Stockholm Environment Institute

Powering Africa

Unlocking opportunities for energy development in Southern Africa

SEI Report

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Contents

1. Introduction

Southern Africa faces an energy crisis. Despite efforts to increase electricity generation, the region still struggles to meet rising demand (AfDB, OECD, UNDP, 2016). Planned increases in generation capacity have been expected to bridge this gap, but investments have been hindered by a range of issues: electricity tariffs that do not reflect costs; poor project preparation; lack of standardised power purchase agreements; and inadequate policy, regulatory and institutional frameworks (Zhou, 2012). Meanwhile, 68% of residents in member states of the Southern Africa Development Community (SADC) remain without access to electricity (REN21, 2015). In addition, the region's energy mix remains dominated by coal, the main source of electricity used in the region's dominant economy, South Africa (Cohen and Winkler, 2014).

There is an urgent need to tap into the region's vast renewable energy potential, to diversify the power mix and thus increase electricity access and ensure the security and reliability of the supply. On the one hand, regional cooperation and integration in power sector planning and development – for example, through the Southern African Power Pool – present an opportunity for effectively exploiting and managing the region's abundant yet climate-vulnerable hydropower resources to overcome the present energy crisis. Even within the SADC it is widely acknowledged that "investment in electricity infrastructure has sadly lagged far behind regional demand, necessitating greater regional cooperation to share the available power" (SADC 2011). On the other hand, decentralised energy solutions – such as mini- and micro-grids – can be a valuable complement to grid-based electrification, particularly in rural areas where grid extension is technically or financially unviable. Both on-grid and off-grid solutions are vital if the universal energy access target set out in Sustainable Development Goal 7 is to be met.

There is an urgent need to tap into the region's vast renewable energy potential and diversify the power mix.

This paper identifies how centralised and decentralised approaches might support development of a secure low-carbon energy infrastructure in Southern Africa to meet increased demand and ensure universal energy access. In doing so, it sets out the energy challenges facing the SADC region, highlights the political economy challenges in achieving greater regional cooperation in the power sector, and presents opportunities for catalysing decentralised energy systems.

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Data gathered for this report come from a variety of sources: grey and academic literature, energy databases produced by SADC, the Southern African Power Pool and the International Energy Agency (IEA), and fieldwork interviews with regional and national stakeholders. It is also informed by two Powering Africa consortium meetings: an inception phase meeting held at CSIR in Pretoria in March 2014 and an open workshop on water and energy held on fringes of the Waternet/GWPSA annual meeting in Mauritius in November 2015.

2. Energy challenges in Southern Africa

The 15 member states[1] constituting the Southern African Development Community (SADC) are bound together in several ways; both in terms of the various agreements forged under the cooperative umbrella provided by the SADC but also by shared water resources, energy assets and climate systems. In this section we explore how an increasing supply-demand gap and increasing pressures from action on climate mitigation and adaptation are affecting infrastructure for power generation from hydropower and fossil fuels. We then highlight the need for an energy transition within the region.

2.1 Electricity supply and demand gap

Demand for electricity is growing in the region and is predicted to follow economic growth trends of between 3 and 6%. In parallel there is a considerable suppressed demand for electricity access in the SADC (SADC 2012). Overall, 32% of the region's population has access to electricity (REN21 2015). If looking at access in the Southern African Power Pool (SAPP), the regional electricity market platform, in 2010 the share of the population with access to electricity only stood at 24%. This can be compared to the West African and East African Power Pools, which during the same year stood at 45% and 37%, respectively (SADC 2012). Electricity access rates vary widely between countries, from very low levels in the Democratic Republic of Congo (9%) and Malawi (9%) to very high levels in Seychelles (97%) and Mauritius (100%). There are also wide disparities in access between urban and rural areas in countries such as Tanzania and Zimbabwe: 71% versus 7% and 80% versus 14%, respectively (REN21, 2015). In addition, a large share of the population still relies mainly on traditional biomass for cooking and heating, which represents more than 45% of final energy consumption in the region (IRENA 2013).

By the end of 2015, the SAPP had an installed electricity generation capacity of 61 859 MW with an operating capacity of 46 910 MW against a normal peak demand of 48 216 MW (SAPP 2015). If including the current peak demand and generation capacity reserve margins, as well as a suppressed peak demand of 55 464 MW and required reserves, the current regional shortfall is 16 536 MW (SAPP 2015). This regional electricity supply is dominated by fossil fuels. Approximately 62% of the installed generation capacity in 2015 came from coal-fired power plants. The second biggest source of electricity is hydropower, accounting for roughly 21% of installed capacity (SAPP 2015). Wind, solar (photovoltaics and concentrated solar power) and biomass contributed little more than 8% of the total mix. The dominance of coal reflects the dominance of South Africa, which is the region's most industrialised nation and its main electricity producer, responsible for 80% of the region's electricity capacity, over 90% of which comes from coal-fired generation (Enerdata 2016).

Both currently and in projections there is a substantial gap between existing capacity and overall demand, in terms of providing a secure electricity supply for domestic and industrial sectors. The SADC region is also facing several problems in terms of electricity supply: rolling blackouts and rotational load-shedding (the engineered blackout of part of a distribution system in order to avoid complete power outage) are frequent.

