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RENEWABLE ENERGY PROSPECTS:

SOUTH AFRICA

REmap
A Renewable Energy Roadmap

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About IRENA

The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. An intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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For further information or to provide feedback, please contact the REmap team at **REmap@irena.org**.

This study and other supporting material are available for download through **www.irena.org/remap**.

RENEWABLE ENERGY PROSPECTS:

SOUTH AFRICA

CONTENTS

FIGURES

TABLES

BOXES

ABBREVIATIONS

a.g.l.	Above ground level
BaU	Business-as-usual
BW	Bid window
°C	Degree Celsius
CFL	Compact Fluorescent Lamp
CHP	Combined heat and power
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CSIR	Council of Scientific and Industrial Research
CSP	Concentrated solar power
CTL	Coal-to-liquid
DEA	Department of Environmental Affairs (South Africa)
DNI	Direct normal irradiation
DoE	Department of Energy (South Africa)
DST	Department of Science and Technology (South Africa)
dti	Department of Trade and Industry (South Africa)
EIA	Environmental impact assessment
EJ	Exajoule
ESCO	Energy Service Company
ESI	Electricity Supply Industry
EV	Electric vehicle
FBE	Free Basic Electricity
FGD	Flue gas desulphurisation
GBCSA	Green Building Council South Africa
GDP	Gross domestic product
GHG	Greenhouse gas
GHI	Global horizontal irradiation
GW	Gigawatt
GWC	Growth Without Constraints
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEP	Integrated Energy Plan
INEP	Integrated National Electrification Programme
IPP	Independent power producer
IRENA	International Renewable Energy Agency
IRP	Integrated Resource Plan
km	Kilometre
km^2	Square kilometre
kWh	Kilowatt hour
LCOE	Levelised cost of electricity
LTMS	Long Term Mitigation Scenarios
LV	Low voltage
m^2	Square metre
MapRE	Multi-criteria Analysis for Planning Renewable Energy
Mt	Megatonnes
MV	Medium voltage
MW	Megawatt
MYPD	Multi-Year Price Determination
NDC	Nationally Determined Contribution
NEES	National Energy Efficiency Strategy
NERSA	National Energy Regulator of South Africa
NHES	New Household Electrification Strategy
NSWHP	National Solar Water Heaters Programme
OCGT	Open cycle gas turbines
PJ	Petajoule

PPA	Power purchase agreement
PPD	Peak-Plateau-Decline
PPP	Purchasing power parity
PV	Photovoltaic
REDZ	Renewable energy development zone
REFIT	Renewable energy feed-in tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
REmap	Renewable energy roadmap
RSA	Republic of South Africa
SABS	South African Bureau of Standards
SADC	Southern African Development Community
SAEON	South African Environmental Observation Network
SANEDI	South African National Energy Development Institute
SANS	South African National Standards
SAPP	Southern African Power Pool
SBO	Single Buyer Office
SEA	Strategic environmental assessment
SEforAll	Sustainable Energy for All
SHS	Solar home system
SIP	Strategic infrastructure project
SSEG	Small-scale embedded generation
SWH	Solar water heater
TFEC	Total final energy consumption
Tonne-km	Tonne-kilometre
TPES	Total primary energy supply
TWh	Terawatt hours
UCT	University of Cape Town
USD	United States dollar
VRE	Variable renewable energy
v/v	Volume/volume
WASA	Wind Atlas of South Africa Project
Wh	Watt hour
Wp	Watt Peak
yr	Year
ZAR	South African rand
≈	Approximately

HIGHLIGHTS

- The REmap initiative is IRENA's assessment of the degree of transformation required for achieving environmental and climate targets, and of related costs, benefits and opportunities. The study for South Africa looks at the realistic potential for higher renewable energy uptake in all parts of the national energy system, including the power sector, transportation, industry, buildings and agriculture. It also provides an overview of measures for achieving higher shares of renewable energy, and of related costs and benefits.

- The study defines a trajectory to 2030 based on current government policies and plans ("Reference Case 2030") and identifies the options for additional renewables deployment by energy-use sector and technology ("REmap Options"). The Reference Case plus the REmap Options equate to the "REmap Case 2030". REmap is not a scenario or a target-setting exercise but an options-based approach. The study is consistent with, and builds off, key government policies. The options identified for additional renewables deployment beyond the government policies can, individually or jointly, provide an input to decision-making actors in the energy sector.

- The study finds that final energy use from renewable sources in South Africa could increase from 196 petajoules (PJ) in 2015 (9% of total final energy consumption, or TFEC) to 568 PJ by 2030 (23% of TFEC). This is a considerable increase compared to the Reference Case 2030 (366 PJ, 13% of TFEC). In the power sector, the total share of renewables in electricity production could increase from ≈9% in 2015 to 49% by 2030 (compared to the Reference Case with 37% by 2030).

- The main power generation technologies identified to contribute by 2030 are onshore wind (21% of electrical energy), utility-scale solar photovoltaic (PV) (14%), biomass/biogas (4%), distributed solar PV (2%), concentrated solar power (CSP) (1%) and hydro (7%; mostly imported). In addition to the deployment of renewables technologies for electricity, REmap technology options in end-use sectors are dominated by solar thermal use in buildings and industry, and bioenergy in transport and industry.

- TFEC under the REmap Case is expected to increase from 2 290 PJ in 2015 to 2 493 PJ by 2030. South Africa has an estimated total potential of 363 PJ by 2030 (compared to the Reference Case) in energy efficiency savings across sectors.

- There are several challenges and barriers to increasing the shares of renewable energy, including the need to understand implications for national power system operations, creating and employing new business models for disruptive technologies, and the emergence of prosumers. Small-scale embedded generation presents a unique challenge for municipalities, as it may challenge the operation of distribution grids and erode their steady income.

- With the share of variable renewables (solar PV, wind) in the electricity mix reaching 37% under the REmap Case 2030, the national grid system would need to be enhanced with technologies and investments to strengthen flexibility, transmission and interconnection.

- At the same time, the increased share of renewables in the South African energy mix offers key opportunities such as diversifying away from a coal-dominated supply mix, reducing the environmental footprint of the energy sector, and domestic manufacturing of renewable energy components.

- Suggestions for accelerated renewables uptake are to optimise the national energy sector structure (through realignment), clarify and simplify the regulatory environment and ensure consistent implementation of polices, undertake research in key areas for the energy transformation (including innovative technologies and socio-economic aspects), realise the potential of embedded generation, increase sector coupling capacity in transportation and industry, and widen the use of private public partnerships in the deployment of renewable energy.

EXECUTIVE SUMMARY

The Republic of South Africa (RSA) is the third-largest economy in Africa and the highest primary energy consumer on the continent. In recent years, South Africa has faced several periods of load-shedding resulting from a lack of investment in the maintenance, rehabilitation and strengthening of power sector infrastructure. At the same time, the country has developed ambitious plans for gradually reducing national coal-based generation capacity and has successfully scaled up national renewables-based generation at a competitive cost, driven by the Renewable Energy Independent Power Producer Programme (REIPPPP). Considering its extensive experience, its exceptional renewable resource base and its favourable policy framework for renewable energy, among other factors, South Africa can further expand its renewable energy use, including in transportation, industry, buildings and agriculture. The country also has opportunities to increase domestic manufacturing of renewable energy components and to be a frontrunner of the energy transformation in Africa.

In 2015, IRENA and the South African government agreed to prepare this Renewable Energy Roadmap (REmap) country study. The main objectives of the South African government for this study are threefold, namely: i) a transversal analysis of additional renewable energy deployment potential to 2030, beyond government policy and against international benchmarks (including the potential of renewables technologies in end-use sectors); ii) an identification of the costs and benefits of deploying these renewable energy technology options; and iii) an assessment of barriers and possible solutions to realising the options, in the context of the policy and regulatory framework of the energy sector.

The study builds off key government policies, foremost of which are the Integrated Resource Plan (IRP) and Integrated Energy Plan (IEP), and assesses technology options for additional renewables development to 2030. Technology options are assessed one-by-one – this is deliberate because REmap is an exploratory study of additional renewable energy potential, not a scenario or target-setting exercise. The study further assesses the resource availability and costs for particular technology options, and the barriers and opportunities related to the renewables deployment in different energy-use sectors. Importantly, the REmap country study is not intended as a substitute for but as a complement to IEP and IRP, and serves as food for thought on further renewables potential not yet identified in government plans and targets.

Methodology

The base year (2015) energy balance and Reference Case 2030 for this study were derived from the draft Integrated Energy Plan 2016 update (adjusted as necessary). Technology options for additional renewables deployment in different energy-use sectors are identified on the basis of resource potential, possible speed and scale of technology deployment and other constraints for development. The study includes text boxes on new policy documents and plans that have been released since writing this study.

Current legislative, regulatory and policy framework

The national utility Eskom, the National Energy Regulator of South Africa (NERSA) and the Department of Energy (DoE) play the key institutional roles in the management of the national energy sector. Eskom dominates power generation, transmission and distribution, and 100% owns and manages the national grid, with a 20-year Strategic Grid Plan. There is increasing power sector liberalisation, which means increased competition within the generation space. In addition, many municipalities in South Africa own and operate distribution grid network infrastructure, while Eskom operates distribution grid infrastructure in other locations (Eskom distributes about 40% of all electricity to end consumers). Consent from Eskom or the respective municipality must be sought for any embedded generation projects.

The IRP (for the power sector) and IEP (for the overall energy sector) are the key policy instruments for planning the country's energy needs and identifying technology options for energy supply and related costs. Both are intended as "living documents" and updates of both documents are currently pending approval. The White Paper on Renewable Energy of 2003 is, to date, the most comprehensive policy document pertaining to the government's vision on renewable energy. The REIPPPP is the central renewable energy support scheme. With regard to energy efficiency, a post-2015 draft National Energy Efficiency Strategy (NEES) was recently gazetted, with a time horizon to 2030.

Most of the greenhouse gas (GHG) emissions in South Africa emanate from energy supply and consumption. South Africa has committed to a policy in which the trajectory of total GHG emissions to 2050 peaks (between 2020–2025), plateaus (until around 2036) and then declines (from 2036–2050).

Recent trends in the South African energy system

The 2015 energy balance provides an overview of the current national energy system and use patterns as a starting point for the analysis to 2030. South Africa's total primary energy supply (TPES) is made up of coal (66.9%), oil (16%) and petroleum products (6.8%), with smaller shares for nuclear (3.5%) and natural gas (2.2%). Coal power plants account for 78% of national capacity, followed by hydropower (3.9%) and nuclear (3.7%). Renewables (excluding hydro) contributed a total of 4.7% to power generation capacity in 2015.

Total electricity production amounted to 272.2 terawatt hours (TWh) in 2015. Coal accounted for over 85% of the mix, followed by nuclear (5.4%) and hydro (1.8%). Electricity demand has been mostly stagnant in recent years. This was mainly due to supply-demand shortages that resulted from poor operational performance at power stations (mainly caused by maintenance backlogs at major power plants and delays in the construction of new mega coal plants). Therefore, Eskom has at times been unable to generate enough electricity to meet needs. As a result, power cuts (load-shedding) were imposed to prevent a collapse of the national electricity grid (*i.e.* a blackout). Further reasons for the stagnant electricity demand in recent years are the improved energy efficiency driven by higher electricity tariffs, the relatively low overall economic growth and an increasingly large share of less energy-intensive service sectors in the economy.

By the end of 2017, the REIPPPP had connected 52 projects to the grid with a further 10 under construction and 28 projects in the approval, planning or financing stage. The projects amount to a total of 3.9 GW of operational renewable grid-connected power capacity and an additional 2.4 GW in the pipeline with power purchase agreements (PPAs) approved. There are around 38 commercial biogas projects in operation in South Africa, with a total installed capacity of over 30 megawatts (MW). Under the small scale REIPPPP programme (*i.e.* projects that are equal to or less than 5 MW capacity), 20 small scale projects have achieved Preferred Bidder Status in South Africa, namely 16 solar PV, 2 wind and 2 biomass projects. In addition, a Ministerial Determination was made for procurement of 800 MW in capacity from cogeneration projects.

There has been an increase in small-scale embedded generation (SSEG) (*i.e.* embedded generation capacity of no more than 1 MW and connected at low voltage) within the distribution grid networks of municipalities and Eskom. In some municipalities, due to a lack of division between rents from power sector services provided directly by municipalities and other taxes/levies, the rents from selling power are also used to cover other municipality services. In this context, the increased embedded generation may pose challenges for the operation of distribution grids and erode the steady income that municipalities have typically realised from stable electricity sales to customers in their jurisdictions.

The current national electrification rate in South Africa is around 86% (in terms of number of households being connected to energy supply infrastructure). Significant progress was made in on-grid electrification between 2005 and 2015. There are still many localised areas with relatively low levels of access. Renewable energy offers ample opportunities to enhance access, including from off-grid solar systems.

South Africa's end-use of energy in 2015 was dominated by transportation (39.1% of total final energy consumption, or TFEC) and the industrial sector (38.5% of TFEC); buildings (residential, commercial, public) accounted for 19% of end use. The agricultural and forestry sectors accounted for around 3% of energy end-use. TFEC amounted to 2 290 PJ/year in 2015.

All energy-use sectors have seen increased use of renewable energy in recent years, particularly of residential and commercial PV installations, solar water heaters, and of industrial combined heat and power (CHP). Key drivers for renewable energy development in South Africa are the gradually lower cost of deployment for renewables, energy access objectives, the diversification of energy supply and environmental benefits. Increased renewables deployment can also lead to positive employment effects.

Significant progress has also been made since 2000 in reducing energy intensity (*i.e.* the units of energy used per unit of gross domestic product, or GDP), thereby exceeding the targets set for 2015 in the National Energy Efficiency Strategy of 2005 for most energy-use sectors. The energy efficiency improvements were the result of numerous causes, mainly deliberate policy and industry interventions, autonomous change and technology advancements.

Reference Case 2030: Trajectory according to current government plans and policies

The Reference Case to 2030 provides a trajectory for the South African energy sector based on current government plans and policy. It is based on the Base Case scenario of the draft IEP 2016.

Under the Reference Case 2030, TPES is expected to increase from 4 555 PJ in 2015 to 4 950 PJ by 2030. The role of coal and traditional biomass supply is expected to be reduced significantly, whereas modern bioenergy is expected to grow from a negligible amount in 2015 to 20 PJ/year by 2030 (in the form of biogas). Solar and wind are expected to play a considerably larger role in primary energy supply in South Africa by 2030, increasing from 7 PJ and 18 PJ in 2015 to 216 PJ and 144 PJ by 2030, respectively.

TFEC in South Africa is projected to increase by 26%, from 2 290 PJ in 2015 to 2 856 PJ by 2030, under the Reference Case. Coal continues to play a significant role in the 2030 energy mix (either by direct use or coal-based electricity generation) while petrol and diesel continue to be the dominant primary energy supply options for the transport, mining and agricultural sectors. The share of renewables in TFEC is expected to move from ≈9% in 2015 to ≈13% by 2030.

In the electricity sector, the share of renewable energy in electrical energy is expected to increase from ≈9% in 2015 to ≈37% by 2030 under the Reference Case. Solar PV and wind are projected to account for a total share of 16% and 11%, respectively, by 2030, with hydro technology at 9% and biomass/biogas playing smaller roles. Coal is still expected to meet the majority of electricity demand (57%) by 2030.

The share of renewables in TFEC in the commercial sector is projected to grow to 32% of TFEC (from 7% in 2015), as a result of electricity assuming the dominant role as energy carrier. In the industrial sector, the role of renewables increases from just above 5% in 2015 (42 PJ) to 18% (206 PJ) by 2030 under the Reference Case. In the transport sector, there is limited deployment of electricity (9 PJ by 2030), natural gas or hydrogen-based transportation in Reference Case 2030. In the agricultural sector, the share of modern renewables is expected to increase from ≈3% in 2015 to ≈13% by 2030.

Traditional biomass usage in the residential sector is expected to be replaced by electricity as 90% of households are expected to be electrified via on-grid connections by 2030. Overall, the electrification rate is expected to increase to 97% by 2030 (*i.e.* "universal access"), including increases in off-grid connections in remote rural areas (likely enabled by a range of distributed energy technologies, including renewables).

The Reference Case does not account for the targets of the draft post-2015 NEES because these are not currently reflected in the latest IRP and IEP versions. Rather, the post-2015 NEES targets are reflected in the REmap Case 2030.

In the Reference Case 2030, carbon dioxide (CO_2) emissions are expected to increase by 17%, from ≈390 megatonnes (Mt) in 2015 to ≈454 MT/year (yr) by 2030. Projected emissions under the Reference Case 2030 are within the bounds of the Peak-Plateau-Decline GHG emissions trajectory.

Renewable energy potential and (future) costs in South Africa

The projection of renewable energy technology deployment requires a robust understanding of the scale and potential of available resources and the costs related to the deployment of different technologies.

South Africa has abundant solar irradiation and wind resources. The resources are distributed across virtually the entire territory. South Africa has identified different renewable energy development zones (REDZs) where generation projects may be developed with minimal risk of disturbing the environment. The potential for solar PV and wind-based power generation is effectively unlimited, to a degree that supplies can be integrated into the power system without risking grid stability. South Africa also has significant potential for further bioenergy deployment (from different resources) and some limited specific sites that are well-suited for small-size and medium-size hydropower generation.

Besides the applicable technological and infrastructure limitations, the degree of exploitation of renewable resources largely depends on the costs related to different technology options. In recent years, primarily as a result of the REIPPPP bidding process, renewables options have become substantially cheaper for electricity generation compared to other new build options in South Africa, such as nuclear and coal. Solar PV and wind are the cheapest new-build generation options.

Specifically, successful bid tariffs achieved in the latest bid windows of the REIPPPP averaged USD 0.046/kWh for both wind and solar PV based electricity. The downward cost trends for solar PV and wind generation technologies are expected to continue for the coming years. Concentrated solar power (CSP) and bioenergy applications under the REIPPPP came in at USD 0.149/kWh and USD 0.082-0.119/kWh, respectively. Baseload coal prices under the Coal Independent Power Producer (IPP) Programme averaged USD 0.074/kWh. The price estimate for nuclear power is USD 0.081/kWh. Notably, additional system-related costs may result from integration of higher shares of variable renewables.

The costs for all key energy commodities are expected to significantly increase between 2015 and 2030 (and further to 2050), pointing to a need to increasingly deploy alternative carriers (including renewables) to replace fossil fuels for heating and cooling, industry, and transportation.

REmap Case 2030: Options for increased uptake of renewables

The REmap Case 2030 represents renewable energy technology options (“REmap Options”) beyond the Reference Case 2030 that are considered feasible and realistic in terms of both resource potential and technology deployment speed. Under the REmap Case 2030, TPES is expected to decrease slightly from 2015 (4 555 PJ) to 2030 (4 407 PJ) with a smaller (while still very significant) role for coal.

TFEC under REmap Case 2030 is expected to increase from 2 290 PJ in 2015 to 2 493 PJ by 2030 (including energy efficiency savings of 363 PJ). REmap Options increase renewable energy use in South Africa to 568 PJ by 2030 (23% of TFEC), a considerable rise compared to the Reference Case 2030.

REmap Options in the power sector could allow for the total share of renewables in electricity production to increase from ≈9% in 2015 to 49% by 2030 (compared to the Reference Case with 37% by 2030). Power generation technologies identified to contribute to the renewable energy share as part of the REmap Options for 2030 are onshore wind (21% of electrical energy), utility-scale solar PV (14%), biomass/biogas (4%), distributed solar PV (on-grid/off-grid; 2%), CSP (1%) and hydro (7%; mostly imported).

With regard to small-scale renewables, 72 *GW* (136 TWh or 38 PJ) of solar PV potential is estimated to be theoretically available for deployment on rooftops. The total expected distributed generation from solar PV in the REmap Case 2030 is 5.8 TWh, including 1.7 TWh in commercial rooftop deployment, 3.7 TWh in residential rooftop deployment and 0.4 TWh for new off-grid solar home systems (SHSs).

In addition to the considerable deployment of renewable energy technologies in the form of solar PV and onshore wind in electricity, identified REmap technology options in end-use sectors are dominated by solar thermal (10% of end-use by 2030 in buildings) and modern bioenergy (6% of industrial end-use by 2030) for heating, cooling and cooking. A total of 5 million solar water heaters (SWH) are expected to be installed in households by 2030 (translating to a total of 30 PJ). While traditional biomass (predominantly in the residential sector) is almost completely removed by 2030, modern forms of biomass are identified for various end-use sectors. The increased use of biomass for power generation and the blending of biofuels for transportation are also included in the REmap Options for 2030. In the transport sector, there is potential to significantly increase the use of electric mobility and hydrogen by 2030.

Although transportation is overall identified as a sector that could shift to alternative energy carriers, fossil-based liquid fuels in the form of petrol and diesel still dominate by 2030 (93% of transport end-use). REmap Options in the transport sector include the use of electricity (2% of transport sector end-use by 2030), renewables-based hydrogen (1%), and biodiesel and bio-ethanol blending (4%).

In line with the post-2015 NEES, potential for improved energy efficiency is identified in the residential sector (20 PJ) with appliances and lighting as well as with regard to absolute reductions in commercial/public building energy consumption (17 PJ). Industrial energy efficiency could be achieved through improving the efficiency of technologies supplying end-use services in manufacturing and mining (estimated potential of 186 PJ). Significant improvements in transport sector energy efficiency are also identified (140 PJ), namely from increased vehicle efficiency supplemented by increased transportation based on electricity, hydrogen and biofuels. Total energy efficiency savings add to 363 PJ by 2030.

Expected annual CO_2 emissions under REmap Case 2030 are expected to decline by 25% from ≈388 Mt in 2015 to ≈295 Mt/yr by 2030. The combined emissions from electricity and liquid fuels reduce significantly as part of the REmap Case 2030, from ≈310 Mt in 2015 to 195 Mt/yr by 2030. CO_2 emissions from other sectors including transportation and final end-use grow from ≈80 Mt in 2015 to ≈100 Mt/yr by 2030.

Besides the reduced CO_2 emissions from increased deployment of renewable energy compared to current policies and strategies, South Africa can also expect positive impacts of increased renewables deployment in terms of reduced air pollution, health benefits, employment gains and financial savings.

Challenges and opportunities for scaling up renewables

There are several challenges and barriers to increasing the share of renewables across the energy sector. These include the need to understand implications for national power system operations, the creation and operation of new business models for disruptive technologies, and the emergence of prosumers.

In the power sector, South Africa will need to enhance energy access (through on-grid and off-grid infrastructure) whilst adding new generation options to substitute the expected reduction in coal capacity and avoid future shortfalls in electricity supply; this mainly relates to increasing investments in power infrastructure, including generation and distribution. South Africa also needs to further study and address potential impacts from higher shares of variable renewables on power system operation/stability. Further, there are regulatory and institutional barriers regarding realignment of the national power sector to the changing landscape. With regard to small-scale embedded generation, the evolving regulatory framework for municipalities needs to provide clarity on their role in the generation space. Key opportunities for additional deployment of renewable energy exist in sector coupling (*i.e.* using renewable energy-based electricity in transportation and heating), the use of renewables as an input to the production of liquid fuels and chemicals (*i.e.* power-to-X), and increased embedded generation.

In the buildings sector, the lack of a standard for quality certification of solar PV modules and for grid-tied small-scale solar PV, as well as the lack of a clear regulatory framework and asset financing products for embedded solar PV, are key barriers for expansion of embedded solar PV and other embedded technologies. Key opportunities that have been highlighted for further deployment of renewables in the residential sector include solar water heating, passive solar designs for space heating, stand-alone solar kits for dwellings and the use of biomass digesters for energy supply in rural residential areas.

In the transport sector, key challenges arise from mode switching to hybrid or fully electric transport. For increased deployment of electric vehicles (EVs), there is a need to address the lack of infrastructure and to provide additional financial support for market uptake. As a complementary benefit, by adding to system flexibility the use of EVs can reduce (or even eliminate) the need for storage of energy by the utility. Biofuels cannot yet compete on the market without policy or financial support mechanisms. The current lack of an effective incentive scheme adversely affects the exploitation of biofuels in transportation and other potential use sectors.

The industry sector generally requires a constant energy supply, and supply interruptions are particularly harmful. The load profile of variable renewables is not well suited for this purpose. There is also considerable employment in the national fossil fuel sector that will need to be accounted for when embarking on a transition to renewable energy. Opportunities in the industry sector are principally in increasing energy efficiency, exploring new manufacturing opportunities for renewables technologies, and using renewables as a cheap input to liquid fuels (*e.g.* hydrogen). A switch to improved efficiency and renewables may be accelerated by introducing reporting requirements for major energy consumers.

Recommendations to accelerate South Africa's renewable energy uptake

Based on the analysis, the study provides recommendations along seven central themes, namely:

- **Realign the national energy sector structure.**
- **Enhance investments in national power sector infrastructure.**
- **Clarify and simplify the regulatory environment (particularly for small-scale embedded generation) and ensure consistent implementation of polices.**
- **Support targeted research and development on innovative renewable energy (enabling) technologies, undertake research on a "just transition" for the energy sector, and devise corresponding measures.**
- **Increase sector coupling to exploit opportunities for renewables-based power to underpin other end-use demand sectors, such as transport and industry.**
- **Widen the use of private-public partnership in the deployment of renewable energy.**
- **Fully realise the potential of embedded generation.**

COVID-19 recovery and beyond

Amid the coronavirus outbreak in early 2020, renewables and energy efficiency have become a key consideration in the country's recovery plans. The newly updated Integrated Resource Plan (IRP), promotes renewables to boost electricity supply and enhance energy security. Renewable energy development can also help to align immediate needs with medium- and long-term energy and climate sustainability.

1 INTRODUCTION

The International Renewable Energy Agency (IRENA), through its Renewable Energy Roadmap (REmap) initiative, aims to pave the way to the promotion of accelerated renewable energy development through a series of activities that include the development of global, regional and country level studies. REmap analyses and activities also serve to inform other IRENA-related publications that focus on specific renewable energy technologies, or energy subsectors.

At the outset, REmap emerged as IRENA's proposal for a pathway to achieve the Sustainable Energy for All (SEforAll) initiative's objective of doubling the global share of renewable energy by 2030, compared to 2010 levels; IRENA was designated as the Renewable Energy Hub for the SEforAll initiative. Today, the widespread deployment of renewables is becoming ever more crucial for meeting the objectives of the Paris Agreement, including the goal of limiting the Earth's global temperature increase to well below 2 degrees Celsius (°C) above pre-industrial levels by 2100. Two-thirds of global greenhouse gas (GHG) emissions stem from energy production and use, which puts the energy sector at the core of efforts to combat climate change.

In 2017, IRENA, based on REmap methodology and in collaboration with the International Energy Agency (IEA), launched the study *Perspectives for the energy transition: Investment needs for a low carbon energy system* (IRENA and IEA, 2017) to provide a view on the degree of transformation required in the global energy sector to reach the "well below 2°C" target of the Paris Agreement. The analysis was undertaken at the request of the German G20 Presidency and was reflected in the Agreed Documents of the G20 Summit in 2017. An updated analysis was provided in 2018 and published in the IRENA report *Global energy transformation: A roadmap to 2050* (IRENA, 2018a).

IRENA's 2018 analysis suggests that existing and future renewable energy expansion, under current government plans and targets, will result in a 27% share of renewables in global total primary energy supply (TPES) by 2050 (IRENA, 2018a). Reaching the climate targets of the Paris Agreement with a probability of two-thirds would require increasing the share of renewable energy in TPES (excluding non-energy uses) to around 66%; this reflects a considerable gap between the current global energy sector trajectory and the energy transformation required to meet the climate targets. The key general ingredients for bridging this gap can include increased use of wind and solar technologies, greater electrification of end-use sectors, the use of biomass (for heating, cooking and power generation) and biofuels, and more effectively combining energy efficiency and renewable energy measures (*e.g.* public sector policies that integrate renewables technologies for the renovation of public buildings).

The REmap global database currently covers 70 countries, representing over 90% of global energy use. Each country in the REmap analysis will play a role in the global transformation, even if by different means and with varying degrees of ambition, depending on the countries' resource base, technological possibilities and other factors. Besides the bottom-up global report, IRENA also provides country studies. So far, REmap reports have been developed for 13 countries.[1]

In 2015, IRENA and the South African Government, through the Department of Energy of South Africa (DoE) and the South African National Energy Development Institute (SANEDI), agreed to prepare this REmap country study (referred to as the "study" throughout the document). The main objectives of the South African government for this study are threefold,

1 All IRENA publications, including all REmap publications, are available at *www.irena.org/*.

namely: i) a transversal analysis of additional renewable energy deployment potential to 2030, beyond government policy and against international benchmarks (including the potential of renewables technologies in end-use sectors); ii) an identification of the costs and benefits of deploying these renewable energy technology options; and iii) an assessment of barriers and possible solutions to realising the options, in the context of the policy and regulatory framework of the energy sector.

In line with these objectives, the government and IRENA jointly established the main research questions. The government emphasised that the REmap country study should be consistent and aligned with key government policies, such as the Integrated Resource Plan (IRP) and Integrated Energy Plan (IEP), and should serve to provide food for thought on further renewables potential that is not identified in the current government plans and targets. Hence, the REmap country study is not meant to substitute or replace other government planning documents, especially the IRP and IEP. Rather, it complements the key government policies by alluding to additional technology potential and options that are currently overlooked. The time horizon of the REmap South Africa study is 2030, with some perspectives to 2050.

South Africa is the second-largest economy in sub-Saharan Africa (in terms of gross domestic product, or GDP) and the highest primary energy consumer in Africa. The total final energy consumption (TFEC[2]) in South Africa amounted to around 2.29 exajoules (EJ) in 2015 (DoE, 2016a). South Africa has significant potential from tapping into renewable energy options.

This study identifies the options for additional renewables deployment beyond the trajectory of current government policies and plans to 2030 (the "Reference Case 2030") by energy-use sector and technology – so-called "REmap Options". The Reference Case plus the REmap Options amount to the "REmap Case 2030", for which related costs and benefits are identified. REmap, notably, is not a scenario or a target-setting exercise but an options-based approach. The study identifies different REmap Options for increased renewables deployment that can, individually or jointly, provide helpful input to decision-making actors in the national energy sector, foremost the government of South Africa and its Department of Energy, which serves as the custodian of energy planning.

This study starts with a brief description of the REmap methodology (Chapter 2). It continues by explaining the energy situation and recent trends of renewable energy use in South Africa based on the currently available data (Chapter 3). Chapter 4 discusses the current energy sector framework in South Africa. Chapter 5 provides an overview of the Reference Case 2030 for South Africa – *i.e.* the trajectory based on current government policies and plans. Chapter 6 discusses the resource potential and costs for different renewable energy technologies in South Africa. Chapter 7 identifies the REmap Options and presents the REmap Case 2030, including an assessment of the costs and benefits from the REmap Options. This is followed by a discussion of the wider challenges and opportunities for renewables use in different energy-use sectors in South Africa (Chapter 8) and suggestions for improving and accelerating national renewable energy uptake (Chapter 9).

2 Total final energy consumption (TFEC) is the energy delivered to consumers, whether as electricity, heat or fuels that can be used directly as a source of energy. This consumption is usually sub-divided into that used in: transport; industry; residential, commercial and public buildings; and agriculture; it excludes non-energy uses of fuels.

2 METHODOLOGY AND DATA SOURCES

IRENA's REmap offers an analytical approach for exploring how to accelerate renewable energy technology deployment beyond the pathway of current government policies and targets. This chapter outlines the REmap methodology and process, and the data sources used for the analysis in South Africa.

In general, REmap country analyses are the result of a collaborative process between the government, IRENA, national REmap experts in the countries and other key stakeholders. The analysis starts with national-level data covering both power generation and end-use energy demand (in buildings, industry, transportation and agriculture). The latest available official national energy balance forms the basis for the analysis (for example, 2015 as the base year for this analysis – see Chapter 3). The Reference Case is based on current and planned government policies and targets (including commitments made in Nationally Determined Contributions [NDCs] under the Paris Agreement). Once the Reference Case has been established, technology options ("REmap Options") for additional renewables development are identified and their deployment potential is assessed. The choice of an options approach instead of scenarios is deliberate: REmap is an exploratory study of additional renewable energy potential, not a scenario or target-setting exercise.

Renewable energy potential is assessed based on the resource potential and possible speed and scale of technology deployment and with consideration of other constraints for development, to identify a realistic degree of technology use. Hence, REmap Options are not purely based on cost optimisation. Rather, each technology option is characterised by its cost, and the benefits are assessed in terms of reduced carbon dioxide (CO_2) emissions and air pollution, as well as health benefits, employment gains and financial savings.

Each REmap Option substitutes a non-renewable energy technology used to deliver the same amount of energy (*e.g.* power, cooking, heat, etc). The implementation of REmap Options results in a new energy mix with a higher share of renewables, which is called the REmap Case. Non-renewable technologies include fossil fuels and nuclear. Throughout this study the renewable energy share is estimated in terms of TFEC. Modern renewable energy excludes traditional uses of bioenergy. The share of modern renewable energy in TFEC is equal to total modern renewable energy consumption in end-use sectors (including consumption of renewable electricity and district heat and direct uses of renewables), divided by TFEC.

The share of renewables in power generation is also calculated. The renewable energy use by end-use sector comprises the following:

- **Buildings**: includes the residential, commercial and public sectors. Renewable energy is used in direct applications for heating, cooling or cooking purposes, or as renewable electricity.
- **Industry**: includes the manufacturing and mining sectors, where renewable energy is consumed in direct use applications that comprise mainly process heat, and as electricity from renewable sources.
- **Transportation**: entails the direct use of renewables through the consumption of liquid and gaseous biofuels, or through the use of electricity generated from renewable energy technologies.
- **Other sectors**: includes agriculture, fisheries and forestry.

At the time of writing this study, the draft IRP 2016 update and draft IEP 2016 of the government of the government of South Africa were the latest available official energy balances and projections. Hence, the base year (2015) energy balance for this study was adopted from the draft IEP 2016 (DoE, 2016a).

The Reference Case 2030 for South Africa is compiled from the Base Case scenario of the draft IEP 2016. To account for relevant developments, the study includes text boxes on new policy documents and plans that have been released since writing this study.

Where necessary, official plans or projections for South Africa have been updated or cross-checked with information originating from other sources, including, amongst others, the following (note that all the below-listed sources are properly cited and referenced in Chapter 6 of this study):

- Renewable energy potential by resource (theoretical and technology-specific): Renewable Energy Development Zones (REDZs), SolarGIS data, Wind Atlas of South Africa (WASA) project and Bioenergy Atlas of South Africa.
- Current and future costs (fixed and capital costs, levelised cost of electricity [LCOE]): 2015 auction outcomes (Renewable Energy Independent Power Producer Procurement Programme [REIPPPP]) in South Africa for solar photovoltaic (PV), wind, and concentrated solar power (CSP); Bloomberg New Energy Finance; IRENA renewable cost database.

In addition, expert opinions from DoE, SANEDI, IRENA and other key stakeholders in South Africa were incorporated into the analysis. Stakeholder comments and inputs were gathered at the occasion of two national review workshops that were convened by the DoE in September 2018 and November 2018 to present and discuss draft versions of the study, and through written comments (including a questionnaire distributed at the first national review workshop), data inputs and feedback by email. The vast amount of helpful stakeholder inputs formed a key information source for this study.

3 CURRENT LANDSCAPE OF THE SOUTH AFRICAN ENERGY SYSTEM

KEY POINTS

- For 2015, TPES is made up of coal (66.9%), oil (16%) and petroleum products (6.8%) with smaller shares for gas (2.2%) and nuclear (3.5%). Renewables begin to gradually account for a larger (while still relatively small) role (around 3% of TPES).
- At the end of 2015, coal-based power accounted for 78% of the national power generation capacity. This was followed by hydropower and nuclear, making up 3.9% and 3.7%, respectively. Renewables (excluding hydro) contributed 4.7% to power generation capacity in 2015.
- South Africa is heavily reliant on coal as a means of electricity production, accounting for over 85% of the power sector energy mix. This is followed by nuclear and hydro energy sources with 5.4% and 1.8% contributions to the power sector generation mix, respectively, in 2015. Electricity demand has been mostly stagnant in recent years.
- Renewables have made progress in recent years with the implementation of the REIPPPP. The Independent Power Producer (IPP) programme aims to procure new electricity generation through a transparent bidding process that drives costs lower over time through competition. To date, the REIPPPP has contributed to an additional 3.9 GW of operational renewable power capacity while a further 2.4 GW is in the pipeline.
- The REIPPPP has connected 52 projects to the grid with a further 10 under construction and 28 in the approval, planning or financing stage. A further two projects are awaiting construction or are partially operational.
- In April 2016 there were estimated to be 38 commercial biogas projects in operation in South Africa. Existing commercial-scale biogas plants have a total installed capacity of over 30 MW. Traditional biomass use amounts to around 127 PJ.
- All sectors have seen increased use of renewable energy in recent years, particularly of residential and commercial PV installations, solar water heaters (SWHs) and industrial combined heat and power (CHP).
- Key drivers for renewable energy development in South Africa are the gradually lower costs of deployment for renewables, energy access, diversification of energy supply and environmental benefits. Higher renewables deployment can also lead to employment benefits.
- Significant progress has also been made since 2000 in reducing energy intensity, exceeding the targets set in the National Energy Efficiency Strategy (NEES) of 2005 for most sectors. The improvements reflect a mix of autonomous change, technology advancements and deliberate interventions on energy efficiency.

This chapter presents the national energy sector data and current trends in the South African energy system as the baseline for the REmap analysis. It presents the current role and uses of renewables in the national energy mix, as well as the drivers for increased renewables deployment and socio-economic and environmental implications from current energy production and use.

The South African energy system must be analysed in the context of the country's economic profile. Table 3.1 below provides an overview of the key economic, socio-economic and energy system indicators. The numbers help to describe the population and economy that the South African energy system serves and to explain some of the energy policy choices of the country.

Table 3.1: Key economic and energy sector indicators for South Africa

Indicator	Value
Population	57 726 000
Land area (total)	1 220 813 km^2
Land use (in % of total land area; 2011 est.)	Agricultural land: 79.4% (arable land 9.9%) Forest: 7.6% Other: 13%
GDP (in 2017 USD) (PPP)	USD 767.2 billion (2017 est.)
Per capita GDP (in 2017 USD) (PPP)	USD 13 600 (2017 est.)
Electricity consumption per capita	4 189 kWh/yr
Energy consumption per capita	16 415 kWh/yr*
Unemployment rate (in % of the labour force)	26.7% (as of Q4 2017)
Population below food poverty line (in % of total population)	16.6% (2016 est.)
Electricity access rate (in % of population)	86% (urban: 90%; rural: 77%)
Hydrocarbon resources/reserves	Crude oil: 15 million barrels (2017 est.)
CO_2 emissions from energy consumption	390 Mt/yr (2015 est.)

**Based on TFEC from 2015 Energy Balance (DoE, 2016a) and 2018 Stats SA population estimate (Stats SA, 2018).*
Note: USD = United States dollars; km² = square kilometre; yr = year; kWh = kilowatt hour; PPP = purchasing power parity; Mt = megatonnes.

Based on DoE (2016a); Stats SA (2018); CIA (2019).

3.1 Base year energy status

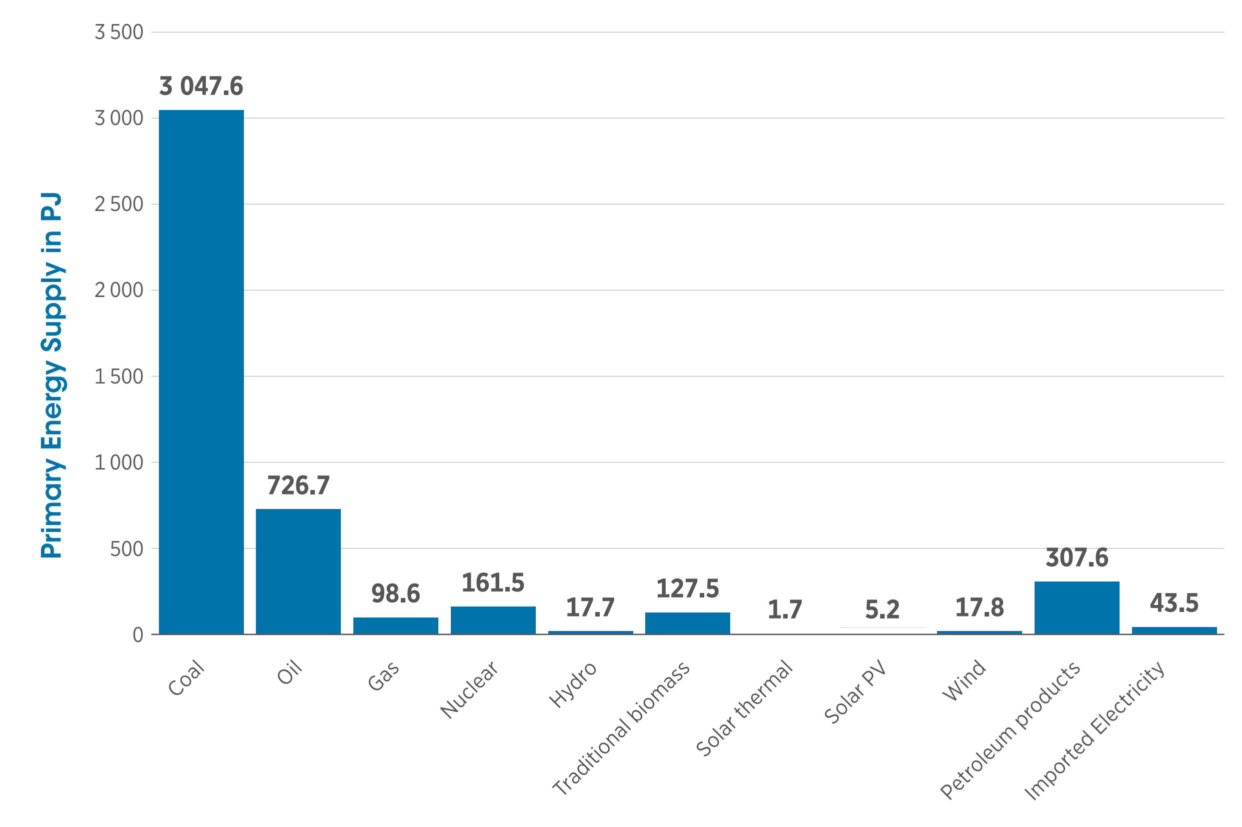
The 2015 base year data for this study are taken from the draft IEP 2016 (DoE, 2016a[3]). At the time of writing this study, the latest official South African Energy Balance available from the South African DoE was for 2014. During 2018, the DoE released the official Energy Balance 2015 (DoE, 2018a). While for purposes of the national REmap analysis the official 2015 Energy Balance could not be adopted as base year data, Box 1 below summarises the official DoE Energy Balance 2015 and key differences compared to the 2015 base year data from the draft IEP 2016.

Primary energy supply

The 2015 primary energy supply is summarised in Figure 3.1. The majority of South Africa's energy requirements are met domestically. Imports are predominantly made up of oil and petroleum products (indicating minimal domestic supply for end-use sectors using these energy carriers, *e.g.* transportation) and some natural gas. The overall share of imports in TPES in 2015 was around 24.7% (IEA, 2016). For 2015, TPES is made up of coal (66.9%), oil (16%) and petroleum products (6.8%) with smaller shares for natural gas (2.2%) and nuclear (3.5%). Renewables have been deployed for power generation as part of the REIPPPP and begin to play a larger role albeit still small in relative terms (4% of TPES).

3 The full draft IEP 2016 report as well as Annexures and further related materials are available from the DoE website at *www.energy.gov.za/files/iep_frame.html*.

Figure 3.1: Primary energy supply summary for South Africa (2015)



Based on DoE (2016a)

Key insight:

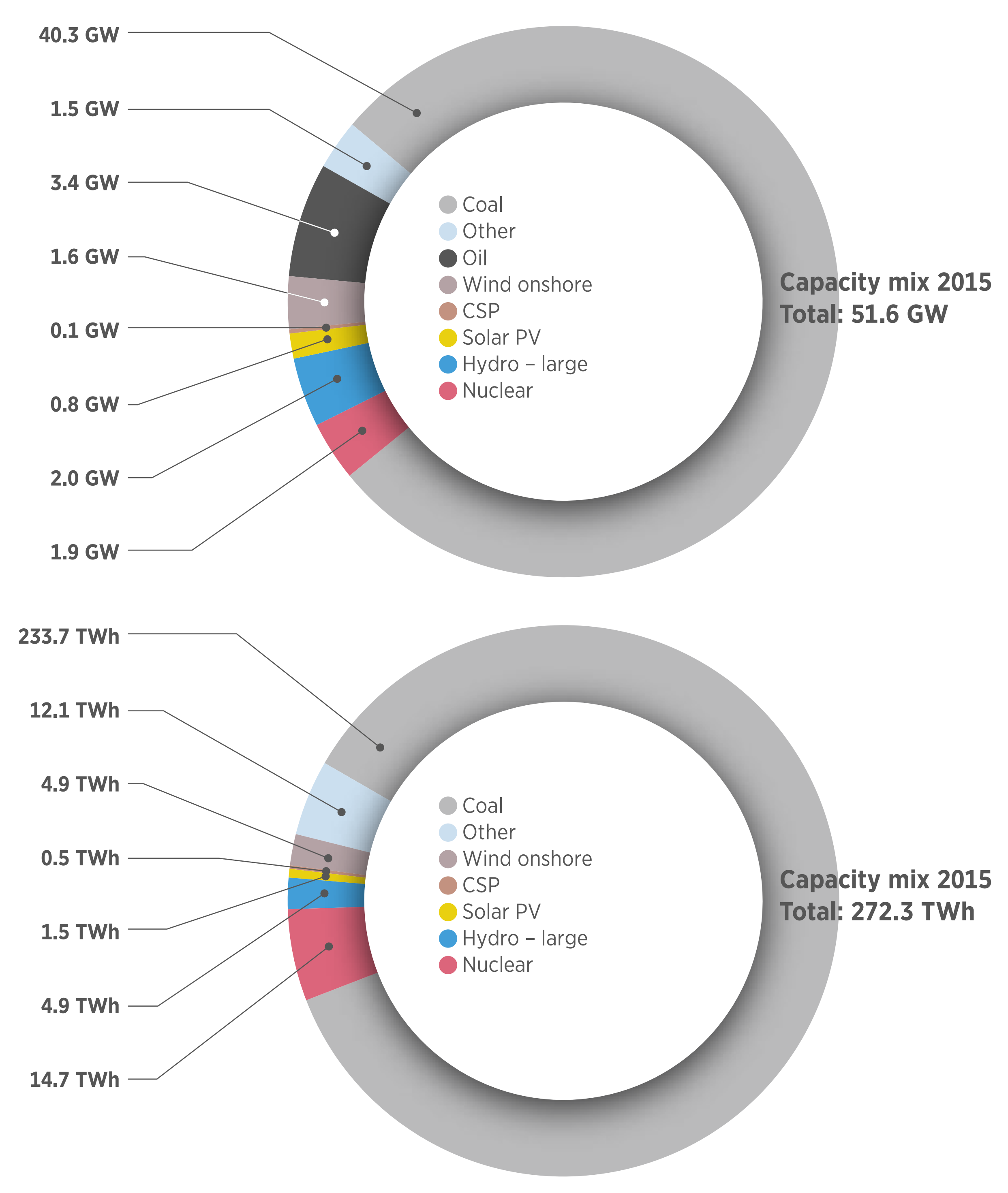
TPES is made up of coal (66.9%), oil (16%) and petroleum products (6.8%) with smaller shares for natural gas and nuclear. Renewables have been deployed for power generation and begin to play a larger role albeit still small in relative terms.

Power sector

Some 96% of South Africa's electricity is supplied by the national vertically integrated utility Eskom. In 2015, coal-based capacity accounted for around 78% of the capacity mix in South Africa, followed by oil, large hydropower and nuclear, making up 6.6%, 3.9% and 3.6%, respectively. Renewables (excluding hydro) contributed 4.7% to power generation capacity.

In terms of national electricity generation (including losses), coal accounted for over 85% of the generation mix. This was followed by nuclear and large hydro energy sources, with 5.4% and 1.8% contributions to the power generation energy mix, respectively. Renewables (excluding hydro) contributed a total 2.5%

Figure 3.2: Power generation mix in South Africa by capacity and electricity supplied (2015)



Based on DoE (2016a)

Key insight:

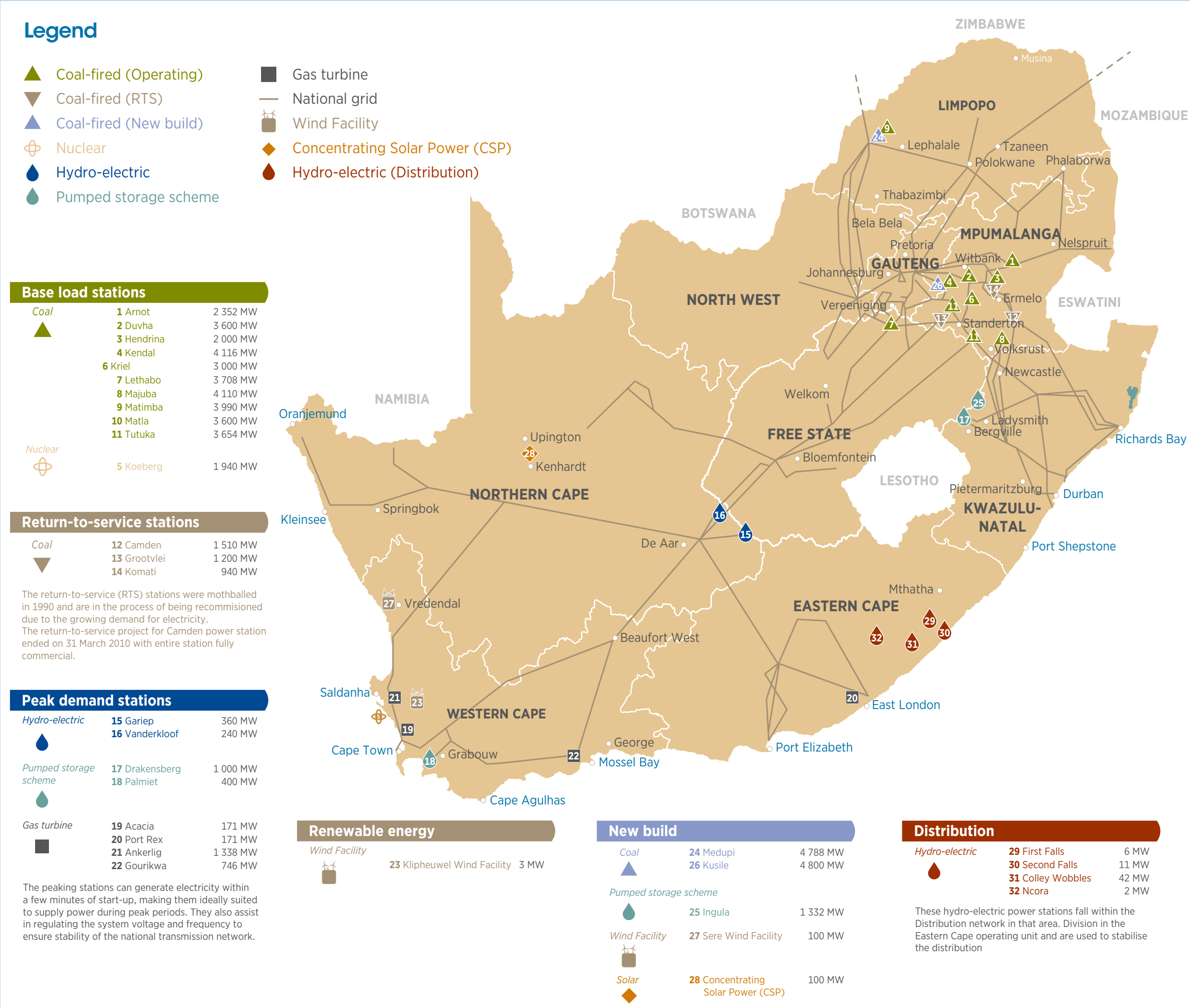
South Africa's installed capacity and electricity supply mix are dominated by coal, while deployment of alternative technologies (including solar PV and wind) is increasing.

to the electricity energy mix in 2015 (DoE, 2016a). Figure 3.2 gives further details of the capacity and generation mix in South Africa in 2015.

