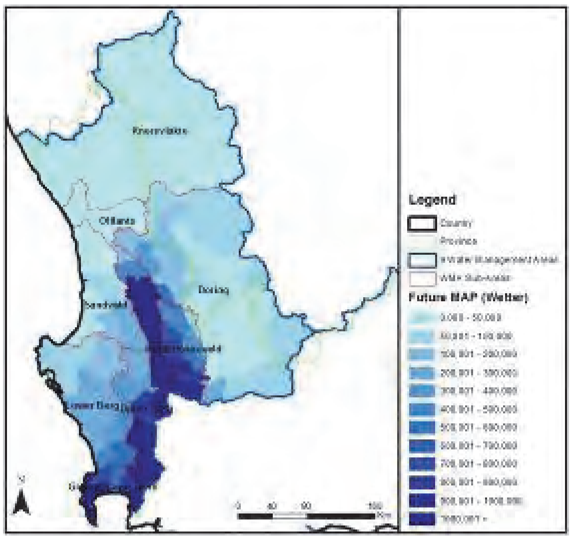


Figure G-106b: Future Rainfall Distribution for the Berg-Olifants WMA under a Wetter Scenario.

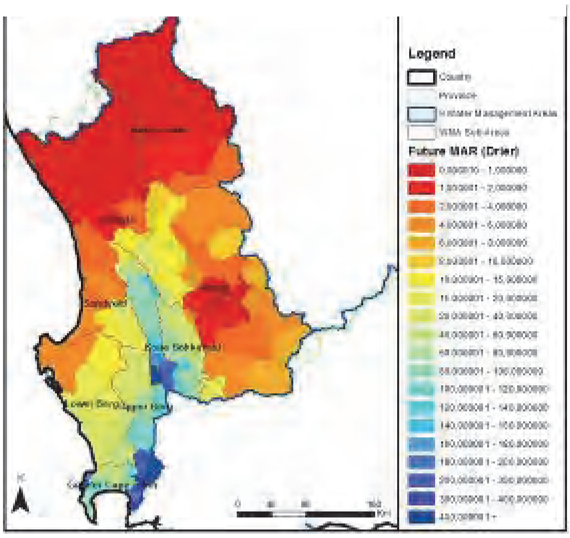


Figure G-107a: Future Mean Annual Runoff (MAR) for the Berg-Olifants WMA under a Drier Scenario.

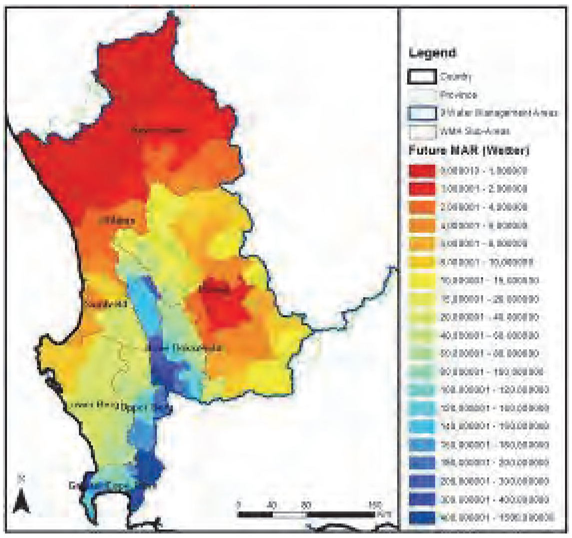


Figure G-107b: Future Mean Annual Runoff (MAR) for the Berg-Olifants WMA under a Wetter Scenario.

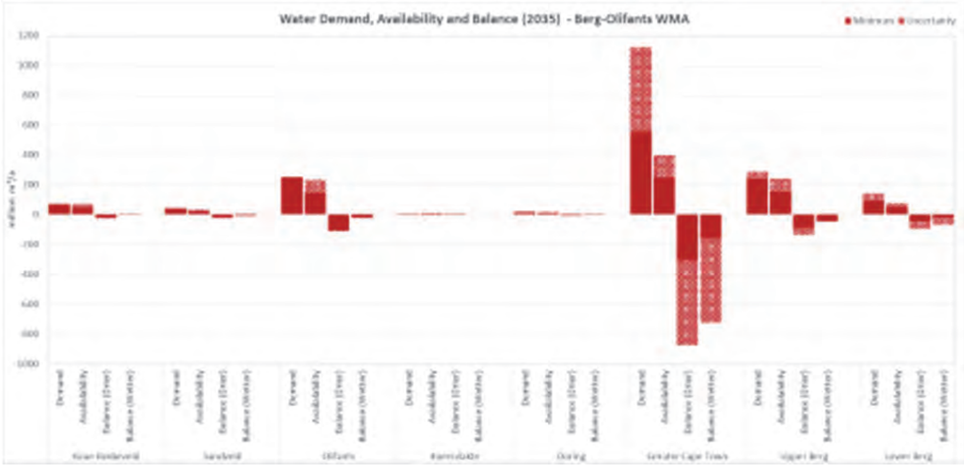


Figure G-108: Future Water Demand, Water Availability and Water Balance.

As can be seen from the figures above, the water balance is negative for all areas in the WMA under a drier future, and is positive in Knersvlakte under a wetter future. However, low growth could potentially also result in a positive water balance in Koue Bokkeveld and Upper Berg under a wetter future. Therefore, the location of energy resources should be aligned with the water availability.

APPENDIX H : WATER DATA FOR CATCHMENTS AND WATER MANAGEMENT AREAS (WMAS) IN SOUTH AFRICA

Table G1 and G2 contains data for current (2000) and projected (2035) water demand, availability and balance for Water Management Areas (WMAs) as wells as regions in each WMA.

Table G1: Water Demand, Availability and Balance for 2000 and 2035 for Water Management Areas (Adapted from NWRS2004).

Water Management Area		Water Demand			Water Availability			Water Balance	Water Balance (Drier Scenario)		Water Balance (Wetter Scenario)	
		2000	2035 (Current Growth)	2035 (High Growth)	2000	2035 (Drier Scenario)	2035 (Wetter Scenario)	2000	2035 (Current Growth)	2035 (High Growth)	2035 (Current Growth)	2035 (High Growth)
1	Limpopo	1506.00	1895.20	2585.40	1526.00	991.90	1831.20	20.00	-903.30	-1593.50	-64.00	-754.20
2	Olifants	1298.00	1471.60	1568.20	1070.00	695.50	1284.00	-228.00	-776.10	-872.70	-187.60	-284.20
3	Inkomati-Usuthu	914.00	1017.60	1084.80	673.00	437.45	816.40	-241.00	-580.15	-647.35	-201.20	-268.40
4	Pongola-Umzimkhulu	1779.00	2105.20	2914.40	1736.00	1128.40	2256.80	-43.00	-976.80	-1786.00	151.60	-657.60
5	Vaal	2058.00	2387.00	3182.20	2113.00	1479.10	2535.60	55.00	-907.90	-1703.10	148.60	-646.60
6	Orange	1996.00	2199.00	2318.00	2321.00	1856.80	2785.20	325.00	-342.20	-461.20	586.20	467.20
7	Mzimvubu-Tsitsikama	1275.00	1457.00	1598.40	1852.00	1481.60	2407.60	577.00	24.60	-116.80	950.60	809.20
8	Breede-Gouritz	970.00	1000.80	1219.20	943.00	612.95	990.15	-27.00	-387.85	-606.25	-10.65	-229.05
9	Berg-Olifants	1077.00	1253.40	1929.60	1014.00	659.10	1064.70	-63.00	-594.30	-1270.50	-188.70	-864.90
	TOTAL	12 873.00	14 786.80	18 400.20	13 248.00	9 342.80	15 971.65	375.00	-5 444.00	-9 057.40	1 184.85	-2 428.55

Table G2: Water Demand, Availability and Balance for 2000 and 2035 for Catchments in Water Management Areas (Adapted from NWRS2004).