Underlying causes include underfunded generation and managing capacities and poorly maintained grid infrastructure. Implementation of planned generation and transmission projects are regularly delayed, while investments have been hindered by a range of issues, including: electricity tariffs that do not reflect costs; poor project preparation; lack of standardised power purchase agreements; and inadequate policy, regulatory and institutional frameworks (Zhou 2012). The varying impacts of these problems can be seen in countries throughout the region. Zambia faces daily blackouts, sometimes for as long as eight hours (Circle of Blue 2015), while in Zimbabwe important industries have been instructed to cut electricity consumption (Reuters 2015). South Africa has also been struggling to meet demand (South Africa.info 2016): rolling blackouts have been frequent in the country since 2008 but have stabilised somewhat after heavy industries were instructed to cut consumption by 10% (The Economist 2015).

1 Angola, Botswana, Democratic Republic of Congo (DRC), Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.

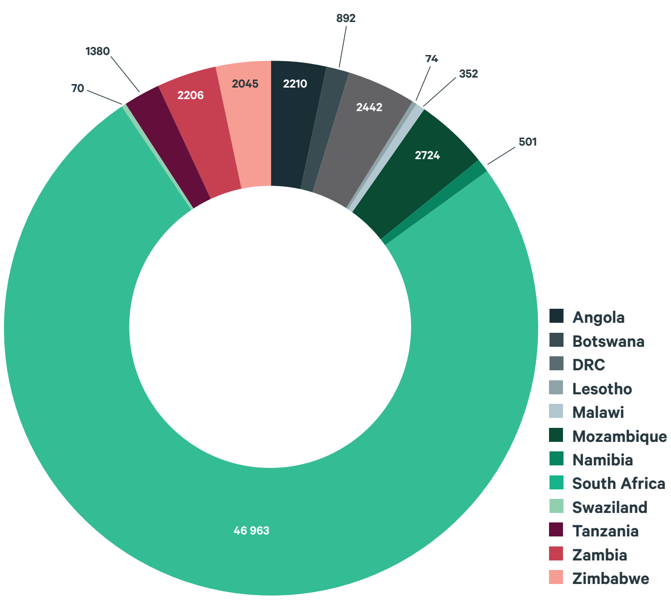
2.2 Climate mitigation and adaptation pressures

South Africa is the main provider of energy to the SAPP joint electrical grid, and its contribution is dominated by fossil fuels, particularly coal, which constitute approximately 90% of domestic electricity supply and about 60% regionally (Department of Energy 2016). Other southern countries in SADC, such as Zimbabwe and Botswana, also rely mainly on coal for electricity generation. Yet there is growing controversy over the continued use of abundant coal resources for electricity generation, given increasing global pressure to mitigate the effects of climate change (Kunambura 2015). This is especially an issue for South Africa, where annual greenhouse gas emissions from coal are already high, estimated in 2012 at 231.9 Mt CO_2 (Cohen and Winkler 2014). While Africa overall contributes little to global CO_2 emissions, with several countries contributing almost none, by contrast South Africa is the world's fourteenth biggest emitter of CO_2 (Carbon Dioxide Information Analysis Center 2016). Evidently, addressing climate issues and associated problems in the SADC region is closely related to tackling South Africa's and SADC's dependence on coal.

At the Conference of the Parties (COP) of the United Nations Framework on Climate Change in Paris in 2016, countries committed through individual pledges to reduce emissions in a common effort to reduce global emission levels. These pledges are known as Nationally Determined Contributions (NDCs). The main purpose of the Paris Agreement is to limit increases in global temperature to below 2°C above pre-industrial levels (United Nations 2014), and all SADC and SAPP members have made NDC pledges. While there is no comprehensive common strategy in the SADC on how to achieve NDC targets at the regional scale, coordinated discussions were held in the lead up to COP 21 on how to interpret and formulate national targets. And the 2012 SADC Regional Infrastructure Development Master Plan sets out an ambition to increase, by 2030, the share of renewable energy in the common grid from 29% to 39%, and to reach an off-grid share of 7.5% (SADC 2012).

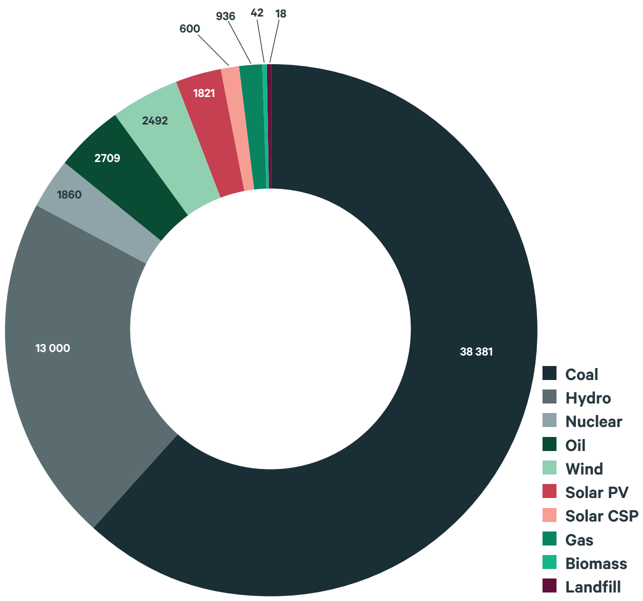
The southern SADC member states that rely on coal for energy (i.e. South Africa, Zimbabwe and Botswana), as well as the northern member states that rely mainly on hydropower, face considerable climate pressures as a result of changing rainfall patterns (SAPP 2015, Zhou 2012). In terms of coal generation, a great deal of water is needed throughout fuel extraction processes, as well as for cooling in thermal power generation. Climate change is exacerbating drought, and the diminishing availability of water is likely to have significant negative impacts on the management of coal-fired power generation. Meanwhile, increasingly irregular rainfall patterns and seasonal droughts pose significant long-term threats to the availability and reliability of hydropower. Present drought conditions and falling hydropower output in both Zambia and Namibia are cases in point.