Figure 3.3 shows the location of all power generation facilities in South Africa that are owned and operated by Eskom. The location of coal power plants highlights that the majority of South Africa's electricity is generated in the north and north-eastern parts of the country (*i.e.* the Limpopo and Mpumalanga provinces).

The power generated must hence be transported over high-voltage transmission lines over hundreds of kilometres to the energy demand centres. Transmission over such long distances leads to considerable power losses in the national grid system in South Africa.[4]

Figure 3.3: Location of utility-scale power generation units owned and operated by Eskom in South Africa

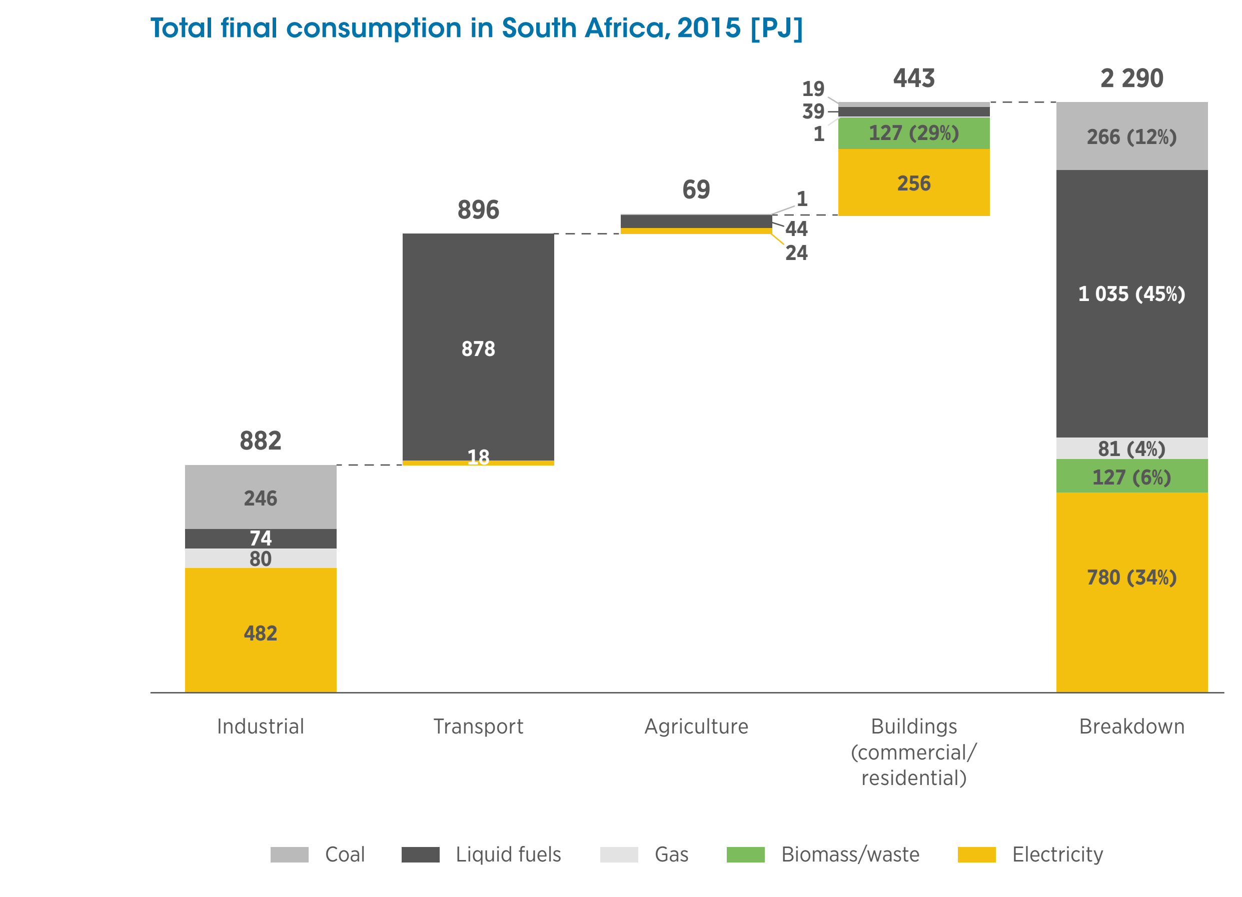


Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.
Based on Eskom (2013), developed by CSIR.[5]

4 IEA (2018) estimated electric power transmission and distribution losses (% of output) in South Africa for 2014 at 8.39%.

5 The original map was issued by the Generation Communication Department of Eskom in 2013 and is available at: *www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Pages/Map_Of_Eskom_Power_Stations.aspx.*

Figure 3.4: TFEC by energy end-use sector disaggregated into energy carriers (2015)



Based on DoE (2016a).

End-use sectors

As shown in Figure 3.4, South Africa's end-use of energy in 2015 was dominated by the transport sector (896 PJ, 39.1% share of TFEC) and the industrial sector (882 PJ, 38.5%); buildings (residential, commercial, public) accounted for 19% (443 PJ) of end use.

The agricultural and forestry sectors accounted for around 3% (69 PJ) of energy end-use. Figure 3.4 also gives an overview of final energy consumption by energy source. Energy end-use in 2015 consisted of liquid fuels (45.2%), electricity (34.1%) and coal (11.6%) with small shares for biomass (5.6%) and natural gas (3.5%) (DoE, 2016a).

Industry

The industrial sector contributed a share of 22.4% to South African GDP in 2015, of which mining and manufacturing (including construction) were responsible for 3% and 17%, respectively (Stats SA, 2016a). Within the industrial sector, the energy-intensive mining, iron and steel and precious and non-ferrous metals industries were large electricity consumers.

Combined, they were responsible for around 60% of the industrial sector's electricity demand. Around 46% of energy was consumed to supply heat, of which coal supplied around 58%. Gas, liquid fuels, biomass/biogas (largely from the pulp, paper, food and beverage industries) produced around 11% of electricity consumed by the sector (Stats SA, 2016a).

Transportation

The transport sector in South Africa includes ports and shipping, roads, railways, airports and airlines. The sector accounted for 39.1% of national TFEC in 2015. Liquid fuels supplied 98% of energy in the transport sector in 2015 (DoE, 2016a). The share of petrol and diesel was roughly equal at around 50%. Freight took the largest share of diesel, making up around 60% of liquid fuel demand in the transport sector. Total freight transported was around 382 billion tonne-km in 2015 (Havenga et al., 2016).

Rail is an important contributor to long-distance freight transport, having carried around 140 billion tonne-km[6] in 2015 (circa 35% of freight transport demand). Electricity accounts for a minor contribution to rail transport in South Africa. The transport sector seldom uses coal directly, instead using liquid fuel products (derived from coal). Over 30% of all liquid fuels in the transport sector that are produced locally are derived from coal using coal-to-liquid (CTL) technology (DoE, 2016a). There is currently no biofuel (biodiesel or ethanol) blending with diesel or petrol at a commercial scale.

In 2016, the National Traffic Information System recorded around 11 million vehicles in South Africa, 7 million of which were passenger vehicles, leading to a motorisation rate of around 125 vehicles per thousand people (eNaTIS, 2016). Although private vehicles provide the bulk of the vehicle population, public transportation has the greater share of passenger trips.

The public transport share of passenger kilometres is around 53%. Privately owned minibus taxis are an important component of the public transport network, accounting for around 35% of total motorised trips compared to bus (9% of trips) and rail (6%) (van Ryneveld, 2014).

6 A tonne-kilometre (tonne-km) represents the transport of one tonne of goods over a distance of one kilometre.

Buildings

Buildings (commercial and residential) were responsible for around 19% of TFEC in 2015. The commercial sector is the fastest-growing economic sector in South Africa, responsible for around 70% of GDP in 2015. Despite its dominant role in GDP, the commercial sectors' share of TFEC is small (less than 5%). The commercial sector relies mainly on electricity, along with small amounts of coal and other fuels for thermal purposes. Electricity use in the commercial sector is dominated by the need for lighting and cooling.

Building regulations/standards in South Africa, such as SANS 10400,[7] have been amended to include energy efficiency provisions, which are likely to reduce the energy intensity of the commercial sector significantly in future. These regulations address building performance parameters encouraging energy efficiency and the use of renewables where possible.

Generally, data availability for heating and cooling in buildings is not as comprehensive as for the power and transport sectors, and thus the energy-use mix is not as well quantified. Space heating and cooling energy services in South Africa have historically either been covered by cheap coal directly (in industry) or in the form of electricity. Renewables have made some progress over recent years as sources for heating and cooling in buildings, as electricity tariffs have increased by an average of over 10% over the 10-year period 2008–2017, making other options more competitive.

Space heating and cooling systems used in the commercial and the residential sectors are mainly heating, ventilation and air conditioning (HVAC) units. Heating and cooling needs vary across the country; the coastal areas tend to require a more moderate amount of heating and cooling, whilst heating and cooling needs are higher in the central regions.

7 SANS 10400 is the Code of Practice for the application of the National Building Regulations. Further information on SANS 10400 can be found in Chapter 4 below and at *www.sans10400.co.za/*.

Heating and cooling degree days (using 18 °C as the base temperature) vary up to a maximum of around 3 300 degree-days annually. Cooling needs are highest in the north, whilst heating needs are highest in the mountainous regions, particularly around Lesotho.

Household use of electricity and other fuels varies widely by income group and between rural and urban areas. Traditional biomass use is still common in the rural areas, where the electrification rate and appliance ownership are lower. The continued use of biomass and other solid fuels in the residential sector is largely linked to poverty. Despite a rapid increase in the overall electrification rate since the early 1990s, and a policy under the DoE for 50 kWh in Free Basic Electricity (FBE) per month to each qualifying indigent household, many households can still only use electricity in limited quantities.

Energy use across all households in the residential sector is dominated by cooking and water heating. In low-income households this is primarily cooking, while in higher-income households it is primarily water heating. Water heating in low-income households is constrained by both an inability to afford the fuel and appliances needed as well as limited access to water.

The percentage of households using electricity as their main fuel for cooking has increased significantly to almost 75%, compared to 51% in 2001 (Stats SA, 2016b). Although many low-income households own electric stoves and use electricity as their primary fuel for cooking, solid fuels are still commonly used to supplement electricity. The DoE estimates that as many as 40% of households across South Africa are using multiple fuels for cooking (DoE, 2013a).

Box 1 provides an overview of the recently released Energy Balance 2015 and key differences against the 2015 base year data from the draft IEP 2016 presented in this chapter.

Box 1:

DoE Official Energy Balance 2015

In 2018, the DoE published the official national Energy Balance 2015 for South Africa. The official 2015 Energy Balance showed overall higher energy consumption compared with the 2015 data presented in Chapter 3, Section 1 of this study (as derived from the draft IEP 2016).

Particularly, the official Energy Balance showed higher biomass use in buildings and industry and higher coal and gas use in industry, while electricity use in industry was reduced compared to the draft IEP 2016 (note: the demand for electricity in the IEP is guided by the IRP). The demand for liquid fuels in the official Energy Balance 2015 did not significantly change compared to what was published in the draft IEP 2016 at the end of November 2016.

The Energy Balance 2015 is available from the DoE website, *www.energy.gov.za/files/media/Energy_Balances.html*.

Energy efficiency

The National Energy Efficiency Strategy (NEES) of 2005 defined energy efficiency targets to be achieved by 2015 for each energy end-use sector. It thereby put energy efficiency on the agenda in South Africa and set the direction for areas of progress. A National Energy Efficiency Action Plan was developed in 2012 describing the implementation of the strategy. In 2014, the Energy Efficiency Target Monitoring System was established to monitor the progress on energy efficiency improvements and work towards meeting the original targets for energy reduction (based on a year 2000 baseline).

Energy efficiency performance is measured in terms of "energy intensity", which is a measure of the productive use of energy (*i.e.* the units of energy per unit of GDP[8]). The results of the monitoring analysis confirmed that significant progress had been made between 2000 and 2012 in improving energy intensity.

These even exceeded expectations for most sectors. The improvements in energy intensity were found to reflect a combination of autonomous change, technological advancements, and deliberate interventions to improve energy efficiencies (DoE, 2016b). Table 3.2 presents the 2015 targets by sector defined in the NEES 2005 and compares them to the progress achieved by 2012.

To build on these achievements and stimulate further improvements in energy efficiency through the combination of fiscal and financial incentives, a robust legal and regulatory framework, and enabling measures, the government published the draft post-2015 NEES for public consultation in late December 2016 (DoE, 2016b). The framework of the Post-2015 NEES (Chapter 4) and the new targets to 2030 (Chapter 7) are discussed below.

Table 3.2: Improvements in energy intensity (2000–2012) compared to NEES 2005 targets

Sector	2015 target	Performance 2000–2012
Economy-wide	12%	23.7%
Industry	15%	34.3%
Residential	10%	28.2%
Commercial and public	15%	0.3% (electricity only, 2003–2013)
Transport	9%	14.1% (reduction in sector-wide energy intensity)
Power sector	15%	Probably achieved, although no baseline against which to measure percentage savings

Based on DoE (2015a)

8 High energy intensities indicate a high price or cost of converting energy into GDP. Low energy intensities indicate a lower price or cost of converting energy into GDP. A lowering of the energy intensity therefore indicates an improvement in efficiency of energy use.

3.2 Trends in renewable energy use in South Africa

The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP)

The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) was developed to stimulate the development of a renewable energy industry in South Africa by encouraging private sector investment. The REIPPPP is a transparent bidding process that drives costs lower over time through competition. More than five competitive bidding rounds were held between 2011 and 2018, including extra and expedited rounds as well as a bidding round dedicated specifically to 200 MW of CSP capacity in 2014. Each potential IPP bids for an opportunity to reach financial close where several key contracts are finalised, including: the power purchase agreement (PPA), the implementation agreement and the grid connection agreement. Bids are generally made for selling electricity using specific technologies, and only bids under the same technology category are allowed to compete against each other. Eligible technologies under the REIPPPP include onshore wind, solar PV, CSP, small-scale hydro, biomass, and biogas or landfill gas (DoE, DNT and DBSA, 2018a).

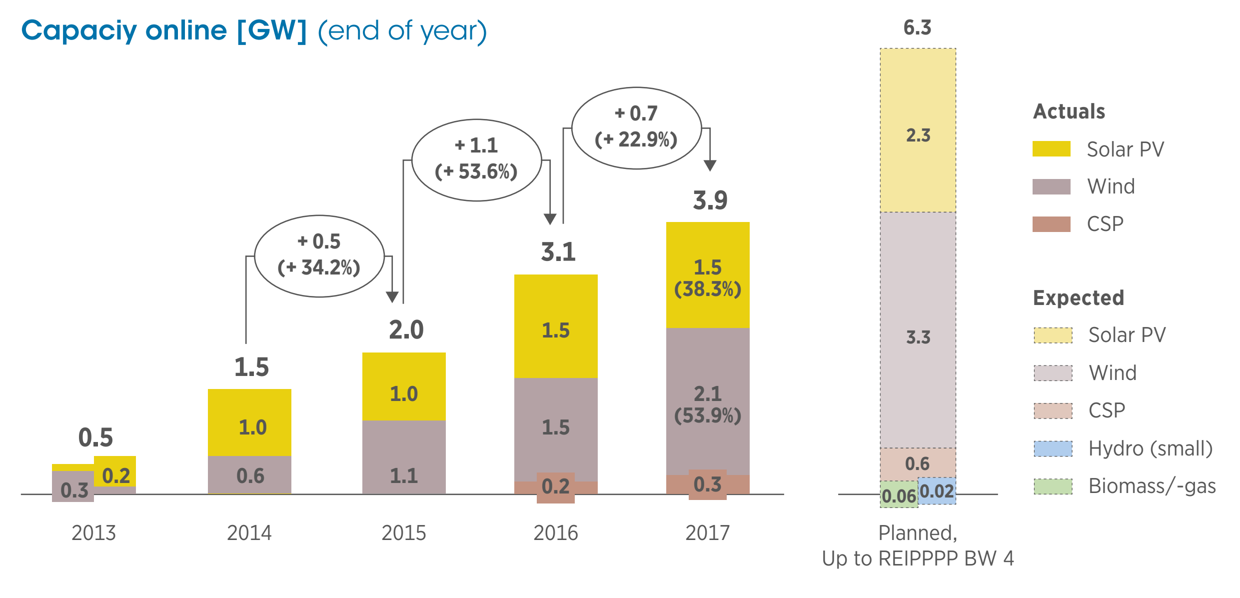
The REIPPPP was designed to assist with multiple national objectives such as meeting national renewables targets, encouraging foreign investment, fostering socio-economic development and protecting the environment. Bids are assessed in terms of their tariff (70% weighting) and their economic development impact (30% weighting) (DoE, DNT and DBSA, 2018b).

Economic development requirements are non-price factors, which promote job growth, community development, black economic empowerment (*i.e.* employment, management, and ownership by previously disadvantaged groups), and domestic industrialisation. For example, there is a black ownership requirement of 12% to 30% of project shareholding and a local community ownership requirement of 2.5% to 5% of project shareholding (DoE, DNT and DBSA, 2018b).

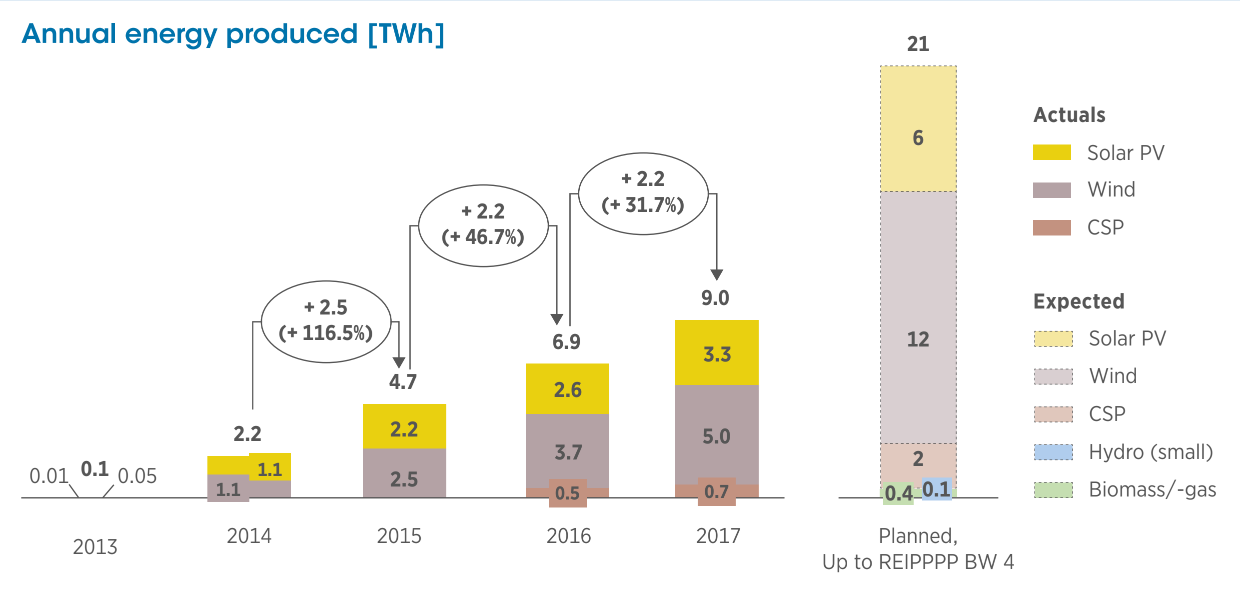
Renewable energy investment accelerated as a result of the introduction of the REIPPPP. As shown in Figure 3.5, at the end of 2017, there was 3.9 GW of renewable energy capacity operational in South Africa, and an additional 2.4 GW with PPAs approved in 2018. At the end of 2017, total solar PV and wind capacity had grown to 1.5 GW (38% of installed capacity under the REIPPPP) and 2.1 GW (54%), respectively, up from 1.0 GW/1.1 GW in 2015 (note that this increase in renewable energy capacity between 2015–2017 is not reflected in Chapter 3, Section 1, which presents 2015 data).

Sources in the literature may differ slightly with regard to the level of solar PV and wind deployment in 2015, depending on whether projects under development and/or construction were included in the statistics rather than only projects that were fully operational. So far, 41 MW of biomass and 18 MW of landfill gas has been procured under the REIPPPP. On a pure LCOE basis, renewables procured in the REIPPPP compete favourably relative to other technologies, including new-build baseload coal. See Chapter 6 for more information on renewable resource potential and related costs.

Figure 3.5: Deployment of renewables in South Africa as part of the REIPPPP, 2013–2017



Note: Solar PV capacity = capacity at point of common coupling; wind includes Eskom's Sere wind farm (100 MW).



Note: BW = bid window.
Based on Data from Eskom; DoE, DNT and DBSA (2018a)

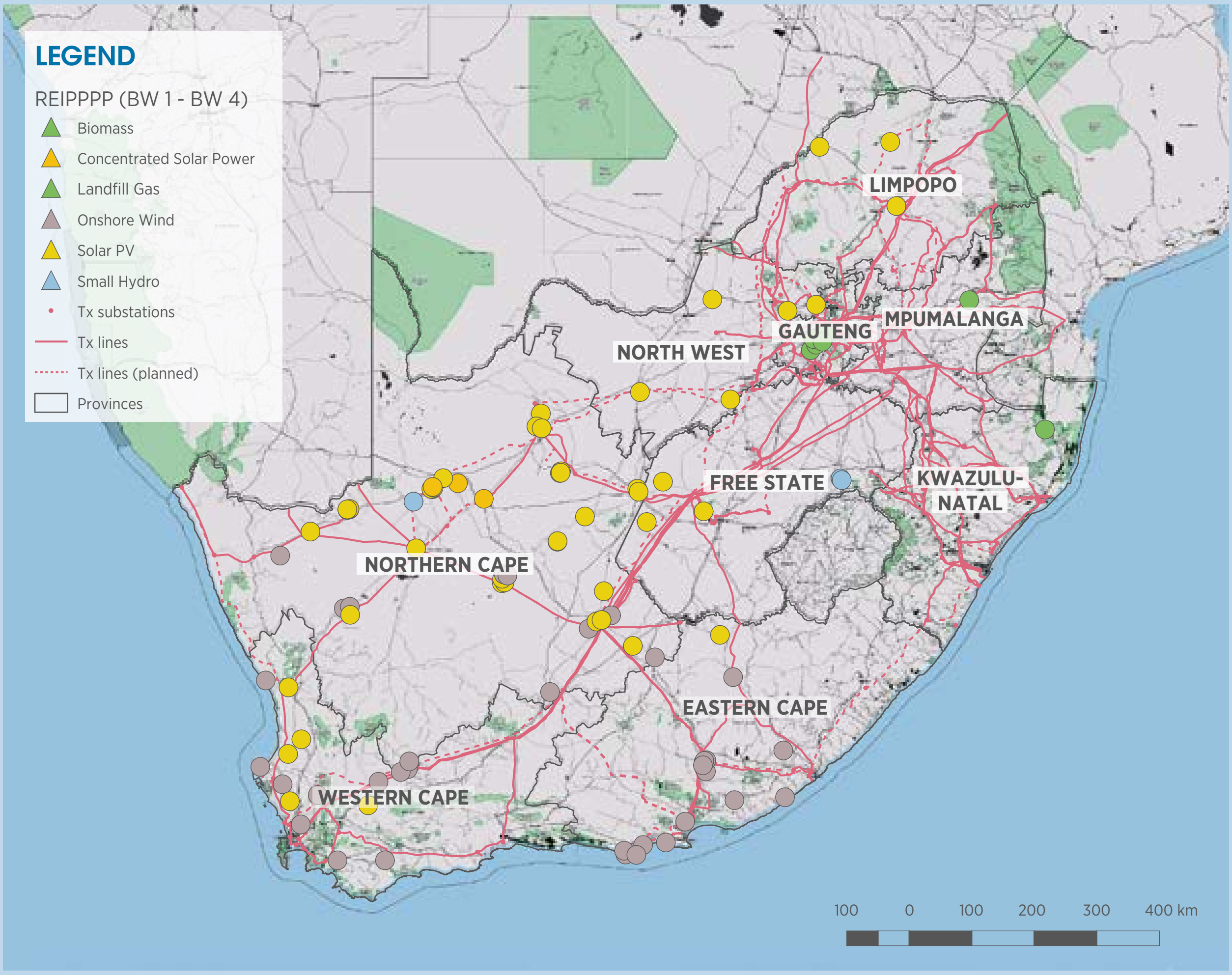
Key insight:

As of 2017, there was 3.9 GW of renewable energy capacity operational, including 1.5 GW of solar PV and 2.1 GW of wind. In addition, 2.4 GW is with PPAs approved in 2018. Power generation from renewable sources has grown steadily in past years. In 2017, generation from solar PV was around 3.3 TWh; wind, 5 TWh; and CSP, 0.7 TWh. This is expected to increase to a total of 21 TWh with additional approved capacities.

Figure 3.6 indicates all projects approved during the REIPPPP (Bid Windows 1–4) as of 2015 and delineates them by technology and location. More than half of all projects approved under the REIPPPP were located in the Northern Cape, Eastern Cape and Western Cape. The considerable solar and wind resources in these areas, combined with low population densities (in the Northern Cape) and few competing land uses, make for suitable project sites for utility-scale renewables.

Major electricity demand centres are located in the far southwestern part of the country (*i.e.* Cape Town), as well as the industrial hubs of Gauteng and Durban. As can be seen in Figure 3.6, most IPPs have built their facilities in close proximity to major substations or transmission lines. This minimises the need to construct additional power network infrastructure (which can become a significant component of total costs for the IPP). The renewable energy resource distribution in South Africa is further shown in Chapter 6.

Figure 3.6: REIPPPP locations by technology with superimposed existing Eskom transmission system (2015)



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Based on Eskom GCCA-2022 data (Eskom, 2015a); developed by CSIR

Small-scale REIPPPP projects

The DoE also introduced a small-scale REIPPPP in 2013 for projects equal to or less than 5 MW of capacity. The small-scale REIPPPP follows the same basic structure as the large-scale REIPPPP. A total capacity of 200 MW is planned to be procured under the small-scale REIPPPP.

Small-scale REIPPPP projects have been slower to develop in South Africa when compared to the utilityscale REIPPPP projects.

They are seen as an entry point for entrepreneurs looking to expand their footprint into renewables. A total of 20 small-scale projects, jointly amounting to a capacity of 99 MW,[9] have achieved Preferred Bidder Status in South Africa as part of the DoE's Small-Scale REIPPPP; namely 16 solar PV, 2 wind and 2 biomass projects. Most of the projects are located in the Northern Cape (11), followed by Free State (4) and Western Cape (3). An overview of the preferred bidders is shown in Table 3.3, while Table 3.4 provides of the geographical distribution of the small-scale projects.

Table 3.3: Preferred bidders under the small-scale REIPPPP

Bid Window 1		Bid Window 2	
Adams Solar Project	Solar PV	Mount Roper Solar	Solar PV
Bellatrix Solar	Solar PV	Danielshuil Solar	Solar PV
Du Plessis Solar	Solar PV	Kakamas Solar	Solar PV
Steynsrus Solar	Solar PV	Keimos Solar	Solar PV
Steynsrus Solar	Solar PV	Disselfontein Solar	Solar PV
Hauningspruit Solar	Solar PV	Skuitdrift 1 Solar	Solar PV
Klawer WInd	Wind	Skuitdrift 2 Solar	Solar PV
Hopefield Community	Wind	Castor Solar	Solar PV
George Bio-to-Energy	Bioenergy	Capella Solar	Solar PV
Busby Renewables	Bioenergy	Augrabies Solar	Solar PV

Source: DoE, DNT and DBSA (2017)

Table 3.4: Location of small-scale REIPPPP projects in South Africa

	Bid Window 1	Bid Window 2
Eastern Cape	-	-
Free State	3	1
Gauteng	-	-
KwaZulu-Natal	-	-
Limpopo	-	-
Mpumalanga	1	-
North West	-	1
Northern Cape	3	8
Western Cape	3	-

Source: DoE, DNT and DBSA (2017)

9 All the projects listed in Table 3.3 have a capacity of 5 MW, except for "Hopefield Community" (Wind, 4 MW).

Further projects signalling diversification away from large-scale coal

A few notable other renewables projects exist outside of the REIPPPP. These include two wind farms and one CSP plant. The Sere wind farm (100 MW) is located in the Western Cape and was commissioned in 2015 by Eskom (Eskom, 2016). The Darling Wind Energy project has an installed capacity of 5.2 MW and was commissioned in 2008 in the Western Cape with the City of Cape Town municipality as the off-taker. Eskom previously embarked on an effort to develop a 100 MW CSP plant near Upington in the Northern Cape. This uncompleted project was discontinued in 2018, and the financial resources earmarked for this project were diverted into research and development for battery technology.

Small-scale embedded generation (SSEG)

"Embedded generation" entails production of electricity on the customer side of the meter and therefore at the same location as where the electricity is consumed. Since part of the demand is satisfied by own-production, net demand is generally lower for a consumer that uses an embedded generator. In South Africa, distribution networks are owned and operated either by a municipality or by the national utility Eskom, depending on the locality they serve. Distribution grids within large urban areas are commonly owned and operated by metro municipalities while smaller or poorer municipalities are served by Eskom-owned distribution grids since these municipalities may not have the capacity to operate the grid infrastructure (NERSA, 2018).

In recent years, municipalities and Eskom have noted an increase in SSEG (*i.e.* embedded generation capacity of no more than 1 MW and connected at a low voltage) within their distribution grid networks. In some municipalities, due to a lack of division between rents from power sector services provided directly by municipalities and other taxes/levies, the rents from selling power are also used to cover other municipality services. The tariffs for generating such revenues are set under a regulated process that is described in Chapter 4. The decreased income poses a grave challenge for municipalities because electricity sales are often their most reliable income stream.

In this context, the increase in embedded generation may pose challenges for the operation of distribution grids and erode the steady income that South African municipalities have typically realised from stable electricity sales to customers in their jurisdictions. For this reason, efforts to monitor such embedded generation deployments have increased and regulations have been drafted on requirements to register such installations. However, embedded generation also offers large opportunities and could be a cheaper solution for renewable power deployment.

Table 3.5 shows the results of the monitoring efforts so far; these numbers are generally accepted to be lower than the actual ones. Given the vast resources needed to investigate and search for illegal embedded generators, the numbers in Table 3.5 are based on voluntary registration or disclosure by the owners of these small-scale systems. The table shows that the number of municipalities that proactively monitor and offer dedicated feed-in tariffs (only available to those with registered and approved grid connections for their systems) for SSEG installations in South Africa is increasing rapidly.

Table 3.5: Municipalities managing SSEG in South Africa (2016)

Province	Number of municipal electricity distributors in each province*	Number of municipalities allowing SSEG installations	Number of municipalities with official application system	Number of municipalities with SSEG tariffs**
Eastern Cape	22	3	2	1
Free State	17	1	1	1
Gauteng	9	4	3	2
KZN	25	1	1	1
Limpopo	15	2	0	0
Mpumalanga	14	2	0	0
Northern Cape	24	3	1	0
North West	13	0	0	0
Western Cape	25	18	13	13
National	**164**	**34**	**21**	**18**

Note: KZN = KwaZulu-Natal
Source: SALGA (2017)

The shortages in electricity supply experienced in South Africa in 2008 and again in 2014 highlighted the urgent need to expand generation capacity to reduce potential economic losses related to electricity shortages. Installed solar PV capacity in the residential and commercial sectors has been growing steadily, from a negligible base in 2010 to an estimate of around 285 MW by 2017 with 90% of the installation occurring in the last four years (PQRS, 2016). This rapid increase in SSEG installations is associated with a sharp decline in technology costs combined with increasing grid electricity costs.

While embedded generation is still in its infancy, the electricity shortages that occurred have also prompted industrial electricity consumers to assess the feasibility of further developing cogeneration and/or rooftop or ground-mounted solar PV facilities. This would provide some protection to industrial consumers against electricity supply interruptions in the future.

Private sector cogeneration

Numerous private sector industrial companies in South Africa are venturing into options for becoming energy independent through embedded generation, and renewables are among the most attractive options available to them. For example, the global paper manufacturer Sappi is taking advantage of cogeneration opportunities.

Sappi has developed two biomass generation facilities in Ngodwana (in Mpumalanga) and Saiccor (southern KwaZulu-Natal) to assist in moments of power supply constraints. On a national level, Sappi (which runs seven mills) generates more electricity than it uses, and it could become a net exporter of power to the national grid (Sappi Group, 2018). In April 2018, Sappi reached financial close on its 25 MW bioenergy project at Ngodwana[10] with a potential additional 200 MW of power generation projects in the pipeline identified as early as 2013 (TAPPSA Journal, 2013). Several other industrial subsectors feature prominently in terms of private sector cogeneration. In 2015, CHP capacity in pulp, paper and sugar mills combined was approximately 350 MW.

The IPP Procurement Programme in South Africa also extends to cogeneration schemes. The Cogeneration IPP programme procures energy through three technologies, namely waste-to-energy, CHP, and industrial biomass. The programme has two criteria that need to be fulfilled for eligibility: i) the fuel and/or energy source originates from an underlying industrial process; and ii) the cogeneration facility is coupled to the industrial process of a host plant. In December 2012, a Ministerial Determination was made for procurement of 800 MW in capacity from cogeneration projects[11] (DoE, 2016c). Under this procurement programme, the price caps as listed in Table 3.6 apply.

Table 3.6: Bidding price caps under the South African Cogeneration IPP Programme

Description	Units	Waste-to-energy	CHP	Industrial biomass
Base rate	USD/kWh*	0.064	0.071	0.086
Peak rate	USD/kWh*	0.084	0.094	0.112
Off peak rate	USD/kWh*	0.031	0.035	0.041

** Rates are based on an exchange rate of South African rand (ZAR) 14 = USD[12]*
Based on DoE (2016c)

10 The 25 MW Ngodwana Energy Biomass Project was South Africa's first biomass project under the REIPPPP to reach financial close. It will be fuelled using waste wood chips from Sappi's plantations and its Ngodwana Mill (ESI Journal, 2018).

11 An amendment is in process that could increase the Determination to 1 800 MW. However, as of March 2019, the process had not reached conclusion (see IPP Cogeneration website at *www.ipp-cogen.co.za/*).

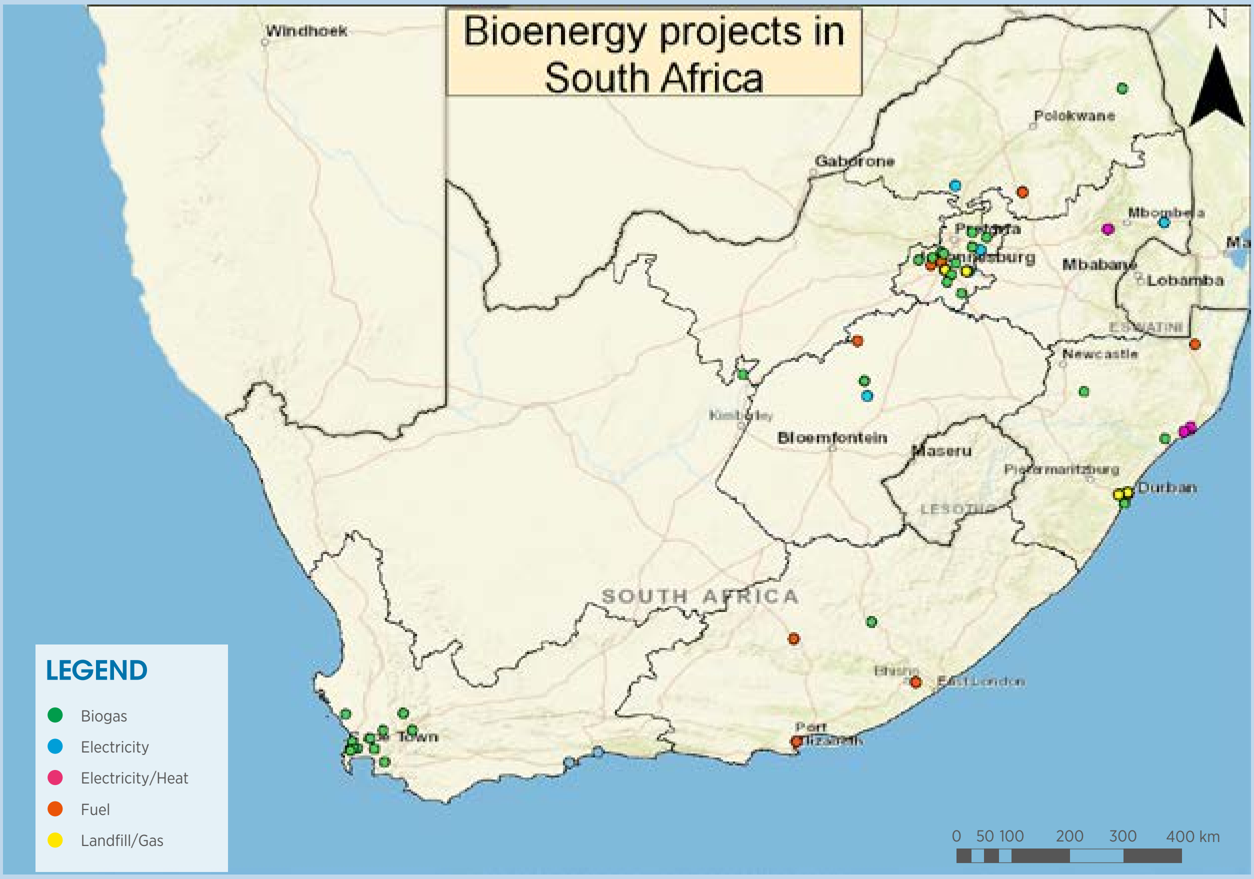
In June 2016, one project in the KwaZulu-Natal was selected as the preferred bidder for 11.18 MW of capacity. The project developer is Tugela Energy Project Company using CHP technology. The project bid a price of USD 0.071/kWh under the Cogeneration IPP Program (DoE, 2016c).

Bioenergy and biogas

The uptake of biogas for both commercial and rural applications has generally been slow. In April 2016 there were estimated to be 38 commercial biogas projects in operation in South Africa. Existing commercial-scale biogas installations have a combined installed capacity of over 30 MW.[13]

The Working for Energy Programme aims to provide sustainable clean energy solutions to rural and low-income urban communities. It is currently involved in three community rural biogas initiatives, namely the iLembe District initiative in KwaZulu-Natal, the Melani Village Biogas Expansion Project in the Eastern Cape and the Mpufuneko Biogas Project in Limpopo (Gibson, 2016) with the aim to provide sustainable clean energy solutions to rural communities. The programme is managed and rolled out by SANEDI. Figure 3.7 gives an overview of the locations of the bioenergy projects.

Figure 3.7: Location of bioenergy projects in South Africa in 2019



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Based on data provided by Logical Waste Ltd, South Africa; prepared by SAEON

12 Note: The default ZAR-USD exchange rate applied in this study is ZAR 14 = USD 1. However, different ZAR-USD exchange rates are applied in some instances to adopt the rate per the respective dates or time periods of statistics/projections (especially when the cost data was taken from existing reports or databases that applied a specific historical exchange rate).

13 Since installations of digesters are not well tracked, this provides a rough lower estimate of installed capacity.

The potential for bioenergy in South Africa is limited by the relatively low primary productivity, largely constrained by rainfall and exacerbated by significant inter-annual variability. These factors, together with competing land uses, combine to limit the attractiveness of energy derived from biomass. The *Bioenergy Atlas for South Africa* (Hugo, 2016) provides a basic techno-economic assessment of options for biomass conversion to energy, and an evaluation of factors such as job creation, impact on rural economies, GHG emissions mitigation and likely subsidies required to make energy products cost-competitive.

The national biomass energy potential identified in the *Bioenergy Atlas* is presented in Chapter 6 of this study. Over the first four bid windows of the REIPPPP, 41 MW of biomass generation capacity and 18 MW of landfill gas-based generation capacity were procured.

The role of storage and flexibility in renewables deployment

Energy storage systems complement electrical grids by capturing excess electricity during periods of low demand. Storage systems can therefore be an important complement to variable renewable energy (VRE) supplies, helping to load-balance. The stored energy is later converted back to electrical power and returned to the grid. Energy storage also includes conversion from electrical energy to mediums such as ice and hot water, which is used for heating and cooling at times when electricity is at a higher demand and thus more expensive. This method can be used by consumers as a way of load shifting. South Africa has made some progress in integrating storage systems into the power system, with utilityscale pumped hydro storage being the most common type (as is the case globally). Table 3.7 shows existing large-scale energy storage projects in South Africa, ordered by technology/type.

Table 3.7: Existing large-scale energy storage projects in South Africa (2015)

Name ***Site***	**Type**	**Energy storage capacity (MWh)**
Drakensberg Pumped Storage Scheme *KwaZulu-Natal and Free State*	Closed loop pumped hydro storage	10 000 (1 000 MW × 10 hours)
Steenbras Pumped Storage Scheme *Western Cape*	Open loop pumped hydro storage	2 790 (180 MW × 15.5 hours)
Palmiet Pumped Storage Scheme *Western Cape*	Pumped hydro storage	4 000 (400 MW × 10 hours)
Ingula Pumped Storage Scheme *KwaZulu-Natal*	Pumped hydro storage	21 312 (1 332 MW × 16 hours)
Khi Solar One Power Plant *Northern Cape*	Thermal storage (steam)	100 (50 MW × 2 hours)
KaXu Solar One *Northern Cape*	Thermal storage (molten salt)	300 (100 MW × 3 hours)
Bokpoort Concentrated Solar Plant *Northern Cape*	Thermal storage (molten salt)	450 (50 MW × 9 hours)

Note: MWh = megawatt hour
Based on EE Publishers (2017)

The Ingula Pumped Storage Scheme (see Table 3.7) expands flexibility and storage capacity. Other planned flexible generation capacity includes gas-fired generation in Richards Bay and Coega. Newly commissioned open cycle gas turbines (OCGTs) operating on diesel at Avon in KwaZuluNatal and Dedisa in the Eastern Cape also provide flexible peaking capacity for the South African power system.

Beyond these planned capacities, South Africa could also look into options for increasing the flexibility of its coal plants. Traditionally, most coal-based generation plants have been designed to meet baseload and cannot be "flexibly" ramped up or down at short notice. However, flexibilisation can be achieved through process improvement, increasing automation or retrofitting certain plant components. For example, at the Weisweiler hard coal power plant in Germany, control system upgrades were carried out and software for power generation process control system and plant operations optimisation was implemented to improve flexibility; these upgrades reduced minimum load by 170 MW and increased ramp rate by 10 MW/minute at Unit G and by 110 MW at Unit H (Agora Energiewende, 2017). Other experiences in flexibilisation of coal plants exist *inter alia* from China, Denmark and India.[14]

Considering South Africa's large coal generation capacity and expertise in the area, the country could look into options to enhance the flexibility of its coal plants to help accommodate the variability resulting from large-scale solar PV and wind generation, adding an additional layer of system flexibility.

3.3 Bulk power supply infrastructure

The installed generation capacity of the South African power system is summarised in Figure 3.2 (see above). New coal-fired generation plants (especially the Medupi and Kusile plants with a combined planned capacity of 9.6 GW) are scheduled to increase coal-based generation capacity. These developments combined with rapid expansion of the renewables sector through the REIPPPP will require large-scale investment into transmission expansion as well as more substations to facilitate the new connections.

However, the investments made in the maintenance, rehabilitation and strengthening of national power sector infrastructure have been insufficient. This has led to a severe backlog and generation deficits and blackouts. This is further explained in Box 2 and Chapter 9, Section 2.

14 For further information and case studies on flexible generation from conventional plants, see the IRENA brief on increasing flexibility of conventional power plants (forthcoming; the brief will be available from the IRENA website, *www.irena.org*).

Box 2: **Lack of investment in the national power sector**

The national power sector in South Africa has been constrained by a lack of investments in the maintenance of existing power plants and construction of new power plants. Many existing plants are under-performing, while the new mega coal plants – Medupi and Kusile (around 4.8 GW planned capacity each) – are years behind schedule, significantly over budget and not properly functioning due to technical problems. Therefore, Eskom has at times been unable to generate enough electricity to meet needs. In the event of these supply shortages, power cuts (load-shedding) are imposed to prevent a collapse of the national electricity grid (*i.e.* a blackout). For example, on 11 February 2019, 4 000 MW of power was cut from the national grid to prevent it from collapsing (The Economist, 2019). Before the rolling outages starting in late 2018, South Africa had already experienced power cuts/load-shedding in 2007–2008 and 2015.

Besides the maintenance of existing power plants and the construction of new plants, the inadequacy of infrastructure investments also concerns the maintenance of ageing grid infrastructure. Many municipalities currently face a severe backlog in terms of distribution grid maintenance (see Chapter 8, Section 1) (EE Publishers, 2016a). The shortage and unreliability of electricity supply and distribution impact the entire economy and suppress economic growth in South Africa (The New York Times, 2019).

Significant investments in power infrastructure are therefore needed. At the same time, despite the significant increase of national electricity tariffs in recent years, Eskom faces significant financial challenges and mounting debt, which hamper its ability to upgrade power infrastructure. To address some of Eskom's structural challenges, President Cyril Ramaphosa in February 2019 announced the unbundling of the utility into three separate parts, declaring that the country would "immediately embark on a process of establishing three separate entities – Generation, Transmission and Distribution – under Eskom Holdings" (Government of South Africa, 2019).[15]

Figure 3.8 indicates the current transmission network infrastructure and maps out planned development of this infrastructure to 2025. South Africa's existing and planned transmission network infrastructure should be able to accommodate further new generation capacity and is periodically updated. While Figure 3.8 gives a guideline of where future network construction may take place, Eskom has also identified strategic corridors (each 100km wide) as shown in Figure 3.9 within which many of these infrastructure developments may occur. The strategic corridors are key focus areas for the grid expansion plans and will allow Eskom to better plan and expedite construction of the necessary transmission infrastructure. Eskom has started the approval process with the Department of Environmental Affairs (DEA) to identify any major environmental concerns related to the strategic corridors.

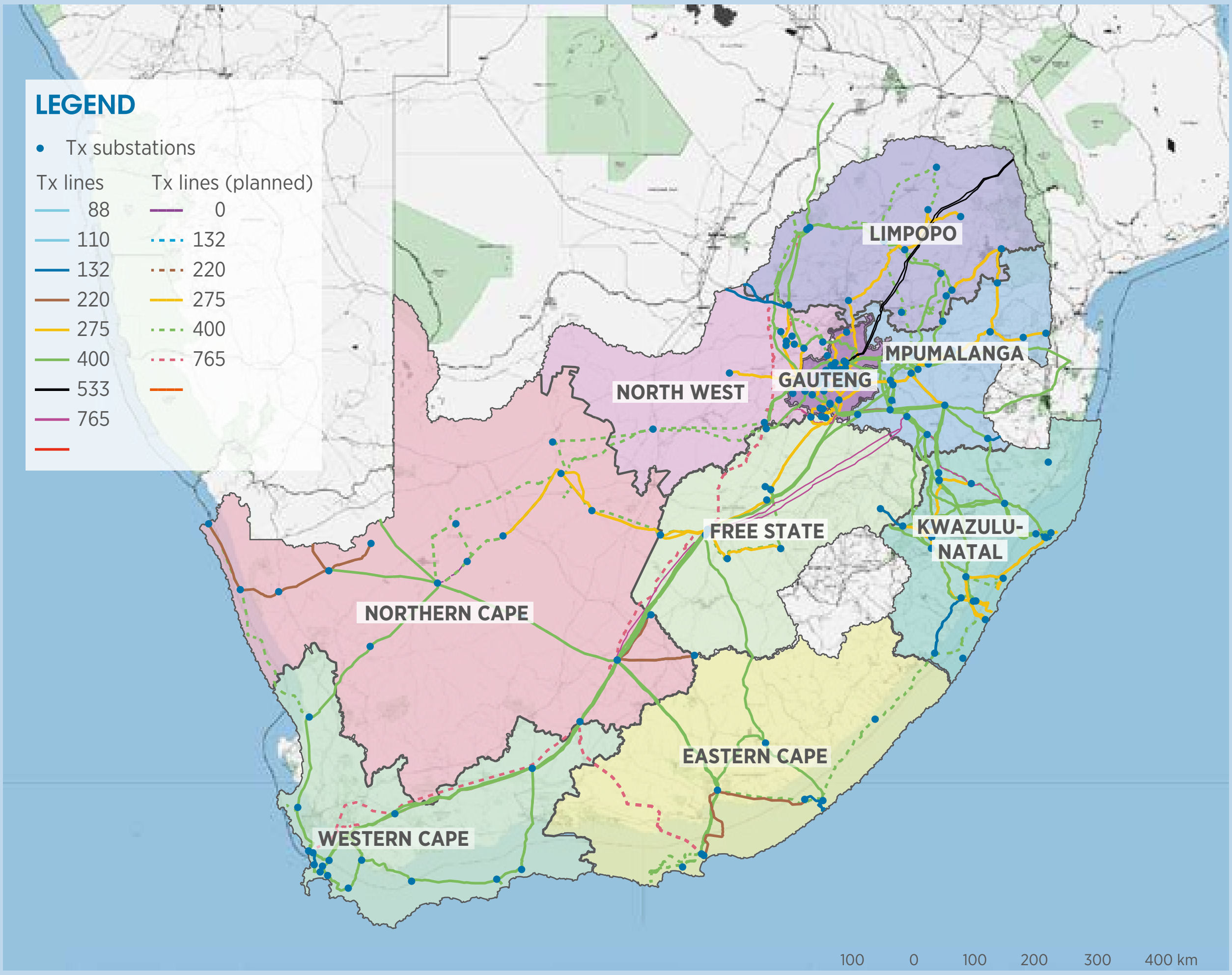
The strategic corridors are generally located to allow for the connection of more renewable energy projects to the grid. In 2012, the DEA appointed the Council of Scientific and Industrial Research (CSIR) to undertake a Strategic Environmental Assessment (SEA) with the aim of identifying geographical areas best suited for the rollout of wind and solar PV energy projects, referred to as Renewable Energy Development Zones (REDZs), in which development will be incentivised and streamlined. The assessment identified eight REDZs in South Africa that are of strategic importance for large-scale wind and solar PV development in the country (see Table 3.8). The eight REDZs in South Africa have a combined size of over 80 000 km^2 and are spread across five provinces.

15 President Ramaphosa made these remarks in his State of the Nation Address on 7 February 2019. The news emerged after the writing of this study and therefore was not reflected in the present findings.

The location of the REDZs, alongside the transmission corridors, is provided in Figure 3.9. The northern corridor primarily caters for solar PV and CSP projects in the Northern Cape Province while the eastern corridor is positioned to cater for onshore wind projects that are commonly implemented in the Eastern Cape Province.

In a similar manner, the central corridor is co-located with many wind and solar PV projects developed in the Western Cape Province and the Northern Cape. REDZs are a key element supporting energy-related strategic infrastructure projects (SIPs) identified by the South African government. Chapter 6, Section 1 of this study provides further details about the REDZs.