Water Management Area		Water Demand			Water Availability			Water Balance	Water Balance (Drier Scenario)		Water Balance (Wetter Scenario)	
		2000	2035 (Current Growth)	2035 (High Growth)	2000	2035 (Drier Scenario)	2035 (Wetter Scenario)	2000	2035 (Current Growth)	2035 (High Growth)	2035 (Current Growth)	2035 (High Growth)
1	**Limpopo**	1506.00	1895.20	2585.40	1526.00	991.90	1831.20	20.00	-903.30	-1593.50	-64.00	-754.20
1a	Matlabas/Mokolo	63.00	61.60	64.40	46.00	29.90	55.20	-17.00	-31.70	-34.50	-6.40	-9.20
1b	Lephalale	42.00	43.40	43.40	42.00	27.30	50.40	0.00	-16.10	-16.10	7.00	7.00
1c	Mogalakwena	79.00	109.80	119.60	75.00	48.75	90.00	-4.00	-61.05	-70.85	-19.80	-29.60
1d	Sand	106.00	107.40	139.60	106.00	68.90	127.20	0.00	-38.50	-70.70	19.80	-12.40
1e	Nzhelele/Nwanedzi	32.00	33.40	33.40	30.00	19.50	36.00	-2.00	-13.90	-13.90	2.60	2.60
3a	Apies/Pienaars	280.00	446.60	770.00	281.00	182.65	337.20	1.00	-263.95	-587.35	-109.40	-432.80
3b	Upper Crocodile	556.00	719.80	1009.60	598.00	388.70	717.60	42.00	-331.10	-620.90	-2.20	-292.00
3c	Elands	113.00	128.40	152.20	133.00	86.45	159.60	20.00	-41.95	-65.75	31.20	7.40
3d	Lower Crocodile	171.00	173.80	182.20	171.00	111.15	205.20	0.00	-62.65	-71.05	31.40	23.00
3e	Marico	40.00	40.00	42.80	25.00	16.25	30.00	-15.00	-23.75	-26.55	-10.00	-12.80
3f	Upper Molopo	24.00	31.00	28.20	19.00	12.35	22.80	-5.00	-18.65	-15.85	-8.20	-5.40
2	**Olifants**	1298.00	1471.60	1568.20	1070.00	695.50	1284.00	-228.00	-776.10	-872.70	-187.60	-284.20
2a	Luvuvhu/Mutale	119.00	133.00	133.00	113.00	73.45	135.60	-6.00	-59.55	-59.55	2.60	2.60
2b	Shingwedzi	3.00	3.00	3.00	3.00	1.95	3.60	0.00	-1.05	-1.05	0.60	0.60
2c	Groot Letaba	174.00	178.20	181.00	148.00	96.20	177.60	-26.00	-82.00	-84.80	-0.60	-3.40
2d	Klein Letaba	37.00	39.80	39.80	32.00	20.80	38.40	-5.00	-19.00	-19.00	-1.40	-1.40
2e	Lower Letaba	0.00	0.00	0.00	1.00	0.65	1.20	1.00	0.65	0.65	1.20	1.20
4a	Upper Olifants	314.00	410.60	489.00	313.00	203.45	375.60	-1.00	-207.15	-285.55	-35.00	-113.40
4b	Middle Olifants	392.00	445.20	449.40	298.00	193.70	357.60	-94.00	-251.50	-255.70	-87.60	-91.80
4c	Steelpoort	95.00	96.40	99.20	61.00	39.65	73.20	-34.00	-56.75	-59.55	-23.20	-26.00
4d	Lower Olifants	164.00	165.40	173.80	101.00	65.65	121.20	-63.00	-99.75	-108.15	-44.20	-52.60
3	**Inkomati-Usuthu**	914.00	1017.60	1084.80	673.00	437.45	816.40	-241.00	-580.15	-647.35	-201.20	-268.40
5a	Komati (W Swazi)	65.00	63.60	67.80	21.00	13.65	25.20	-44.00	-49.95	-54.15	-38.40	-42.60
5b	Swaziland	67.00	106.20	106.20	68.00	44.20	81.60	1.00	-62.00	-62.00	-24.60	-24.60
5c	Komati (N Swazi)	232.00	233.40	233.40	192.00	124.80	230.40	-40.00	-108.60	-108.60	-3.00	-3.00
5d	Crocodile	364.00	387.80	446.60	209.00	135.85	250.80	-155.00	-251.95	-310.75	-137.00	-195.80
5e	Sabie	117.00	150.60	147.80	95.00	61.75	114.00	-22.00	-88.85	-86.05	-36.60	-33.80
6a	Upper Usutu	69.00	76.00	83.00	88.00	57.20	114.40	19.00	-18.80	-25.80	38.40	31.40
4	**Pongola-**	1779.00	2105.20	2914.40	1736.00	1128.40	2256.80	-43.00	-976.80	-1786.00	151.60	-657.60

	Umzimkhulu											
6b	Pongola	255.00	257.80	257.80	615.00	399.75	799.50	360.00	141.95	141.95	541.70	541.70
6c	Mkuze	78.00	76.60	78.00	63.00	40.95	81.90	-15.00	-35.65	-37.05	5.30	3.90
6d	Mfolozi	80.00	78.60	88.40	33.00	21.45	42.90	-47.00	-57.15	-66.95	-35.70	-45.50
6e	Mhlatuze	235.00	243.40	342.80	237.00	154.05	308.10	2.00	-89.35	-188.75	64.70	-34.70
7a	Upper Thukela	88.00	96.40	110.40	17.00	11.05	22.10	-71.00	-85.35	-99.35	-74.30	-88.30
7b	Mooi/Sundays	102.00	109.00	139.80	94.00	61.10	122.20	-8.00	-47.90	-78.70	13.20	-17.60
7c	Buffalo	91.00	92.40	149.80	81.00	52.65	105.30	-10.00	-39.75	-97.15	12.90	-44.50
7d	Lower Thukela	53.00	54.40	54.40	39.00	25.35	50.70	-14.00	-29.05	-29.05	-3.70	-3.70
11a	Mvoti	114.00	125.20	137.80	82.00	53.30	106.60	-32.00	-71.90	-84.50	-18.60	-31.20
11b	Mgeni	504.00	785.40	1342.60	414.00	269.10	538.20	-90.00	-516.30	-1073.50	-247.20	-804.40
11c	Mkomazi	98.00	99.40	100.80	30.00	19.50	39.00	-68.00	-79.90	-81.30	-60.40	-61.80
11d	Coastal	41.00	46.60	70.40	25.00	16.25	32.50	-16.00	-30.35	-54.15	-14.10	-37.90
11e	Umzimkulu	40.00	40.00	41.40	6.00	3.90	7.80	-34.00	-36.10	-37.50	-32.20	-33.60
5	**Vaal**	2058.00	2387.00	3182.20	2113.00	1479.10	2535.60	55.00	-907.90	-1703.10	148.60	-646.60
8a	Wilge	60.00	54.40	85.20	59.00	41.30	70.80	-1.00	-13.10	-43.90	16.40	-14.40
8b	Vaal Dam – upstream	216.00	272.00	294.40	235.00	164.50	282.00	19.00	-107.50	-129.90	10.00	-12.40
8c	Vaal Dam – downstream	769.00	1032.20	1639.80	770.00	539.00	924.00	1.00	-493.20	-1100.80	-108.20	-715.80
9a	Rhenoster-Vals	54.00	52.60	69.40	45.00	31.50	54.00	-9.00	-21.10	-37.90	1.40	-15.40
9b	Middle Vaal	129.00	147.20	161.20	127.00	88.90	152.40	-2.00	-58.30	-72.30	5.20	-8.80
9c	Sand-Vet	187.00	187.00	205.20	204.00	142.80	244.80	17.00	-44.20	-62.40	57.80	39.60
10a	Harts	494.00	496.80	508.00	493.00	345.10	591.60	-1.00	-151.70	-162.90	94.80	83.60
10b	Vaal d/s Bloemhof	113.00	111.60	176.00	141.00	98.70	169.20	28.00	-12.90	-77.30	57.60	-6.80
10c	Molopo	36.00	33.20	43.00	39.00	27.30	46.80	3.00	-5.90	-15.70	13.60	3.80
6	**Orange**	1996.00	2199.00	2318.00	2321.00	1856.80	2785.20	325.00	-342.20	-461.20	586.20	467.20
13a	Senqu Lesotho	23.00	23.00	23.00	32.00	25.60	38.40	9.00	2.60	2.60	15.40	15.40
13b	Caledon Lesotho	40.00	40.00	40.00	31.00	24.80	37.20	-9.00	-15.20	-15.20	-2.80	-2.80
13c	Caledon RSA	105.00	103.60	106.40	119.00	95.20	142.80	14.00	-8.40	-11.20	39.20	36.40
13d	Kraai	103.00	152.00	156.20	44.00	35.20	52.80	-59.00	-116.80	-121.00	-99.20	-103.40
13e	Riet / Modder	351.00	433.60	507.80	350.00	280.00	420.00	-1.00	-153.60	-227.80	-13.60	-87.80
13f	Vanderkloof	346.00	347.40	353.00	725.00	580.00	870.00	379.00	232.60	227.00	522.60	517.00
14a	Orange	989.00	1063.20	1082.80	989.00	791.20	1186.80	0.00	-272.00	-291.60	123.60	104.00
14b	Orange Tributaries	31.00	28.20	33.80	22.00	17.60	26.40	-9.00	-10.60	-16.20	-1.80	-7.40
14c	Orange Coastal	8.00	8.00	15.00	9.00	7.20	10.80	1.00	-0.80	-7.80	2.80	-4.20
7	**Mzimvubu-Tsitsikama**	1275.00	1457.00	1598.40	1852.00	1481.60	2407.60	577.00	24.60	-116.80	950.60	809.20
12a	Mzimvubu	33.00	34.40	35.80	91.00	72.80	118.30	58.00	38.40	37.00	83.90	82.50
12b	Mtata	53.00	64.20	54.40	136.00	108.80	176.80	83.00	44.60	54.40	112.60	122.40
12c	Mbashe	11.00	9.60	9.60	199.00	159.20	258.70	188.00	149.60	149.60	249.10	249.10
12d	Kei	174.00	181.00	189.40	274.00	219.20	356.20	100.00	38.20	29.80	175.20	166.80