Figure 1. Total installed capacity in SAPP by country (MW)



Source: SAPP 2015

Figure 2. Total installed capacity in SAPP by source (MW)



Source: SAPP 2015

2.3 Diversifying the energy mix

There is an urgent need to tap into the region's vast renewable energy potential, to diversify the power mix and thus increase electricity access and ensure the security and reliability of the supply. SADC has great potential in renewable energy, especially in wind power, solar photovoltaic (PV), and hydropower. There is also some potential for concentrated solar power (CSP).

The International Renewable Energy Agency (IRENA) estimates annual solar potential at 2195 TWh for solar PV and 1093 TWh for solar thermal (IRENA 2013). But less than 1% of SADC's solar potential is currently being utilised (REN21 2015). There are several different investment programmes aimed at increasing solar power generation in different SADC nations, most notably in South Africa's Renewable Energy Independent Power Producer Programme (REIPPP), in which solar projects contributed 2299 MW (REN21 2015). However, some countries with major solar potential, such as Zambia and the Democratic Republic of Congo, are yet to implement any kind of large-scale solar power system.

The SADC region has an approximate wind power potential of 800 TWh (REN21 2015) and, as is the case with solar power, less than 1% of this potential is being used. But in contrast to solar power potential, which is evenly distributed across the region, wind potential is concentrated in coastal areas. South Africa has the largest installed wind capacity in the region, totalling 2660 MW in the REIPPPP (REN21 2015). Otherwise, investments in wind capacity are generally lagging in the SAPP, although Namibia has announced plans to install 132 MW.

The African continent as a whole is well-endowed with hydropower resources, of which only 8% have been developed (IHA 2013), and SADC is no exception, with most nations having exploitable hydropower resources. The Democratic Republic of Congo stands out with its massive endowment, and the long-planned Grand Inga scheme on the Congo River is envisioned to support a hydro generating capacity of 46 GW (REN21 2015). However, other member states also have generating capacities above 1 GW, including Angola (6.8 GW), South Africa (4.7 GW), Mozambique (3.7 GW), Zambia (2.6 GW) and Zimbabwe (1.1 GW) (REN21 2015). Close to 100% of installed hydropower capacity in the SADC is large-scale, which normally refers to stations generating more than 10 MW (REN21 2015).

With adequate political support, renewable energy (solar and wind) could expand sufficiently to displace fossil fuels. A mix of 50% wind and solar and 20% hydro by 2030 would put the SADC at the level of countries such as Sweden when it comes to overall renewable electricity generation. This would require an adjustment for reaching appropriate reserve margins from 2025, which means that the SADC would increase its energy generating capacity by 10% above minimum requirements to meet demand, i.e., increasing the entire energy generating portfolio now based on renewables, as required to balance the system and manage intermittency.

2.4 Achieving an energy transition

In order to maintain current service levels – which are already severely stretched – electricity generating capacity will need to almost double by 2030. To ensure a secure, reliable and affordable service for those already connected and the many millions seeking access to electricity, significant investment is needed in centralised and decentralised generation, transmission and distribution.

At the centralised level, hydropower continues to have a major role to play in the transition to low-carbon energy systems. Multiple-use water reservoirs – which distribute water between competing demands, such as irrigation, drinking water, and electricity production – are a promising option. Water reservoirs that are reserved for power generation during peak times, and which can also be used for regulating downstream water flows, are an attractive option for balancing on-grid generation from intermittent renewable sources such as wind and solar. At the same time there are great opportunities for developing decentralised renewable energy generation – both off-grid and mini-grids – to meet suppressed demand in areas currently without access to electricity, and where grid expansion may be financially and technically unfeasible (at least in the short-term).

A transformation of the energy system and electricity generating technologies offers several advantages. Firstly, the region would be able to reverse current CO_2 emission trends while still growing the power sector. Consequently, SADC would become a substantial contributor to global commitments on climate change while also serving its own interests by reducing its contribution to climate related impacts. Secondly, transformation of the energy system would lead to a reduced water footprint from the energy sector, which could free up water resources that could contribute to development in other sectors. Secondly, transformation of the energy system would lead to a reduced water footprint from the energy sector, which could free up water resources in the region that could contribute to development in other sectors. Lastly, hydropower could be utilized in different ways, particularly through multi-purpose dams and hydropower storage.

Beyond investment in technology, pursuing low-carbon development of centralised and decentralised energy systems will require considerable investment in new skills, business models, and institutional and regulatory arrangements. Such investment could future-proof the SADC region in a shift to a greener global economy.

3. Connecting centralised power systems in Southern Africa

It is widely agreed that regional cooperation and integration in energy planning and development can help to unlock the potential for economic development in Southern Africa. A recent report by McKinsey argues that "regional integration, such as power pools, and promotion of renewable generation are game changers that could shape the energy landscape in sub-Saharan Africa over the next 25 years." (Castellano 2015). Furthermore, it is estimated that long-term gains of coordinated electricity investments are USD 100 million per annum (ECA 2009). In the following sections we look at barriers to regional cooperation on energy, particularly in terms of strengthening the Southern African Power Pool (SAPP).

