Southern Africa
Southern Africa Energy-Water Nexus
Background Paper to Support Dialogue in the Region

June 30, 2016
Acknowledgments

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### Abbreviations and Acronyms

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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AEZ</td>
<td>agroecological zoning</td>
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<tr>
<td>ARWRs</td>
<td>actual renewable water resources</td>
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<td>BC</td>
<td>Bass Chute</td>
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<td>BNL</td>
<td>Brookhaven National Laboratory</td>
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<td>BPC</td>
<td>Botswana Power Corporation</td>
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<tr>
<td>ºC</td>
<td>degrees centigrade</td>
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<tr>
<td>CAEWDP</td>
<td>Central Asia Energy–Water Development Program</td>
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<tr>
<td>CCS</td>
<td>carbon capture and storage</td>
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<td>CHP</td>
<td>combined heat and power</td>
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<td>CIWA</td>
<td>Cooperation in International Waters in Africa</td>
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<td>CLEWs</td>
<td>climate, land-use, energy, and water strategies</td>
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<td>CMAs</td>
<td>catchment management agencies</td>
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<td>CSP</td>
<td>concentrating solar power</td>
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<td>CUVECOM</td>
<td>Cuvelai Watercourse Commission</td>
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<td>DAM</td>
<td>day-ahead market</td>
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<td>DNA</td>
<td>National Directorate of Water</td>
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<td>DNI</td>
<td>Direct Normal Irradiation</td>
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<td>DRC</td>
<td>Democratic Republic of Congo</td>
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<td>DWA</td>
<td>Department of Water Affairs</td>
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<td>ECA</td>
<td>Economics of Climate Action</td>
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<td>EdF</td>
<td>Électricité de France</td>
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<td>ESMAP</td>
<td>Energy Sector Management Assistance Program</td>
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<td>FAO</td>
<td>Food and Agriculture Organization (of the UN)</td>
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<td>GCM</td>
<td>general circulation model</td>
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<td>GDP</td>
<td>gross domestic product</td>
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<td>GHG</td>
<td>greenhouse gas</td>
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<td>GIZ</td>
<td>German Agency for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit)</td>
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<td>Acronym</td>
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<tr>
<td>GW</td>
<td>gigawatts</td>
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<td>GWh</td>
<td>gigawatt-hours</td>
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<td>HEAT</td>
<td>Hands on Energy Toolkit</td>
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<td>IAEA</td>
<td>International Atomic Energy Agency</td>
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<td>IBRD</td>
<td>International Bank for Reconstruction and Development</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<td>IGCC</td>
<td>integrated gasification combined cycle</td>
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<td>IIASA</td>
<td>International Institute for Applied Systems Analysis</td>
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<td>IISD</td>
<td>International Institute for Sustainable Development</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>IRENA</td>
<td>International Renewable Energy Agency</td>
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<td>IRP</td>
<td>integrated resource plan(ning)</td>
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<td>IWRM</td>
<td>integrated water resource management</td>
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<td>IWRWE</td>
<td>Integrated Water Resources and Water Efficiency</td>
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<tr>
<td>km²</td>
<td>square kilometers</td>
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<tr>
<td>KTH</td>
<td>Royal Institute of Technology (Kungliga Tekniska högskolan)</td>
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<td>LEAP</td>
<td>Long-range Energy Alternatives Planning</td>
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<td>LHDA</td>
<td>Lesotho Highlands Development Authority</td>
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<td>LHWC</td>
<td>Lesotho Highlands Water Commission</td>
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<td>LHWP</td>
<td>Lesotho Highlands Water Project</td>
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<td>LIMCOM</td>
<td>Limpopo Watercourse Commission</td>
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<tr>
<td>m</td>
<td>meters</td>
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<td>m³</td>
<td>cubic meters</td>
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<td>MARKAL</td>
<td>Market Allocation model</td>
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<td>mm</td>
<td>millimeters</td>
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<td>MW</td>
<td>megawatts</td>
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<td>MWh</td>
<td>megawatt-hours</td>
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<td>MWSCs</td>
<td>marginal water supply costs</td>
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<td>NSDP</td>
<td>National Strategic Development Plan</td>
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<td>OKACOM</td>
<td>Okavango River Basin Water Commission</td>
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<td>Acronym</td>
<td>Description</td>
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<tr>
<td>ORASECOM</td>
<td>Orange–Senqu River Commission</td>
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<tr>
<td>PPA</td>
<td>power purchase agreement</td>
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<td>PoE</td>
<td>Protocol on Energy (SADC)</td>
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<td>PV</td>
<td>photovoltaic</td>
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<td>RBCs</td>
<td>river basin commissions</td>
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<td>RBOs</td>
<td>river basin organizations</td>
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<td>RIDMP</td>
<td>Regional Infrastructure Development Master Plan</td>
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<td>RSAP</td>
<td>Regional Strategic Action Plan</td>
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<td>SADC</td>
<td>Southern African Development Community</td>
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<td>SADCC</td>
<td>Southern African Development Coordinating Conference</td>
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<td>SAPP</td>
<td>Southern African Power Pool</td>
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<td>SATIM</td>
<td>South African TIMES model</td>
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<td>SATIM-W</td>
<td>South African TIMES water-smart model</td>
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<td>SDGs</td>
<td>Sustainable Development Goals</td>
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<td>SEI</td>
<td>Stockholm Environment Institute</td>
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<td>SIWI</td>
<td>Stockholm Integrated Water Institute</td>
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<td>STEM</td>
<td>short-term energy market</td>
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<td>SWAT</td>
<td>Soil and Water Assessment Tool</td>
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<td>SWISH</td>
<td>SADC Water Information Sharing Hub</td>
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<tr>
<td>T&amp;D</td>
<td>transmission and distribution</td>
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<tr>
<td>tcf</td>
<td>trillion cubic feet</td>
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<td>UN</td>
<td>United Nations</td>
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<td>UNDESA</td>
<td>United Nations Department of Economic and Social Affairs</td>
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<td>WBSCD</td>
<td>World Business Council for Sustainable Development</td>
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<td>WEAP</td>
<td>Water Evaluation and Planning</td>
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<td>WEC</td>
<td>World Energy Council</td>
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<td>WEF</td>
<td>water–energy–food</td>
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<td>WEF</td>
<td>World Economic Forum</td>
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<td>WELMM</td>
<td>water, energy, land, materials, and manpower</td>
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<td>WSS</td>
<td>water supply and sanitation</td>
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<td>Abbreviation</td>
<td>Full Name</td>
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<td>WWC</td>
<td>World Water Council</td>
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<td>ZAMCOM</td>
<td>Zambezi River Watercourse Commission</td>
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<td>ZRA</td>
<td>Zambezi River Authority</td>
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<tr>
<td>ZRB</td>
<td>Zambezi River Basin</td>
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<td>ZESA</td>
<td>Zimbabwe Electricity Supply Authority</td>
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<tr>
<td>ZESCO</td>
<td>Zambia Electricity Supply Corporation</td>
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<tr>
<td>ZRA</td>
<td>Zambezi River Authority</td>
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Executive Summary

Purpose and Scope

The objective of this paper is to provide high-level background information on the interdependency between the supply of electricity and water in Southern Africa. The paper assimilates information based on an extensive review of recent work on the energy and water sectors in the region and beyond, and the World Bank’s sector dialogue in the region. The paper is intended to help facilitate a dialogue on the energy-water nexus in the region, especially from the perspective of electricity sector planning, and help the World Bank engage key sector stakeholders on the issue.

The value of this paper is in bringing together the latest knowledge work and other key information relevant for energy-water nexus dialogue in Southern Africa. This information has been derived from a number of fragmented sources, and an effort has been made to present the information in a logical framework, in one document that can help initiate discussions in the region.

This paper was conceptualized as a background discussion paper and does not seek to make any recommendations on policy alternatives to tackle challenges facing the region on energy-water nexus issues. Any recommendations should be rooted in a thorough assessment of the specific challenges, institutions and objectives of the region; and most importantly should follow from a constructive regional dialogue amongst key stakeholders.

The issues and implications that surround the energy-water nexus are numerous. The use of electricity and water as critical inputs to economic activity, implies that there are many interlinkages that can be explored. To increase the usefulness of the information and the framework presented, this paper focuses on the perspective of electricity supply, and highlights nexus issues that are directly relevant to it. Important related nexus issues such as agriculture and its dependence on reliable water and electricity (the energy-water-food nexus) are not considered and are left for future work. Thus, in referring to the energy–water nexus, the paper considers issues on electricity and water sectors in relation to electricity supply and long-term planning around it, including the feedback loop to water.

By highlighting key analytical work and drawing insights relevant to Southern Africa, this paper aims to support an informed regional dialogue on decision making about the energy–water nexus in the region.

Key Messages from Section A: What Is the Energy–Water Nexus?

The energy–water nexus refers to the interdependence between water and energy supply. Addressing the nexus means internalizing this interdependence in the decision making for both sectors. In the context of major energy investments expected in Southern Africa, the scope of the paper is focused specifically on the subset of the nexus addressing electricity supply. Water is important for hydropower generation and for cooling in thermal generation plants. Electricity is needed to advance various stages of the water supply and sanitation value chain. Energy and water security are thus strongly interlinked and should be recognized as so by planners, policy makers, and investors alike.
With population growth, urbanization and its associated increase in well-being, and economic growth, there is increasing pressure on water and energy resources. In seeking to improve allocation of resources in an increasingly scarce environment, a nexus approach can be extremely helpful. Such a holistic approach helps to build synergies, reduce trade-offs, and improve overall governance and decision making. It potentially has important implications for the way decisions are made in the sectors going forward. Long-term decision making is also made more challenging by the likelihood of climate change—which adds complexities in understanding patterns in future resource availability and societal demands on those resources.

The link between energy, water, and climate change has been studied for several years. The water–energy–food (WEF) nexus was broadly accepted when it was presented at the Rio+20 Summit in 2012, and two seminal frameworks—those by SEI/Hoff (2011) and the World Economic Forum (WEF 2011b)—support this. The energy–water nexus sits within the wider WEF nexus and focuses solely on the interaction between energy and water (this narrower lens is particularly appropriate for electricity supply planning). Critical to the energy–water nexus approach is the role of water resources acting as both a state and a control variable—determining current situations and future changes. Also fundamental to the nexus is the interconnectivity of energy and water supply security. If water supply security is low, then depending on the technology, this negatively affects energy supply security. There are important trade-offs here, especially when considering the various other uses for water.

A key challenge to implementing nexus planning is how to determine the optimal allocation of water across competing demands. In most privately traded commodities, the market acts as an efficient allocation mechanism. Price signals allocate goods to their highest-value use. However, such a mechanism is not well suited for water, because of its public good characteristics, associated externalities in its use, and fundamental concerns of equity in access to potable water as a basic necessity to human well-being. As a result, nonmarket valuation of the societal net benefits from various uses of water guides allocation decisions.

Another key challenge is accommodating climate change uncertainty when making investment decisions. Climate change could have a significant impact on water and energy systems. The current state of knowledge is inadequate for understanding the likelihood of various future scenarios and the quantification of associated impacts. This introduces ‘deep uncertainty’ into decision making regarding the energy–water nexus. As a result, decision makers may have to adapt their approach to investment planning, opting instead for solutions that minimize potential losses under a range of climate change scenarios. The strong interdependency between the two sectors and fundamental uncertainty about the impact of climate change make robust long-term nexus planning very challenging. Recent literature assesses the role of such uncertainties and shows the significant benefits of considering adaptation to climate change for energy sector investment planning.
Cross-sectoral linkages and the transboundary nature of water resources put an onus on good governance – effective and harmonized planning and decision making. Poor governance, including ‘silo’ decision making, can have serious consequences. Decisions—whether at the local, national, river basin, or regional level—would need to take into account these cross-sectoral linkages, and the institutions overseeing these decisions would need to be equipped to do so.

Numerous technical tools are being developed to support the work of policy makers. These tools enable the integration of energy and water system issues and climate change impacts to equip planners with evidence on synergies and trade-offs. This work is not new—there are models dating back to the 1970s. However, there is significant recent and highly practical work to produce frameworks and models that can be adapted to address a range of issues with limited data requirements. The climate, land-use, energy, and water strategies (CLEWs) framework featured significantly at Rio+20 in 2012. Two recent important applications of this framework for energy–water nexus issues include the national-level use for energy policy work in Mauritius and the global CLEWs for use in addressing the United Nations’ Sustainable Development Goals. This latter model allows policy makers, for example, to consider the impact of imposing fossil fuel limits or a carbon tax on water consumption.

The World Bank is currently working with the Government of South Africa on the Thirsty Energy Initiative. This initiative is seeking to address the fact that the current energy sector least-cost model for South Africa (known as SATIM, from the South African TIMES, a public domain model developed by the University of Cape Town) does not address water demand-side considerations (World Bank 2015b). The SATIM-W model, coming out of this work, will include marginal water supply cost functions to produce “water-smart” outcomes. Key features of the model include extending data on water demand beyond power plant water intensity to include broader water-use data, enabling decision makers to understand which water infrastructure will be needed for the energy sector, when, and where. Climate change is also considered through scenario analyses. Initial outputs from the work suggest that Southern Africa’s water resources appear relatively resilient to a range of potential climate change impacts, and that water for power is supported by major interbasin transfers. The work is providing justification for decisions about dry-cooling versus wet-cooling technology for thermal power stations and is providing guidance in relation to investment in concentrating solar power, shale gas, and renewable energy technologies under future climate scenarios.

Key Messages from Section B: Focus on Southern Africa

The paper focuses on the Southern Africa region, which is taken as all countries in the Southern Africa Development Community (SADC)—i.e., those including and south of the Democratic Republic of Congo (DRC) and Tanzania. The countries in this region have significant variation in terms of their physical geography, economic performance, population, and the levels of water and energy services these populations can use. In addressing this region, focus
countries for this phase of work included South Africa, Lesotho, Botswana, Swaziland, and Namibia.¹

**Hydrological resources in the region are very unevenly distributed.** The southernmost countries—South Africa, Botswana, and Namibia—receive much lower levels of rainfall than the northern countries, such as DRC, Angola, and Zambia. Differences across the region are as large as 2,000 millimeters per year. The region is characterized by 15 major transboundary river basins. More than 70 percent of the region’s freshwater resources are shared between two or more countries. The largest river basins are the Congo, the Zambezi, and the Orange–Senqu basins.

**The region is also well endowed in terms of energy resources.** Historically, coal has been the source of most power generation activity in the east and northeast regions of South Africa. While an additional 10,000 megawatts (MW) of coal-fired generation capacity is in various stages of development, the expectation is for a number of supplementary sources of generation to become important in the region. For instance, the region has potential for 56,000 MW of hydropower in DRC and Mozambique alone, and recent finds of gas off the coast of Mozambique are globally significant quantities that could supply exports to Asia and the Southern Africa region simultaneously. However, considerable investment will be required for both of these forms of energy to be developed in significant quantities. Also relevant is the development of increased renewable energy, including solar and wind power. The different forms of energy generation will have very different implications for water demand in the region.

While several studies show considerable uncertainty about the likely impacts of climate change on the region, recent evidence suggests they could be significant. For instance, the effect of El Niño during 2015–16 has led to a more than 50 percent reduction in power generation output from the Kariba Dam on the Zambia–Zimbabwe border and Swaziland. The dam’s typical annual level of rainfall is only 10 percent below that of the world average, but it is currently in severe drought.

For the five focus countries—South Africa, Lesotho, Botswana, Namibia, and Swaziland—the paper considers national water sector priorities, energy sector priorities, the extent of coordination between the two, and how these priorities fit into a broader agenda of regional coordination. Despite the many economic and geographical differences among these countries, there are a number of common themes in relation to water and energy security.

- **All countries face water shortages, either because of a general lack of available resource, or because economic centers are located far from national water resources.** Thus, policies are focusing on both water storage and significant water transfer schemes (implying a need to join up water–energy investment decisions).

- **Water allocation is also a common challenge.** Although countries recognize the need to implement an integrated approach to managing their water resources, and indeed most have published an integrated water resource management (IWRM) plan, doing so is a complex, data-

¹ This initial phase of countries is the set of countries that were under one World Bank Country Management Unit at the time that the study was conceived. Future phases may focus on additional countries.
and resource-intensive task, which many countries (and particularly Namibia and Swaziland) are struggling to develop and implement.

- **The majority of the countries in this study have recently experienced load shedding due to their reliance upon electricity supply from Eskom.** As a result, all countries now prioritize self-sufficiency, and there is significant interest in developing hydropower and renewable energy generation. The exception is South Africa, which is considering investments in gas-fired generation and power imports from the broader region, including future major hydropower projects, such as Inga 3 in DRC and Mphanda Nkuwa in Mozambique.

- **In terms of joint planning between the water and energy sectors, only South Africa appears to be actively incorporating water resource availability into its energy planning.** There is still room for improvement, though. The Thirsty Energy modeling initiative (World Bank 2015b) notes that South Africa’s approach to such incorporation is relatively crude, with no consideration of regional disparities in water supply and costs; auxiliary water use by, for example, coal mining; or water treatment requirements.

The shared water resources through the region’s large transboundary river basins and significant history of electricity trade create the potential for a strong regional dimension to addressing the national water and energy priorities.

**SADC is the key institution focusing on regional integration in the region.** The SADC treaty provides that member states should develop a set of legal and institutional instruments—referred to as protocols—that have clearly stated objectives, scope, and institutional mechanisms to facilitate cooperation and integration on key issues for the region. SADC currently has 26 protocols, including the protocols on energy (SADC 1996) and shared watercourses (SADC 2000).

**The disparities between individual countries’ water resource endowments and their overall demand for water suggest that operating at a regional level should increase benefits and reduce risks.** A coordinated approach with benefit-sharing mechanisms to manage the region’s shared waters could minimize social costs and improve allocative efficiency. There is significant evidence of efforts to coordinate.

**Water resource management in the region is governed by the Revised Protocol on Shared Watercourses in the Southern African Development Community (SADC 2000).** This protocol seeks to promote and facilitate watercourse agreements and institutions, including harmonization and monitoring of legislation and policies for the planning, development, conservation, and protection of shared resources, and their allocation. The protocol also lays out an institutional framework for its implementation, comprising the Committee of Ministers, Committee of Water Senior Officials, Water Sector Coordinating Unit (based at the SADC secretariat), Water Resources Technical Committee, and shared watercourse institutions.

**Water planning at the regional level takes place at the transboundary level and has not yet moved to the level of full regional integrated development (Schreiner and Baleta 2015).**
Bilateral water transfer agreements are in place to address the problem of uneven water resource distribution in the region through interbasin transfers, and to coordinate on large infrastructure projects, such as the Kariba Dam on the Zambezi River.

The most significant water transfer agreement is between Lesotho and South Africa—the Lesotho Highlands Water Project—which aims to address South Africa’s water scarcity through the transfer of some of Lesotho’s abundant water resources to the Gauteng region. The revenues from this project are enabling Lesotho to develop its hydropower capacity and improve water distribution within the country.

The Kariba Dam is managed by a bilateral agreement between Zambia and Zimbabwe. The Zambezi River Authority (ZRA) agreement was signed in 1987 to manage the part of the Zambezi River that forms the border between Zambia and Zimbabwe “to obtain, for the economic, industrial and social development of the two countries, the greatest possible benefit from the natural advantages offered by the waters of the Zambezi River.” The main responsibilities of the ZRA today are to operate and maintain the Kariba Dam, investigate the development of new dam sites on the Zambezi River, and analyze and disseminate hydrological and environmental information pertaining to the Zambezi River and Lake Kariba.

A number of river basin commissions (RBCs) have been created through basinwide agreements among the respective riparian states. To date, five RBCs have been established to promote IWRM and development:

- Cuvelai Watercourse Commission (CUVECOM), established in 2014 between the riparian states of Angola and Namibia;
- Limpopo Watercourse Commission (LIMCOM), established in 2003 between the riparian states of Botswana, Mozambique, South Africa, and Zimbabwe;
- Okavango River Basin Water Commission (OKACOM), established in 1994 between the riparian states of Angola, Botswana, Namibia, and Zimbabwe;
- Orange–Senqu River Commission (ORASECOM), established in 2000 between the riparian states of Botswana, Lesotho, Namibia, and South Africa; and
- Zambezi River Watercourse Commission (ZAMCOM), established in 2011. In 2014, ZAMCOM was successfully transitioned to a permanent organization, based in Zimbabwe (World Bank 2015g). Its main objective is “to promote the equitable and reasonable utilization of the water resources of the Zambezi Watercourse as well as the efficient management and sustainable development thereof” (ZAMCOM 2016).

While RBCs have the potential to act as basin-level coordinators, in practice their capacity to do so is limited. Most RBCs have been established to coordinate pollution control and water resource information sharing. Two RBCs—ZAMCOM and ORASECOM—are more sophisticated, but to date lack the institutional capacity to implement cross-sectoral IWRM plans. ZAMCOM is producing a strategic plan for the development of the basin in accordance with the provision of the ZAMCOM agreement (with support from a World Bank-administered grant).
high number of riparian states gives rise to complex issues about how to share the river’s significant water resource.

Since 2015, a series of projects supported by the multidonor trust fund Cooperation in International Waters in Africa (CIWA)\(^2\) is helping to overcome some of the institutional and financial issues that have hindered progress in developing the Zambezi basin. These projects are being delivered through CIWA’s Zambezi Basin Program, which provides an integrating framework to coordinate World Bank and other development partner programs and achieve the key objectives of ZAMCOM.

**Regional energy development is at the core of SADC’s agenda, which has developed strategies and established dedicated agencies that together form a consolidated institutional architecture driving integration in the energy sector.** The key actor is the Southern African Power Pool (SAPP), created by SADC in 1995 through an intergovernmental memorandum of understanding in August 1995, and guided by the SADC protocol on energy (SADC 1996). The SAPP’s mandate includes enhancing regional cooperation in power development and trade and producing nonbinding regional plans to guide the delivery of electricity generation and transmission infrastructure.

There is still significant room for improvement regarding the SAPP’s regional coordination capacity. Further integration and market competition in the SAPP critically hinge on increasing generation and transmission capacity. In 2012–13, 28 bilateral electricity-trading contracts were in place, but only 15 were active because of generation and transmission constraints. The current constraints in transmission infrastructure are an obstacle to freely trading power on the spot market. On average, the short-term energy market accounted for 5–10 percent of the energy traded in the region, while the day-ahead market currently accounts for around 1 percent.

National demands for energy have also led to various regional treaties and bilateral and multilateral agreements for the advancement of hydropower projects, such as for Inga 3 (DRC and South Africa) and Mphanda Nkuwa (ongoing dialogue between Mozambique and South Africa).

While all these efforts are being made at a regional level, it is clear that the priority of countries in the region is to develop physical self-sufficiency in generation capacity within their own national boundaries—and to primarily look at regional trade as an opportunity to finance larger generation projects (than may be required to meet national demand) based on demand from export to the region. South Africa is the clear exception: it is explicitly looking to import power. Its 2013 update to its Integrated Resource Plan for Electricity refers to hydropower in the region being a source of power for South Africa (RSA/DoE 2013a). South Africa is actively engaging with DRC and Mozambique, among others, toward this end. The role of South Africa in backstopping power purchase agreements will be critical in attracting credible investors and developing bankable projects for financing by the private sector.

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\(^2\) The CIWA trust fund is a partnership between the World Bank and the governments of Denmark, Norway, Sweden, the Netherlands, and the United Kingdom to address constraints to cooperative management and development of Africa’s international waters.
Looking at planning, there is little evidence of cross-sectoral planning in the current version of the SAPP regional pool plan. When it comes to decisions about projects, typically the prioritization criteria do not include broader water issues or water opportunity costs. There are also no formal links with SADC water institutions when undertaking such work. Since 2015, the SAPP has been developing a new Regional Power Sector Master Plan. The Plan is taking an approach that identifies not just least-cost—but also robust—solutions, given all the uncertainties relating to regional power sector development. It is expected that water resources and climate change will play a role in the uncertainty scenarios.

Conclusions

The interrelationship between water and energy supply, water resources, and climate change is particularly relevant to decision making in Southern Africa. The region’s water resources are unevenly distributed both spatially and temporally, leading to significant water scarcity in some parts of the region and relative abundance in others. There is also limited knowledge about the region’s overall water resource levels. Climate change is expected to reduce rainfall levels, increase rainfall variability, and increase ambient temperatures, but there is little certainty about when and by how much (Bates et al. 2008).

In light of these spatial differences, water and energy sector planning needs to be approached in tandem at a local, national, river basin, or regional level, depending on the nature of the issue. Both sectors need to assess the value of the water resources they consume and use this knowledge to improve overall efficiency in terms of the freshwater they consume or withdraw, and need to ensure that planning minimizes the overall cost and maximizes the benefits for the two sectors.

While substantial progress has been made to recognize water–energy links in many countries’ legislation and plans, there is evidence of significant barriers across the region with regard to implementing a cross-sectoral approach to planning. These barriers appear to result from capacity constraints at many levels, including a lack of data (and capacity to collect and further analyze data), and limited institutional capacity to facilitate data sharing and the necessary cross-sectoral coordination to implement plans and strategies.

The significant gaps in regional water resource data prevent, for example, the development of water resource allocation plans (ODI, ECDM, and GDI/DIE 2012). There is a need to improve knowledge of the amount of water that is being withdrawn and details on streamflow rates (Miralles-Wilhelm 2013; Droogers, de Boer, and Terink 2014). Data on energy generation technology water use (withdrawal and consumption) could also be improved to provide data that are reflective of the local climate, rather than relying on international data (IEA and World Bank 2015). In some instances, these data may exist, so there is a need to coordinate at a regional level to share this information.

In terms of data analysis, climate change imposes deep uncertainty and with it a need to analyze investment opportunities from a different perspective, opting instead for climate-
resilient strategies that minimize potential losses under a range of scenarios (World Bank 2016a). Again, capacity within the region to undertake this analysis needs to be developed. Associated with this is the significant need to develop practical integrated energy–water planning tools, to enable decision makers to quantify power generation investment trade-offs at both the national and the regional level, and take account of the uncertainties imposed by climate change (Miralles-Wilhelm 2016). The current work by the World Bank’s Thirsty Energy Initiative to develop a national South African integrated model provides the first regional example of such a tool (World Bank 2015b). The Bank’s support to the SAPP with the development of its new Regional Power Sector Masterplan is expected to incorporate approaches that seek robust options under the various outcome scenarios (including climate change).