Figure 3.8: Existing and planned network infrastructure in South Africa



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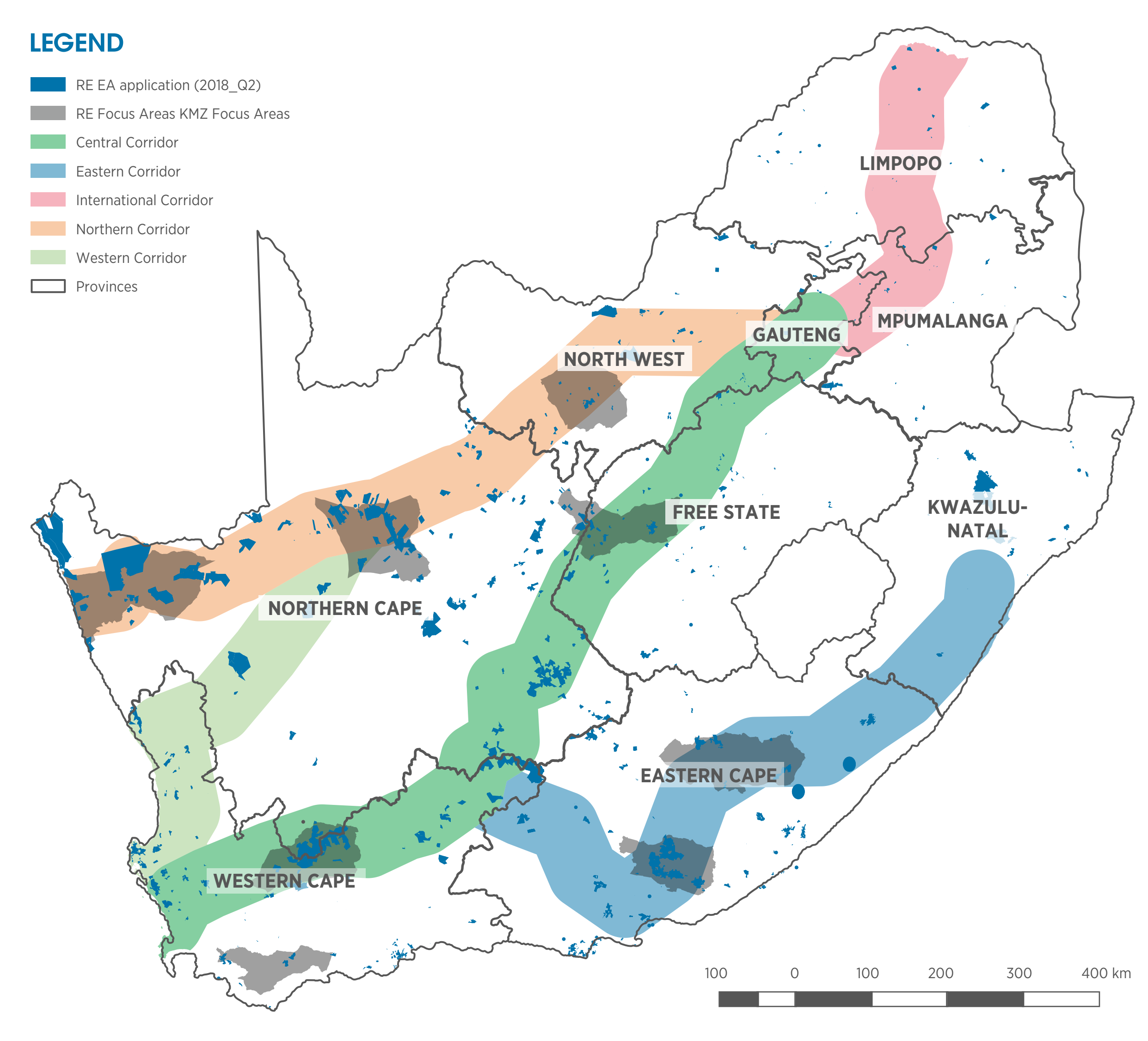
Source: Eskom (2015b)

Figure 3.9: REDZs and transmission corridors in South Africa



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Source: DEA (2017a)

Key insight:

Strategic transmission corridors provide focal areas that allow Eskom to better plan and expedite necessary transmission infrastructure to interconnect new generation capacity; particularly, projects located within the government-approved REDZs.

Table 3.8: REDZs in South Africa

NAME	SIZE	PROVINCE
Overberg	5 263 km^2	Western Cape
Komsberg	8 846 km^2	Western Cape
Cookhouse	7 366 km^2	Eastern Cape
Stormberg	12 041 km^2	Eastern Cape
Kimberley	9 568 km^2	Free State & Northern Cape
Vryburg	9 204 km^2	North West
Upington	12 833 km^2	Northern Cape
Springbok	15 214 km^2	Northern Cape
Total	**80 355 km^2**	

Based on DEA (2017a)

In addition to expanding national power generation and transmission capacities, South Africa engages in regional integration of energy systems with neighbouring countries.

Box 3 gives an overview of the status and prospects of regional integration of energy systems in Southern Africa.

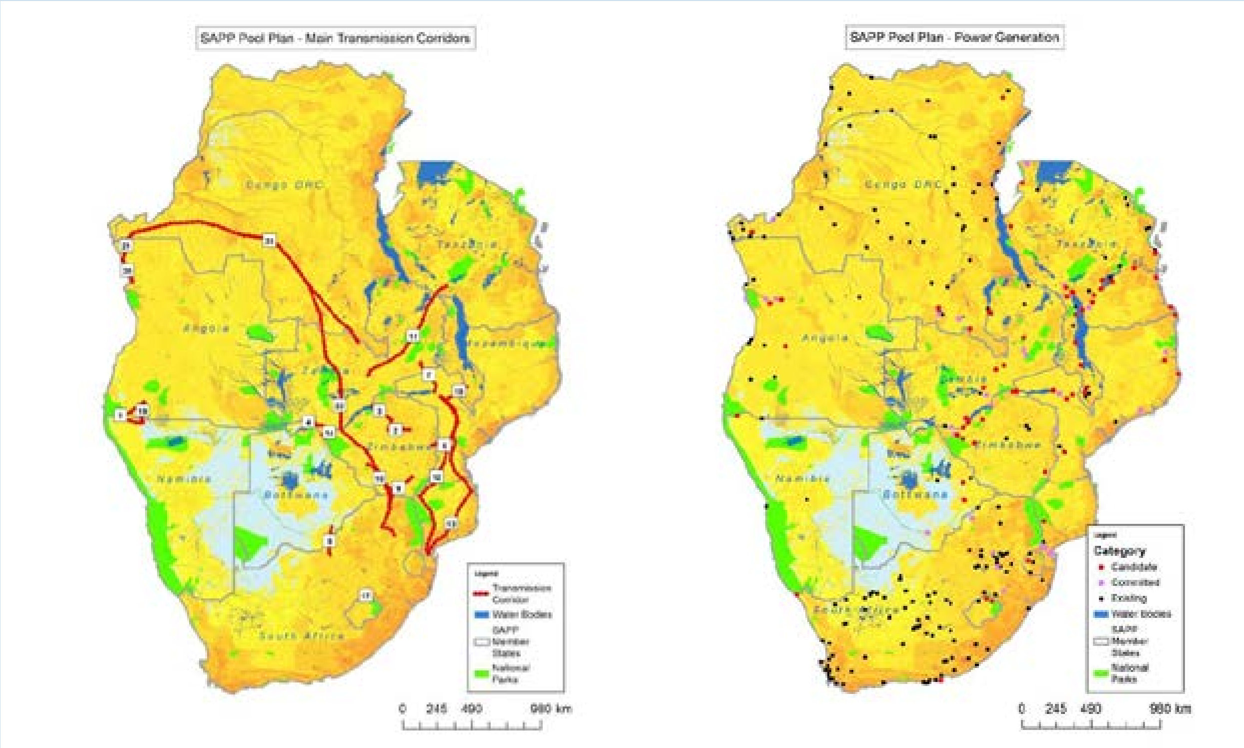
Box 3: **Regional integration of energy systems in Southern African countries**

Southern African countries are endowed with different types and quantities of energy resources. The regional integration of energy systems can provide a catalyst for the development of energy capacity in South Africa (for export), while imports can help expand or balance out domestic supplies. Specifically, the regional market can also provide a driver for the expansion of renewable energy capacity in South Africa (see *e.g.* IRENA, 2013).

South Africa is a member of the Southern African Development Community (SADC). In 1995, the 12 mainland countries of the SADC established the Southern African Power Pool (SAPP)[16], which aims to promote regional co-operation in the production and trade of electricity, and to provide regional masterplans to guide the development of electricity generation and transmission infrastructure. Figure 3.10 shows the location of regional transmission corridors and power generation capacity from the SAPP Pool Plan 2017.

Table 3.9 outlines the installed capacity from all sources of energy, net capacity and maximum demand in the countries of the SAPP in 2017–2018. It shows that South Africa contributes over three-quarters to the total regional installed capacity, operating capacity and maximum demand of all countries in the SAPP. South Africa also has the largest infrastructure for generation and transmission.

Figure 3.10: SAPP regional transmission corridors and power generation capacity



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on these maps do not imply any official endorsement or acceptance by IRENA
Based on SAPP (2017)"

Table 3.9: Installed capacity of energy, operating capacity and maximum demand in the SAPP, 2017–2018

Country	Installed capacity (MW)	Operating capacity (MW)	Maximum demand (MW)
Angola	3 129	2 500	1 869
Botswana	927	459	610
Democratic Republic of the Congo	2 457	1 076	1 376
Eswatini	70	55	232
Lesotho	74	70	150
Malawi	352	351	326
Mozambique	2 274	2 279	1 850
Namibia	538	354	647
South Africa	50 774	48 463	38 897
United Republic of Tanzania	1 366	823	1 051
Zambia	2 734	2 734	2 194
Zimbabwe	2 045	1 555	1 615
Total	**66 740**	**60 719**	**50 817**

Based on SAPP (2018)

There is great potential to generate electricity from renewable energy in the region. In 2015, renewable energy contributed 21.5% to the electricity generation mix of SAPP countries; most of this was from hydropower. Renewable energy technologies assume a much larger share in new-built generation capacity (*e.g.* around 54% in 2017) (SAPP, 2018), but the renewable resources in the region are still under-exploited, as illustrated by large gaps between total installed capacity and estimated potential (see Table 3.10). The SADC secretariat expects that the region could achieve a renewable energy share of at least 35% in power generation capacity by 2030, under current conditions (SADC and SARDC, 2013).

Table 3.10: Renewable energy estimated potential and capacity in the SADC region

Resource	Estimated potential	Total installed capacity
Hydro	40 874 MW	15 996 MW
Solar	20 000 TWh/year	Solar PV: 2 503 MW CSP: 600 MW
Wind	800 TWh/year	2 122 MW (onshore)
Biomass	9 500 MW (based on agricultural waste alone)	515 MW biomass/waste 23 MW other bioenergy (*e.g.* landfill)
Geothermal	4 000 MW	-

Based on REN21 (2018)

In terms of concrete existing or potential trade of electricity in the region, South Africa signed a treaty for 2 500 MW of hydropower by 2030 with the Democratic Republic of Congo (DRC) to facilitate RSA-DRC co-operation on the Inga Hydro Power Project (as reflected in the IRP). The project has the potential to energise and unlock regional industrialisation. Also, options exist for imports of hydroelectricity and natural gas from neighbouring Mozambique and for the export of power generated from solar PV and wind in South Africa, though this has not widely materialised in practice because most of the neighbouring countries also have very good solar (and some wind) resources and build capacity domestically. Overall, South Africa is expected to remain a net importer of power (mainly from the DRC and Mozambique).

3.4 Energy demand and access

Energy access

The current national electrification rate in South Africa is around 86% (in terms of the number of households connected to energy supply infrastructure). Significant progress was made in on-grid electrification between 2005 and 2015, when 3.95 million households were electrified (Stats SA, 2016b). Table 3.11 presents the electrification rates by province as of March 2017.

Most relative progress in recent years was made in Eastern Cape, Limpopo and KwaZulu-Natal which, as of March 2017, had achieved electrification rates of 81%, 96% and 82%, respectively (DoE, 2017a). Yet there are still many localised areas with relatively low levels of access and, while the electrification rate increases across the country, funding and implementation capacity need to be priorities (DoE, 2017a).

*Table 3.11: National electrification rates by province**

Province	Projected households (April 2016-March 2017)	Houses without electricity	Houses electrified	Access per province (%)
Eastern Cape	1 826 480	353 125	1 473 355	80.67
Free State	891 184	110 352	780 832	87.62
Gauteng	4 231 251	704 248	3 527 003	83.36
KwaZulu-Natal	2 748 760	501 262	2 247 498	81.76
Mpumalanga	1 164 143	98 533	1 065 610	91.54
Northern Cape	326 250	41 071	285 179	87.41
Limpopo	1 534 999	50 689	1 484 310	96.70
North West	1 149 559	152 075	997 484	86.77
Western Cape	1 768 694	160 547	1 608 147	90.92
Total	**15 641 320**	**2 171 902**	**13 469 418**	**86.11**

** As of March 2017*
Source: DoE (2017a)

Energising rural households has two key components, namely accessibility and affordability, particularly of modern fuels that provide alternatives to traditional biomass. The ability of households to afford electricity once access to the grid infrastructure is provided is an important consideration.

The majority of un-electrified households are predominantly in rural areas of South Africa. In these areas, poverty is common, service delivery is often weak, and traditional biomass use remains widespread. The 2011 census reported 27% of households (*i.e.* 4 million) in South Africa living in rural areas. Of these households, 37% were using biomass as their main fuel for cooking, and 50% were using electricity as their main fuel for cooking (Stats SA, 2011). The percentage of households that used electricity for cooking increased to 78.1% in 2015; yet, over 10% of the total number of households in South Africa still used biomass as their main fuel for cooking (Stats SA, 2016b). Rural households, in particular, typically use several thermal fuels, often using combinations of wood, electricity, paraffin and other fuels depending on access, location, weather, socio-demographic and various household socio-economic characteristics.

As the population grows, degradation of the local environment is increasingly severe, and the time and labour spent on harvesting biomass is increasing.

A major barrier to increased use of electricity for thermal purposes is the cost of electricity. More than half of South Africans were poor in 2015 and this status remains largely unchanged today. The poverty headcount increased to 55.5% in 2015 from a series low of 53.2% in 2011[16] (Stats SA, 2017). This translates into over 30.4 million South Africans living in poverty in 2015, which suggests serious affordability constraints for a large share of the South African population. To ensure a minimum level of energy services even for poor households, the government introduced a policy of FBE in 2003. According to this policy, an allocation of 50 kWh per month would be provided to all poor households connected to the grid. As of March 2015, the total number of customers configured for FBE was around 1.18 million, but only 911 075 customers had collected their FBE tokens (EE Publishers, 2016b).

16 These figures are calculated using the upper-bound poverty line of ZAR 992 per person per month in 2015 prices (which translates to approximately USD 2.50 per person/day in 2015 prices, based on an exchange rate of ZAR 13.50 = USD 1.00).

Renewables in national electrification

Grid electrification is unlikely reach all households, especially those in remote rural areas, in the medium term. Off-grid solar home system (SHSs) are installed as a temporary alternative in areas that lie further than 2 kilometres from the grid and do not fall inside any areas earmarked in 3-year grid extension plans by either Eskom or the relevant municipality. Small-scale SHSs were installed in over 82 517 households from 2002 to 2014 through an off-grid electrification programme implemented as a collaboration between the DoE (which was responsible for the programme) and the Department of Cooperative Governance and Traditional Affairs.

The SHSs (generally 50–100 watts in size) can only deliver limited services and have been installed primarily in the Limpopo, Eastern Cape and KwaZulu-Natal provinces, where grid connection is unlikely or uneconomical (DoE and GIZ, 2015).

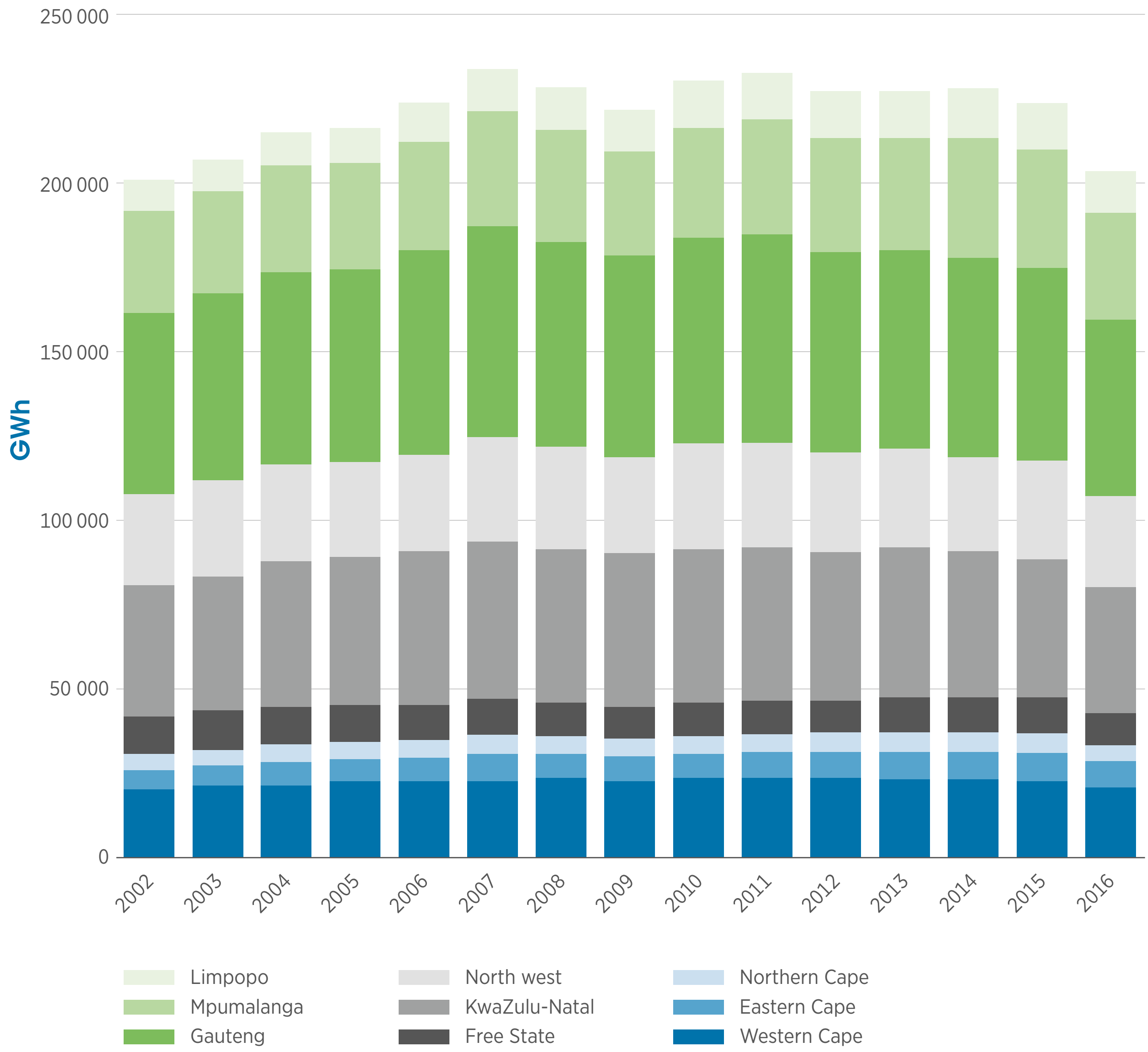
The SHSs are installed primarily by private sector service providers, with municipalities playing a small role. The SHSs require no connection fee, but households are charged a fixed monthly service fee based on the business plan of the approved service provider. The systems include a 50-Watt Peak (Wp) panel (able to supply around 250 watt hour (Wh)/day), a charge controller, wiring and outlets for small appliances, a 105 amp-hour battery and four Compact Fluorescent Lamps (CFLs) (DoE, 2012).

Energy consumption by province

Within South Africa, provincial GDP (in terms of sectoral contributions and GDP growth), land area, climate and populations differ widely between provinces. These distinctions between provinces result in widely different fuel mixes, energy intensity levels and transport sector demand. The province with the highest overall electricity consumption is Gauteng (53 TWh) followed by KwaZulu-Natal and Mpumalanga (see Figure 3.11). The Northern Cape has the lowest electricity demand. The province with the highest liquid fuel demand is also Gauteng whilst that with the lowest is Limpopo.

Between 2004 and 2011, there appeared to be a slight decoupling of energy and economic growth in the large metropolitan areas. Economies in these areas grew by an average annual rate of 4.2%, whereas energy consumption grew by only 1.8%. The slight decrease in electricity use from 2007 to 2011 seen in Figure 3.11 is attributable to supply-demand shortages and blackouts experienced over this period due to poor operational performance at power stations mainly due to maintenance backlogs at major power plants (see Box 2). Overall, electricity demand has been mostly stagnant in recent years.

Figure 3.11: Electricity consumption by province, 2002–2016



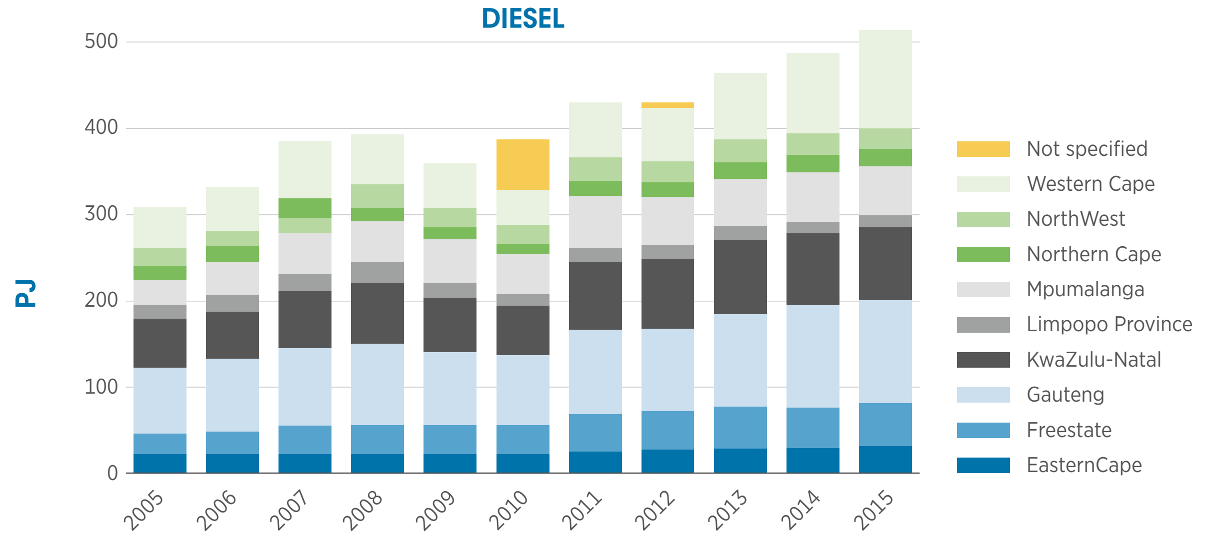
Based on Stats SA (2016a)

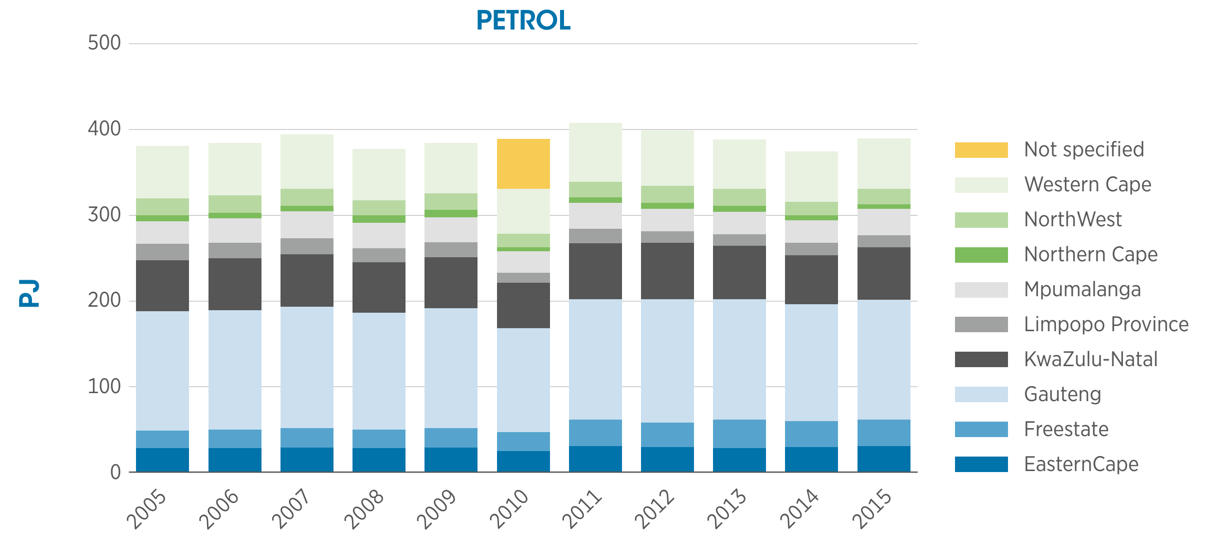
The stagnant electricity demand in South Africa, and particularly the decrease in electricity use observed from 2014, is underpinned by different factors: increasing energy efficiency driven by higher electricity tariffs, low overall economic growth, and an increasingly large share of less energy-intensive service sectors in the economy. As indicated above, the continued decrease in demand relative to economic growth may point to a decoupling of economic growth and energy use.

Key insight:

Electricity demand has been mostly stagnant in recent years.

Figure 3.12: Diesel and petrol consumption in South Africa by province, 2005–2015[17]





Based on DoE (2014a and 2017b)

Key insight:

Between 2005 and 2015, diesel consumption increased, while petrol fuel demand remained virtually unchanged.

17 Note: There have been minor adjustments to provincial boundaries, with small implications for fuel use.

In 2015, cities were home to 64% of South Africa's population. Combined, they generated more than 70% of the country's wealth and were large energy consumers. Urbanisation in South Africa is taking place at a rapid pace. Forecasts show that the urban share of the population is likely to reach 70% by 2030 and 80% by 2050 (SEA, 2015). Cities in South Africa are poised to play an important role in sustainable development, driving change and ensuring national energy policies are met.

3.5 Drivers for renewables in South Africa

Accelerated deployment of renewable energy and energy efficiency in South Africa is underpinned by several drivers, which are discussed in this section. Drivers are a combination of market factors and deliberate government efforts to support the development of renewable energy.

Lower costs: The most compelling driver for renewables in South Africa is the gradually lower deployment cost that renewable energy has demonstrated through the stages of the REIPPPP. Bidding prices under the REIPPPP have decreased by over 50% for both solar PV and onshore wind since the launch of the procurement programme in 2011, and forecasts show that further cost reductions are possible (see Chapter 6 for further information). This is mainly due to high technology learning rates and market maturity/economies of scale. At present, both solar PV and onshore wind are cheaper than new-build coal on a pure LCOE basis in South Africa. This does not consider possible grid integration costs. VRE (*i.e.* solar PV, wind) grid penetration levels in South Africa are rather low (*i.e.* below 10% of national generation) while the distribution system is expected to be able to handle a share of over 25% of the load from variable renewables by 2030 as more new flexible capacity is deployed to complement wind and solar PV (Wright et al., 2017a).[18]

Diversification: South Africa's energy system is currently heavily dependent on coal. The power sector is dominated by large, centralised coal-based generation (see Chapter 4 for information on how coal is contracted to supply power generation). Diversifying into renewables can lower the severity of unplanned outages due to a more decentralised nature of generation and to better electricity price stability, which would be delinked from finiteness and pricing of fossil fuels. The environmental benefits of diversifying into renewables are discussed below.

Energy access: The percentage of households with grid-based electricity supply in South Africa increased from 77.1% in 2002 to over 86% in 2017. Further progress in energy access is largely being hampered by the high cost of providing electricity to remote rural households and the difficulty of providing electricity to predominantly informal or unplanned settlements. Alternative sources of energy are increasingly being deployed to expand access, and more emphasis is being placed on off-grid renewable energy solutions to improve energy access for remote areas that are difficult to service (see Chapter 3, Section 4).

18 Based on the analyses undertaken by CSIR for comments on the draft IRP update 2016 (Wright et al., 2017a). CSIR analysis found that, from a least-cost optimal perspective, the penetration level of VRE in the South African power system by 2030 was around 31%. With a lower demand forecast, the level was 24% (mostly due to a large component of the coal fleet still being online). CSIR found that 20–25% VRE by 2030 is least-cost optimal, but the national system could probably handle a significant amount more as new flexible capacity is deployed to complement variable renewables (Wright et al., 2017a).

Supply security: South Africa has experienced several years of tight electricity supply, with operating reserve margins well below the targeted 15% (Eskom, 2016b). These tight operating reserve margins and insufficient plant availability led to multiple rolling outages in 2008 and 2014, forcing Eskom to operate expensive peaking generation units (namely, diesel-fired OCGTs) at higher-than-expected levels as well as to load-shed on a rotational basis to balance the power system. This has led to significant economic losses for the South African economy. Renewables have had a positive impact during these times by helping to supply power during high demand periods, thereby lowering diesel fuel and operating costs as well as reducing the level of load-shedding required.

Customer choice: In an effort to contain rising electricity costs, customers are increasingly turning to renewables as an alternative option versus power supplied by the national utility or via the distribution grid owned by the local municipality. Renewables are also seen as a remedy for potential power supply interruptions, particularly if deployed in combination with battery technology. However, battery storage is still rather expensive, and as such, not many customers have been able to use it.

Job creation: The renewable energy sector is regarded as more labour intensive than the conventional energy sector (IRENA, 2018b). While not an explicit driver, job creation can therefore be regarded an important benefit of renewables deployment. The REIPPPP has demonstrated the potential for localisation and job creation. To date, the programme has succeeded in delivering more job years – defined as the equivalent of a personyear of full-time employment – than was anticipated, providing employment to some of the most impoverished areas in South Africa. By December 2018, the 63 projects that had successfully completed construction had delivered 52% more job years than planned, with 29 620 job years achieved (DoE, DNT and DBSA, 2018a). In line with these observations, IRENA (2018b) estimates that South Africa has generated a total of 15 000 jobs in solar PV, close to 8 900 jobs in the CSP industry, 10 400 jobs in the wind sector, and some employment in the small hydro sector, overall amounting to a total of close to 35 000 renewable energy sector jobs.[19] Generally, though, long-term job creation post-construction is so far limited in South Africa and, as the renewable energy sector grows, the aspiration is that more permanent jobs can be created.

Besides these market drivers and central energy policy objectives, the reduction of environmental impacts from energy use is a key driver for accelerated deployment of renewable energy and energy efficiency.

The following section provides an overview of the environmental impacts of using renewable energy technologies, fossil fuels and nuclear power in the South African context.

19 Note: The job estimate for CSP could be regarded as rather high given the low deployment levels of CSP compared to solar PV and wind in South Africa.

Reduction of environmental impacts as driver

One of the key policy drivers for investment in renewables in South Africa is environmental policy. This section outlines major environmental impacts from renewable energy use. The net environmental impact of renewables use depends on the type of liquid fuel production that is substituted. In the national power sector, renewables generally displace coal production and coal-based generation.

Environmental benefits of renewable energy (displacing coal)

Reduced negative impacts on agricultural land

Only 1.5% of South Africa's land surface consists of fertile agricultural land; 46.4% of this land is located in Mpumalanga Province, which is also the location of most of the country's currently exploited coal deposits. Currently, 12% of this land is subject to coal mining activities, with an additional 13.4% subject to mining licence applications. The substitution of coal with renewables can avoid long-term land damage from mining activity and make fertile land available for agricultural use (DEA, 2011a).

Reduced emissions and local air pollution

Overall, approximately 80% of South Africa's GHG emissions originate in the energy sector, mostly from combustion of coal (DEA, 2017b). Methane emissions from coal mining in 2010 were estimated to be 2.27 Mt of carbon dioxide equivalent (CO_2-eq) based on global warming potential over a 100-year time horizon (DEA, 2011a). Deploying larger shares of renewables can reduce mining-based emissions of methane, emissions arising from liquid fuels used in the mining process, as well as indirect emissions from use of coal-based electricity.

As a result of coal combustion in power plants, boilers and synthetic fuels plants, the central areas where coal fields are situated have extremely high pollution levels and have been declared "priority areas" for action on air quality by the DEA. As these installations are phased out over the long term and renewable energy options take their place, local air pollution can be greatly reduced.

Reduced impact on water resources

South Africa is a water-scarce country. This was illustrated when, in 2018, the City of Cape Town had to enact drastic measures to reduce water use to avoid running out of water. Water scarcity is expected to be further aggravated by the impacts of global temperature rise. Electricity production (excluding water for mining) currently utilises around 2% of South Africa's water. Coal power plants in particular require large quantities of water for evaporative cooling. A transition to onshore wind and solar PV can assist with reducing the water footprint of the power sector (*e.g.* solar PV technology uses only minimal amounts of water, which is required for panel cleaning).

Specific environmental impact of coal in relation economic activities in South Africa

Disruptions to local hydrology and significant impacts on local water resources

Coal production requires water for washing, beneficiation and dust suppression. Added to this is the problem of acid mine drainage, which has severe and long-lasting impacts on local water resources and, if unchecked, regional catchments. Acid mine drainage is regarded as a particularly serious environmental problem due to the high toxicity of the drainage itself and the persistence of the problem long after mines have ceased to function. Acid mine drainage and the threat to water resources is a high action priority in South Africa, particularly in the Gauteng area, with rehabilitation costs estimated to run into the hundreds of millions of rand (McCarthy, 2011), or tens of millions of dollars.

Spontaneous combustion of abandoned coal mines and coal dumps

Due to the volatility of coal deposits and increased access to oxygen provided by mine workings, various abandoned coal mines in South Africa have been burning for some time – in some cases for decades. In addition to this, most South African coal mines contain large stockpiles of “discard” coal (*i.e.* coal with a calorific value too low for commercial use). Some of these stockpiles have been burning for long periods. Uncontrolled surface or underground coal fires lead to several serious environmental impacts, including local air pollution as well as GHG emissions, and a collapse of surface layers. GHG emissions from combustion in abandoned coal mines are currently not accounted for in South Africa’s national GHG inventory (see DEA, 2017b), and there are very few estimates for emissions from coal fires – Cook and Lloyd (2012), one of the only studies of coal fires, estimate that emissions from coal fires contribute an additional 2 Mt annually to national emissions (≈0.5% of the current 390 Mt of total CO_2 emissions per year).

Waste disposal

South Africa is highly dependent on coal as an energy option for the production of both electricity (Eskom) and petrochemicals (Sasol), which subsequently results in the production of large volumes of ash from the two major operations. Eskom generates about 3 336 million tonnes/year of mostly pulverised coal boiler ash and Sasol generates 1 011 million tonnes/year of mostly clinker ash from the gasification process (dti, 2019). This poses significant waste management challenges unless viable reuse options are developed.[20]

20 Potential for re-use exists in concrete and brick and block making, and different initiatives exist in South Africa to improve re-use. In 2017, the DEA hosted a Chemicals and Waste Economy Operation Phakisa that identified coal ash, amongst other outcomes, as a priority waste stream and set a higher annual country utilisation target of approximately 30% (10 million tonnes) by 2022. Large-scale ash utilisation initiatives identified by Phakisa include use as a sub-base for road construction, soil amelioration and mine backfilling. In terms of concrete government activities, the Department of Trade and Industry (dti) participates in the South African Bureau of Standards (SABS) Technical Committee to facilitate the development of the South African National Standards (SANS) standard for coal ash as concrete aggregate use, and the DEA continues to commission other studies jointly with industry as part of further sector interventions (dti, 2019).

Environmental impacts from processing and use of other fossil fuels

Environmental impacts from the processing and use of other fossil fuels are potentially significant but dwarfed by the environmental impact of coal-based activities. Currently, natural gas and crude oil are produced in small amounts off the southern coast, with negligible environmental impacts, mostly due to the small scale of production. There are proposals to explore the recovery of unconventional gas resources in the Karoo Basin, which could have significant impacts on the scarce water resources in the Karoo, both in terms of increased water demand and of potential leakage of toxic chemicals into underground water resources. These potential impacts have led to extensive stakeholder engagement around new fracking regulations for South Africa.[21]

Crude oil and refined petroleum products are imported, and crude oil is refined in four refineries (three at the coast and one in-land). The key environmental impacts are local air pollution, especially in the south Durban area. Natural gas is imported from the region via pipeline, and environmental impact is limited to fugitive emissions and GHG emissions from combustion. A synthetic fuels Gas-to-Liquid plant in Mossel Bay has capacity for 36 000 barrels per day and uses gas produced off the southern coast as a feedstock.

The expected environmental impacts from increased deployment of renewables per the REmap Options (compared to the Reference Case 2030) are presented in Chapter 7 of this study.

21 The South African government generally supports investigations for more accurate estimation of its domestic shale gas resources; this may include fracking, provided it is done in an environmentally sustainable manner. In the remarks by the Minister of Energy to the Gas-to-Power Congress 2018 held in Cape Town, shale gas resources in South Africa are seen as a significant opportunity to boost economic growth, employment and investment. The Department of Mineral Resources had proposed “Regulations for Petroleum Exploration and Production (Fracking Regulations)” for South Africa; however, the regulations were declared invalid by the Eastern Cape High Court on 17 October 2017 (Go Legal, 2017).

4 CURRENT LEGISLATIVE, REGULATORY AND POLICY FRAMEWORK

KEY POINTS

- The Constitution of the Republic of South Africa (RSA) and other key laws and regulations directly or indirectly provide for the energy sector.
- The DoE, Eskom and the National Energy Regulator of South Africa (NERSA) play the key institutional roles in the management of the energy sector, including the advancement of renewables. There is increasing power sector liberalisation, which means increased competition within the national power generation space.
- The national grid is 100% owned and managed by Eskom with a 20-year Strategic Grid Plan. For embedded generation, the relevant institutions are the municipalities, Eskom, NERSA and the buyer of the generated electricity.
- The IRP and IEP are the key policy instruments for planning the country's energy needs, and for identifying technology options for energy supply and the costs associated with meeting projected demand. Both are intended as "living documents" that are updated regularly.
- The White Paper on Renewable Energy of 2003 is the most comprehensive policy document pertaining to the government's vision on renewable energy. The REIPPPP placed renewables in the limelight.
- The range of GHG emissions in the RSA is projected to reach a maximum level between 2020 and 2025. Thereafter, the trajectory is projected to remain flat for ten years and to start declining in 2036. This is referred to as Peak-Plateau-Decline GHG emissions trajectory.

This chapter provides an account of how the legislation and policy framework for the energy sector evolved in South Africa after the end of apartheid in 1994. This narrative gives particular attention to the key actors and processes in the national energy sector, and the way in which renewable energy rose to prominence in the energy landscape. The chapter also assesses how legislation and policy can further promote sound renewable energy deployment.

4.1 Constitutional and legal framework

In South Africa, the Constitution is the overarching legal instrument that guides all laws and policies adopted by the government. Since 1994, the legislative and policy framework relating to the national energy sector has evolved significantly, including changes that are aimed at promoting the growth of the renewable energy industry. A summary of the major milestones in the evolution of the legislative framework for the South African energy sector is presented in Table 4.1.

Table 4.1: Milestones of the post-1994 legislative framework for the national energy sector[22]

Year	Legislative milestone	Status	Most important provisions relating to renewable energy
1996	Constitution of the Republic of South Africa	In effect	Provides for the right of everyone to an environment that is not harmful to their health or wellbeing (Section 24(a) of the Constitution) and to have the environment protected (Section 24(b); Section 27(b)); recognises international agreements as legal instruments (Section 231).
1998	National Environmental Management Act (Act No. 107 of 1998)	In effect	Defines some requirements of sustainable development: avoidance of pollution and degradation of the environment (Section 2(4) (a)(ii) of the Act); exploitation of renewable resources should be within sustainable limits (Section 2(4)(a)(v) of the Act).
2006	Electricity Regulation Act 2006 (Act No. 4 of 2006)	In effect	Some of the objectives of this Act are: i) to attain the sustainable and orderly development and operation of electricity supply infrastructure in the South Africa; and ii) to promote the use of diverse energy sources and energy efficiency (Section 2 of the Act).
2008	National Energy Act (NEA), 2008 (Act No. 34 of 2008)	In effect	One of the aims of this Act is to provide for energy planning and increased generation and consumption of renewable energies (Section on aims of the Act). Some relevant objectives of the Act are: i) to promote diversification of supply of energy and its sources (Section 2(b) of the Act), and ii) to contribute to the sustainable development of the South African economy (Section 2(l) of the Act).
2009	Electricity Regulation Act: Regulations: New Generation Capacity	In effect	Section 2(1)(a) of the Regulations provides for new generation capacity derived from renewable energy and cogeneration (DoE, 2009).
2011	Application of the National Building Regulations (SANS 10400-S:2011)	In effect	Regulations provide for environmental sustainability (Part X of the regulations) and energy usage in buildings (Part XA of the regulations) (SABS, 2011a).
2012	Regulations regarding the Mandatory Blending of Biofuels with Petrol and Diesel (promulgated under Government Notice R.671, 2012)	In effect	Whole document (see Chapter 4, Section 1 of this study). Regulations came into operation 1 October 2015.
2014	South African Biofuels Regulatory Framework	Pending approval	Whole document (see Chapter 4, Section 1 of this study).

22 For a comprehensive overview, please refer to the *State of renewable energy in South Africa 2015* report (DoE and GIZ, 2015).

Structure of the South African Electricity Supply Industry

Under the legal framework described above, the South African Electricity Supply Industry (ESI) has introduced more private sector participation, especially over the last five to ten years as more renewable energy projects have been implemented. To date, the general structure of the industry still remains with the national utility, Eskom, dominating power generation, transmission, and distribution as depicted in Figure 4.1 below. Most of the electricitygenerated nationally is physically fed into the national transmission network prior to distribution.

Commercially, the purchase of bulk electricity is done through the Eskom Single Buyer Office (SBO). The SBO makes the purchase decision from competing generation units based on various considerations. Key factors include cost and the nature of the PPA between the generator and the SBO. In terms of renewable energy, however, the DoE decides which projects to procure energy from. The procurement decision by the DoE IPP Office is exercised through the REIPPPP where renewable energy projects are chosen as preferred bidders and ultimately granted the ability to sell their generated power to Eskom.

Despite the dominant role of Eskom, increased competition is occurring within the generation space. Only a few municipalities in South Africa have a generation license, typically for a specific power plant within their jurisdiction. Municipalities in South Africa do not commonly have generation licenses, and these can be regarded as exceptional cases occurring in large municipalities or within metropolitan areas. In 2016, out of more than 200 South African municipalities, only 16 had generation licenses.

Figure 4.1: Structure of the South African ESI

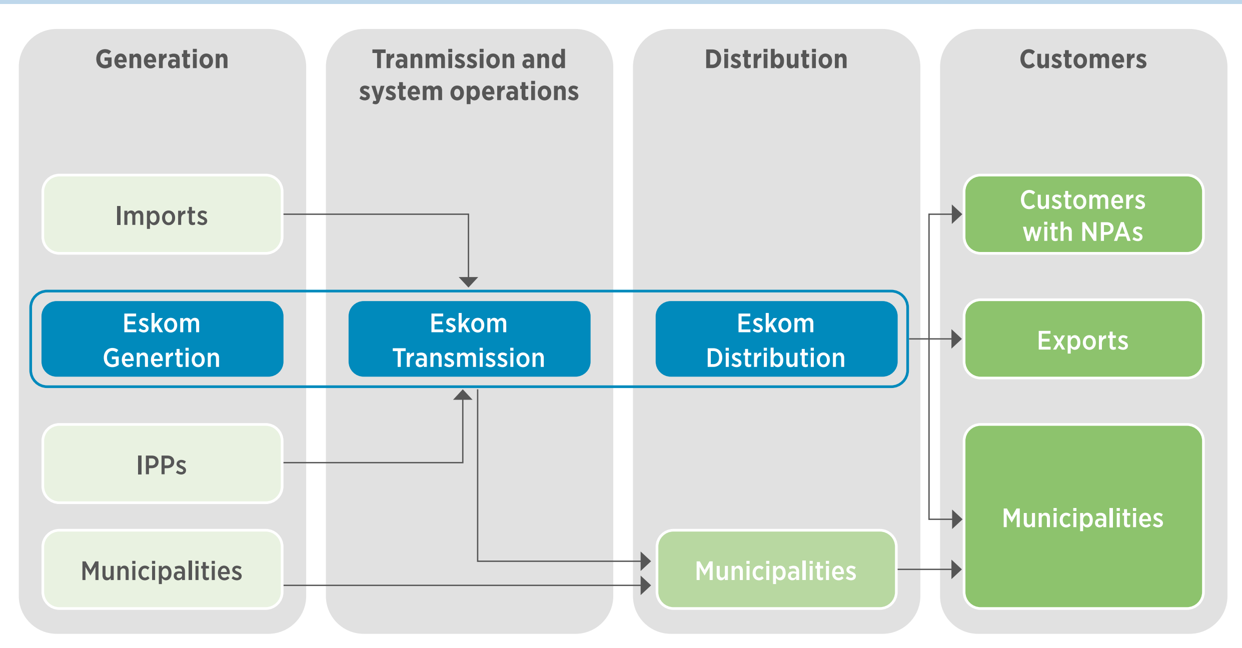


Figure developed by the authors.

Municipalities have the executive authority for electricity service delivery, distribution, and reticulation; however, many customers are supplied directly by Eskom as some municipalities do not provide electricity reticulation services and rely on Eskom as a distributor. Although both Eskom and municipalities are active at the distribution level, there is no direct competition for end-users. Rather, end-users are served by either of the distributors depending on various factors, including location.

Parallel to greater participation from renewable energy IPPs, SSEG is spurring competition within both the generation and the distribution space. Generation companies are seeing slight decreases in market share due to embedded generation, while distributors (particularly municipalities) are being forced to rethink their business models due to embedded generation potentially reducing the use of their distribution grid networks.

Key players in the South African Electricity Supply Industry

In addition to Eskom and municipalities, there are several other entities that are essential for proper functioning of the ESI within the sector's legal framework. The most important of these include the DoE, NERSA and the DEA. These key players and their respective roles in the ESI are further explained in the following sections.

DoE

The DoE is responsible for ensuring development, utilisation and management of South Africa's energy sources. The Department comprises six divisions that address specific focus areas. Out of the six divisions, four directly impact the renewable energy sector, as described below:[23]

Policy and Planning: The Policy and Planning division within the Department has the mandate to ensure evidence-based planning, policy setting and investment decisions in the energy sector to improve energy security through supply-side and demand-side management options and to increase competition through regulation. It spearheads development of the IRP and IEPs, which give guidance on the share of renewable energy to be brought into the electricity and energy mix, respectively, over the long term.

Petroleum & Petroleum Products Licensing: The Petroleum division within the Department has the mandate to manage the regulation of petroleum and petroleum products to ensure optimum and orderly functioning of the petroleum industry for the achievement of the government's development goals. The division is pivotal in driving initiatives for biofuels deployment into the mainstream petroleum supply value chain.

Special Programmes and Project Management: The Special Programmes and Project Management division is in charge of managing, co-ordinating and monitoring programmes and projects focused on access to energy. Its flagship programme is the Integrated National Electrification Programme (INEP) of 2013 (see DoE [2015b] for further information). Over half of the DoE budget is earmarked for the INEP. Where grid-based electricity access is not feasible under the INEP, renewables-based interventions are used. Hence, the INEP is an important platform for further deployment of renewables.

Clean Energy: This division manages and facilitates the development and implementation of clean and renewable energy initiatives, energy efficiency, and demand-side management. It spearheads targeted initiatives for renewables such as the South African Wind Energy Programme and the Wind Atlas of South Africa Project (WASA), production of the State of Renewable Energy in South Africa reports and participates in the National Biogas Platform, which is a collaboration between public entities, the private sector, and development agencies.

23 The information presented is taken from the DoE website, www.energy.gov.za/.

NERSA

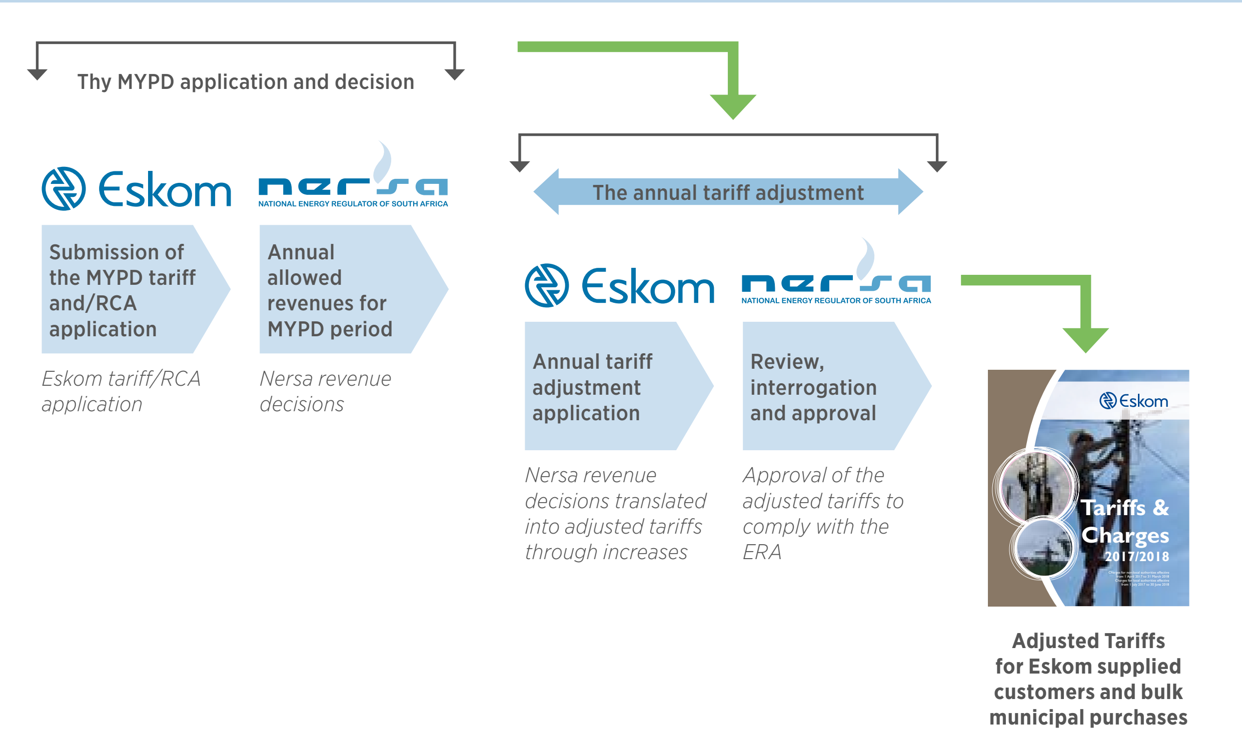
The mission of NERSA is to regulate the energy industry in accordance with the government's laws, policies, standards and international best practices in support of sustainable development.

Under Chapter II, Section 4 of the Electricity Regulation Act of 2006, the key roles entrusted to NERSA are to:

- Issue generation, transmission and distribution licensing (and set pertinent conditions).
- Set and/or approve tariffs and prices.
- Monitor and enforce compliance with licensing conditions.
- Resolve disputes, including mediation, arbitration and handling of complaints.
- Gather, store and disseminate industry information.
- Set rules, guidelines, standards and codes.
- Register import and production activities.

Among these roles, the setting of electricity tariffs is a pivotal role that NERSA performs, particularly in light of the overall economic impact and the effect that conventional electricity prices have on the prospects for deployment of renewable energy. NERSA sets electricity tariffs on a multi-year basis through a process called the Multi-Year Price Determination (MYPD). Under the MYPD, the national utility presents forecasts over the coming determination period for all costs to be incurred in ensuring reliable and adequate power supply. These costs, combined with a regulated return on investment on the utility asset base, allows Eskom to arrive at a revenue requirement. NERSA assesses the cost forecasts, interrogates the revenue requirements, and makes a judgement on the fairness of the revenue application in terms of prices for the final consumer and the sustainability of Eskom. With the revenue allowance determined, Eskom then translates the outcome into annual tariff increases for its different customer classes. Figure 4.2 provides a simple schematic overview of the MYPD process.

Figure 4.2: Tariff setting under the MYPD process



Source: Eskom (2017)

Electricity tariffs in South Africa are guided by the Electricity Pricing Policy of 2008 (Government Notice No. 1398 of 2008), which is mainly implemented by NERSA (DME, 2008). The Policy provides guiding principles and an overall framework for determining electricity prices. Guiding principles include, among others, environmentally sustainable short-term and long-term usage of natural resources, accelerated access to electricity for the disadvantaged, efficient use of electricity as a scarce resource, lowered cost of electricity as input to economic activity, and more renewable energy generation in the energy mix (DME, 2008).

DEA

In terms of the legal framework, the DEA acts as the custodian of environmental policy for the country. The DEA exerts its policy impact in two main domains of key relevance to renewable energy deployment: climate change and the natural environment.