12e	Amatola	99.00	135.40	185.80	149.00	119.20	193.70	50.00	-16.20	-66.60	58.30	7.90
12f	Wild Coast	4.00	4.00	4.00	5.00	4.00	6.50	1.00	0.00	0.00	2.50	2.50
15a	Fish	473.00	545.80	552.80	542.00	433.60	704.60	69.00	-112.20	-119.20	158.80	151.80
15b	Bushmans	22.00	31.80	37.40	22.00	17.60	28.60	0.00	-14.20	-19.80	-3.20	-8.80
15c	Sunday	182.00	184.80	186.20	187.00	149.60	243.10	5.00	-35.20	-36.60	58.30	56.90
15d	Gamtoos	111.00	112.40	113.80	133.00	106.40	172.90	22.00	-6.00	-7.40	60.50	59.10
15e	Algoa	91.00	128.80	200.20	87.00	69.60	113.10	-4.00	-59.20	-130.60	-15.70	-87.10
15f	Tsitsikamma	22.00	24.80	29.00	27.00	21.60	35.10	5.00	-3.20	-7.40	10.30	6.10
8	**Breede-Gouritz**	970.00	1000.80	1219.20	943.00	612.95	990.15	-27.00	-387.85	-606.25	-10.65	-229.05
16a	Gamka	55.00	55.00	62.00	48.00	31.20	50.40	-7.00	-23.80	-30.80	-4.60	-11.60
16b	Groot	53.00	51.60	53.00	42.00	27.30	44.10	-11.00	-24.30	-25.70	-7.50	-8.90
16c	Olifants	74.00	75.40	96.40	71.00	46.15	74.55	-3.00	-29.25	-50.25	-0.85	-21.85
16d	Gouritz	58.00	58.00	62.20	58.00	37.70	60.90	0.00	-20.30	-24.50	2.90	-1.30
16e	Coastal	98.00	123.20	214.20	55.00	35.75	57.75	-43.00	-87.45	-178.45	-65.45	-156.45
18a	Upper Breede	465.00	467.80	532.20	466.00	302.90	489.30	1.00	-164.90	-229.30	21.50	-42.90
18b	Riviersonderend	53.00	51.60	54.40	52.00	33.80	54.60	-1.00	-17.80	-20.60	3.00	0.20
18c	Lower Breede	31.00	31.00	35.20	69.00	44.85	72.45	38.00	13.85	9.65	41.45	37.25
18d	Overberg East	4.00	2.60	8.20	4.00	2.60	4.20	0.00	0.00	-5.60	1.60	-4.00
18e	Overberg West	79.00	84.60	101.40	78.00	50.70	81.90	-1.00	-33.90	-50.70	-2.70	-19.50
9	**Berg-Olifants**	1077.00	1253.40	1929.60	1014.00	659.10	1064.70	-63.00	-594.30	-1270.50	-188.70	-864.90
17a	Koue Bokkeveld	66.00	66.00	64.60	67.00	43.55	70.35	1.00	-22.45	-21.05	4.35	5.75
17b	Sandveld	38.00	38.00	43.60	32.00	20.80	33.60	-6.00	-17.20	-22.80	-4.40	-10.00
17c	Olifants	247.00	247.00	252.60	218.00	141.70	228.90	-29.00	-105.30	-110.90	-18.10	-23.70
17d	Knersvlakte	7.00	7.00	7.00	7.00	4.55	7.35	0.00	-2.45	-2.45	0.35	0.35
17e	Doring	15.00	15.00	15.00	14.00	9.10	14.70	-1.00	-5.90	-5.90	-0.30	-0.30
19a	Greater Cape Town	394.00	553.60	1120.60	377.00	245.05	395.85	-17.00	-308.55	-875.55	-157.75	-724.75
19b	Upper Berg	229.00	237.40	286.40	229.00	148.85	240.45	0.00	-88.55	-137.55	3.05	-45.95
19c	Lower Berg	81.00	89.40	139.80	70.00	45.50	73.50	-11.00	-43.90	-94.30	-15.90	-66.30

Table G2: Water Demand, Availability and Balance for 2000 and 2035 for Catchments in Water Management Areas (Adapted from NWRS2004).

Water Management Area		Water Demand			Water Availability			Water Balance	Water Balance (Drier Scenario)		Water Balance (Wetter Scenario)	
		2000	2035 (Current Growth)	2035 (High Growth)	2000	2035 (Drier Scenario)	2035 (Wetter Scenario)	2000	2035 (Current Growth)	2035 (High Growth)	2035 (Current Growth)	2035 (High Growth)
1	**Limpopo**	1506.00	1895.20	2585.40	1526.00	991.90	1831.20	20.00	-903.30	-1593.50	-64.00	-754.20
1a	Matlabas/Mokolo	63.00	61.60	64.40	46.00	29.90	55.20	-17.00	-31.70	-34.50	-6.40	-9.20
1b	Lephalale	42.00	43.40	43.40	42.00	27.30	50.40	0.00	-16.10	-16.10	7.00	7.00
1c	Mogalakwena	79.00	109.80	119.60	75.00	48.75	90.00	-4.00	-61.05	-70.85	-19.80	-29.60
1d	Sand	106.00	107.40	139.60	106.00	68.90	127.20	0.00	-38.50	-70.70	19.80	-12.40
1e	Nzhelele/Nwanedzi	32.00	33.40	33.40	30.00	19.50	36.00	-2.00	-13.90	-13.90	2.60	2.60
3a	Apies/Pienaars	280.00	446.60	770.00	281.00	182.65	337.20	1.00	-263.95	-587.35	-109.40	-432.80
3b	Upper Crocodile	556.00	719.80	1009.60	598.00	388.70	717.60	42.00	-331.10	-620.90	-2.20	-292.00
3c	Elands	113.00	128.40	152.20	133.00	86.45	159.60	20.00	-41.95	-65.75	31.20	7.40
3d	Lower Crocodile	171.00	173.80	182.20	171.00	111.15	205.20	0.00	-62.65	-71.05	31.40	23.00
3e	Marico	40.00	40.00	42.80	25.00	16.25	30.00	-15.00	-23.75	-26.55	-10.00	-12.80
3f	Upper Molopo	24.00	31.00	28.20	19.00	12.35	22.80	-5.00	-18.65	-15.85	-8.20	-5.40
2	**Olifants**	1298.00	1471.60	1568.20	1070.00	695.50	1284.00	-228.00	-776.10	-872.70	-187.60	-284.20
2a	Luvuvhu/Mutale	119.00	133.00	133.00	113.00	73.45	135.60	-6.00	-59.55	-59.55	2.60	2.60
2b	Shingwedzi	3.00	3.00	3.00	3.00	1.95	3.60	0.00	-1.05	-1.05	0.60	0.60
2c	Groot Letaba	174.00	178.20	181.00	148.00	96.20	177.60	-26.00	-82.00	-84.80	-0.60	-3.40
2d	Klein Letaba	37.00	39.80	39.80	32.00	20.80	38.40	-5.00	-19.00	-19.00	-1.40	-1.40
2e	Lower Letaba	0.00	0.00	0.00	1.00	0.65	1.20	1.00	0.65	0.65	1.20	1.20
4a	Upper Olifants	314.00	410.60	489.00	313.00	203.45	375.60	-1.00	-207.15	-285.55	-35.00	-113.40
4b	Middle Olifants	392.00	445.20	449.40	298.00	193.70	357.60	-94.00	-251.50	-255.70	-87.60	-91.80
4c	Steelpoort	95.00	96.40	99.20	61.00	39.65	73.20	-34.00	-56.75	-59.55	-23.20	-26.00
4d	Lower Olifants	164.00	165.40	173.80	101.00	65.65	121.20	-63.00	-99.75	-108.15	-44.20	-52.60
3	**Inkomati-Usuthu**	914.00	1017.60	1084.80	673.00	437.45	816.40	-241.00	-580.15	-647.35	-201.20	-268.40
5a	Komati (W Swazi)	65.00	63.60	67.80	21.00	13.65	25.20	-44.00	-49.95	-54.15	-38.40	-42.60
5b	Swaziland	67.00	106.20	106.20	68.00	44.20	81.60	1.00	-62.00	-62.00	-24.60	-24.60