Southern Africa has institutions at the regional level that are well positioned to undertake integrated, regionwide planning. SADC already recognizes the nexus and the importance of understanding the scarcity value of water resources through such initiatives as the economic accounting of water and the SADC Water Information Sharing Hub. An analysis of SADC’s Regional Infrastructure Development Master Plan (SADC 2012a) reveals limited regional coordination for its proposed water infrastructure projects, with no projects planned involving three or more countries. RBCs have been established to coordinate information, and in some cases, integrated planning at the river basin level, but evidence on their performance to date suggests they are quite limited in their ability to implement cross-sectoral plans, and in most cases their role remains limited to that of information coordination (CRIDF/DfID 2014a). Also, their geographical basin-level focus means they are unable to act on issues that extend beyond the basin. The SAPP provides a basis for regional coordination through power trading, but there appears to be a lack of political will to rely on neighboring countries: national plans continue to emphasize self-reliance, despite the clear potential benefits of planning and working at a regional level.

Suggested Next Steps

A priority for the region is to bring together regional stakeholders in an organized manner to discuss the nexus and ultimately agree on what the key priorities are for cross-sectoral coordination in the region and who are the main “champions” to help address each of these priorities. The recent SADC Energy and Water Joint Ministerial Workshop held on June 20, 2016 has helped create awareness and context for such a process. This Paper proposes the following next steps:

- Convene focused meetings at the SADC level to better inform regional stakeholders on the key overarching nexus issues for the region. These meetings would include the main findings contained in this background paper. As an output of these meetings, there would be a need to pull together an overarching matrix that sets out the key priorities identified by the stakeholders, and for each, identify the relevant stakeholders connected with these issues and champions for addressing them in the region. A potential convener for these meetings would be the SADC Secretariat.

- A following step would be to conduct focused workshops at various levels (national, regional, sectoral, and cross-sectoral) on key analytical nexus-related issues, such as water valuation, robust decision-making techniques and their application to climate-resilient
investment, and integrated modeling tools. A key output of these workshops would be a view on the current data and analytical capacities of individual member states to carry out such analyses, to identify significant data gaps and whether in the first instance it is most appropriate to develop these capacities at a national and/or regional level.

- Regional energy and water planning stakeholders would subsequently need to reconvene to discuss the identified priorities, gaps and relevant champions and determine how implementation will be taken forward.
Chapter 1: Setting the Scene

In recognition of the growing international focus on the linkages between the energy and water sectors, both the 2014 United Nations (UN) World Water Development Report (WWAP 2014) and the 2015 World Water Week (SIWI 2015) focused on issues surrounding the energy–water nexus. The thematic focus was a culmination of analytical work and policy experience that have highlighted the importance of improving integrated policy making in the energy and water sectors to achieve allocative efficiency by accounting for cross-sector impacts and feedbacks.

With vast hydrological resources, growing population pressures, increasing energy investments, and the threat of climate change, understanding and harnessing the energy–water nexus are critical to Southern African countries achieving the socially efficient and sustainable expansion of electricity and water supply. In addition, because of unequally distributed resources and demand, cross-sector planning in Southern Africa needs to be coordinated at the regional level.

The objective of this work is to present key existing knowledge on the energy–water nexus, with a special focus on Southern Africa, to inform policy makers, development partners, and other sector stakeholders in the region. The study structures the existing knowledge in a way that clearly focuses on the current state of analytical and policy knowledge along with the key gaps. By highlighting key analytical work and drawing insights relevant to Southern Africa, this study aims to support an informed regional dialogue on decision making about the energy–water nexus in the region.

There are certain clear limitations to the scope of this paper:

- This is a literature review of existing work and does not conduct any primary analysis. The value of this paper is in bringing together critical information, often available only in various fragmented forms, as one document to support initial discussions in the region.

- In referring to the energy–water nexus, the focus of the paper is on the key considerations for the two sectors in relation to electricity supply and long-term planning around it, including the feedback loop to water. Alternative uses of water, such as for agriculture, are not the focus, though alternative uses of water will affect decisions about electricity investments and supply.

- During the conceptualization of the scope for this paper, it was decided that it would act as a background paper for discussions. The paper would not, at this stage and prior to meetings in the region, seek to articulate the key challenges facing the region on these issues and the policy alternatives that could be considered for addressing them. Such findings would be set out in a potential follow-on piece of work after the meetings with stakeholders.
SECTION A: WHAT IS THE ENERGY–WATER NEXUS?

Photo: © Dana Smillie / World Bank.
Chapter 2: Introducing Energy–Water Interconnectivity and the Nexus Concept

Globally, population growth, urbanization and its associated increase in well-being, and economic growth are likely to put increasing pressure on water and energy resources.

Water resources are particularly challenging as they form complex natural and artificial systems over large areas. Activities such as intensification of agriculture, expansion of industrial processes, and increased supply of tapped water will have a significant impact on the water system, by affecting groundwater, river flow, or other forms of water storage and transmission.

Energy is needed for water supply. The level of energy needed is a function of many variables, including water source (surface-water pumping typically requires less energy than groundwater pumping), type of water treatment needed (high-ambient-quality raw water requires less treatment than brackish or seawater), the intended end use, distribution (water pumped long distances requires more energy), amount of water loss in the system through leakage and evaporation, and level of wastewater treatment (stringency of water quality regulations to meet discharge standards). Likewise, the intensity of energy use for water supply depends on such characteristics as topography, climate, seasonal temperature, and rainfall (Copeland 2014).

In the context of major energy investments expected in Southern Africa, the scope of the paper is focused specifically on the subset of the nexus addressing electricity supply. Electricity generation often depends on the reliable supply of water—for example, hydropower and cooling processes at thermal plants. Increased electricity access to underserved populations and greater energy intensity of the lower-income economies will spur greater demand for energy resources, including electricity in many parts of the world.

The pressure on energy and water resources from direct demand is supplemented by the feedback between demand and supply in the two sectors: the increased demand for electricity will spur a greater demand for water, which in turn will increase the demand for electricity, and so on (Figure 1).
In addition to the direct human pressures, climate change is likely to result in greater uncertainty and variability in resource availability and also possibly in increased demand for energy and water in response to extreme weather conditions. The likelihood of greater water and energy stress and increased vulnerability of existing systems in the future requires planning a response that is well informed with regard to water and energy that adequately accounts for the long-term impacts on human well-being.

The clearest examples that show the salience of the case of water and energy being interconnected is in the case of the impact of droughts on hydropower resources. Countries or regions reliant on hydropower for their electricity needs are by design directly dependent on the regular availability of adequate water resources and resilient water systems. In cases where the system breaks down or is subject to a negative shock, there can be significant impacts on both the energy and the water sectors. Further, given the degree of linkages of the two sectors to other parts of the economy, the impacts are often significantly broader. Two relatively recent examples from Uganda and California illustrate how drought and climate change can bring energy and water interconnectivity issues to the fore for policy makers (Boxes 1 and 2).
Box 1: Drought and the Energy–Water Nexus in Uganda

In Uganda, drought conditions during 2004–05 led to a large drop in the level of Lake Victoria, which acts as a natural reservoir for the hydropower facility at the Nalubaale (formerly Owen Falls) and Kiira dams. The drop of almost one meter in the level of the lake led to a reduction in the power generation ability of the dams on which Uganda was fully dependent. With demand for electricity already outstripping supply, the further reduction in generation forced the government to buy emergency power from expensive thermal generators, with widespread impacts on the economy and environment. The extract below summarizes the situation:

“In Uganda, reduced water resources caused by climate change have set off a damaging chain reaction. After the extreme and prolonged drought of 2004 and 2005, Lake Victoria’s water level dropped by one meter in 2006. This reflected not only evaporation and low rainfall but also the fact that so much water had been removed from the lake to fuel generation of electric power at the Owen Falls dam. With less water available for Owen Falls, Uganda was forced to ration power for both industrial and domestic use. This has had a negative impact on the entire economy. To meet electricity demand, the government started using expensive thermal power. Electricity tariffs per unit of domestic consumption nearly doubled from 216 shillings to 426 shillings ($0.13 to $0.25). Higher electricity prices have increased pressure on forest resources. Around 95 percent of Ugandan households use wood fuel to meet at least some of their energy needs, and exorbitant power tariffs only heightened the population’s dependence on tree and forest products for fuel. Even urban households that had tended to use electricity for cooking have reverted to wood fuel. Demand for the wood fuel has outstripped supply, and the process of the charcoal and wood fuel have [sic] rocketed. The heavy cutting of forest, coupled with the unsustainable slash-and-burn practices, has contributed to the degradation of land and soil, leading to poor yields on food crops and threatening Uganda’s food security” (McKinsey Global Institute 2011).

In the case of California, the ongoing drought over the past few years has put a severe strain on the water availability and energy supply from hydropower facilities. The drought conditions not only affect the state of California, but also neighboring states within the United States and Mexico that share common water resources. The severity of the situation has brought attention to such issues as allocation of rights to water use, water and energy pricing, and the need for intersectoral polices and planning to improve efficiency in supply and consumption. Box 2 provides a glimpse of these energy–water connectivities in the California context.4
The recent drought conditions in California brought the linkages between energy and water to the fore in the state. In January 2014, the governor of California declared a statewide emergency. As of September 2014, 58 percent of the state was classified as under the most intense drought category.

The prolonged and severe drought conditions led to a significant decline in hydropower generation: on average, hydropower accounts for about 20 percent of the in-state generation during the first six months of the year; this fell to about 10 percent in the first half of 2014.

According to a Pacific Institute report published in March 2015 (Gleick 2015), during the three years preceding October 2014, the reduction in hydropower generation resulted in an additional $1.4 billion in electricity bills and an 8 percent increase in metric tons of carbon dioxide-equivalent as a result of the compensating increase in fossil fuel (natural gas) production.

While the drought is in part a natural weather shock, the severity of the impacts has focused attention on issues surrounding the sustainability of resource use and mitigation of extreme weather risks. The drought has spurred discussion about ways of improving the sustainability of water and energy use and the role of optimal pricing and improvement of efficiency in the water and energy sectors.

Cross-sectoral planning and response are being undertaken through working groups, such as the interagency Drought Task Force, that comprise sector utilities, such as the California Energy Commission, Department of Water Resources, State Water Resources Control Board, and California Public Utilities Commission.

The policy response to the drought has been in the form of a mandated 25 percent reduction in urban potable water use statewide, standards and rebates for water-efficient household appliances, grants for energy- and water-saving research, and monitoring and collection of data on the impact of water scarcity on electricity generation to allow decision makers to better evaluate the situation and devise solutions.
2.1 Establishing the Energy–Water Nexus Concept

This section examines the research that has developed the energy–water nexus concept and shows how climate change significantly interacts with the nexus. It also shows how holistic decision making about the use of these resources can increase efficiency, reduce trade-offs, build synergies, and improve governance. This holistic approach to decision making has far-reaching global implications for how decisions are made, particularly those regarding how to invest in energy and water supply.

Research on the Water–Energy Nexus Frameworks and the Impact of Climate Change

The link between energy, water, and climate change has been studied for several decades. A study by Gleick (1993)—a collaboration between the Stockholm Environment Institute (SEI) and the Pacific Institute—discussed the possible effects of climate change on water resources and the use of water for energy and food production. The World Bank (2004) analyzes the water–energy nexus as the basis for improving regional cooperation in the Syr Darya Basin in Central Asia, and Koch and Vögele (2009) presented dynamic modeling of water demand, water availability, and power plants’ strategies for adapting to global change.

The energy–water nexus sits within that of the wider water–energy–food (WEF) nexus, for which the first presentation was made by the World Economic Forum in 2011 (WEF 2011b). This was followed by work by SEI/Hoff (2011) for the 2011 Bonn Nexus Conference. The WEF nexus was broadly accepted when it was presented at the Rio+20 Summit (UN Conference on Sustainable Development, or Earth Summit) in Rio de Janeiro in June 2012.

Table 1 lists what are widely considered to be the seminal contributions to the nexus literature, although this list is intended as illustrative and is by no means exhaustive. Annex 1 presents the SEI/Hoff (2011) and the World Economic Forum (2011a) nexus frameworks, while the climate, land-use, energy, and water strategies (CLEWs) framework (IAEA 2009; Howells et al. 2013) and its various applications to integrated modeling are discussed later in Chapter 3: Energy–Water–Climate Nexus Decision Tools. The International Institute for Sustainable Development (IISD) and the Food and Agriculture Organization of the United Nations (FAO) frameworks’ focus on landscape and food make them less relevant to this particular study, but they are included in Table 1 for completeness.

Table 1: Summary of the Key Water–Energy–Food Nexus Literature

<table>
<thead>
<tr>
<th>Organization</th>
<th>Framework</th>
<th>First publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAO, IAEA, IIASA, KTH, SEI, UNDESA, and UNIDO</td>
<td>CLEWs</td>
<td>2009</td>
</tr>
<tr>
<td>World Economic Forum</td>
<td>WEF</td>
<td>2011</td>
</tr>
<tr>
<td>SEI/Hoff</td>
<td>WEF</td>
<td>2011</td>
</tr>
<tr>
<td>International Institute for Sustainable Development</td>
<td>WEF</td>
<td>2013</td>
</tr>
<tr>
<td>FAO</td>
<td>WEF</td>
<td>2014</td>
</tr>
</tbody>
</table>

Note: CLEWs = climate, land-use, energy, and water strategies; FAO = Food and Agriculture Organization of the United Nations; IAEA = International Atomic Energy Agency; IIASA = International Institute for Applied Systems Analysis; KTH = Royal Institute of Technology, Sweden; SEI = Stockholm Environment Institute; UNDESA = United Nations Department of Economic and Social Affairs
Considering an Energy–Water Nexus Framework

For electricity generation investment decisions, it is helpful to simplify the framework by focusing on an energy–water nexus framework, rather than the broader WEF framework. The SEI/Hoff (2011) WEF framework (see Annex 1) is highly relevant to this and can be adapted as shown in Figure 2 below. The framework and definitions in Figure 2 illustrate the relationship between energy supply security and water supply security and how this relationship is challenged by a series of “global trends”—notably climate change, urbanization, and population growth—and can be protected by “action fields” that serve as enabling factors or incentives—notably governance, innovation, and finance.

**Figure 2: An Energy–Water Nexus Framework**

**Figure 2 Definitions**

**Water supply security:** Access to safe drinking water and sanitation, and availability of and access to water for other human and ecosystem uses.

**Energy security:** Access to clean, reliable, and affordable energy services for cooking and heating, lighting, communications, and productive uses and uninterrupted physical availability of energy at a price that is affordable while respecting environmental concerns.

*Source: SEI/Hoff 2011.*
2.2 Key Implications of the Energy–Water Nexus for Electricity Generation Investments

Given the focus of this paper to assist decision making, particularly regarding investment in electricity generation and its related water infrastructure, this paper identifies a set of key implications and fundamental challenges.

Knowledge of water resource availability is central to both energy and water investment decision making.

The energy–water nexus framework depicted in Figure 2 puts water resources at the center, so that water determines the current state of the system as represented by the framework, and is also the key driver of future changes that are affected by human decision making.5

Water resource availability is characterized by distinguishing between various types of water resources and use. Water resources exist in various forms: blue water refers to the water available as surface water and groundwater, whereas green water refers to water present in soil that may be productively used for agriculture. In terms of the types of use, water may be withdrawn and may or may not be returned to the original source (water withdrawal), or it may be consumed without being returned to its source (water consumption). Both of these types of use can have differing and significant impact on water resources and the energy–water nexus.

Water resource availability dictates both water supply and energy security: insufficient water resources infer low water and energy security. This directly implies that energy supply decisions need to take into account water resource availability.

Energy and water supply security is intertwined. This implies a need for coordinated decision making that accounts for opportunities for synergy and fully internalizes the societal economic costs of water.

As has been discussed, the interdependencies between water and energy can lead to a supply shortage in one, when there is a supply shortage in the other. Both resources are critical to meeting basic human needs, but are finitely available in a given location at a given point in time. This implies that decision making in each sector must fully account for the resource availability of the other and weigh the full societal economic costs associated with the resource use against its use for other competing purposes—the concept of opportunity cost. Water, in particular, has a large number of competing uses. A clear example is a multipurpose dam, which may need to trade-off use of water for irrigation versus electricity generation. However, while there is conceptual clarity regarding the trade-off with multiple uses, the implementation of the allocation decision is subject to various quantifiable and nonquantifiable constraints. At the heart of the challenge is the difficulty in estimating the true economic value of water to society from various uses.

Another challenge related to accounting for the full societal costs of resource use is the need for joint decision making across sectors and, often, political boundaries. This challenge is relatively

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5 In the terminology for dynamic programing, a tool that is often used to optimize intertemporal allocations in such dynamic systems, under this framework water is both a “state” variable, used to determine the state of the system, and a “control” variable, the main choice variable used to determine future states of the system.
clear in the case of hydropower investments, where the very direct link between water resource availability and electricity generation necessitates the joint optimization of water use and electricity generation, along with possible cross-boundary water use issues and power trading. Even when not considering hydropower, water supply systems form over large regions, most clearly demonstrated by large river basins.

The management of rivers whose catchment areas extend into several countries requires diplomacy as well as technical expertise. The classic example of a river basin under composite management is the Rhine River, which rises in Switzerland, receives tributaries from France, Germany, and Luxembourg, and flows through the Netherlands to the North Sea. The management body is the River Rhine Commission, comprising representatives from all the riverine countries (Shaw 1988). In these instances, broad decision making, in line with the natural geography of water resources, is required. Energy security, when based on water supply, is thus also potentially a transboundary issue.

The impact of climate change is to introduce a fundamental uncertainty regarding future water and energy scenarios, thereby further exacerbating the challenges of optimal decision making on the energy–water nexus.

Climate change has a significant impact on the energy–water nexus framework. Under certain scenarios, climate change may increase the pressure on energy and water systems through greater scarcity and variability in the resource availability. This may make the trade-offs between energy and water supply more stark. Higher temperatures and changed rainfall patterns can reduce available levels of water resources and can decrease hydropower outputs. Low-carbon electricity generation technologies may require more water than conventional processes (for example, concentrating solar power (CSP) is highly water intensive).

The water–energy–climate change interrelationship implies a need for joint, long-term planning accounting for the possible impacts of climate change. The fundamental challenge to such a decision-making process is how to account for the fundamental uncertainties regarding the future interaction of key drivers of resource availability, the probability of various scenarios, and the valuation of each outcome, along with its associated distribution among society.6 These issues have implications for how decision making is governed. Significant challenges for decision makers include investing in climate change adaptation to improve the climate resilience of infrastructure, and employing decision-making methodologies that accommodate the deep uncertainty that climate change imposes on many infrastructure investment decisions (discussed in greater detail below).

Good governance that facilitates cross-sectoral decision making at the local, national, basin, and regional levels can facilitate nexus decision making.

Another important implication deriving from the nexus model is the issue of governance. Cross-sectoral linkages, water resources that span political boundaries, and the uneven spatial distribution

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6 This, roughly, is the concept of “deep uncertainty” that is used to characterize the limited knowledge and lack of consensus among experts on the relative likelihood of the occurrence of future climate change scenarios and associated impacts.
of resources and demand for them (implying opportunities to improve overall well-being through trade) mean that, to be optimized, water and energy decision making will also need to be cross-sectoral, and often transboundary or regional. There is often some transboundary coordination for river basins, but in many cases this could be more formalized and holistic—and associated energy-related coordination is in most cases completely lacking.

This issue of governance represents a considerable challenge. Decision makers can promote optimum decision making through enabling factors and incentives, by using the tools illustrated in the nexus framework of innovation and finance. Conversely, they have the power to prevent optimal decision making through poor governance—for example, through uneven bargaining power between sectors; a lack of communication within and between sectors during key decision periods; and a preference for sectors to adhere to a silo mentality, making decisions in isolation from other sectors. Integrated modeling tools are being developed to assist cross-sectoral decision making (see Chapter 3), but cross-sectoral planning also needs to be in evidence in national and regional plans and strategies (discussed in the context of Southern Africa in Chapters 4 and 5). Achieving decision making at the transboundary or regional level is likely to be region specific (guided by existing institutional frameworks) and is discussed in the context of Southern Africa in Chapter 5.

2.3 Challenges of Applying the Energy–Water Nexus Framework to Investment Decisions

The discussion in the previous sub-section highlighted a number of key challenges that face decision makers with respect to electricity generation investment decisions. This is not an exhaustive list, but an indicator of some of the main issues that are specific to the water-energy-climate nexus and so may be overlooked if a nexus approach is not employed. These include cross-sectoral coordination from the outset of the planning process to identify potential investment synergies to be identified; ensuring that the economic value of water is included in the investment appraisal; and ensuring investment options are climate resilient which may imply adopting a different approach to the investment appraisal process.

From a policy perspective, the energy–water nexus framework does force decision makers to consider the significant trade-offs in the degree and allocation of resource use, identify co-benefits or synergies across water and energy investments, and account for the impacts of climate change. In doing so, they cannot ignore important spatial and intertemporal relationships in resource availability, and the associated costs and benefits. Moving from an optimization of investment decisions that is fixed in time, to an intertemporal dynamic optimization requires a greater understanding of costs and benefits and how they will evolve over time based on both exogenous and endogenous conditions.

Harnessing Energy–Water Synergies, or Co-benefits

The energy–water nexus presents significant opportunities for investment to harness synergies, or co-benefits. In this context, co-benefits are the result of decision making that jointly considers the positive feedback between energy and water supply investments and produces more valuable outcomes than a situation where the two investments are made independent of each other. As
Benson, Gain, and Rouillard (2015) note, all else being equal, not taking into consideration the co-benefits would lead to underinvestment in resource development:

“Although definitions vary, one critical normative condition for effective nexus approaches is held to be identifying cross-sectoral, multi-scale policy interdependencies that reduce mismatches in policy making, increase synergies and hence promote resource security.”

Therefore, policy making should seek to identify potential synergies and provide the enabling conditions for investments that maximize aggregate net benefits across interlinked sectors.

Some opportunities exploit the synergies between the energy and water sectors to deliver joint benefits. They either deliver co-benefits from investments in a particular sector (for example, water efficiency investments reducing associated power demand) or help spread capital costs over the joint production of energy and water products (for example, a coastal thermal power plant providing excess heat for seawater desalination). The following synergy solutions are suggested in the literature (see references for more detail on any particular solution):

- **Multiuse reservoirs.** Hydropower provides a stable power source, while the reservoir can also provide a secure supply of drinking water and irrigation water. The recent EdF/WWC research and the “SHARE” concept provide a framework that aims to address related issues, including help to avoid or minimize tensions among users, governance issues for all stages, and financial and economic models to develop and operate multipurpose reservoirs (EdF/WWC 2015)).

- **Combined heat and power (CHP) production at sewage treatment plants.** Anaerobic digesters produce methane biogas and fertilizer (which can be sold) from sewerage sludge. Further investment in a CHP plant converts the biogas to heat, (which is used by the water treatment plant) and electricity (which can be sold) (Rodriguez et al. 2013).

- **Co-location of thermal power generation and desalination plants.** Desalination is a potential solution to water scarcity in coastal areas, but is not always viable as a standalone investment, given the high electricity intensity of the process. Co-location with thermal power generation offers a way of reducing both desalination operating costs and the water consumption of thermal power generation. Thermal electricity generation creates waste heat in the form of steam. Rather than using additional freshwater to cool the steam, co-location with a desalination plant can recycle the steam to reduce the energy required for desalination. In this case, energy generation uses less freshwater for cooling, and water desalination uses less electricity. The solution becomes less efficient if the demand for power in the region is significantly different from the demand for water (this may be the case if there is seasonal variation in energy demand (Rodriguez et al. 2013)). Co-locating (energy-intensive) desalination plants with (water-intensive) CSP plants takes advantage of the fact that areas suffering from water shortages tend to have access to abundant solar energy. Co-location produces significant synergy benefits by reducing the otherwise significant transmission costs of the water and electricity required by both processes (World Bank 2012).

- **Impact of electricity supply reliability on water supply quality.** Urban water contamination from lack of pressure in water pipes (or energy-intensive mitigation
measures, such as private booster pumps, heating up the water, or bringing water in from elsewhere) can be avoided through investments in more reliable energy supply (Jägerskog et al. 2014).

- **Household heating water efficiency measures.** For example, using water-saving showerheads to reduce water consumption will also reduce associated energy consumption (Prasad 2012).

The nexus also implies that where there are spatial disparities in relation to water scarcity, there may be economic gains from both producing hydropower where competition for water resources is lowest, and trading this power, rather than physically transporting water (avoiding significant capital costs and operational costs (including power)), to the mutual benefit of both parties (Entholzner and Reeve 2016). This “invisible synergy” (Allan 2006) is discussed in relation to Southern Africa in section 5.6.

**Valuing Water in Energy Investment Decisions**

The optimal allocation of any finite resource should be based on the evaluation of the full set of societal benefits and costs accrued by alternative investments. For investments in the water sector, the cost of energy inputs can be established through market prices and can thus be easier to internalize to the investment decision (although subsidies, which lower the market price, will distort this—with negative consequences, such as overinvestment in irrigation). As a result, the economic viability of water investments is easier to assess (and for this reason, potential energy-intensive water supply projects, such as desalination, or large-scale water transfer schemes are often considered unviable). Valuing water inputs for energy investment decisions is significantly more complex, in terms of both knowing how much water will be required by an investment and knowing what value to place on it and its competing uses.

**Estimating water consumption and withdrawal volumes for energy investment decisions**

Many energy generation technologies consume or withdraw significant volumes of water. Knowing how much water will be withdrawn or consumed is relatively well documented at a global level (for example, Macknick et al. 2011; Mekonnen, Gerbens-Leenes, and Hoekstra 2015). Figure 3 and Figure 4 illustrate the variation in electricity generation technology withdrawal (water use that involves a temporary diversion of water from groundwater) and the water consumption rates (water use that involves a “loss” of water from the immediate system from evaporation, transpiration, or incorporation into products or crops). The figures also illustrate the influence that the choice of cooling technology has over any given generation technology’s water consumption and withdrawal volumes. For example, recirculating cooling consumes the most water, and once-through cooling systems withdraw the least water. Across cooling technologies, nuclear power generation is generally the most water-intensive solution, and gas-fired generation is the least intensive. Generation technologies that do not require cooling (such as photovoltaic and wind power) are the least water-intensive technologies overall.
Figure 3: Variation in Operational Water Consumption for Different Energy Generation Technologies

Source: Macknick et al. 2011.

Note: Boxes represent the 25th percentile, the median, and the 75th percentile. Whiskers present the minimum and maximum. CCS = carbon capture and storage; CSP = concentrating solar power; IGCC = integrated gasification combined cycle; MWh = megawatt-hour; PV = solar photovoltaics.
Water withdrawal and consumption must be taken into account by investment decisions because of the social costs they impose. Because water that is withdrawn for cooling purposes will be returned at a higher temperature, the cost of returning it to its original state must be taken into account by investment decisions. Similarly, because hydropower generation alters downstream flow rates and silting patterns, these costs are also relevant to investment decisions (IEA 2012).