With regard to climate change, the DEA spearheads efforts to formulate and implement South Africa's contributions to international efforts for climate change mitigation, including development of the NDC for South Africa under the Paris Agreement. The DEA is also the national lead for drafting the Climate Change Bill, which proposes the legal framework for addressing the national climate challenge.

With regard to the natural environment, the principal/applicable legislation with regard to the construction of any major infrastructure is the National Environmental Management Act (Act No. 107 of 1998). Determining whether any proposed energy infrastructure project is compliant with the relevant regulations is done through completing environmental impact assessments (EIAs) that comprise investigation of impacts on natural vegetation, water resources, air quality, ambient noise, heritage sites and aviation air space.

Legislation covering deployment of renewables in power, transport and building sectors

Specific legal instruments in South Africa make provisions for the deployment of renewable energy. The National Energy Act (Act No. 34 of 2008), the Biofuels Regulatory Framework, and the Green Building regulations are the most prominent instruments regarding the power sector, liquid fuels (*i.e.* transport fuel sector) and buildings sector, respectively. The three legal instruments are described in detail below.

At present, there are no legal instruments that specifically address heat demand. Under the NEES, however, targets are set for improved energy efficiency in the industrial sector, among others (see Chapter 3, Section 3 and Chapter 7, Section 1 for further information on the NEES).

National Energy Act of 2008

The National Energy Act (Act 34 of 2008) spells out the need for increased generation and consumption of renewable energy. This legal instrument empowers the DoE to undertake certain measures to ensure energy security, including integrated energy planning, energy research and collection of information regarding energy generation, supply and demand. The National Energy Act tasks the Minister of Energy to develop and publish an Integrated Energy Plan (see Chapter 4, Section 2).

South African Biofuels Regulatory Framework of 2014

The DoE has published a Draft Position Paper on the South African Biofuels Regulatory Framework, with the aim of initiating an enabling national regulatory environment for the biofuels industry (Notice 24 of 2014) (DoE, 2014b). This draft framework includes the regulation of mandatory blending of biofuels with petrol and diesel and the licensing of biofuels producers. The framework was presented to the cabinet for consideration but was not endorsed (as of February 2019). Regulations on blending of biofuels are proposed to allow for a minimum concentration of 5% volume/volume (v/v) for blending biodiesel with diesel, and for a concentration of 2% to 5% v/v for blending bioethanol with petrol.

Licensed manufacturers of petroleum fuels are obliged to buy biofuels only from licensed manufacturers. Biofuels producers need to be licensed by the Petroleum Products Controller.

Green building regulations

In line with the provisions of the National Building Regulations and Building Standards Act (Act No. 29 of 1996), a policy framework on green buildings was developed in 2011; the policy was launched in October 2018 (Government of South Africa, 2018). One of the strategic pillars of this framework was to adopt green building regulations, standards and best practices. Various aspects of the green buildings legislation were outlined under this strategic pillar.

Among other things, the draft policy framework identified the need to adopt new building regulations and standards that could foster an increased exploitation of resource-efficient designs and technologies, and sustainable utilisation of natural resources. In this regard, South Africa has a national standard on energy efficiency in the built environment – SANS 204:2011 (SABS, 2011b) – which specifies requirements for energy efficiency and services in buildings. Comprehensive building regulations are also contained in the SANS 10400 regulations (SABS, 2011a).

This set of building regulations includes components on Environmental Sustainability (SANS 10400-X) and Energy Usage in Buildings (SANS 10400-XA). The SANS 204 became optional when the SANS 10400-X and SANS 10400-XA standards came into effect because energy usage in buildings includes energy efficiency. There is also a standard (SANS 1307) that specifies requirements for solar water heaters (SABS, 2014a) that can promote the utilisation of renewable energy in the built environment. Other initiatives on green buildings have been taken by the Green Building Council South Africa (GBCSA).[24]

24 The GBCSA is a non-profit company that was formed in 2007 to promote, encourage and facilitate green building in the RSA. GBCSA has developed the Green Star SA rating system, which is in effect; GBCSA serves as the official certification body.

4.2 Policy framework

A policy framework assists in promoting the vertical alignment and the horizontal harmonisation of key government and political commitments. Various national and sector policies need to be considered within planning for energy supply and demand.

A summary of the major milestones in the evolution of the policy framework for the South African energy sector since 1994 is presented in Table 4.2. A summary of the context and provisions of key policies is provided under the table.

Table 4.2: Evolution of the post-1994 policy framework for the national energy sector

Year	Policy milestone	Status	Most important provisions relating to renewable energy
1998	White Paper on the Energy Policy of the Republic of South Africa	In effect	In the post-apartheid era, the White Paper on the Energy Policy was the first document relating to energy that was aimed at promoting sustainable development as enshrined in the Constitution of the RSA (DME,[25] 1998). One of the policy objectives is to manage energy-related environmental and health impacts (Section 3.2.2.4 of the policy). Renewable energy is recognised as supply sector (Section 3.4.7 of the policy).
2003	White Paper on Renewable Energy	In effect	Whole document (see Chapter 4, Section 2 of this study) (DME, 2003).
2005	National Energy Efficiency Strategy (NEES)	In effect	Sets energy efficiency improvement targets to 2015 (DME, 2005). An updated, post-2015 version of the NEES, with targets to 2030, is under development (see Chapter 7, Section 1 of this study).
2007	Biofuels Industrial Strategy of the Republic of South Africa	In effect	Whole document (see Chapter 4, Section 2 of this study) (DME, 2007a).
2007	Criteria for licenses to manufacture biofuels	In effect	Whole document (see Chapter 4, Section 2 of this study) (DME, 2007b).
2008	Electricity Pricing Policy	In effect	Provides for the generation of electricity from renewable energy resources (Section 4.4 of the policy) (DME, 2008).
2011	Integrated Resource Plan (IRP) 2010–2030	In effect	One of the planning objectives of the IRP is to consider environmental and other externality impacts and the effect of renewable energy technologies (Section 2 of the IRP); the IRP provides a recommended 20-year long-term electricity sector plan that includes renewable energy supply options (Section 5 of the IRP) (DoE, 2011).
2011	National Climate Change Response White Paper	In effect	Renewable Energy Flagship Programme (DEA, 2011a).
2011	Green Building Policy Framework: Draft	In effect	One of the key objectives of this policy framework is to design buildings that are energy efficient and maximise use of renewable energy (Section 6.5 of the policy) (DPW, 2011). The Green Building Policy was launched at the annual GBCSA Convention in October 2018 (Government of South Africa, 2018).

Year	Policy milestone	Status	Most important provisions relating to renewable energy
2013	Carbon Tax Policy Paper	In effect	Recognises the role of renewable energy in reducing carbon emissions (Section 2.5 of the CTPP) (DNT, 2013).
2013	12L, 12I and 12B tax incentives (arising under the Income Tax Act, 1962 (Act No. 58 of 1962))	In effect	Section 12B provides for an accelerated capital allowance for qualifying machinery, plant implements, utensils or articles. Section 12I provides for an additional investment allowance on manufacturing assets (new or used), applied to a project that qualifies as an Industrial Policy Project.
2013	The Bio-economy Strategy	In effect	Industrial bio-economy focuses on bio-based chemicals, biomaterials and bioenergy (Section 6.2 of the strategy) (DST, 2013).
2016	Draft Integrated Energy Plan (IEP)	Pending approval	One of the key objectives of the IEP is to ensure adequate, sustainable and reliable forms of energy for end-consumers (Section 1.4 of the Draft IEP). In this vein, the policy recognises renewable energy as one of the primary sources of energy (Section 2.1.5 of the Draft IEP). The plan covers the whole energy sector (electricity and other forms of energy) over a time horizon of up to 2050 (DoE, 2016a).
2017	Industrial Policy Action Plan (IPAP)	In effect	IPAP includes three important milestones that have been achieved by domestic Green Industries (dti, 2017), namely: i) A total of 6 376 MW of electricity had been procured by October 2016 under the REIPPPP; ii) The REIPPPP attracted a total investment value of ZAR 194.1 billion (USD 14 bn); and iii) Green Industries created 28 484 job years and generated ZAR 256.2 million (USD 18 million) in socio-economic development contributions and ZAR 80.5 million (nearly USD 6 million) in enterprise development contributions.
2018	Draft Integrated Resource Plan (IRP) update	Pending approval	The 2018 IRP draft provides an update to the IRP 2010–2030. The draft policy update incorporates government objectives on carbon mitigation and decarbonisation of the electricity sector in South Africa (Section 2 of the draft IRP). The simulation of scenarios of the energy supply includes GHG constraints and renewable energy cap removal (Section 6 of the draft IRP). These aspects allow higher shares of renewable energy. The plan covers a time horizon of up to 2050 (DoE, 2018b). The IRP focuses on the electricity sector only.

White Paper on Renewable Energy of 2003

The White Paper on Renewable Energy was formulated and came into effect in 2003 (DME, 2003). It is the most comprehensive policy document pertaining to the government's vision on renewable energy. It informs institutions of roles, encourages the use of renewable energy technologies and stimulates market investment in renewable energy technologies. The Renewable Energy White Paper set a target of 10 000 GWh of electricity to be generated from renewable energy resources by 2013, but it did not specify how this target would be met (DME, 2003). This target has been revised through the IRP (see below) and the target period was extended to 2030.

National Energy Efficiency Strategy (NEES) of 2005

The Government of South Africa through the Department of Minerals and Energy released the first NEES in 2005. This strategy aimed to respond to the increasing demand for energy alongside a growing commitment to improving resource use and reducing South Africa's national environmental footprint. The NEES derived its mandate from the White Paper on Energy Policy (1998). A National Energy Efficiency Action Plan was developed in 2012 detailing the implementation of the strategy. In December 2016, the post-2015 draft NEES was gazetted, with a time horizon to 2030. This post-2015 strategy considers the current economic and development context in South Africa and aims to encourage continued growth by reducing energy inefficiency. The targets for reductions in energy intensity by sector are presented in Chapter 3, Section 1 of this study (for the framework to 2015) and Chapter 7 (for the post-2015 draft NEES).

Integrated Resource Plan (IRP)

The IRP is intended to be a key policy instrument for planning the country's future electricity needs, and for identifying technology options for generating capacity and the costs associated with meeting projected demand. The IRP results are obtained through the use of a least-cost optimisation model. Once the least-cost electricity supply mix under "normal" conditions has been determined, model adjustments are then made to test implications of specific policy interventions for national objectives such as job creation, localisation, etc. The varied combinations of policy interventions are modelled and reported as "scenarios". Since policy objectives introduce certain constraints or targets in the model, the different scenarios feature different electricity mix outcomes.

The IRP 2010–2030 was promulgated in May 2011 and covers capacity expansion up to 2030. The IRP 2010–2030 calls for update/revision every two years. The draft IRP update 2016 and draft IRP update 2018, both described in this study, are updates to the IRP 2010–2030.

In the draft IRP update 2016, new capacity for renewable energy was planned to be 17.3 GW and 57.5 GW by 2030 and 2050, respectively, under the Base Case scenario (DoE, 2016d). The aspiration for greater diversification and the gradual increase in the national share of renewable energy, especially as the result of steep cost declines, is also reflected in the draft IRP 2018 update (see Chapter 5 for more information). Its objective is to develop a sustainable electricity investment strategy for generation capacity and supporting infrastructure for South Africa over the next 20 years.

Meanwhile, until the updated IRP document comes into effect, the IRP 2010–2030 continues to be the official government plan for the electricity sector. As outlined, the IRP focuses on power sector planning only and does not provide a roadmap for all other energy-use sectors. This leads to the concept of an integrated energy plan (IEP) that covers the entire energy sector.

Integrated Energy Plan (IEP)

The development of an IEP was envisaged in the White Paper on Energy Policy of 1998 and is enshrined in the National Energy Act of 2008. The IEP is the national umbrella plan which, among others, guides policy development in South Africa, sets the framework for regulations and informs the selection of technologies to meet future energy demand. In scope, the IEP covers the entire energy sector and considers all elements of the energy value chain. It therefore integrates the IRP (*i.e.* electricity sector plan) that provides one of the sub-sections of the IEP.

The purpose of the IEP is to provide a roadmap for the future energy landscape in South Africa that guides future energy infrastructure investments and policy development. It should have a planning horizon of not less than 20 years. The development of the IEP is meant to be a continuous process because it needs to be reviewed annually to account for changes in the macro-economic environment, technological innovations, national priorities and other developmental factors. The base year 2015 data and the 2030 Reference Case in this study are both taken from the Base Case of the draft IEP 2016. An updated IEP, to which the draft IRP 2018 update provides an input, is pending development.

Biofuels Industrial Strategy of South Africa of 2007

Published in 2007, the Biofuels Industrial Strategy of South Africa set a target of achieving 2% penetration of biofuels (estimated to be approximately 400 million litres) in the national liquid fuels mix by 2013 (DME, 2007a). To stimulate agriculture in under-developed agricultural areas, sugar cane, sugar beet and sorghum were recommended as feedstocks for bioethanol, and soya beans, sunflower and canola were recommended as feedstocks for biodiesel. Biodiesel was to receive a rebate of 50% on the fuel tax, and bioethanol would be 100% fuel tax exempt. The Biofuel Industrial Strategy has facilitated the development of the regulations regarding mandatory blending of biofuels with petrol and diesel and criteria for licenses to manufacture biofuels, both of which came into effect (see Chapter 4, Section 1 of this study). However, there has been little progress in this sector over the years mainly due to concerns about the possible impacts of biofuels on food security; these concerns have been further exacerbated by frequent drought experiences.

Low global oil prices in recent years have also been a significant influencing factor, particularly since they made biofuels less economically attractive as a potential substitute for conventional fossil-based liquid fuels (while high oil prices make biofuels a more attractive alternative). More recent plans and strategies that directly promote renewable energy in the transportation sector include the National Transport Master Plan 2050 (Department of Transport, 2016) and the Green Transport Strategy (Department of Transport, 2017).

4.3 Policy instruments

Procurement of energy (in all its forms) occurs within a wider overall national framework that influences the policy instruments used. Although the renewable energy sector is still nascent in South Africa, there is already a track record of instruments deployed to promote their deployment. The instruments described in this section are auctions, tariffs and emissions targets.

Renewable energy feed-in tariffs (REFITs) and REIPPPP

The Renewable Energy White Paper 2003 sought to increase the production of energy from renewable resources. In the context of this objective, the first stage of attempts for implementation started with the introduction of a renewable energy and finance subsidy scheme that provided support to at least six projects. Through this scheme, the Department of Energy offered about ZAR 14.95 million (*i.e.* roughly USD 1.07 million based on an exchange rate of ZAR 14 = USD 1) to small-scale hydro, landfill and wind projects with a total capacity of 23.9 MW between 2005 and 2010 (see Table 4.3).

Table 4.3: Projects supported by the Department of Energy between 2005 and 2010

Project name	Province	Capacity (MW)	Subsidy	
			(ZAR)	(USD equiv.)
Bethlehem Hydro	Free State	3.9	1 950 000	139 000
Methcap biogas-to-electricity	Western Cape	4.2	2 100 000	150 000
Clanwillian Hydro	Western Cape	1.5	750 000	54 000
Bethlehem Hydro	Free State	3.1	1 550 000	111 000
Darling Wind Farm	Western Cape	5.2	2 600 000	186 000
eThekwini landfill	KwaZulu-Natal	6.0	6 000 000	429 000
Total		**23.9 MW**	**ZAR 14 950 000**	**USD 1.1million**

Source: compiled by the DoE.

Following on the success of this programme, in 2009 NERSA made proposals on REFIT rates in an attempt to facilitate large-scale, grid-connected renewable energy from IPPs (Baker, 2011; Eberhard, Kolker and Leigland, 2014). Indeed, the NERSA published feed-in tariffs for wind, small hydro, landfill gas and CSP in March 2009 (see Table 4.4) (NERSA, 2009a). Before any PPAs were concluded, however, NERSA published a consultation paper in July 2009 that called for lower feed-in tariffs.

Specifically, the paper called for tariffs between 13% and 41% lower than what had been proposed before, depending on the technology (NERSA, 2009b). Combined with some concerns that feed-in tariffs would amount to a non-competitive procurement process, which is against the Constitution of the RSA, this back-and-forth threw the nascent industry into disarray and led to the review and re-adaptation of the REFIT policy instrument in 2011 (Eberhard, Kolker and Leigland, 2014).

Table 4.4: Proposed REFIT rates (Phase 1) in March 2009

Technology	Unit	REFIT (ZAR/kWh)	USD/kWh equiv.
Wind	ZAR/kWh	1.25	0.089
Small hydro	ZAR/kWh	0.94	0.067
Landfill gas	ZAR/kWh	0.90	0.064
CSP	ZAR/kWh	2.10	0.150

Based on NERSA (2009a)

The second stage of implementation of the Renewable Energy White Paper of 2003 targets was the development of a competitive bidding process, *i.e.* the REIPPPP that was launched in 2011. As reported in Chapter 3, the REIPPPP has been able to contribute 3.9 GW in new operational renewable energy capacity to date, and an additional renewable energy capacity of 2.4 GW is to become operational under remaining successful projects from Bid Windows 14. The signing of PPAs for Bid Window 4 was approved between the main parties – Eskom, the IPPs and the IPP Office – in May 2018.

The National Solar Water Heating Programme (NSWHP)

Another significant initiative in the development of the national renewable energy subsector is the NSWHP of 2007. The installation of SWHs to supply domestic hot water has been touted by national and local governments as a means to improve the standard of living for poor households and as part of the demand-side management programmes. This programme kicked off with only a handful of suppliers in the country (numbers range from 9 to 20), little industry regulation and no minimum product or installation standards in place (Eskom, 2011).

The DoE mandated Eskom as the implementing agency for the NSWHP in 2008. In that year, Eskom introduced the Solar Water Heating Rebate Programme, which resulted in an increased rate of SWH installations. By 2011, there were 122 accredited suppliers, 351 registered distributors and 180 registered independent installers (Eskom, 2011). After Eskom reduced the rebate rate from May 2011, installations dropped, but began picking up again later in that year, albeit more slowly.

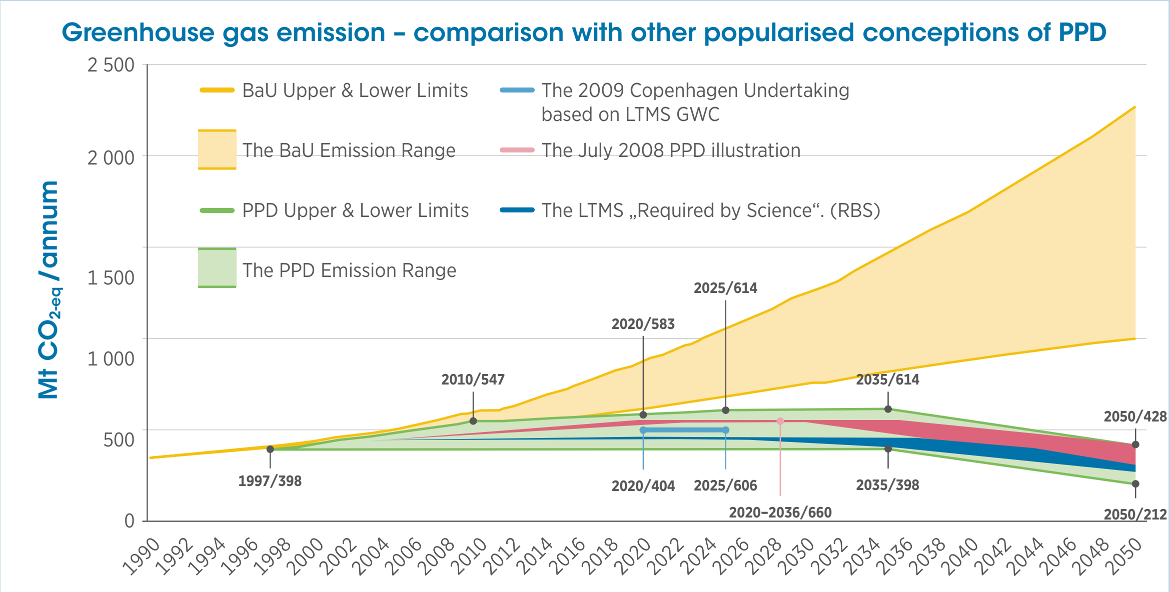
Between 2014 and September 2015, however, just over 400 000 SWHs (320 000 low-pressure and 80 000 high-pressure units, respectively) had been installed in residential communities (Steyn, 2015).

In response to this, the DoE terminated Eskom's implementation mandate and took over responsibility for implementation of the NSWHP. Thereafter, the DoE planned to install 45 141 new SWH units for residential and commercial buildings during the 2015/16 financial year; it actually achieved 5 000 new units (DoE, 2016e). Overall, the DoE has procured a total of 87 206 Baseline Systems from 12 manufacturers and has initiated the process of appointing service providers to install SWHs (DoE, 2018c).

Emissions targets

As reported in Chapter 3, South Africa has abundant reserves of coal, and most of the electricity is generated by coal-fired thermal plants. Overall, approximately 80% of South Africa's GHG emissions originate in the energy sector, mostly from the combustion of coal. In this context, the country has committed to shift from business-as-usual to a policy in which the trajectory of GHG emissions to 2050 peaks (between 2020–2025), plateaus (until around 2036) and then declines (from 2036–2050), as specified in the National Climate Change Response White Paper (DEA, 2011a; DEA, 2011b). Figure 4.3 illustrates this trajectory, in terms of CO_2-equivalent (CO_2-eq) emissions per year). In South Africa's NDC under the Paris Agreement on Climate Change, the trajectory is referred to as "Peak-Plateau-Decline" (PPD) GHG emissions trajectory (DEA, 2015). For more information on South Africa's actions on climate change, see Climate Action Tracker (2017).

Figure 4.3: Illustration of the Peak-Plateau-Decline GHG emission trajectory in South Africa



Note: The first number indicates the year, the second number indicates the Mt CO_2-eq/year.
BaU = business-as-usual; PPD = Peak-Plateau-Decline; LTMS = Long Term Mitigation Scenarios; GWC = Growth Without Constraints.
Based on Letete (2011); DEA (2011b); dti (2013).

Key insight:

The Figure outlines the trajectory to 2050, under which national GHG emissions peak (between 2020–2025), plateau (until around 2036) and then decline (from 2036–2050).

Specifically, GHG emissions are expected to reach a maximum level between 2020 and 2025 in a range with a lower limit of 398 Mt CO_2-eq/yr and upper limits of 583 Mt CO_2-eq/yr and 614 Mt CO_2-eq/yr for 2020 and 2025, respectively. Thereafter, the level of GHG emissions will be flat for about ten years within the range with a lower limit of 398 Mt CO_2-eq/yr and an upper limit of 614 Mt CO_2-eq/yr. The declining trend will commence in 2036 within the range with a lower limit of 212 Mt CO_2-eq/yr and an upper limit of 428 Mt CO_2-eq/yr by 2050. South Africa used these emission levels in its NDC document under the Paris Agreement on Climate Change (DEA, 2015).

These targets were informed by the National Development Plan (NPC, 2011) and the 2011 National Climate Change Response White Paper and are consistent with the national pledge made under the Copenhagen Climate Accord of 2011.

Most of the GHG emissions in South Africa emanate from energy supply (electricity and liquid fuels) and consumption (mining, industry and transport).

In view of this, mitigation actions with the greatest potential for emission reduction are focused on these areas (DEA, 2011a). Increasing the share of renewable energy in the energy supply mix and implementing energy efficiency on the demand side are the most promising options for reducing GHG emissions in the country. However, the present structure of the country's economy is carbon-intensive and, therefore, many sectors require flexibility in the transition to a low-carbon economy.

A national carbon tax has been planned since 2015. In the 2019 Budget Speech on 20 February 2019, the minister of finance reiterated the ambition to expand renewable energy and announced that the national carbon tax will come into effect from 1 June 2019 (DNT, 2019). There is already a levy on CO_2 emissions from new motor vehicles manufactured in South Africa, which became effective from 15 August 2014 (South African Revenue Service, 2014).

4.4 National grids and transmission

As outlined in Chapter 3, the South African national grid is spatially concentrated around the coal mines and power plants in the northeast of the country and is 100% owned and managed by Eskom with a 20-year Strategic Grid Plan. This grid plan is intended to provide a framework for future infrastructure investments, and Eskom is required to produce an annually updated ten-year Transmission Development Plan as a guide to investment (see the 2016–2025 Plan in Figure 3.8).

The implementation of Eskom's grid and transmission development plans are, in large part, facilitated by ensuring sufficient funding through the MYPD (see Chapter 4, Section 1 of this study) applications to NERSA. The Electricity Regulation Act of 2006 provides the legal basis for the MYPD methodology (see NERSA, 2016) to determine Eskom's allowed revenue. This is supplemented by the Electricity Pricing Policy of 2008, which guides NERSA's approval of prices and tariffs for the ESI. The MYPD calculation takes into account the recovery of primary energy costs, operating and maintenance costs, invested capital, depreciation of any principal debt, return on assets and invested capital, and it also includes a risk management mechanism to address the risk of excess or inadequate returns (NERSA, 2016). See Chapter 4, Section 1 of this study for further details on the Pricing Policy and MYPD.

Eskom has faced challenges in integrating IPP projects into its grid because of congestion at some specific connection points in the grid. This challenge contributed to the delay in the financial close of Bid Window 3 of the REIPPPP and also the announcement of winning projects in Bid Window 4 (see also Chapter 4, Section 3 of this study). Signing of the PPAs for the projects in Bid Window 4 was achieved in May 2018 after a delay of over six months.

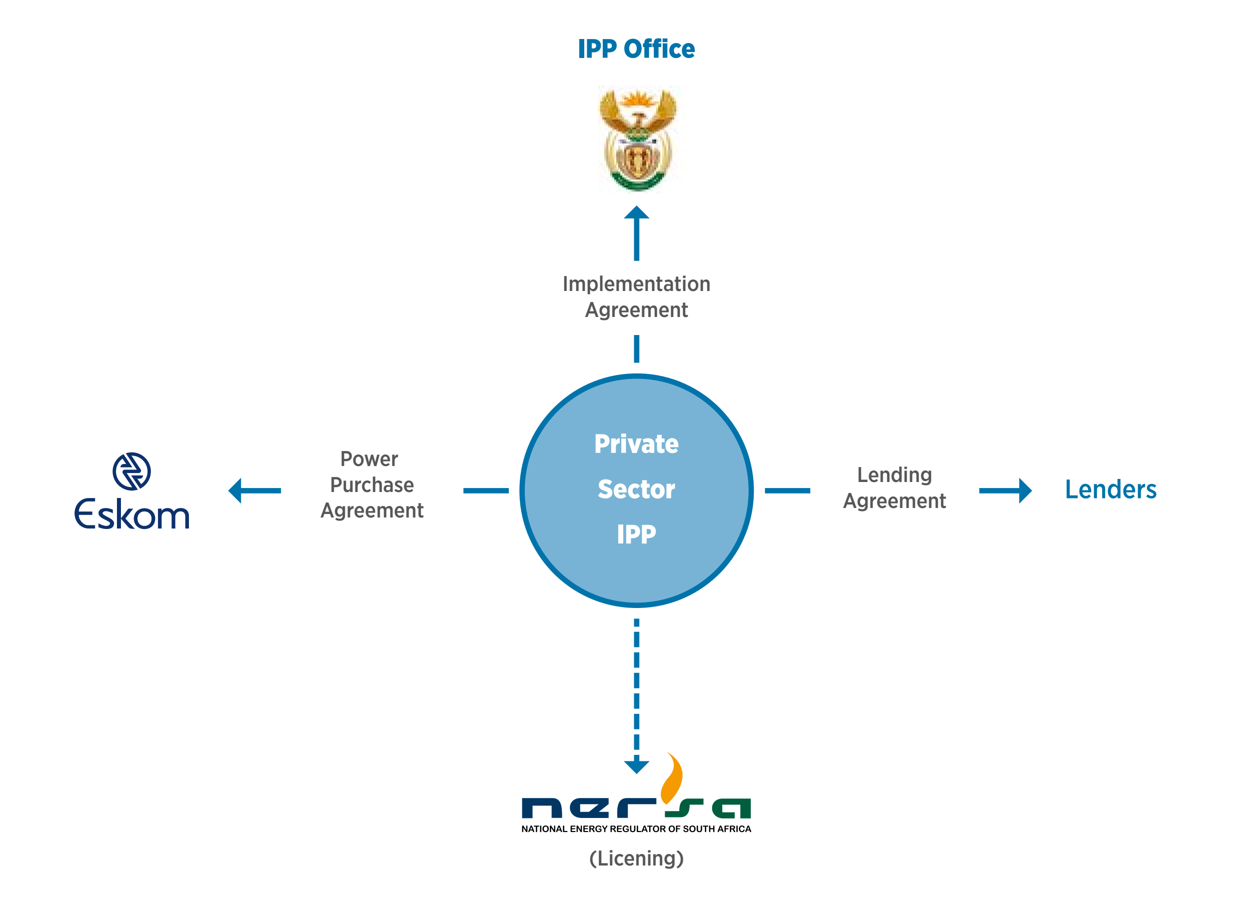
While IPPs could act as distributors and sell directly to customers in theory, there are considerable practical barriers to this arrangement. These obstacles include feeding into the physical transmission infrastructure owned by Eskom (IPPs encounter some difficulties in obtaining wheeling agreements) and accessing the distribution networks of Eskom and municipalities at competitive rates. Notwithstanding the absence of legislative prohibition, the licence conditions of existing IPPs do not permit them to sell electricity to third parties (DoE, DNT and DBSA, 2018a).

4.5 Institutional arrangements

Arrangement under the REIPPPP

Policies, regulations and provisions to increase the renewable energy share in the national energy mix cut across different institutions, both from government and the private sector. For example, the collaboration between Eskom, NERSA and the DoE saw a switch from the initial feed-in tariff approach to a competitive bidding process for procurement of utility-scale renewable energy generation (see Chapter 4, Section 3 for further information). The success of the REIPPPP has resulted in an unprecedented increase in private sector expertise and investment into grid-connected renewable energy in South Africa. As illustrated in Figure 4.4, the bankability of projects under the REIPPPP is secured through the terms and conditions of four non-negotiable agreements that involve five key institutions or stakeholders: the private sector IPP, lenders, the national utility Eskom, NERSA and the Government IPP Office (which itself is a partnership between the DoE, the National Treasury and the Development Bank of Southern Africa) (DoE, DNT and DBSA, 2018b; DoE, DNT and DBSA, 2018c).

Figure 4.4: Key agreements under the REIPPPP framework



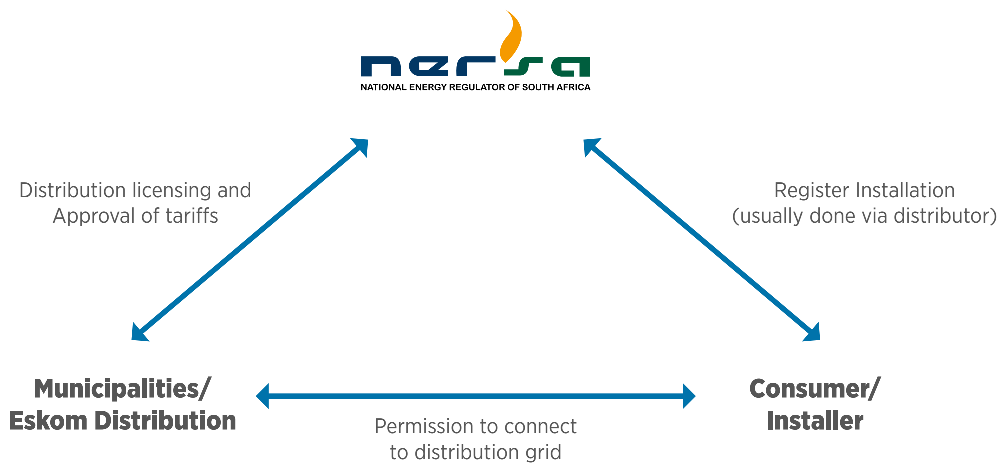
Based on DoE, DNT and DBSA (2018b) and known REIPPPP attributes

Arrangement under embedded generation

As outlined in Chapter 3, renewable energy is also attractive due to its potential for embedded generation capabilities, that help reduce potentially detrimental externalities associated with long-distance transmission. Often, municipalities are the owners and operators of distribution grid network infrastructure, while Eskom operates distribution grid infrastructure in other locations. Eskom distributes about 40% of all electricity to end consumers.

As a result of this, consent from the municipalities or Eskom (distribution) must be sought for any embedded generation projects. Certain municipalities offer a feed-in tariff for excess generation from embedded generators. This tariff may only be offered with approval from the national regulator. The main relevant institutions for embedded generation are therefore the municipalities, Eskom (*i.e.* the distribution department), NERSA and the buyer of the electricity. The landscape of these key actors is illustrated in Figure 4.5.

Figure 4.5: Key stakeholders in embedded generation



Compiled on the basis of SSEG rules (see NERSA, 2018)

Co-operation and alignment among institutions for renewable energy deployment

The effective integration and distribution of higher shares of electricity from renewable energy will require co-ordination among Eskom, NERSA, municipalities and the DoE. Electricity distributors have to be licensed by NERSA; by 2014, a total of 188 distributors were licensed (SALGA, 2014). Electricity services from renewable energy for development-related planning purposes can be included by municipalities to ensure the provision of efficient and sustainable services that are affordable.

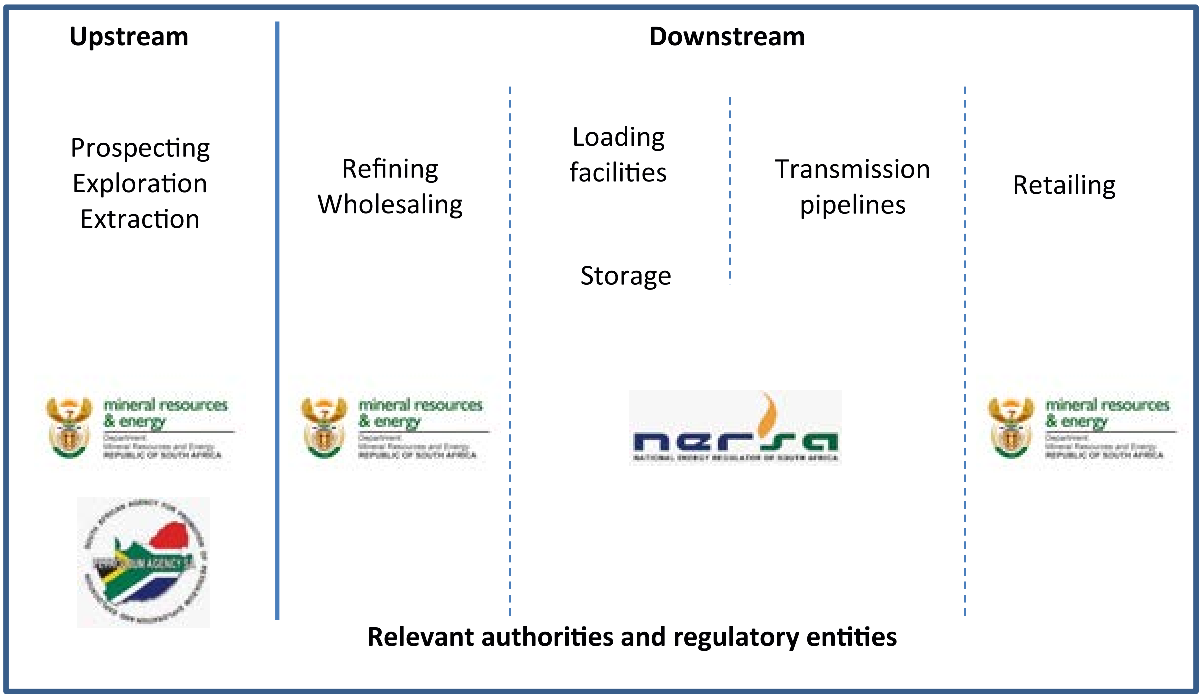
According to SALGA (2014), "there may be real or perceived conflict in law between the right of the municipality to determine tariffs for municipal services (including electricity) in terms of Municipal System Act and power of regulator to approve electricity tariffs in terms of the Electricity Regulation Act". The conflict in law between the tariff-setting authority and municipalities regarding electricity distribution is perceived to have a negative effect on municipalities' revenue generation and ability to manage outstanding debtors.

Arrangement under the petroleum industry

The liquid fuels industry generally consists of the upstream segment (*i.e.* prospecting, exploration, extraction) and the downstream segment (*i.e.* refining, wholesaling, transmission and retailing). Within these segments, different institutions participate to ensure the security of supply and the sustainability of the sector, as well as fair pricing to end-consumers.

Figure 4.6 below shows the institutions involved in the regulation of the sector and their respective roles. The clear distinctions between the authorities responsible for each segment need to be noted. The upstream portions of the sector are the domain of the Department of Mineral Resources, while the downstream activities are the domain of the DoE and NERSA (with NERSA presiding over pipelines only).

Figure 4.6: Key institutions in the structure and regulation of the petroleum industry



Based on NERSA (2014)

Note:

This report only considers information up to 2019 and as such does not capture policy developments since then because they occurred after the completion of this analysis.

5 REFERENCE CASE 2030 FOR SOUTH AFRICA

KEY POINTS

- The Reference Case to 2030 provides a trajectory for the South African energy sector based on current government policy and plans. It is primarily based on the Base Case scenario of the draft IEP 2016.
- Under the Reference Case 2030, total final energy consumption (TFEC) in South Africa is projected to increase by 26%, from 2 290 PJ in 2015 to 2 856 PJ by 2030.
- In the Reference Case 2030, coal continues to play a significant role in the 2030 energy mix (either by direct use or coal-based electricity generation) while petrol and diesel continue to be the dominant primary energy supply options for the transport, mining and agricultural sectors.
- In the electricity sector, the share of renewable energy in electrical energy is expected to increase from ≈9% in 2015 to ≈37% by 2030 under the Reference Case (including imported hydro).
- Under the Reference Case 2030, the share of renewable energy in TFEC is expected to move from ≈9% in 2015 to ≈13% by 2030.
- Traditional biomass use in the residential sector is expected to be replaced by electricity as 90% of households are expected to be electrified via on-grid connections by 2030. Overall, the electrification rate is expected to increase to 97% by 2030, including an increase in off-grid connections in remote rural areas (likely enabled by a range of distributed energy technologies, including renewables).
- In the Reference Case 2030, CO_2 emissions are expected to increase by 17%, from ≈390 Mt in 2015 to ≈450 Mt/yr by 2030. Increased CO_2 emissions are mainly from the transport sector and from increased energy supply from fossil-based sources. The expected emissions are within boundaries of the Peak-Plateau-Decline trajectory.

The Reference Case to 2030 provides a projection of the South African energy sector based on current government policy and plans. It is primarily based on the Base Case scenario of the draft IEP 2016. The IEP (for the energy sector) and the IRP (for the electricity sector) are the two most important strategic plans in South Africa. As outlined in Chapter 4, updated draft versions of both the IEP and IRP are under development (see Box 4 for an overview of the updated draft 2018 IRP). However, at the time of writing this study, the draft IEP 2016 was the latest existing national draft available from the DoE. The outcomes from the draft IEP 2016 Base Case are therefore used as basis for the Reference Case to 2030 (DoE, 2016a).

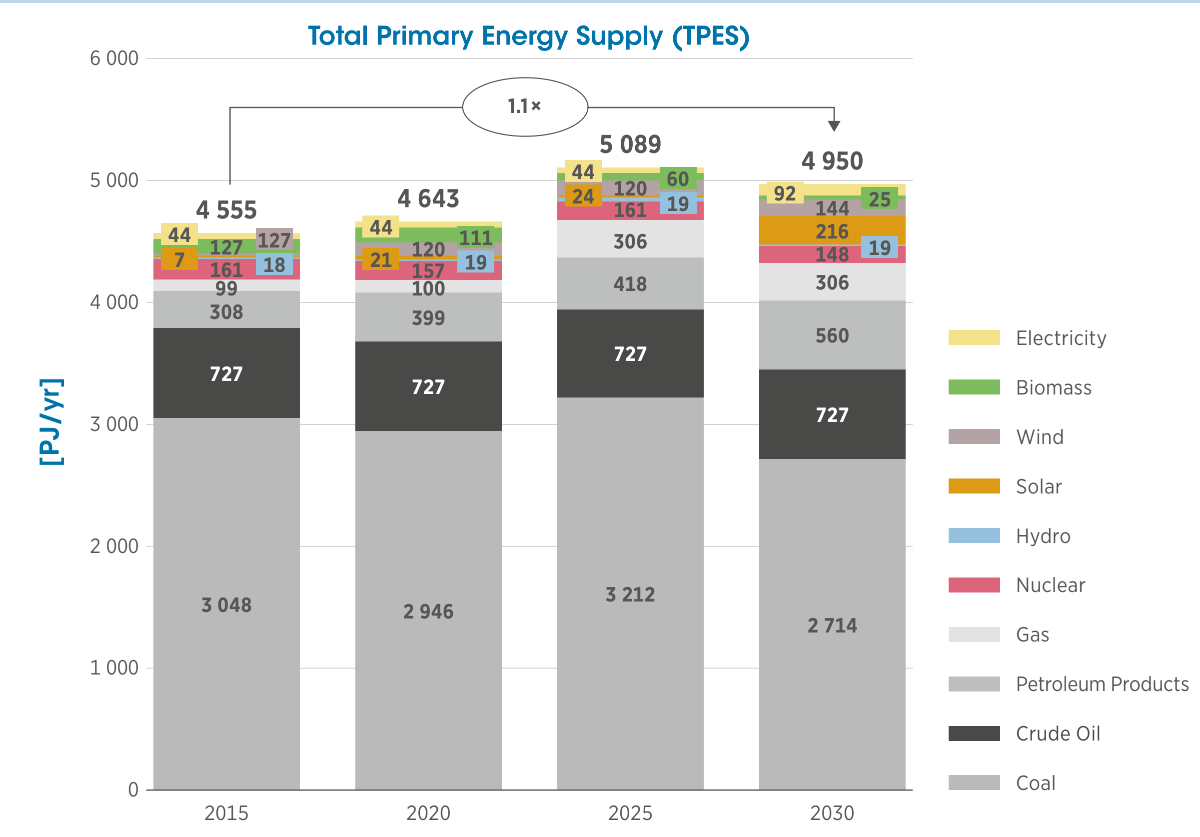
5.1. Developments in primary energy supply and TFEC

Total primary energy supply (TPES)

The expected TPES for the Reference Case is summarised in Figure 5.1. TPES is expected to increase from 4 555 PJ in 2015 to 4 950 PJ by 2030. The TPES from coal is expected to decrease from 3 048 PJ in 2015 to 2 714 PJ by 2030 (from ≈70% of TPES to 55% of TPES). The role of traditional biomass supply is also expected to decrease significantly, from 127 PJ in 2015 to 4 PJ by 2030, whereas modern bioenergy (in the form of biogas) will grow from a negligible amount in 2015 to 20 PJ by 2030. Solar (including solar PV and solar thermal) and wind are expected to play a considerably larger role in primary energy supply in South Africa by 2030, increasing from 7 PJ and 18 PJ in 2015 to 216 PJ and 144 PJ by 2030, respectively. Crude oil supply (largely imported) will remain at 727 PJ, while the TPES from petroleum products is expected to increase notably from 308 PJ in 2015 to 560 PJ by 2030. Natural gas in the TPES also increases considerably, from 99 PJ in 2015 to 306 PJ by 2030.

The total costs under the Reference Case 2030 are dominated by liquid fuel imports at 58% of total discounted energy system costs, electricity production at 23% and liquid fuels extraction/production at 19% (DoE, 2016f). The Reference Case 2030 features moderate economic growth expectations, of 1.3–3.7% annual economic growth to 2025 and 3.7–4.2% annual economic growth thereafter, until 2030.

Figure 5.1: TPES by energy carrier, 2015–2030 (Reference Case 2030)



Note: Net production only is presented. Production + imports (no exports shown).
Based on DoE (2016a)

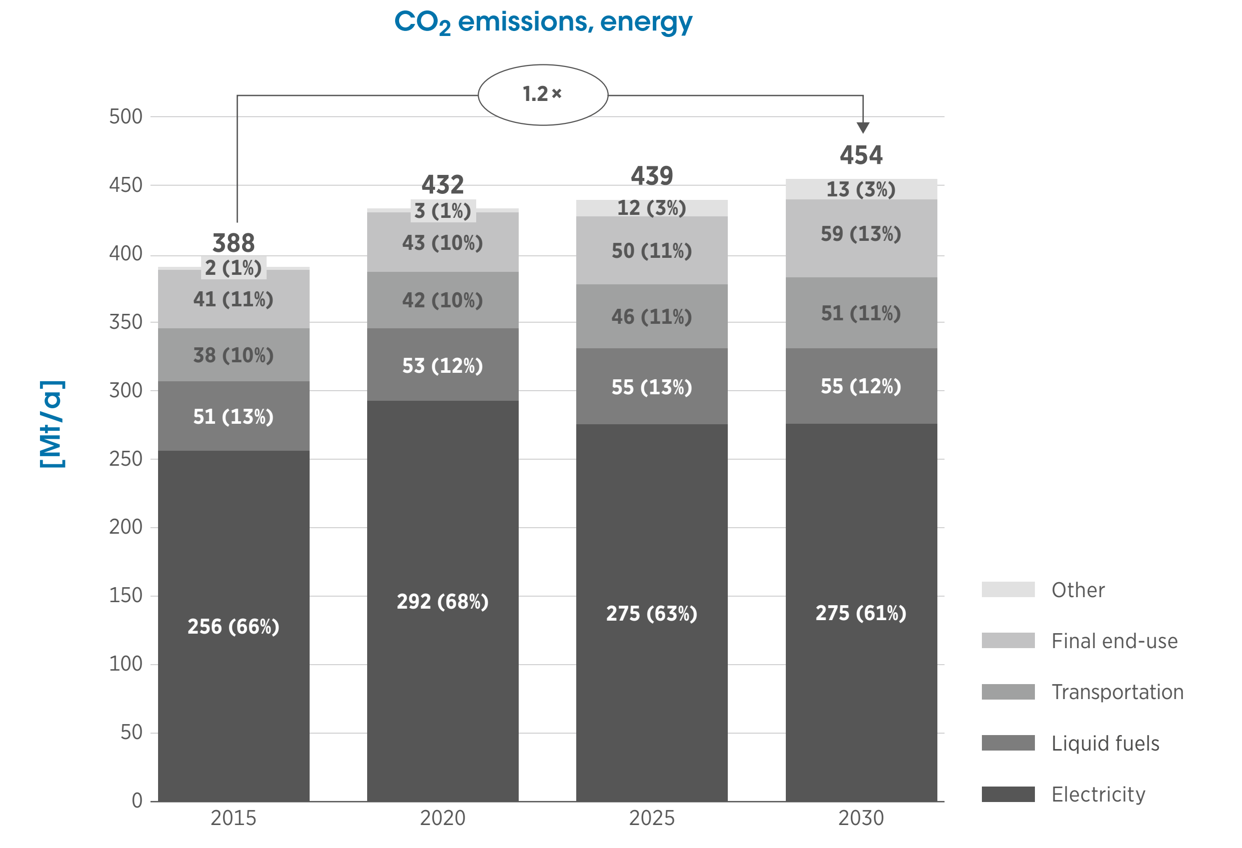
Key insight:

The TPES under the Reference Case 2030 shows a reduction in biomass and coal, while there is an increased role for petroleum products, solar, wind and natural gas.

The CO_2 emissions trajectory for the Reference Case 2030 is shown in Figure 5.2. The electricity sector accounts for the largest share of CO_2 emissions. Under the Reference Case 2030, emissions from the power sector are expected to increase to 2020 but not exceed the Peak-Plateau-Decline limit of 275 Mt/yr from 2025 onwards, due to some diversification away from coal-based power supply. Overall, CO_2 emissions under the Reference Case 2030 are expected to increase by 17% relative to 2015.

From 2020 onwards, emissions from the electricity sector stabilise and marginally decrease. The expected overall increase in CO_2 emissions stems mainly from the transport sector (38 Mt in 2015 to 51 Mt by 2030) and other energy uses outside of the power sector. Overall, the expected trajectory towards 2030 is within the boundaries of South Africa's Peak-Plateau-Decline emissions trajectory (which defines a range of 398 Mt CO_2eq/yr – 614 Mt CO_2eq/yr between 2025 and 2035).

Figure 5.2: CO_2 emissions trajectory 2015–2030 (Reference Case 2030)



Based on DoE (2016a)

Key insight:

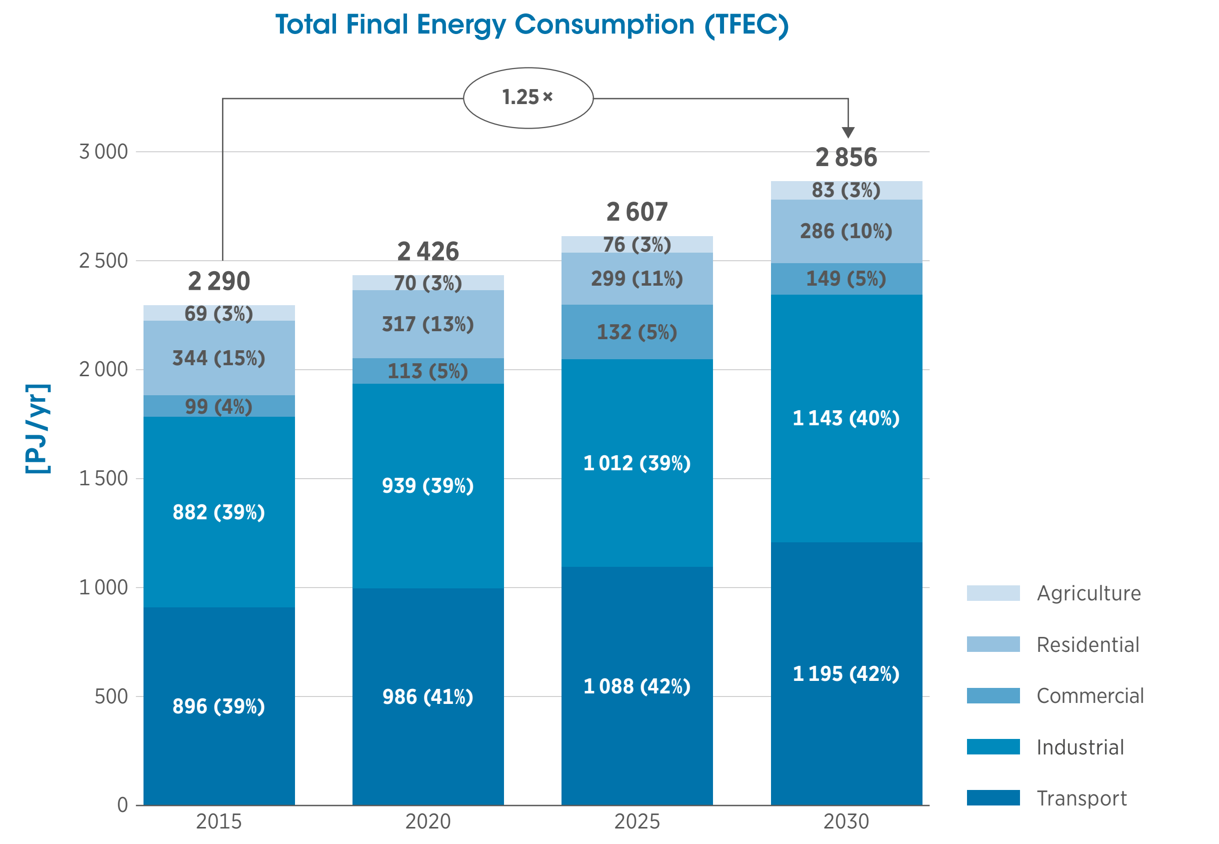
Under the Reference Case 2030, South Africa's national CO_2 emissions increase by 17% from 2015 to 2030. The electricity sector accounts for 66% of total energy sector CO_2 emissions in 2015, and still slightly over 60% by 2030.