5c	Komati (N Swazi)	232.00	233.40	233.40	192.00	124.80	230.40	-40.00	-108.60	-108.60	-3.00	-3.00
5d	Crocodile	364.00	387.80	446.60	209.00	135.85	250.80	-155.00	-251.95	-310.75	-137.00	-195.80
5e	Sabie	117.00	150.60	147.80	95.00	61.75	114.00	-22.00	-88.85	-86.05	-36.60	-33.80
6a	Upper Usutu	69.00	76.00	83.00	88.00	57.20	114.40	19.00	-18.80	-25.80	38.40	31.40
4	**Pongola-Umzimkhulu**	1779.00	2105.20	2914.40	1736.00	1128.40	2256.80	-43.00	-976.80	-1786.00	151.60	-657.60
6b	Pongola	255.00	257.80	257.80	615.00	399.75	799.50	360.00	141.95	141.95	541.70	541.70
6c	Mkuze	78.00	76.60	78.00	63.00	40.95	81.90	-15.00	-35.65	-37.05	5.30	3.90
6d	Mfolozi	80.00	78.60	88.40	33.00	21.45	42.90	-47.00	-57.15	-66.95	-35.70	-45.50
6e	Mhlatuze	235.00	243.40	342.80	237.00	154.05	308.10	2.00	-89.35	-188.75	64.70	-34.70
7a	Upper Thukela	88.00	96.40	110.40	17.00	11.05	22.10	-71.00	-85.35	-99.35	-74.30	-88.30
7b	Mooi/Sundays	102.00	109.00	139.80	94.00	61.10	122.20	-8.00	-47.90	-78.70	13.20	-17.60
7c	Buffalo	91.00	92.40	149.80	81.00	52.65	105.30	-10.00	-39.75	-97.15	12.90	-44.50
7d	Lower Thukela	53.00	54.40	54.40	39.00	25.35	50.70	-14.00	-29.05	-29.05	-3.70	-3.70
11a	Mvoti	114.00	125.20	137.80	82.00	53.30	106.60	-32.00	-71.90	-84.50	-18.60	-31.20
11b	Mgeni	504.00	785.40	1342.60	414.00	269.10	538.20	-90.00	-516.30	-1073.50	-247.20	-804.40
11c	Mkomazi	98.00	99.40	100.80	30.00	19.50	39.00	-68.00	-79.90	-81.30	-60.40	-61.80
11d	Coastal	41.00	46.60	70.40	25.00	16.25	32.50	-16.00	-30.35	-54.15	-14.10	-37.90
11e	Umzimkulu	40.00	40.00	41.40	6.00	3.90	7.80	-34.00	-36.10	-37.50	-32.20	-33.60
5	**Vaal**	2058.00	2387.00	3182.20	2113.00	1479.10	2535.60	55.00	-907.90	-1703.10	148.60	-646.60
8a	Wilge	60.00	54.40	85.20	59.00	41.30	70.80	-1.00	-13.10	-43.90	16.40	-14.40
8b	Vaal Dam – upstream	216.00	272.00	294.40	235.00	164.50	282.00	19.00	-107.50	-129.90	10.00	-12.40
8c	Vaal Dam — downstream	769.00	1032.20	1639.80	770.00	539.00	924.00	1.00	-493.20	-1100.80	-108.20	-715.80
9a	Rhenoster-Vals	54.00	52.60	69.40	45.00	31.50	54.00	-9.00	-21.10	-37.90	1.40	-15.40
9b	Middle Vaal	129.00	147.20	161.20	127.00	88.90	152.40	-2.00	-58.30	-72.30	5.20	-8.80
9c	Sand-Vet	187.00	187.00	205.20	204.00	142.80	244.80	17.00	-44.20	-62.40	57.80	39.60
10a	Harts	494.00	496.80	508.00	493.00	345.10	591.60	-1.00	-151.70	-162.90	94.80	83.60
10b	Vaal d/s Bloemhof	113.00	111.60	176.00	141.00	98.70	169.20	28.00	-12.90	-77.30	57.60	-6.80
10c	Molopo	36.00	33.20	43.00	39.00	27.30	46.80	3.00	-5.90	-15.70	13.60	3.80
6	**Orange**	1996.00	2199.00	2318.00	2321.00	1856.80	2785.20	325.00	-342.20	-461.20	586.20	467.20
13a	Senqu Lesotho	23.00	23.00	23.00	32.00	25.60	38.40	9.00	2.60	2.60	15.40	15.40
13b	Caledon Lesotho	40.00	40.00	40.00	31.00	24.80	37.20	-9.00	-15.20	-15.20	-2.80	-2.80
13c	Caledon RSA	105.00	103.60	106.40	119.00	95.20	142.80	14.00	-8.40	-11.20	39.20	36.40
13d	Kraai	103.00	152.00	156.20	44.00	35.20	52.80	-59.00	-116.80	-121.00	-99.20	-103.40
13e	Riet / Modder	351.00	433.60	507.80	350.00	280.00	420.00	-1.00	-153.60	-227.80	-13.60	-87.80
13f	Vanderkloof	346.00	347.40	353.00	725.00	580.00	870.00	379.00	232.60	227.00	522.60	517.00
14a	Orange	989.00	1063.20	1082.80	989.00	791.20	1186.80	0.00	-272.00	-291.60	123.60	104.00
14b	Orange Tributaries	31.00	28.20	33.80	22.00	17.60	26.40	-9.00	-10.60	-16.20	-1.80	-7.40
14c	Orange Coastal	8.00	8.00	15.00	9.00	7.20	10.80	1.00	-0.80	-7.80	2.80	-4.20
7	**Mzimvubu-Tsitsikama**	1275.00	1457.00	1598.40	1852.00	1481.60	2407.60	577.00	24.60	-116.80	950.60	809.20
12a	Mzimvubu	33.00	34.40	35.80	91.00	72.80	118.30	58.00	38.40	37.00	83.90	82.50
12b	Mtata	53.00	64.20	54.40	136.00	108.80	176.80	83.00	44.60	54.40	112.60	122.40

12c	Mbashe	11.00	9.60	9.60	199.00	159.20	258.70	188.00	149.60	149.60	249.10	249.10
12d	Kei	174.00	181.00	189.40	274.00	219.20	356.20	100.00	38.20	29.80	175.20	166.80
12e	Amatola	99.00	135.40	185.80	149.00	119.20	193.70	50.00	-16.20	-66.60	58.30	7.90
12f	Wild Coast	4.00	4.00	4.00	5.00	4.00	6.50	1.00	0.00	0.00	2.50	2.50
15a	Fish	473.00	545.80	552.80	542.00	433.60	704.60	69.00	-112.20	-119.20	158.80	151.80
15b	Bushmans	22.00	31.80	37.40	22.00	17.60	28.60	0.00	-14.20	-19.80	-3.20	-8.80
15c	Sunday	182.00	184.80	186.20	187.00	149.60	243.10	5.00	-35.20	-36.60	58.30	56.90
15d	Gamtoos	111.00	112.40	113.80	133.00	106.40	172.90	22.00	-6.00	-7.40	60.50	59.10
15e	Algoa	91.00	128.80	200.20	87.00	69.60	113.10	-4.00	-59.20	-130.60	-15.70	-87.10
15f	Tsitsikamma	22.00	24.80	29.00	27.00	21.60	35.10	5.00	-3.20	-7.40	10.30	6.10
8	**Breede-Gouritz**	970.00	1000.80	1219.20	943.00	612.95	990.15	-27.00	-387.85	-606.25	-10.65	-229.05
16a	Gamka	55.00	55.00	62.00	48.00	31.20	50.40	-7.00	-23.80	-30.80	-4.60	-11.60
16b	Groot	53.00	51.60	53.00	42.00	27.30	44.10	-11.00	-24.30	-25.70	-7.50	-8.90
16c	Olifants	74.00	75.40	96.40	71.00	46.15	74.55	-3.00	-29.25	-50.25	-0.85	-21.85
16d	Gouritz	58.00	58.00	62.20	58.00	37.70	60.90	0.00	-20.30	-24.50	2.90	-1.30
16e	Coastal	98.00	123.20	214.20	55.00	35.75	57.75	-43.00	-87.45	-178.45	-65.45	-156.45
18a	Upper Breede	465.00	467.80	532.20	466.00	302.90	489.30	1.00	-164.90	-229.30	21.50	-42.90
18b	Riviersonderend	53.00	51.60	54.40	52.00	33.80	54.60	-1.00	-17.80	-20.60	3.00	0.20
18c	Lower Breede	31.00	31.00	35.20	69.00	44.85	72.45	38.00	13.85	9.65	41.45	37.25
18d	Overberg East	4.00	2.60	8.20	4.00	2.60	4.20	0.00	0.00	-5.60	1.60	-4.00
18e	Overberg West	79.00	84.60	101.40	78.00	50.70	81.90	-1.00	-33.90	-50.70	-2.70	-19.50
9	**Berg-Olifants**	1077.00	1253.40	1929.60	1014.00	659.10	1064.70	-63.00	-594.30	-1270.50	-188.70	-864.90
17a	Koue Bokkeveld	66.00	66.00	64.60	67.00	43.55	70.35	1.00	-22.45	-21.05	4.35	5.75
17b	Sandveld	38.00	38.00	43.60	32.00	20.80	33.60	-6.00	-17.20	-22.80	-4.40	-10.00
17c	Olifants	247.00	247.00	252.60	218.00	141.70	228.90	-29.00	-105.30	-110.90	-18.10	-23.70
17d	Knersvlakte	7.00	7.00	7.00	7.00	4.55	7.35	0.00	-2.45	-2.45	0.35	0.35
17e	Doring	15.00	15.00	15.00	14.00	9.10	14.70	-1.00	-5.90	-5.90	-0.30	-0.30
19a	Greater Cape Town	394.00	553.60	1120.60	377.00	245.05	395.85	-17.00	-308.55	-875.55	-157.75	-724.75
19b	Upper Berg	229.00	237.40	286.40	229.00	148.85	240.45	0.00	-88.55	-137.55	3.05	-45.95
19c	Lower Berg	81.00	89.40	139.80	70.00	45.50	73.50	-11.00	-43.90	-94.30	-15.90	-66.30

APPENDIX I : TRADE-OFF BETWEEN ENERGY AND WATER RESOURCES

This appendix considers the trade-offs between water and energy resources. Drawing on the insight provided by phase one to four of this research project, an analysis of existing and potential water impacts of those different energy sources is conducted.

South Africa is currently heavily reliant on non-renewable energy sources, but is increasingly considering renewable energy resources in long-term energy planning. According to the Draft IEPR 2012*,* the Department of Energy embarked on an aggressive programme which will see an increase in the share of renewable energy technologies in the energy mix. In 2003, a 10-year target of 10 000 Gigawatt hour (GWh) was set for renewable energy by the White Paper on Renewable Energy Planning of 2003, however under existing policy few renewable energies have been deployed (UNEP 2010). The IRP 2010-2030 envisaged that electricity generated from hydropower would maintain its share of 5% by 2030, while other renewable energy sources would increase their contribution to 9 percent in the period.