3.1 A brief history of the Southern African Power Pool

Power sector development in SAPP member states was primarily designed to satisfy industrial demand on a site-specific basis, and cumulatively on a national basis. The first sub-Saharan power-trading infrastructure was built between DRC and Zambia (then known as Northern Rhodesia) in the 1950s, when a bilateral agreement to trade electricity prompted the construction of a 1700-kilometre high-voltage line. This was "developed in large part due to the early influence of demands from the power-intensive copper mining industry in the DRC [Democratic Republic of the Congo] and in Zambia" (Stratfor 2014). In the 1960s two 330 kV lines between Zambia and Zimbabwe capable of transmitting 1400 MW were developed, followed in 1975 by the construction of a 500 kV high-voltage, direct current 2000 MW line between Mozambique and South Africa (Theron 2012).

SAPP was established in 1995, bringing together the twelve non-island member states of SADC[2] in a formal agreement that connected hydropower-dominated generation in the north of the region and coal-dominated generation in south. Over the years the SAPP transmission network has continued to consolidate around its member states and although the grid networks of three SAPP members – Angola, Malawi, and Tanzania – are not connected to the power pool, the power they produce is routinely cited in SAPP statistics as part of the region's overall electricity profile. In 2001, a short-term energy market was introduced and in 2004 a competitive electricity market was initiated. In 2009 the day-ahead market was established, followed in 2015 by forward physical markets and the intra-day market.

3.2 Limited investment in infrastructure in Southern Africa

SAPP has the potential to ensure secure electricity supply through trade of power generated by more diverse energy resources. But regional power trade is limited by inadequate generation and transmission infrastructure, poor policy coordination across borders, unnecessary non-tariff barriers, and inconsistency between regional goals and national priorities. An issues paper recently presented at the first SADC joint Energy and Water Ministerial called on SADC to address infrastructure deficits at the "national and regional levels" (SADC 2016). Table 1 shows the demand and supply balance among SAPP member states in 2015.

In Southern Africa, and also across the continent, lack of investment in new and rehabilitated generation and transmission infrastructure is commonly attributed to the insolvency of national electricity utilities, brought about by politically-motivated low tariffs, which have resulted in low revenues and little return on investment (Africa Progress Panel 2015; Eberhard et al. 2008). Other factors that contribute to lost generating capacity include mismanagement of utility companies, corruption, and bad business practice (Africa Progress Panel 2015; Foster and Briceño-Garmendia 2010). These contribute to a real or perceived lack of available financial capital for investment and refurbishment of existing generating capacity.

At the same time, electricity subsidies responsible for keeping electricity prices low for the consumer have a number of negative effects across the electricity industry, and on economies as a whole. A 2013 study by the International Monetary Fund (IMF) on energy subsidies in sub-Saharan Africa points out that:

2 Angola, Botswana, the Democratic Republic of the Congo, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.

Table 1. Demand and supply balance with current peak demand in SAPP countries, 2016.

Country	Utility	Installed capacity (MW)	Operating capacity (MW)	Current peak demand (MW)	Capacity excess/ shortfall excluding reserves	Number of customers	Transmission system losses
Angola	ENE	2210	1772	1599	173	251 952	10.0
Botswana	BPC	892	410	610	-200	251 773	3.7
DRC	SNEL	2442	1098	1359	-261	861 661	9.0
Lesotho	LEC	74	70	140	-70	58 900	11.0
Malawi	ESCOM	366	351	323	28	374 400	6.0
Mozambique	EDM/HCB/MOTRACO	3074	2279	1780	499	1 010 780	6.4
Namibia	Nampower	508	354	629	-275	3449	3.2
South Africa	Eskom	46 963	44 134	34 122	10 012	5 976 557	0.1
Swaziland	SEC	61	55	232	-177	182 562	6.0
Tanzania	TANESCO	1367	1225	1051	173.9	2 013 839	6.0
Zambia	ZESCO/CEC/LHPC	2878	1385	2005	-620	831 362	6.2
Zimbabwe	ZESA	2045	1555	1521	34	579 006	4.0

Source: SAPP 2017

Reforming energy (fuel and electricity) subsidies in sub-Saharan Africa (SSA) is critical to ensuring future energy supply to realize Africa's growth potential. Although subsidies continue to absorb a large share of public resources, power generation and access levels in SSA remain well below those in other low-income countries. There is a link between those facts because energy subsidies create at least two set of problems. First, they are poorly targeted … Second, subsidies often create a disincentive for maintenance and investment in the energy sector, perpetuating energy shortages and low levels of access (Alleyne and Hussain 2013).

Furthermore, as noted by the African Development Bank (2011), "[c]ountries often give priority to the development of domestic energy resources to the detriment of joint exploitation of regional energy potential." If SADC member states are to meet their objectives for electricity supply, electricity access, trade-in-electricity and larger policy objectives (such as diversifying SADC's regional economy through industrialisation) they must prioritise national over regional policies. Unless countries in SADC increase cooperation with one another, demand for electric power will continue to outpace supply, real prices for electric power will remain high, and aspirations for wide-scale SADC industrialisation will remain suppressed by inadequate supply of electric power available at reasonable prices.

3.3 The dominance of South Africa and South African coal

Lack of investment, or efforts to attract investment in generation, transmission and distribution infrastructure, means that fuel supply and generation technology remains limited across the SADC region. South Africa is dominant in regional energy production, so neighbouring countries are vulnerable to shocks to its energy system. This means it is difficult for SAPP to achieve a secure and reliable supply across interconnected energy systems.