Total final energy consumption (TFEC)

TFEC by end-use sector in South Africa in the Reference Case 2030 is shown in Figure 5.3. TFEC in South Africa is expected to grow by 26%, from 2 290 PJ in 2015 to 2 856 PJ by 2030. The largest growth is expected in the commercial sector (demand increase of 33%).

Absolute energy consumption is expected to decrease in the residential sector largely due to an anticipated decline in traditional biomass use and switching to electricity. Small growth is expected in agricultural energy demand, from 69 PJ in 2015 to 83 PJ by 2030.

Figure 5.3: TFEC by end-use sector, 2015–2030 (Reference Case 2030)



Based on DoE, 2016a.

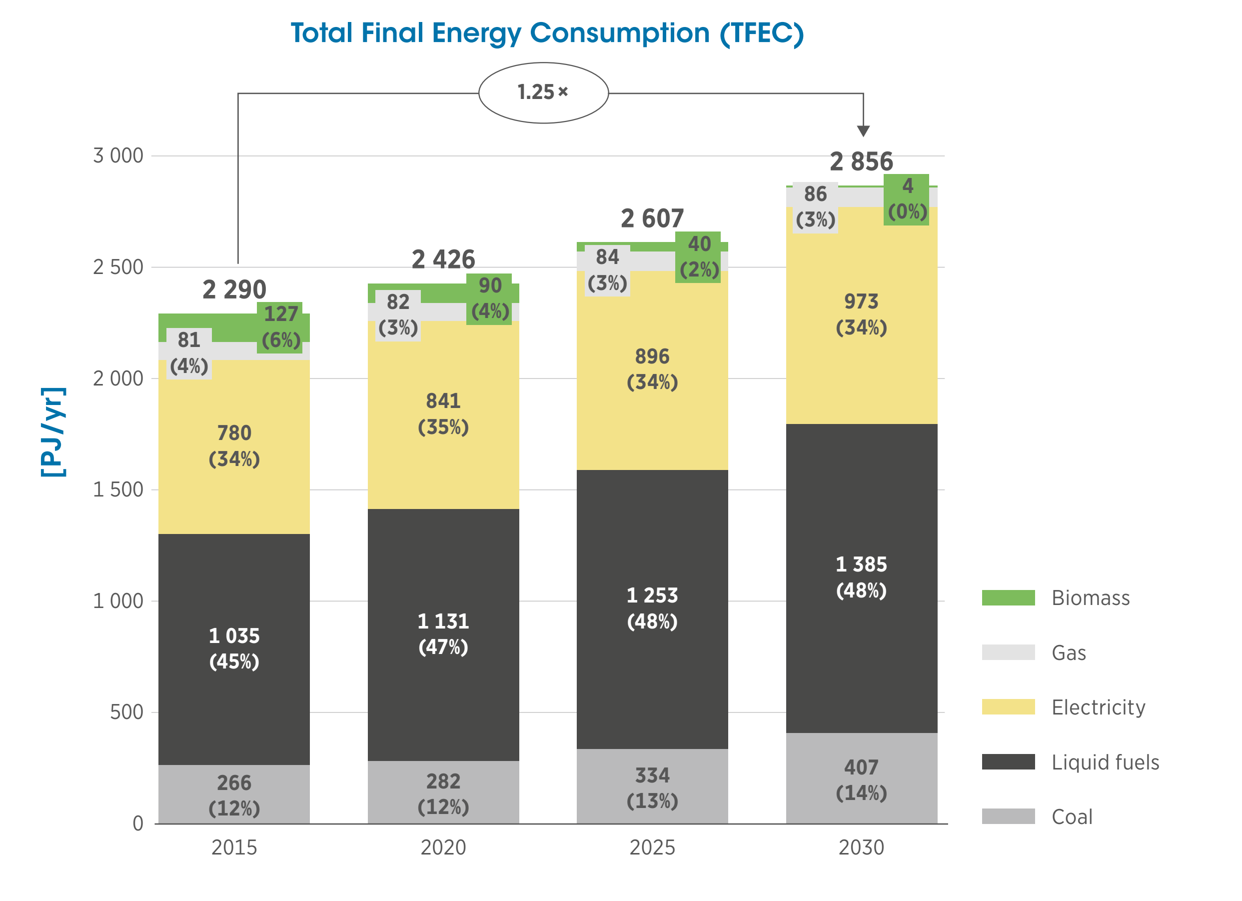
Key insight:

TFEC in South Africa is expected to grow by 26% between 2015 and 2030. Of the end-use sectors, the largest growth is expected in the commercial and industrial sectors.

End-use by energy carrier is summarised in Figure 5.4. Liquid fuels (1 385 PJ by 2030) and coal (407 PJ by 2030) are still expected to play a significant role in South Africa's future energy mix. The role of coal will be via direct-use, for the synthesis of liquid fuels or via coal-based electricity generation (shown in Figure 5.5 below).

Electricity also continues to contribute significantly to energy end-use as an energy carrier (from 780 PJ in 2015 to 973 PJ by 2030) but remains constant on a relative basis, at a share of around 34%, with significant absolute increases in residential and commercial end-use sectors. Natural gas for end-use remains largely unchanged at 86 PJ whilst that of traditional biomass nearly disappears by 2030.

Figure 5.4: TFEC by energy carrier, 2015–2030 (Reference Case 2030)



Based on DoE (2016a)

Key insight:

Under the Reference Case 2030, coal is expected to continue to play a significant role in South Africa's future energy mix either by direct use, for liquid fuels or coal-based electricity generation. Electricity also continues to contribute significantly.

Table 5.1 shows the overall energy and electricity used to heat water in the residential and commercial sectors along with the energy and electricity used for water and process heating in the industrial sector in 2015 and under Reference Case 2030. As shown, the share of energy for water heating in the commercial sector was 21% in 2015, with water heating estimated to be responsible for 3.7% of electricity consumption in this sector. In the industrial sector, the share of water heating is estimated to be 0.5% of the sector's TFEC in 2015. Under the Reference Case 2030, the TFEC in industry and commercial sector is expected to grow between 2015 and 2030. In the residential sector, overall TFEC is expected to decrease, while electricity use increases (mainly due to displacement of biomass with electricity and other fuels supplying energy services at higher efficiencies).

As outlined in Chapter 4, the DoE has drafted a post-2015 NEES with targets for energy-use reductions to 2030. The draft strategy is undergoing public consultation. The Reference Case 2030 does not account for the targets of the draft post-2015 NEES. Rather, the 2030 targets of the draft strategy are accounted for in the REmap Case 2030 (see Chapter 7).

5.2 Developments in power generation and capacity

New generation capacity under the draft IRP 2016

The electricity sector outcomes for the Reference Case 2030 are based on the draft IRP 2016 update, as reflected in the draft IEP 2016 Base Case (DoE, 2016a). The projections for installed capacity and energy mix from the draft IRP 2016 update are shown in Figure 5.5. There is a notable difference in the electrical energy demand forecast between the IRP 2010–2030 promulgated in 2010 and forecasts based on more recent analysis for the draft IRP 2016 update. Namely, in the 2016 version, demand growth is expected to be much lower due to increased energy efficiency and lower future economic growth.

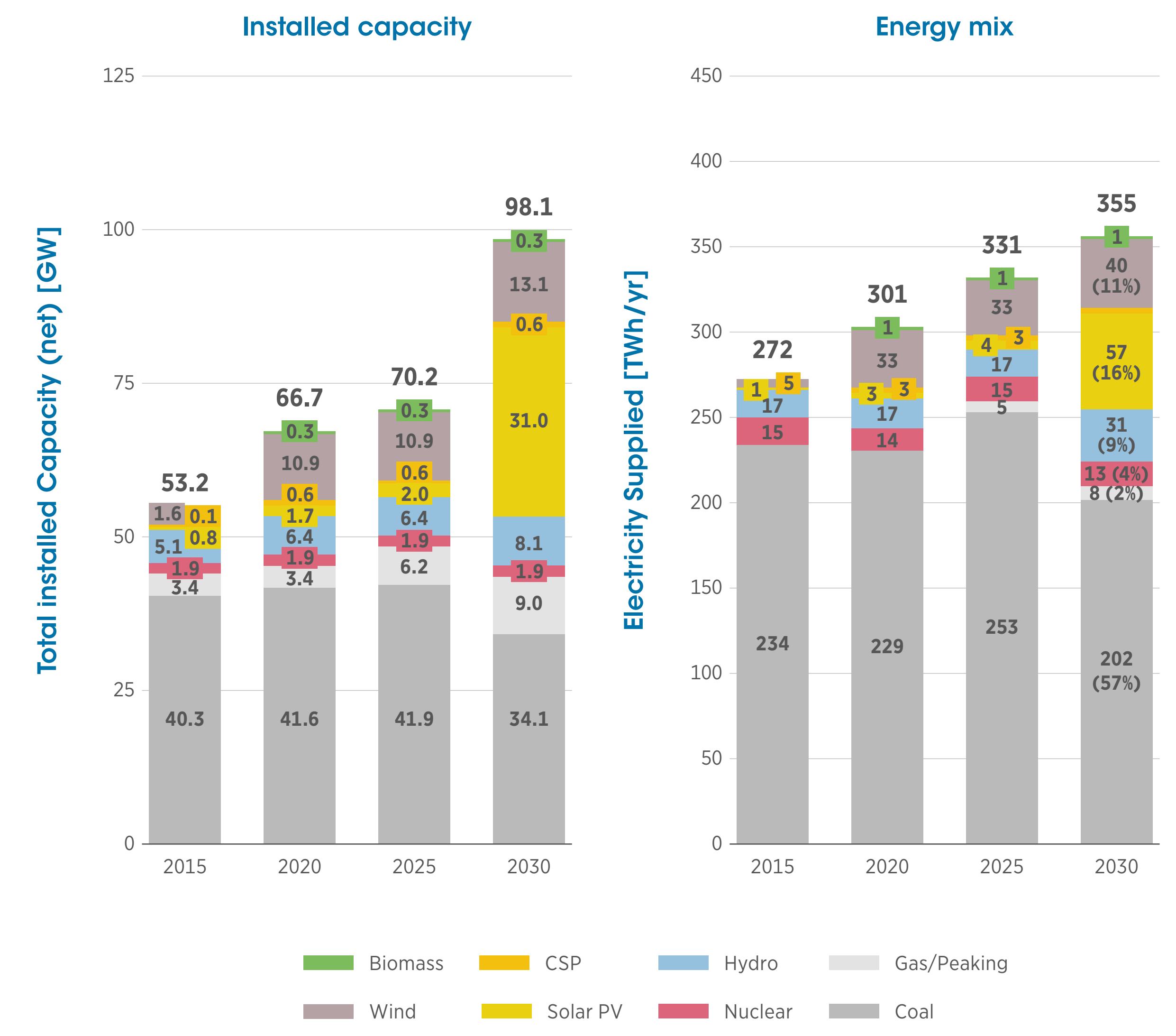
In addition, as a result of considerable cost reductions and cost certainty associated with renewable energy technologies (in particular, solar PV and wind), there is an increased expected future role for these technologies. In the Reference Case 2030, solar PV and wind are projected to account for a total share of 16% and 11%, respectively, in the electricity sector by 2030, while coal is expected to continue to meet the majority of electricity demand (57%). Furthermore, in contrast to the promulgated IRP 2010–2030, there is no new-build coal or nuclear capacity under the draft IRP 2016 update.

Table 5.1: Sectoral use of energy for process and water heating

Sector	TFEC (2015) (PJ)	Electricity (2015) (PJ)	Water and process heating share of TFEC (2015) (%)	Water and process heating share of electricity (2015) (%)	Reference Case 2030 demand* (PJ)	Reference Case 2030 demand (electricity) (PJ)
Residential	344	177	21%	39%	286	234
Industrial	882	482	67%	1%	1 143	555
Commercial	99	79	21%	4%	149	128

** The decrease in residential demand is largely due to displacement of biomass with electricity and other fuels supplying energy services at higher efficiencies.*

Figure 5.5: Installed generation capacity and energy generated under the Reference Case 2030



Note: Installed capacities are based on assumed typical capacity factors as preliminary data are not available.
Based on DoE (2016a) and Wright et al. (2017a)

Key insight:

Under the Reference Case 2030, the installed capacity increases to 98.1 GW, with growth especially in solar PV, natural gas, wind and hydro capacity. The generation in the 2030 mix is still largely dominated by coal but features a renewables' share of 37%.

As indicated in Chapter 4 of this study, the draft IRP 2018 update was circulated for public comments in mid-2018; too late to be fully accounted for in this study. Box 4 gives a brief overview of the draft update and the overall evolution of renewable energy targets in national power sector planning since the IRP 2010–2030.

Box 4: **Draft IRP 2018 update**

The objective of the draft IRP 2018 update is to develop a sustainable electricity investment strategy for generation capacity and supporting infrastructure for South Africa. The modelling period for the draft IRP 2018 update extends to 2050, while the main time horizon is to 2030.

The actual net electrical energy sent-out for South Africa declined at an average compound rate of minus 0.6% over the past years. That was in stark contrast to the expectation of an average growth rate of 3.0% in the IRP 2010–2030. The result was that the actual net sent-out in 2016 was 244 TWh, in comparison with the 296 TWh expected in the IRP 2010–2030 (*i.e.* an 18% difference).

Due to the unexpectedly fast cost reductions for generation from solar PV and onshore wind and to the successful deployment of renewable energy technologies under the first rounds of the REIPPPP, renewables play an earlier and elevated role in the power mix projected in the draft IRP 2018 update, as compared to IRP 2010–2030 and to draft IRP 2016 update. Specifically, due to the sharp cost reductions, the new-build capacity in the least-cost supply scenario to 2050 (*i.e.* unconstrained; including, without renewable energy annual build limits) of the draft IRP 2018 update only contains solar PV, wind and gas (as a proxy for system adequacy and flexibility).

Table 5.2 shows the least-cost capacity development plan for the period up to 2030 with annual build limits (1 000 MW for solar PV, 1 600 MW for wind), from the draft IRP 2018 update. The annual build limits provide for smooth roll-out of renewables capacity, which can help better sustain the national industry. The capacity development plan of the draft 2018 IRP update also includes 1 000 MW of new additional coal-to-power capacity in 2023–2024, based on two already procured and announced projects. Further, it features inclusion of 2 500 MW of hydropower in 2030 to facilitate the RSA-DRC treaty on the Inga Hydro Power Project in line with South Africa's commitments contained in the National Development Plan to partner with regional neighbours. It also includes annual allocations of 200 MW for generation-for-own-use between 1 MW to 10 MW, starting in 2018.

The degree of ambition for renewable energy deployment has gradually increased, starting from the IRP 2010–2030 and continuing with the draft IRP 2016 update and the draft IRP 2018 update. At the same time, the ambition to decommission existing ageing coal capacity has also increased. The draft IRP 2018 update expects a decommissioning of coal of 12.0 GW by 2030 and of a total of 33.8 GW by 2050. Close to 75% of the current Eskom coal fleet would have reached end-of-life status by 2040. Under this schedule, coal is expected to contribute less than 30% of the energy supplied by 2040 and less than 20% by 2050. Figure 5.6 shows the schedule for the decommissioning of coal capacity under the draft IRP 2018 update.

Table 5.2: New generation build plan under the draft 2018 IRP

	Coal	Nuclear	Hydro	Storage (Pumped Storage)	PV	Wind	CSP	Gas/Diesel	Other (CoGen Biomass, Landfill)	Embedded Generation
2018	39 126	1 860	2 196	2 912	1 474	1 980	300	3 830	499	Unknown
2019	2 155					244	300			200
2020	1 433				114	300				200
2021	1 433				300	818				200
2022	711				400					200
2023	500									200
2024	500									200
2025					670	200				200
2026					1 000	1 500		2 250		200
2027					1 000	1 600		1 200		200
2028					1 000	1 600		1 800		200
2029					1 000	1 600		2 850		200
2030			2 500		1 000	1 600				200
Total installed	**33 847**	**1 860**	**4 696**	**2 912**	**7 958**	**11 442**	**600**	**11 930**	**499**	**2 600**
Installed Capacity Mix (%)	**44.6**	**2.5**	**6.2**	**3.8**	**10.5**	**15.1**	**0.9**	**15.7**	**0.7**	

Installed Capacity

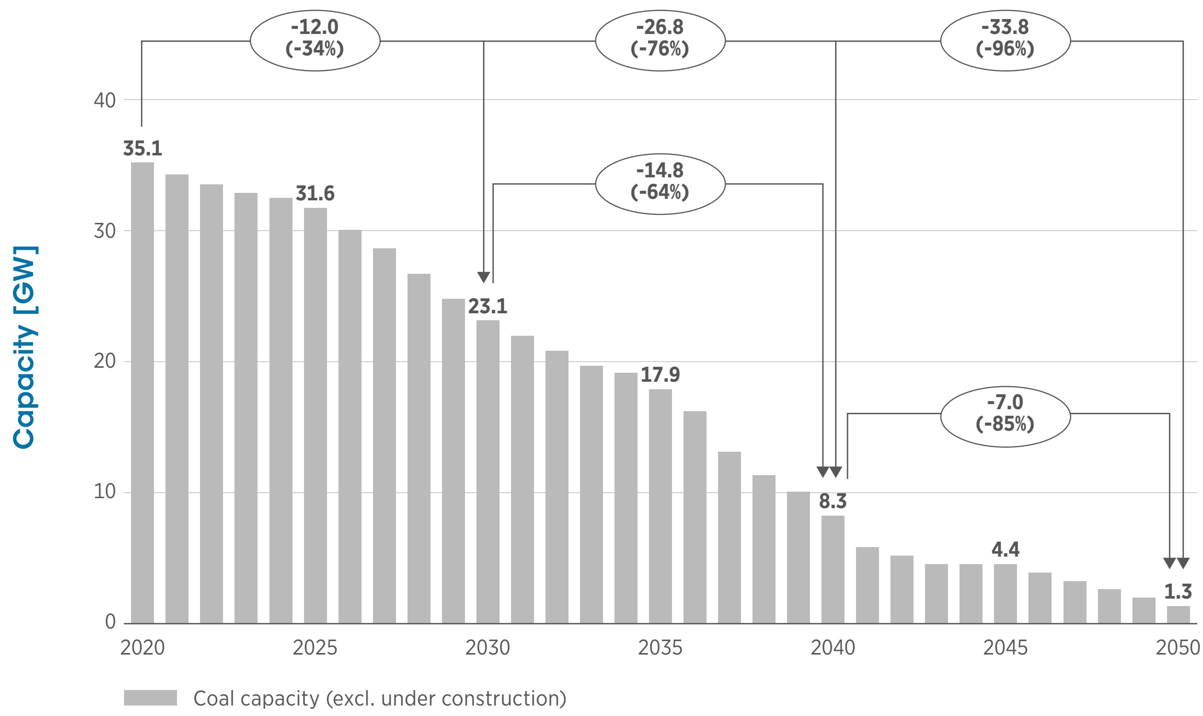
Commited/Already Contracted Capacity

New Additional Capacity (IRP Update)

Embedded Generation Capacity (Generation for use allocation)

Source: DoE (2018b)

Figure 5.6: Planned decommissioning of coal capacity under the draft IRP 2018 update



Based on DoE (2018b)

In addition to the decommissioning of coal capacity, 1 800 MW of nuclear power capacity will reach end-of-life status between 2044 and 2045. As indicated, the draft IRP 2018 update may yet be subject to change. However, its draft version provides a clear indication of direction.

Energy access

Chapter 3 presented the overall status of national electrification. While considerable progress has been achieved in recent years, considerable further effort is still required to achieve universal electrification in South Africa by 2030, as established in the New Household Electrification Strategy (NHES) that was adopted by the cabinet in 2013 (see DoE [2013b] for further information about the NHES and its objectives). The Reference Case 2030 is aligned with the target for universal access[25] by 2030.

25 As full electrification is unlikely to be feasible due to growth and delays in the process of formalising informal settlements, the national cabinet in 2013 approved the defining of universal access as 97% of households (DoE, 2013b). The NHES defined a goal for universal access by 2025, while the National Development Plan 2030 sets the target for 2030.

As outlined in Chapter 3, Section 4, this can be enhanced through the increased deployment of renewables.

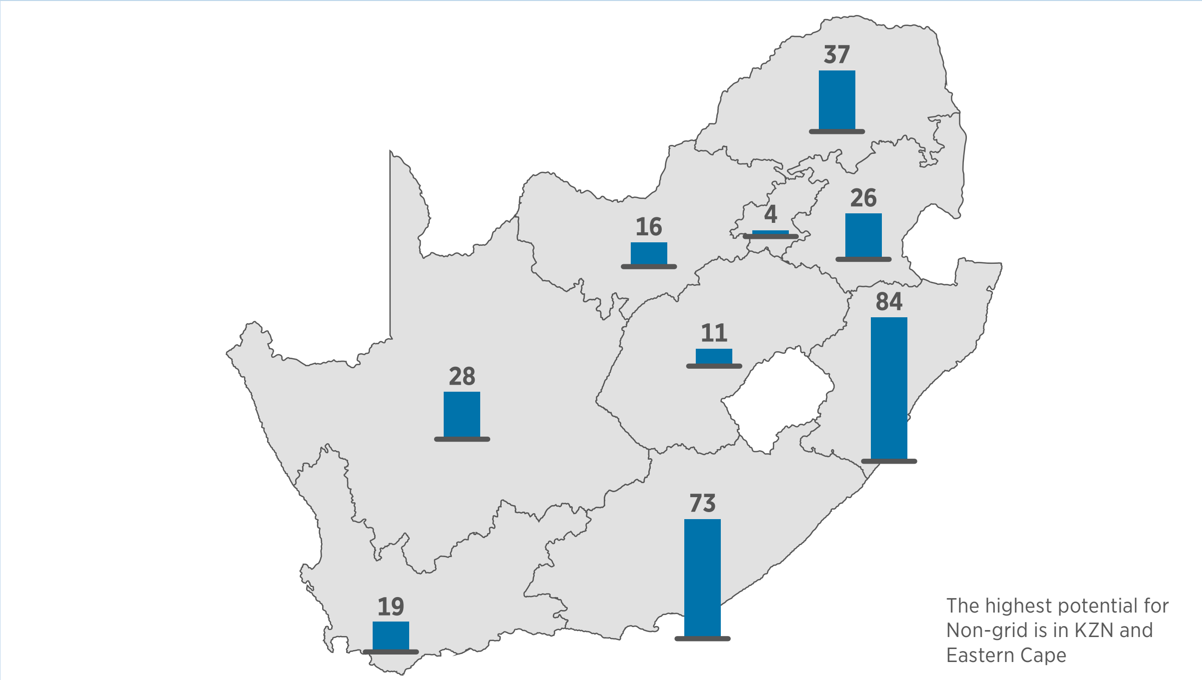
The target of universal access by 2030 is defined in the National Development Plan 2030 (NPC, 2011). For universal access, at least 90% of electrification is envisioned to be provided by on-grid access, with the remainder being provided by off-grid options including alternative energy options (not via electrification: *e.g.* liquefied petroleum gas, bioenergy) (DoE, 2013b). This target can be achieved through continued on-grid electrification efforts as discussed in Chapter 3, combined with off-grid electrification and alternative energy options (where appropriate). Chapter 3, Section 3 presents national grid expansion plans, while this section focuses specifically on non-grid options.

Although non-grid electrification is already a component of the INEP, there will need to be an increased focus on non-grid electrification going forward. More specifically, remote locations where deep rural on-grid electrification would be impractical or uneconomical in comparison to off-grid electrical connections will need to be considered along with alternative energy options. Suitable options for off-grid access include individual dwelling and household electrification via SHSs (as is currently the case) or alternative renewables technologies like distributed solar PV, wind, biomass/biogasenabled digesters or the increased deployment of other alternatives like liquefied petroleum gas.

Community-level and town-level micro-grids may be established on the basis of distributed renewable energy technologies.

These include modern biomass or biogas, micro-hydro, solar PV and/or wind combined with other flexible resources like diesel generation, energy storage and the necessary network infrastructure can enable reliable, affordable and sustainable electricity access. More than 7.4 million households have been connected to the grid and more than 160 307 households were connected through non-grid technology between 1994 and March 2018. To reach the universal access targets, the DoE has analysed the potential for deployment of non-grid-based solutions. The NHES aims to provide 300 000 households with quality non-grid solutions (including mini-grid/hybrid and biogas systems) by 2025, which is in line with the ambition to meet 10% of universal access with non-grid solutions (DoE, 2013b). Figure 5.7 below shows the estimated potential for deployment of such solutions in each province of South Africa up to 2025.

Figure 5.7: Potential of non-grid electricity supply to households by province to 2025



Note: KZN = KwaZulu-Natal.
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Source: DoE (2013b; 2015b)

Key insight:

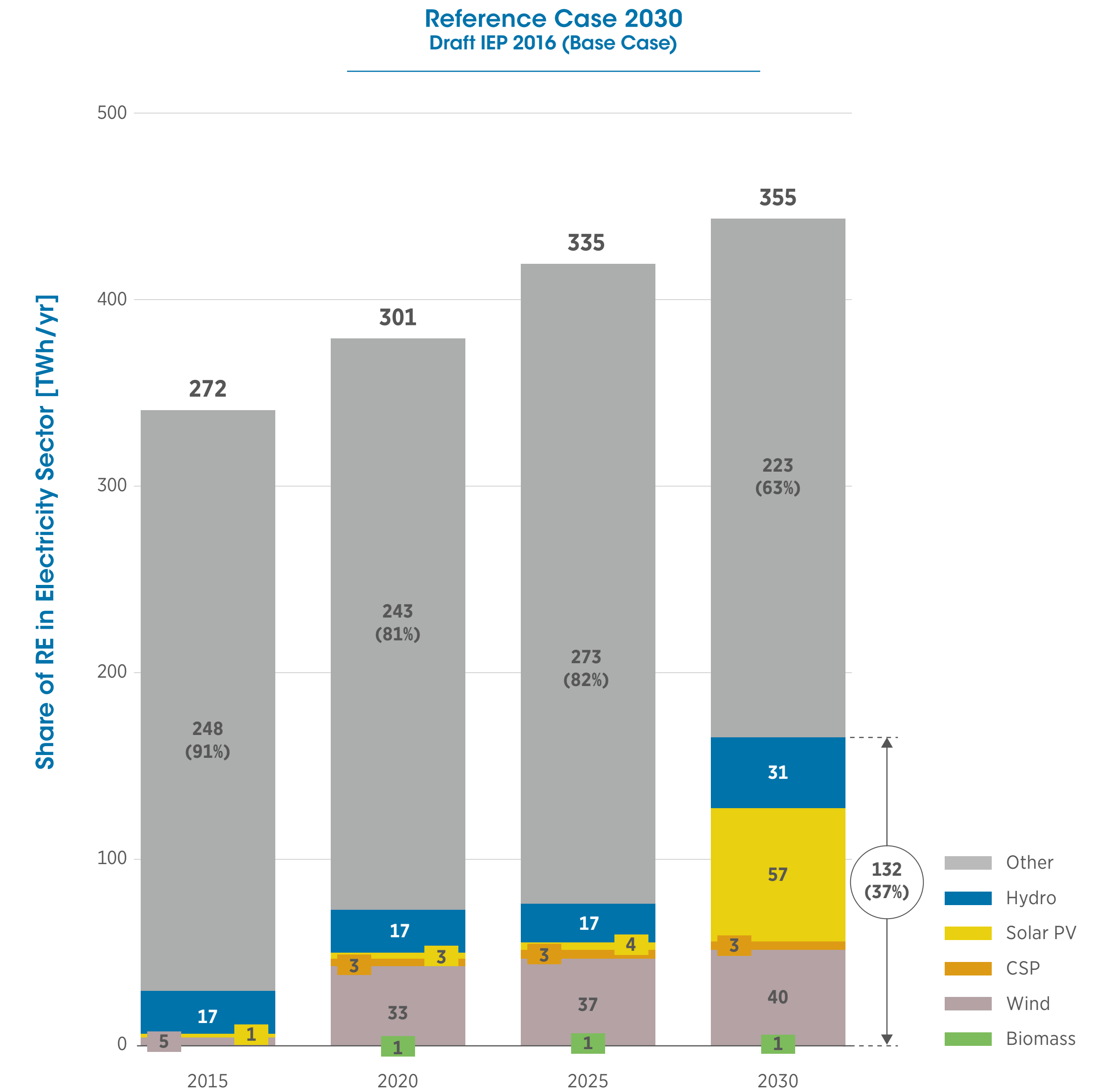
The NHES aims to provide 300 000 households with quality non-grid supply by 2025. The highest potential is identified in the KwaZulu-Natal and Eastern Cape provinces.

5.3 Development of renewable energy use in the Reference Case 2030

Figure 5.8 shows the expected share of renewable energy sources in the power sector under the Reference Case 2030. The Reference Case 2030 suggests rising use of renewable power.

South Africa would thereby increase its renewable power generation from 9% in 2015 to 37% by 2030 (including imported hydropower). The primary renewable energy carriers in the Reference Case 2030 include solar PV (share of 16% in electricity generation), wind (11%) and hydro (9%), with a small role played by biomass/biogas (see also Figure 5.5).

Figure 5.8: Share of renewables by technology in the electricity sector (Reference Case 2030)



Based on DoE (2016a)

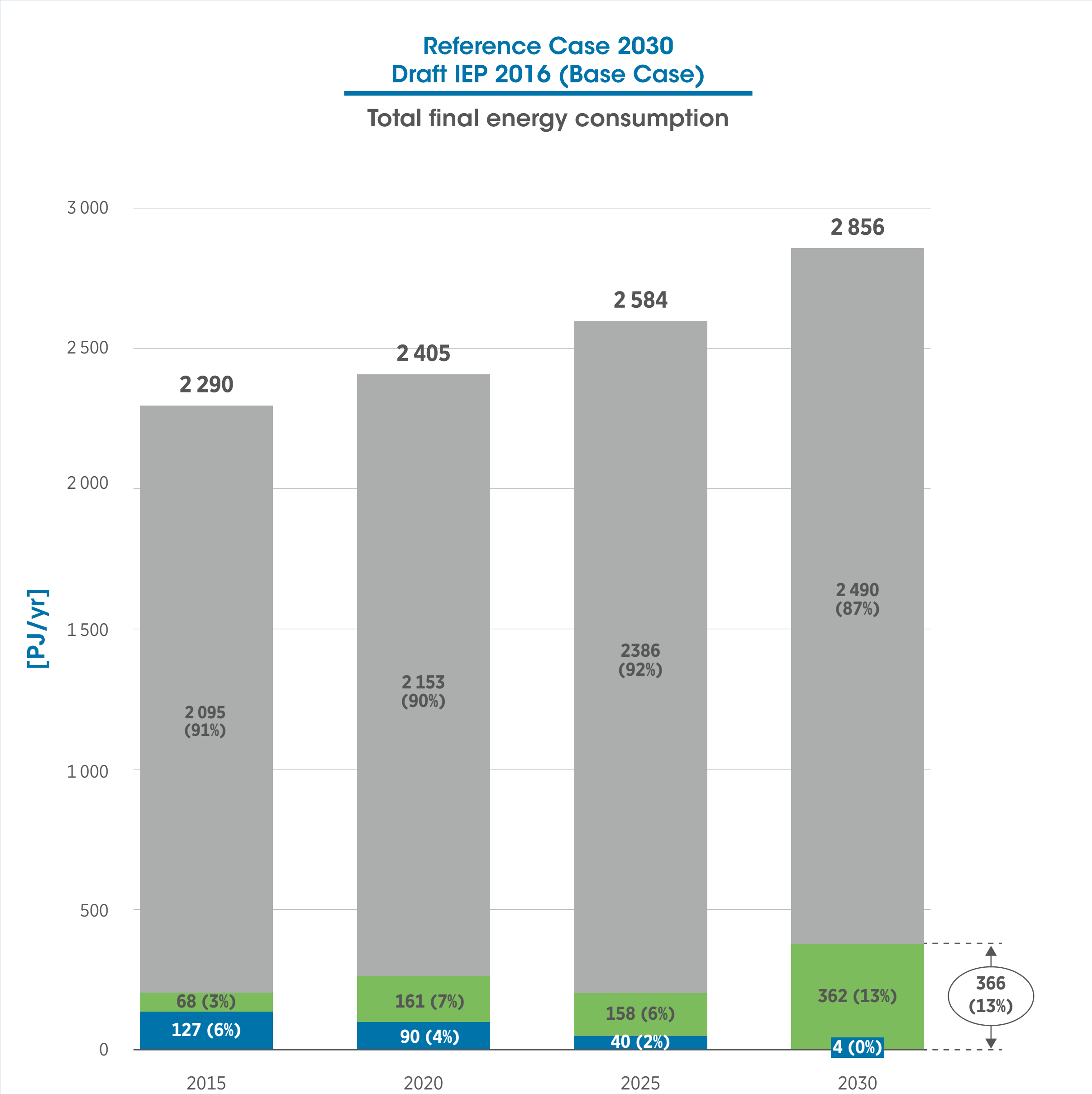
Key insight:

In the Reference Case 2030, the share of renewable energy in electricity generation is expected to grow from 9% of electricity generation in 2015 to 37% by 2030.

The expected share of renewables in the overall energy sector under the Reference Case 2030 is summarised in Figure 5.9. The Reference Case 2030 suggests that the share of renewables in the overall energy sector is expected to move from ≈9% in 2015 to ≈13% of TFEC by 2030.

The main renewable energy technologies are solar PV and wind followed by hydro, whilst the role of biomass is reduced significantly (from 127 PJ in 2015 to 4 PJ by 2030). This is further elaborated in the next section.

Figure 5.9: Share of renewables expected in the South African energy sector, 2015–2030 (Reference Case 2030)



Based on DoE (2016a)

Key insight:

A moderate growth in renewables' share in the overall energy sector is expected in the Reference Case 2030 from around 9% of TFEC in 2015 to ≈13% by 2030.

5.4 Development of renewables by sector and technology mix

The TFEC by end-use sector and the renewables use across sectors under the Reference Case 2030 are summarised in Figure 5.10 and Figure 5.11, respectively. The shares of renewables by technology and end-use sector in 2015 and 2030 are compared in Figure 5.12. Owing to the considerable deployment of renewables for power generation under the Reference Case 2030, especially from solar PV and wind, the share of renewables is higher in those end-use sectors that use electricity as energy carrier.

The significantly reduced role of traditional biomass in the residential sector (currently predominantly used for cooking and heating) results from a switch to the use of electricity, as universal energy access is reached in the Reference Case 2030. As can be seen in Figure 5.11, a result of this is that residential TFEC actually decreases in absolute terms under the Reference Case 2030. The overall share of renewables in the residential sector also declines due to this switch to electricity, but the elevated role of modern renewable energy power generating technologies in the electricity sector means that renewables still play an important role (91 PJ, or 32% of residential TFEC by 2030).

The share of renewables in TFEC in the commercial sector is the highest of all end-use sectors under the Reference Case 2030. By 2030, the share of renewables is projected to grow to 32% of TFEC (from 7% in 2015), as a result of electricity assuming the dominant role as energy carrier in the commercial sector (80% of TFEC in 2015 and 86% by 2030) as it replaces coal (predominantly for space heating).

In the industrial sector, TFEC increases under the Reference Case 2030 as can be seen in Figure 5.11. The industrial sector continues to use coal, liquid fuels and natural gas, though predominantly for industrial process heat and transportation requirements. The role of renewables in the industrial sector increases from just above 5% in 2015 (42 PJ) to 18% (206 PJ) by 2030 under the Reference Case.

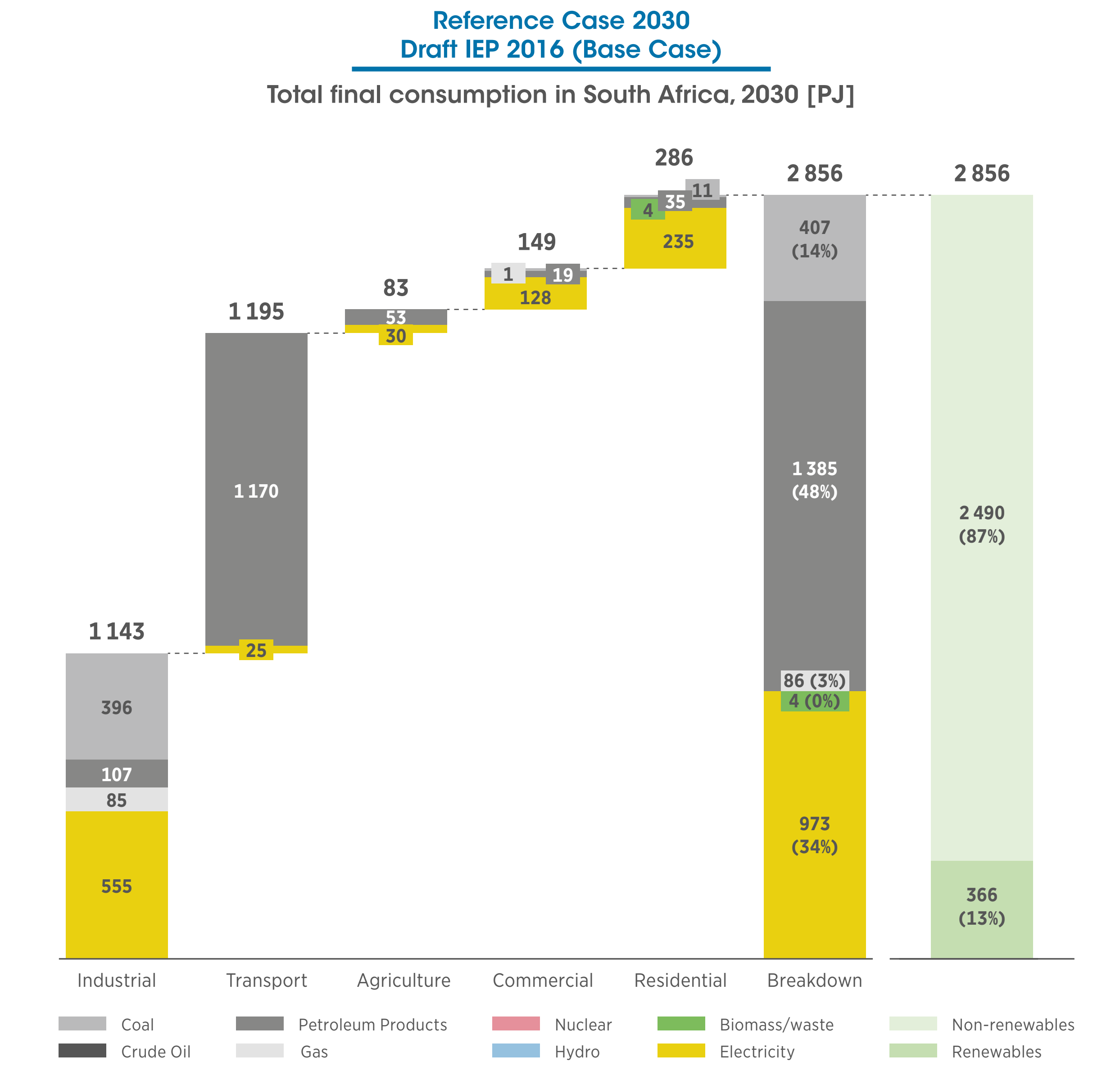
In the transport sector, the limited deployment of electricity (9 PJ by 2030), natural gas or hydrogen-based transportation for freight and passenger road, rail and/or air transportation in the Reference Case 2030 (*i.e.* the draft IEP 2016 Base Case) is primarily a result of the following:

- No further cost reductions for electric vehicles are assumed in the time horizon to 2030.
- Upfront electric vehicles' penetration constraints of 0.3% (2020), 0.8% (2025) and 1.5% (2030) as share of the total vehicle fleet.
- Improved internal combustion engine (ICE) fuel efficiency.
- No significant mode shifting between road and rail transportation.
- No expected significant increase in natural gas and/or hydrogen-based transportation.

This results in a continued dominance of liquid fuels in the transport sector to 2030 (99% of TFEC). The limited electricity end-use (predominantly in rail and small electric vehicle deployment) makes up the remainder of TFEC in transportation. As a result of this, the share of renewable energy changes only slightly under the Reference Case, from near-zero in 2015 to just under 1% by 2030.

In the agricultural sector, the share of modern renewables is expected to increase from ≈3% in 2015 to ≈13% by 2030 under the Reference Case. This is primarily a result of energy carriers in agriculture. It remains largely unchanged in the Reference Case 2030 (*i.e.* there remains an even split between electricity and diesel), and because renewables assume a much-increased role in the electricity mix.

Figure 5.10: TFEC by energy end-use sector disaggregated into energy carriers, 2030 (Reference Case 2030)

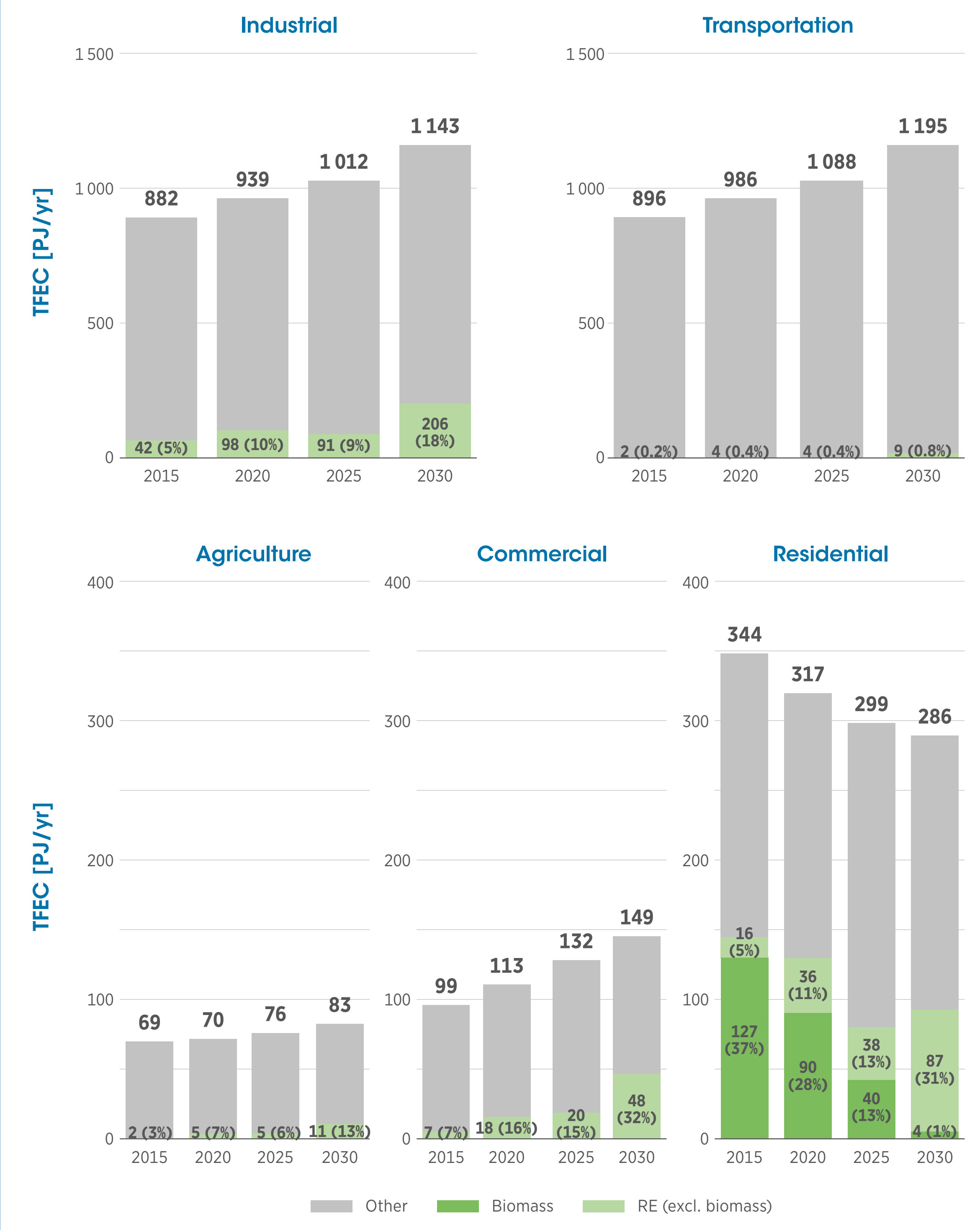


Based on DoE (2016a)

Key insight:

Under the Reference Case 2030, modern renewables have an elevated share in TFEC in South Africa (around 13%), predominantly as a result of increased deployment of renewable power generation technologies (solar PV and wind).

Figure 5.11: Renewables share of TFEC by end-use sector, 2015–2030 (Reference Case 2030)

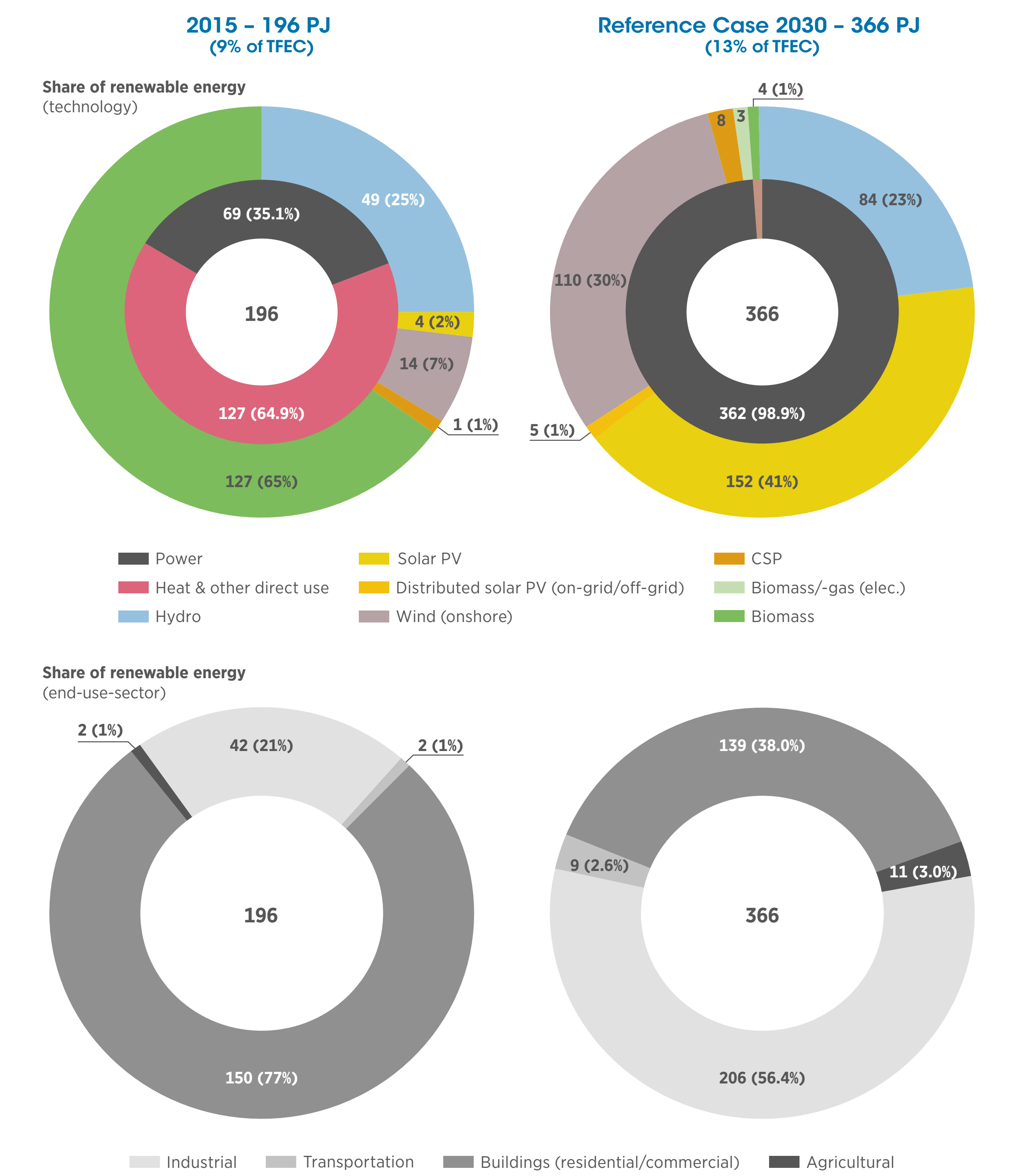


Based on DoE (2016a)

Key insight:

Under the Reference Case 2030, there is an increased share of renewables in the industrial, residential, agricultural and commercial sectors by 2030 compared to 2015, while the role of renewables in transportation remains rather minimal.

Figure 5.12: Renewables share by technology and use of renewables by end-use sector in 2015 and 2030 (Reference Case 2030)



Note: Power sector is after network losses.
Based on DoE (2016a)

Key insight:

Under the Reference Case 2030, there is a considerable increase in the use of renewables for power generation (especially from solar PV and wind technology) while the role of traditional biomass is reduced. The total use of renewables is expected to almost double, and to particularly increase in industry and commerce.

6 RENEWABLE ENERGY POTENTIAL AND (FUTURE) COSTS IN SOUTH AFRICA

KEY POINTS

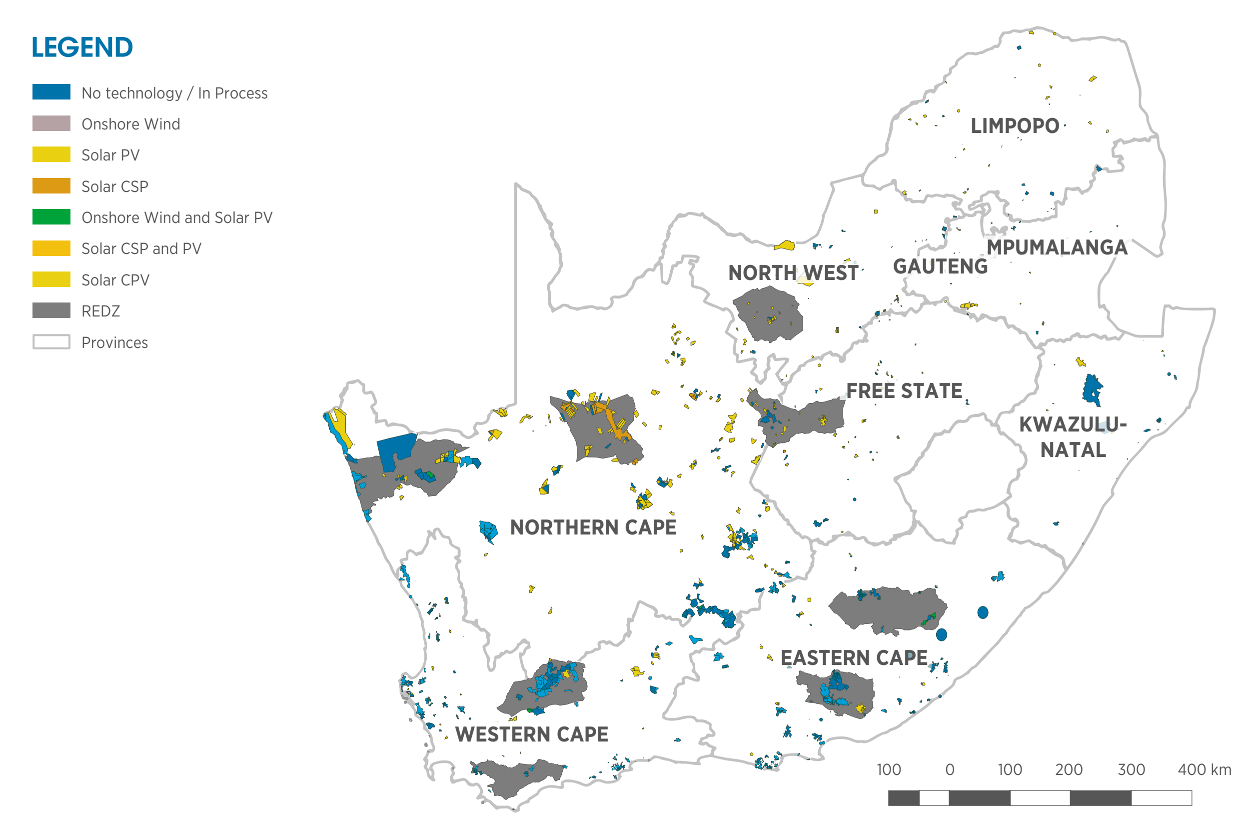
- South Africa has abundant solar irradiation and wind resources. The resources are distributed across virtually the entire territory. South Africa also has significant potential for further bioenergy deployment (from different resources) and some limited specific sites that are well-suited for small-size and medium-size hydropower generation.
- Over recent years, renewables options have become substantially cheaper for electricity generation compared to other new-build options in South Africa such as nuclear and coal. In addition to the reductions in renewable energy technology costs, this is partly a result of the REIPPPP competitive bidding process.
- Successful bid tariffs achieved in the latest bid windows of the REIPPPP averaged USD 0.046/kWh for both wind-based and solar PV-based electricity. The downward cost trends for solar PV and wind generation technologies are expected to continue for the coming years.
- CSP and bioenergy applications under the REIPPPP came in at USD 0.149/kWh and USD 0.082–0.119/kWh, respectively. Baseload coal prices under the Coal IPP Programme averaged USD 0.074/kWh. The price estimate for nuclear power is USD 0.081/kWh. Solar PV and wind are overall the cheapest new-build generation options in South Africa, although additional system-related costs may result from integration of higher shares of variable renewables (*i.e.* solar PV, wind).
- Although further cost reductions in some technologies are assumed in the draft IRP 2016 update for the medium term, no further considerable cost reductions are expected in any technology options from 2030 onwards.
- The assessment of resource potential and expected cost trends provides a key input to the identification of technology deployment options (see Chapter 7).