The Draft IEPR 2012 notes that the Northern Cape of South Africa has very good conditions for generating solar power, and that much of South Africa's coastal region is suitable for wind power, though erratic wind flow resulting in inconsistent supply of electricity is a challenge for realising wind power.

While government has been planning to move away from 'dirty' towards 'cleaner' energy production, it has attempted to incentivise private sector involvement in the renewable energy space. For example, the Department of Energy has launched the REIPPPP which considers onshore wind, concentrated solar thermal, solar photovoltaic, biomass solid, biogas, landfill gas and small hydro projects. The programme involves a bidding process by independent power producers to provide renewable energy to the national grid. The power producers would be expected to enter into an agreement with the DoE, and a Power Purchase Agreement (PPA) with a buyer, namely Eskom (Carbon Tax Policy Paper 2013).

Historically, Eskom, as the electricity producer, has found it relatively straight forward to access water in order to provide for the country's electricity requirements. This is because water supply for power generation is regarded as a strategic resource under the National Water Resource Strategy (NWRS). However, with the increasing scarcity of water in South Africa, especially in certain catchments, the charges for raw water have increased dramatically and the process of negotiation for water for Eskom has become more rigorous. For example, in the Olifants River system, the present water demand exceeds the 98% level of assurance for supply. As a result, the charge for additional water supply is expected to be ten times higher than their current value by 2020 at a costly R20/m^3 (UNEP FI 2012).

Eskom has demonstrated increased awareness of water risk associated with its operations (both those established and planned). As an entity it is taking an increasing interest in understanding the environmental impacts of its energy production, and as a signatory to the CEO Water Mandate it aims to take comprehensive approach to water stewardship. Eskom acknowledges that its coal-focused generation mix requires a significant use of water, a scarce and important resource in South Africa (Eskom 2011), and notes that over the coming years there will be a need to increase its water-usage efficiency in order to reduce water consumption. Importantly, the new coal-fired power stations Medupi and Kusile will use dry rather than wet-cooling technology.

For long-term planning processes, it is important that South Africa does not rely on international energy supply, such as hydroelectric energy from Lesotho or the Zambezi and gas from Mozambique. This is because an increase in development in these countries will result in an increase in the energy demand, thus possibly influencing the countries' water supply policies. Therefore, South Africa needs to harness its own available resources, and provide a planning and regulatory environment that allows the private and public sector to maximise the available natural resources.

Therefore, for planning processes, the proposed location of renewable energy resources in South Africa that is based on available natural resources is provided in Figure I-1.

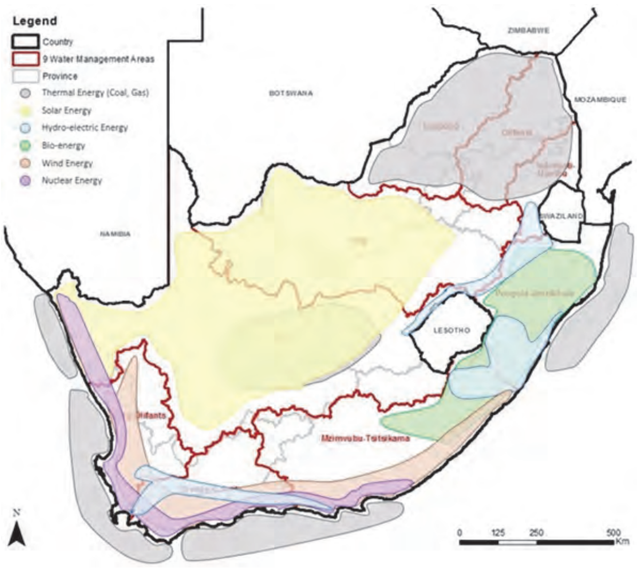


Figure I-1: Recommended location of energy resources in South Africa.

In addition, the quantity of production should be aligned with sufficient availability of the required water resource for the energy resources (as summarised in Table I-1).

Table I-1: : Water resource requirements.

Water Resource	Energy Resource	Recommended Location (WMAs)
Yield	Coal Gas Solar Wind	Limpopo, Olifants and Inkomati-Usuthu Limpopo, Olifants and Inkomati-Usuthu Vaal and Orange Berg-Olifants, Breede-Gouritz and Mzimvubu-Tsitsikama
Runoff (MAR)	Hydro-electric	Mzimvubu-Tsitsikama and Pongola-Umzimkhulu
Precipitation (MAP)	Bio-fuels	Mzimvubu-Tsitsikama and Pongola-Umzimkhulu
Sea Water	Nuclear	Orange, Berg-Olifants, Breede-Gouritz and Mzimvubu-Tsitsikama

The remainder of this section will investigate each of the energy resources provided in Figure I-1, by using the trade-offs between water and energy at the recommended location.

I 1. Thermal energy

Thermal energy, such as coal and gas, require large amounts of water for the energy production and other life cycle processes. Therefore, water planning for these energy resource should be considered at a regional level, where transfers can also be implemented should the regional yield be insufficient.

The location of thermal energy is, and in future should be, concentrated in the northern parts of the country, namely the Limpopo, Olifants and Inkomati-Usuthu WMAs. Other thermal energy options that are considered are Shale gas in the Orange WMA as well as off-shore gas along the western, south-western and north-eastern coastal areas.

For long-term planning, the assurance of long-term water supply necessitates the consideration of long-term water resource availability. Figure I-2 and I-3 illustrate the long-term water availability probabilities under a wetter and drier future for the Limpopo, Olifants and Inkomati-Usuthu WMAs. A decrease in water availability will pose a risk for the energy resources. However, as the energy resources require large amounts of water, water transfers could be implemented to ensure sufficient water supply. As Lesotho is projected to have an increase in water availability in a wetter or drier future, the Vaal and Orange WMAs would ideally provide water to the Limpopo, Olifants and Inkomati-Usuthu WMAs. However, development in the region and in the Vaal and Orange WMAs will also pose increasing pressure on water supply.

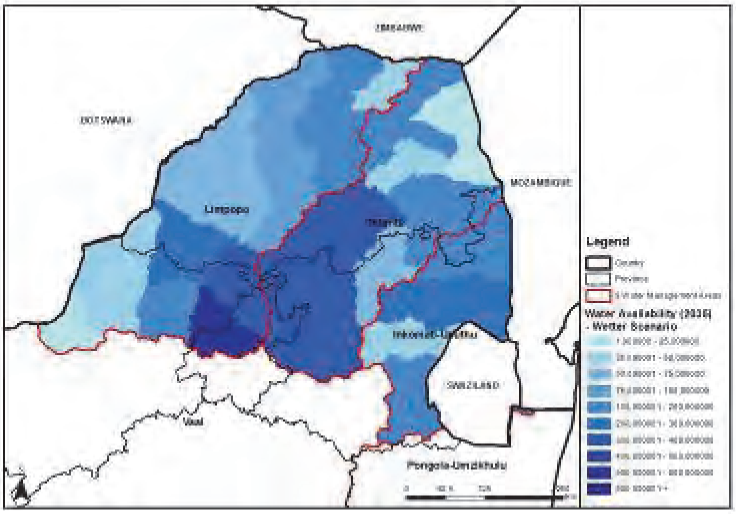


Figure I-2: Future Yield – Wetter Scenario (Limpopo, Olifants and Inkomati-Usuthu).

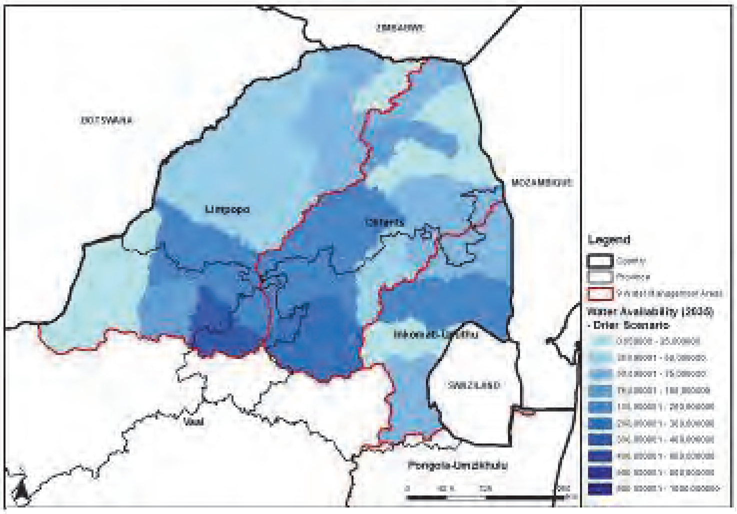


Figure I-3: Future Yield – Drier Scenario (Limpopo, Olifants and Inkomati-Usuthu).

General predictions indicate that the region is expected to be drier, however, localised predictions indicate variability in rainfall. Although decreased rainfall is predicted, there is expected to be an increase in rainfall events and large storms. Temperature rises and longer drier periods are also expected, which will impact operational efficiency (Pegasys 2014).

I.1.1 Coal energy

Due to the very high use of coal in electricity production, SA emits a large amount of carbon dioxide, and is thus a significant contributor to climate change. Additionally, disadvantages of coal-electricity production include contribution to greenhouse gas emissions, requirement of water with low salinity (i.e. high quality) in a variety of processes, and building coal-fired power stations is a long and expensive undertaking. A further challenge of South African coal-fired power plants lies upstream in the supply chain. Coal mines have an impact on water quality which, if situated in the same catchment as coal power generation, has downstream consequences on water supply for generation. (Pegasys 2013).