A key problem with estimating the water intensity of energy technologies relates to water’s sensitivity to the local climate and time of year (IEA and World Bank 2015). Indeed, water withdrawal and consumption volumes can vary by as much as 20 percent (Macknick et al. 2011). Some information is available at the national level, but the data rely on the technology being operational in that country and on reliable data-gathering practices. For example, in their estimation of the opportunity cost of water for two of South Africa’s thermal plants, Inglesi-Lotz and Blignaut (2012) were able to use operational data for the thermal plants but had to rely on global estimates (such as those provided by Macknick et al. 2011) for alternative generation technologies, such as CSP.
Therefore, local information and data gathering on energy technology water intensity are important. Once these withdrawal and consumption volumes are known for the project, they need to be turned into an opportunity cost, taking into account spatial and intertemporal impacts.

**Valuation of water consumption and withdrawal**

How to value water—and optimally allocate it—is a major global issue. In the case of most goods, markets may be well suited to determine scarcity value, and thus market prices act as an optimal allocation mechanism. This is not the case for allocation of water for different uses, because market prices may be inadequate in reflecting the societal value of water consumption for various purposes, including drinking water. Potable water is a basic human necessity, and water is an input into many processes that produce goods that are fundamental to human well-being and survival, such as drinking water and food. Further, many people consider access to water a basic human right, and are thus a fundamental determinant in its allocation. In addition, the public good characteristics of many water resources (such as groundwater aquifers) and uses (such as water sanitation) imply that prices reflecting private costs and benefits will not lead to an optimal allocation of resources.

Public good characteristics are defined either by nonrival or nonexcludable consumption, or by both (pure public good). Nonrival consumption implies that consumption by one user does not tangibly reduce the availability for another user, thus implying the marginal cost of supplying an additional user is zero. Nonexcludable implies that it is impossible (or very costly) to exclude users from consumption, which implies the ability to free ride without payment. The latter, in particular, implies that market-based allocation of the resource will not be optimal, and may lead to underprovision or overexploitation of the resource. Figure 5 shows the dual properties of water as a private good and a public good, and implies that markets alone will not be able to determine the price that reflects water’s true economic cost. Water’s nonexcludability in some instances (such as access to rivers and aquifers) also makes policing any water-pricing scheme challenging.

**Figure 5: Defining the Properties of Water**

*Source: Global Water Forum 2015.*
In the absence of a market price for water as a basis to determine its economic value, energy planners must use alternative methods to estimate the full value and economic cost of water. One method is to estimate the opportunity cost. The full marginal economic cost of a good is represented by its opportunity cost or the lost opportunity to derive net benefit from the highest-value alternative use. The opportunity cost can be calculated as the sum of the marginal direct, external, and user costs (Turner et al. 2004). Figure 6 defines each of these cost categories.

**Figure 6: Defining the Marginal Opportunity Cost of Water**

- **Marginal opportunity cost**
  - equals the marginal direct cost
  - plus the marginal external cost
  - plus the marginal user cost

The marginal opportunity cost of water reflects the full societal cost of consuming an additional unit of water.

The marginal direct cost reflects the costs of obtaining water (labor, capital used in abstraction) adjusted for taxation and subsidies and market imperfections.

The marginal external cost reflects the net value of any losses or gains that water consumption imposes on individuals not directly involved in the activity (e.g., downstream pollution).

The marginal user cost reflects the scarcity premium attached to depletion of a fixed water resource (e.g., aquifer depletion).

*Source: Adapted from Turner et al. 2004.*

Ideally, energy investment decisions will take on board all three categories of water costs. In practice, this is a significant task. The most readily achievable method is to include marginal direct costs in the investment equation, because they are usually incurred within the boundary of the project, while external costs (primarily spatial in nature) and user costs (primarily intertemporal in nature) are usually unknown to decision makers. In practical terms, this could mean estimating and including the full project infrastructure costs related to supplying water to an energy investment (for example, the project costs of a dam construction project); the costs associated with water delivery (for example, the capital, operational and maintenance costs of water transportation); and/or the costs associated with treating water to be used for power generation. The Thirsty Energy integrated modeling project for South Africa (described in section 3.1) provides a practical example of how marginal direct costs have been incorporated into energy decision making.

External and user costs may also be important, and their omission could result in significant unintended negative consequences. These costs are particularly relevant to hydropower.
investments, which have the potential to impose costs on downstream farmers as the result of restricted river flows and change downstream silting patterns (see Sousa Júnior and Reid (2010) for an illustration of how taking on board social costs altered the economic viability of Amazon hydropower development). But these costs are also relevant to thermal power investments, which need to take on board the costs of returning withdrawn water back to its original state. The necessity of including social costs in power sector economic appraisal is widely accepted, but its implementation is not straightforward.

For hydropower and other renewable power projects, the World Bank published an overarching set of guidelines for the economic analysis of renewable energy power sector projects at the end of 2015 (World Bank 2015f). In addition, the World Business Council for Sustainable Development (WBSCD 2013) illustrates the wide range of approaches that have been used to incorporate water value into investment decisions, including qualitative and quantitative assessments based on national water tariffs (see also WBSCD 2012, which presents Électricité de France’s (EdF) recent water and energy nexus research). The Water for Energy Framework (W4EF) Action Group, a joint initiative between EdF, the World Energy Council (WEC) and the World Water Council (WWC) has a mandate to “develop a conceptual framework offering energy actors a common terminology and calculation framework with which to evaluate and communicate in a simple, understandable and numerical way, at local and corporate level, on how energy sites interact with their local water environment... (which) should be usable anywhere in the world for any energy production process from source to service” (EdF/WEC/WWC 2016). The initiative recently published its first phase report evaluating the local interactions between energy sites and water (ibid.). The World Bank’s (2015b) current Thirsty Energy Initiative to provide an integrated modeling tool for energy planning in South Africa reflects external (social) costs in the decision-making framework by including waste-discharge mitigation charges (further discussed in section 3.1).

**Responding to Climate Change**

It is widely agreed that climate change will affect the energy–water nexus, by altering the amount of available freshwater resources and by increasing demand both for electricity and for low-carbon, yet water-intensive electricity generation solutions. All of these climate change nexus impacts must be considered in the context of extreme uncertainty.

As a result, planners must identify risks and vulnerabilities, attempt to quantify them, and learn the likelihoods of their occurrence where possible. In an ideal world, with full information on all outcomes, it would be possible to make fully informed decisions by balancing risks with net benefits. However, drivers and impacts of climate are extremely complex and nearly impossible to predict with any amount of certainty. Regardless, planners must start by identifying vulnerabilities and using the best available information to make their decisions.

Figure 7 illustrates the different ways climate change interacts with the energy–water supply and demand nexus elements.
The impact of climate change on water resource demand

Climate change—in particular, the predicted increases in global temperatures—will increase the demand for water from a variety of sources, including increased evaporative demand from crops (FAO 2011). Water withdrawn by Africa’s agriculture sector represents more than 80 percent of total annual global freshwater withdrawals, so even small increases in water demand from this sector will have a significant impact on overall freshwater availability (FAO 2015).

Policy making for climate change favors the external costs of carbon emissions being factored into investment decisions. Thus, such decisions may favor clean energy generation solutions, such as CSP, solar photovoltaics (PV), or biofuels. Certain technologies, such as CSP, are water intensive (Figure 3 and Figure 4), so as their costs reduce over time and their take-up will reduce carbon costs, but their water opportunity costs may increase. IEA (2012), WEF (2011b), Macknick et al. (2011), and World Bank (2015b) provide further detail on these impacts.

The impact of climate change on water resource supply

Climate change is generally predicted to increase water scarcity through higher evaporation rates and more variable rainfall patterns (though effects in a particular region will vary by region). As a result, groundwater reserves will come under increasing pressure; freshwater reservoirs will suffer from changed recharge patterns and increased irrigation demand; and aquifers, which store around 30 percent of the world’s groundwater, will become increasingly important as a buffer against
climate change-led impacts, such as variable rainfall patterns. These resources will also come under pressure from increased irrigation demands, and their water quality may decline as a result of greater groundwater evaporation and rising sea levels that push seawater inland (making the water that drains into the aquifers more saline). Climate-led initiatives, such as using solar-powered pumps, while effective as a measure to reduce pollution and greenhouse gas (GHG) emissions associated with pumping water, need to be carefully considered, as their use in some water-stressed locations may have the undesirable effect of depleting scarce freshwater reserves being held in aquifers (FAO 2011; World Bank 2016a).

**The impact of climate change on energy demand**

Water shortages from reduced rainfall and river flows may lead to greater use of electricity for water transportation over longer distances, intensive desalination techniques to produce freshwater, and increased irrigation pumping (ODI, ECDPM, and GDI/DIE 2012; Bates et al. 2008; IEA-ETSAP and IRENA 2012). In addition, hotter climate and extreme temperatures will increase the demand for energy for cooling and heating (ODI, ECDPM, and GDI/DIE 2012; Bates et al. 2008).

**The impact of climate change on energy supply**

An unpredictable climate means unpredictable output levels for many energy generation technologies. Unpredictable changes in wind patterns will alter the efficiency of wind turbine electricity generation. Similarly, unpredictable changes in precipitation patterns will alter the efficiency of hydropower generation and biomass crop growing (Bates et al. 2008; ODI, ECDPM, and GDI/DIE 2012). These outcomes will affect investment decisions, as investors faced with higher uncertainty will demand demonstration of a higher expected return.

In such high-temperature regions as Southern Africa, any further temperature increases will reduce the efficiency of many generating technologies, including thermal power generation and solar cells, and will cause evaporative losses from hydropower reservoirs (Bates et al. 2008; ODI, ECDPM, and GDI/DIE 2012; ESMAP 2011; Linnerud, Mideksa, and Eskeland 2011).

Furthermore, climate change may increase the complexity of designing approaches for improving climate resilience, resulting in higher capital costs. It may also render solutions to water scarcity (such as desalination technologies) counterproductive, as they have a significant environmental impact in terms of both brine production and GHG emissions (World Bank 2016a).

**Implications for decision makers**

The significance of climate change for the nexus sets out a number of implications and challenges for decision makers, including the need to:

- Invest in climate change adaptation; and
- Employ decision-making methodologies that accommodate the deep uncertainty brought about by climate change.

*Invest in climate change adaptation*
Climate resilience is an increasingly important aspect of water and energy decision making. The co-dependence of the water and energy sectors amplifies the need to ensure that both water and energy sectors invest to ensure they minimize their vulnerability to climate-induced changes, including extreme weather events. There is evidence that taking action can be economically beneficial. Economics of Climate Adaptation (ECA) examined a series of case studies from a selection of global climate-sensitive regions, to understand the overall costs and benefits of responding to climate change risks (ECA 2009). The analysis concluded that 40–68 percent of the expected losses under severe climate change scenarios to 2030 could be avoided through adaptive measures where the economic benefits outweigh the costs.

For the energy sector, climate change adaptation has received considerable attention only recently, with the mainstay of research being focused on climate change mitigation for the sector (World Bank 2016a). However, investment in adaptation can avoid significant climate-related costs, such as decreased generation efficiency, increased maintenance costs, and reduced lifespans. Identifying these opportunities during the investment planning process is important, especially where investment lifespans can be significant (generation infrastructure has a typical lifespan of 15–40 years, and transmission infrastructure lifespans can extend to 40–75 years).

The Energy Sector Management Assistance Program (ESMAP 2011) describes two ways the energy sector can adapt to climate change:

- Technological adaptation—through investments that protect infrastructure from extreme weather events; and
- Behavioral adaptation—for example, by changing the location of an investment to minimize exposure to extreme weather events, or improving meteorological forecasting (together with emergency strategies), or adapting operation and maintenance of infrastructure.

Supply-side examples of these measures include diversifying energy sources, shifting production to safer areas (for example, siting renewable energy sources locally in safe locations and thus replacing large centralized energy supply infrastructure), and adapting hydropower operations to accommodate changed river flow rates. Demand-side measures could include actions to reduce energy demand (such as coordinating with the water sector, changing thermal generation cooling technologies, and using energy storage measures), and adapt the operation or maintenance of infrastructure (such as adapting hydropower operations to changed river flow rates). ESMAP’s (2011) summary of potential technological and behavioral adaptation measures is shown in Figure 8.
**Figure 8: Examples of Climate Change Adaptation Measures for the Energy Sector**

<table>
<thead>
<tr>
<th>ENERGY SYSTEM</th>
<th>TECHNOLOGICAL</th>
<th>BEHAVIORAL</th>
<th>Operation and maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINED RESOURCES (inc. oil and gas, thermal power, nuclear power)</td>
<td>Improve robustness of installations to withstand storms (offshore), and flooding/drought (inland)</td>
<td>(Re)locate in areas with lower risk of flooding/drought</td>
<td>Manage on-site drainage and runoff</td>
</tr>
<tr>
<td></td>
<td>Replace water-cooling systems with air-cooling, dry-cooling or recirculating systems; improve design of gas turbines (inlet guide vanes, inlet air fogging, inlet air filters, compressor blade washing techniques, etc.)</td>
<td>(Re)locate to safer areas, build dykes to contain flooding, reinforce walls and roofs</td>
<td>Change coal handling due to increased moisture content</td>
</tr>
<tr>
<td></td>
<td>Expand strategic petroleum reserves; consider underground transfers and transport structures</td>
<td></td>
<td>Adapt regulations so that a higher discharge temperature is allowed</td>
</tr>
<tr>
<td>HYDRO-POWER</td>
<td>Build desalting gates, increase dam height; construct small dams in the upper basins; adapt capacity to flow regime (if increased)</td>
<td>(Re)locate based on changes in flow regime</td>
<td>Consider water reuse and integration technologies at refineries</td>
</tr>
<tr>
<td>WIND</td>
<td>Improve design of turbines to withstand higher wind speeds</td>
<td>(Re)locate based on expected changes in wind speeds</td>
<td>Adapt plant operations to changes in river flow patterns</td>
</tr>
<tr>
<td>SOLAR</td>
<td>Improve design of panels to withstand storms</td>
<td>(Re)locate based on expected changes in cloud cover</td>
<td>Achieve operational complementarities with other sources (e.g., natural gas)</td>
</tr>
<tr>
<td>BIOMASS</td>
<td>Build dikes; improve drainage; expend/improve irrigation systems; improve robustness of energy plants to withstand storms and flooding</td>
<td>Introduce new crops with higher heat and water stress tolerance; substitute fuel sources</td>
<td>Adjust crop management and rotation schemes</td>
</tr>
<tr>
<td>DEMAND</td>
<td>Invest in high-efficiency infrastructures and equipment; invest in decentralized power generation, such as rooftop PV generators or household geothermal units</td>
<td>Repair plans to ensure functioning of distributed solar systems after extreme events</td>
<td>Adjust planting and harvesting dates</td>
</tr>
<tr>
<td>TRANSMISSION AND DISTRIBUTION</td>
<td>Improve robustness of pipelines and other transmission and distribution infrastructure; bury or cable re-rating of the power grid</td>
<td>(Re)locate based on areas with lower risk of flooding/storms</td>
<td>Introduce soil moisture conservation practices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Early warning systems (temperature and rainfall); support for emergency harvesting of biomass</td>
<td></td>
</tr>
</tbody>
</table>

*Source: ESMAP 2011 (adapted from Williamson et al. 2009).*
Hydropower investments will be particularly vulnerable where climate change impacts reduce rainfall or make it more unpredictable. For example, output from the Kariba Dam has been reduced by more than 50 percent as a result of climate change (see Box 3 in section 4.5), evidencing the need to adopt a climate-resilient approach to hydropower investment. Increasing reservoir storage is seen as one solution to climate-led water shortages (FAO 2008, table 5). A coordinated cross-sectoral response may result in the construction of multipurpose dams, which harnesses important synergies by spreading the overall investment cost of the dam construction over the dual benefits of increased water storage and increased (hydro) electricity generation.

_**Employ decision-making methodologies that accommodate deep uncertainty**_

Despite general climate change trends being known, there is deep uncertainty concerning the magnitude and timing of their impacts. Lempert, Popper, and Bankes (2003) define “deep uncertainty” as situations where decision makers do not know of or cannot agree on one or more of the following: the models that relate the key forces that shape the future; the probability distributions of key parameters and variables in these models; and the values of alternative outcomes. As a result, decision makers need to adapt their decision-making methodologies, moving away from least-cost optimization models to ones that prioritize solutions that are robust to a range of potential climate change-led outcomes.

The recent _High and Dry_ World Bank (2016a) publication describes a number of potential “decision making under uncertainty” techniques, including using a robust decision-making process, which explores a project’s vulnerabilities and sensitivities to a range of outcomes; applying a decision-tree approach, which uses judgments and sensitivities to guide the assessment of a proposed project and its alternatives through a series of decision nodes; selecting measures that yield a positive benefit, regardless of what happens climate-wise in the future (such as reducing water pipe leaks); and employing strategies that can be flexed in response to new information. See also World Bank (2010c) which develops new methodologies and estimates for climate change adaptation costs, both globally and for seven case study countries: Bangladesh, Plurinational State of Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam.

For the water sector, the decision-tree approach was developed by the World Bank’s Water Global Practice (Ray and Brown 2015; World Bank 2016b). This approach is particularly relevant to high-value hydropower investment assessments when a wide range of climate risks must be considered. It sets out a pragmatic four-stage process for assessing the risks of water resource projects that can serve as a decision-support framework and provides a way of taking climate change into account in investment decisions without needing to predict the future. The decision tree is different from other project-level assessments in focusing first on a project’s climate change vulnerabilities, where it guides project leaders through the decision-making process to understand the strengths and limitations of projects under a wide range of conditions and helps identify adaptation strategies for long-term success. The approach should be conducted at both project and basin scales to provide answers at the individual investment level and to assess potential investment alternatives - see for example its application to assess the proposed Upper Arun Hydropower Project in eastern Nepal and at the basin level to assess the overall hydropower portfolio in the Koshi basin (World Bank 2015j).
For the energy sector, ESMAP (2010) has designed the Hands-on Energy Adaptation Toolkit (HEAT) to guide energy sector decision makers through an assessment of climate vulnerabilities and adaptation options. Piloted in Albania and Uzbekistan to help these countries develop climate-resilient policies and projects, the toolkit can identify key direct risks to energy supply and demand, and options for adaptation to establish where to focus subsequent in-depth analyses. HEAT also identifies additional research needed to better understand the implications of extreme climatic events for the energy sector, as well as potential indirect impacts, such as possible adaptation actions in the agriculture sector that may affect energy supply.

A minimum-regret, worst-outcome avoidance approach is appropriate in situations where decision makers do not have a way of assessing the likelihood of different outcomes. This approach attempts to balance the risk of inaction with the risk of misguided action, taking into account different possible preferences of decision makers and attitudes toward risks. Cervigni et al. (2015) apply this approach to the issue of climate change and hydropower expansion plans for Africa’s main river basins (Volta, Niger, Nile, Zambezi, Senegal, and Congo). The conceptual framework used in this analysis consisted of two broad stages:

- **Impact analysis**: Assuming no adaptation, what is the range of impacts that will be caused by various climate futures? Under a drier climate, this would include lower hydropower output levels, and so costs through lower generation revenues. Under a wetter climate, it would include lower the possibility of generating more hydropower, and thus the potential for the opportunity cost of revenues foregone by not installing the extra hydropower capacity.

- **Adaptation analysis**: What is the cost of adapting investments to minimize these impacts across as many climate futures as possible (including the risk of overdimensioning projects and incurring excess capital costs and underdimensioning projects and incurring the opportunity cost of lost revenues)?

Cervigni et al. (2015) present a detailed discussion of the methodology and results, and Box 5 in section 4.5 summarizes the results for the Zambezi basin.
Chapter 3: Energy–Water–Climate Nexus Decision Tools

Decision tools that quantify integrated energy and water systems and climate change impacts are vital, as they equip national energy and water planners with hard evidence on the available synergies and trade-offs that are implicit to their investment decisions. To be practical, these tools need a high degree of temporal and spatial definition and need to be adapted to countries’ capacity limitations for data collection and processing (Cohen et al. 2014).

The concept of developing a systems analysis approach to analyze the interactions between the water and energy sectors is not new. The seminal Limits to Growth by Meadows et al. (1972) provided valuable insights to policy analysis and the WELMM (water, energy, land, materials, and manpower) concept (Grenon and Lapillonne 1976), which linked these systems to analyze energy service provision. However, this approach was not developed into a practical software application that could be used by national analysts.

Despite the early advances, practical integrated energy–water–climate planning tools are not generally available to today’s policy makers. These tools tend to focus on just one resource, have oversimplified spatial representations, and tend not to be short-term applied policy decision-support models and instead analyze impractically long-term scenarios (Miralles-Wilhelm 2016). As a result, the standard approach to modeling energy and water demand systems reflects the fragmented sectoral approach that is generally applied to water and energy decision making (Bazilian et al. 2011). For example, while climate change impacts are often incorporated into water models, few climate studies integrate hydrologic phenomena with electricity sector models (Cohen et al. 2014), and studies analyzing the energy–water nexus tend to use decoupled electricity and water models where water impacts are analyzed off the back of the electricity model results (for example, Chandel, Pratson, and Jackson 2011).

For developed countries, recent work by the National Renewable Energy Laboratory has been addressing this gap for energy planning in the United States, by expanding its Regional Energy Deployment System model to include the cooling-water demands of thermal power plants and water availability, and integrating the impacts of climate change on water availability (Cohen et al. 2014). However, there is a need to develop capacity in this area to provide practical integrated modeling tools that can help bring the nexus agenda into international development investment decisions (Miralles-Wilhelm 2016).

3.1 Current Integrated Modeling Tools for Developing Countries

While several tools have been developed to model specific issues related to the energy–water nexus in developing countries, both the modeling and the framework have been developed by the authors and are specific to the particular case study. As a result, opportunities for methodological transfer can be limited.

Several accessible planning tools are available to policy makers, including the MESSAGE, MARKAL (Market Allocation), and LEAP models for energy system analysis and the WEAP,
REsSIM, MIKE HYDRO Basin, SWAT, and PODIUM/PODIUMSim models for water (and PODIUM/PODIUMSim for food and SWAT for land) systems analysis. The choice of modeling tool, particularly for water resources, is somewhat complicated by the lack of an emerging standard, and there are probably more than a thousand such tools. A common way of classifying water resource models is by reference to their spatial scale and the amount of physical detail required to run the model (see Figure 9 for an illustration of this for some of the models mentioned above). These characteristics in turn determine, for example, the model’s user friendliness, accuracy, required expertise, and data needs (see Droogers and Immerzeel 2006 for further discussion on water resource modeling tools).

Figure 9: Character of Water Resource Modeling Tools

![Character of Water Resource Modeling Tools](source: Droogers and Immerzeel 2006.)

Work is now underway to develop some of these tools into general, accessible, integrated energy–water tools, including the WEAP-LEAP and MARKAL-Water models, briefly described below. See Annex 3 of Rodriguez et al. 2013 for a more in-depth treatment of these and other models, as well as a review of energy modeling tools.

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7 REsSIM was developed by the U.S. Army Corps of Engineers Institute for Water Resources, Hydrologic Engineering Center. It is used to model reservoir operations at one or more reservoirs for a variety of operational goals and constraints. See [http://www.hec.usace.army.mil/software/hec-ressim/](http://www.hec.usace.army.mil/software/hec-ressim/) for more details.

8 MIKE HYDRO Basin was developed by the DHI group. It is a multipurpose, map-based, decision-support tool for integrated water resource analysis, planning, and management of river basins. The tool is designed for analyzing water-sharing issues at international, national, and local river basin scales. See [https://www.mikepoweredbydhi.com/products/mike-hydro-basin](https://www.mikepoweredbydhi.com/products/mike-hydro-basin) for further details.

9 SWAT—the Soil and Water Assessment Tool—was developed by the Texas Water Resources Institute. See [http://swat.tamu.edu/documentation/](http://swat.tamu.edu/documentation/) for further details.

10 PODIUM/PODIUMSim was developed by the International Water Management Institute to develop scenarios of water and food supply at river basin, sub national and national level. See [http://www.iwmi.cgiar.org/resources/models-and-software/podiumsim/](http://www.iwmi.cgiar.org/resources/models-and-software/podiumsim/) for further details.
Developed by SEI, the WEAP (Water Evaluation and Planning) system and LEAP (Long-range Energy Alternatives Planning) system are intended as policy planning tools and can be adapted to allow policy makers operating in a capacity-constrained environment to explore the impact of changing policy, investment costs, and demand levels through an (unlimited) set of scenarios. Both of these widely used tools can also be used to model the impacts of climate change on energy and water planning by inputting the results of climate change forecasts. For example, the WEAP system can predict impacts on river basins and national supply by inputting climate change forecasts (see, for example, the World Bank’s (2015c) work in Lesotho and Box 4 later in this report). Similarly, the LEAP system can track GHG emissions and be used to analyze climate change mitigation policies (see, for example, the Climate & Clean Air Coalition’s Supporting National Planning initiative, which applies LEAP to the issue of short-lived climate pollutants).\textsuperscript{11} WEAP and LEAP can be linked together to provide a consideration of the nexus trade-offs (SEI 2012) (see the discussion below on modeling applications of the CLEWs framework).

A MARKAL-Water tool is also being developed to produce a user-friendly integrated decision-support tool. This has so far been developed by the Brookhaven National Laboratory (BNL) as a pilot study to demonstrate the viability of integrated resource modeling for New York City and has yet to be developed into a general-use model. The TIMES/MARKAL-SATIM was the basis for the Thirsty Energy energy–water integrated model that is currently being developed for South Africa (see discussion below).

### Applications of Integrated Modeling Tools to the Energy–Water Nexus

Collaborative work by the International Atomic Energy Agency (IAEA), SEI, FAO, International Institute for Applied Systems Analysis (IIASA), International Renewable Energy Agency (IRENA), United Nations Department of Economic and Social Affairs (UNDESA), and BNL has produced the CLEWs framework. CLEWs is an example of a standard nexus framework that can be adapted to quantitatively evaluate policy decision trade-offs; policy assessments (enabling policies that address multiple objectives to be analyzed); policy harmonization and integration (by analyzing policy conflicts, such as electricity use and aquifer depletion); technology comparisons; and scenario development (enabling identification and analysis of future development opportunities and their implications) (Bazilian et al. 2011). Unlike the SEI/Hoff (2011) and World Energy Forum (WEF 2011b) frameworks presented above in section 2.1, CLEWs focuses on both identifying and quantifying the interactions between the nexus dimensions. This quantification can be performed by soft-linking sector- or resource-modeling tools. Any resource- or sector-modeling tool can be used to perform this quantification, provided they can be interlinked.