6.1 Theoretical and technological potential of renewables by resource

The projection of renewable energy technology deployment requires a robust understanding of the scale and potential of available resources. This section outlines the renewable energy resource endowment of South Africa and the resource distribution over the territory of the country. The most abundant renewable resources are solar, wind and biomass (mostly plant residues and organic waste); also, some specific sites are well-suited for hydropower generation at both medium and small scale.

As explained in Chapter 3, Section 3 of this study, South Africa's national government, through its Department of Environmental Affairs (DEA), approved so-called renewable energy development zones (REDZs) where generation projects may be developed with minimal risk of disturbing the environment. Outside of these zones, projects may only be developed if respective approvals can be obtained from the relevant authorities. Figure 6.1 below shows the location of the REDZs and of proposed solar PV and wind power projects in South Africa for which EIAs have been submitted to the DEA (as of Q2 2018). The map shows that the eight REDZs are distributed widely over the land area of South Africa. The location of the REDZs (as also presented in Figure 3.9 above) appears to not be a constraint to the development of renewable energy projects, many of which lie outside of REDZs.

Figure 6.1: Location of the REDZs and proposed solar PV and wind power projects for which EIAs have been submitted to the DEA (as of Q2 2018)



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Source: DEA and CSIR (2014)

Table 6.1 shows the theoretical resource potential for all REDZs in terms of capacity and generation, as well as the solar PV and wind generation capacity proposed by project developers.

Table 6.1: Theoretical total resource potential of all REDZs and capacity of proposed solar PV and wind projects

Technology	Usable land area of REDZs	REDZ share of South Africa's land area	Capacity potential in REDZs	Generation potential in REDZs	Total area of EIA projects	Total capacity in EIA projects (as of 2016)
Units	km²	%	GW	TWh	km²	GW
Solar PV	53 472	4.5%	1 069–1 604	2 060–3 091	9 874	197–296
Onshore wind	53 472	4.5%	267–428	889–1 425	8 894	44–71

Note: The assumed power densities are wind = 5–8 MW/km² and solar PV = 20–30 MW/km².
Based on CSIR, Fraunhofer IWES et al. (2016)

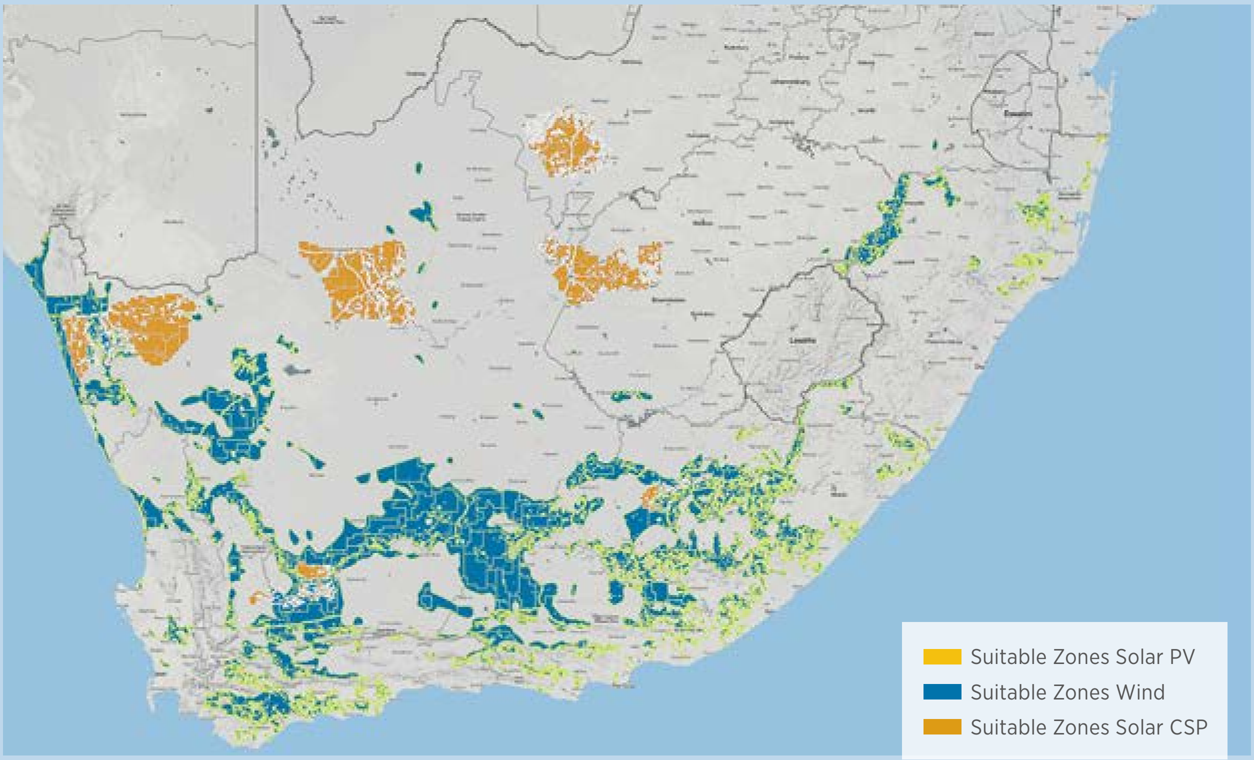
In total there are eight areas marked as REDZs, with a theoretical potential to host a total of over ≈1 300–2 000 GW of solar PV and onshore wind generation combined. The total area of all REDZs is approximately 78 000 km², and 53 472 km² after the exclusion of environmentally sensitive areas, bird migration paths, rivers, built infrastructure such as roads, human settlements, etc. This is about 6.5% of South Africa's land area (4.5% after exclusions).

In addition to the REDZs, South Africa participated in the Multi-criteria Analysis for Planning Renewable Energy (MapRE) study conducted by IRENA and Lawrence Berkeley National Laboratory in 2015 (Wu *et al*., 2015). The study identified zones for cost-effective, equitable and environmentally sustainable wind, solar PV and CSP deployment in the countries of the Eastern and Southern African power pools. The analysis applied a multi-criteria framework to come up with a cumulative score for determining the suitability of land areas in the order of 100 km² ("zones") for solar PV, CSP and wind deployment.

Criteria included the LCOE of power generation, capacity value, distance to load centres, distance to grid, and population density, among others. The analysis resulted in inventories of possible high-potential zones for wind and solar projects; the database is available via the MapRE website.[26]

The map below shows the renewable energy zones for South Africa identified in the MapRE analysis as well as the existing and proposed relevant infrastructure. The map also indicates the REDZs for South Africa (see purple crossed areas); the zones identified in the MapRE analysis and the REDZs determined by the DEA are widely convergent with regard to those areas that are identified as suitable for solar PV and wind projects. The MapRE analysis identifies a larger overall area and consequently a larger overall theoretical capacity and generation potential. The factors considered as developmental constraints for renewable energy projects are not shown in the map but accounted for in the zone

Figure 6.2: Renewable energy zones in South Africa from the MapRE database



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Source: Wu et al. (2015) and MapRE database

26 The MapRE database is accessible at: *http://mapre.lbl.gov/*.

Table 6.2: Sum of areas and discounted generation potential identified in the zoning analysis

Wind		CSP		PV	
Generation potential TWh	Sum of areas km^2	Generation potential TWh	Sum of areas km^2	Generation potential TWh	Sum of areas km^2
924	135 411	369.8	48 474	262.3	41 156

Source: Wu et al. (2015) and MapRE database

Table 6.2 provides the sum of the areas identified for wind, solar PV and CSP generation in the MapRE analysis, and the respective theoretical discounted generation potential in the areas. The discounted generation potential deviates from the REDZ estimates due to some difference in assumptions.

The following sections provide further detail on renewable resource potential in South Africa.

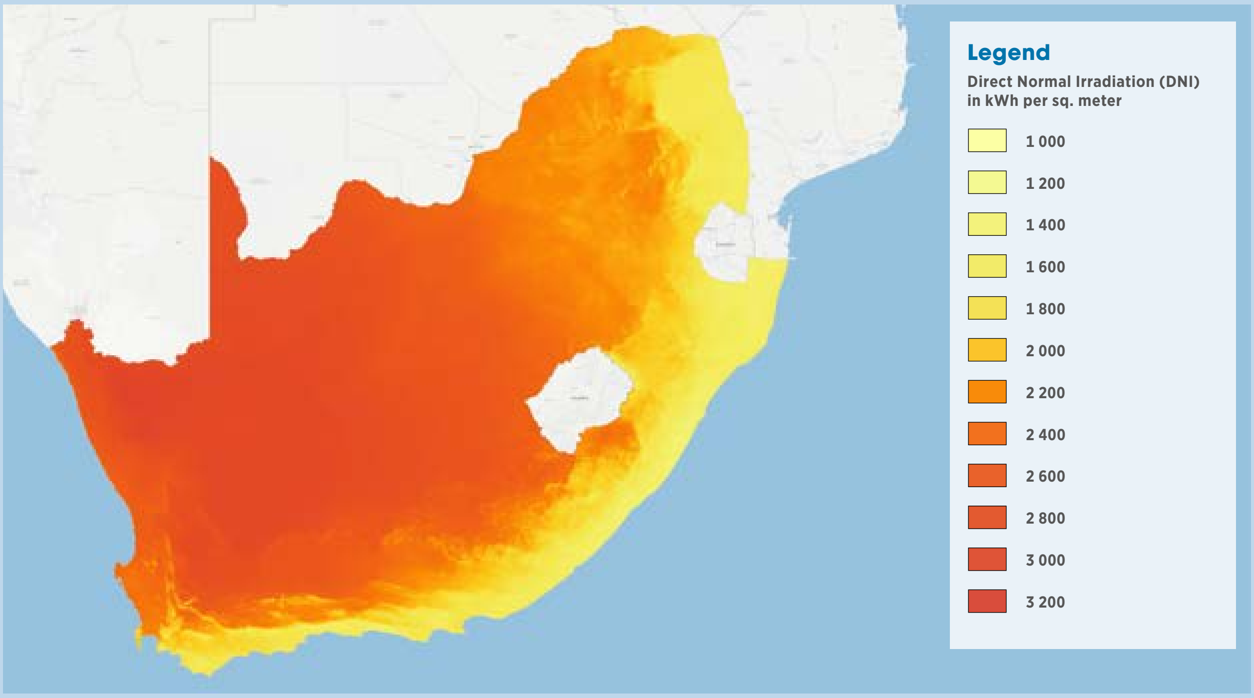
Solar irradiation

CSP technology requires direct irradiation, as it converts concentrated irradiation to heat to drive an engine connected to an electrical power generator. The average annual direct normal irradiation (DNI) for South Africa is shown geographically in Figure 6.3. The DNI in South Africa is among the highest in the world (other top locations include Australia, Chile, and most of the Middle-East North Africa region). The DNI is particularly high in the Northern Cape Province of South Africa, with large areas exhibiting annual irradiation levels of up to 3 000 kWh per square metre (m^2) per year.

Consequently, existing and planned CSP capacity projects are located in the Northern Cape Province. The map in Figure 6.3 shows that even the central areas of South Africa feature DNI levels of approximately 2 500 kWh/m^2/year. Such DNI levels are comparable to regions in Europe that have hosted CSP projects, such as the Helios and Manchasol 50 MW CSP plants located in Spain, where DNI levels are 2 200–2 500 kWh/m^2/year.

Besides the DNI level, the suitability of areas for CSP deployment is also affected by geotechnical attributes of the land area (*i.e.* how stable the ground is for the construction of heavy infrastructure such as the power block of a thermal generation plant); the availability of water for cleaning panels, heliostats or parabolic troughs; as well as good road infrastructure for delivery of project components. Proximity to grid infrastructure is also an important factor in South Africa given that, under the REIPPPP, project developers must bear the costs for connection to the national grid.

Figure 6.3: South Africa long-term average DNI (kWh/m²), 1994–2015



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Source: World Bank (2017)

Key insight:

South Africa hosts some of the best sites in the world in terms of DNI. The Northern Cape Province, which has the highest such irradiation levels, hosts all CSP plants being planned and constructed in South Africa so far.

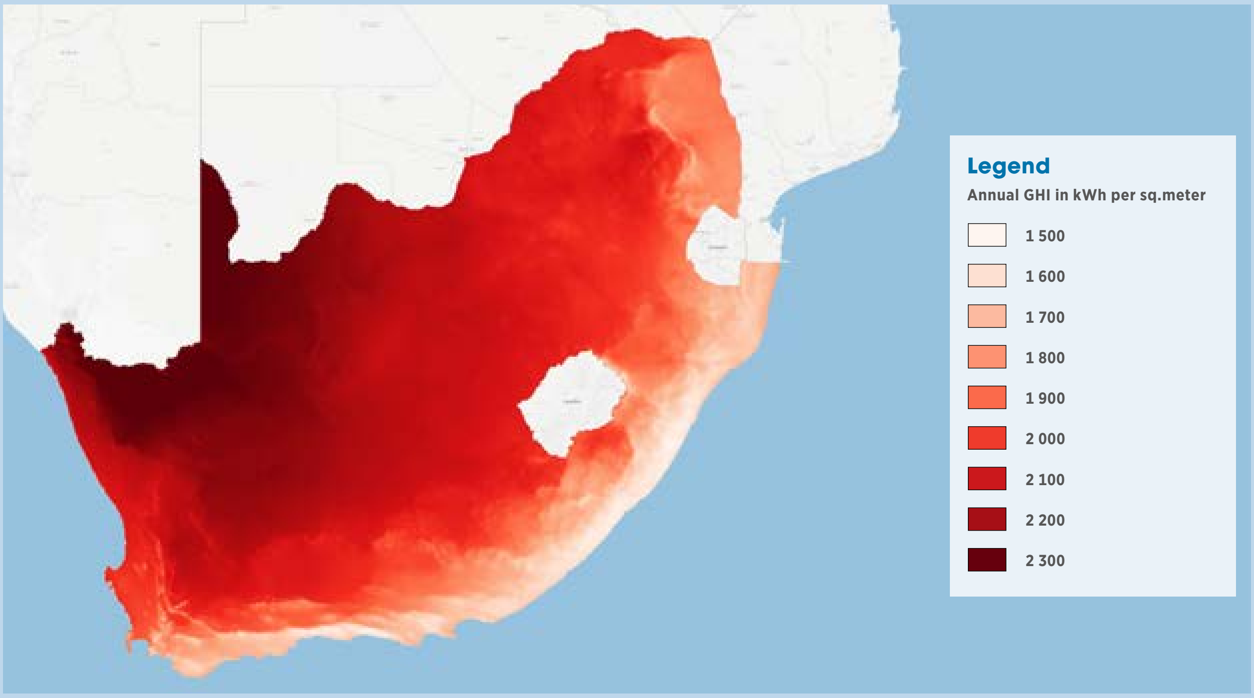
The global horizontal irradiation (GHI) serves as indication of the relative resource for solar PV applications. Figure 6.4 shows the GHI levels across the land areas of South Africa. The entire territory of South Africa has GHI levels higher than 1 300 kWh/m²/year, which indicates the theoretical suitability of virtually any location in South Africa for solar PV deployment.

The wide distribution of GHI in South Africa is important to support high grid penetration of solar PV since project sites can be spread across the country to avoid grid congestion and to ease VRE integration. The geographical flexibility in choosing project sites is also important from a socio-economic standpoint, as plants can be located in areas where they contribute to a just transition in the energy sector (see chapters 7 and 9 for further information).

As part of a study by CSIR, Fraunhofer IWES, SANEDI and Eskom from 2016, significant solar PV potential was found from a few pre-selected areas in South Africa, including urban settlement areas for rooftop solar PV (amounting to 1.2% of total land area) with total solar PV installation capacity potential of approximately 72 GW (generating 136 TWh).

Sites for which EIA applications to the DEA have been made as of 2016 are equal to 0.8% of total land area, with 197–296 GW in potential installed capacity (see Table 6.1), generating around 420 TWh.

Figure 6.4: GHI levels across the land areas of South Africa (average annual sum, kWh/m²)



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Source: World Bank (2017)

Key insight:

South Africa has excellent solar GHI resources across virtually the entire area of the country. Solar PV projects, therefore, can be expanded, located away from areas of grid congestion and strategically placed close to major load centres.

Onshore wind

Figure 6.5 shows an image from the Wind Atlas of South Africa (WASA), developed jointly by the DoE, CSIR, SANEDI, South African Weather Service (SAWS), the Technical University of Denmark Wind Energy Group, and University of Cape Town (UCT).

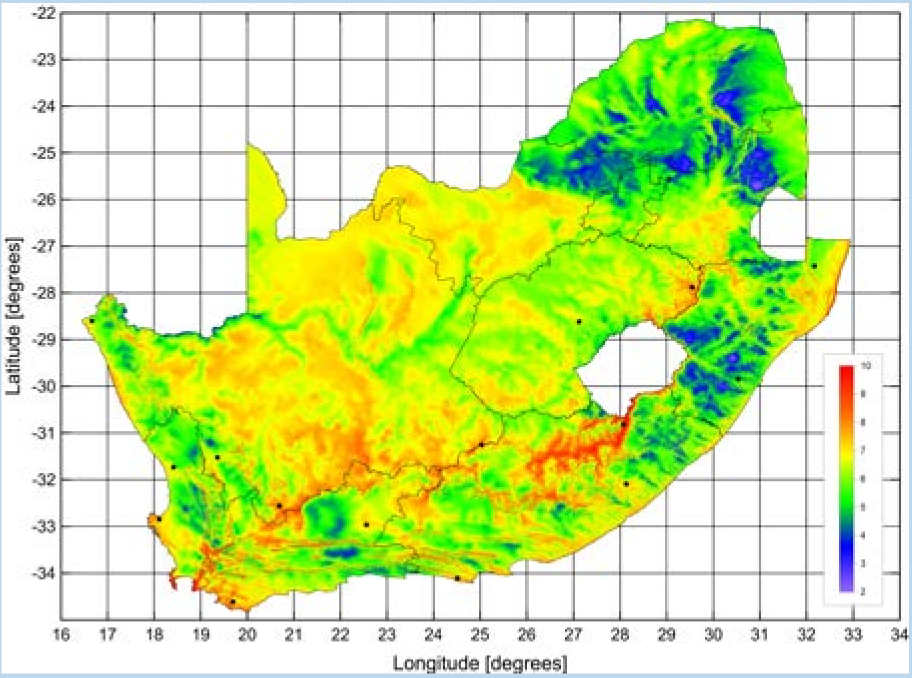
Figure 6.5 shows that the South African wind resource is well dispersed geographically even outside of coastal areas, which were previously thought to be the only areas suitable for the development of wind projects.

Vast areas of the Northern Cape are also suitable for wind power, and this has been reflected in the numerous wind projects approved in this province under the REIPPPP. The model time series data that were utilised to create the Wind Atlas show that average wind speeds are seldom below 5 meters/second at 100 m above ground level in most of South Africa's area.

Further evidence of South Africa's substantial wind resource may be found in the average capacity factors that can be calculated using the underlying data from the Wind Atlas of South Africa. As shown in Figure 6.6, around 75% of the land area (conservatively estimated) exhibits wind load factors[27] above 0.3, while 50% of the land area even exhibits load factors above 0.35. This is significant because wind energy projects generally require capacity factor levels of 0.25 or above to be economically viable.

27 Note that the "wind load factor" is the same as the capacity factor. It is the average power generated divided by the rated peak power. For example, if a 10 MW wind turbine produces power at an average of 4 MW, then its capacity factor/load factor is 40%.

Figure 6.5: WASA High-resolution wind resource map: Mean wind speed [ms-1] at 100m above ground level, Dec 2018

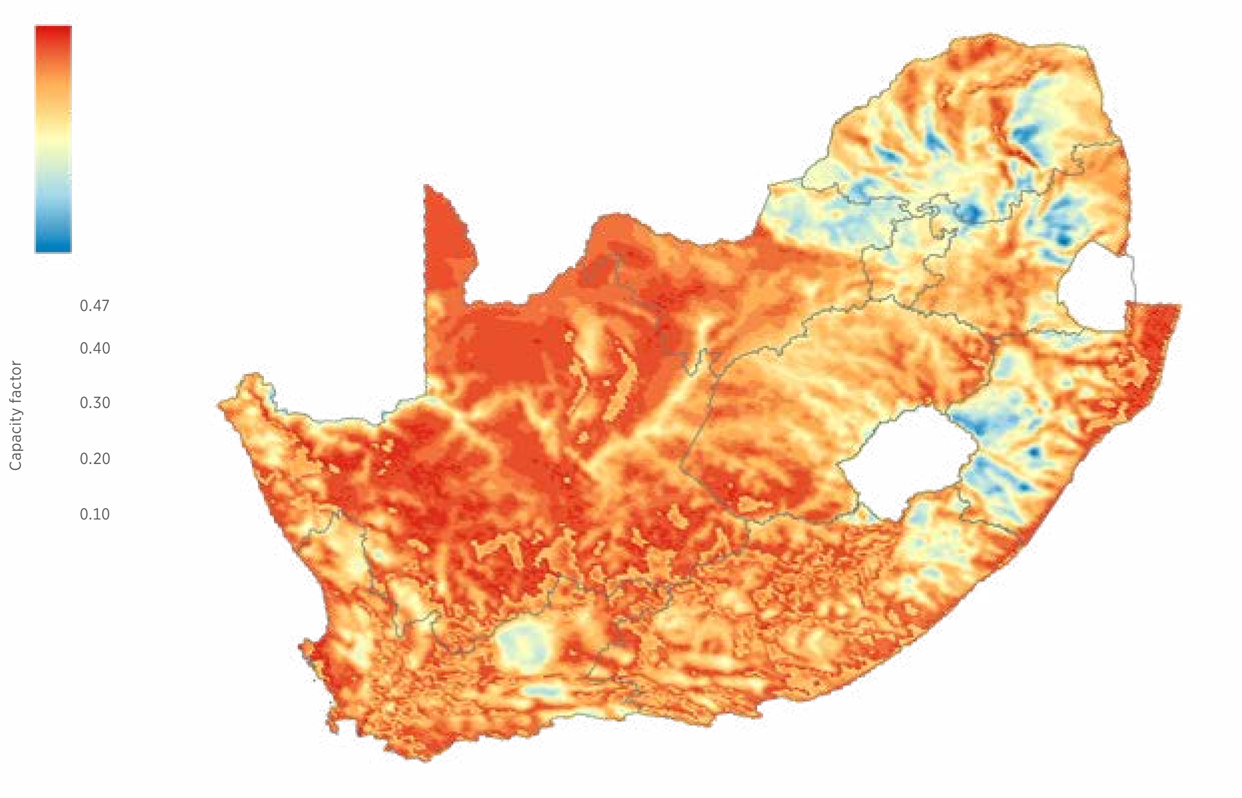


Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Note: a.g.l. = above ground level.
Source: Wind and Solar Atlas (DoE et al.)

Key insight:

The map shows the large available wind resource in South Africa. Substantial wind resource exists even outside of coastal areas.

Figure 6.6: Expected load factor for wind



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Based on CSIR et al. (2016)

In addition, according to the solar PV and wind aggregation study conducted by CSIR, Fraunhofer IWES and others (2016), there is sufficient land in South Africa to accommodate a level of generation potential from onshore wind that matches the current size of the entire South African power system from the perspective of installed capacity. This effectively signifies an unlimited wind resource potential, to the degree that it can be integrated into the power system with sufficient flexibility.

Bioenergy

In South Africa, bioenergy has historically been used directly in the residential sector for heating and cooking, as well as industrial processes, on-site power generation and, more recently, utility-scale power generation (under the REIPPPP).

The primary energy supply from traditional biomass totalled approximately 127 PJ in 2015 (see Chapter 3), all for residential end-use. Under the Reference Case, the use of traditional biomass is reduced to 4 PJ by 2030. The use of biomass in the future would likely be for either biofuels or power generation. South Africa plans for 345 MW of generation capacity from bioenergy to be deployed by 2030 through current allocations under the REIPPPP, including biomass (210 MW) and biogas/landfill gas (135 MW) (DoE, DNT and DBSA, 2018a). So far, 41 MW of biomass and 18 MW of landfill gas have been procured for power generation.

The *Bioenergy Atlas for South Africa,* published in 2016 (Hugo, 2016), noted significant potential for further bioenergy deployment. The potential is constrained, primarily due to prioritisation of food security in South Africa, combined with low productivity and inter-annual weather variability.

The *Bioenergy Atlas* found that an additional 487 PJ/year of biomass (≈350 PJ/year if purposefully cultivated crops are excluded for food security reasons) is currently available for energy use in South Africa. Specifically, the *Bioenergy Atlas* resulted in the following set of options for biomass utilisation:

- Utilisation of all available urban domestic (household) organic waste, from solid waste and from wastewater, is the most feasible option, with an acceptable end-product cost. Some local authorities may choose to use wastewater biogas for in-situ electricity generation. The estimated contribution from feasible project options is up to 1 400 MW.
- The development of household or communal digesters in rural (unserved) areas in combination with cattle dung in areas where this is available. The estimated contribution from feasible project options is up to 250 MW.
- The combination of all available lignocellulose biomass (invasive alien plants, plantation residues, sugar mill bagasse and agricultural residue) can make a significant contribution to electricity generation in mid-size regional power stations (typical size of 50–300 MW). Projects may have a limited lifetime due to the objective of eradication of invasive alien plants over a 20-year period. Some of the project options are in areas of poor electricity availability (rural Mpumalanga, Eastern Cape, KwaZulu-Natal) and will be able to underpin rural electrification projects. The costs are comparable to new electricity from coal. The estimated contribution from feasible project options is up to 1 300 MW.

Table 6.3: Summary of biomass potential in South Africa

Source	Mass potential (Million tonnes/ yr)	Mass available (Million tonnes/ yr)	Energy equivalent available (PJ/yr)	% of total estimated bioenergy potential
Waste agricultural products	36.2	5.8	58.0	11.9%
Sugar cane bagasse/residues	10.4	0.6	6.0	1.2%
Plantation residue	6.7	1.5	18.8	3.9%
Sawmill waste	3.1	1.0	9.9	2%
Invasive species	11.3	8.1	118.6	24.3%
Fuelwood	14.0	4.0	58.8	12.1%
Organic solid waste/sewage	9.0	8.1	81.0	17%
Purposefully cultivated crops	9.3	9.3	136.1	27.9%
Total			**487.2**	**100%**

Source: Hugo (2016)

Key insight:

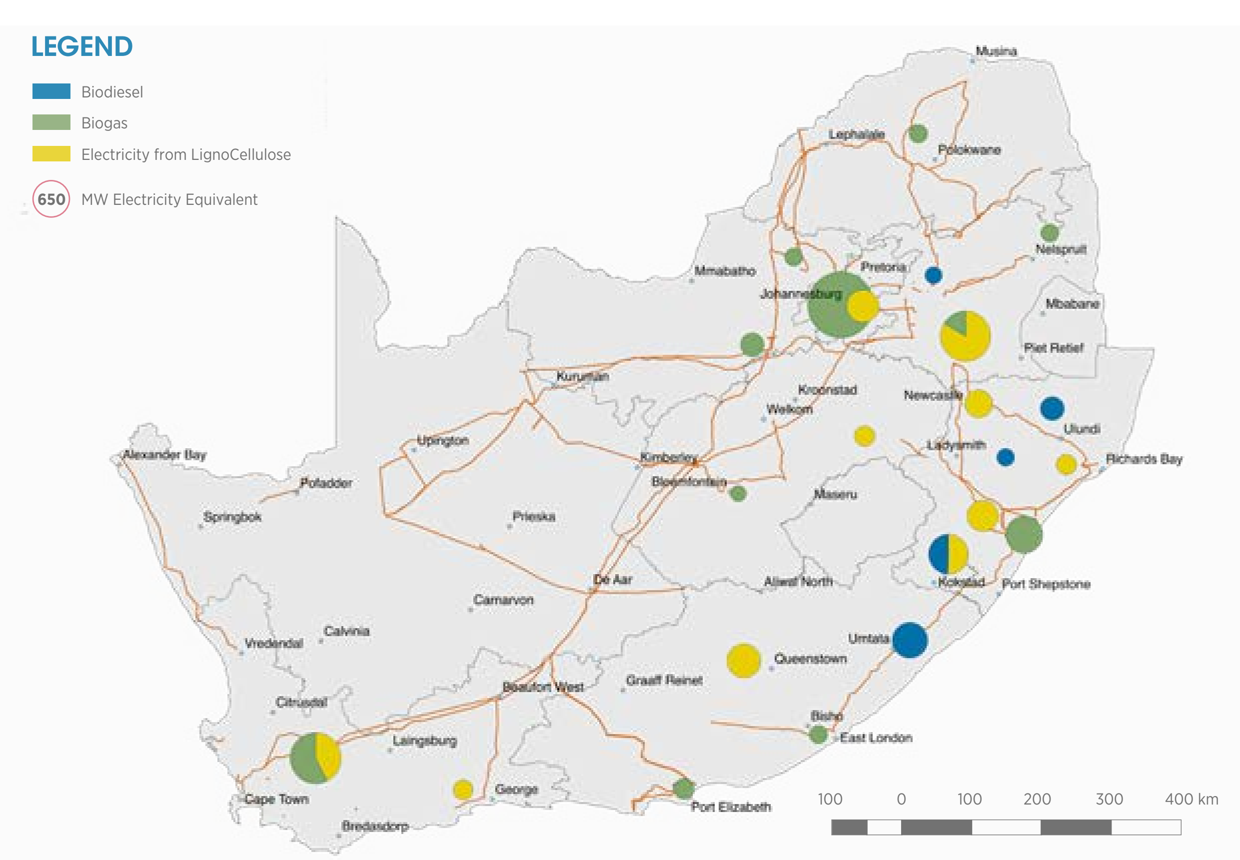
South Africa has significant (while constrained) potential for bioenergy, of 487 PJ/yr.

Table 6.3 outlines the identified biomass energy potential in South Africa in further detail, in terms of the mass potential and actual available mass and the energy equivalent (in PJ/year), by energy carrier.

As shown in Table 6.3, according to the *Bioenergy Atlas for South Africa* (Hugo, 2016), an additional 90 PJ/yr in bioenergy is nationally available from a combination of sawmill waste (including bark), organic solid waste, and organic sewage sludge. Small-scale bio-digesters in rural communities could contribute a further 250 MW (0.5–1.0 TWh/yr). The potential for using invasive alien species, agricultural waste and plant residues amounts to over 200 PJ/yr and could allow for 11–19 TWh/yr in medium-sized power generation facilities distributed across the country. The use of purposefully cultivated crops for biodiesel has the potential to supply 570 million litres/yr (around 5% of current diesel fuel demand in South Africa) (Hugo, 2016).

Figure 6.7 shows the potential project locations for biodiesel, biogas and electricity generation from bioenergy, as identified in the *Bioenergy Atlas*. The most suitable project options are associated with the major metropolitan areas of the country, which include Gauteng, Nelson Mandela Bay, Cape Town and surrounds, eThekwini, and Buffalo City. These areas allow for significant economies of scale to be realised, with facilities that remain viable even with transport costs for distances of up to 150 km from the biomass feedstock to the bio-digester.

Figure 6.7: Potential project locations for biodiesel, biogas and electricity generation from bioenergy



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Source: Hugo (2016)

Key insight:

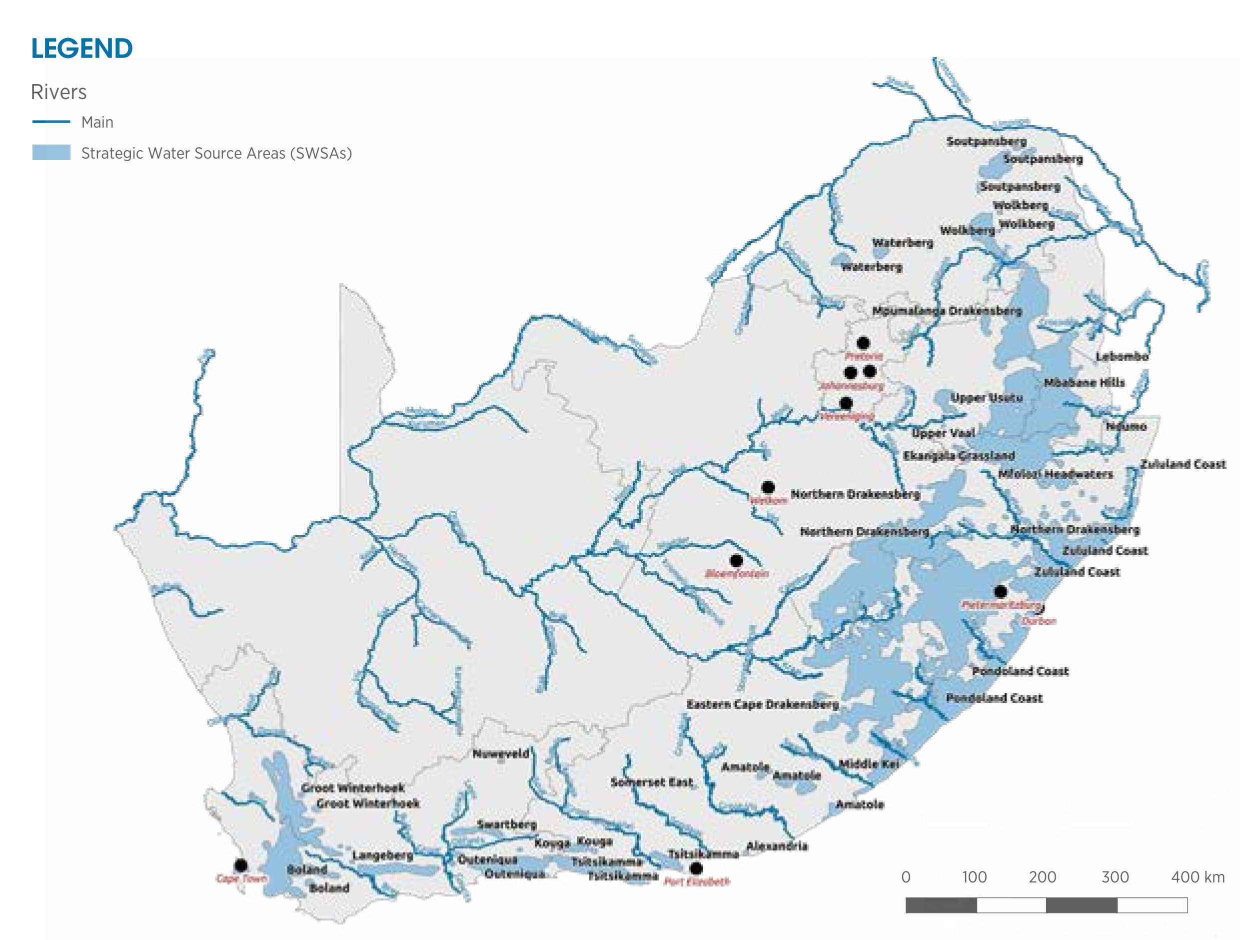
The map shows the ten largest feasible projects aggregated per district municipality. The largest potential for biodiesel, biogas and electricity generation from bioenergy in South Africa is concentrated in the Western Cape, Gauteng and KwaZulu-Natal.

The Bioenergy Atlas also gives key insights that underpin efforts to diversify the bioenergy focus into other areas, including synthetic biofuels, finding alternative markets in energy for the local sugar cane industry, and modern cooking fuels such as biochar and dried wood pellets from woody biomass.

Hydropower

Medium-scale and small-scale hydropower presents an additional renewable energy option for South Africa. Figure 6.8 provides a map of high water yield areas where hydropower sites may be found. It shows that the south-eastern coastal areas of South Africa are the most viable for investigating the feasibility of hydropower projects, from micro-scale to small-scale. The map is based on a collaborative project between CSIR, WWF, United Nations Environment Programme and Global Environment Facility (2013). In recent years, South Africa has experienced lower rainfall, and the issue of water scarcity is increasingly becoming a high priority for policy makers. This limits the potential for hydropower. At present, Eskom has approximately 3.4 GW of installed hydropower – over half of which is pumped storage hydropower.

Figure 6.8: High water yield areas in South Africa



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.
Based on CSIR et al. (2013)

Key insight:

The south-eastern coastal areas are most viable for hydropower projects. Sites for largescale hydropower have generally already been developed in South Africa, while many potential small-scale and micro-scale hydropower sites remain undeveloped.

6.2 Costs of renewable power currently, in 2030 and beyond

How much of the theoretical resource potential identified in Chapter 6, Section 1 will ultimately be harnessed will largely depend, besides the applicable technological and infrastructure limitations, on the costs related to different technology options. The South African power sector has seen ever-increasing prices over the last decade and this trend is expected to continue over the decade to come as older, fully amortised generation units are decommissioned and new plants are constructed.

Of the new-build options, deployment costs for renewable energy technologies, such as wind and solar PV, continue to be in decline. This section explores the cost comparison of different power generation options in South Africa, currently and into the future, based on a range of cost parameters.

Capital/overnight and fixed costs

Table 6.4 gives an overview of the capital/overnight and fixed costs of all electricity generation options in South Africa, based on cost data from the draft IRP 2016 update (DoE and EPRI, 2015). Capital costs are one-time expenses incurred on the purchase of land, buildings, construction and equipment used for the generation of electricity – they indicate the total cost for bringing a project to a commercially operable status. For renewable energy projects, the bulk of total costs is capital cost (and virtually no expenses for fuel inputs are incurred).

For this reason, renewable energy projects are typically linked to a long-term PPA where the once-off upfront capital costs can be amortised over a long period using the proceeds from the electricity generated. A fixed cost is an expense for operations and maintenance that does not change with an increase or decrease in the amount of electricity generated or sold. Fixed costs have to be paid regardless of or independently from any business activity.

Table 6.4: Capital and fixed costs of electricity generation options for South Africa in 2015

Generation options	Capital/Overnight cost (USD/kW)	Fixed cost O&M (USD/kW)
RENEWABLE GENERATION		
Solar PV (utility scale – tracking)	1 276	18
Solar PV (utility scale – fixed tilt)	1 204	21
Onshore wind	1 372	40
Concentrated PV	3 289	21
CSP (tower with 3-hour storage)	5 040	67
CSP (tower with 9-hour storage)	7 021	70
Biogas	5 046	127
Bagasse generation	2 231	25
Landfill gas	2 027	155
Pumped storage	1 458	13

Generation options	Capital/Overnight cost (USD/kW)	Fixed cost O&M (USD/kW)
CONVENTIONAL GENERATION		
Natural gas (OCGT)	534	11
Natural gas (CCGT)	586	11
Nuclear (non-OECD)	3 947	63
Coal (pulverised with FGD)	2 315	60

Note: O&M = operations and maintenance; FGD = flue gas desulphurisation. Costs are based on the draft IRP 2016 update, quoted in 2015 ZAR and converted using an exchange rate of ZAR 14 = USD 1.

There is some difference between the cost levels in South Africa and global cost figures (*e.g.* see IRENA Renewable Cost Database for global cost figures). This difference can be due to how disparate jurisdictions exhibit different input costs such as labour, supporting services etc; these would affect the fixed operations and maintenance costs. Capital costs may vary due to conditions on the sale of the capital equipment in different jurisdictions.

Current levelised cost of electricity (LCOE)

The LCOE, essentially the tariffs achieved through procurement programmes, provides a comprehensive metric for comparing the costs of different technology options, going beyond capital and fixed costs. The LCOE is defined as the net present-day monetary cost per kWh unit of electricity delivered, which, when adjusted for inflation each year over the lifetime of the plant, will recover its full costs. This metric includes the initial investment cost, cost of finance (including dividends and interest), fuel costs and all other fixed and variable operation and maintenance costs. LCOE does not account for grid integration costs and the specific value or role that each technology plays in the overall performance and functioning of the power system.

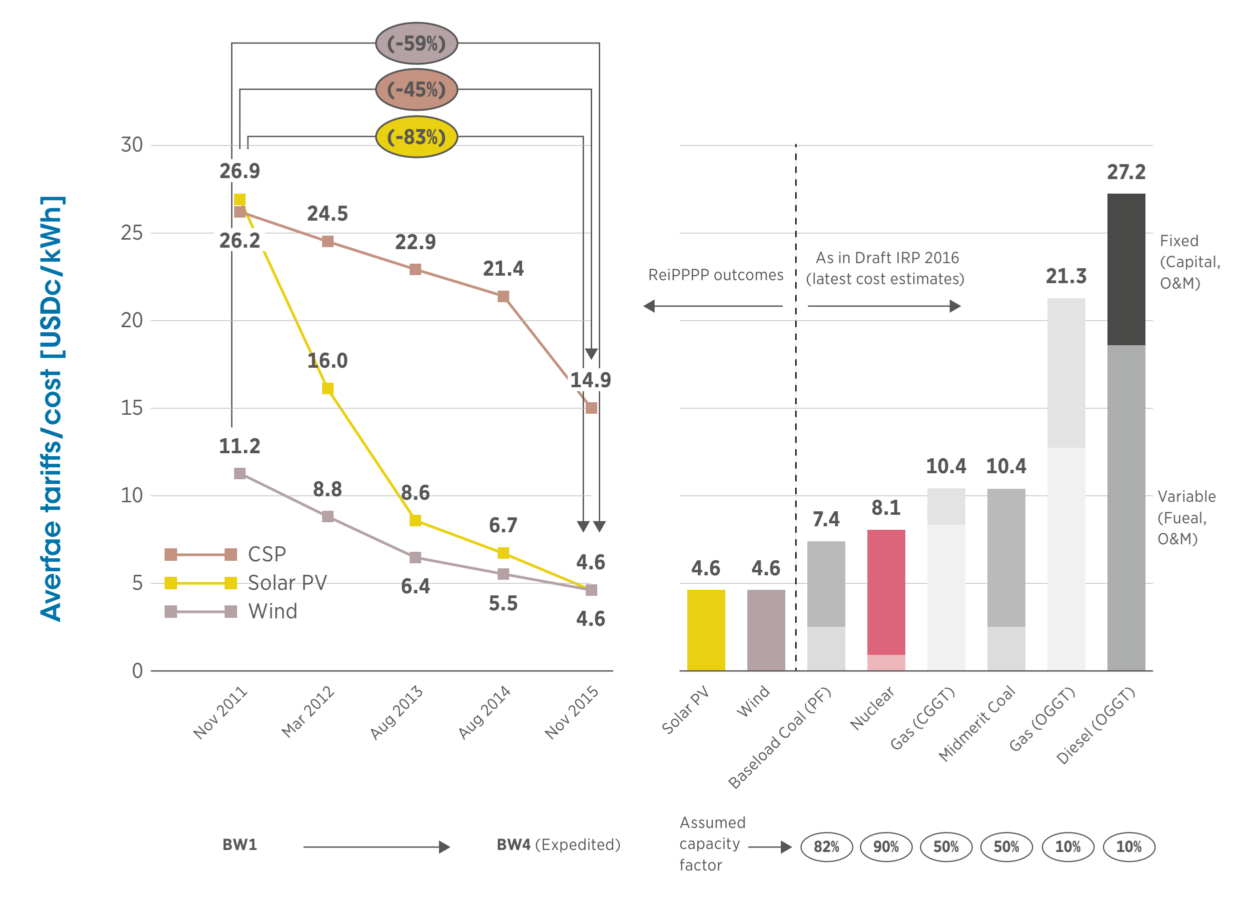
In light of this, LCOE may be used to assess trends on how the costs of certain technologies are increasing or decreasing – thereby pointing out which technologies are likely to feature more prominently in a national energy plan. An all-encompassing cost comparison across technologies should, however, include a detailed power system analysis to account for integration costs and the operation of the power system as a whole.

The cost levels that have been realised since 2011 from the competitive bidding process for utility-scale renewable energy deployment (*i.e.* REIPPPP) are summarised in Figure 6.9. A significant decrease in costs is notable for solar PV (reductions of over 80% since 2011), onshore wind (around 60% cost reductions) and CSP (45% cost reductions). Successful bid tariffs achieved in the 2015 expedited Bid Window 4 of the REIPPPP were below USD 0.05/kWh for electricity generation from both wind and solar PV. CSP and bioenergy (not shown in Figure 6.9) applications have reached average prices of around USD 0.15/kWh and USD 0.082–0.122/kWh, respectively, under the REIPPPP. The general cost levels for biogas are estimated at around USD 0.1-0.15/kWh, for electricity from lignocellulose at around USD 0.15–0.2/kWh, and for biofuels at around USD 0.2/kWh (Hugo, 2018).

On the right-hand side of Figure 6.9, the average tariffs for solar and wind technologies are compared to those for conventional technologies. For example, baseload coal prices under the prospective coal IPP programme averaged about USD 0.074/kWh, thus almost 40% higher than solar PV and wind. All other costs shown in Figure 6.9 for new-build options reflect cost estimates used in the IRP update.

These are based on developments in other markets rather than on actual competitive bid outcomes in South Africa. Gas and diesel open cycle turbines are the most expensive options in terms of LCOE, due to their low capacity factors and high fuel costs – both options have an LCOE above USD 0.2/kWh (at around 10% capacity factor).

Figure 6.9: Competitive auction outcomes in 2015 for solar PV, wind and CSP from REIPPPP in South Africa compared to conventional technologies



BW = bid window; O&M = operation and maintenance
Based on DoE (2016f) and Wright et al. (2017a)

Key insight:

The trend lines show the considerable cost reductions for solar PV, wind and CSP realised since 2011 as part of the REIPPPP and the increasing cost-competitiveness of renewable energy options compared to conventional technologies.

Future LCOE, to 2030 and beyond

Forward-looking cost trends for energy technology deployment can vary since the trajectory depends on various assumptions and on having a stable policy environment and a consistent procurement programme over the long term. The naturally resulting divergence in projections, both for South Africa and globally, is illustrated in this section, with reference to DoE, IRENA and BNEF cost projections for different generation options from renewable resources.

The view from the South African DoE with regard to applicable technology learning rates and cost projections is found in the national IRP. The learning rate is the percentage cost reduction experienced for every doubling of cumulative installed capacity; it is therefore an expression of how costs decline as a technology is increasingly deployed. Higher learning rates imply faster cost reductions for a given rate of technology deployment. In the IRP 2010–2030 and the draft IRP 2016 update, very modest learning rates are assumed for wind and bioenergy technologies. Only marginal further cost reductions are therefore assumed to materialise going forward.

The draft IRP 2016 update considers a higher cost assumption for solar PV for 2015 (based on REIPPPP Bid Window 3 at USD 0.067–0.097/kWh) than cost levels reached under REIPPPP Bid Window 4. A projection that follows the trajectory of the draft IRP 2016 update, using Bid Window 3 as the baseline, reaches costs of USD 0.05–0.075/kWh by 2030; while taking Bid Window 4 as a starting point into the future results in solar PV costs of USD 0.043/kWh by 2030 (Wright *et al*., 2017a; see also Figure 6.11 below). The most recent bid windows of the REIPPPP exhibited LCOE levels that, according to assumptions in the draft IRP 2016 update, had been assumed to only materialise in 2030 (CSIR, 2016).

In other words, learning rates for renewable energy in South Africa have exceeded expectations, and the LCOE levels are decreasing at a higher rate than previously expected. The higher-than-expected decrease in LCOE for solar PV is a result of two main drivers. Firstly, manufacturing costs globally are decreasing rapidly as economies of scale are achieved, and this benefit filters down into the South African market. Secondly, the REIPPPP has engendered strong competition among bidders, particularly in the most recent bid windows, hence driving LCOE costs down even further. In South Africa, the costs for solar PV and CSP are expected to further decrease significantly to 2030, while the costs for onshore wind are expected to decrease more moderately. At the global level, costs are expected to decrease substantively for solar PV and onshore wind to 2020 and further to 2030. Table 6.5 provides an overview of LCOE of selected renewable energy technologies in South Africa and at the global level, showing the expected costs to 2030 relative to current cost levels in South Africa.

Table 6.5: Comparison of LCOE of selected renewable energy technologies (2015–2030)

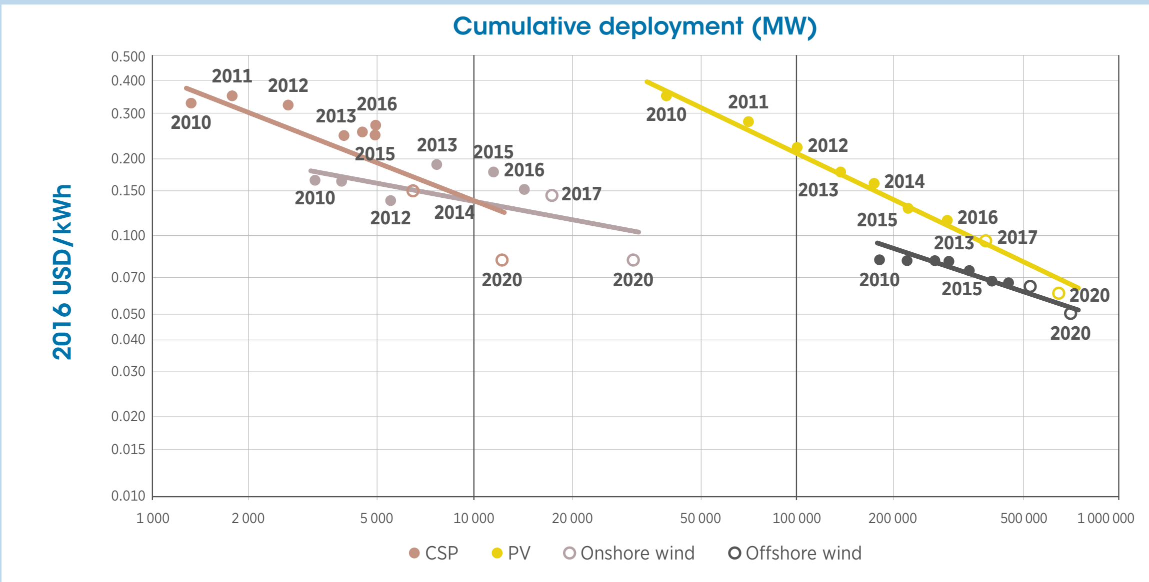
Technology	South Africa			Global		
	REIPPPP (2015)*	Draft IRP 2016 update (2016)	Draft IRP 2016 update (2030)	IRENA (2017)	IRENA (2020)	BNEF (2030)
	[USD/kWh]	[USD/kWh]	[USD/kWh]	[USD/kWh]	[USD/kWh]	[USD/kWh]
Onshore wind	0.046	0.055–0.06	0.05–0.06	0.06	0.05	0.034
Solar PV	0.046	0.06–0.097	0.05–0.075	0.1	0.06	0.028
CSP (3-hour storage)	0.149	0.17–0.2	0.08–0.1	0.22	0.06–0.1	
Biomass	0.119–0.122	0.22–0.26		0.07	–	
Biogas	0.082	0.1–0.15		-	-	

** Based on Bid Window 4 (expedited) of the REIPPPP (as of November 2015)*
Note: BNEF = Bloomberg New Energy Finance.
Values for South Africa (initially stated in 2015 ZAR) were converted at exchange rate of ZAR 14 = USD 1.
Based on DoE (2016f); DoE and EPRI (2015); Wright et al. (2017a); IRENA (2018c); IRENA (2016); BNEF (2018)

Figure 6.10 illustrates in more detail the IRENA analysis on the global average LCOE reduction potential of wind-based and solar-based technologies up to 2020. According to the analysis, the largest reduction potential lies with solar PV and CSP, with LCOE figures of USD 0.06/kWh and around USD 0.08/kWh, respectively, by 2020.