Predicted impacts of climate change on electricity generation and on water resource use by the energy sector are considerable. Reduced water availability during longer dry periods will impact on the operational requirements (such as production and cooling processes) of thermal power plants, compounding the already negative impacts associated with higher water and ambient air temperatures (Pegasys 2014).

I.1.2 Gas energy

As part of the IRP, the proposed gas generation consists of three components, namely imported gas, CCGT units and OCGT units. The imported gas will be sourced from both

Namibia and Mozambique, crossing the borders in the Oranjemund and Komatipoort areas respectively. All the CCGT and OCGT units are considered to be installed at the five main port areas of Saldanha, Mossel Bay, Port Elizabeth (Coega), Durban and Richards Bay. This is to either import the gas as LNG initially or as a result of massive shale gas resources to collect the gas in the port areas for generation or shipping out as LNG (Pegasys 2014).

Locally in SA, gas resources (specifically shale gas and coal bed methane) have recently been estimated in the Southern Karoo Basin, though further exploration is required to determine the extent of the recoverable resource. There are however environmental risks associated with extracting 'tight' gas such as shale since the process (hydraulic fracturing) requires large amounts of water, and the Karoo is a particularly water scarce area. There are also environmental concerns of possible contamination of ground water as a result of the improper disposal of fluids during the hydraulic fracturing process (Draft IEPR 2012*).*

Although natural gas is a fossil fuel and is thus non-renewable, it is relatively clean compared to gasoline, diesel fuel, oil and coal. Natural gas also has the advantage of having minimal impacts on water resources compared to other fuels, with only solar and wind power consuming less water (DHI Group 2008).

I 2. Solar Energy

Solar energy, especially PV, requires minimal amounts of water for the energy production and other life cycle processes. Therefore, water planning for this energy resource should be considered at a local level. In addition, the long-term planning process does not have to consider long-term water availability. Lifecycle processes that have water requirements can be sourced from the available municipal water resources, and water availability can be optimised through innovative water management and adaptive supply chain management.

The location of solar energy is, and in future should be, concentrated in the western parts of the country, namely the Vaal and Orange WMAs. This is mainly due to the current and future natural resource availability (i.e. solar) as well as the minimal water requirements, which is aligned with the low water availability in the region.

Figure I-4 and I-5 illustrate the long-term water availability probabilities under a wetter and drier future for the Vaal and Orange WMAs. All these areas are predicted to have increased temperatures. An increase in available sunshine will increase the resource available for absorption and conversion into electricity (Pegasys 2014).

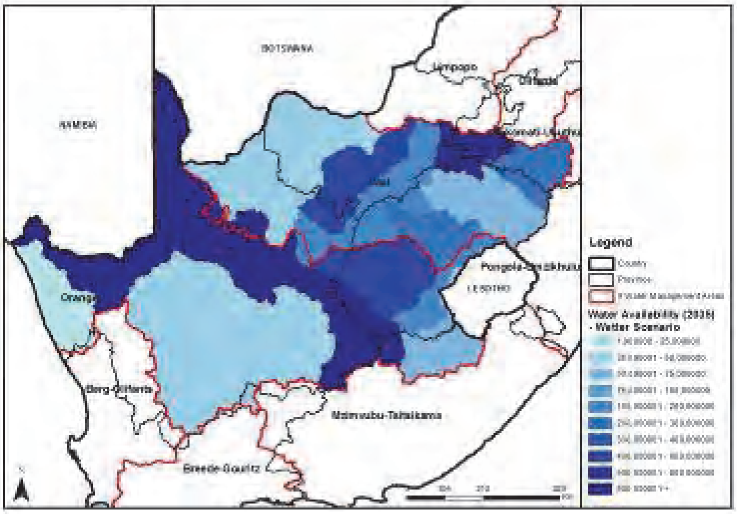


Figure I-4: Future Yield – Wetter Scenario (Vaal and Orange)

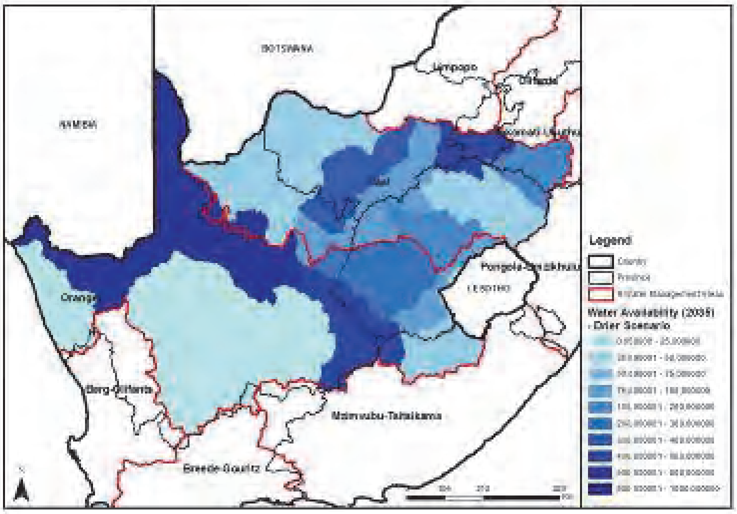


Figure I-5: Future Yield – Drier Scenario (Vaal and Orange)

While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement; these emissions are far less than the lifecycle emission rates for natural gas and coal (Union of Concerned Scientists 2013).

The environmental impacts associated with solar power can include land use and habitat loss, water use, and the use of hazardous materials in manufacturing, though the types of impacts vary greatly depending on the scale of the system and the technology used, i.e. photovoltaic (PV) solar cells or concentrating solar thermal plants (CSP). Solar PV cells do not use water for generating electricity. However, as in all manufacturing processes, some water is used to manufacture solar PV components. Concentrating solar thermal plants (CSP), like all thermal electric plants, require water for cooling. Water use depends on the plant design, plant location, and the type of cooling system (Pegasys 2014).

I 3. Wind energy

Similarly to solar energy, wind energy requires minimal amounts of water for the energy production and other life cycle processes. Therefore, water planning for this energy resource should be considered at a local level. In addition, the long-term planning process does not have to consider long-term water availability. Lifecycle processes that have water requirements can be sourced from the available municipal water resources, and water availability can be optimised through innovative water management and adaptive supply chain management.

The location of wind energy is, and in future should be, concentrated in the western parts of the country, namely the Berg-Olifants, Breede-Gouritz and Mzimvubu-Tsitsikama WMAs. This is mainly due to the current and future natural resource availability (i.e. wind) as well as the minimal water requirements. The wind resource in these areas is not projected to decrease in future.

Figure I-6 and I-7 illustrate the long-term water availability probabilities under a wetter and drier future for the Berg-Olifants, Breede-Gouritz and Mzimvubu-Tsitsikama WMAs. As these are coastal regions, wind resource availability should be continuous. However, as flood and droughts are also predicted, topography and geology of areas should be properly examined before installation of wind farms; this will minimise the infrastructure damage caused by floods, erosion or slope stability.

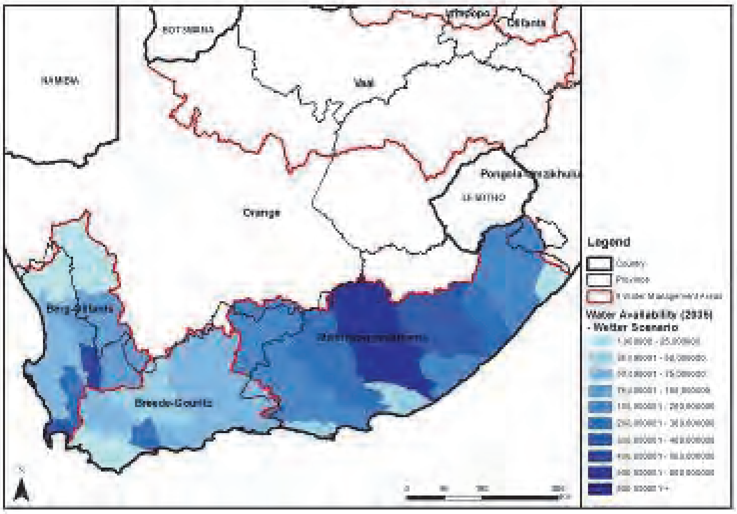


Figure I-6: Future Yield – Wetter Scenario (Berg-Olifants, Breede-Gouritz and Mzimvubu-Tsitsikama)

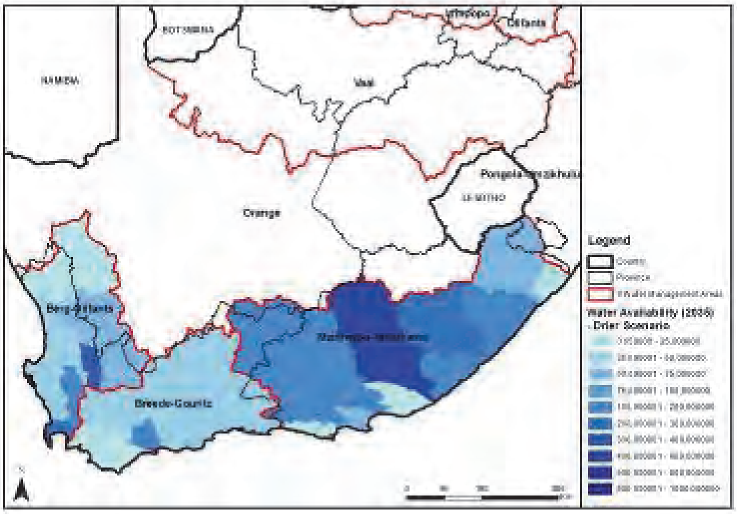


Figure I-7: Future Yield – Drier Scenario (Berg-Olifants, Breede-Gouritz and Mzimvubu-Tsitsikama)

Sound and visual impact are the two main public health and community concerns associated with operating wind turbines. There is no water impact associated with the operation of wind turbines. As in all manufacturing processes, some water is used to manufacture steel and cement for wind turbines. (Union of Concerned Scientists 2013).