To date, significant applications of the CLEWS framework (which incorporate land resources in the analysis, and so represent a wider nexus analysis) include an application of the CLEWs

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\textsuperscript{11} Led by SEI, the Institute for Governance and Sustainable Development, the International Union of Air Pollution Prevention and Environmental Protection Associations, Mexico, and the Kingdom of Morocco (http://www.ccacoalition.org/fr/initiatives/snap).
framework at a national level to energy policy in Mauritius, and also the application of the framework at a global scale to support the UN’s Sustainable Development Goals (SDGs).12

An alternative approach to developing an integrated modeling tool is being undertaken by the World Bank’s Thirsty Energy Initiative. In this case, South Africa’s public domain energy model—the TIMES/MARKAL-SATIM tool—is being developed to produce an integrated energy–water–climate change modeling tool for South Africa (World Bank 2015b). This tool is also presented below.

Also relevant to the discussion of integrated modeling, but not discussed below, is IISD’s ANEMI model (Simonović 2012), which aims to operationalize the broader climate–land–energy–water nexus framework (incorporating the biosphere–climate system—climate, carbon cycle, land use, population, surface water flow, water use, water quality, and the economy). This model requires more than 600 state variables (NERC 2012), making it generally unsuitable for policy makers in countries with data limitations.

**Applying the CLEWs framework to energy policy in Mauritius**

The CLEWs framework was developed for Mauritius by integrating the LEAP (energy),13 WEAP (water),14 agroecological zoning (AEZ—land), and general circulation model (GCM—climate) models to produce results on GHG emissions and energy, water, and coal balances (Figure 10).

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12 For further applications of the CLEWs framework, see also Hermann et al. (2012), who apply the framework to understand agricultural intensification and bioenergy production in Burkina Faso.
13 The long-range energy alternatives planning system is maintained and supported by SEI. No charge is made for its use by not-for-profit, academic, and governmental organizations based in developing countries.
14 The water evaluation and planning system is maintained and supported by SEI. No charge is made for its use by not-for-profit, academic, and governmental organizations based in developing countries.
Figure 10: The CLEWS Framework Is Founded upon the LEAP, WEAP, AEZ, and GCM Models


A case study approach was used to develop the model, looking at the potential impacts of substituting imported gasoline with domestic ethanol produced from sugarcane for the island of Mauritius. The modeling parameters and data inputs were developed by analyzing the key climate, land, energy, and water system interactions for ethanol production (Figure 11).
Figure 11: Simplified CLEWS Representation of Ethanol Production

Source: IAEA 2009.
**Results and next steps**

The outcomes of this modeling exercise go beyond simply demonstrating the benefits of developing such a policy (under various assumptions) to substitute imported gasoline with domestic ethanol. Not only does this illustrate the advantages of an integrated systems approach to identify benefits and costs that could not be identified through isolated single resource analysis, but it also demonstrates a CLEWs resource assessment approach through the linking of existing single-resource modeling tools.

Looking forward, practical challenges concern adapting the modeling to data type and availability and the time frames imposed by policy decisions (which may be considerably shorter than the time required in practice to develop the tool and carry out the necessary checks on its results) (Howells et al. 2013).

**A Global CLEWs model**

The global CLEWs model was developed from the CLEWs framework by KTH in cooperation with the UN’s Division for Sustainable Development to inform Rio+20 discussions (KTH/UNDESA 2016). The model is now being developed into a tool to inform policy makers on the linkages (synergies and trade-offs) between climate, land, materials, energy, and water, and is intended to help make progress toward the UN’s SDGs. The current version enables policy makers to explore the impact of imposing fossil fuel limits or a carbon tax on water consumption and materials and energy generation investment on a global scale.

Figure 12 illustrates how the model is structured. It depicts the extraction, use, and transformation of primary energy into secondary energy carriers and resources and the use of primary and secondary energy to produce food, materials, and water services. The figure also incorporates the emissions that are produced from the use of carbon fuels by the energy, land, and food sectors and water use.

**Figure 12: The KTH/UN Department of Economic and Social Affairs Global CLEWS Model**

![Diagram of the KTH/UN Department of Economic and Social Affairs Global CLEWS Model](source: KTH/UNDESA 2016)

Going forward, the model is being developed to enable further policies to be analyzed that are linked to achieving the SDGs.
**SATIM-W model (World Bank Thirsty Energy Initiative)**

Current research by the World Bank (2015b) through its Thirsty Energy Initiative is addressing the need to develop an integrated model for South Africa, but is using an approach different from the CLEW's approach.

In this case, a pragmatic decision-making tool is being created based on the South African TIMES model (SATIM)—a public domain energy model developed by the University of Cape Town. The TIMES model combines engineering and economic data to solve least-cost energy optimization problems. The three main supply-side input components are technologies (covering the full energy supply chain from mining technologies through energy conversion technologies to final use technologies), commodities (these are either produced or consumed by a technology), and commodity flows (Figure 13). The water sector is currently represented by aggregate data on power plant water intensity. The model can be run under different policy scenarios—for example, specifying a minimum share of renewable energy generation.

![Figure 13: Simplified Representation of the Power Sector in SATIM](source: World Bank 2015b.)

In their current form, neither the TIMES model nor the South African SATIM model recognizes the energy–water nexus. The Thirsty Energy Initiative is seeking to address this by extending the water demand-side consideration of the model and by constructing marginal water supply cost functions to produce a “water-smart” SATIM model (SATIM-W).

**Integrating water demand and supply**

The SATIM-W model extends data on water demand beyond power plant water intensity to include broader water use data—for example, water use during fuel extraction, processing, plant cleaning, and end-of-pipe technologies to reduce emissions, as well as any treatment required before returning water to its original source (Figure 14).

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15 The TIMES model generator was developed by IEA’s Energy Technology Systems Analysis Program.
SATIM-W also adds marginal water supply costs (MWSCs) by considering different technological options for meeting regional increases in water demand (for example, dam construction and water transfer projects). These take into account regional differences in both the supply cost and the quality of water available. The full specification of the MWSC function is shown below:

\[
MWSC = WRMC + WSSIC + WDMC + WSDC + WSEC + PWTC + SWTC
\]

- **WRMC**—water resource management charges
- **WSSIC**—water supply scheme infrastructure costs (the full project implementation costs associated, for example, with a dam construction project)
- **WDMC**—waste discharge mitigation charge (associated with discharging water containing waste into a water resource or onto land)
- **WSDC**—water supply delivery costs (capital and operation and maintenance costs of water transportation)
- **WSEC**—water supply energy costs
- **PWTC** and **SWTC**—primary and secondary water treatment costs (to achieve a basic water quality standard (primary) and to reduce the salinity of a portion of the source water (secondary))


**Modeling climate change impacts**

SATIM-W addresses climate change impacts and the uncertainty associated with them through scenario analysis. The model can explore the impact of climate change on the overall cost of meeting future energy demands by adjusting a number of variables. From an environmental perspective, the model can specify lower water supply levels and higher nonenergy water demands. It can also reflect climate change policy response by specifying technological requirements, such as retrofitting coal power plants with wet flue-gas desulphurization.
technology, producing energy from shale gas fracking, and setting limits to overall cumulative energy sector carbon emissions.

**Results and next steps**

Initial (unpublished) results from the SATIM-W model provide further practical evidence of the benefits of integrated modeling as a tool for making energy policy decisions. The model’s great benefit is its ability to represent the water needs of the energy sector by region and to understand which water infrastructure will be needed for the energy sector when and where. This capability is particularly crucial for a country such as South Africa, where all water resources are fully allocated, so any additional water requirements will need to be integrated in long-term planning decisions.

In terms of specific results for South Africa, the draft results of the modeling exercise show that overall, South Africa’s water resources seem to be quite resilient to climate change impacts, and that water for power is supported by major interbasin transfers, with energy consuming 40 percent of all water in the Waterberg region. The results also provide “further economic justification” (World Bank 2015b) for Eskom’s investment in dry cooling (whereas conventional energy modeling—not taking into account water costs—would opt for wet cooling in new coal-fired builds and a 60 percent increase in water consumption for power generation). Regarding climate change, the integration of climate change scenarios shows that, contrary to expectations, expanding CSP in the arid region served by the Orange River system is not constrained by water supply, and overall, climate change is shown to bring forward investment in renewable technologies. The draft results also present the results of a series of scenario analyses, such as carbon dioxide cap scenarios that affect the cost of water supply differently in each regional water basin and show the potential to lead to stranded coal assets and increased use of renewables.

This exercise is seen as work in progress toward developing a fully integrated modeling tool for South Africa. To produce the model, the World Bank has been working with the University of Cape Town’s Energy Research Center. Potential future developments include harmonizing the assumptions about energy and water growth, disaggregating nonenergy water consumption in the model to examine water reallocation schemes and the impact of water efficiency measures, and incorporating power production. Ultimately, similar projects may be conducted in Morocco and China. (See World Bank (2015b) for further details.)

**A Nexus Planning Research Agenda**

The importance of integrated modeling tools as a way of incorporating nexus synergies and trade-offs into investment decisions makes this an important area for continued development. Miralles-Wilhelm (2016) proposes a collaborative international research agenda to support food–energy–water nexus planning. The agenda is aimed at bringing together the expertise from a wide range of nexus research agendas (including that of U.S. institutions, such as the National Science Foundation, U.S. Department of Energy, U.S. Department of Agriculture, National Oceanic and Atmospheric Administration, and Environmental Protection Agency, and that of international development organizations, such as the World Bank, U.S. Agency for International Development, and regional development banks) to ultimately produce an interactive modeling system “…to explore trade-offs, explore potential synergies, and evaluate alternatives among a broad list of food/energy/water options and objectives” that is “flexible
in order to facilitate tailored analyses over different geographical regions and scales (e.g., national, state, county, watershed, interconnected regions)” (Miralles-Wilhelm 2016).

The research agenda identifies a wide range of research topics that would support the development of an integrated model. These include a study and modeling of water systems to quantify water allocation; an analysis of future water demand, the impact of climate change on water availability and energy demand, and the costs and benefits of different solutions and synergies; and a review of integrated system modeling hubs for nexus analysis.16

16 There is on-going work at the World Bank on the power and agriculture integration in sub-Saharan Africa (Banerjee et al., 2016). The study focusses on the synergies between rural electrification and agricultural electricity demand. The findings from the study show that the main source of demand for electricity from agriculture in 2030 will be from irrigation.
SECTION B: FOCUS ON SOUTHERN AFRICA

Chapter 4: The Southern African Landscape

For the purposes of this study, the Southern African region can be considered to comprise the 15 member states that are a part of SADC.\(^{17}\) As well as a broad consideration of the region, the scope for this work sets out the following as focus countries:\(^{18}\)

- South Africa
- Lesotho
- Botswana
- Swaziland
- Namibia

The SADC region covers an area of 555,000 square kilometers (km\(^2\)) and is inhabited by a population of approximately 277 million (SADC n.d.). Southern Africa is characterized by an uneven distribution of economic well-being, water resources, energy production capacity, and potential climate change impacts. This unevenness gives rise to geographic areas of resource stress and resource abundance, making the nexus particularly relevant to decision making. The Southern African economy grew by 5.1 percent in 2011, and its population grew by 28 percent over the period 2001–11 (SADC n.d.).

4.1 Regional Distribution of Economic Well-being

There are vast differences in the levels of well-being of economies in the region. In 2013, Mauritius, Botswana, and South Africa had the highest per capita gross domestic product (GDP) in the region, whereas Malawi and the Democratic Republic of Congo (DRC) were at far lower levels of economic well-being (Figure 15). For example, in 2013 the per capita GDP of Botswana ($7,300) was 16 times that of DRC ($450) and more than 30 times that of Malawi ($220).\(^{19}\)

These differences in economic well-being are also affected by the uneven distribution of population. In 2011, 60 percent of the population in the region resided in just three countries—DRC, South Africa, and Tanzania. South Africa accounted for 18 percent of the population and 63 percent of the total regional GDP. In contrast, DRC accounted for 27 percent of the population and 2.5 percent of the regional GDP. As the largest overall economy in the region, South Africa also accounted for 49 percent of the exports and 50 percent of the imports of goods and services in 2011.\(^{20}\) The debt-to-GDP ratio, which is indicative of the sustainability of government finances, reduced significantly for many countries over the period 2001–11, so that all countries had a ratio below 50 percent in 2011, except Zimbabwe, with 142 percent.

\(^{17}\) Angola, Botswana, DRC, Lesotho, Malawi, Mauritius, Mozambique, Madagascar, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe.

\(^{18}\) This initial phase of countries is the set of countries that were under one World Bank Country Management Unit at the time that the study was conceived. Future phases may focus on further countries.

\(^{19}\) All currency is in U.S. dollars unless otherwise specified.

\(^{20}\) Angola is second.
The uneven distribution of economic well-being creates uneven demand pressures on raw materials and natural resources. As a result, demand for water and energy resources is generally concentrated in the southern parts of the region. In contrast, the northern parts of the region (for example, the Congo and Zambezi river basins) are endowed with the abundant water resources that could sustainably deliver these inputs.

4.2 Distribution of Water Resources

The geography of Southern Africa imposes specific characteristics on the nature of the nexus between the water and energy sectors.

Figure 16 illustrates the uneven distribution of hydrological resources across the region. The southern countries in the region—such as South Africa, Botswana, and Namibia—receive much lower levels of rainfall than the northern countries—such as DRC, Angola, Zambia, and Mozambique. Differences in rainfall across the region range from as great as 2,000 millimeters (mm) per year in some areas to less than 100 mm per year in others (CRIDF/DfID 2014b).

The areas receiving greater rainfall also benefit from the endowment of large river basins draining the region and providing large amounts of freshwater and hydropower potential.

### 4.3 Southern Africa’s River Basins

More than 70 percent of the SADC region’s freshwater resources is shared between two or more member states. Figure 17 shows the recognized major transboundary river basins in the SADC region (also listed in Table 2).
Figure 17: Southern Africa’s River Basins

Table 2: Southern Africa’s River Basins

<table>
<thead>
<tr>
<th>River Basin</th>
<th>Riparian Countries</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congo</td>
<td>Democratic Republic of Congo, Central African Republic, Angola, Republic of Congo, Zambia, Tanzania, Cameroon, Burundi, Rwanda, Gabon, Malawi</td>
<td>3,800,100</td>
</tr>
<tr>
<td>Zambezi</td>
<td>Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, Zimbabwe</td>
<td>1,570,000</td>
</tr>
<tr>
<td>Orange-Senqu</td>
<td>Botswana, Lesotho, Namibia, South Africa</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Limpopo</td>
<td>Botswana, Mozambique, South Africa, Zimbabwe</td>
<td>408,000</td>
</tr>
<tr>
<td>Okavango</td>
<td>Angola, Botswana, Namibia, Zimbabwe</td>
<td>323,192</td>
</tr>
<tr>
<td>Cuvelai</td>
<td>Angola, Namibia</td>
<td>167,000</td>
</tr>
<tr>
<td>Ruvuma</td>
<td>Malawi, Mozambique, Tanzania</td>
<td>152,000</td>
</tr>
<tr>
<td>Save/Sabi</td>
<td>Mozambique, Zimbabwe</td>
<td>115,700</td>
</tr>
<tr>
<td>Kunene</td>
<td>Angola, Namibia</td>
<td>106,560</td>
</tr>
<tr>
<td>Incomati</td>
<td>Mozambique, South Africa, Swaziland</td>
<td>46,740</td>
</tr>
<tr>
<td>Pungwe</td>
<td>Mozambique, Zimbabwe</td>
<td>31,000</td>
</tr>
<tr>
<td>Maputo-Usutu-Pongola</td>
<td>Mozambique, South Africa, Swaziland</td>
<td>29,970</td>
</tr>
<tr>
<td>Buzi</td>
<td>Mozambique, Zimbabwe</td>
<td>27,000</td>
</tr>
<tr>
<td>Umbeluzi</td>
<td>Mozambique, South Africa, Swaziland</td>
<td>10,900</td>
</tr>
</tbody>
</table>

Three of the river basins in Figure 17 and Table 2—Orange, Limpopo, and Incomati—can be considered pivotal because water resources have been nearly or fully allocated, leading them to be considered “closed.” Riparian states with a level of economic development (Namibia, Botswana, South Africa, and Zimbabwe) are highly dependent on these basins.

The three largest river basins—Congo, Zambezi, and Orange–Senqu—are particularly relevant to this study because of their potential to generate significant regional benefits through water transfer and hydropower generation.

**The Congo River Basin**

The Congo River Basin is the largest of SADC’s recognized transboundary basins, covering an area of 3.7 million km² (around 12 percent of the continent) and spanning nine political boundaries (Angola, Burundi, Central African Republic, DRC, Cameroon, Republic of Congo, Rwanda, Tanzania, and Zambia) (World Bank 2014a). Inga Falls, on the Congo River, houses two hydropower generation plants that were commissioned more than 30 years ago, with combined installed capacity of 1,775 megawatts (MW), and has significant untapped power generation potential that is being targeted by the Grand Inga project—a scheme that could produce as much as 40,000 MW (more than a third of the total electricity currently being produced in Africa and an amount equivalent to the total installed generating capacity of Sub-Saharan Africa, excluding South Africa). (See the discussion later in this report and also Taliotis et al. (2014).)

**The Zambezi River Basin**

The Zambezi River Basin (ZRB) is the second-largest river basin in the region, and is one of the most diverse and valuable natural resources in Africa (World Bank 2010b). In addition to meeting the basic needs of some 30 million people and sustaining a rich and diverse natural environment, the river plays a central role in the economics of the eight riparian countries in Southern Africa—Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe. The ZRB covers 1.37 million km². Its source is in Zambia, which is 1,450 meters above sea level. The main stem then flows southwest into Angola, south into Zambia again, through Namibia and northern Botswana, then through the Victoria Falls shared by both Zambia and Zimbabwe, before massing in Lake Kariba. The Kariba Dam was built here in 1958. After being joined by the Kafue River, the Zambezi pools behind Cahora Bassa Dam (built in 1974) in northwestern Mozambique. It is then joined by the Shire River flowing from Malawi, and finally flows down into the Indian Ocean. As can be seen in Figure 18, the hydrology of the ZRB varies, with generally high rainfall in the north (up to 1,400 mm/year) and lower rainfall in the south (as little as 500 mm/year) (World Bank 2010b).

Figure 18 presents information on the ZRB’s current and projected hydropower capacity and irrigation opportunities. Of the approximately 33,000 gigawatt-hours (GWh) of hydropower produced per year in the ZRB, 5 percent is in Malawi, 45 percent is in Mozambique, 36 percent is in Zambia, and 14 percent is in Zimbabwe. The Kariba and Cahora Bassa dams dominate. Other hydropower plants include the Upper Kafue (including Itezhi-Tezhi) and the Nkula, Tedzani, and Kapichira plants on the Shire River in Malawi.

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Figure 18: Details of the Zambezi River Basin

The Orange–Senqu River Basin

The third-largest river basin in the region, the Orange–Senqu, spans a total area of 1 million km² and is shared by the riparian states of Namibia, Botswana, South Africa, and Lesotho. The Orange-Senqu is considered a pivotal basin for the region, as almost all of its resources have been allocated to productive uses and it is depended upon by the pivotal (high-growth) riparian states of Namibia, Botswana, and South Africa for a significant proportion of their economic activity. Therefore, water quality is an issue for the basin (as it is for all basins whose resources are fully, or close to being fully, allocated).

Lesotho is the upper riparian state and relies heavily on the basin for its income through the Lesotho Highlands Water Project (LHWP), which transfers water to the Gauteng region of South Africa. As a result, South Africa’s economy depends on interbasin water transfers from this basin. Namibia is a downstream riparian state with a high reliance on the Orange River for its economic activity. Although Botswana neither contributes to the LHWP’s streamflow nor uses its surface water, the country’s legal status is allowing it to consider a future water supply from the LHWP. (See Turton 2010 for further details.)

Six strategic issues face the river basin (Turton 2010):

• High economic reliance on the basin by South Africa and Namibia
• Water allocation away from agriculture to industry and services
• Deteriorating water quality owing to the basin being closed and suffering from effluent flows and acid mining drainage
• Balancing resource protection with resource use
• Interbasin transfers
• The location of the river relative to the border between Namibia and South Africa

4.4 Distribution of Energy Resources

Electricity generation capacity and demand for electricity are unevenly distributed across the region. Most of the region’s generating plants are located in the eastern and northeastern areas of South Africa (where coal resources are plentiful), and most of the region’s hydropower potential is located to the north of Southern Africa. Demand for electricity in the region is mostly from the major cities and industries of South Africa, which are around Johannesburg and Gauteng in the northeast, but also around the major cities along the coast. Figure 19 illustrates the spatial distribution of electricity generation capacity in the region. Historically, South Africa’s generation capacity has met significant proportions of neighboring countries’ peak demand.
Figure 19: Distribution of Electricity Generation Infrastructure across Southern Africa

[Map of Southern Africa showing distribution of energy resources and electricity generation infrastructure.]
Generation investment needs are expected to grow rapidly in the region, and significant long-term infrastructure investment will take place in the coming years. SADC forecasts that peak loads will be 77 gigawatts (GW) by 2020 and 115 GW by 2030, compared with total installed capacity of 57.1 GW in January 2013 (SADC 2012a). Figure 20 illustrates the electricity supply and peak demand situation for the region as of May 2015. As of the end of 2015, the SAPP reports that the region had a total installed capacity of 61,859 MW and an operating capacity of 46,910 MW to meet a normal peak demand of 48,216 MW. In practice, the regional capacity gap is significantly greater: 8,247 MW when taking into account normal generating capacity reserve margins, and 16,536 MW when also taking into account estimated suppressed demand (SAPP 2015).

While coal is currently the source of most generation capacity in the region, and further coal-fired generation capacity is under construction (two giant coal-fired generation plants in South Africa—Medupi and Kusile—will each have a generating capacity of 4,800 MW), the expectation for the region as a whole is for greater diversification. In addition to development of hydropower (potential generating capacity at the Inga site in DRC is estimated at 40,000 MW and on the Zambezi in Mozambique at 18,000 MW), there have been significant findings of gas off the coasts of Mozambique and Tanzania. While nearshore gas from both countries has been available for some time—Mozambique’s Pande and Temane nearshore fields, which have been supplying the region since 2004, have reserves (3P22) of 3.5 trillion cubic feet (tcf)—the major resources are expected to take some time to develop. In 2010, gas discoveries in the Rovuma gas field off the northern coast of Mozambique put reserves (3P) at 128 tcf. Further renewable energy, such as solar and to a lesser extent wind, is expected to make up a small but steadily growing source of electricity in the region.

Different forms of electricity generation in the region (thermal, hydropower, and CSP) will have different water requirements. Within given technologies, water use will also vary by type of plant and type of thermal cooling technology. For hydropower, water storage and use will be very specific to the river in question, the design of the plant, and the profile for water discharge followed by the operators of the plant.23 Rules of thumb are that CSP technologies need to withdraw as much as 3,500 liters per megawatt-hour (MWh) generated, compared with 2,000 liters/MWh for new coal-fired power plants and 1,000 liters/MWh for more efficient natural gas combined-cycle power plants.

Figure 20 shows the region’s existing and planned power transmission lines. Of the SADC countries, only Angola, Malawi, and Tanzania are not interconnected.

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22 The total amount of reserves that a company estimates having access to, calculated as the sum of all proved and unproved reserves. Unproved reserves are broken into two segments: those based on geological and engineering estimates from proved sources (probable) and those that are less likely to be extracted due to financial or technical difficulties (possible). Therefore, 3P refers to proved plus probable plus possible reserves.

23 The region’s investment program in hydropower generation alone amounts to $17.8 billion during 2011–20 and $50.2 billion during 2020–30.
Figure 20: Regional Power Transmission Interconnectors (Existing and Planned)

Source: SAPP 2015.
4.5 Impact of Climate Change on the Region

Climate change is expected to have a significant impact on the region in terms of both higher temperatures and increasingly unpredictable rainfall patterns (Bates et al. 2008). By the end of the 21st century, the Intergovernmental Panel on Climate Change’s (IPPC’s) high emissions scenario suggests summer temperatures are likely to increase by 3.1 degrees centigrade (ºC) and by 3.4–4.2 ºC with rapid warming in semi-arid southwestern parts of Southern Africa—northwestern South Africa, Botswana, and Namibia (CDKN 2014). This warming will increase rainfall intensities, decrease frequencies of low-intensity rainfall, and cause longer dry periods between events (Prasad 2012). As a result, it is widely agreed that climate change will exacerbate water scarcity in Southern Africa. By 2025, annual water availability in South Africa is predicted to be less than 1,000 cubic meters (m³) per person, and less than 1,700 m³/person in Lesotho, Zimbabwe, and Mozambique (Bates et al. 2008). Furthermore, climate change is likely to increase water demand, which is forecast to increase, for example, by 0.6 percent per year in the Cape metropolitan region of South Africa (New 2002).

These predictions mask a layer of considerable complexity in understanding the impacts of climate change. In practice, there is little consensus among various climate change forecasting models. For example, the GCM datasets that were examined to predict Lesotho’s climate for the period 2030–50 (World Bank 2015c and Box 4) projected air temperature increases of 0.8–2.9 ºC and had little consensus on future precipitation, with results ranging from increases and decreases of 160 mm (20 percent) (see Figure 21). There is also significant spatial variation (as shown in Figure 16) and intertemporal variation (Lesotho’s rainfall averages 12 mm in June and 120 mm in January24 (World Bank 2015c), both of which need to be taken into account by climate forecasts.

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These impacts and their unpredictability pose significant challenges for and risks to regional energy and water planning (IEA 2007), particularly given the region’s current water scarcity, reliance on hydropower (World Bank 2015a), transmission limitations, and predicted growth in demand. Regarding demand, electricity generation is projected to be seven times higher in 40 years than it is today (IEA 2012), and water demand is projected to triple (World Energy Council 2010).

Southern Africa’s climate vulnerability is well illustrated by the current drought being experienced in some parts of the region as a result of El Niño (Box 3).
Box 3: The impact of El Niño on Kariba Dam Hydropower Output in 2015–16

The Kariba Dam is situated on the Zambezi River and straddles the border between Zambia and Zimbabwe. It is the largest constructed reservoir in the world, by water storage capacity, and has been a key source of regional energy security since its commissioning in 1960. The Kariba Reservoir supplies water to two underground hydropower stations, with a total capacity of 1,830 MW generating more than 10,035 GWh of electricity annually.

Power output potential at Kariba is directly related to the overall reservoir water level, which is a function of Zambezi River inflow. Lower than expected rainfall levels in late 2014/early 2015, as a result of El Niño, led to the reservoir being reported at just 11 percent full on January 27, 2016 (compared with being more than 50 percent full at the same time the previous year). As a result, potential annual power generation has been reduced by more than 50 percent to 4,060 GWh (see graph below), strongly highlighting the need for regional investment in climate-resilient projects.