When SAPP was established in 1995, South Africa was already the region's dominant energy producer and consumer. Isolation from the international community over decades of apartheid drove it to maximise opportunities for self-sufficiency in fuels and electric power to drive its own national industrialisation process. As such, the country remains overwhelmingly influential in regional decisions around power trade. In 2011, South Africa provided 82.5% of all of SADC's electric power. And in 2014, Eskom figures suggested that it purchased 9 425 GWh from outside the country, mostly from Mozambique where the Cahora Bassa hydropower plant provides up to 1500 MW of electricity every day (enough to power almost one million homes) under a bilateral trading arrangement (SADC 2015).

The dominance of South Africa means that events in the country can have significant reverberations across the region, contrary to the notion that regional power trade will make countries more resilient to shocks in their energy systems and the energy systems of their neighbours. This is best illustrated by the example of turmoil in South Africa's energy sector in 2008/2009 caused by a combination of interconnected shifts in supply and demand.

During the 2008 global economic recession, South African GDP fell from a growth rate of approximately 5% in March 2008 to minus 6% in March 2009. This was compounded by a 22% fall in electricity production from 23 000 GWh per month to 18 000 GWh per month. In the face of limited investment in new generation, existing plants faced considerable pressure and many had to be shut down for unplanned but much-needed maintenance. With limited electricity supply available from South Africa's state-owned energy utility, Eskom, energy-intensive mining activity declined by 10%. The impact of this energy crisis was not confined within the country's borders: exports were halted to neighbouring Namibia, Botswana, and Zimbabwe – despite these exports accounting for only 6% of Eskom's capacity (Fin24 2008). As the remaining SAPP members failed to absorb the shortfall from South Africa, blackouts spread to these neighbouring countries.

The dominance of South Africa in the regional electricity system translates into the dominance of coal in the regional electricity mix. Coal-fired power in South Africa has significant political and economic value beyond the kilowatt hours it produces. For example, according to statistics provided by the Government of South Africa, coal as a source of economic value is now more important to its economy than gold (STATS SA 2015). The coal mining industry contributed approximately ZAR 37 billion to the economy in 1993, with gold contributing ZAR 115 billion (value added at constant 2010 prices). In 2013, coal contributed ZAR 51 billion to South Africa's economy, compared with gold's ZAR 31 billion. By 2012, the mining industry – including coal, gold, platinum and other minerals, such as diamonds and uranium – employed 535 457 people (Mining Review Africa 2014), more than the entire South African workforce employed by the South African government, numbering 455 701 (STATS SA 2014). Although this is far less than the number of civil servants employed in South Africa (2.161 million) (Africa Check 2014).

3.4 Rethinking regional power trade

It is clear that trade in electric power in SADC reflects the overall pattern of trade in the region, which is low. South Africa continues to dominate power production and consumption across the region, with little competition, thus making other states feel politically vulnerable. The regional repercussions of energy crises in South Africa have led SADC member states to be wary of future regional approaches to electricity sector generation and power sharing. So greater regional integration should focus on cooperation to increase energy access and foster energy development in each member state and balance the energy mix across the region. A number of areas of cooperation could help to do this.

Firstly, there is scope for greater harmonisation of policies and regulation among SADC member states. By 2002 SADC countries had shared lessons under the Regional Electricity Regulators Association of Southern Africa (RERA), and by 2017, 11 out of 12 SAPP countries had a national regulatory body. RERA helped to develop voluntary regional regulatory guidelines, which were approved by the SADC Energy Ministers in 2010, but more remains to be done to ensure regulation that supports regional power trade. More could be done to enhance the role of RERA and SAPP to ensure more formal coordination of regulation and energy development to strengthen and enhance regional power trade.

Secondly, transboundary projects offer potentially real economies of scale, reduced financial risk, greater market opportunities and a lower (real) delivered price of electric power compared to electric power projects confined to a single market on a national scale. However, large transboundary projects need to be justified by guaranteed access to markets of a size sufficient to make them financially viable. Coordination and cooperation amongst SADC and SAPP member states is essential if they are to take advantage of these opportunities.

Thirdly, linking energy development with industrial development throughout the region could help identify areas of mutual benefit from regional cooperation on energy.

4. Promoting decentralised power systems in Southern Africa

For many years the SADC member states have expanded electricity access mainly by extending the national grid. Supplying electricity through the national grid is important, especially because regional interconnection increases stability and security. But achieving a larger, diverse, secure and low-carbon energy sector requires a variety of solutions. Mini- and micro-grids – small-scale power generation (as little as 1 kW or as much as 10 MW) and a distribution grid – can be a valuable complement to grid-based electrification, particularly in areas where grid extension is technically or financially unviable (REN21 2015; Szabó et al. 2011; Anderson et al. 2012; Africon 2008). A study by IRENA indicates that 59% of rural electricity demand would be met through decentralised generation by 2030 (IRENA 2013). In this section, we explore the role that mini-grids can play in expanding electricity access in Southern Africa, including business models and policy support required to scale-up their use.