I 4. Hydro-electric energy

Hydro-electric energy can be implemented at either a large or small scale. Large hydro, such as pumped Storage systems and dams, require large amounts of water for the energy production and other life cycle processes. Therefore, water planning for these energy resource should be considered at a regional level. Run-of-River hydropower plants, however, requires less water, and can therefore be implemented at a smaller.

As this energy resource relies on runoff (MAR), it is essential that the energy resource is located in water abundant areas where the flow is sufficient. The location of hydro-electric energy is, and in future should be, concentrated in the eastern parts of the country, namely the Mzimvubu-Tsitsikama and Pongola-Umzimkhulu WMAs.

Some of the challenges for hydropower plants in SA include the following – hydropower generation on a large scale is limited due to the scarcity of water together with pressures regarding the environmental impact and displacement of settlements by huge storage dams. Secondly, as a water-stressed country, SA cannot rely on smaller-scale hydropower resources during dry periods, particularly in areas of the country where the climate is expected to be drier in the future (Pegasys 2014). Figure I-8 and I-9 illustrate the long-term water availability probabilities under a wetter and drier future for the Mzimvubu-Tsitsikama and Pongola-Umzimkhulu WMAs.

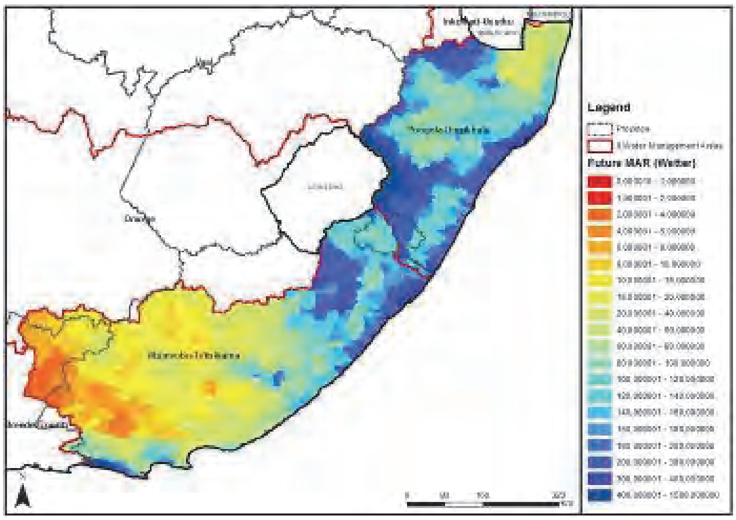


Figure I-8: Future MAR– Wetter Scenario (Mzimvubu-Tsitsikama and Pongola-Umzimkhulu)

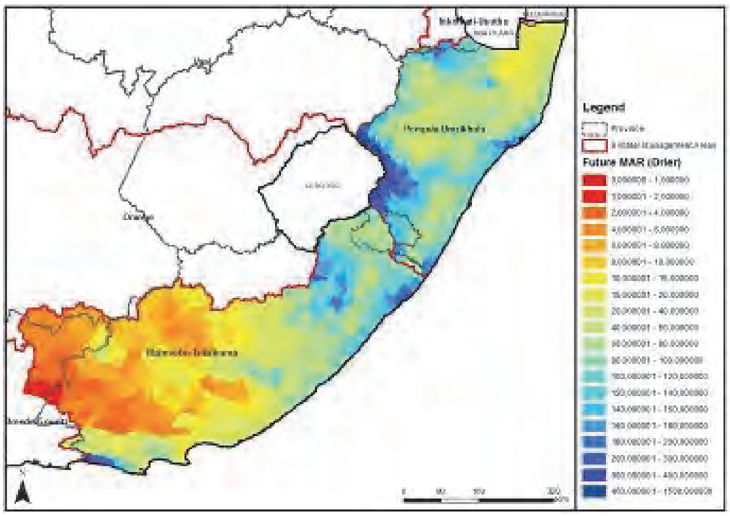


Figure I-9: Future MAR– Drier Scenario (Mzimvubu-Tsitsikama and Pongola-Umzimkhulu)

With climate change, the magnitude of floods is likely to increase and droughts are likely to lengthen with increased frequency. These conditions are likely to impact on hydro-power supply most directly through higher anticipated evaporation losses. The planned lifetimes of dams are likely to be reduced through increased sedimentation (Martin and Fischer 2012). A decrease in flow will also impact the ability of Run-of-River hydropower plants to produce energy. In addition to this, an increase in water temperatures will be a major factor.

Large hydro-power schemes have significant effects on surrounding groundwater levels and streams and can change the climatic conditions of a region. Other climate-related adverse effects occur through changed siltation and sedimentation patterns – more upstream and less downstream, which impacts on the ecosystems of rivers and river estuaries. Dams also contribute significantly to climate change through the release of substantial amounts of greenhouse gases. This is mainly due to plant material in flooded areas decaying in an anaerobic environment. Socio-economic and health impacts through displacement of communities and an increase in water-borne diseases around large dams are often neglected by the authorities. Run-of-River hydropower plants, on the other hand, may have an impact on erosion and aquatic ecosystems (Pegasys 2014). For imported hydro, SA may be exposed to climate change impacts in the supply chain.

I 5. Bio-energy

Bio-energy can be produced by using various types of feedstock materials (as illustrated in Figure I-10). Therefore, there are numerous ways in which bio-energy can be produced, and each requires different sources of water;

- Irrigated bio-energy requires water and relies on the local yield, and should thus be located in areas with sufficient yield (i.e. positive water balance).
- Non-irrigated and alternative bio-energy requires municipal water supply, and should thus be located in areas with a sufficient local yield (i.e. positive water balance).
- Rain-fed bio-energy requires rainfall, and should thus be located in areas with sufficient rainfall.

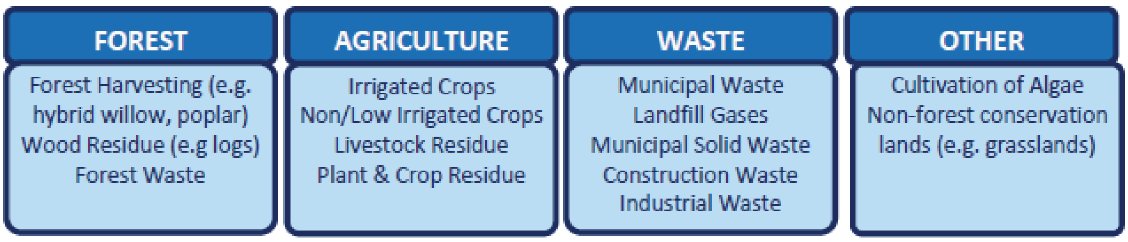


Figure I-10: Sources of feedstock materials for conversion to bioenergy (Source: Pegasys 2014)

As indicated earlier, the eastern parts of the country are projected to have an increase in water availability. Bio-energy resource relies on yield or rainfall, and it is essential that the energy resource is located in water abundant areas with sufficient yield or rainfall (dependent on the feedstock used). Therefore, the location of bio-energy is, and in future should be, concentrated in the eastern parts of the country, namely the Mzimvubu-Tsitsikama and Pongola-Umzimkhulu WMAs. At a smaller scale however, bio-energy can be located throughout the country, as long as the available water resources are sufficient to meet the water requirements for the energy resource.

Figure I-11 and I-12 illustrate the long-term rainfall availability probabilities under a wetter and drier future for the Mzimvubu-Tsitsikama and Pongola-Umzimkhulu WMAs. Figure I-13 and I-14 illustrate the long-term yield availability probabilities under a wetter and drier future for the Mzimvubu-Tsitsikama and Pongola-Umzimkhulu WMAs.