![Figure 22: Impact of Climate Change on Kariba Dam Hydropower Generation in 2015](image)

**Source:** World Bank 2015i; SADC 2016.

The need for increased institutional capacity to develop an informed climate strategy poses a significant challenge for these countries. Adapting the available practical and flexible modeling tools, such as the LEAP, WEAP, MARKAL, Energy Flow Optimisation, and Aquarius²⁵ models and the Soil and Water Assessment Tool,²⁶ can help Southern African countries understand the potential impacts of climate change on future energy and water supply and demand.²⁷ Based on this information, these countries can start to develop a range of policy solutions to address these impacts and test them for their robustness against the range of potential climate-related outcomes. This approach was adopted by the World Bank to help Lesotho both assess the vulnerability of its water management systems to climate change and start to address its lack of climate strategy (Box 4).

²⁷ See also Bhattacharyya and Timilsina (2010) for a review of energy system models for developing countries.
The World Bank’s Lesotho Water Security and Climate Change Assessment project is the first systematic analysis of the vulnerabilities of Lesotho’s water management system to climate change. The project has developed a Lesotho WEAP model to explore how a set of potential climate adaptation strategies will perform under varying future climate and economic conditions.

To obtain the data required for the modeling and to construct a series of adaptation strategies, the project conducted an iterative information-gathering process with government stakeholders to understand such issues as rainfall and runoff routines, historical streamflow rates, current and planned water management infrastructure, climate change forecasts, domestic and industrial water demand, agricultural production, changes in water transfer opportunities, potential adaptation strategies (including new infrastructure, such as the Lowlands Bulk Water Supply Scheme and future phases of the LHWP), and the key management metrics for water supply to evaluate the performance of these strategies.

To understand the potential vulnerabilities of water management systems, the project used historical and forecast climate data to generate a large number of scenario outcomes, and analyzed and interpreted the results within a robust decision-making framework that assessed which of Lesotho’s proposed water management strategies demonstrate a positive performance over a broad range of circumstances.

The modeling identified key vulnerabilities within the system, including water supply for domestic and industrial purposes, irrigation, and water transfers to South Africa. It found that delays in implementing the water transfer and hydropower components of the LHWP could undermine water security in South Africa and economic growth in Lesotho. The modeling also identified adaptation strategies, such as building the proposed Polihali Dam and other infrastructure for the LHWP, increasing system reliability, eliminating the risk of a water deficit in all but the driest of futures, and boosting the economy.


Another study by the World Bank (Cervigni et al. 2015), which modeled the impact of climate change on the performance of the region’s hydropower capacity in the Congo and Zambezi river basins, found potentially large impacts of climate change on infrastructure in the region (Box 5).
Box 5: The Impacts of Climate Change on Hydropower Assets in the Zambezi River Basin

A study by Cervigni et al. (2015) used IPCC climate change predictions to forecast changes in the physical performance of hydropower in the Congo and Zambezi river basins. The study found that, in the driest scenarios, failure to integrate climate change in the planning and design of power and water infrastructure could entail significant losses of hydropower revenues and increases in consumer expenditures for energy. For the period 2015–50, for the Congo River Basin, these forecasts could imply a $16.6 billion loss or $0.9 billion gain, while for the ZRB, they could imply a $42.1 billion loss or $15.4 billion gain.

Focusing on the ZRB results, the study found that the effects of climate change on river flow and evaporation rates could have a significant impact on future hydropower output. The worst-case scenario could see a loss of baseline revenues of up to 18 percent, while the best-case scenario could see gains of 6 percent (+$15.4 billion) on baseline revenues. However, the best-case scenario is unlikely to be fully realizable with current power-trading agreements and transmission infrastructure.

Given the impossibility of predicting actual climate outcomes, the study advocates investment in “worst-outcome avoidance” through changes in generation capacity and water-use efficiencies. Practically, this could involve a mix of responses across the two basins, including investing in additional generation capacity, increasing water-use efficiency, and downsizing facilities to avoid underutilization in dry climates. For the ZRB, avoiding the worst-case outcome could reduce baseline revenue losses from 18 percent to 10 percent.

The need for integrated nexus planning for future investment is particularly relevant in the Southern Africa region. Prasad (2012) concludes that there is a strong need for integrated water–energy planning in the context of climate change, including detailed regional modeling for defined regions in Southern Africa. Current research by the World Bank’s (2015b) Thirsty Energy Initiative is responding to this need by developing the first energy–water–climate change nexus modeling tool for the region using South Africa as a case study (see Section 3.1.)

As well as the information challenges, implementing climate-resilient infrastructure projects can be challenging because of their size and long delivery time scales (often spanning more than one political cycle), generating a need to de-politicize approval, planning, and financial models as far as possible (SADC 2016).

4.6 Water and Energy Resource Planning at the National Level

The region’s water and energy resources, and the institutions that manage them, exhibit significant spatial variation. This section looks at the study’s five focus countries (Botswana, Lesotho, Namibia, South Africa, and Swaziland) and sets out a national analysis of their water and energy resources, a commentary on each country’s planning priorities, and also evidence of a recognition of the link between water and energy in the respective national planning documents and their implementation. The information is summarized in a series of four tables for ease of reference.
These tables provide a comparative summary of the following issues for each of the study’s focus countries:

- Table 3 provides an overview of national water resources;
- Table 4 summarizes national water resource knowledge and planning priorities;
- Table 5 summarizes evidence of national cross-sector planning by the water sector; and
- Table 6 provides an overview of national energy sector priorities and evidence of cross-sector planning in the study’s focus countries.

For further detail, a more in-depth treatment for each country is provided in Annex 2.

Each country faces a different set of challenges with respect to its water and energy resources. These challenges are driven by past levels of investment in water supply and electricity, current national natural resource endowments and how these are affected by climate change, anticipated levels of demand for water and electricity, and the current economic situation. These challenges lay down the national priorities for water and energy policy, which are reflected in national legislation and planning.

For planning processes to be efficient, there needs to be cross-sector coordination, and in particular, the (social and economic) value of water needs to be accounted for. While pronouncements suggest that most SADC countries recognize the importance of water as a driver of economic and social development, and are ready at an institutional level to start constructing national economic water accounts, the capacity to implement such accounts varies considerably from one country to the next (see EBI 2010 for further details). Failure of one sector to consult another sector leads to inefficiencies, such as overinvestment in interbasin transfers or extensive groundwater pumping (when water planning does not take into account energy costs). Similarly, from an energy supply perspective, the economic costs of water may not be adequately recognized in the choice of location and technology while investing in electricity generation, leading to overinvestment in certain technologies, such as once-through cooling systems.

Despite the differences between the five study countries, a few common themes emerge from this analysis. For water, all countries face significant challenges, either (as in the case of South Africa and at present, Swaziland) because of a general lack of available water resources throughout these countries, or because of an uneven distribution of water resources, as is the case for Namibia, Botswana, and Lesotho. Because these three countries’ economic centers are located far from their river basins, policy is focusing on both water storage and significant water transfer schemes (implying a need to integrate water and energy investment decisions). Water allocation is a challenge for all countries. Although countries recognize the need to implement an integrated approach to managing their water resources and indeed most have published an integrated water resource management (IWRM) plan, doing so is a complex, data- and resource-intensive task, which many countries (particularly Namibia and Swaziland) are struggling to develop and implement.

For energy, the majority of the countries in this study have recently experienced load shedding (the deliberate shutdown of electric power in a part or parts of a power-distribution system, generally to prevent the failure of the entire system when the level of demand strains its capacity)
as a result of their dependence on Eskom for their electricity supply. This inability to rely on Eskom has pushed all the focus countries to prioritize self-sufficiency (and in the case of South Africa, to target additional generation capacity). There is significant interest in developing hydropower and renewable energy generation. South Africa, which needs to significantly expand its capacity, is considering investing in gas-fired generation using imported natural gas, and is also in discussions with DRC with regard to a power purchase agreement (PPA) for Inga 3. In terms of joint planning between the water and energy sectors, only South Africa appears to be actively incorporating water resource availability into its planning. However, there is still room for improvement. The current World Bank Thirsty Energy modeling initiative (World Bank 2015b) to develop a joint energy–water–climate change planning tool for South Africa notes that the previous approach was relatively crude, with no consideration of regional disparities in water supply and costs; auxiliary water use, for example, by coal mining; or water treatment requirements.
Table 3: An Overview of National Water Resources for the Study’s Focus Countries

<table>
<thead>
<tr>
<th>Resources</th>
<th>Botswana</th>
<th>Lesotho</th>
<th>Namibia</th>
<th>South Africa</th>
<th>Swaziland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall(^{28})</td>
<td>400 mm (low)</td>
<td>760 mm (average)</td>
<td>254 mm (very low) (annual evaporation 3,400 mm(^{29}))</td>
<td>497 mm (low)</td>
<td>788 mm (average)</td>
</tr>
<tr>
<td>Freshwater withdrawal (%)(^{30})</td>
<td>1.6%</td>
<td>1.4%</td>
<td>1.6%</td>
<td>24%</td>
<td>23%</td>
</tr>
<tr>
<td>Water availability near the main economic centers</td>
<td>Low—no surface water in western regions, endemic drought, varied rainfall</td>
<td>Captures 50% of Southern Africa’s total catchment runoff. But access is low, especially in lowlands where 2/3 of the population lives and light industry and manufacturing are located(^{31}).</td>
<td>Low. Main economic center is far from surface freshwater sources (closest river to Windhoek is 750 km). Investment in desalination in coastal areas for mining, investment in water recycling for urban centers.(^{32})</td>
<td>Good for the region, but development is constrained by lack of water resources.</td>
<td>Currently experiencing severe drought due to highly variable weather patterns.</td>
</tr>
<tr>
<td>Main water supply source</td>
<td>Groundwater (49%), reservoirs (42%), international rivers (1%), dams (8%), recycled (49%), water transfer (North–South Carrier—Gabarone 50%), Moletedi Dam (Gabarone and Mochudi)(^{33})</td>
<td>Metalong Dam (opened December 2015, serving 2/3 population)(^{14}).</td>
<td>Groundwater, desalination (8,000 liters/day), recycling, aquifers.oreholes (4.6%), surface water (74%), reclaimed (15%), irrigation (5.8%)(^{35})</td>
<td>Dams and water transfer from the LHWP scheme.</td>
<td>Dams (total storage 585 m(^{3}))(^{36})</td>
</tr>
<tr>
<td>Water consumption(^{37})</td>
<td>Agriculture (41%), industry (including mining, 18%), municipal (41%)</td>
<td>Agriculture (8%), Industry (46%), municipal (46%)</td>
<td>Agriculture (70%), industry (5%), municipal (25%)</td>
<td>Agriculture (63%), Industry (6%), municipal (31%)</td>
<td>Agriculture (96.5%), Industry (1.2%), municipal (2.3%)</td>
</tr>
</tbody>
</table>

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\(^{28}\) Source: Figure 16. Assessment of rainfall level is intended only as a guide and is based on 860-mm world average annual rainfall.

\(^{29}\) Du Pisani (n.d.).

\(^{30}\) Conway et al. 2015.

\(^{31}\) GoL 2012.

\(^{32}\) Du Pisani (n.d.).

\(^{33}\) WAVES (2014).


\(^{35}\) Du Pisani (n.d.).

\(^{36}\) http://www.fao.org/nr/water/aquastat/countries_regions/swz/index.stm

\(^{37}\) FAO AQUASTAT database (accessed June 2016).
Table 4: An Overview of Water Resource Knowledge, and Planning Priorities for the Study’s Focus Countries

<table>
<thead>
<tr>
<th>Categories</th>
<th>Botswana</th>
<th>Lesotho</th>
<th>Namibia</th>
<th>South Africa</th>
<th>Swaziland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water resource knowledge/data</td>
<td>Low level of knowledge. Water sector reform based on IWRM will drive data improvements. Water accounting framework in place. No or little knowledge on rural, irrigation abstraction or self-providers (half of national water consumption), regional mapping.</td>
<td>Some knowledge (see discussion of WR2012 in South Africa column. WR2012 also describes the water resources of Lesotho). But limited data, capacity, and tools to predict climate change impacts.</td>
<td>Some knowledge—e.g., aquifer vulnerability study carried out in 1998.</td>
<td>Some knowledge due to water resource appraisals by the Water Resources of Africa, 2005 (WR2005) and 2012 (WR2012) projects (see WR2012). Still a lack of understanding of some hydrological processes and lack of data on land-use changes, water use, and streamflow (Miralles-Wilhelm 2013).</td>
<td>Low level of knowledge—e.g., groundwater resource levels are unknown, but see also WR2012 which brings together knowledge on Swaziland’s water resources. Limited data, capacity, and tools to predict climate change impacts.</td>
</tr>
<tr>
<td>Water priorities</td>
<td>Develop a water pricing policy and a Water Resources Board and water regulator. Invest in surface-water catchment and transfer. Improve water efficiency.</td>
<td>Increase water access to urban and rural populations.</td>
<td>Increase water access in main economic centers, improve sector coordination, develop an equitable tariff policy, and establish a water regulator.</td>
<td>Continue to seek access to international water resources—e.g., from the Zambezi and Orange–Senqu river basins. Improve water use efficiency and limit water use by coal-fired plants.</td>
<td>Develop IWRM and the country’s hydropower potential.</td>
</tr>
<tr>
<td>Current major investments</td>
<td>Dams: Dikgatlhong, Lotsane, Thune, Mosetse. Water transfer schemes: Expanding the North–South Carrier (NSC-2 and NSC-3)</td>
<td>Lesotho Highlands Water Project Phase II and Lesotho Lowlands Water Supply Programme, including Metalong Dam</td>
<td>Under consideration: Abstraction from the Okavango River (from 25 m³ rising to 105 m³ in 2023); desalination of seawater from coastal regions (17 m³ in 2023)</td>
<td>Construction or expansion of six dams</td>
<td>Feasibility study underway for a multipurpose dam on a tributary of the Lusushwana River</td>
</tr>
</tbody>
</table>

38 WAVES (2014) for all.
40 Du Pisani (n.d.).
42 Ibid.
43 GoN 2008.
44 Setlhogile and Harvey 2015.
46 Including the dam at the Mzimvubu River in the Eastern Cape, the expansion of the Clanwilliam Dam in the Western Cape, the Nwamilwa Dam and Tzaneen Dam in Limpopo, the Hazelmere Dam in KwaZulu-Natal, and the Polihali Dam in Lesotho, which will provide water to Gauteng.
Table 5: Evidence of cross-sector planning for the study’s focus countries

<table>
<thead>
<tr>
<th>Planning activities</th>
<th>Botswana</th>
<th>Lesotho</th>
<th>Namibia</th>
<th>South Africa</th>
<th>Swaziland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evidence of cross-sectoral planning coordination and implementation of IWRM</td>
<td>Integrated Water Resources and Water Efficiency (IWRWE) plan approved in 2013, including water for energy plans. Implementation will be challenging because of limited knowledge of IWRM and data.</td>
<td>Limited to Water Commission’s involvement in developing the Lesotho Energy Policy (GoL n.d.).</td>
<td>Water Resources Management Act (GoN 2013) yet to be implemented because of lack of funding and policy implementation capacity.</td>
<td>Only 2 out of 19 water management institutions established. Revisions now underway. Implementation of IWRM is an open question in the country (Mehta et al. 2014).</td>
<td>The National Water Policy aspires to implementing IWRM principles but is hampered by capacity constraints (Manyatsi and Brown (2009). The National Water Act (GoS 2003) states the need to integrate power generation and water infrastructure planning, and the National Water Policy (GoS 2009) contains several policy statements concerning international and regional coordination (GoS, 2009, 2014).</td>
</tr>
</tbody>
</table>

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48 GoB 2013.

49 Manyatsi and Brown (2009) comment that much of the technical capacity to collect, collate, and develop strategies is limited to a few individuals. Similarly, the human capacity may not be available to introduce economic water accounts (see p. 30).
<table>
<thead>
<tr>
<th>Categories</th>
<th>Botswana</th>
<th>Lesotho</th>
<th>Namibia</th>
<th>South Africa</th>
<th>Swaziland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed capacity (% suppressed and forecast demand)</td>
<td>352 MW (58%)</td>
<td>72 MW (52%)</td>
<td>393 MW (62%)</td>
<td>44,170 MW (104%)</td>
<td>70 MW (27%)</td>
</tr>
<tr>
<td>Generation mix</td>
<td>22% domestic supply (coal) 66% imported from South Africa, 22% imported from Mozambique.</td>
<td>100% hydropower from the Muelta hydropower generation plant. Heavily dependent on imports from South Africa and Mozambique.</td>
<td>Hydropower (67%), coal fired (25%), diesel (8%)</td>
<td>Coal fired (93%); nuclear (5.7%), pumped storage (1.2%), hydropower (0.5%), gas turbine (0.1%)</td>
<td>Hydropower (100%) (the country’s two diesel engines are no longer viable)</td>
</tr>
</tbody>
</table>

Energy generation sector priorities

**Address current power shortfalls and become a net exporter of electricity to the region using coal and solar resources. Implement off-grid rural photovoltaic electrification.**

**Increase clean energy production, attain self-sufficiency, and export energy. Additional power expected to come from hydro, wind, pumped storage, and solar power. Increase domestic electricity access (currently 25%) to at least 35% by 2020, potentially through solar power proliferation in sparsely inhabited mountainous regions.**

**To be published in Namibia’s forthcoming first Integrated Resource Plan. Expected to include development and diversification of power sources, demand management, and promoting regional integration. Potential new power generation sources include Kudu power project (currently shelved); Baynes hydropower project; and coal-fired, gas, and renewable energy sources.**

**Eliminate load shedding. South Africa needs 40,000 MW of new capacity by 2025.**

**RSA/DoE (2013a) focuses on regional hydropower (e.g., Mozambique), additional coal and gas (including Mozambique), additional coal and nuclear power. The REIPPP aims to increase renewable energy mix to 19 GW of installed capacity by 2030.**

**Achieve security of supply and self-sufficiency and improve rural electrification. Develop hydropower capacity using multipurpose water structures and the country’s renewable energy potential. Improve overall energy efficiency.**

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50 Source: SAPP 2014 (installed capacity statistics as at March 2013).
51 Load shedding is the deliberate shutdown of electric power in a part or parts of a power-distribution system, generally to prevent the failure of the entire system when the demand strains the capacity of the system.
53 www.sec.co.sz/electricity/.
<table>
<thead>
<tr>
<th>Current projects</th>
<th>1,200-MW Kobong pumped storage project, wind mapping project, Maluti-Drakensberg wind power project (42 turbines)</th>
<th>Kudu 885-MW gas-to-power project decision expected mid-2016; Baynes 600-MW hydropower project in feasibility phase</th>
<th>Commitment to build 18,576-MW new power generation capacity by 2012 (World Bank 2015b)</th>
<th>Independent power producer solar farm 21.5-MW project following launch of pilot projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evidence of coordination with the water sector during planning</td>
<td>Integrated Water Resources and Efficiency (IRWRE) plan approved in 2013 supports cross-sectoral coordination, but implementation is hindered by limited institutional capacity and data.</td>
<td>The Water Commission was involved in developing the Lesotho Energy Policy (GoL n.d.). Moderate degree of practical coordination, with institutional arrangements appearing to provide for joint planning at project level.</td>
<td>Namibia recently developed an energy planning tool that takes into account consumption across sectors, but does not integrate water resource availability (Rämä et al. 2013). Namibia’s two solar desalination plants provide some evidence of cross-sector planning to realize synergy benefits (Prasad 2012).</td>
<td>Power generation planning makes reference to water resource availability, but fully dynamic two-way coordination is not in evidence. National policies and laws do not reference the nexus. Water and energy connection made for Cape Town and Johannesburg, but not at the local rural level (Prasad 2012).</td>
</tr>
</tbody>
</table>

58 [https://www.esmap.org/re_mapping_lesotho](https://www.esmap.org/re_mapping_lesotho)
Chapter 5: A Regional Approach to Addressing National Priorities

The shared water resources through the region’s large transboundary river basins and significant history of electricity trade create the potential for a strong regional dimension to addressing national water and energy priorities.

5.1 Southern African Development Community

The key institution focusing on regional integration in the region is SADC, which owes its origins to the nine-member Southern African Development Coordinating Conference (SADCC), formed in 1980 as a means of overcoming economic dependence on apartheid South Africa. As South Africa approached its political and social transformation in the late 1980s, the relevance of SADCC’s primary objective diminished. This coincided with a desire among the membership for streamlining SADCC’s project portfolio, which had grown significantly and comprised numerous projects that were more national than regional. In addition, it was recognized that global “changes in the organization of production and trade” demanded far greater integration across the region and an entity that could spearhead this integration.

The SADC treaty was signed in 1992 in Windhoek, Namibia. The objectives of SADC are to:

- Achieve development and economic growth, alleviate poverty, enhance the standard and quality of life of the people of Southern Africa, and support the socially disadvantaged through regional integration;
- Evolve common political values, systems, and institutions;
- Promote and defend peace and security;
- Promote self-sustaining development on the basis of collective self-reliance, and the interdependence of member states;
- Achieve complementarity between national and regional strategies and programs;
- Promote and maximize productive employment and use of the region’s resources;
- Achieve sustainable use of natural resources and effective protection of the environment; and
- Strengthen and consolidate the long-standing historical, social, and cultural affinities and links among the people of the region.

Since the establishment of SADC, regional integration within Southern Africa has increased, including in both the water and the energy sectors. This integration has occurred despite the perennial need to enhance “institutional and human capacity to design, prepare, sequence, coordinate implementation, and monitor regional operations” at the secretariat. In addition, member states have tended to jealously guard their sovereignty, with consensus at the head-of-state level being the means for resolving contentious matters. An attempt to formalize the resolution of disputes related to the SADC treaty, through the establishment of a tribunal in 2003, did not succeed and the body was disbanded in 2012.

62 The founding members of SADCC were Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe.
The SADC treaty provides that member states should develop a set of legal and institutional instruments—referred to as protocols—that have clearly stated objectives, scope, and institutional mechanisms to facilitate cooperation and integration on key issues for the region. A protocol is a legally binding document that commits all member states to its objectives and procedures. For a protocol to be valid, it needs to be signed by at least two-thirds of SADC member states. SADC currently has 26 protocols, including the Revised Protocol on Shared Watercourses (SADC 2000) and the Protocol on Energy (SADC 1996). These documents provide the SADC community with a foundation for regional cooperation and integration in water and energy.

5.2 Regional Water Resources

The disparities between individual countries’ water resource endowments and their overall demand for water (discussed in the previous chapter) suggest that operating at a regional level can increase benefits and reduce risks. A coordinated approach with benefit-sharing mechanisms to manage the region’s shared waters could minimize social costs and improve allocative efficiency. There are also challenges to regional coordination on water, including difficulties with resource mobilization and allocation and the perception that regional processes extend project timelines (World Bank 2015g).

Institutional Arrangements for Managing the Region’s Shared Water Resources

Water resource management in the region is governed by the Revised Protocol on Shared Watercourses in the Southern African Development Community (SADC 2000). The objectives of the protocol are to:

- Promote and facilitate the establishment of shared watercourse agreements and shared watercourse institutions for the management of shared watercourses;
- Advance the sustainable, equitable, and reasonable use of the shared watercourses;
- Promote coordinated and integrated environmentally sound development and management of shared watercourses;
- Promote the harmonization and monitoring of legislation and policies for planning, developing, conserving, and protecting shared resources, and for allocating their resources; and
- Promote research and technology development, information exchange, capacity building, and the application of appropriate technologies in shared watercourse management.

The protocol also lays out an institutional framework for its implementation comprising the Committee of Ministers, Committee of Water Senior Officials, Water Sector Coordinating Unit.

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63 Including those not yet entered into force (http://www.sadc.int/about-sadc/overview/sa-protocols/).
Water planning at the regional level takes place at the transboundary level and has not yet moved to the level of full regional integrated development (Schreiner and Baleta 2015). Furthermore, the shared watercourse protocol does not allocate the regional planning responsibility to any institution, though the SADC Water Sector Coordinating Unit appears to be the natural candidate for such a role and may already be carrying out ad hoc planning assignments.

Based on the provisions of the protocol, several entities manage the affairs of Southern Africa’s river basins. These include the Cunene River Basin Commission, Limpopo Watercourse Commission, Lesotho Highlands Water Commission, Lesotho Highlands Development Authority, Trans-Caledon Tunnel Authority, Orange–Senqu River Commission, Zambezi River Watercourse Commission (ZAMCOM), and Zambezi River Authority (ZRA). The protocol does not prescribe

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**Figure 23: SADC Water Sector Legislation, Policies, and Strategies**

Source: SADC 2016.

Note: RBOs = river basin organizations; RISDP = Regional Indicative Strategic Development Plan; RSAP = Regional Strategic Development Plan; SADC = Southern African Development Community.
the role of these institutions, but states that “the responsibilities of such institutions shall be determined by the nature of their objectives which must be in conformity with the principles set out ... in the protocol” (SADC 2000).

Information Sharing—The SADC Water Information Sharing Hub (SWISH)

Through 2012 and 2013, with support from the German Agency for International Cooperation (GIZ) Transboundary Water Management in SADC Programme, the SADC Water Division embarked on a project to develop a system to support the sharing of vital water-related information across the Southern African region. The SWISH is an exchange hub that acts as a conduit for water-related news, events, and documents and also provides access to a unified water glossary. To engage with the SWISH, partners simply need to add RSS capabilities to the news, calendar, and document libraries of their websites. These information feeds are then integrated into the SWISH and made available to anyone wishing to either view them or integrate the information into a website. In turn, partners are then able to display SWISH information on their websites. Feeds from the SWISH can be filtered to enable partners to display the thematic or geographic information that is relevant to their stakeholders.65

Infrastructure Planning

There is considerable potential for coordinated infrastructure investment to improve overall use of the region’s water resources. For example, just 14 percent of the SADC region’s actual renewable water resources (ARWRs) are currently stored, and just 8 percent of its hydropower potential is being realized.

The SADC Regional Infrastructure Development Master Plan (RIDMP) (SADC 2012a) sets out the region’s infrastructure development. The RIDMP Water Sector Plan is structured around a series of “Vision 2027” targets, which include developing storage for 25 percent of ARWRs (eventually to reach 75 percent) and increasing installed hydropower generation capacity from 12 GW to 75 GW (50 percent of potential) (SADC 2012c).

The RIDMP sets out an ambitious goal of a series of investments with a total expected value of $200 billion in three phases (the total cost includes studies, facilitation projects, and capacity building projects). Implementation of Phase 1 is currently underway to deliver 34 projects, between 2013 and 2021, with an estimated total project cost of $16 billion.