Onshore wind shows an LCOE Figure of USD 0.05/kWh by 2020. The cost projections for all VRE technologies for 2020 fall within the expected cost range from fossil fuels (marked in green).

Figure 6.10: Global weighted average LCOE from solar and wind projects 2010–2020, with LCOE data to 2017 and auction price data to 2020



Source: IRENA (2016)

Key insight:

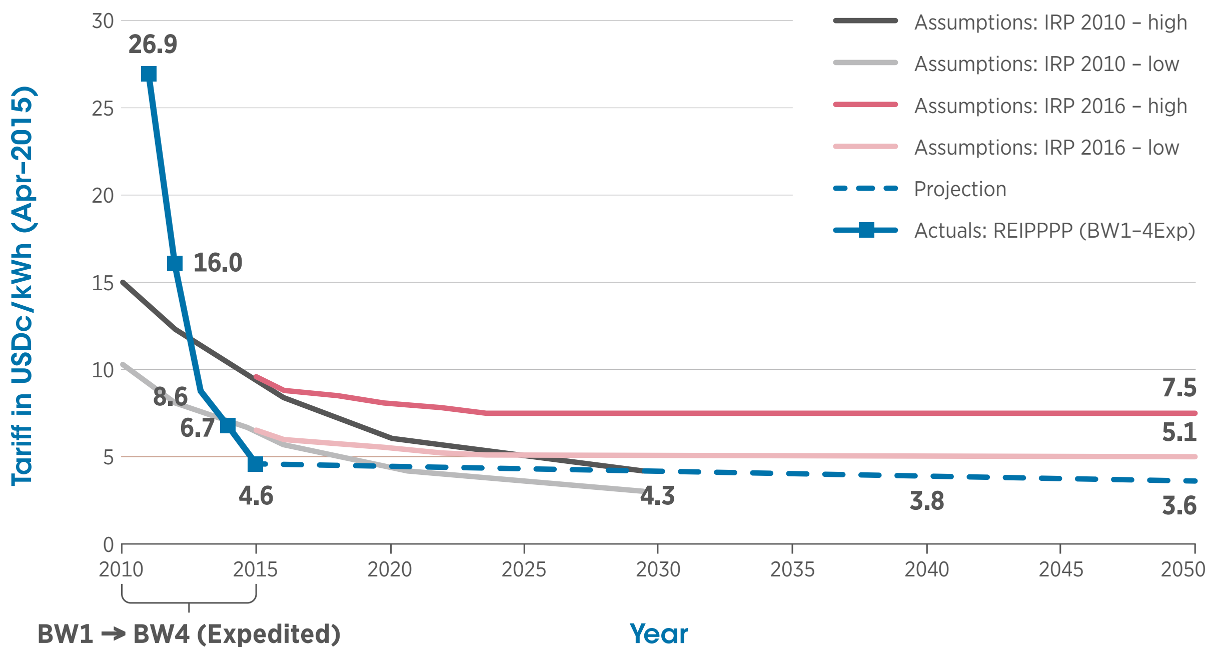
At the global level, the largest estimated LCOE reduction potential to 2020 is for CSP and solar PV technology, followed by onshore wind. All cost expectations for renewables for 2020 fall within the expected fossil fuel cost range.

As shown in Figure 6.11, the draft IRP 2016 update assumes no further cost reductions for any technology options after 2030, indicating an assumption that technologies will have reached maturity and no further cost reductions will be achieved with additional manufacturing economies of scale. The "high" and "low" cost trajectories outlined in the IRP 2010–2030 and draft IRP 2016 update (see Figure 6.11) refer to the range of resource potential available. For example, solar PV profiles are divided into 27 regions with varying levels of resource availability. The "high" cost trajectory represents areas that have low resources (such as regions around Gauteng) while the "low" costs represent regions predominantly in the Northern Cape.

Figure 6.11 shows that upper-bound costs for solar PV expected only by 2030 have already been reached through competitive bidding under the REIPPPP.

The estimates for South Africa can generally be seen as rather conservative when compared to global trends. Costs of USD 0.02/kWh have already been achieved for solar PV in other regions of the world with comparable solar irradiation.[28] While a comparison between countries in terms of PPA prices cannot be perfectly aligned due to *inter alia* differences in the cost of capital and plant sizes, it does provide an indicative understanding of what is achievable in terms of technology-specific costs.

Figure 6.11: Solar PV cost projections in South Africa up to 2050



Note: Exchange rate of ZAR 12.77 = USD 1 applied across the modelling period; BW= bid window.
Source: CSIR (2016) and Wright et al. (2017a)

Key insight:

Cost levels under the REIPPPP have already undercut cost projections under both the IRP 2010–2030 and the draft IRP 2016 update. Solar PV has already reached levels of USD 0.05/kWh in 2015, while the IRP forecasted that these levels would not be reached by 2050.

28 For example, solar PV projects in Dubai have reached price levels as low as USD 0.02/kWh with an average GHI resource of 2 021 kWh/m^2/year (with many areas in South Africa exhibiting similar GHI levels).

For CSP, the cost projections are also based on the expedited fourth bid window of the REIPPPP. Applying learning rates found in the IRP shows a decrease in the cost of CSP to USD 0.092/kWh by 2030. This can be regarded as a conservative estimate, as CSP projects globally have already seen prices as low as USD 0.06/kWh for plants commissioning in 2020 (The National [UAE edition], 2017).

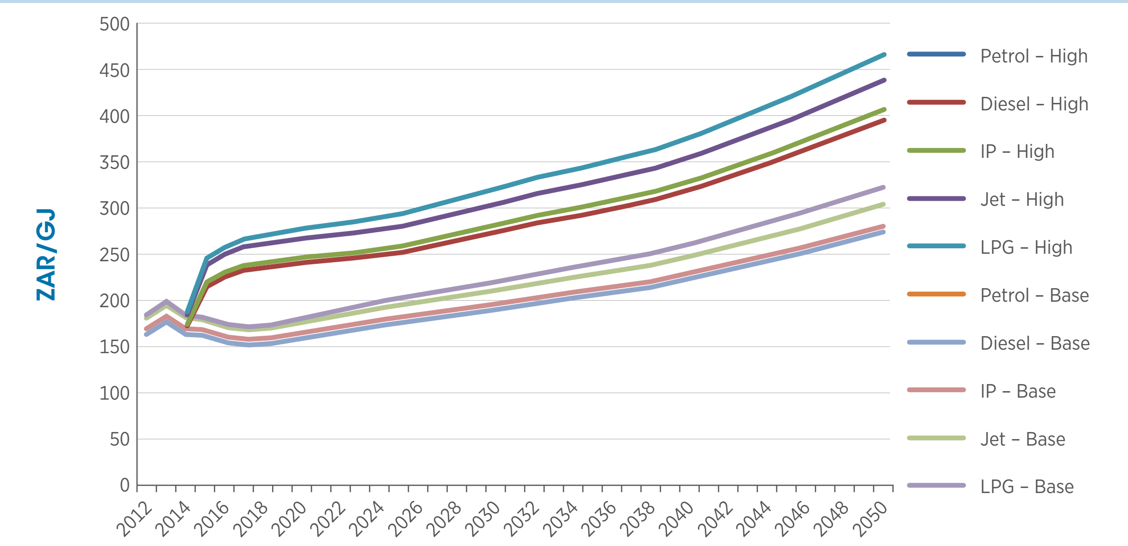
For a complete picture, total system costs for power supply have to be considered when making comparisons between technologies, and the impact of different generation technologies on the operation of the power system should be accounted for when assessing the potential that each technology offers. Fluctuating supplies from weather-dependent renewable sources (solar, wind) can cause grid stability challenges as they require balancing or flexibility measures (see Chapter 3, Section 2 for an overview of flexibility options). Accounting for potential additional integration costs for VREs could therefore make for a more objective comparison against conventional power supply technologies.

Since this study does not include a detailed network analysis, its scope does not extend to assessing and quantifying grid integration costs.

Commodity prices

Figure 6.12 provides an overview of expected costs for key energy commodities (namely, refined petroleum products) to 2030 and 2050, taken from the macroeconomic assumptions of the draft IEP 2016 (DoE, 2016f). The figure shows that, in line with crude oil price projections, the costs for all the energy carriers are expected to significantly increase between 2015 and 2050, pointing to a need to increasingly deploy alternative end-use options, including renewables. Coal technology prices (pulverised coal and fluidised bed combustion coal) are also expected to increase significantly. The commodity price projections are quoted in South African rand (ZAR). Figure 6.12 does not account for future assumptions on how the national currency will perform against foreign currencies in which such commodities are commonly quoted. Yet, the trend of steadily increasing commodity prices is apparent.

Figure 6.12: Comparison of commodity prices by energy-use sector, 2015–2050



Note: IP = Illuminating Paraffin; GJ = gigajoule.
Source: DoE (2016f)

Key insight:

Costs for all the energy carriers are expected to significantly increase to 2050, pointing to a need to increasingly deploy alternative end-use options, including renewables.

7 REMAP CASE 2030 FOR SOUTH AFRICA

KEY POINTS

- The REmap Case 2030 represents renewable energy technology options ("REmap Options") beyond the Reference Case 2030 that are considered feasible and realistic in terms of both resource potential and technology deployment speed.
- Total final energy consumption (TFEC) under the REmap Case 2030 is expected to increase from 2 290 PJ in 2015 to 2 493 PJ by 2030 (after energy efficiency savings of 363 PJ). The analysis identifies REmap Options that could increase renewable energy use in South Africa to 568 PJ by 2030 (23% of TFEC). This is a considerable increase compared to the Reference Case, which expects 13% of TFEC to be based on renewable energy by 2030 (366 PJ).
- REmap Options in the power sector could allow for the total share of renewables in electricity production to increase from ≈9% in 2015 to 49% by 2030 (compared to the Reference Case with 37% by 2030).
- Power generation technologies identified to contribute to the renewable energy share as part of the REmap Options for 2030 are onshore wind (21% of electrical energy), utility-scale solar PV (14%), distributed solar PV (on-grid/off-grid; 2%), CSP (1%), biomass/biogas (4%) and hydro (7%; mostly imported).
- Under the REmap Case 2030, coal plays a lesser while still significant role in the energy sector by 2030 (either by direct end-use, for liquid fuel production or coal-based electricity generation).
- In addition to the considerable deployment of renewable energy technologies in the electricity sector, identified REmap technology options in end-use sectors are dominated by solar thermal (10% of end-use by 2030 in buildings) and modern bioenergy (6% of industrial end-use by 2030) for heating, cooling and cooking.
- Although traditional biomass (predominantly in the residential sector) is almost completely removed by 2030, modern forms of biomass and enabling technologies are identified for various end-use sectors, including foremost the residential sector. Increased use of biomass for power generation and the blending of biofuels for transportation are two REmap Options identified for 2030.
- Although transportation is identified as a sector that could shift to alternative energy carriers, fossil-based liquid fuels in the form of petrol and diesel still dominate in the REmap Case 2030 (93% of transport end-use by 2030). REmap Options in the transport sector are the use of electricity (2% of transport end-use by 2030), renewables-based hydrogen (1% of transport end-use by 2030), biodiesel and bio-ethanol blending (4% of transport end-use by 2030).
- Potential for energy efficiency improvements is identified in the residential sector (20 PJ) with appliances and lighting as well as absolute reductions in commercial/public building energy consumption (17 PJ). Industrial energy efficiency could be achieved through improving the efficiency of technologies supplying end-use services in manufacturing and mining (estimated potential of 186 PJ). Significant potential improvements in transport sector energy efficiency are also identified (140 PJ), namely from increased vehicle efficiency supplemented by increased electricity-, hydrogen- and biofuels-based transportation.
- The increased deployment of renewables in South Africa is found to offer significant environmental (in terms of reduced emissions and air pollution, etc) and socio-economic benefits (in terms of health benefits, employment and financial savings).

7.1 Renewable energy technologies in 2030

Chapter 5 outlined the Reference Case 2030, which provides a projection to 2030 of the South African energy sector based on current government energy policy and plans. In the Reference Case 2030, the share of renewables in TFEC increases from 9% in 2015 to 13% by 2030.

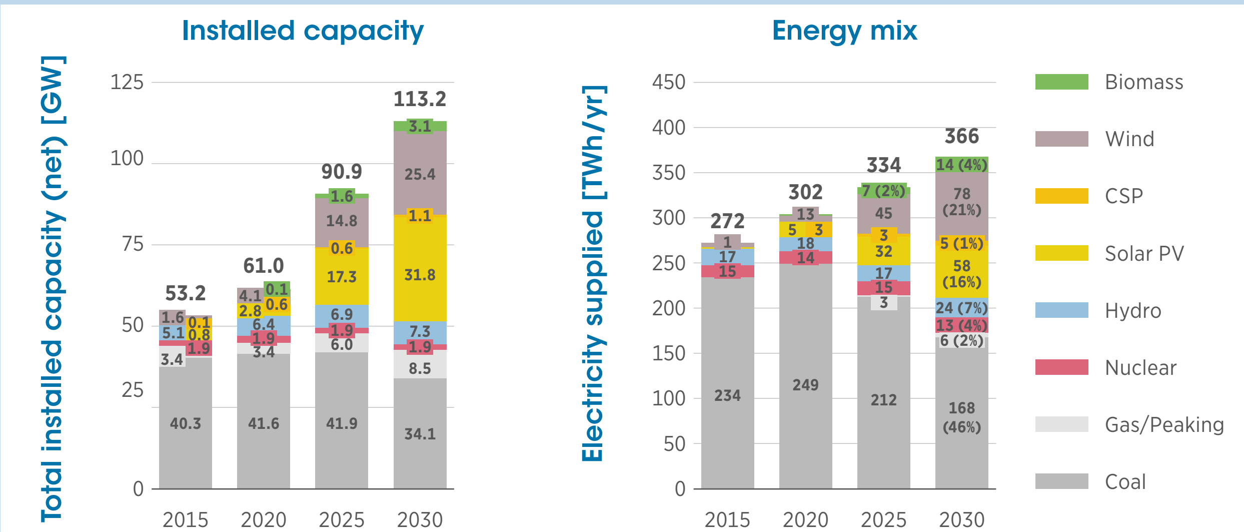
The REmap Case 2030 represents additional renewable energy technology options, so-called "REmap Options", that are considered feasible and realistic in terms of both resource potential and technology deployment speed. REmap Options are not necessarily driven by economic cost minimisation criteria, but also consider positive externalities from renewables use, including emission reductions, health benefits, financial savings and employment creation potential (see Chapter 7, Section 3 of this study).

Power sector technology potential beyond the Reference Case

The electricity sector projections of the REmap Case 2030 are summarised in Figure 7.1, in terms of generation capacity and production. Based on significant resource availability and the technology cost assumptions presented in Chapter 6, as well as the modelling undertaken for the draft IEP 2016, the dominant power sector technologies in the energy mix under the REmap Case 2030 are expected to be onshore wind (21%) and solar PV (16%), with a supplementary role for hydro (7%; predominantly imported from the Southern African region) and bioenergy (4%).

Although only a small deployment of CSP (1%) is foreseen, owing to the significant resource available across the country an increased role of CSP could be considered if technology costs decline sufficiently. A key benefit of CSP technology is dispatchability for the power system when coupled with storage. However, under the current design of the REIPPPP, this dispatchability only benefits project owners rather than the system operator, as the CSP projects are not system operator dispatched (but rather self-dispatched by the project owner).

Figure 7.1: Installed generation capacity and energy mix 2015–2030 (REmap Case 2030)



Note: Installed capacities are based on assumed typical capacity factors. Values for 2020 and 2025 are estimated.
Based on DoE (2016a)

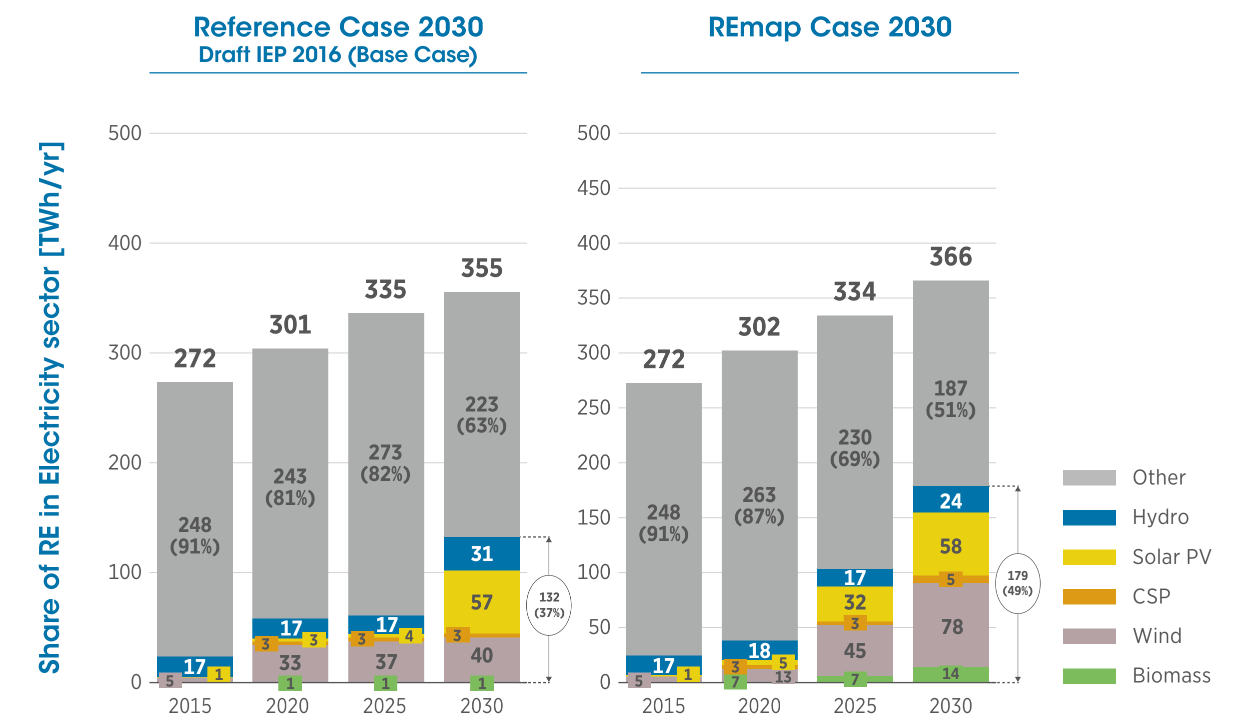
Key insight:

Under the REmap Case 2030, the renewable energy share considerably increases to 49% of the total electrical energy mix by 2030 (from 9% in 2015), driven mainly by the deployment of solar PV and wind technology.

The expected share of renewable energy in the electricity sector under the Reference Case 2030 and REmap Case 2030 are compared in Figure 7.2. The share of renewable energy in electricity generation increases significantly in both the Reference Case 2030 (to 37% by 2030) and under the REmap Case (to 49% by 2030).

This increase reflects the increasing ambition of renewables use in the power sector, which is to a large degree driven by renewables deployment and the cost reductions realised under the REIPPPP in recent years, which are expected to further continue in the future (see Chapter 6).

Figure 7.2: Share of renewables by technology in the power sector 2015–2030, Reference Case vs. REmap Case 2030



Note: RE = renewable energy. Values for 2020 and 2025 are estimated.
Based on DoE (2016a)

Key insight:

Both the Reference Case 2030 and REmap Case 2030 show consistent growth of renewables share in the South African electricity sector, moving from 9% in 2015 to 37% and 49%, respectively, by 2030, dominated by wind and solar PV.

Potential in end-use sectors

Under the Reference Case 2030, demand for energy in commercial buildings grows from 99 PJ in 2015 to 149 PJ by 2030. Residential demand drops from 344 PJ to 286 PJ by 2030, primarily due to electrification, which allows energy services demand to be met at higher efficiencies. Demand for energy in the industrial sector grows from 882 PJ in 2015 to 1 143 PJ by 2030 whilst energy use in transport grows from 896 PJ to 1 195 PJ by 2030. Energy demand in the agricultural sector is expected to increase from 69 PJ in 2015 to 83 PJ by 2030. This is the baseline for 2030, taken from the draft IEP 2016. The largest potential for increasing the renewables share of TFEC in end-use sectors beyond the Reference Case 2030 lies in the use of solar thermal and modern bioenergy for heating, cooling and cooking, whilst the transport sector could see increased use of electric mobility, hydrogen and biofuels.

The analysis also addresses the absolute reduction in energy end-use in each sector (beyond the Reference Case 2030) resulting from energy efficiency measures.

Solar thermal

As illustrated in Chapter 6, South Africa has considerable solar resources. These resources can be applied to industrial process and water heating, as well as to water heating in the residential and commercial sectors. While there is an existing target for 1 million SWHs to be installed by 2030, the Reference Case 2030 (as based on the draft IEP 2016 Base Case) does not include any targets for solar thermal technology deployment. Yet, the "Cleaner Pastures" scenario in the draft IEP 2016 includes a target for 5 million SWHs by 2030 (not explicitly included in the outcomes), a figure that originates from the National Development Plan of 2011. This figure serves as benchmark for the REmap Case.

Currently, large-scale SWHs are used primarily to serve domestic water heating needs (Joubert, Hess and Niekerk, 2016). The potential for solar thermal energy use via high-pressure SWHs, as an alternative to electric geysers,[29] in the residential sector (*i.e.* households) is dependent on the type of housing, access to water and the electrification status. Low-pressure SWHs could be deployed in low-income households to displace the use of other fuels including for electricity (*e.g.* coal) and petroleum products (*e.g.* liquefied petroleum gas, paraffin). The National Building Regulations (SANS 10400) introduced in 2011 require that 50% of water heating demand in new buildings be met with SWHs or heat pumps. If the overall share of water heating in energy end-use in the residential sector remains as it is today (21%), solar thermal heating of water could provide a considerable share of the estimated demand for household energy by 2030. In addition, as access to water and formal housing improves in South Africa, the share of water heating in energy end-use is likely to increase further.

Assuming 60% and 40% shares of high-pressure and low-pressure SWHs, respectively, meeting the target for 5 million SWHs translates to an opportunity for SWHs to contribute ≈30 PJ towards household energy by 2030. This will require significant growth in the rate of SWH installations compared to current rates. SWHs displace electricity demand and therefore, at higher shares of renewable energy in electricity, the overall contribution of SWHs to renewables share reduces.

In addition to individual households, large-scale SWHs can be installed in multi-unit residential dwellings (flats, residences, etc) and commercial properties. The South African *Solar Thermal Technology Roadmap* (CRSES, 2015) estimates a potential for around 4 million m^2 of commercial and industrial installations by 2030. Conservatively assuming an estimated heat output of around 800 kWh/m^2 (CRSES, 2015), there is potential for SWHs to supply 11.5 PJ of commercial and multi-unit residential water heating demand by 2030. Thus, the total deployment of solar thermal technologies in buildings (residential and commercial) under the REmap Case 2030 is ≈41 PJ.

In the industrial sector, large-scale SWHs can be installed in industries that have low-temperature heat requirements. The potential for SWHs to serve process needs in the industrial sector lies primarily in the food and beverage, textile, and chemical industries. Certain agri-processing sectors could also be applicable (Janse van Vuuren *et al.*, 2017). Due to the temporal and spatial variability of solar resources combined with the distribution of different industries throughout the country, estimates of the potential contribution of solar thermal heat to industry vary widely. The estimated potential for solar thermal use in industry by 2030 is around 3.4–15.5 PJ. In light of the baseline of negligible use of solar thermal in 2015, a moderate solar thermal use of around 6 PJ in industry is adopted under the REmap Case 2030, for process heating in the food and beverage, textile, and chemical industries.

29 The term "geyser" is specific to a few countries. It means the same as tankless electric water heaters.

Bioenergy

Based on the *Bioenergy Atlas for South Africa* (Hugo, 2016), as presented in Chapter 6, there is a notable potential for bioenergy in the residential, commercial and industrial sectors. The bioenergy use identified in the industrial sector is predominantly for own-process heating purposes. The resource potential lies primarily in organic waste, forest and agricultural residues, and the eradication of invasive alien species (280 PJ of the total 350 PJ per year, excluding purposefully cultivated crops).

Estimates of biogas potential (for electrical power generation or process heating) show widescale potential for livestock, meat processing and agro-industries, which is mostly located in the Western Cape, KwaZulu-Natal and Gauteng. The largest potential for biogas lies in livestock, representing over 50% of total biogas potential in all provinces except Limpopo and Gauteng. In KwaZulu-Natal and Mpumalanga, sugar mills dominate, whilst in the Western and Northern Cape wineries exhibit the largest potential. In these areas, biomass for process heat and/or electrical power generation could be considered. In much of the rest of South Africa, the potential is dominated by fruit processing and breweries (ARC, 2016).

Assuming 30% of available biomass potential for thermal energy is utilised by 2030, biomass is estimated to supply up to 60 PJ of heat in the industrial sector as part of the REmap Case 2030 (compared to no deployment of bioenergy in this sector under the Reference Case 2030). According to the *Bioenergy Atlas*, household or communal digesters in rural areas could contribute up to 2 500 MW (10–16 TWh) and are included in the REmap Case 2030 as distributed production.

The REmap Case 2030 also includes limited use of traditional biomass (4 PJ) in buildings by 2030.

Biofuels (transportation)

Transport sector end-use was 896 PJ in 2015 and is projected to be 1 195 PJ by 2030 in the Reference Case 2030 based on the draft IEP 2016 Base Case (an increase of ≈35% between 2015 and 2030).

Assuming they would be blended with existing liquid fuels (*i.e.* diesel and petrol), liquid biofuels are an important but limited option for higher renewable energy use in transportation in South Africa. As an indicator of this, the maximum resource potential for blends of 10% bioethanol (e10) and 100% biodiesel (b100) could only provide 65–70% of South African liquid fuel demand by 2030. However, land requirements for this would amount to approximately 120 000–130 000 km^2, which is 9–11% of South Africa's total land area and almost all existing arable land. Of course, importing biofuels could also be an option but would not assist in alleviating the liquid fuels import risk that South Africa currently faces.

Mandatory blending regulations have resulted in manufacturing licenses being issued for a total of ≈400 million litres for bioethanol per year and ≈1000 million litres of biodiesel per year. By 2020 (*i.e.* the expected operational date of these regulations), this would meet a share of ≈4% of domestic petrol demand. Land-use requirements for this level of biofuel production would amount to ≈6 000 km^2 (for soybean and grain sorghum for biodiesel and bioethanol, respectively), which equates to 0.5% of South Africa's total land area. By 2030, minimum blend regulations would require total land cultivation of around ≈7 000–7 500 km^2, amounting to a total of 39–42 PJ of liquid fuels from renewables (≈4% of total demand in the transport sector). Thus, 42 PJ of biofuels use (from a combination of ethanol and biodiesel blending) is assumed under the REmap Case 2030.

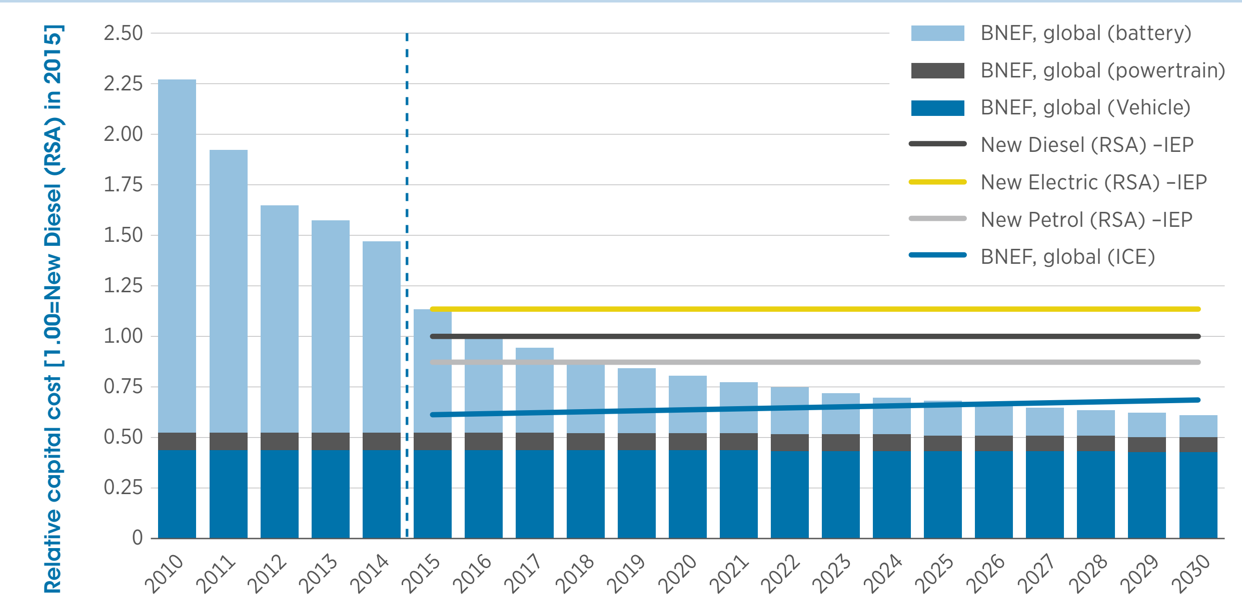
Electricity, hydrogen and natural gas (transportation)

Aside from liquid biofuels in the transport sector, the opportunity exists for electricity, hydrogen and, potentially, biogenic natural gas (or conventional natural gas) to be key energy carriers that could enable a low-carbon transport sector in South Africa. Although the use of electricity, biofuels and hydrogen are described as potential alternative fuel sources as part of the draft IEP 2016, they are not explicitly included under the Base Case (and therefore in the Reference Case 2030 of this study).

Expected cost trajectories for EVs are currently quite conservative, and not very competitive relative to internal combustion engine (ICE) vehicles in South Africa (see, for example, DoE, 2017b).

This is summarised in Figure 7.3, which provides a relative comparison to recent global market outlook expectations from Bloomberg New Energy Finance (BNEF) (Curry, 2017).[30] Capital cost trajectories for EVs relative to conventional ICE vehicles (also shown based on data from BNEF and the draft IEP 2016) have declined sharply in recent years and are expected to further decline in the future. Combining this with expectations for efficiency improvements in both ICE and EVs, the deployment of EVs is likely to increase significantly (including, relative to the minimal deployment in the Reference Case 2030). Yet, the adoption and acceleration of EV uptake is highly dependent on, and could be constrained by, the associated investment in and deployment of suitable and convenient EV charging infrastructure.

Figure 7.3: Forecasted capital cost of EVs relative to ICE vehicles



Note: EV capital cost assumptions are normalised to BNEF in 2015.
Based on Curry (2017), DoE (2016f) and CSIR analysis

Key insight:

Significantly reduced costs for lithium-ion batteries have made electric vehicles (EVs) increasingly cost-competitive with internal combustion engine (ICE) vehicles, with further expected capital cost reductions in the future.

30 The 2017 IRENA technology brief on EVs found that, in line with expected reductions in electric vehicle body and battery costs (and depending on the exact definition of costs), global EV total costs may reach parity with ICE vehicles in 2025 or even 2020. This is roughly in line with, while more optimistic than, the global cost trajectory presented in Figure 7.3.

With cost parity between EVs and ICE vehicles on the horizon, electric mobility for freight, private and public travel could potentially account for shares of 15%, 20% and 2% (in terms of total vehicle-kilometres), respectively, of road transport activity in South Africa by 2030 (Caetano *et al.*, 2017). Thus, by 2030, of a potential 15 million vehicles on the road, around 2 million could be electric (a 13% share). This will increase electrical energy demand but will also reduce the requirement for liquid fuels. A mix of new electrical generation capacity, predominantly renewables (wind and solar PV) combined with flexible capacity (supply/demand side), would likely be required to meet this additional electricity demand (that amounts to an additional ≈7.5–10 TWh/yr). As a result, by 2030, liquid fuels (mostly petrol and diesel) would be displaced by an additional 27–36 PJ of electricity. Taking a conservative estimate of a total 48 PJ electricity use in the transport sector by 2030, and assuming a 49% renewable energy share in electricity generation by 2030, 24 PJ are estimated as the REmap Option for renewable electricity use in transportation by 2030 (from about 2 PJ in 2015).[31]

Furthermore, the Ricardo-AEA road vehicle cost and efficiency calculation framework 2010–2050 suggests that, globally, costs for natural gas and hydrogen fuelled vehicles could be comparable to EVs at least from 2030 onwards. The use of hydrogen and/or natural gas vehicles has not been included in current national energy planning in South Africa and could present a significant opportunity. Consumption of hydrogen could amount to 22 PJ in 2030 for fuel-cell vehicles for which electrolysis partially or fully powered by renewables could be possible. However, production of hydrogen via coal gasification or gas reformation are likely the economic preferences (if no binding constraints on carbon emissions are applicable). The estimate for renewables-based hydrogen use under the REmap Case 2030 is 11 PJ.

Although a potential 40 PJ of biogas substitution has been identified (DEA, 2016), recent modelling indicates that these gas volumes may best serve as an interim transport fuel approaching 2030 with potentially 15 PJ of gas consumed during the period from 2020 to 2030 (Ahjum *et al.*, 2018; DEA, 2016). As such, biogas is not considered a viable/contending fuel from 2030 onwards, as hydrogen and electricity emerge as primary competing fuels (Ahjum *et al.*, 2018; DEA, 2016).

To complement the overview of technology options (REmap Options) to 2030, Box 5 provides a summary of potential future technology options that are not accounted for in the REmap analysis. At this point, quantifying the potential of these respective technologies in South Africa would be merely speculative, and is therefore avoided in this study.

31 In light of the quickly increasing global availability and sales of EVs, as well as the forecasted cost reductions, these projections for electricity use in the transport sector by 2030 could yet be considered conservative, and projections may have to be adjusted upward in coming years, in line with market developments.

Box 5: **Upcoming renewable energy (enabling) technologies not reflected in the REmap Options**

This box provides an overview of potential future technology options, based on literature research as well as on comments received at the two national stakeholder meetings that preceded this study.

The IEP and IRP explicitly account only for mature, commercial technologies that have a reasonably certain pathway for further development and use/deployment. In the same way, the REmap Options focus on commercial, mature technologies that have a proven track record and allow for robust, quantifiable assessments and recommendations. However, nascent renewables technologies that are not yet commercialised but could eventually reach maturity could also play a role in the future energy supply mix.

In terms of power generation technologies, ocean/wave energy technology has reached a certain level of maturity. The long coastline of South Africa could provide ample opportunity for deployment, but the national potential and price levels have not been ascertained in detail. Key national stakeholders have suggested these aspects be analysed as part of a broader national strategy for research and development of ocean/wave energy.

Other technologies that should be further assessed in the context of South Africa's energy system are offshore wind, CSP and hydropower. In addition, the national stakeholders suggested the development of smart meters and smart grid infrastructure (especially for areas where embedded generation from solar PV will play a key role) be accelerated. In terms of enabling technologies for renewables power generation, storage options, including hydro pump storage (*e.g.* in the mining sector) and battery storage (Eskom is currently testing energy storage at grid level), should be further explored and their additional research requirements and deployment potential further ascertained. In addition, the option of flexibilisation of existing coal plants should be assessed (see Chapter 3, Section 2 of this study).

In addition to power sector technologies, additional research and development should be focused on renewables options for end-use sectors. Key technologies to be further explored include steam and heat production from solar thermal and use of hydrogen in industry (already considered by some industrial players in South Africa). Stellenbosch University in South Africa also ran a research and development project on solar thermal use in the mining sector, which could be an option for replacing fuel use for heating requirements.

In the transport sector, the increased use of hydrogen and fuel cells is being assessed (led by the Department of Science and Technology [DST], with some work supported by Gesellschaft für Internationale Zusammenarbeit [GIZ]). South Africa has more than 80% of the world's platinum reserves (required for fuel cell production) and is well-placed to promote the technology. Yet, there are no comprehensive estimates of potential for hydrogen fuel cell use in the national transport sector by 2030. To assess the potential for hydrogen production from pyrolysis with renewables, South Africa is looking for lessons from Japan.[33] Additional research is focused on assessing the potential for hydrogen solar cells (by the National Resource Environment [NRE]) and for use of fuel cells in buildings. Overall, there is much active research on hydrogen and fuel cells, even though the technology needs to be developed to maturity, and its exact potential and actions need to be ascertained.

32 In 2018, IRENA produced the publication *Hydrogen from renewable power: Technology outlook for the energy transition*, which provides an overview of technology developments and an outlook. The work was kindly supported by the Government of Japan. The publication is available from the IRENA website, *www.irena.org.*

South Africa should also further assess options for efficiency improvements across all sectors. As outlined below, the draft post-2015 NEES sets out the targets for all energy-use sectors to 2030. The post-2015 NEES serves as central reference point for national energy efficiency ambition.

Besides technology deployment potential, these nascent technologies may also drive the development of a domestic manufacturer market for full systems or parts. When exploring new renewables technologies, South Africa should consider opportunities for creating a domestic manufacturing basis or for contributing to the technology value chain, and identify support policies.

Generally, for all these potential future technology options, further work needs to be done to understand their potential and the research and development required to achieve maturity and commercialisation.[34] At this point in time, quantifying the potential of these respective technologies in South Africa would be merely speculative, and is therefore avoided in this study.

Energy efficiency

The REmap Options for energy efficiency are based on the draft post-2015 NEES of South Africa. It includes targets to 2030 for energy efficiency in all energy-use sectors. These targets are not reflected in the draft IEP 2016 Base Case, and therefore not captured in the Reference Case 2030.

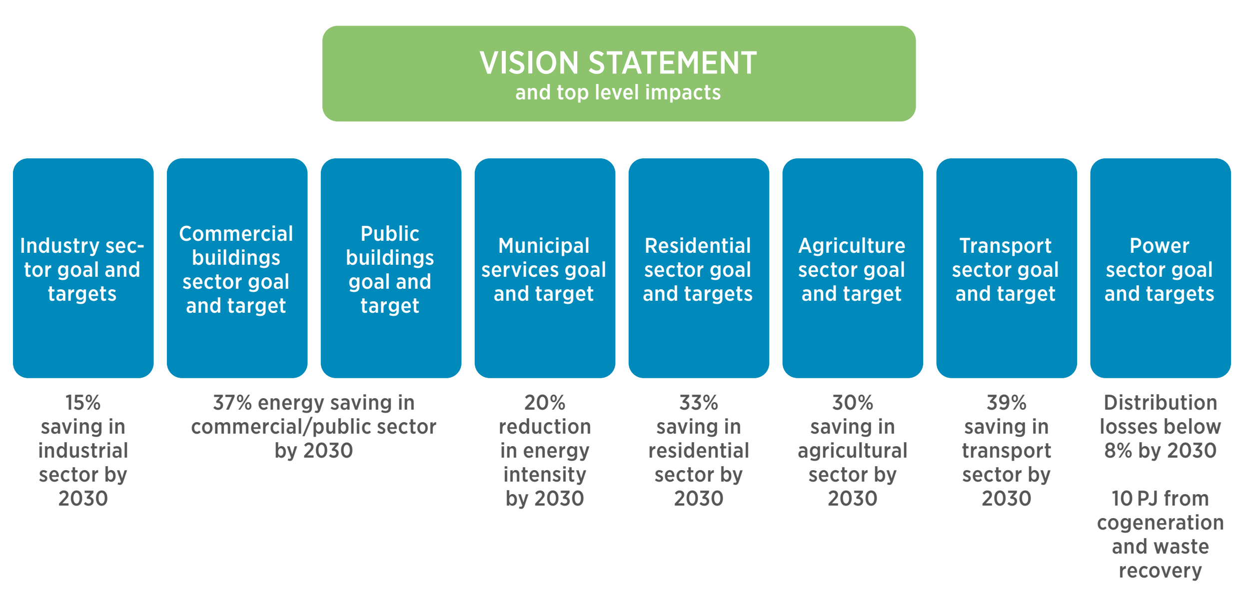
The post-2015 NEES targets in the industrial sector include energy savings of 40 PJ in mining and a 16% improvement in energy efficiency in manufacturing by 2030 resulting in savings of 146 PJ. In addition, a 37% reduction in specific energy consumption in the commercial sector by 2030 (compared to 2015) leading to savings of 17 PJ (note: partly attributed as savings in the industry sector under REmap Case). The post-2015 NESS also includes targets for improving the efficiency of new appliances by 33% by 2030 relative to 2015 in the residential sector and for improving the average thermal performance of buildings by 20%, resulting in a 20 PJ saving in residential sector energy end-use.

These measures across the industrial, commercial and residential sectors amount to total savings of 223 PJ by 2030 as part of the REmap Case 2030. Finally, energy efficiency in the transport sector, as a result of improved vehicle efficiency, yields savings of 140 PJ as part of the REmap Case 2030 (as derived from Ricardo-AEA, 2012), which can be regarded as an optimistic evolution. Combined, these savings reduce the TFEC in the REmap Case 2030 by 363 PJ relative to the Reference Case 2030.

Figure 7.4 shows the draft post-2015 NEES results framework, including the targets introduced above (note that some of the sector-specific efficiency targets are not adopted as part of the REmap Case 2030). The DoE has a vision to promote energy efficiency as the "first fuel" in driving a balanced, socially inclusive and environmentally sustainable energy sector that supports economic growth.

33 For a global stock-take and trends of energy technology innovation, see the work of the IRENA Innovation team and the IRENA technology briefs that are available from the IRENA website, *www.irena.org. The report Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables brings together key insights on emerging innovations in the power sector*.

Figure 7.4: Summarised results framework for the post-2015 NEES



Source: DoE (2016b)

Key insight:

Significantly reduced costs for lithium-ion batteries have made electric vehicles (EVs) increasingly cost-competitive with internal combustion engine (ICE) vehicles, with further expected capital cost reductions in the future.

Potential for small-scale renewables

Small-scale renewables in this context refers to renewable energy capacity that could be stand-alone and small individually (in the kW range) but could also aggregate up to large overall renewable energy contributions. These renewables in the form of distributed and embedded generation capacity have not yet scaled significantly in South Africa (there were negligible deployment levels in 2015). Compared to the utility-scale REIPPPP, the small-scale REIPPPP has reached a rather small total scale (see Chapter 3, Section 2 of this study for additional information about the small-scale REIPPPP and the awarded bidders).

The South African standard for grid interconnection of embedded generation, NRS 097-2-3:2014 (SABS, 2014b), provides simplified utility connection criteria for embedded generators that are smaller than 1 MW in low voltage (LV) distribution networks.

Included in the criteria is an allowable connection limitation for total installed embedded generation peak power capacity of 15% of the upstream medium voltage (MV) feeder's peak load before more detailed grid impact studies would be required. This is inclusive of all potential embedded generator types. Compliance to this standard is not yet a national legal requirement, and discretion can be exercised by owners of LV distribution networks. Yet, the standard does provide a useful and helpful benchmark for future grid interconnection at LVs. This will inherently limit the initial deployment of favourable small-scale generation technologies like solar PV but should not be a long-term binding constraint. Deployment of solar PV in these sectors could also be constrained by the availability of accessible roof and land area, actual localised network capacity, and affordability (or access to finance).

As an upper estimate of the potential for rooftop solar PV, it was shown that in settlement areas of South Africa, 72 GW (136 TWh or 38 PJ) of solar PV potential is available for deployment on rooftops (Knorr *et al.*, 2016). This can be considered an absolute upper limit to potential rooftop solar PV deployment if all households in settlement areas deploy rooftop solar PV. In 2016, deployment levels of rooftop solar PV in South Africa was estimated to be 280 MW.

Demand for electricity in the commercial and residential sectors is expected to grow considerably, with over 60% and 25% growth, respectively, between 2015 and 2030 in the Reference Case 2030. Similar growth is assumed under the REmap Case 2030. In the commercial sector specifically, rooftop solar PV installations are becoming increasingly viable as solar PV technology costs decline and wholesale electricity prices increase. In combination with the good correlation between the electricity demand profile of commercial end-users and the supply profile of solar PV, this could further drive significant deployment of rooftop solar PV in the future.

A 2014 study of perceptions of solar PV affordability in the commercial sector in the Western Cape showed that many businesses already consider solar PV to be competitive and worth considering as an alternative electrical energy option (Millson, 2014). Taking all factors into account, Conservative estimates suggest that rooftop solar PV in the commercial sector in South Africa could be 0.5–0.9 GW (≈0.9–1.7 TWh or 3.3–6.0 PJ) by 2030[34] under the REmap Case 2030, which is similar to the Reference Case 2030.

Correlations between residential electricity demand and solar PV generation profiles are lower, since household demand peaks in the evening.

Even so, rooftop solar PV combined with deployment of stationary electrical energy storage (batteries) could also allow for considerable deployment in future. Uptake of embedded solar PV by households (including off-grid installations) is highly dependent on affordability.

In 2015, approximately 14% of households in South Africa had an income above ZAR 153 000 (≈USD 10 930) per year. Household income is projected to grow in real terms, and by 2030 the percentage of households in this income band is estimated to increase to 25%. Of these households, ≈80% live in single-family dwellings, 12% live in medium-density houses and the remaining 8% live in high-density flats. Conservatively, assuming a 15% embedded solar PV uptake in the residential sector, the REmap Case 2030 estimates that 1.4-2.0 GW (2.5–3.7 TWh or 9.0–13 PJ) of grid-connected electricity could be provided by rooftop solar PV by 2030.

The New Household Electrification Strategy of 2013 recognised that grid electrification will not reach all households. It identified a target to electrify 300 000 households with high-quality non-grid solutions by 2025 (see Chapter 5, Section 2 of this study). If these households are supplied with electricity at the Tier3 SE4ALL level of 322–1 318 kWh/yr (Bhatia and Angelou, 2015), with SHSs and/or integrated off-grid systems including biogas digesters, supplying these households could translate to an additional 0.4–1.4 PJ (0.1–0.4 TWh) of renewables end-use as part of the REmap Case 2030.

In sum, assuming the upper bounds for all the deployment options, the total expected distributed power generation from solar PV in the REmap Case is 5.8 TWh, including 1.7 TWh in commercial rooftop deployment, 3.7 TWh in residential rooftop uses, and 0.4 TWh for new off-grid SHSs.

34 This estimate is based on an indicative increase in commercial floor area from 137 km^2 (in 2015) to 170 km^2 (by 2030), an estimated roof area of ≈25–30 km^2 and an installation potential of 20–30 MW/km^2 by 2030.

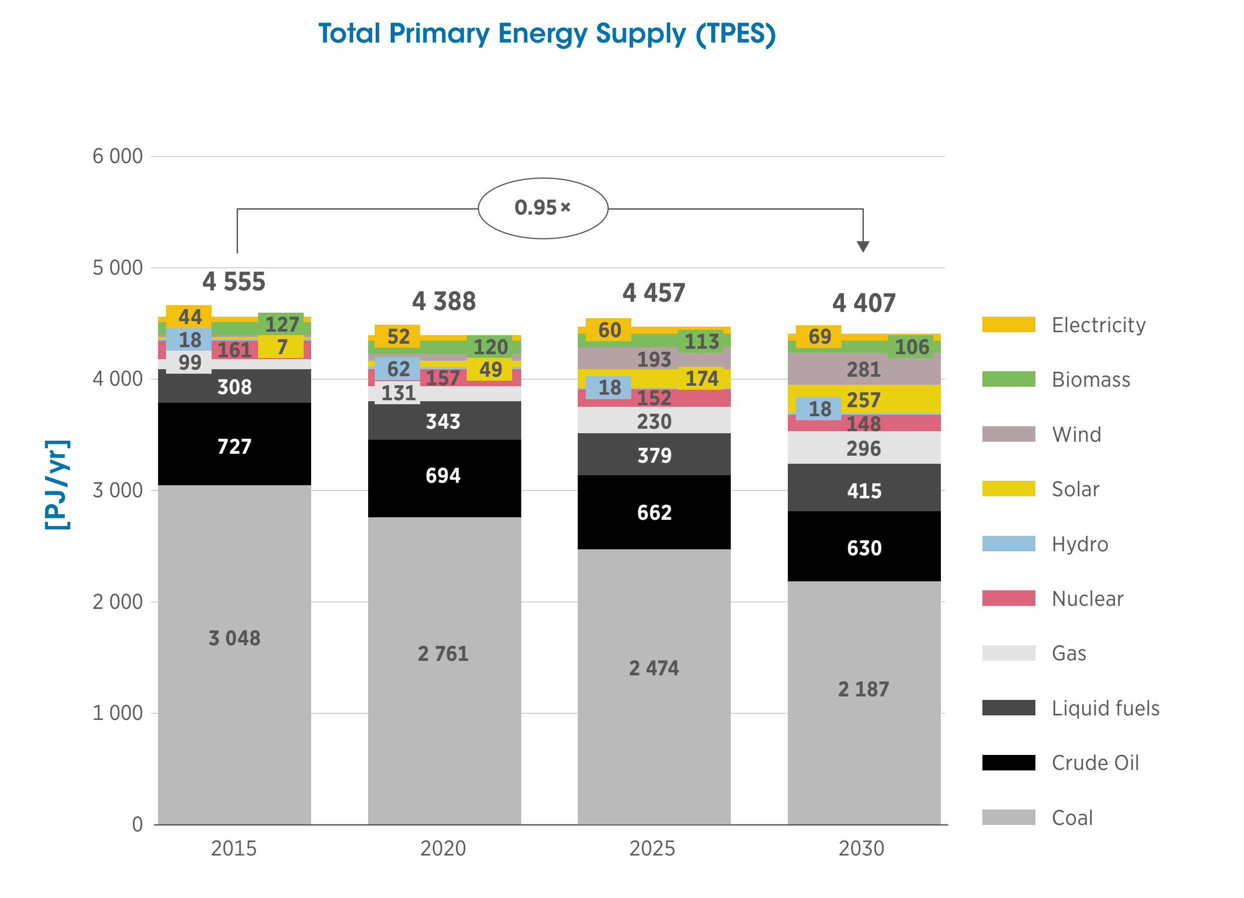
7.2 REmap Case 2030 mix and roadmap table

This section serves to bring all the findings from Chapter 7, Section 1 together and present the overall picture under the REmap Case 2030. Based on the REmap Options presented in Chapter 7, Section 1, the expected TPES and TFEC by energy carrier for the REmap Case 2030 are summarised in Figures 7.5 and 7.6, respectively. Figure 7.7 compares the overall expected share of renewable energy in TFEC under the REmap Case and Reference Case 2030.

The specific uptake of renewables across all end-use sectors for the REmap Case 2030 is graphically shown in Figure 7.8. Table 7.1 presents the technology deployment in all energy-use sectors for 2015, Reference Case 2030 and REmap Case 2030.

As illustrated in Figure 7.5, under the REmap Case 2030, TPES is expected to decrease slightly from 4 555 PJ in 2015 to 4 407 PJ by 2030 with a smaller (while still dominant) role for coal relative to the Reference Case 2030. The use of renewable energy is significantly increased and replaces some use of fossil fuels, especially of coal.