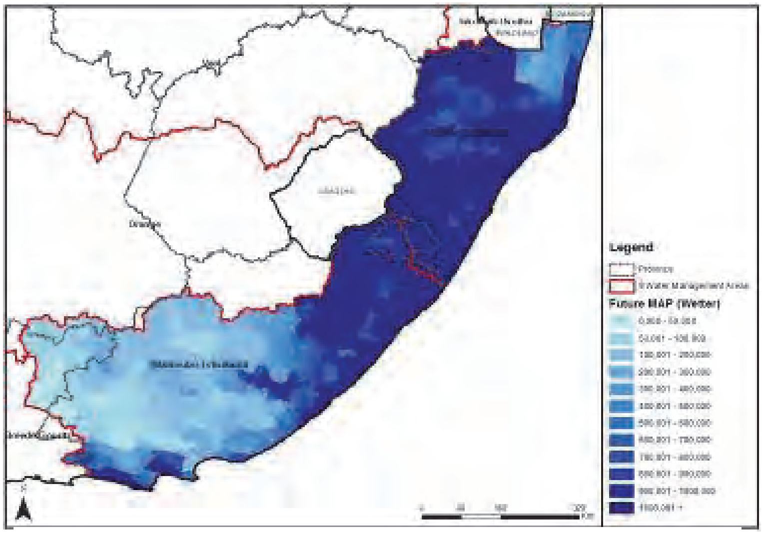


Figure I-11: Future MAP – Wetter Scenario (Mzimvubu-Tsitsikama and Pongola-Umzimkhulu)

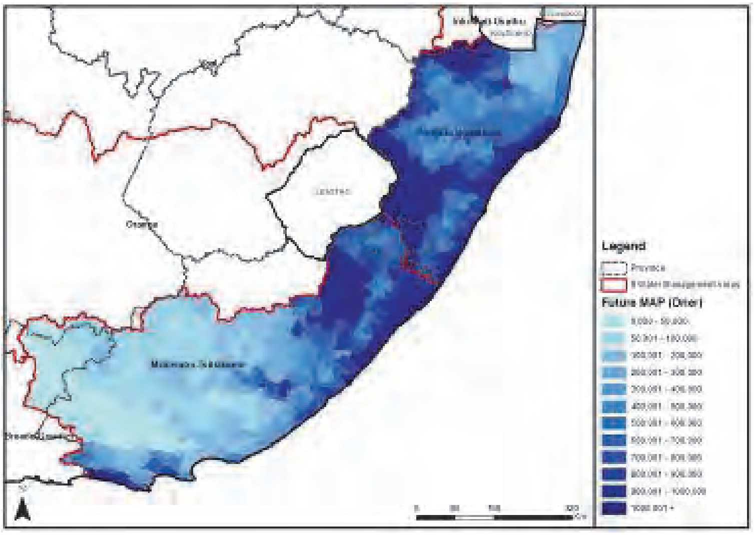


Figure I-12: Future MAP – Drier Scenario (Mzimvubu-Tsitsikama and Pongola-Umzimkhulu)

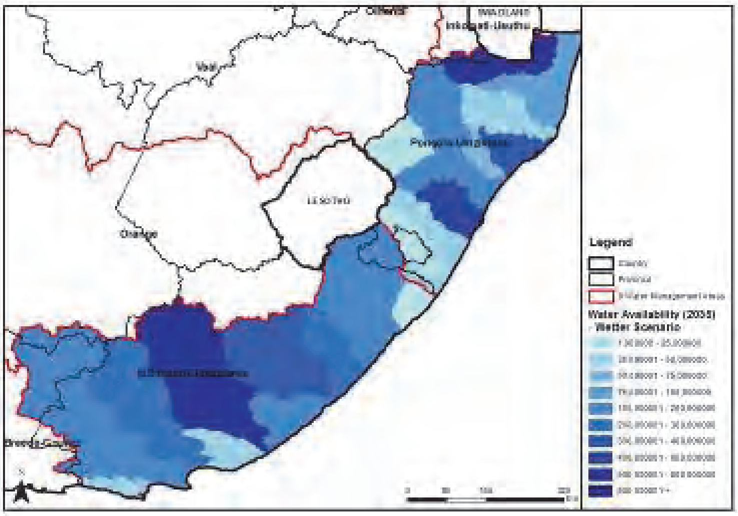


Figure I-13: Future Yield – Wetter Scenario (Mzimvubu-Tsitsikama and Pongola-Umzimkhulu)

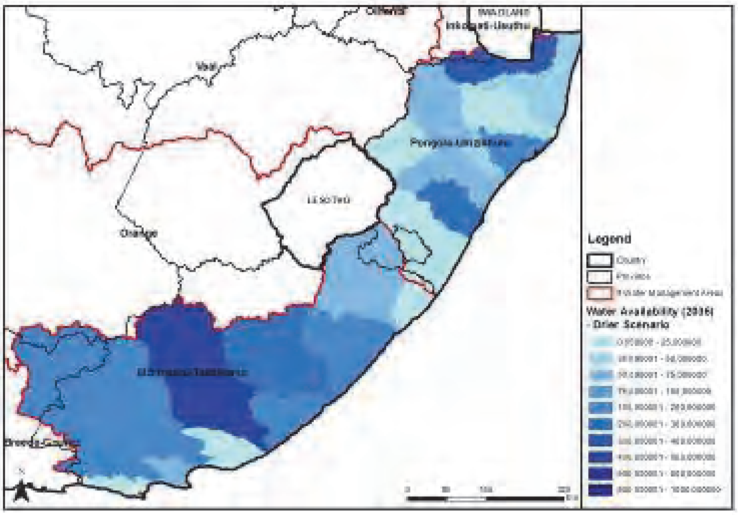


Figure I-14: Future Yield – Drier Scenario (Mzimvubu-Tsitsikama and Pongola-Umzimkhulu)

Irrigated crops (i.e. soy and corn based) are highly water consumptive during the cultivation phase. This can have localized impacts on receiving waters, particularly when the source is tributaries which have threats to base flow conditions. Other feedstock options, such as algae and grasslands do not consume high amounts of water, and are not expected to compete with food for water, or reduce land-use impact (Pegasys 2014). Alternative biofuel sources are also in development and address water concerns, such as residues, perennial grasses, no/low irrigation crops, etc. Further advancements in technology need to be directed at reducing biofuels' impact on water quantity and quality and the collateral inputs of fertilizers and pesticides, particularly given the large amounts required for irrigation (Krantzberg and Bassermann 2010).

Municipal solid waste is often categorized alongside biofuels as another potential fuel source. Its water consumption depends on the original source of the waste. However, these new technologies will take time to develop. Increased demand for agricultural crops to produce energy invariably leads to a series of unresolved discussions regarding food security and the relationship with increased demand for energy crops, and to what extent this drives the conversion of forests into agricultural land (Glassman *et al.* 2011).

The Department of Water Affairs notes that much of the country is water stressed and that there are severe limitations on the availability of additional water for allocation to new users. The potential impacts on water quality (erosion and siltation, and fertiliser and pesticide runoff) mean that best practice management for both land and water will have to be applied to all biofuels cropping, both irrigated and dry-land. Irrigated agriculture already uses about 60% of the total available resource, and crops for biofuels will have to find its water from existing allocations, or compete for scarce new water (Biofuels Industrial Strategy 2007). Despite these concerns, policy seems to be towards an expansion of the biofuels industry (Pegasys 2013).

I 6. Nuclear energy

Fresh water for the nuclear power plants is produced on site through desalination. Therefore, the location of nuclear energy is, and in future should be, concentrated in the coastal areas of the country, namely the Orange, Berg-Olifants, Breede-Gouritz and Mzimvubu-Tsitsikama WMAs. Climate impacts such as flooding and increases in water temperature is likely to impact the production processes. Known impacts on marine life are through the returned brine from the desalination plants and the water used for cooling, which returns at higher temperatures (Martin and Fischer 2012).

SA has significant uranium resources, thus nuclear power generation has the potential to be expanded in the country. This could play a significant role in reducing South Africa's carbon footprint from power generation, since nuclear reactors have low carbon impacts (Draft IEPR 2012). There may however, be water impacts during the uranium mining processes.

I 7. Crude oil

Oil explorations are limited in SA. Small oil and gas fields are situated off the south coast of Mossel Bay. Due to limited oil fields in the country, the bulk of crude oil is imported from the Middle East and Africa (Saudi Arabia, Iran, Kuwait, Yemen, Qatar, Iraq, Nigeria, Egypt and Angola). Because most of the production happens offshore, oil will therefore have a minimal impact on water resources. This does however imply that the country is dependent on exports, which depending on their origin, may be exposed to climate change impacts along the supply chain.

APPENDIX J: Stakeholder questionnaire

Water-Energy nexus in the context of climate change: investigating trade-offs between water use efficiency and renewable energy options for South Africa

Structured questions

Respondent should be told that their identity will be kept anonymous

Name of organization:____

Fuel /Technology type:____

Introductory remarks

South Africa (SA) is an arid country, where water supply is often from a distant source. There is also increasing pressure on the limited water resources due to economic and population growth, with a concomitant increase in the energy requirement for water production. This problem will be exacerbated by the onset of climate change. Nevertheless, water providers in SA are not compelled to assess energy consumption and the carbon footprint of water production and distribution in spite of the growing concerns about the increase in greenhouse gas emissions as a result of the intense use of fossil fuels for energy supply.

Energy requirements in the water sector need to be properly examined to establish the overall carbon footprint of the water supply chain in SA. Several alternatives to the energy-intensive water supply chain do exist, including the use of renewable energy sources and local waste-water re-use. However, the impact of deploying renewable energy technologies on water resources need to be considered properly. Some issues require scrutiny in order to understand the water footprint of renewable energy production in SA. For example, to allocate water for biofuel production will require a shift in the current water allocation policy. Due to the large gap that exists between water supply and demand, trade-offs in water allocation amongst different users and policy makers are critical. The main objective of this study is therefore to investigate trade-offs between water use efficiency and renewable energy in SA.

Questions

1. What is your rank in this organization? (*Question should not be asked if information is already known*).
2. Is water used in any stage of the power production chain? Yes/No
3. If yes, do you know or have information on how much water is used in the following stages? (*Respondent may give quantities in any units or point to the right source of required data*).

Stage	**Withdrawal (m^3/kWh)**	**Consumption (m^3/kWh)**
Fuel acquisition		
Fuel preparation		
Plant construction		
Power Generation		
Fuel disposal		

4. Do you have any comments on water use in the production of energy in your organization?

This is the end of my interview, thank you very for your assistance.