These projects show little regional integration. Of the 34 identified Phase 1 investment projects, only 4 are between two countries, and 1 (irrigation efficiency project) stretches across the entire region. There are no projects between three or more countries (Schreiner and Baleta 2015) (Table 7).

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Table 7: The SADC RIDMP Water Plan Investment Projects—Phase 1

<table>
<thead>
<tr>
<th>Project</th>
<th>Lead agency</th>
<th>Project cost (US$ in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inga III hydropower</td>
<td>Ministry of Energy, DRC</td>
<td>8,000</td>
</tr>
<tr>
<td>Lesotho Highlands—Phase 1</td>
<td>LHDA and LHWC, Lesotho</td>
<td>1,001</td>
</tr>
<tr>
<td>Batoka Gorge hydropower scheme</td>
<td>ZRA/ZESA/ZESCO</td>
<td>4,000</td>
</tr>
<tr>
<td>Songwe River Basin development project</td>
<td>Malawi and Tanzania</td>
<td>328</td>
</tr>
<tr>
<td>Vaal-Garnagara water supply</td>
<td>DWA Botswana</td>
<td>175</td>
</tr>
<tr>
<td>Ressano Garcia Weir</td>
<td>DNA Mozambique</td>
<td>6</td>
</tr>
<tr>
<td>Lomahasha/Namaacha water supply</td>
<td>Mozambique and Swaziland</td>
<td>31</td>
</tr>
<tr>
<td>Water supply and sanitation at 12 locations</td>
<td>Zambia</td>
<td>165</td>
</tr>
<tr>
<td>Water supply and sanitation—Lubango Phase 2</td>
<td>Angola</td>
<td>120</td>
</tr>
<tr>
<td>Water supply and sanitation—Kinshasa</td>
<td>Ministry of Energy DRC</td>
<td>220</td>
</tr>
<tr>
<td>Lesotho lowlands water supply scheme—Zone 1</td>
<td>LHWC Lesotho</td>
<td>78</td>
</tr>
<tr>
<td>Mombezi multipurpose dam</td>
<td>Blantyre Water Board Malawi</td>
<td>210</td>
</tr>
<tr>
<td>Water supply and sanitation—13 housing estates</td>
<td>Mauritius</td>
<td>11</td>
</tr>
<tr>
<td>Moven Dam</td>
<td>DNA Mozambique</td>
<td>11</td>
</tr>
<tr>
<td>Artificial recharge of Windhoek aquifer—Phases 2B and 3</td>
<td>NamWater</td>
<td>55</td>
</tr>
<tr>
<td>Reducing nonrevenue water and increasing use efficiency</td>
<td>Seychelles</td>
<td>26</td>
</tr>
<tr>
<td>Nondvo multipurpose dam</td>
<td>DWA Swaziland</td>
<td>150</td>
</tr>
<tr>
<td>Ruhuhu Valley irrigation scheme</td>
<td>Tanzania</td>
<td>13</td>
</tr>
<tr>
<td>Climate change adaptation to drought—agro region 1</td>
<td>Zambia</td>
<td>80</td>
</tr>
<tr>
<td>Bulawayo–Zambezi water supply scheme</td>
<td>Zimbabwe</td>
<td>600</td>
</tr>
<tr>
<td>Improved agricultural water application efficiencies</td>
<td>SADC Water Division</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Source: SADC RIDMP Water Plan (Table 4.2) (SADC 2012a).

Note: DNA = National Directorate of Water; DWA = Department of Water Affairs; LHDA = Lesotho Highlands Development Authority; LHWC = Lesotho Highlands Water Commission; RIDMP = Regional Infrastructure Development Master Plan; ZESA = Zimbabwe Electricity Supply Authority; ZESCO = Zambia Electricity Supply Corporation; ZRA = Zambezi River Authority.
In addition, a prefeasibility study is being developed by Botswana to transfer water from Lesotho via South Africa. However, in practice very little infrastructure is actually being developed (Schreiner and Baleta 2015).

Large hydropower investment projects in the region present significant potential environmental, social, and technical risks. These risks are recognized by the International Hydropower Association’s Hydropower Sustainability Assessment Protocol—a framework to enable hydropower developers to assess the sustainability of their projects (IHA 2016). The protocol covers cross-cutting issues, such as climate change, IWRM, and transboundary issues. However, since its launch in 2011, no assessments have been conducted in the region. The World Bank is addressing this through its Zambezi Hydropower Sustainability Assessment Protocol, which aims to “assist the riparian states of the Zambezi River to develop and utilize the Zambezi hydropower potential in a sustainable and responsible way...” (World Bank 2015h). The Bank will provide support to the technical Committee of Zambezi Dam Operators and other key associations to implement the protocol, and in doing so will help mitigate the risks associated with hydropower development within the basin. Project inception consultations were held in April 2016, and the project is expected to be completed by October 2017.

**Bilateral Water-Sharing Projects**

Bilateral water transfer agreements are in place between SADC member states both to address the problem of uneven water resource distribution in the region through interbasin transfers, and to coordinate on large infrastructure projects, such as the Kariba Dam on the Zambezi River.

**Interbasin transfers**

Figure 24 illustrates current and planned interbasin transfers in the SADC region. The most significant of these transfers is between Lesotho and South Africa. The LHWP aims to address South Africa’s water scarcity through the transfer of some of Lesotho’s abundant water resources to the Gauteng region. The revenues from this project are enabling Lesotho to develop its hydropower capacity and improve water distribution within the country.

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Figure 24: Current and Planned Transboundary Interbasin Transfers in the SADC Region


Note: Red lines indicate current transfers; purple lines indicate planned transfers.
Lesotho Highlands Water Project

The LHWP is an example of transboundary nexus benefit sharing that takes advantage of significant synergy benefits. The project has the dual aims of providing water to the Gauteng region of South Africa and generating hydroelectricity for Lesotho. It was established by the 1986 treaty signed by the governments of Lesotho and South Africa. The LHWP harnesses the waters of the Senqu–Orange River Basin in the Lesotho Highlands through the construction of a series of dams for the mutual benefit of the two countries.

At its inception, the LHWP was designed to include five phases implemented over 30 years and is expected to transfer about 70 m$^3$ of water to Gauteng Province in South Africa. Phases 1A and 1B have been completed. The main physical features of Phase 1A are the Katse Dam, the transfer tunnel from Katse to the Muela Hydropower station, the Muela Hydropower station and appurtenances, and the delivery tunnel to the border with South Africa. Phase 1B involved the construction of the Mohale Dam and the diversion tunnel to the Katse Dam. Both phases also involved the construction of infrastructure, such as tarred roads, feeder roads, bridges, camps, and health facilities, as well as environmental and social programs.67

Phase II is now underway and is expected to be largely complete by the end of 2024. It consists of two separate but related components: water transfer and hydropower generation. The water-transfer component of Phase II comprises an approximately 165-m-high Concrete Faced Rockfill Dam at Polihali downstream of the confluence of the Khubelu and Senqu (Orange) rivers, and an approximately 38-km-long concrete-lined gravity tunnel connecting the Polihali Reservoir to the Katse Reservoir. Other Phase II activities include advance infrastructure (such as roads, accommodation, power lines, and telecommunications) and the implementation of environmental and social mitigating measures. The hydropower component of Phase II, which is currently undergoing further feasibility studies, may include a pumped storage scheme and conventional hydropower, such as the expansion of the ‘Muela infrastructure or new greenfield sites. Its exact form will be determined on completion of further feasibility studies.68

The governance structure of the LHWP is shown in Figure 25. Lesotho’s and South Africa’s “good practice” water treaty was noted to have features that may be relevant for other transboundary organizations, in particular, (1) clarity and detail in the treaty document, including procedures for adjusting to changing circumstances; (2) appropriate institutions—a bridging institution has worked well in coordinating actions between the two countries; (3) focused objectives; and (4) independent dispute resolution mechanisms within the institutions themselves (World Bank 2010a).

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67 http://www.lhda.org.ls/Phase1/.
The Zambezi River has significant hydropower potential. The river’s main dam, the Kariba Dam, is managed by a bilateral agreement between Zambia and Zimbabwe. The ZRA agreement was signed in 1987 to manage the part of the Zambezi River that forms the border between Zambia and Zimbabwe “to obtain, for the economic, industrial and social development of the two countries, the greatest possible benefit from the natural advantages offered by the waters of the Zambezi River.” The main responsibilities of the ZRA today are to operate and maintain the Kariba Dam, investigate the development of new dam sites on the Zambezi River, and analyze and disseminate hydrological and environmental information pertaining to the Zambezi River and Lake Kariba.

5.3 Multilateral Water Planning and the River Basin Commissions

Most of the region’s 21 transboundary river basins are covered by international agreements (or regimes), and have established a river basin organization (RBO). River basins that are fully within SADC territory are under the jurisdiction of the SADC shared watercourse protocol (SADC 2000). Basins that are covered by an international agreement or regime and that have established an RBO are shaded in green in the map in Figure 26. The Rovuma basin, shaded in orange, has an

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69 This is a broader definition of regional transboundary river basins than used above, to include those not recognized as major SADC transboundary basins but that lie geographically within the Southern African region.
established treaty, but not an RBO, whereas the Cuvelai basin, also in orange, established its river basin commission (RBC) in 2014. The basins shaded in red have neither. For many basins without an RBO or a treaty, further cooperation is not justified, either on the basis of their hydrological regime, because the vast majority of resources resides in one member state, or because the river basin is shared with non-SADC member state(s). Only the Rovuma (treaty, but no RBO) and Save–Runde (no treaty or RBO) river basins stand to benefit from (increased) cooperation. (See Turton (2010) for a more detailed discussion on river basin cooperation, relevant treaties, and RBOs.)
Figure 26: International Agreements Relating to SADC Transboundary River Basins

RBCs are created by establishing basinwide agreements between the respective riparian states. To date, five RBCs have been established in the region to promote IWRM and development:70

- Cuvelai Watercourse Commission (CUVECOM), established in 2014 between the riparian states of Angola and Namibia;
- Limpopo Watercourse Commission (LIMCOM), established in 2003 between the riparian states of Botswana, Mozambique, South Africa, and Zimbabwe;
- Okavango River Basin Water Commission (OKACOM), established in 1994 between the riparian states of Angola, Botswana, Namibia, and Zimbabwe;
- Orange–Senqu River Commission (ORASECOM), established in 2000 between the riparian states of Botswana, Lesotho, Namibia, and South Africa; and
- ZAMCOM, established in 2011.

These RBCs vary in terms of the complexity of their activities. They range from simple activities, such as pollution control and information sharing, to drawing up resource allocation agreements and executing integrated river basin management.71 From a technical point of view, the RBCs are reasonably well equipped—though political constraints limit the extent of their power. It is felt that national interests mean that few if any RBCs are intended to satisfy a well-thought-out regional agenda. ZAMCOM and ORASECOM are discussed in more detail below.

**ZAMCOM**

ZAMCOM was established in 2011 as an interim secretariat by the eight countries that share the Zambezi River Basin72 and in accordance with the revised SADC Revised Protocol on Shared Watercourses (SADC 2000). In 2014 ZAMCOM was successfully transitioned to a permanent organization, based in Zimbabwe (World Bank 2015g). Its main objective is “to promote the equitable and reasonable utilization of the water resources of the Zambezi Watercourse as well as the efficient management and sustainable development thereof” (ZAMCOM 2016).

ZAMCOM is developing a strategic plan for the development of the basin in accordance with the provision of the ZAMCOM agreement (with support from a World Bank-administered grant). The high number of riparian states gives rise to complex issues concerning how to share the rivers’ significant water resource. In 2012, there were seven actors73 and seven projects focusing on transboundary issues throughout the basin (SIWI 2012). The Climate Resilient Infrastructure Development Facility’s 2014 analysis of Zambian water policy commented: “The ZAMCOM is still in its infancy and various principles such as ERU [equitable and reasonable utilization] will

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71 These RBCs establish development scenarios and carry out impact assessments, which in turn may lead to basin-level and sector-level strategies.
72 The riparian states of the Zambezi River Basin are Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe (ZAMCOM 2016).
73 Actors are defined by SIWI as any regional or international organization, institution, or network working with transboundary water management.
need to be developed into operational technical policies, particularly with respect to national plans that may affect the other riparian States” (CRIDF/DfID 2014a).

Since 2015, a series of projects supported by the multidonor trust fund Cooperation in International Waters in Africa (CIWA)\(^7\) is helping to overcome some of the institutional and financial issues that have hindered progress in developing the Zambezi basin. These projects are being delivered through CIWA’s Zambezi River Basin Program, which provides an integrating framework to coordinate World Bank and other development partner programs and achieve the key objectives of ZAMCOM (see box below).

**Box 6: The Zambezi River Basin Program**

CIWA is working with ZAMCOM to strengthen its ability to facilitate collaborative action and to make it more financially sustainable and efficient. The potential gains are significant. For example, it is estimated that coordinated operation of the river basin’s hydropower facilities could increase energy production by 23 percent without additional investment. Water supplies could be secured for the drylands of Botswana, Namibia, and Zimbabwe and further afield, and cooperation on strategic disaster management could reduce flood and drought risks, potentially averting water-shock losses of up to $1 billion per year.

One project, the Zambezi River Basin Management Project, is being implemented by ZAMCOM and is supported through a $4 million CIWA grant. This project will develop the strategic plan for the river basin, conduct an equivalence assessment of national water laws among riparian states, and carry out Component 3 of the Zambezi Water Resources Information System Enhancement: Hydro-Met Database and Decision Support System.

Another project, the Zambezi River Basin Development Project, is being implemented by ZRA and financed through a $7.5 million grant from CIWA. This includes several activities to improve the Bakota Gorge Hydro-Electric Scheme investment to address the prevailing power supply shortages within the SAPP.

*Source: World Bank 2015g.*

**ORASECOM**

Established in 2000, ORASECOM represents the first multilateral agreement between all the riparian states of the river basin: South Africa, Lesotho, Botswana, and Namibia. Key challenges for the basin include managing its 30 dams and inter- and intrabasin transfers, and addressing increasing unsustainable water resource demands and pollution and land degradation. In 2012, there were 11 actors and 10 projects focusing on transboundary issues throughout the basin (SIWI 2012).

A key ORASECOM achievement with assistance from the United Nations Development Programme and Global Environment Facility was the establishment of the Orange–Senqu Water

\(^7\) The CIWA multidonor trust fund is a partnership between the World Bank and the governments of Denmark, Norway, Sweden, the Netherlands, and the United Kingdom to address constraints to cooperative management and development of Africa’s international waters.
Information System. This web-based portal provides access to spatial and time-series data, as well as scientific research relating to the basin, and is expected to be replicated by other RBCs in Southern Africa. While ORASECOM can be considered to be an effective coordinator of information and an advisor on regulatory issues and beneficial and harmful practices within the river basin, it is less effective as a regional coordinator of investment planning and joint investments. This may in part relate to a lack of clarity on its mandate in relation to these areas.

5.4 Regional Priorities for Water Resources and Supply

In 2012, SADC launched its Regional Water Supply and Sanitation Programme, an integral part of the 2011–15 SADC Regional Strategic Action Plan (RSAP) on Integrated Water Resources Development and Management (SADC 2011). The program’s priorities reflect the key challenges faced by SADC countries in achieving their sustainability and development goals and visions. The priorities were identified as a result of past SADC projects and investigations, and reflect the national priorities discussed in the previous chapter, which are presented under five pillars:75

1. Financing—improving the financial efficiency of the water supply and sanitation (WSS) sector in SADC member states;
2. Institutional capacity—institutional arrangements, rationalization, and strengthening;
3. Infrastructure development—WSS infrastructure development support;
4. Monitoring and reporting—development and implementation of a WSS monitoring and reporting program; and
5. Knowledge management and information sharing—structured around the basic WSS services needed to meet the Millennium Development Goals.

The SADC water sector is currently coordinating implementation of the third phase of the 2011–15 RSAP, which focuses on three strategic areas (SADC 2011):

- Water governance;
- Infrastructure development; and
- Water management.

5.5 SADC Protocol on Energy and the SAPP

The SADC Protocol on Energy (PoE) (SADC 1996) defines the guidelines for regional energy cooperation, which include

- Promoting electricity trading and power pooling, such as that described in the SAPP intergovernmental memorandum of understanding and the SAPP Agreement between Operating Members, all as adopted by the member states;

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Regional energy development is at the core of SADC’s agenda, which has developed strategies and established dedicated agencies that together form a consolidated institutional architecture driving integration in the energy sector. The key actor is the SAPP, created by SADC in 1995 through an intergovernmental memorandum of understanding in August 1995, and guided by the SADC PoE. The SAPP’s mandate includes enhancing regional cooperation in power development and trade and producing nonbinding regional plans to guide the delivery of infrastructure for generating and transmitting electricity. Individual member states are not bound to these plans and have the right to implement national plans without regard to regional plans (Schreiner and Baleta 2015).

The SAPP has a sound governance structure, with its key establishing agreements and operating guidelines signed by both members’ governments and utilities. In 2002, a SAPP Coordination Centre was established in Harare, Zimbabwe, as an arm of the Operating Subcommittee to monitor operations and transactions within the SAPP, including controlling dispatching operations and serving as a trading center for electricity auctions. The Coordination Centre is the first body with responsibility for regional power market oversight and operation established in Africa.

Power trading

Currently the most advanced and organized of all power pools in Africa, the SAPP coordinates trade between 12 SADC countries (Angola, Botswana, DRC, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe), of which 9 are operating members—namely, via the interconnected grid that carries around 97 percent of the energy produced in the SAPP (see Figure 20 and Figure 27). The nonoperating members—which are yet to construct transmission links to the regional grid—are Angola, Malawi, and Tanzania.

The SAPP is also the power pool with the largest volume of power traded and the only one with some form of competitive power market in Africa. Unlike the other African power pools, the SAPP has active power trading. A short-term energy market (STEM) was introduced in 2001, which was replaced in 2009 by the day-ahead market (DAM), a fully competitive auction market open to utilities, independent power producers, transmitters, and distributors. Although STEM and DAM constitute notable innovations, the majority of energy sales and purchases continues to take place through negotiated bilateral agreements. As of today, 28 contracts for bilateral trading of power are registered in the region, 18 of which entail long-term provision of firm capacity, with an overall volume of power traded that is the largest among all Africa’s regions. Power trade is driven by South Africa, because of its relatively large power needs within the region and more creditworthy status as a power offtaker. The 2013 update to the 2010 South African Integrated Resource Plan (IRP) 2010–30 includes significant emphasis on sourcing power from regional sources (RSA/DoE 2013a). Overall, power trade in the region is poised to increase. It is estimated that by 2025, exports
could reach 62 terawatt-hours—a four-time increase over 2010—accommodating 11–13 percent of total demand in the region (Nexant 2009).

Regional coordination issues

There is still significant room for improvement regarding the SAPP’s regional coordination capacity. Further integration and market competition in the SAPP critically hinge on increasing generation and transmission capacity and are restrained by most sellers and buyers wanting to have long-term PPAs. Of the 28 bilateral electricity-trading contracts in place in 2012–13, only 15 were active because of generation and transmission constraints (Schreiner and Baleta 2015). The current constraints in transmission infrastructure are an obstacle to freely trading power on the spot market. As a result, on average, STEM accounted for 5–10 percent of the energy traded in the region in 2012–13, while DAM currently accounts for around 1 percent.
In reality, full integration of multiple national electricity systems and a competitive regional power market with multiple buyers and sellers takes significant political and institutional will, coordination, and time to materialize. So far, it has only been achieved in a few industrialized regions (Nord Pool in Scandinavia is probably the closest to this model). In Southern Africa, concerns about security of supply and counterparty creditworthiness constitute key reasons for countries opting to trade bilaterally based on long-term PPAs (see the discussion of the Inga 3 project and the treaty between the DRC and South Africa in the Regional Energy Priorities section, below). Going forward, generation projects will be developed with private-sector financing. Thus, certainty in power sale and credit worthiness of offtakers will be critical, and PPAs will continue to be the standard for the majority of the power being sold.

The benefits attached to power trade—whether through bilateral contracts or through a more competitive market—and the prospects for trade in the near future make a strong case for regional generation and transmission projects. The focus of the SAPP has thus shifted more and more to the preparation and implementation of priority regional energy projects that further such regional integration.

Accordingly, the SAPP set up a Projects Advisory Unit in Johannesburg during 2015. The office includes staff members who are specialists in project preparation and structuring for financing. The unit is funded by a World Bank $20 million grant, with funds from this grant also available for regional analytical work and for direct support in preparation of regional priority energy projects. The Swedish International Development Cooperation Agency and other donors are also moving to support this new unit and its work.

**Regional Energy Priorities**

The SADC region faces a number of challenges in relation to energy availability, facing a capacity gap of between 8,247 MW and 16,536 MW; delivery; access (36 percent overall and less than 10 percent in rural areas of most member states; and affordability (SADC 2016).

The SAPP Regional Generation and Transmission Expansion Plan, commissioned by the SAPP in 2001 and updated in 2009, has identified a detailed list of priority generation and transmission projects that allow accommodating rapidly increasing electricity demand in the region at the least cost over the period 2006–25. The SAPP selects priority projects on the basis of the selection criteria shown in Table 8). Project costs and size are given the highest weight in deciding which projects to select, and the number of coordinating countries is given the lowest weight. A standard project is regarded as one that delivers benefits (employment and GDP) mainly at the national level.

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76 See the following link for further details: http://www.worldbank.org/projects/P126661?lang=en.
77 Refers to difference between normal peak demand and operating capacity taking into account generation capacity reserve margins.
78 Refers to the difference between suppressed demand and operating capacity taking into account generating capacity reserve margins.
79 A new Regional Power Sector Masterplan is currently being developed, funded by the World Bank.
## Table 8: SAPP Priority Project Selection

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Measure</th>
<th>Weighting (%)</th>
<th>Definition of “Standard”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Size of project</td>
<td>Expected output in MW</td>
<td>15</td>
<td>200–500 MW</td>
</tr>
<tr>
<td>2. Levelized costs</td>
<td>Discounted operations and maintenance, variable, environmental mitigation, and transmission integration costs</td>
<td>25</td>
<td>71–100 US¢/MWh</td>
</tr>
<tr>
<td>3. Availability of associated transmission infrastructure</td>
<td>Transmission infrastructure needed to evacuate power from the plant</td>
<td>10</td>
<td>50–100 km</td>
</tr>
<tr>
<td>4. Economic impact</td>
<td>Economic benefits accruing to the participating countries and to the region as a whole</td>
<td>10</td>
<td>Mainly national benefit (jobs, GDP increase), some regional benefit</td>
</tr>
<tr>
<td>5. Commissioning date</td>
<td>Date construction will be completed and the plant will be ready for operation</td>
<td>10</td>
<td>2017</td>
</tr>
<tr>
<td>6. Share of capacity already committed</td>
<td>The amount of power that has been committed for sale through PPAs, etc.</td>
<td>10</td>
<td>36–50%</td>
</tr>
<tr>
<td>7. Share of capacity available for regional power trade after commissioning</td>
<td>The amount of capacity that will be available for exports after project commissioning</td>
<td>15</td>
<td>36–50%</td>
</tr>
<tr>
<td>8. Number of participating countries</td>
<td>Number of countries involved in the project</td>
<td>5</td>
<td>3 countries</td>
</tr>
</tbody>
</table>


*Note: Projects are scored using the following scoring system with reference to the definition of standard set out in the fourth column of the table above: weak (1), below standard (2), standard (3), above standard (4), and best (5). Outcomes that are less than standard will achieve a lower score and outcomes that are better than standard, a higher score.*

SAPP’s key transmission projects include (SAPP 2015):

- Zambia–Tanzania–Kenya interconnector
- Mozambique Transmission Backbone Project (STE)
- Central Transmission Corridor in Zimbabwe
- Botswana North West Transmission Grid Connection Project Phase 1 and 2 (completion 2018/19)
- Mozambique–Malawi Interconnector
- Namibia–Angola–Interconnector
- Zimbabwe–Zambia–Botswana–Namibia Interconnector
- Mozambique–Zimbabwe–South Africa Interconnector (MOZISA) Transmission Project
- Grand Inga Phase 1 Transmission Integration

National demands for energy have also led to various regional treaties and bilateral and multilateral agreements for the advancement of hydropower projects, such as for Inga 3 (DRC and South Africa) and Mphanda Nkuwa (ongoing dialogue between Mozambique and South Africa).

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80 The Second DRC–Zambia 220-kilovolt Interconnector project listed in the SAPP 2015 annual report has since been completed (SAPP 2015).
While all these efforts are being made at a regional level, it is clear that the priority of countries in the region is to develop physical self-sufficiency in generation capacity within their own national boundaries—and to primarily look at regional trade as an opportunity to finance larger generation projects (than may be required to meet national demand) and to export power to the region. South Africa is the clear exception—looking to import power. Its 2013 update to its IRP refers to hydropower in the region being a source of power for South Africa, and the country is actively engaging with DRC and Mozambique, among others (RSA/DoE 2013a). The role of South Africa in backstopping PPAs will be critical in attracting credible investors and developing bankable projects.

5.6 Cross-sectoral Activity at the Regional Level

In recognition of the energy–water nexus and driven by a need to respond to the region’s current drought crisis, SADC has produced a draft energy–water nexus action plan, as shown in Figure 28 (SADC 2016).

Figure 28: The SADC Energy–Water Nexus Action Plan Conceptual Framework

Source: SADC 2016.
Despite the plan’s energy-water nexus focus, very few of its activities are directly cross-sectoral in nature. The majority of them on individual sector efficiencies, such as household and industrial reuse and recycling of water and solar-powered street lighting. The only exception is to “Implement a SADC Regional policy to reduce the consumption of energy for water heating by banning the use of electric geysers, boilers and other electric water heating equipment regionally in all new building and industrial developments” (SADC 2016).

**Energy**

There is little evidence of cross-sectoral planning in the current version of the SAPP regional pool plan. As stated in the energy protocol’s guidelines for regional cooperation in electricity, the SAPP is the custodian of regional planning. Considerations regarding water resource availability are part of the generation planning process for hydroelectric schemes. However, when it comes to decisions about projects, typically there are no prioritization criteria that are linked to broader water issues or water opportunity costs. There are also no formal links with SADC water institutions when undertaking such work. Since 2015, the SAPP has been developing a new Regional Power Sector Master Plan. The work is being driven by the Planning Subcommittee of the SAPP, which consists of representatives of all the member utilities. This master plan is taking an approach that identifies not just least-cost but also robust solutions, given all the uncertainties relating to regional power sector development. It is expected that water and climate change will play a role in the uncertainty scenarios.