4.1 Decentralised electricity technologies and business models

SADC countries, particularly those with low rural electrification rates, are increasingly promoting renewable energy-based mini-grids as an alternative to grid extension in sparsely populated rural areas that will not be connected to national electricity grids in the short to medium term (REN21 2015). Each SADC country uses a different set of energy resources and business models, but in nearly all countries, penetration of these solutions in the total energy mix remains low. Existing mini-grids systems are powered by a range of energy sources, described below:

- **Mini- and micro-hydropower plants:** All SADC member states, except Botswana, have significant hydropower potential. Although most existing and planned hydropower projects are mainly large and medium-scale, mini- and micro-hydro-based mini-grids already exist in most countries. There is also a growing interest in developing mini-hydro plants and rehabilitating small older dams.[3] Several countries, including Angola, the Democratic Republic of the Congo (DRC), Tanzania, Zambia, Zimbabwe and Mozambique, have identified potential mini-hydro sites and started implementing a number of planned mini- and micro-hydro projects.

- **Solar mini-grid systems:** Off-grid rural electrification programmes in the region have mainly been based on solar power. Solar photovoltaic (PV) mini-grids have been or are being established in rural communities in all SADC countries. South Africa has invested primarily in large-scale solar projects[4] and DRC has underutilised its solar power potential (REN21 2015).

- **Wind and solar-wind hybrid mini-grids:** Countries with wind energy potential, such as Namibia, Malawi, South Africa, Madagascar and Mozambique, have piloted decentralised wind and wind-solar hybrid systems, which are generally used for power generation and water pumping for farms. Mauritius currently has a 1.28 MW wind mini-grid on Rodrigues Island and is constructing a 9 MW grid-connected facility at Plaine des Roches. Seychelles has a 6 MW grid-connected wind farm supplying around 2.2% of the country's power needs (REN21 2015).

- **Biomass, and biomass-solar PV-diesel mini-grids:** A number of small-scale biomass power generation projects have been implemented in South Africa, Tanzania, Zimbabwe, Zambia, Mauritius and Mozambique, among others. Mostly, in these countries, sugar companies and timber companies use bagasse or wood fuels to generate power for their own needs. They may also sell excess power to the national grid (e.g. in Zimbabwe, Tanzania and Mauritius). Tanzania is developing four biomass-solar PV-diesel hybrid mini-grids in Malolo, in the Morogoro region in the southern highlands (REN21 2015)

3 The REN21 report (2015) uses four classifications for hydropower plant size that have been adopted in this study: macro (> 10 MW); mini (1–9 MW); micro (100–999 KW); and pico (<100 kW)

4 For instance, the 96 MW Jasper project in the Northern Cape of South Africa, commissioned in 2014, is SADC's largest single solar PV project (REN21 2015).

- **Diesel, diesel-solar hybrid and natural gas mini-grids:** In almost all SADC countries, diesel mini-grids have existed for decades in rural areas, providing electricity to isolated communities. These diesel-based systems are progressively being replaced by renewable energy or diesel-solar PV hybrid systems in Mozambique, Malawi, Tanzania, the DRC, Namibia, Botswana and Zambia, in order to reduce fuel costs and the pollution associated with diesel. In addition, grid-connected and off-grid diesel mini-grids are used in urban and peri-urban areas (e.g. in Angola and Seychelles) for baseload power, peak supply and emergency generation (ECA and Practical Action 2013a; Ministry of Energy and Water and UNDP 2015). Tanzania also has an isolated mini-grid powered by natural gas, the 7.5 MW Somanga Fungu Plant (Msaky 2013).

The business model for mini-grids – the way they are designed, financed and operated – can vary widely, particular with regard to financing and operation. For example, investment may come in the form of donor grants or concessional loans, government budget allocations or private debt and equity. In general, the management of mini-grids typically falls into one of the following four categories (see Franz et al. 2014):

- *Utility operator:* a government or parastatal utility manages all aspects of a mini-grid.
- *Private operator:* a private company manages all aspects of a grid, in a regulated or non-regulated environment.
- *Community operator:* community members organise to manage generation and distribution in a regulated environment, with support and/or coordination from an NGO or a private company.
- *Hybrid operator:* private actors generate electricity, and a utility distributes it, or the reverse. Or a private entity commercialises electricity generated by and distributed through public assets.

In the SADC region, the development of mini-grids typically falls under national rural electrification programmes implemented by rural electrification agencies or state-owned utilities. The grids are generally co-funded by governments (by special tariff levies through rural electrification agencies or national utilities) and development partners, although the private sector is increasingly supporting the implementation of renewable energy mini-grids.

Mini-grid systems in SADC countries are owned and operated by a range of different actors: rural electrification agencies, state-owned utilities, private independent power producers, faith-based organisations, and municipalities (particularly in South Africa). A number of donor-funded mini-grids have been implemented by NGOs (e.g. Oxfam, Practical Action, World Vision). Once operational, mini-grids are left to be managed and operated by rural communities (REN21 2015).

The most successful mini-grids have tended to pursue the anchor-business-community (A-B-C) approach, which is widely used in the telecommunications industry. In this approach, the mini-grid prioritises the supply of power to an “anchor” consumer – such as a large business – that provides steady, predictable demand and reliable revenue. Surplus power is then provided to small local businesses or institutions with medium energy demand, and lastly to rural households, whose demand and ability to pay are typically less consistent (Pedersen 2016; Mukherjee 2013).

There have been many instances in the SADC region in which this approach has not been pursued, however. The result has been that the mini-grids cannot always be sustained once donor and government support has been withdrawn.