**Water**

There is significant potential for regional benefit sharing across Southern Africa’s watercourses. For example, water-stressed countries in the southern basins of the region (such as South Africa) would benefit from developing the hydropower resource potential elsewhere in the region, such as in DRC (Congo Basin) and Mozambique (Zambezi Basin) to source cost-effective and reliable electricity supply to meet its fast-growing electricity resource needs. In turn, countries with hydropower potential, such as DRC, can benefit from the revenues derived from the sale of power to South Africa.

Figure 29 illustrates the current situation for Southern Africa. The northern river basins have large water resources, low energy demands, and relatively low incomes. In contrast, the southern basins have relatively poor water resources, high energy demand, and relatively high incomes. Adopting a regional approach to benefits could result in the northern basins investing in additional hydroelectric generation to meet the high electricity demands of the southern river basins and, in so doing, could generate much-needed income for the northern basins (MRC 2012).

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81 Funded by the World Bank with an International Development Association grant to the SAPP.
The Grand Inga scheme in the Congo basin presents an opportunity to put benefit sharing into practice in the region. The rapids on the Congo River at Inga in the province of Bas Congo have an estimated hydropower potential of 40,000 MW, and have long attracted the imagination of power developers (World Bank 2014b). The Inga 1 hydropower plant was commissioned in 1972, and Inga 2 was added in 1982. Inga 1 and Inga 2 have a combined installed generation capacity of 1,800 MW. However, the available operational capacity of both plants has dropped below 900 MW, and both plants are currently undergoing rehabilitation with World Bank financing. A Grand Inga scheme was first studied in the 1970s, and would require the construction of a large dam across the Congo. A new approach of a series of smaller hydropower developments was adopted in 2011. The staged development of the Inga site is considered more in step with local and regional energy demand growth, limits the needed upfront investment, and significantly reduces risks.

The next stage of the Inga site development would be Inga 3 Bass Chute (BC). Figure 30 illustrates the project, which will include a diversion of part of the water of the Congo River into the Bundi tributary, a dam across the Bundi valley, a hydropower station equipped with 11 units for a total installed capacity of 4,755 MW, and transmission lines connecting the power station to Kinshasa and to DRC’s border via Kolwezi (Katanga region) (World Bank 2014e). South Africa has shown strong interest in the low-cost clean energy that could be produced at Inga. On November 2011, presidents Joseph Kabila and Jacob Zuma signed a memorandum of understanding on the phased development of Inga. During the October 2013 state visit of President Zuma to Kinshasa, the governments of South Africa and DRC signed a treaty on Inga governing the electricity trade between the two countries. The treaty provides the framework for the facilitation of power generation from the Grand Inga project and its delivery to the border between DRC and Zambia, including the agreement that DRC will purchase 2,300 MW and South Africa will purchase 2,500 MW from the first phase of the Inga 3 BC development (see DRC&RSA 2013 for more details.)
Given the extremely high cost of this scheme and the many countries that will need to be passed through to deliver power to South Africa, the Inga 3 project will be extremely complex to structure and finance. A smaller and less politically complex project (at least on the face of it), the 1,500-MW Mphanda Nkuwa hydropower project on the Zambezi River downstream of Cahora Bassa has taken many years to advance. It is hoped that the new SAPP Project Advisory Unit—with more skilled staff in project preparation and funding from donors—will be able to advance these complex regional programs.
Figure 30: Development of the Inga Site on the Congo River

**Evidence on cross-sector planning**

The Revised Protocol on Shared Watercourses in the Southern African Development Community (SADC 2000) makes no mention of the energy sector, which contrasts with the earlier 1995 version that included monitoring the establishment of hydroelectric power installations and monitoring the generation of hydroelectric power in the functions of river basin management institutions.

**Box 7: The 2013 SADC Multi-Stakeholder Water Dialogue**

In 2013, the SADC Multi-Stakeholder Water Dialogue focusing on the WEF nexus was held in Lusaka. The key outcomes of the meeting were as follows:

- The nexus approach must be tailored to the context of SADC countries and enable growth and development of the economies. As such, the approach to the nexus should concentrate on infrastructure development and institutional capacity building based on the nexus approach that helps deliver these development goals.
- The SADC Regional Indicative Development Plan, the SADC Regional Water Policy, and the SADC Regional Infrastructure Plan all recognize the need for more integrated planning across sectors and countries.
- Both policy and economic instruments (such as pricing) are important to achieving desired outcomes under a nexus approach.
- Champions of the approach at different levels need to be identified to drive the process in their respective constituencies and sectors.
- Integrated platforms need to be created to plan, manage, and implement cross-sector solutions and to build deeper understanding.
- For sustainable and effective solutions, consideration must be given to actively engaging the private sector; expanding the mandate of regional institutions, such as the river basin organizations; promoting opportunities and capacities for integrated research; and drawing attention to the role of ecosystems.
- In the SADC region, about half of the member states have the water and energy sectors situated in one ministry, thereby improving possibilities of intersectoral linkages.

*Source: SADC 2013.*

**5.7 Information Gaps**

Implementing a cross-sectoral approach to power and water planning that takes into account climate change can be restrained by a lack of information and capacity to apply information through water and planning tools:

- Cross-sectoral power sector investment planning requires knowledge of the water intensity of potential investment technologies and how climate change may affect power supply.
- Water sector planning and how to allocate water among users require knowledge of current levels of available resources and future weather patterns, taking into account climate change. This information is complex, and there is a need to develop tools that integrate sector supply and demand and climate change impacts.
Overall statistical capacity for most of the countries is relatively low compared with the International Bank for Reconstruction and Development (IBRD) country average of 74.8 (Figure 31), and there is significant disparity among the region’s countries in terms of available data. While data and research are relatively well advanced for South Africa, far less data are available—for example, on water resources and climate impacts—for many other countries in the region.

Figure 31: Statistical Capacity Indicators for Selected Southern African Countries (2015)


Water Intensity Data on Regional Energy Generation Technologies

Currently, data on energy technologies’ water demands (consumption and withdrawal) are global and are often depicted as a range, indicating the difficulty of providing a definitive figure for energy technology consumption. IEA and World Bank (2015) disputes the usefulness of such global data to help planning or operations in developing countries, as there is no single factor for a specific energy process (see also Madani and Khatani 2015).

There is evidence that South Africa is using data on the estimated water intensity of its power plants (World Bank 2015b), but it is not clear whether the data can be applied to other locations.

Regional Water Resource Data

Water resource scarcity is the central point of the water–energy nexus. Knowledge of water resources and how they will vary in the future is therefore fundamental to any energy–water nexus decision. There is evidence of significant underinvestment in water information as an input to decision making in Africa and a critical lack of adequate hydrological data to estimate current and future water resource availability (SIWI 2010; Miralles-Wilhelm 2013).

Hydrological data availability across the region
Although significant research has been conducted privately by riparian states, very little information in the public domain is available on river volumes and flows. This presents a significant challenge that needs to be addressed (Turton 2010). A study for the SADC secretariat (EBI 2010) reviewed the level of data available by member state for the purposes of economic accounting of water. The results, presented in Figure 32, show that data availability by country is variable. Where data use and supply data are generally available, information on water quality is generally not. In fact, no reliable data are available at the regional level to provide an indication of water quality trends (Turton 2010). This is a concern, given the general trend in the SADC region toward deteriorating water quality (Turton, Ashton, and Jacobs 2008).

Figure 32: Data Availability by Member State

<table>
<thead>
<tr>
<th>Country</th>
<th>Surface &amp; groundwater infrastructure</th>
<th>Water supply sources &amp; returns to environment</th>
<th>Water uses &amp; allocation</th>
<th>Waste water</th>
<th>Waste efficiency</th>
<th>Water charges (taxes, taxes, subsidies)</th>
<th>GDP</th>
<th>Water financing &amp; production costs</th>
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<tr>
<td>Angola</td>
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<td>Democratic Republic of Congo</td>
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Source: EBI 2010.

The EBI study concludes that data availability is a major constraint in SADC countries, noting that although data exist, the information tends to be scattered among institutions and not in a usable format. Remedy this problem could take at least a full year of intensive data collection and processing (EBI 2010).

5.8 Parallel Work in Other Regions

The need to strengthen the capacity of regional and national institutions to facilitate an integrated, climate-resilient approach to water and energy planning at the national and regional levels is not peculiar to Southern Africa. Information and institutional capacity shortfalls are a global issue to a greater or lesser extent, depending on the region. This report has already referenced the global effort on developing integrated resource modeling (Chapter 3) and work.

The purpose of economic accounting is to provide a consistent framework for analyzing the impact of the economy on water resources and the contribution of water resources to the economy.
carried out in Europe by Électricité de France and the World Water Council to integrate water valuation into energy planning (Bellet and Spurgeon 2012; EdF/WWC 2015).

The World Bank is currently delivering a number of projects in Central Asia to improve the region’s capacity to reflect the role of water in its economy, and improve energy and water sector investment in climate resilience. These projects are listed in Annex 3 as an illustration of support that is being offered by the Bank in relation to nexus capacity issues.
Chapter 6: Conclusions

The term energy–water nexus is used to describe the intertwining of energy and water supply and demand. Energy is used to produce and distribute water that is needed, in many cases, to produce energy. Water resource availability lies at the heart of the nexus, in part because of the dependence of energy and water supply upon this availability, and because water resources tend to be undervalued, leading to their unsustainable use. The effects of climate change—namely, changes in ambient temperatures and rainfall patterns—interact with the nexus, changing water resource availability and the performance of energy technology (to name a few of its potential impacts). Most importantly, climate change imposes deep uncertainty on decision-making processes, since only the general trend and not the timing and magnitude of its impacts are known.

The energy–water nexus is widely recognized at the international level, and a number of frameworks have been developed to assist policy makers with developing their understanding (for example, SEI/Hoff 2011). Also, substantial international data relate to the nexus. For example international research provides information on how climate change may affect individual countries and there are datasets on power generation’s water requirements. Research is ongoing to develop robust decision-making approaches that ensure that investments are climate resilient. A recent development is integrated energy–water planning tools that enable policy makers to quantify the trade-offs to inform investment decisions.

6.1 Relevance of the Energy–Water Nexus for Regional Planning

The interrelationship between water and energy supply, water resources, and climate change is particularly relevant to decision making in Southern Africa. Its regional water resources are unevenly distributed both spatially and temporally, leading to significant water scarcity in some parts of the region and relative abundance in others. There is also limited knowledge on the region’s overall water resource levels. Climate change is expected to reduce rainfall levels, increase rainfall variability, and increase ambient temperatures, but there is little certainty about when and by how much (Bates et al. 2008).

In light of these spatial differences, water and energy sector planning needs to be approached in tandem at a local, national, river basin, or regional level, depending upon the nature of the issue. Both sectors need to assess the value of the water resources they consume and use this information to improve overall efficiency in terms of the freshwater they consume or withdraw. They also need to ensure that planning minimizes overall costs and maximizes benefits. Examples of some of the key issues relating to water and energy planning are highlighted as follows.

Climate change may result in increased water scarcity for the region. One response to this could be to construct additional reservoirs. In doing so, by using a nexus approach, planners should be considering opportunities for synergy benefits, such as investment in multipurpose reservoirs (such as for storing water and producing hydropower). The region has a number of large-scale, energy-intensive (sometimes transboundary) water-transfer schemes underway or under consideration. While water trading has the potential to generate mutual benefits, the nexus between energy and water suggests that where water is being transferred for the purposes of energy production, it may be more efficient to invest in hydropower generation in areas of abundant water and to import power (Entholzner and Reeve 2016; Allan 2006). For coastal
countries, such as Namibia, desalination offers another solution, but is again energy intensive; therefore, these countries should look to co-locate thermal or renewable energy production with desalination technologies to exploit synergies.

Hydropower generation is an important and increasing contributor to regional power supply. Its obvious connection with regional water resources makes a direct link to the nexus. The recent drought and its impact on hydropower output (power output from the Kariba Dam has been reduced by 50 percent, for example) illustrate hydropower’s vulnerability to climate change and implies a different approach to investment decisions that accommodates deep uncertainty by employing robust decision-making techniques to ensure that future hydropower investments are resilient to climate. Another significant challenge is the need to take into account the full economic costs of the water that is withdrawn for hydropower generation, including downstream impacts, such as changes to river flow rates, and silting patterns, and to consider synergy solutions, such as multipurpose reservoirs.

Significant coal reserves mean the region continues to be heavily reliant upon coal-fired power generation. Cooling technologies vary significantly in terms of the amount of freshwater they withdraw, and despite lowering the overall efficiency of power generation, dry-cooled solutions may be the most effective solution when water costs are fully accounted (as the recent Thirsty Energy research proved for South Africa power generation investment (World Bank 2015b)). Because power generation and cooling technologies perform differently under different ambient conditions, international data on power generation and its water consumption and withdrawal decisions should be supplemented by local performance data, wherever possible.

6.2 Key Areas to Be Addressed

While substantial progress has been made to recognize water–energy links in many countries’ legislation and plans, there is evidence of significant barriers across the region with regard to implementing a cross-sectoral approach to planning. These result from capacity constraints at many levels, including a lack of data (and capacity to collect and further analyze data), and limited institutional capacity to facilitate data sharing and the necessary cross-sectoral coordination to implement plans and strategies.

There are significant gaps in regional water resource data, preventing for example, the development of water resource allocation plans (ODI, ECDM, and GDI/DIE 2012). There is a need to improve knowledge of the amount of water that is being withdrawn and detail on streamflow rates (Miralles-Wilhelm 2013; Droogers, de Boer, and Terink 2014). Data on energy generation technology water use (withdrawal and consumption) could also be improved to provide data that are reflective of the local climate, rather than relying on international data (IEA and World Bank, 2015). Because these data may exist in some instances, there is a need to coordinate at a regional level to share this information.

In terms of data analysis, climate change imposes deep uncertainty, and with it a need to analyze investment opportunities from a different perspective, opting instead for climate-resilient strategies that minimize potential losses under a range of scenarios (World Bank 2016a). Again, capacity within the region to undertake this analysis needs to be developed. Associated with this is the significant need to develop practical integrated energy–water planning tools, to enable decision makers to quantify power generation investment trade-offs
at the national and regional levels and take account of the uncertainties imposed by climate change (Miralles-Wilhelm 2016). The current work by the World Bank’s Thirsty Energy Initiative to develop a national South African integrated model provides the first regional example of such a tool (World Bank 2015b). The Bank is also supporting the SAPP with the development of its new Regional Power Sector Masterplan, which is expected to incorporate approaches that seek robust options under the various outcome scenarios (including climate change).

Southern Africa has institutions at the regional level that are well positioned to undertake integrated, regionwide planning. SADC already recognizes the nexus and the importance of understanding the scarcity value of water resources through such initiatives as the economic accounting of water and the SADC Water Information Sharing Hub. An analysis of SADC’s RIDMP reveals limited regional coordination for its proposed water infrastructure projects, with no projects planned involving three or more countries (SADC 2012a). While RBCs have been established to coordinate information, and in some cases, integrated planning at the river basin level, evidence on their performance to date suggests they are quite limited in their ability to implement cross-sectoral plans, and in most cases their role remains limited to that of information coordination (CRIDF/DfID 2014a). Also, their geographic basin-level focus means they are unable to act on issues that extend beyond the basin. The SAPP provides a basis for regional coordination through power trading, but there appears to be a lack of political will to rely on neighboring countries: national plans continue to emphasize self-reliance, despite the clear potential benefits of planning and working at a regional level.

6.3 Suggested Next Steps

A priority for the region is to bring together regional stakeholders in an organized manner to discuss the nexus and ultimately agree on what the key priorities are for cross-sectoral coordination in the region and who are the main “champions” to help address each of these priorities. The recent SADC Energy and Water Joint Ministerial Workshop held on June 20, 2016 has helped create awareness and context for such a process. This Paper proposes the following next steps:

- Convene focused meetings at the SADC level to better inform regional stakeholders on the key overarching nexus issues for the region. These meetings would include the main findings contained in this background paper. As an output of these meetings, there would be a need to pull together an overarching matrix that sets out the key priorities identified by the stakeholders, and for each, identify the relevant stakeholders connected with these issues and champions for addressing them in the region. A potential convener for these meetings would be the SADC Secretariat.

- A following step would be to conduct focused workshops at various levels (national, regional, sectoral, and cross-sectoral) on key analytical nexus-related issues, such as water valuation, robust decision-making techniques and their application to climate-resilient investment, and integrated modeling tools. A key output of these workshops would be a view on the current data and analytical capacities of individual member states to carry out such analyses, to identify significant data gaps and whether in the first instance it is most appropriate to develop these capacities at a national and/or regional level.
• Regional energy and water planning stakeholders would subsequently need to reconvene to discuss the identified priorities, gaps and relevant champions and determine how implementation will be taken forward.
Annex 1: A Summary of the Key Water–Energy–Food Nexus Frameworks

Since the Bonn 2011 conference on the WEF nexus, several nexus frameworks have been published. These frameworks demonstrate sector interdependency and the exogenous impacts of population growth and climate change, which will impose significant pressures on the nexus. This annex presents the framework developed by SEI/Hoff (2011) and the World Economic Forum (WEF 2011b) and the Forum’s discussion of the WEF interlinkages (WEF 2011a).

A1.1 Stockholm Environment Institute/Hoff WEF Nexus Framework

The SEI/Hoff (2011) nexus framework focuses on resource security (Figure A1.1). It illustrates (1) the links between the water, food, and energy sectors and their reliance on limited water resources; and (2) the pressure that external factors, such as urbanization, population growth, and climate change, impose on resource security. The purpose of the framework is to help policy makers address the current issue of unsustainable patterns of growth under resource constraints through a better understanding of WEF relationships. Solutions are to be found in terms of innovation and finance and better governance where transaction costs are outweighed by the benefits of reorganization.

Figure A1.1: Stockholm Environment Institute/Hoff WEF Nexus Framework

Source: SEI/Hoff 2011.
A1.2  World Economic Forum WEF Nexus Framework: Global Risks

The World Economic Forum defines the WEF nexus as a risk cluster that acts as a chronic impediment to economic growth and social stability (WEF 2011b). Economic growth and population growth are defined as risk drivers that lead to resource-intensive consumption patterns, and climate change further drives resource insecurity through changed rainfall patterns. Governance failures in terms of shared resource management generate tension that can lead to conflict. Economic disparity exacerbates all three risks as governments seek short-term unsustainable solutions, such as importing water-intensive crops to address food insecurity (Figure A1.2).

Figure A1.2: System Diagram for Global Risks Associated with the WEF Nexus

The World Economic Forum describes the implications of the WEF nexus risk cluster in terms of risks that may subsequently affect governments, society, and business as a direct consequence of the WEF nexus. These implications are summarized in Figure A1.3.

Figure A1.3: Impacts of Risks Related to the WEF Nexus (Nonexhaustive)

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Direct Impacts</th>
<th>Indirect Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact on governments</td>
<td>Stagnation in economic development</td>
<td>Increased social costs linked to employment and income loss as agriculture is negatively affected National security risks/conflict over natural resources</td>
</tr>
<tr>
<td></td>
<td>Political unrest</td>
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<td></td>
<td>Cost of emergency food relief</td>
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<td></td>
<td>Significantly reduced agricultural yields</td>
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<td></td>
<td>Threats to energy security</td>
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<tr>
<td>Impact on society/</td>
<td>Increased levels of hunger and poverty</td>
<td>Migration pressures Irreparably damaged water resources Loss of livelihoods</td>
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<td>populations</td>
<td>Increased environmental degradation</td>
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<td>Severe food and water shortages</td>
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<td></td>
<td>Social unrest</td>
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<td></td>
<td>Food price spikes</td>
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<td>Impact on business</td>
<td>Export constraints</td>
<td>Lost investment opportunities</td>
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<td></td>
<td>Increased resource prices</td>
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<td></td>
<td>Commodity price volatility as shortages ripple through global markets</td>
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<td>Energy and water restrictions</td>
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</table>

Source: WEF 2011b.
Proposed risk response strategies include recognizing the trade-offs in the WEF nexus, integrated and multistakeholder resource planning, regionally focused infrastructure development, market-led resource planning, innovation, regionally focused infrastructure development, and community-level empowerment (WEF 2011b).

A1.3 World Economic Forum: Water Security

The significant relationship between the energy and water sectors was given special attention by the World Economic Forum, in conjunction with Cambridge Energy Research Associates, in the 2009 report *Thirsty Energy: Water and Energy in the 21st Century* (WEF and IHS/CERA 2009; WEF 2011a). The research highlights the dichotomy that producing (most types of) energy requires water and that producing water (usually) requires energy, both in varying degrees, depending on the technology, processes, and type of energy or water being produced.

The 2011 research proposes addressing the energy–water nexus from a technological perspective, for example, by:

- Changing electricity generation technology from water cooling to air cooling or to integrated gasification combined-cycle generation plants;
- Investing in clean energy and clean water synergy solutions, such as renewable energy-powered desalination plants;
- Marketing wind as a low-water and low-carbon power alternative; and
- Combining water and energy efficiency measures to improve provision of both services.

Further, the report highlights an absence of “joined-up” thinking at either the technological or the political decision level between the energy and water sectors—something that one contributor to World Economic Forum (2011a) describes as a “choke point.” This is particularly poignant for climate change policy. The *Thirsty Energy* book notes the high water intensity of clean energy solutions, such as shale gas and biofuels, and asks: “Are energy policies promoting low carbon and low water use really possible?” (IHS/CERA 2009).

The research sets out questions for the energy sector and the broader decision-making community, which today in 2016 remain relevant:

- How will the energy sector’s share of water use change in the future?
- How can energy companies measure and monitor their water use, given the local nature of water resources and the differing values of water from place to place?
- What role will water markets play in allocating future resources? How might water markets change the economics of various energy technologies?
- How can the energy industry best engage with other stakeholders, including agriculture, other industries, and government, to shape future water policy?
- What technologies can improve the water efficiency of the energy industry? How can the energy industry become better integrated with other industries, agriculture, and municipal and wastewater operations to optimize water use and reuse?
Annex 2: Understanding National Planning and Cross-sector Coordination

A continuing theme across all the national country analyses that follow is the need for additional water infrastructure investment to improve access. Thus, looking forward, a priority for cross-sectoral policy making is to ensure the policy attracts water infrastructure investment (CRIDF/DfID 2014c).

On cross-sectoral coordination, although some countries allude to this in their national plans (for example, many national water plans refer to an IWRM approach), most countries have yet to fully develop and implement plans. There is even less evidence of cross-sectoral coordination in energy planning. While some countries’ planning documents (such as South Africa, for example) may explicitly refer to the water requirements of power generation, it is not clear that these references are evidence of full two-way coordination between the two sectors. Countries, such as Lesotho, that are principally reliant on hydropower as their national power source have an automatic link between the water and energy sectors for the purposes of power planning because of the power sector’s reliance on water resources. However, again this relationship often works in one direction, with the power sector investing considerable resources in researching water requirements and availability, and obtaining the needed water, and investing less in considering the sector’s impact on water resources. There is also the feeling that despite the plethora of individual national strategic plans and projects, not enough effort and resources are being channeled into ensuring that their many objectives are met within the allocated timescales (SADC 2016).

A2.1 South Africa

Water Priorities

South Africa is a riparian state to five of the region’s major river basins: the Orange–Senqu, Limpopo, Incomati, Maputo–Usutu–Pongola, and Umbeluzi basins (see Table 2 and Figure 17). While water resource management is overseen by the Department of Water and Sanitation, administration has been decentralized to the level of 19 water management areas (soon to be reduced to nine) (World Bank 2015b).

Table 3 shows that South Africa withdraws the highest proportion of available renewable water resources of the key study countries (24 percent). This is the result of both high levels of demand for water as well as relatively low levels of mean annual rainfall (Figure 16). Another complication arises from the location of key economic centers in areas of low rainfall. To manage this demand, the country has constructed a large number of dams and is reliant on water imports through transfer schemes, such as the LHWP (discussed below).

Continuing to seek access to water resources beyond its national boundaries is a key priority for South Africa. Current activity includes seeking regional solutions through the creation of joint committees (for example, with Zimbabwe) to secure water from the Zambezi basin (see discussion on ZAMCOM) and the Orange–Senqu basin (see discussion of the RBCs in section 5.2 Regional Water Resources).

Given the constraints on water resources, another key priority is to reprioritize water use, limit the use of water in the country’s coal-fired plants, and promote water-efficient technologies (World Bank 2011). The water sector is also seeking to improve its:
Institutional framework; Value for money; Monitoring and evaluation; Rural water supply—understanding how to address sustainability issues; and Urban water supply—improving supply quality and pricing.

In 2015, South Africa announced that it would build or expand six dams over the next decade to address the long-term water and sanitation needs of the country. These include the dam at the Mzimvubu River in the Eastern Cape, the expansion of the Clanwilliam Dam in the Western Cape, the Nwamitwa Dam and Tzaneen Dam in Limpopo, the Hazelmere Dam in KwaZulu-Natal, and the Polihali Dam in Lesotho, which will provide water to Gauteng. In announcing these investments, the Presidential Infrastructure Coordinating Commission stated a need to improve coordination with local water distribution services to avoid delaying the operation of these projects.  

As background for the World Bank’s Thirsty Energy Initiative to create an integrated energy–water–climate model for South Africa, Miralles-Wilhelm (2013) analyzed South Africa’s water data resources and identified a number of challenges for policy makers:

- High degree of spatial and temporal variation in hydrometeorological variables and resulting streamflow;
- Lack of adequately long or continuous records of rainfall (and other hydrometeorological variables) and streamflow;
- Lack of information on land-use changes and both spatial and temporal variations in water use; and
- Lack of quantitative understanding of the mechanisms of some critical hydrological process, notably channel transmission loss and surface water and groundwater interactions.

To address hydrological data gaps, the SADC secretariat, with the support of the World Bank, has launched a regional project to build sustainable groundwater management in the region. One component of the project is to operationalize the SADC Groundwater Management Institute as a regional center of excellence. Another component focuses on improving the availability of and access to knowledge, scientific research, and data on groundwater.  

**Energy Priorities**

South Africa’s electricity supply is provided by the state-owned utility, Eskom, which also owns transmission and distribution networks. Eskom generates approximately 95% of South Africa’s electricity and supplies about half of electricity generated, with the other half distributed through a large number of municipalities. Eskom operates 23 power stations, with a total installed generating capacity of 42.1 GW, of which 85 percent is coal fired. Although installed capacity exceeds demand, the plant availability of the generation fleet, most of which

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was constructed in the 1970s and 1980s, has declined. This has resulted in a low reserve margin, to the extent that Eskom imposed rolling blackouts (load shedding) in 2008, 2014, and 2015 in order to preserve the integrity of the national grid. Figure A2.1 shows that Eskom’s capacity factor and reserve margin have dropped significantly in the last decade. An investment program is underway: in 2015, South Africa commissioned 1,479 MW of new generating capacity and decommissioned 90 MW from its coal-fired plants (SADC 2016), and has committed to building a total of 18,576 MW new power generation capacity by 2021 (World Bank 2015b).

**Figure A2.1: Eskom’s Capacity Factor and Reserve Margin (2003–14)**

Source: World Bank, based on sector dialogue.

South Africa’s energy priorities are set out in a combination of documents, including the 2013 update of the 2010 IRP (RSA/DoE 2013a). More recently, Eskom’s actions in 2015 were driven by priority actions aimed at eliminating the need for load shedding. The longer-term priorities relate to development of further generation capacity. The update to the IRP focuses on regional hydropower, additional coal, and gas and includes the possibility of nuclear power. Figure A2.2 shows that hydropower from Mozambique (Mphanda Nkuwa is a planned 1,500-MW generating plant on the Zambezi River) is the least-cost source of energy, followed by coal and assorted gas-based generation. The short-term focus is on repairs to existing plants, increased demand-side management, and a more focused attempt to exploit gas-fired generation (both through global liquefied natural gas and through purchase of currently available and future potential gas from Mozambique).
South Africa’s Renewable Energy Independent Power Producer Procurement Programme aims to increase the proportion of renewable energy in the generation mix to up to 19GW installed capacity by 2030. As a result there has been significant private sector renewable energy activity including four successful tenders for wind and solar Independent Power Producers totaling 3.9 GW and private sector investment amounting to US$14bn (World Bank 2014d, sector dialogue).

**Legislation, Planning, and Evidence on Cross-sectoral Coordination**

South Africa’s energy planning is guided by its 2008 National Energy Act, the IRP for electricity, and the draft 2013 Integrated Energy Planning Report (RSA/DoE 2008, 2013a, 2013b). A review of these documents suggests that energy planning takes into account water availability to some extent by explicitly referring to the water requirements of power generation. Access to water resource is limited by overall national water constraints and policy measures to reduce overall water consumption by the energy sector. A fully dynamic, two-way approach to planning between water and energy is not in evidence.

Prasad’s 2012 analysis of the energy–water nexus in South Africa states that the nexus is not sufficiently recognized in its policies, regulations, and laws, and that although the connection has been made by the mining industry, Eskom, and the banking sector, there are still many important aspects of the economy that have not. At a national level, policies and laws do not yet mention the energy–water nexus. Institutional barriers pose a serious challenge, and information dissemination, stakeholder involvement, and a culture of consultation and participation need to be created. At a local level, the study finds that the local governments of Johannesburg and Cape Town make the connection between water and energy in their respective spatial development frameworks and plans; however, this is not the case for local rural governments (based on an analysis of the rural municipality of Elundini and its Spatial
Development Framework). Overall, Prasad (2012) describes the general level of awareness of the nexus in local, rural government as “concerning.”

South Africa’s water planning is guided by the National Water Act of 1998 (RSA 1998) and the first and second national water resource strategies (RSA 2004, 2012). As Table A2.1 shows, practical application of these laws and plans is proving to be difficult, and implementation progress is slow.

**Table A2.1: Implementation analysis of South Africa’s First National Water Resource Strategy**

<table>
<thead>
<tr>
<th>Achievements</th>
<th>Outstanding challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water reconciliation strategies in major urban areas and improved insights into reliable future water demands and supplies</td>
<td>Achievement of water conservation and water demand management targets</td>
</tr>
<tr>
<td>Improved sector collaboration and participation</td>
<td>Streamlined water allocation reform to redress past racial and gender imbalances in access to water for productive uses and to address poverty and inequality</td>
</tr>
<tr>
<td>Water-sharing agreements and institutional arrangements in place in all transboundary basins</td>
<td>Implementation of environmental flow monitoring</td>
</tr>
<tr>
<td>A significant proportion of reserve determinations have been conducted with different levels of confidence</td>
<td>Establishment of water management institutions and the decentralization of water resource management</td>
</tr>
<tr>
<td>Development of new water resources and water supply infrastructure and an investment in improved dam safety for state dams</td>
<td>Strengthening of regulation of water resources and water quality</td>
</tr>
<tr>
<td>Incentive based regulation through Blue and Green Drop assessments</td>
<td>Improvement of technical and management skills to implement developmental water management</td>
</tr>
<tr>
<td>A learning academy to improve skills and capacity within the sector</td>
<td>Improvement in the integration of monitoring and information management</td>
</tr>
<tr>
<td>Two catchment management agencies established</td>
<td>Reduction in the backlog of infrastructure maintenance</td>
</tr>
</tbody>
</table>

*Source: World Bank*

The country is having difficulty establishing new water management institutions. Only two catchment management agencies (CMAs) are fully functional out of the 19 that were envisaged (Mehta et al. 2014). Although RBOs were a key concept, the political emphasis of improving water supply means that water resources continue to be managed in a centralized fashion (Muller 2014), and converting the irrigation boards into multisectoral user organizations has
been fraught with problems. An institutional realignment is underway advocating the establishment of nine CMAs, rather than 19. Overall, implementation of an IWRM approach is an open question in the country (Mehta et al. 2014).

A2.2 Lesotho

Water Priorities

Water is Lesotho’s most important natural resource. The country is a riparian state to the Orange–Senqu River Basin (Table 2) and located in the wetter areas of Southern Africa, including the headwaters of three main river systems—the Senqu, Mohokare–Caledon, and Makhaleng. Lesotho’s abundant water resources enable it to generate 3 percent of its overall GDP (World Bank 2015c). The main source of water revenue comes from the LHWP (discussed in Section 5.2 Regional Water Resources).

Despite Lesotho’s abundant water (around 1.4 percent of its available renewable resources are withdrawn (Table 3)) and significant investment (World Bank 2015d), water access is low. Around 64 percent and 57 percent of rural and urban households, respectively, have access to water (GoL 2012). Severe water access problems are experienced in the lowlands, where about two-thirds of the population lives and where the country’s key industries of textiles and light manufacturing are based (particularly Maseru and its surrounding areas). It follows that key priorities for the country are water supply services for industries, commercial centers, households, and other institutions (GoL 2012).

The Lesotho National Strategic Development Plan (NSDP) identifies strategically investing in water infrastructure as one of the top national priorities (GoL 2012)—namely, the LHWP Phase II and Lesotho Lowlands Water Supply Programme. The first phase of the latter—the Metolong Dam and Water Supply Programme—was launched in 2008 and was inaugurated in November 2015 (major areas complete). This $31.8 million project is being financed by the World Bank and other development partners to provide two-thirds of the population living in the country’s lowlands with clean and abundant water. The project is expected to meet domestic and industrial requirements for at least the next 40 years (GoL 2012).85 To date, the project has increased security of supply to Maseru, Teyateyanang, Rom, Morija, and other surrounding towns. A further phase is recommended to mitigate potential climate change and current variability (World Bank 2015c).

A lack of data, capacity, and tools is hindering Lesotho’s understanding of how its water resources will be affected by climate change. World Bank (2015c) identifies the following issues and actions:

- Currently, data limitations undermine the country’s ability to monitor climate predictions and respond to changes. This problem could be addressed by designing and implementing an optimized hydrometeorological network;
- The country does not have information on the economic use or value of water;

85 Also see http://www.metolong.org.ls/inauguration.html.
• The sophistication of the tools required to monitor and respond to climate necessitates sustained capacity development are an issue and capacity building should be incorporated into the government planning process; and
• The WEAP tool developed to undertake analysis could be improved to create one-day steps to analyze competing water uses, and could expand the geographic scope of the model to include the demand areas of South Africa that rely on Lesotho’s exports to improve analysis of potential vulnerabilities and trade-offs.

Energy Priorities

The key national energy priorities for Lesotho are to:

• Increase clean energy production capacity to attain self-sufficiency;
• Export energy and have a greener economy; and
• Have at least 40 percent of the population connected to electricity by 2020.

Lesotho’s energy and water priorities are strongly linked because of its abundant water reserves. Royalties from the completion of Phase 1 of the LHWP enabled the country to construct the Muelta hydroelectric generation plant with a generation capacity of 72 MW, meeting 52 percent of the country’s overall electricity needs. Overall demand is 138 MW (Table 6), and the country’s overall power requirement is around 140 MW in peak periods (winter 2011). Therefore, Lesotho imports approximately 68 MW (40 MW from Mozambique and 28 MW from South Africa). A key national energy priority set out by Lesotho is energy supply self-sufficiency and the potential to use its natural resources to export electricity (as well as water) to the region (GoL 2012). Additional electricity generation capacity is expected to come from wind, pumped storage, conventional hydropower, and solar power.

Despite Lesotho’s potential to generate significant power from its water sources, it faces a significant challenge in terms of connecting its population to the grid because of its sparsely inhabited mountainous terrain (59 percent of total land space and a further 15 percent in the foothills (World Bank 2015d)) and the current low level of electrification, even for rural villages that are well connected to the urban centers of both Lesotho and South Africa (GoL 2012). According to Lesotho’s NSDP, in 2011, an estimated 25 percent of households had access to electricity, and only 5 percent of these are in rural areas (GoL 2012). The aim is to have at least 40 percent of the population connected to electricity by 2020 (GoL 2004). About 70 percent of Basotho’s households use biomass as the main source of energy for cooking and space heating. The cost of increasing access to a dispersed population is a significant barrier. However, the use of solar panels is proliferating in the country and could help overcome this challenge (World Bank 2015d).

Legislation, Planning, and Evidence on Cross-sectoral Coordination

Lesotho’s water planning is guided by the Lesotho Water Act 2008 (GoL 2008) and the Electricity and Water Authority Strategic Plan 2014/15–2018/19 (LEWA 2014). Lesotho’s energy planning is guided by the Lesotho Energy Policy 2015–25 (GoL n.d.) and the Electricity and Water Authority Strategic Plan (2014/15–2018/19) (LEWA 2014). The institutions have been created, but full implementation of the Water Act and associated plans is limited by human capacity and financial constraints.
Aside from the Lesotho Water Commission’s involvement in developing Lesotho’s energy policy (GoL n.d.), neither sector’s documents suggest significant cross-sectoral coordination. In practical terms, there is a moderate degree of coordination between the two sectors. Institutional arrangements seem to provide for joint planning, at least at the project level, and water resources agencies are deeply involved in water-related energy development initiatives.

A2.3 Botswana

Water Priorities

Botswana is a riparian state to three of the region’s major river basins: the Zambezi, Orange–Senqu and Okavango (see Table 2, above). Despite these sources, western Botswana has no surface water and is entirely reliant on groundwater sources (Figure A2.3). Overall, the country is considered water scarce, with endemic drought and varied rainfall (Setlhogile and Harvey 2015).
Figure A2.3: Botswana Groundwater Depth and Population

Priorities for Botswana are to improve its demand management through developing a water pricing policy (water is currently heavily subsidized) and establishing the Water Resources Board and Water Regulator; and to continue to invest in surface water catchment and transfer infrastructure. The country’s water policy framework emphasizes conservation and demand management but implementation is limited and there is limited awareness of the state of water resources in the country, compounded by shortages of data and ineffective monitoring (Rahm, Swatuk, and Matheny 2006). Groundwater withdrawal limits are set but often exceeded. There are also distributional problems with system water losses estimated at 19-26 percent per annum. (Setlhogile and Harvey 2015). Increasing water resource efficiency is listed as a priority in the National Water Master Plan (World Bank 2015e).

Another priority is to shift water supply from ground water to surface water. The government is investing in dams (the Dikgatlhong, Lotsane, Thune, and Mosetse dams) to increase overall dam capacity from 400m3 to 948 m3, (and water transfer schemes (for example, expanding the North–South Carrier and investing in a second carrier the NSC-2 (transferring water to
Southern Botswana) and a further carrier (the NSC-3) to withdraw water from the Chobe–Zambezi River, which will supply irrigation and augment water supply in southeastern Botswana (Setlhogile and Harvey 2015).

**Energy Priorities**

A key priority for Botswana is to address current power supply shortfalls and become a net exporter of energy to the region. Peak power demand is set to increase by 56 percent from 578 MW to 902 MW between 2012 and 2020. Botswana’s power sector has been historically highly dependent on South Africa, but recent supply cuts from Eskom have increased the need to develop indigenous generation options. In 2011, the Botswana Power Corporation (BPC) had installed capacity to supply approximately 12 percent of national demand, leaving 66 percent to be sourced from South Africa. Botswana also sources power from other providers, including Mozambique’s Cahora Bassa hydropower plant and Electricidade de Moçambique (Ofetotse and Essah 2012). These other providers accounted for 22 percent of total supply in 2011.

Botswana’s significant coal and solar resources are being used to develop self-sufficiency. Coal reserves are estimated at around 200 billion tons and an additional 600 MW of coal-fired power generation has been developed with the commissioning of the Morupule B plant (World Bank 2015e). The impact of Morupule B is already being felt. Imports were 2,813 GWh in 2013, falling to 1,623 GWh in 2015, coinciding with increased operation of the first four units. However, Botswana will continue to be dependent on imports until at least 2020, when the rest of Morupule B’s 900-MW total capacity should be operational (BPC, sector dialogue).

Solar power is seen as a natural solution for addressing Botswana’s power shortages. It has Direct Normal Irradiation (DNI) of 3000 kwh/m2/year, which is among the highest in the world (SE4All 2015). The government commissioned its first PV plant in 2012 (the 1.3-MW Phakalene plant). The 100-MW Jwaneng concentrating solar thermal power station project is being discussed. It is envisaged that further PV power will be developed.

Rural access to electricity is another priority for Botswana. At 15 percent, it remains very low by global standards. The cost of rolling out access to dispersed rural populations is a significant barrier, and the use of distributed technologies (such as solar panels) to overcome these challenges has been limited (World Bank 2015e). The government continues its nongrid rural electrification scheme using PV power, which was started in 2006 by the government and the UN. A subsidiary of BPC, BPC Lesedi, is offering solar home systems to rural consumers, as well as other off-grid and renewable energy solutions, such as solar power PV products, rechargeable lanterns, and improved financial support.

**Legislation, Planning, and Evidence on Cross-sectoral Coordination**

Botswana is implementing a reform of its water sector. While water planning is still guided by the Water Act of 1968 and the National Water Master Plan Review (SMEC and EHES 2006),

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86 http://www.reegle.info/policy-and-regulatory-overviews/BW.  
87 In 2009, Eskom supplied 350 MW of electricity, but by 2012 this was cut back to 150 MW. www.finance.gov.bw.  

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a new national water policy has been drafted but has not yet been approved by Parliament, and an Integrated Water Resources and Water Efficiency (IWRWE) Plan was approved in 2013. The latter contains a detailed action plan and the following policy statement regarding water for energy (GoB 2013):

- “Water must be applied efficiently and at a cost that permits the attainment of energy supply security for all sectors of the economy to support the foundations for sustainable economic development and diversification.”

This policy statement is supported by a number of strategy statements:

- “Incorporate water development guidelines into the energy equation and promote the application of technologies to ensure efficient use of water resources.
- Develop comprehensive water accounts and spatial demand forecasts to enable the timely development of water supply solutions integrated within the national water resources planning framework.
- Encourage the adoption of technologies that are more efficient and allow minimal use of water for the cooling of industrial processes and for electric power generation stations in pursuit of energy self-sufficiency and export targets.
- Identify and implement alternative energy solutions, such as development of renewable and bio-energies, that can be integrated into the national energy mix to reduce the carbon contributions through increased water use and energy efficiency.”

Implementation of Botswana’s IWRWE plan will be challenging. The document itself states that knowledge of IWRM is limited, particularly at district level. Also, data collection is expensive, and analysis and interpretation of the data are often forgotten (GoB 2013).

Energy planning in Botswana is guided by the Energy Master Plan (GoB 1996 (reviewed 2003)) whilst the National Energy Policy is still being drafted. There is no IRP and no evidence on cross-sectoral coordination. Planning decisions for coal plants are guided by the location of the country’s coal mines, not by the availability of water resources.

Overall, implementation of the new plans is slow, and while the importance of cross-sectoral planning is acknowledged by the government (for example, through publishing the IWRWE plan), water management is still centralized and stakeholder participation is often nonexistent. There is also a pressing need to revise and expand the water sector’s legal instruments to be more in line with governance arrangements in other sectors (Selthogile and Harvey 2015).

A2.4 Swaziland

Water Priorities

Swaziland is a riparian state to three of the region’s major river basins: the Incomati, Maputo–Usutu–Pongolo, and Umbeluzi. Swaziland’s relatively high average levels of annual rainfall in the western part of the country suggest that it should have abundant water reserves (Figure 16). Yet the country withdraws 23 percent of its available renewable freshwater resources (almost as high as South Africa) (Table 3), and in 2016 it faced countrywide water rationing and
declared a state of national emergency.\textsuperscript{90} The discrepancy is driven by highly variable weather patterns: since 2014, Swaziland has been in drought as a result of the El Niño weather event.\textsuperscript{91}

Swaziland’s total renewable water resources are 4.51 km\textsuperscript{3}/year, with 42 percent originating from South Africa. The level of groundwater resources is unknown. The country has nine major dams with a total storage capacity of around 585 million m\textsuperscript{3}—seven are used for irrigation, one for hydroelectric power, and one for water supply (95 percent of withdrawals is used for irrigation) (FAO 2015). In February 2016, the Hawane Dam, which feeds the capital Mbabane, was at 17 percent capacity (one to three weeks’ supply).\textsuperscript{92}

Priorities for the water sector focus on developing water allocation based on IWRM principles and using water resources to develop the country’s hydropower potential. The National Development Strategy (GoS 2012) sets out the following water resource development strategy goals for 2022:

- Develop an overall policy to cover all water use;
- Establish a water sector committee and initiate the statutory adoption of the draft water act;
- Enter into negotiations for shared waters guided by a national water master plan; and
- Promote catchment management plans for major river systems, dams, and irrigation works.

However historically, strategy implementation in the country has been slow, and stakeholders are concerned that implementation of the 2003 Water Act with its modern foundation on internationally recognized principles, water management institutions, and governance and decentralization of responsibility, is taking too long (GoS 2003). The slow pace of developing important regulations on allocation, pricing, water use efficiencies (particularly for irrigated agriculture), recreational use of water bodies and others while the resource supply dwindles in the face of changing environmental and land-use patterns, is threatening the ability of stakeholders to eventually manage the resource. The formulation of the revised IWRM plan is still a work in progress, and such progress has been hampered by the capacity constraints of water professionals in the country. Much of the technical capacity to collect, collate, and develop strategies is limited to a few individuals. Similarly, the human capacity may not be available to introduce economic water accounts, and IWRM capacity may also be limited in the country (Manyatsi and Brown 2009).

With regard to developing national hydropower generation capacity, the 2009 National Water Policy (GoS 2009) states: “Swaziland shall promote and prioritize the generation of hydroelectric power at mega and micro generation levels to enhance energy security.”

\textsuperscript{90} http://www.times.co.sz/news/106245-water-rationing-goes-countrywide.html.
\textsuperscript{92}http://reliefweb.int/sites/reliefweb.int/files/resources/Swaziland%20Drought_RC%20Situation%20Report_Feb%202016%20RC%20Final%20%20.pdf.
Energy Priorities

Swaziland has the capacity to generate around 70 MW from four hydropower stations (60 MW) and two diesel engines (9 MW), though the latter are no longer economically viable, meeting 27 percent of its total 255-MW suppressed and forecast demand (Table 6). A key priority for the country is to achieve energy security by developing hydroelectric power generation capacity, where possible using multipurpose water structures. Many of Swaziland’s watercourses are not suitable for the development of hydroelectric power generation, and the country is dependent on relatively expensive power imports. In addition, reliance on wood fuel is driving unsustainable levels of deforestation (GoS 2014).

Legislation, Planning, and Evidence on Cross-sectoral Coordination

Swaziland’s water resource planning is guided by its 2003 National Water Act (GoS 2003), the 2009 National Water Policy (GoS 2009), and the National Development Strategy for 2022 (GoS 2012). The National Water Act states the need to integrate power generation and water infrastructure planning, and the National Water Policy contains several policy statements concerning international and regional coordination (GoS 2009, 2014):

- “Planning, development and management of water resources in Swaziland shall be based on the principles of IWRM;
- Swaziland shall adopt a river basin approach in the planning, development and management of water resources; and
- Integrated planning, development and management of dams will be promoted to optimize the use of water resources, maximize derived benefits (such as hydropower, tourism, flood control, irrigation and water supply) and take both positive and negative externalities into account.”

Swaziland’s energy planning is led by the Energy Department of the Ministry of Natural Resources & Energy and the Electricity Company Act of 2007. A National Energy Policy Implementation Strategy project was completed in 2009. This project aimed to guide the realistic fulfillment of the energy policy statements and elaboration of strategies, as well as a time frame for implementing the policies during the short and medium/long terms. In addition the Sustainable Energy for All—Country Action Plan was published in 2014 (GoS 2014).

A2.5 Namibia

Water Priorities

Namibia has low levels of average annual rainfall (Figure 16), but withdraws just 1.6 percent of its available renewable freshwater resources (Table 3). Namibia’s population and water-intensive industries (mining) are located in the coastal regions. This prompted the country to invest in a seawater desalination plant despite hosting the Orange, Zambezi, and Okavango rivers. The plant was intended to produce freshwater for the uranium mining industry, but has been mothballed because of low uranium prices. In addition, two solar desalination plants provide 8,000 liters of drinking water a day (Prasad 2012). There are also plans to revive a

93 http://www.sec.co.sz/electricity/.
scheme to transfer water from the Cubango–Okavango river system to the country’s main centers of demand (Bybee 2014).

Namibia’s water policy priorities (GoN 2008) are to:

- Improve sector coordination;
- Develop an equitable tariff policy; and
- Establish a water regulator.

Energy Priorities

Namibia is a net importer of electricity. Its current installed electricity generation capacity (393 MW) is equivalent to 62 percent of its suppressed and forecast demand (Table 6).

Priorities for the country are to be revealed in the country’s first IRP, which was under review in late 2015, but are expected to include:

- Developing and diversifying Namibia’s energy sources (including the recently shelved Kudu power project, the Baynes hydropower project, a series of coal-fired power stations, and gas power stations, as well as a range of renewable power options);96
- Implementing demand management;97 and
- Promoting regional integration in the electricity sector (improve transmission structure to play a full role in the SAPP).98

Legislation, Planning, and Evidence on Cross-sectoral Coordination

Namibia’s Water Resources Management is currently guided by its National Water Policy (GoN 2000) and its Water Supply and Sanitation Policy (GoN 2008), both of which are implemented. The National Water Policy calls for an integrated (cross-sectoral) approach to water management, but there is no evidence of this approach in practice. The Water Resources Management Act (GoN 2013) has not yet been implemented because of a lack of funding and policy implementation capacity.

Namibia’s energy policy is guided by its 1998 Energy Policy White Paper (GoN 1998). The country recently developed a Namibian-specific energy planning tool based on the TIMES modeling system. This modeling tool takes into account other sectors’ energy consumption (primarily the mining industry), but does not integrate water resource availability (see Rämä et al. 2013 for further details).

Namibia’s two solar desalination plants in the Omusati region, which produce 8,000 liters of drinking water per day, provide one of the region’s few examples of cross-sector working to realize significant synergy benefits between the water and energy sectors (Prasad 2012).

96 Ibid.
97 Ibid.
Annex 3: World Bank Nexus Projects in Central Asia

Central Asia Water Resources Management (P152346)

This project is developing a long-term framework to increase the accessibility and reliability of water resource information and the analytical capacity to use this information for improved water resource planning, monitoring, and management in selected Central Asian water institutions. The project is acting in three areas: information gaps, such as information and planning tools for water resource management; capacity strengthening of the institutional and policy framework; and investment in monitoring systems and related infrastructure.

Central Asia Knowledge Network of Water–Energy–Climate Change CoPs and Institutions (P147959)

There is a strong need to improve the region’s knowledge of climate change impacts and thereafter the resilience of its energy sector to climate change to enable informed investment decisions. Numerous studies are being undertaken to highlight the vulnerabilities of and identify adaptation responses for the regional energy sector at the national and regional levels, through the development of coordinated adaptation policies. The completed Tajikistan study makes the following recommendations: (1) mainstream robust decision making on climate change and plans for the energy sector; (2) build institutional capacity and knowledge networks; (3) improve the use of monitoring, forecasting, and modeling; (4) support climate change-resilient engineering, design, and operation of hydropower plants and transmission and distribution networks; (5) diversify sources of energy supply; and (6) establish measures to improve energy efficiency and water efficiency with win-win climate-resilience benefits.

Central Asia Water and Energy Portal (P147696)

Access to quality information in the public domain is very limited in the region, despite a number of attempts to improve the region’s portals and databases. The World Bank has been working to improve public-domain online access to water- and energy-related spatial information through a number of initiatives. One such initiative is to develop an online portal—a platform that integrates global and local multisector data and raises awareness of the Central Asian water and energy spatial context.

Capacity Building for Improving the Water Sector Professional Development System in Central Asian States (P152685)

This project is designed to improve IWRM capacity through training and curriculum development and to enhance regional knowledge sharing and cooperation through regional training centers.

Capacity Strengthening for IWRM Modeling (P148326)

This project aims to strengthen knowledge and modeling skills, leading to a more effective base on which to identify modeling architecture options and priorities for IWRM in Central Asia. The clients will include a range of the national and regional stakeholders—sector specialists, educators and institutions, and decision makers. The approach supports broader engagement of countries in regional analysis of IWRM, allowing national stakeholders to adapt
or create a system of models and modules that assist in regional analysis, while contributing to more effective understanding of national implications and trade-offs.

**Central Asia Energy–Water Development Program (CAEWDP) Trust Fund (P120142, P155607, P155943)**

The CAEWDP is a multidonor trust-funded initiative supported by the Switzerland’s State Secretariat for Economic Affairs, the United Kingdom’s Department for International Development, the European Union, and the United States Agency for International Development. The goal of the CAEWDP is to help build energy and water security for Central Asia through enhanced regional cooperation among the five Central Asian countries, including Afghanistan, when appropriate.

The CAEWDP has the following main sectoral components:

- Energy development to promote highest-value energy investments and management. Areas of focus include infrastructure planning, winter energy security, energy trade, energy accountability, and institutional development.
- Water productivity to enhance the productivity and efficiency of water use in the agriculture and energy sectors. Areas of focus include capacity strengthening, the Third Aral Sea Basin Management Program, national action plans for water productivity, and rehabilitation of infrastructure.
- Energy–water linkages to strengthen the analytical tools for IWRM to improve the understanding of linkages between water and energy at the national and regional levels. Areas of focus include energy–water modeling, regional hydrometeorology, climate vulnerability, and energy–water dialogue in support of IWRM.
References


87. REEGLE Country Profiles http://www.reegle.info/countries


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