4.2 Penetration of mini-grids in SADC member states

Although development of mini-grids in the SADC region has increased, their contribution to total national installed capacity is still minimal. Table 2 provides an overview of types of mini-grid systems that are operating or actively under development in the region. It includes their indicative installed capacity, as well as their share of the total installed capacity in 2014. The table does not take into consideration planned mini-grid projects. However, it is important to note that the indicated installed capacity of mini-grids is based on the limited available information extracted from literature on mini-grid solutions, and does not reflect the actual installed capacity on the ground. Furthermore, for some technologies, there are scarce data on the number of mini-grids and their capacity.

Table 2. Installed capacity of mini-grid systems in SADC member states in 2014

Country	Installed capacity (operational and under development) of mini-grid systems (MW)										Total	% of total installed capacity (MW)
	Biomass and Biomass-solar-PV-diesel hybrid	Natural gas	Diesel	Diesel-solar Hybrid	Mini-hydro (1–9 MW)	Micro-hydro (100–999 KW)	Pico-hydro (< 100 KW)	Solar PV	Wind	Solar-wind hybrid		
Angola	-	-	139	-	21.3	-	-	0.051 - 0.085	0	0	160.35 - 160.38	6.8
Botswana	-	0	-	0.05	0	0	0	1.3	0	0	1.35	0.2
DRC	-	0	39	-	-	-	-	0.09	0	0	39.09	1.6
Lesotho	-	0	-	-	0	0.72	0	0.065	0	0	0.785	1.0
Madagascar	-	0	-	-	10	1	1	3	0.157	-	15.157	2.3
Malawi	-	0	1.05	-	5.9	0	0	1	-	0.02 - 0.024	7.97	2.2
Mauritius	-	0	-	1.2	19	0	0	18	1.28[a]	-	39.48	5.1
Mozambique	-	0	-	-	1.85	0.428	0.1	1.2[b]	0.3	0.001	3.88	0.1
Namibia	-	0	1.1	0.23	0	0	0	4.5	0.29	-	6.12	1.2
Seychelles	0	0	84	-	0	0	0	0.92	6	0	90.92	100.0
South Africa	4.4	-	-	-	195.3	1.88	0.05	-	-	-	201.63	0.4
Swaziland	-	0	-	-	7.7	0	0	0.12	0	0	7.7	9.9
Tanzania	11.5[c]	7.5	53	-	15	2	0.01	11[d]	0	0	99.81	6.7
Zambia	3	0	11.3	0	25.5	0	0	2	0	0	38.8	1.7
Zimbabwe	0.5	0	-	-	6.1	0.34	0.01	5	0	0	11.95	0.6

Data sources: REN21 (2015); SAPP (2014).

Notes: An entry of " - " means data on installed capacity are not available. Mini-grids under development are cited in footnotes.

[a] *Mauritius is constructing a grid-connected 9 MW facility at Plaine des Roches (REN21 2015, p.40).*

[b] *FUNAE is currently constructing 400–500 kW off-grid solar photovoltaic plants in Mavago, Mecula, Muembe in Niassa province. With these projects, the total capacity of photovoltaic systems installed by FUNAE since 2000 will reach 2250 kW (REN21 2015, p.39).*

[c] *Four biomass-solar-PV-diesel hybrid mini-grids with a combined generation capacity of 300 kW are being developed in Malolo, in the Morogoro region in the southern highlands.*

[d] *Rex Energy is also developing a 2 MW hybrid solar photovoltaic mini-grid in Lake Victoria Islands.*

4.3 Policy framework for mini-grid development

Scaling up renewable energy mini-grids and stand-alone solutions requires significant policy support. Yet there are two main barriers to achieving this: existing policy frameworks are generally vague, with no specific targets or support mechanisms for mini-grids; and policy implementation is limited to or biased towards grid-based electrification.

A varied policy mix

Typically, the policy environment for mini-grids falls under a variety of policies and targets for countries' energy systems, renewable energy, and rural electrification (see Table 3).

All SADC countries have general energy policies, promoting access to electricity both through grid extensions and on- and off-grid renewable energy technologies. A few set explicit universal access targets

Table 3. Policies guiding development of mini-grid systems

		Angola	Botswana	DRC	Lesotho	Madagascar	Malawi	Mauritius	Mozambique	Namibia	Seychelles	South Africa	Swaziland	Tanzania
Energy	Policy													
	Universal access targets													
Renewable energy	Policy													
	Targets													
Rural electrification	Strategy													
	Targets													
Mini-grids	Policy													
	Targets													

Source: national policy documents

a. Energy policy: (Department of Minerals and Energy 1998; Henri Esseqqat 2011; Ministry of Energy and Meteorology (Lesotho) 2015; Ministry of Energy and Minerals (Tanzania) 2003; Ministry of Energy and Mining (Malawi) 2003; Ministry of Energy and Water (Angola) 2011; Ministry of Energy and Water Development (Zambia) 2007; Ministry of Energy and Water Development (Zambia) 2007; Ministry of Mines and Energy (Namibia) 1998; Ministry of Renewable Energy & Public Utilities (Mauritius) 2009; REN21 2015)
b. Rural electrification and mini-grids policy: (AfDB 2015; AfDB 2015; Agence de Développement de l'Electrification Rurale (ADER) 2009; (South Africa) 2012; ECA and Practical Action 2013b; EU Energy Initiative Partnership Dialogue Facility 2011; Gauri Singh et al. 2013; International Monetary Fund 2007; IRENA 2012; JICA 2009; REN21 2015; UNDP 2015)
c. Renewable Energy: (Department of Minerals and Energy (South Africa) 2003)

(i.e. Botswana, Lesotho, Seychelles, Swaziland and Zimbabwe) (REN21 2015). More targeted renewable energy policies are scarce: out of 15 SADC member states, only South Africa has a renewable energy policy with specific targets for both small- and large-scale applications. Angola, Tanzania, Mauritius and Zimbabwe are currently developing theirs.

Most SADC countries also have rural electrification master plans and/or strategies to guide the implementation of rural electrification projects through grid extension and off-grid electrification. A number even include specific rural electrification targets (i.e. Angola, Botswana, DRC, Madagascar, Mozambique, Namibia, Malawi, South Africa, Tanzania, Zambia and Zimbabwe) (REN21 2015).

Decentralised solutions have received more specific policy support in Tanzania. Through its Small Power Producers Framework (2009), Tanzania has developed an advanced policy and regulatory framework for the promotion of on- and off-grid renewable energy-based mini-grids. Through this framework, a standardised power purchase agreement and a specific tariff methodology have been developed for small power producers (i.e. 100 kW to 10 MW) (AfDB 2015; ECA and Practical Action 2013a)

At the regional scale, in 2010 the SADC developed its Regional Energy Access Strategy and Action Plan (REASAP), setting broad goals for improving access to modern energy sources. The REASAP provides a detailed discussion of grid-based and off-grid approaches that SADC countries can draw on to formulate strategies to enhance access to modern energy, focusing on renewable energy-based mini-grids and off-grid solutions as alternatives to grid extension (SADC 2010). Meanwhile, the SADC Renewable Energy and Energy Efficiency Strategy and Action Plan 2016–2030 was approved in October 2016 (REN21 2015).

Selective policy implementation

Despite at least somewhat supportive policies and growing interest, the deployment of renewable energy mini-grids remains slow in the region. The real challenge lies in policy implementation, which is often skewed towards grid extension, with decentralised solutions to electrification only being introduced more recently (SADC 2010).

Investments in power generation infrastructure have typically been channelled to large-scale projects that will be integrated into the SAPP. Off-grid solutions, on the other hand, are often seen by policy-makers and users as temporary pre-electrification solutions (ECA and Practical Action 2013a). Existing renewable energy mini-grid solutions are also typically subsidised by governments or donors where financial constraints, such as customers' low ability to pay, hamper wider deployment. The relatively small size of the off-grid market and low income of end-users in rural areas tend to make them unattractive to private investors (IRENA 2015; IRENA 2013).

Where policy support exists, it has not always translated into the development of appropriate financing mechanisms for decentralised solutions, or in improvements to the complex administrative procedures related to project implementation (e.g. concessions, environmental impact assessments, licensing, tariff-setting). As a result, most mini-grids are still considered as "pilots", driven by governments, donors and technology developers rather than by market demand. As a result, most existing projects have limited potential to be replicated or scaled up (ECA and Practical Action 2013c).

4.4 Looking ahead

Mini-grids in the SADC region vary widely in terms of their size, the technologies used, their share of total generating capacity, who owns them, and the investment and operator models involved. Given this diversity, it is clear there is no one-size-fits-all approach to ensuring successful implementation. Yet given the important contribution that renewable energy mini-grids can make to increasing access to modern energy services, there is an acute need to explore further approaches that enable scaling-up beyond pilot projects. The challenge is then how to overcome the key issue of financial sustainability of mini-grids in rural areas and develop sustainable and replicable business models that are appropriate to the technology used and adapted to local context.

We believe the recently established SADC Centre for Renewable Energy and Energy Efficiency (SACREE) in Namibia could play an important role in helping to coordinate knowledge sharing on appropriate policy and regulatory frameworks that can help to build investor confidence and catalyse private investment in mini-grids and sustainable and scalable mini-grid business models. Such models should be designed around a reliable customer base and strong understanding of local social, economic and cultural contexts.

5. Conclusions and recommendations

This paper highlighted the low-carbon energy challenge faced in the SADC region – particularly with regards to security, reliability and accessibility of electricity services – and explored how centralised regional power trade and decentralised power systems can provide complementary solutions to overcoming these challenges.

The SADC region has experienced unprecedented economic growth during the last decade but investment in electricity infrastructure has sadly lagged far behind regional demand. As such, electricity access across the region remains low and power generation remains no more diversified than it was in 1994, when SADC was established. Regional power trade has potential, but significant historical, political and economic barriers continue to plague expanding the SAPP network. We argue that for regional power trade to go beyond the current bilateral arrangements and reach its full potential, there needs to be greater power placed in the hands of regional planning and regulation bodies – namely SAPP and RERA. In addition, developing transboundary projects can help to establish mutually beneficial cooperation that can act as exemplars for other regional energy cooperation projects. Furthermore, linking such projects to industrial development objectives can help to ensure benefit-sharing beyond the energy sector.

We also argue that there is a need for regional cooperation when it comes to decentralised energy options. While these options are necessarily small-scale and localised, there is huge scope for sharing lessons at the regional level about effective national and sub-national policy frameworks and business models for making mini-grids work. There are also opportunities for combining resources to develop regional support programmes to scale-up successful national and sub-national efforts. The SADC Centre for Renewable Energy and Energy Efficiency (SACREE) can play a major role in this endeavour.

Pursuit of centralised and decentralised energy solutions are essential throughout the SADC region if affordable and reliable low-carbon energy access is to be harnessed for well-being and economic development. Regional cooperation in power trading, transboundary projects, regional support mechanisms and knowledge sharing can do much to help make this a reality. However, it remains to be seen if political rhetoric can be matched by political action.

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