Figure 7.5: TPES by energy carrier (REmap Case 2030)



Note: Only net production is represented. Production + Imports (no exports). Values for 2020 and 2025 are estimated. Based on DoE (2016a) and CSIR analysis

As seen in Figure 7.6, TFEC is expected to grow 1.1x by 2030 with the largest relative growth expected in the commercial sector (50% growth, from 99 PJ in 2015 to 149 PJ by 2030). The TFEC by energy carrier under the REmap Case 2030 (presented in Figure 7.7) reveals how the role of coal in end-use moves slightly from 12% in 2015 to 11% by 2030 with an increased role for direct use of renewables (in the form of bioenergy and solar thermal energy). Electricity continues to contribute significantly to energy end-use as an energy carrier contributing 839 PJ of TFEC by 2030 (34%), as compared to 780 PJ in 2015 (34%). The end-use of liquid fuels, predominantly in the transport sector, also stays relatively constant at around 45% of TFEC (1 035 PJ in 2015 to 1 125 PJ by 2030). The end-use of traditional bioenergy as an energy carrier (mostly in the residential sector) is expected to shift away from traditional forms of bioenergy to modern forms of bioenergy and electricity, which results in similar absolute levels of bioenergy in end-use by 2030 (106 PJ by 2030, compared to 127 PJ in 2015).

The REmap Case 2030 shows how the share of modern renewables could increase from 62 PJ (3% of TFEC) in 2015 to 564 PJ (23% of TFEC) by 2030, based on technology options that have been identified as available (in terms of resources) and technically feasible (in terms of technology deployment speed). As outlined in Chapter 7, Section 1, implicit energy efficiency savings in the REmap Case 2030 total 363 PJ of TFEC, dominated by energy efficiency in the industrial sector followed by transportation (there is a relative reduction of TFEC by 15% from energy efficiency savings).

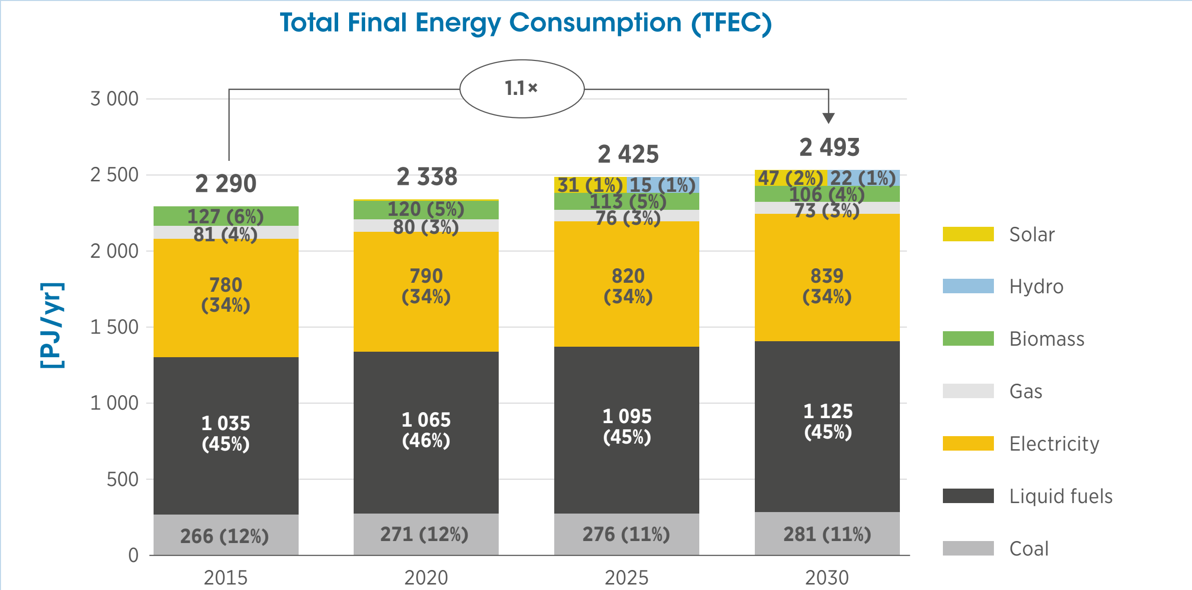
As part of the REmap Case 2030, the industrial sector could increase its contribution of renewables from 42 PJ in 2015 to 290 PJ by 2030 (an increase from 5% of sector end-use in 2015 to 30% by 2030). This would be driven mostly by renewables deployment in the electricity sector (225 PJ) combined with options for bioenergy in wood and pulp, paper and print industries (60 PJ) as well as solar thermal technologies for process heating in the food and beverage, textile, and chemical industries (6 PJ).

In the transport sector, REmap Options identified for further renewables share include the electrification of transportation (24 PJ), limited blending of biodiesel (24 PJ) and ethanol (18 PJ) into liquid fuels as well as the use of hydrogen based on renewable power (11 PJ). This results in the share of renewables in the transport sector moving from a little over 0% of the 896 PJ TFEC in 2015 to 7% (76 PJ) of end-use by 2030 (total transport sector end-use of 1 054 PJ by 2030). This share of renewables under the REmap Case 2030 is considerably higher than under the Reference Case 2030.

For buildings (commercial and residential), TFEC is expected to decrease from 443 PJ in 2015 to 401 PJ by 2030. The absolute reduction is dominated by the near-complete removal of traditional biomass end-use in the residential sector to more efficient energy carriers (4 PJ use of traditional biomass by 2030). REmap Options for these sectors include solar thermal for process and water heating (41 PJ) and an increased use of electricity (increasingly based on renewables by 2030 – 142 PJ). Under the REmap Case 2030, buildings (residential and commercial) move from a modern renewables' share of 4% of sector end-use in 2015 (23 PJ) to 46% by 2030 (183 PJ). This is considerably higher than the Reference Case 2030 (135 PJ of modern renewables; share of 31%).

In the agricultural sector, REmap Options identified include the use of solar thermal technologies for process, water and space heating (specifically in agri-processing) whilst electricity with increasing levels of renewables continues to be used. The energy end-use in agriculture moves from 69 PJ in 2015 where modern renewables contributed 3% (2 PJ) to an energy end-use of 83 PJ by 2030 with modern renewables contributing 18% (15 PJ). This is almost entirely accounted for by renewables-based electricity, while the use of solar thermal and biomass residues is rather marginal. Under the Reference Case, renewables are expected to contribute 13% (11 PJ) in the agricultural sector by 2030.

Figure 7.6: TFEC by energy carrier (REmap Case 2030)

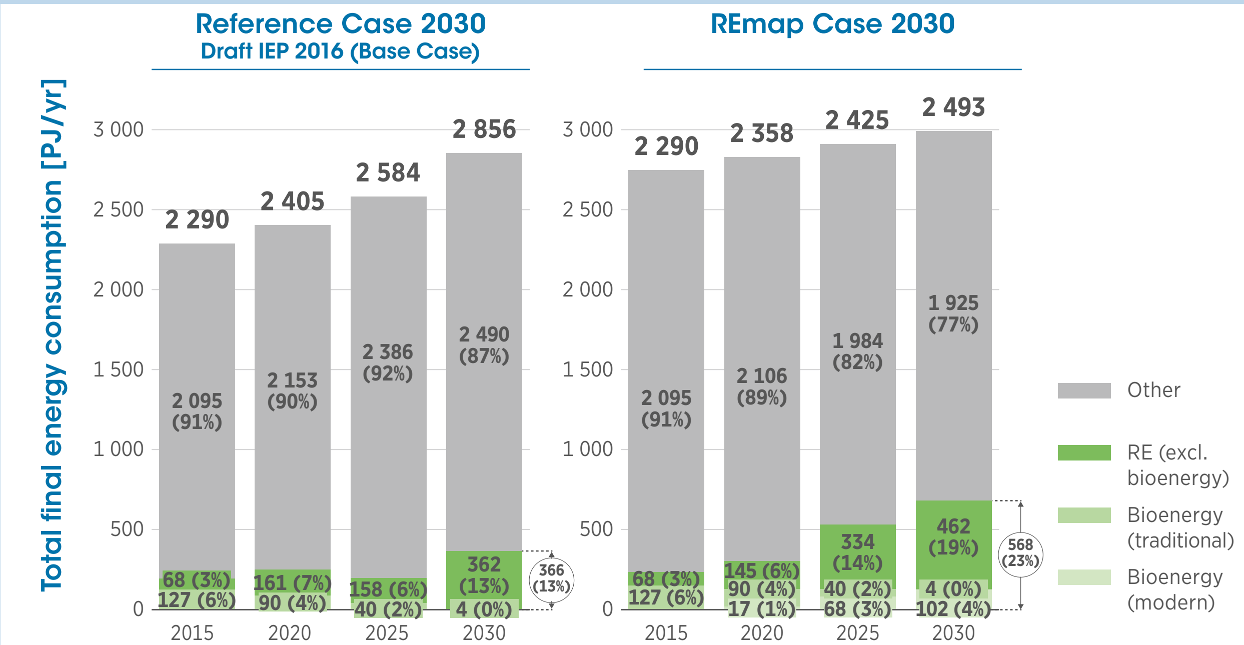


Note: Only net production is represented. Production + Imports (no exports). Values for 2020 and 2025 are estimated.
Based on DoE (2016a) and CSIR analysis

Key insight:

Under the REmap Case 2030, coal shows growth in end-use whilst liquid fuels and natural gas remain largely unchanged. There is significant growth in electricity use and the introduction of solar, hydrogen and modern bioenergy in end-use sectors.

Figure 7.7: Share of renewables in TFEC, Reference Case vs. REmap Case 2030

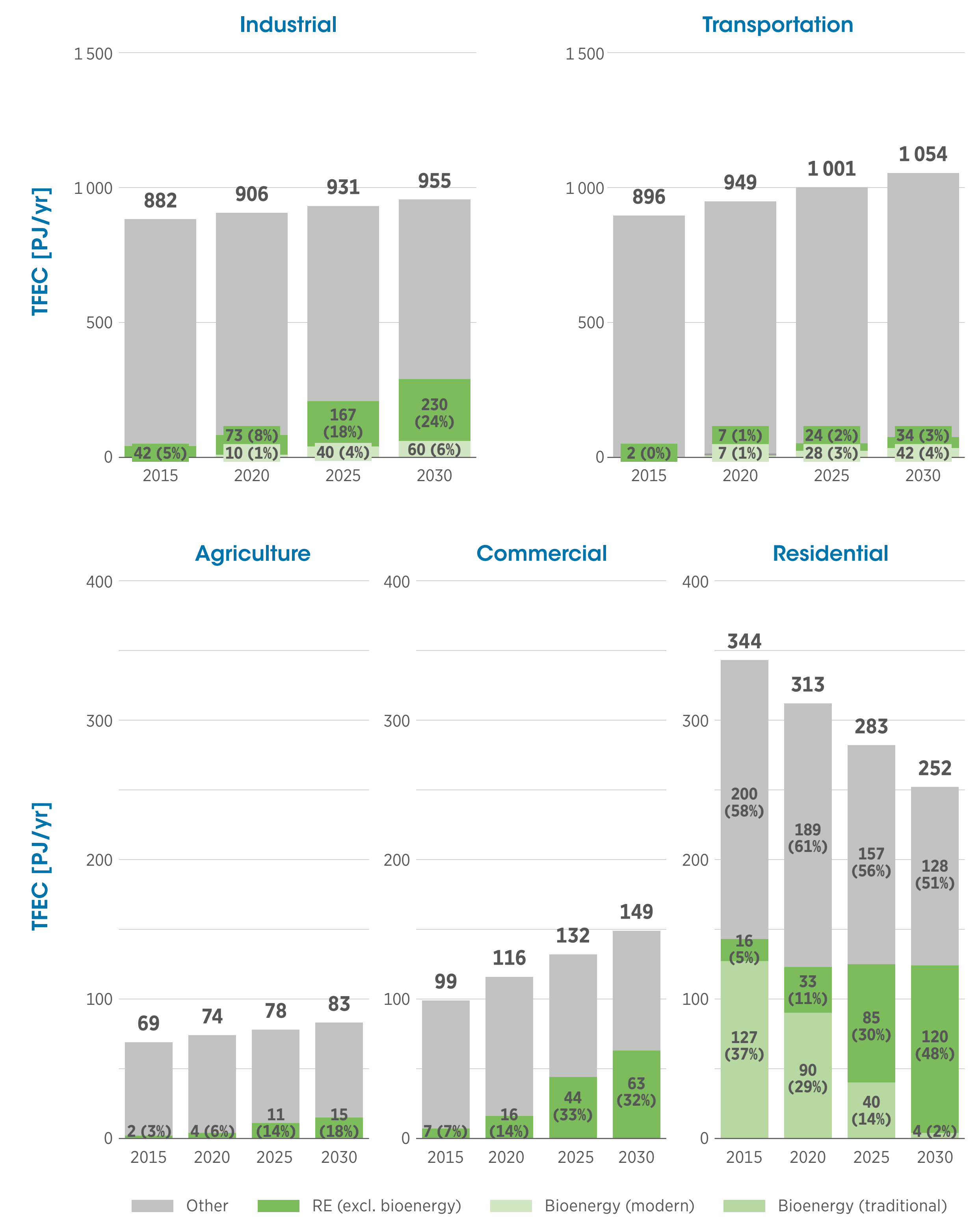


Note: RE = renewable energy. Values for 2020 and 2025 are estimated.
Based on DoE (2016a) and CSIR analysis

Key insight:

Under the REmap Case 2030, there is considerable growth in the share of renewables in TFEC, from 9% in 2015 to 23% by 2030 (compared to 13% in the Reference Case).

Figure 7.8: Share of renewable energy in end-use sectors (REmap Case 2030)



Note: Values for 2020 and 2025 estimated. RE = renewable energy.
Based on DoE (2016a) and CSIR analysis

Key insight:

Under the REmap Case 2030, there is considerable growth in the share of renewables in TFEC, from 9% in 2015 to 23% by 2030 (compared to 13% in the Reference Case).

Table 7.1: Summary of renewables share in TFEC by sector (2015, Reference Case 2030 and REmap Case 2030)

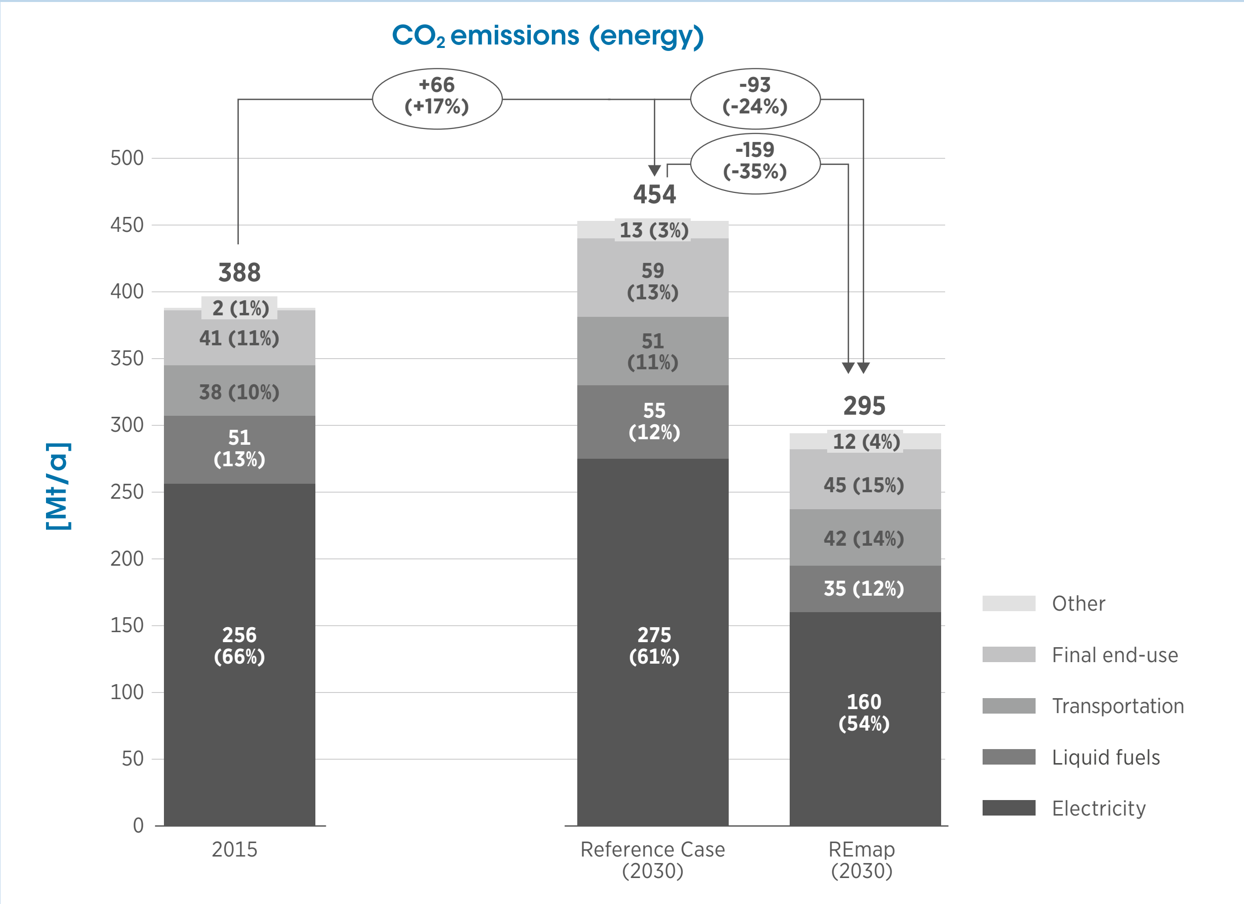
	2015		2030 (Reference Case)		2030 (REmap Case)	
	[PJ/yr]	[% share]	[PJ/yr]	[% share]	[PJ/yr]	[% share]
Industrial sector [PJ/yr]	**882**	**39%**	**1 143**	**40%**	**955**	**38%**
Non-renewable energy	*840*	*95%*	*936*	*82%*	*665*	*70%*
Renewable energy	42	5%	206	18%	290	30%
Modern renewable energy	**42**	**5%**	**206**	**18%**	**290**	**30%**
Solar thermal	0	0%	0	0%	6	1%
Bioenergy	0	0%	0	0%	60	6%
Electricity (renewables)	42	5%	206	18%	225	24%
Transportation [PJ/yr]	**896**	**39%**	**1 195**	**42%**	**1 054**	**42%**
Non-renewable energy	*895*	*99.8%*	*1 186*	*99.2%*	*978*	*92.8%*
Renewable energy	2	0.2%	9	0.8%	76	7.2%
Modern renewable energy	**2**	**0.2%**	**9**	**0.8%**	**76**	**7.2%**
Biodiesel	0	0.0%	0	0.0%	24	2.3%
Ethanol	0	0.0%	0	0.0%	18	1.7%
Fuel-cell vehicles (hydrogen)	0	0.0%	0	0.0%	11	1.0%
Electricity (renewables)	2	0.2%	9	0.8%	24	2.2%
Buildings (commercial/residential) [PJ/yr]	**443**	**19%**	**435**	**15%**	**401**	**16%**
Non-renewable energy	*292*	*68%*	*296*	*68%*	*214*	*53%*
Renewable energy	150	32%	139	32%	187	47%
Biomass (cooking/heating)	127	29%	4	1%	4	1%
Modern renewable energy	**23**	**4%**	**135**	**31%**	**183**	**46%**
Solar thermal	0	0%	0	0%	41	10%
Biogas digesters	0	0%	0	0%	0	0%
Electricity (renewables)	23	4%	135	31%	142	35%
Agricultural [PJ/yr]	**69**	**3%**	**83**	**3%**	**83**	**3%**
Non-renewable energy	*67*	*97%*	*72*	*87%*	*68*	*82%*
Renewable energy	2	3%	11	13%	15	18%
Modern renewable energy	**2**	**3%**	**11**	**13%**	**15**	**18%**
Solar thermal	0	0%	0	0%	0	0%
Boiler (biomass residue)	0	0%	0	0%	0	0%
Electricity (renewables)	2	3%	11	13%	15	18%
Total Final Energy Consumption [PJ/yr]	**2 290**	**100%**	**2 856**	**100%**	**2 493**	**100%**
Non-renewable energy	*2 095*	*92%*	*2 490*	*87%*	*1 925*	*77%*
Renewable energy	195	9%	366	13%	568	23%
Biomass (cooking/heating)	127	6%	4	1%	4	1%
Modern renewable energy	**68**	**3%**	**362**	**13%**	**564**	**23%**
Power sector (generation, TWh)	**272**		**355**		**366**	
Non-renewable energy	*248*	*91%*	*223*	*63%*	*187*	*51%*
Share of all renewables	**24**	**9%**	**132**	**37%**	**179**	**49%**
Hydro	17	6%	31	9%	24	7%
Share of renewables (excl. hydro)	7	3%	101	29%	155	42%
Solar PV	1	1%	55	16%	53	14%
Distributed solar PV (on-grid/off-grid)	0	0%	2	0%	6	2%
Wind (onshore)	5	2%	40	11%	78	21%
CSP	0	0%	3	1%	5	1%
Biomass/-gas	0	0%	1	0%	14	4%

7.3 Benefits linked to the REmap Options

Under the REmap Case, annual CO_2 emissions are expected to decline by 25% from ≈388 Mt in 2015 to ≈295 Mt/yr by 2030. The combined emissions from liquid fuels and electricity decrease significantly as part of REmap Case 2030, from ≈310 Mt in 2015 to 195 Mt/yr by 2030. CO_2 emissions from other sectors, including transportation and final end-use, grow from ≈80 Mt in 2015 to ≈100 Mt/yr by 2030.

As shown in Figure 7.9, the emissions under the REmap Case 2030 are considerably lower than under the Reference Case 2030, where emissions grow from ≈390 Mt in 2015 to ≈454 Mt/yr by 2030; the difference in CO_2 emissions is almost 160 Mt/yr by 2030. The reductions under the REmap Case 2030 stem mainly from electricity and liquid fuels use, as there is a notable increase in renewables in the power sector combined with a notable electrification of the transport sector and blending of biofuels.

Figure 7.9: Energy-related CO_2 emissions per sector in 2015 and under the Reference Case and REmap Case 2030



Note: Emissions estimated based on DoE draft IEP 2016 data.
Based on DoE (2016a).

Key insight:

Increased energy efficiency and deployment of renewables as part of the REmap Case result in significant reduction in energy sector CO_2 emissions by 2030.

Besides the reduced CO_2 emissions from increased deployment of renewable energy compared to current policies and strategies, different analyses have also observed positive impacts of increased renewables deployment in South Africa in terms of health benefits, employment and financial savings.

For example, IASS, CSIR and other partners (2019), based on a national dialogue process, developed a series of four studies that assess different co-benefits of decarbonising the power sector in South Africa. Their study on skills and job creation finds that increasing the share of renewable energy in the electricity production mix of South Africa can lead to positive net employment effects in the power sector despite significant job losses in the coal sector. The analysis finds that increasing the share of renewables can be expected to increase employment by 40% in the period 2018 to 2030, translating to an additional 580 000 job years[35] along the renewable energy value chain. In addition to an increased number of jobs, there is also an expected gain in the quality of jobs; the share of high-skilled jobs in the economy is expected to grow.

The large majority of the employment gains are concentrated in service sectors (trade, financial, business, sales) while some new employment opportunities also arise in renewable energy technology manufacturing and other industries (IASS and CSIR, 2019a). The majority of additional jobs in the national power sector are located in the solar PV and wind segments.

At the same time, in line with coal capacity reductions, there is an expected 35–40% decline in coal sector-based employment between 2020 and 2050, which corresponds to around 19 000 jobs in total (IASS and CSIR, 2019a). The South African Federation of Trade Unions even estimated that without measures to safeguard the livelihoods of mining and energy workers, some 40 000 jobs will be lost (SAFTU, 2018). The process needs to be managed politically, and a broader strategy is required for a "just transition" in the coal sector and other sectors negatively impacted by the renewable energy transition, to mitigate negative impacts on affected workers and communities. Support will be especially crucial for current coal mining regions and workers, including through the establishment of new industries in coal regions, offers of re-skilling trainings for coal workers and other supporting measures.

Many powerful national actors, like trade unions, support the move to renewable energy while demanding the government enact "just transition" measures. For example, the German government established a national commission to set out an agreement that can align social, economic and environmental objectives for the coal phase-out schedule and for accompanying support measures for communities and workers (Greenpeace, 2019). A similar commission could be set up in South Africa to foster a dialogue and develop a comprehensive coal phase-out plan. Such actions will also be crucial to foster social acceptance for the renewable energy transition (Cock, 2019).

35 "Job years" are defined as the total number of jobs multiplied by the (maximum) number of years for which those jobs are required. An alternative measure is "jobs" (the number of people employed) (IASS and CSIR, 2019a).

In addition to job gains, the increased renewables deployment in South Africa can lead to significant health benefits. The health costs of coal power generation in 2018 were estimated at USD 0.79-2.14 billion (ZAR 11–30 billion[36]), which translates to a health cost externality of USD 0.0038-0.0107/kWh (ZAR 0.05–0.15/kWh) of coal-based electricity.

The health effects are most severe in those areas where coal-fired power plants are located (*e.g.* Highveld Priority Area [IASS and CSIR, 2019b]). Increasing the deployment of renewables in line with the draft IRP 2018 update (see Box 4), compared with the Reference Case 2030, could cut health costs from the power sector by an estimated 25%. In absolute terms, this would mean savings of USD 0.27–0.91 billion (ZAR 3.8–12.7 billion) health-related costs by 2035 (IASS and CSIR, 2019b).

Some "low-hanging fruits" that have been identified, including the decommissioning of Eskom's oldest and dirtiest coal-fired power plants in the 2020s, which could significantly reduce health costs in the medium term, including health impacts on workforce productivity (around 27% of health costs are associated with restricted activity days) (IASS and CSIR, 2019b).

Notably, these health savings only refer to reduced coal power generation, while additional significant health benefits are expected from the reduced combustion of fuels resulting from increased renewables use and improved energy efficiency in end-use sectors.

The increased deployment of renewable energy can also lead to significant financial savings for producers and consumers. For example, due to the large increases in tariffs in recent years and the rapid decrease in the cost of solar PV systems, solar rooftop systems are estimated to offer residential prosumers savings in the range of USD 14.29–38.79 (ZAR 200–543) per month for a representative 2kW system. IASS and CSIR (2019c) find that combined annual savings for residential prosumers in the metropolitan areas of South Africa could add up to around USD 0.91 trillion (ZAR 12.8 trillion) by 2030.

For typical commercial customers, annual savings achieved in a 1 MW system could range from USD 1 429–4 708 (ZAR 20 000–65 914). This serves as an example of the vast potential for financial savings from deploying renewable energy options across the energy sector.

36 The ZAR values in this section were converted at an exchange rate of ZAR 14 = USD 1.

8 CHALLENGES AND OPPORTUNITIES FOR A RENEWABLE ENERGY TRANSITION

KEY POINTS

- The opportunities for additional deployment of renewable energy in different energy-use sectors are assessed in Chapter 7 from a technology perspective and with regard to environmental and socio-economic implications. This chapter identifies the key challenges and barriers for realising the options by sector. For each sector, it then discusses opportunities to set appropriate framework and enabling conditions to seize the technology options.
- There are several challenges and barriers to increasing the share of renewable energy. These include the need to understand implications for national power system operations, the creation and employment of new business models for disruptive technologies, and the emergence of prosumers.
- Small-scale embedded generation (SSEG) presents a unique challenge for municipalities that are generally interested in exploring the possibilities for deploying renewable energy in their jurisdictions. A key need in this regard is an evolving regulatory framework for municipalities to provide clarity on their role in the generation space.
- Key opportunities to enhance the additional deployment of renewable energy exist in sector coupling (*i.e.* using renewable energy-based electricity in transportation and heating), in using renewables as an input to the production of liquid fuels and chemicals (*i.e.* power-to-X), and in increasing the options for and the use of SSEG.
- The South African industrial sector is very energy-intensive and offers major opportunities for energy efficiency. This may be accelerated by introducing reporting requirements for major energy consumers.
- As presented in Chapter 7, biofuels and electric mobility are key opportunities for increasing the use of renewables in the transport sector. To grow, biofuels require the implementation of existing national policy for blending into petroleum fuels, while electric mobility requires adequate infrastructure, as well as basic incentives that fairly recognise its benefits in terms of dispatchable load and of emission reductions (provided that input electricity is generated from renewable sources).

Based on the technology options identified in Chapter 7, this chapter outlines the main existing barriers and challenges for realising the REmap Options to 2030 by energy-use sector.

For each sector, it then discusses opportunities to set appropriate framework and enabling conditions for seizing the technology options. Finally, Chapter 9 offers suggestions for concrete measures and next steps.

8.1 Current challenges and opportunities in the power sector

South Africa has the largest power system in Africa with approximately 6 million customers (including individuals, municipalities, large industrial users, etc) served by the national utility Eskom. South Africa also exhibits comparatively high levels of electricity access compared to other countries in Sub-Saharan Africa. Over the last five years, the power system has seen increasing participation of the private sector through IPPs offering gas, coal and renewables-based power generation. Disruptive technologies such as SSEG, particularly solar PV, are challenging traditional approaches to expanding and operating the power system, with marked impacts on the current business models of the national utility and municipalities. Although there are several diverging views on the pace of electricity demand growth in South Africa, the future power system must evidently exhibit more diversity of generation options in order to enhance the supply security and reduce the high dependence on fossil fuels that yields high carbon and pollutant emissions.

Renewable energy presents a path for diversification. The barriers and challenges described in this chapter highlight some of the potential hindrances to this path. Parallel to the growth in national electricity demand, several old coal-fired power plants are being evaluated to assess the merits of extending their operational lifetime. Indeed, the recently released draft IRP 2018 update includes targets for decommissioning a total of 12.0 GW by 2030 and 33.8 GW by 2050 (see Box 4). Where coal power plants are decommissioned in the coming decades, there will be a magnified need for new generation options to avoid future shortfalls in electricity supply.

The barriers and challenges also highlight areas where South Africa may need to adopt new approaches – hence, new opportunities also emerge. The optimal path for development of the power system is informed by policy directives, the costs of the various generation options, and the characteristics of available supply options and their environmental and social impacts. Along all these parameters there are disparate views and uncertainties about how different development paths for the power system will affect South Africa. These areas of uncertainty present a challenge in their own right and can contribute to policy uncertainty if not investigated thoroughly. The following points attempt to yield some certainty with regard to key barriers and challenges in the power sector that require further analysis or action in South Africa, but also with regard to related opportunities.

Understanding the power system impacts of deploying renewable energy

The benefits of renewable energy are well understood and appreciated in South Africa, particularly from an environmental perspective. The drive for increased levels of renewable energy, however, needs to consider multiple aspects, including the impact on power system operations. As part of their review of the draft IRP 2016 update, CSIR (Wright *et al.*, 2017a) undertook an analysis of the levels of VRE that the national grid system could handle. They found that 20–25% of variable renewables by 2030 is least-cost optimal but the system could probably handle a significantly higher amount as new flexible capacity is deployed to complement variable wind and solar PV. Increased flexibility of the system is expected as more inflexible coal is decommissioned (while options for flexibilisation of remaining coal capacity should be assessed). Storage technology could add to this.

The REIPPPP deployed 0.5–0.75 GW per year of wind and solar PV, respectively, between 2013–2017 (largely limited by the procurement of additional renewables) (Calitz and Wright, 2017). This is 1–2% of South Africa's maximum system demand per year from a nascent renewables industry. In terms of international experiences from wind deployment, Germany, Spain and Ireland installed on average 2.7–4.6% of maximum power system demand between 2006 and 2016 whilst developing countries like China, India and Brazil installed on average 1.7–2.5% of maximum power system demand in the same period (Wright *et al.*, 2017b). Similarly, for solar PV, Germany, Spain and Italy installed 1.3–5.4% of maximum power system demand between 2007 and 2015 whilst others like Japan, India and China installed 0.4–1.9% of maximum power system demand during the same period. For South Africa's power system, at least 1.4–2.5 GW/yr for wind and 0.7–3.0 GW/yr for solar PV should be possible by 2030. This is well above the level of deployment identified in the REmap Case 2030.

A further detailed assessment is required to determine the grid stability impacts of various levels of variable renewable energy penetration. Particularly, total solar PV and wind penetration levels of 30–40% by 2030 would require some additional technical analysis in terms of system stability and flexibility. Further research is required to assess the levels at which VRE-based generation starts to cause grid operation outside prescribed technical limits. Power system inertia is a key parameter when assessing the operation of the grid. This topic is currently receiving much attention from the national utility and researchers trying to understand which remedial actions are most cost-effective to accommodate higher levels of variable renewables deployment. A more detailed understanding of the grid stability impacts can remove or nuance the perception that an increased penetration of variable renewables poses a significant threat to the safe and efficient operation of the power grid. Also, the national power system must adhere to a grid code and operate within defined technical limits.

Ageing grid infrastructure

The national utility has an expansive transmission grid network and strategic plans that identify potential bottlenecks up to ten years in advance, based on the forecasted demand and generation mix. At the distribution level, however, many municipalities have severe backlogs in terms of distribution-grid maintenance. According to an approach-to-distribution-asset-management report, the backlog in maintenance, rehabilitation and strengthening work for electricity infrastructure amounted to around ZAR 27 billion (USD 1.93 billion[37]) in 2008 and had increased to ZAR 68 billion (USD 4.86 billion) by 2014. Moreover, this backlog has continued rising, according to NERSA (EE Publishers, 2016a). Poorly maintained and ageing distribution grids limit prospects for more renewable energy-based SSEG, particularly in the residential sector.

With a significant share of variable renewables in the power sector identified as part of the country's REmap Options, there will be an implicit need to ensure that sufficient network infrastructure is developed in a timely and appropriate manner. The range of integration challenges experienced globally in power systems with high penetrations of solar PV and wind will need to be sufficiently addressed in South Africa's context as VRE penetration levels increase. A stable and resilient electrical power system is essential, and planning in this regard should be adequately prioritised.

This also links to the broader need to increase investments in national power-sector infrastructure, particularly to address supply shortages, avoid the resulting need for load-shedding, avert grid collapse, and strengthen the network. These considerations are further outlined in Box 2 and Chapter 9, Section 2.

37 USD values are based on an exchange rate of ZAR 14 = USD 1.

Limited experience with new business models

The South African electricity sector is characterised by a vertically integrated utility with a virtual monopoly in generation and transmission. In terms of electricity distribution, the national utility and municipalities are the primary actors. Over the last ten years, this operating model has experienced difficulties, with several episodes of national load shedding, falling electricity demand, competition from disruptive price-competitive technologies and increasing environmental constraints.

This calls for an assessment of whether the current business models and institutional structures are still adequate. There is, however, limited local experience with alternative business models for the future electricity supply industry. The long-standing status quo may create resistance because the implications of various reforms are not fully understood. For example, potential reforms may include:

- Restructuring the national utility to separate the generation and transmission businesses. Through this, an independent market and transmission operator could be created.
- Evolving the distribution business structure and business models to move away from selling energy and rather securing revenue on the basis of using grid infrastructure as an enabler, where energy is traded across the grid infrastructure.

Financial challenges at the national utility (Eskom)

Despite the fact that electricity tariffs have increased by over 300% since 2000, the financial standing of the national power utility (Eskom) has deteriorated. Furthermore, the tariff increases impact the competitiveness of South African industries and have indirectly led to a decline in grid-based electricity demand as businesses have closed or have resorted to alternative electricity supply options. Its high levels of debt and the falling electricity demand suggest further future price increases by Eskom (*e.g.* in 2017 Eskom requested a 19.9% tariff increase from the regulator). The severe financial challenges may also affect Eskom's ability to act as an offtake buyer for PPAs with renewable energy IPPs.

An alternative approach to a single-buyer model could be to create a power pool structure and allow Eskom to operate as a market participant, including investing into renewable energy. Such an approach could increase the value of the company and benefit consumers (by means of cheaper prices).

Updating the Integrated Resource Plan (IRP)

All national power sector stakeholders take a keen interest in the IRP for the insight it provides into government plans for future electricity supply. Over the last seven years since the completion of the IRP 2010–2030, the costs of renewable energy technologies have decreased at a pace that has exceeded expectations. Although these cost reductions benefit the renewable energy sector, they have also posed a challenge in terms of ensuring that the IRP and its ambition remain aligned with market realities. There is a need to ensure the timeliness of completing and approving IRP updates while maintaining the rigour, review, transparency and due process of IRP updates, including comments from multiple stakeholders and approval from several government actors.

Institutional barriers

Securing unhindered, transparent and consistent access to the transmission network requires a neutral and independent party that matches electricity supply from generators to demand from customers in real time. Such a market co-ordination entity may require reforms to the current institutional structure of the sector. South Africa's draft plans to implement an independent system and market operator could be revisited for implementation in a manner suited to the national context and conditions.

Regulatory barriers

The regulatory framework for utility-scale renewable energy projects is clear and proved to be most effective for utility-scale renewable energy projects. SSEG, typically installed within municipal distribution networks, has emerged as a new frontier for deployment of renewables, particularly solar PV. Regulations to enable the procurement and deployment of small-scale and distributed power generation capacity at the local government level (municipalities) are currently still evolving.

Furthermore, in 2017 the DoE published the Licensing Exemption and Registration Notice under the Electricity Regulation Act. Despite the clarity provided by this notice, the Municipal Finance Management Act does not allow municipalities to enter into procurement agreements for longer than three years. This presents a barrier for renewable energy projects given that long-term PPAs (*i.e.* generally, 15 to 25 years) with favourable tariffs are required to enable financing of such projects. There are means to overcome this barrier, such as following the steps set out in Section 33 of the Municipal Finance Management Act. This provision calls for wider and more extensive consultation with stakeholders regarding any contract that exceeds a period of three years (SEA and USAID, 2016).

Several opportunities exist in the South African power sector. Their realisation can enhance several policy-related objectives, including increasing the diversity and security of electricity supply, reducing the carbon footprint of the power sector and supporting domestic industrial development.

Small-scale embedded generation (SSEG)

The growing trend of electricity consumers generating electricity for self-consumption presents the opportunity for municipalities (and other electricity distributors) to diversify their service offering. Municipalities may step into the role of being a provider of such embedded systems and thereby preserve their share of the distribution market, albeit under a different business model. In addition, buying excess electricity from local renewable energy generators can mitigate against rising electricity prices from the wholesale market and limit the exposure of distributors to high peak-time electricity pricing. Purchases of excess power (*i.e.* effectively using the distribution grid as a "storage" medium) would maintain the use of the grid while avoiding unnecessary investment in energy storage by end-consumers.

Promoting embedded generation in distribution networks can also potentially delay investments in transmission infrastructure that are needed to deliver electricity from large centralised power plants to end-consumers. Placing more generation assets closer to points of consumption can also reduce energy losses associated with long-distance transmission. The solar industry in South Africa has the capability to install small-scale embedded solar PV at a rate of over 500 MW per year. This pace would provide a meaningful offtake for solar PV modules and other components manufactured locally.

The advent of SSEG also presents distributors with the opportunity to revisit the manner in which wire costs are recovered, leading to changes in tariff structure and more transparent charges for wires and energy-related costs.

Bioenergy and cogeneration

Significant potential exists in South Africa for power generation from sugar mills, particularly in KwaZulu-Natal Province (see Chapter 6, Section 1 for further information). At present, the sugar industry is experiencing slow growth, and establishing a framework for sugar industry participation in electricity supply may be a way to stimulate the growth of this sector. The sugar sector is particularly well-suited to support local economic development and job creation because a large portion of the jobs would be in agriculture. Although the sugar industry provides one of the most prominent examples of the contribution from biomass and waste products, other industries are also poised to benefit from an energy procurement framework that covers waste energy recovery (see Chapter 3, Section 2 for information on cogeneration options under the national IPP programme). Given that waste-to-energy projects typically have secondary benefits that may not necessarily be reflected in electricity costs, a national framework is required for the pricing thereof. Secondary benefits include, amongst others, avoided use of landfill sites for waste disposal (see Chapter 3, Section 5 for a detailed list of environmental externalities).

Mini-grids for rural locations

Over the last 20 years, South Africa's DoE has conducted a successful Integrated National Electrification Programme (INEP) under which access to electrification has increased from 36% in 1994 to over 86% in 2017, with more than 5.9 million households being connected to the grid. Remote rural households for which grid-based electricity supply is not immediately feasible may provide an opportunity for mini-grids that could serve communities with a modest number of households. The service offering to households may be scaled depending on needs that vary from providing basic lighting and charging small mobile devices to operating large appliances such as televisions and other productive end-uses that cater to the specific needs of each community.

Mini-grid systems are already deployed in South Africa where appliances, and the electricity to run them, are available to the client at a cost of less than ZAR 1 (about USD 0.07, or seven USD cents) per hour. The need lies largely in understanding the best business models to allow deployment of mini-grids, even in communities that have limited purchasing power. Furthermore, the planning for grid expansion, off-grid interventions and mini-grids needs to be better co-ordinated and integrated.[38]

Opportunities for sector coupling

Sector coupling is defined as the process of interconnecting the power sector with the broader energy sector (*e.g.* heat, gas, mobility) (IRENA, 2018d). Several possibilities are emerging to use electricity as a primary energy source for the entire energy system, including in South Africa. As penetration of EVs continues to grow and freight or public passenger transport shifts from road to rail, the national energy system becomes increasingly dependent on electricity, thereby opening a way to use renewables for an increasing number of energy-related services, including transportation and heating.

The use of renewable energy instead of fossil fuels increases the overall efficiency of the national energy system as ICEs and thermal-based power are increasingly eliminated from the transportation and generation sectors, respectively. Using electricity for heating and cooling load, and combining this with energy storage, may also provide flexible demand to assist in managing the variable power output from solar and wind resources. As end-use sectors are increasingly using electricity, the prospects for further decarbonisation of the economy also grow. Coupling energy sectors in this way will require a significant investment in new infrastructure – such as charging stations for electric mobility – as well as strengthened grids, especially at the distribution level.

38 IRENA has published a range of reports on mini-grids that provide further technical information and international experiences on these aspects (*e.g.* see IRENA, 2018e). All IRENA reports are available for download from the IRENA website, *www.irena.org*.

8.2 Current challenges and opportunities in the buildings sector

Challenges in the buildings sector

Electricity supply (solar PV deployment)

The residential sector is already starting to show signs of a ramp-up in installations for small-scale embedded solar PV where installations are typically sized up to 5 kilowatt peak. Particular attention is given to solar PV, considering its suitability for use in this sector compared with other renewable energy technologies such as wind. In terms of the potential for further deployment (as identified in Chapter 7), several challenges still exist despite the favourable economics for embedded solar PV and other embedded technologies. These are presented and discussed in the following sections.

Lack of standards for quality certification of solar PV modules

Technical standards play a vital role in promoting safety and the quality of power. Using a common standard also allows a meaningful comparison of the performance of different PV modules. Most of the technical requirements for grid connection of embedded generation are covered in the NRS097 series of standards, and Part 2 of this series (NRS097-2) deals specifically with SSEG. The International Electrotechnical Commission (IEC) stipulates 19 tests to establish the quality of PV modules, with reference to the Standard IEC 61215-2 (IEC, 2016). South Africa has yet to develop and enforce such a comprehensive set of tests to ensure that all panels sold or used in South Africa adhere to a set minimum quality standard. This may hamper national deployment of solar PV.

Lack of universal standard for grid-tied small-scale embedded solar PV

Eskom and many of South Africa's municipalities are licensed to own and operate distribution networks. So, an embedded generator can connect either to an Eskom or municipal distribution network. Eskom does not allow connection of an embedded generator to any part of its low-voltage grid infrastructure. There is, however, a provision to allow connection of embedded generators on medium-voltage sections of the grid. Some municipalities allow embedded generators to connect to their distribution grids while others prohibit such connections. For the municipalities that allow connections, the rules, by-laws and procedures for connection are not uniform. For instance, some municipalities do not permit excess generation to be fed into their network.

Lack of a clear regulatory framework for the country

According to the Electricity Regulation Act of 2006, all generation of electricity requires a licence from NERSA. However, in 2011, NERSA prepared and issued regulations governing standard conditions for small-scale (less than 100kW) embedded generators in municipal boundaries (NERSA, 2011). Under these regulations, an embedded generator does not require a license to operate. Procurement of small-scale (1–5 MW) and large-scale (greater than 5 MW) projects is provided through the REIPPPP. However, the REIPPPP regulatory framework does not provide for projects of less than 1 MW in capacity. Hence, until recently, there was a gap in regulation of small-scale projects falling in the range between 100 kW and 1 MW in municipalities. In November 2017, this gap was addressed by an amendment to Schedule 2 of the Electricity Regulation Act. However, the suitability of this amendment is yet to be determined through observing developments in the SSEG sector.

Lack of asset financing products for embedded solar PV

Electricity supply from municipalities and Eskom has become more expensive after the tariff increases of over 300% during the last 10–15 years, thereby contributing to an increase in the demand for rooftop PV systems. This increase in demand for rooftop PV systems is a great opportunity for Energy Service Companies (ESCOs). The volume of the national ESCO PV market has been estimated at ZAR 75 billion (about USD 5.4 billion) by 2035 (GreenCape, 2018). Given the ESCO market growth, commercial finance institutions potentially have a viable market that will require specific solutions for financing residential, commercial and industrial small-scale embedded solar PV. Banks such as Nedbank and Amalgamated Banks of South Africa have already started offering such solutions for their industrial business customers. However, many potential customers (especially residential) so far cannot afford to meet the cost of acquisition and installation of a solar PV system.

Opportunities in the buildings sector

Opportunities that have been highlighted for further deployment of renewables in the residential sector in South Africa include solar water heating, passive solar designs for space heating, stand-alone solar kits for dwellings and the use of biogas digesters for energy supply in rural residential areas.

Solar water heating and its value as a demand-side management tool

Peak demand for electricity in South Africa is generally observed in the morning and evening, with electric cooking and water heating being the major contributors to these peaks. Eskom has to run gas turbines (for peak periods) to meet the demand. These turbines are driven by diesel fuel and have a high operational cost and carbon footprint.

A solar water heater harnesses solar radiation to heat water that is stored in a tank for later use, at night or during periods of low or no sunshine. The tank is properly insulated to curtail heat loss to the ambient environment. Consequently, this technology provides dispatchable thermal energy. Therefore, solar water heating provides an excellent opportunity to absorb part of the demand for electricity (which is predominantly produced from thermal power plants driven by fossil fuels) and for reducing carbon emissions. In view of this, there are initiatives to promote solar water heating. The DoE has set targets for SWH installations (see Chapter 4, Section 3 of this study), and SWHs provide a technology option for increased renewables use in buildings by 2030 (see Chapter 7 of this study).

Passive solar designs for space heating

As reported in Chapter 4, Section 1, South Africa has comprehensive national standards on green buildings. The regulations came into effect in 2011 and are meant for new buildings. Furthermore, the hope is that, where feasible, the regulations can be taken into consideration during the maintenance of old buildings. The regulations take into account passive building design.

Passive solar design aims to exploit solar energy to assist in establishing thermal comfort in buildings without the use of electrical or mechanical equipment (Stevanović, 2013). For example, suitable orientation and fenestration allow transmission of adequate solar radiation into the building, where it is converted to heat when incident on surfaces in the building (such as the floor, walls and furniture). The heat gain from solar radiation helps reduce the heating load. Opportunities do exist for the integration of passive solar design strategies at the conceptual design level. This can be done by determining values of variables that have significant influence on the performance of the building.

Some of the variables include the building shape, opaque components of the building (such as walls), glazing and shading. The SANS 10400-XA stipulates, amongst others, requirements for orientation, floors, external walls, fenestration and roof assemblies. Consequently, these regulations (which promote and incorporate passive solar design elements) provide an opportunity for the development of more energy-efficient buildings.

Stand-alone solar kits for dwellings

The main barrier to achieving "universal access" to electricity in South Africa is the cost of providing electricity to remote rural households and the challenge of providing electricity to predominantly informal or unplanned settlements. For rural areas where the population is sparse, an alternative is the development of mini-grids which, unlike solar home systems, help to stimulate economic growth and productivity (Comello *et al.*, 2017). With mini-grids, capital equipment can be deployed for value addition to products and services such as agro-processing and other small-scale industries. (See, for example, IRENA [2018e] for further information on mini-grids.)

Recently, tariffs of grid electricity supplied by Eskom and municipalities have been rising, and load shedding has occasionally been implemented to meet the demand for electricity in suburbs. At the same time, the cost of producing electricity from solar PV technology has been declining. Consequently, this provides an opportunity for consumers in these areas to adopt stand-alone solar PV kits if municipalities can develop a suitable policy for this kind of business.

Use of biogas digesters for energy supply in rural residential areas

One way of converting waste to energy is via the production of biogas by using biogas digesters. The biogas can be used directly (such as for cooking/heating) or indirectly (through generation of electricity). About 700 biogas digesters have been installed in South Africa (Mutungwazi, Mukumba, and Makaka, 2018). The most common are small-scale installations for direct usage of the biogas in households or small facilities. This category of biogas digesters can be used in cooking, heating and lighting in villages and schools.

Coincidentally, most of the biogas operations are in rural areas of South Africa, which indicates the opportunity for exploitation of biogas in rural residential areas.

8.3 Current challenges and opportunities in the transport sector

South Africa's transport sector is still dominated by liquid fuels from an energy supply perspective. The following sections mainly discuss challenges to the introduction of higher shares of biofuels from the perspectives of liquid biofuels (which may be blended with petroleum) and biogas (which may be used in hybrid buses that are already in use in certain municipalities), as well as hybrid or fully electric modes of public transport (buses, public vehicles), fuel-cell vehicles (hydrogen), and increased market penetration of electric cars. This section complements the technology options identified in Chapter 7.

Hybrid or fully electric modes of public transport

The rate of adoption of EVs in South Africa is relatively low. Two possible reasons for this are: i) a lack of incentives such as tax rebates and subsidies to encourage use of EVs; and ii) the absence of political will to extensively promote the exploitation of EVs. Another major challenge is the limited number of stations where EV operators or owners can charge their vehicles. The consequence of this is that conventional vehicles continue to dominate the national market.

There is a need to address the lack of infrastructure for EVs and to provide other support for market uptake. While some EV models are available on the national market, hybrid electric vehicle (HEV) buses are currently more expensive to purchase than conventional diesel buses or buses that run on natural gas. A more detailed analysis is required to establish the economics of hybridising buses in South Africa. Furthermore, there should be a comparative analysis between ICE vehicles and EVs as well as between "full" EVs and hybrid EVs in terms of costs (including at purchase and over the lifetime of these vehicles). (See, for example, IRENA [2017] for a further overview on EVs.)

Use of biofuels for blending into the mainstream supply of petroleum fuels

South Africa has a regulatory framework for the development of the local biofuels industry (see Chapter 4). Besides water availability and competing land uses, one particular challenge is that, under the current fuel market structure and incentive levels, biofuels are more expensive than petroleum fuels. Hence, at present, biofuels cannot compete on the market without policy or financial support mechanisms. As a result, projects for the production of biofuels are not yet economically feasible on their own without some form of support (DoE, 2017c).

The government of South Africa has put in place some incentives, including a Biofuels Pricing Mechanism (biodiesel manufacturers receive a 50% rebate on the general fuel levy), and an Accelerated Depreciation Allowance (all renewable energy projects qualify for this allowance of 50:30:20 over a period of three years) (DoE, 2017c). There is a need to further strengthen the regulatory and policy landscape for support of the biofuels industry. The lack of economic feasibility for biofuel projects adversely affects the exploitation of biofuels in transportation and other potential use sectors.

Hybrid or fully electric modes of public transport

At present, at the level of individual consumers, particularly in the residential sector, there is no proper match between daily profiles of demand and supply of electricity from renewable sources in South Africa, resulting in excess electricity supply during certain times of the day. In view of this, the national utility Eskom has to store excess electricity during off peak times (mostly through pumped storage). Use of EVs can reduce (or even eliminate) the need for storage by adding to system flexibility. Particularly, in the case of power supply shortages during certain day times, EVs can assist in meeting peak demands by feeding the electricity stored in the EVs' batteries into the central grid.

8.4 Current challenges and opportunities in the industrial sector

Challenges in the industrial sector

The industrial sector hosts many industries that are major employers in the South African economy. For the transition to an energy system based on renewables, many stakeholders point out the need to ensure that large-scale job losses do not occur as coal mining becomes less of a central pillar in the energy landscape of the country. Given the scale and role of the coal mining sector in the country and the very high unemployment in South Africa, this is not only a matter of jobs but a wider social issue, since many communities and families stand to be affected if the energy transition is not managed carefully. This will require well-defined social plans and processes to ensure any transition into new industries in the future is well managed. Also, mining is a highly specialised trade and essential to the South African economy. How well such skills can be adapted to other sectors remains to be seen. The requirements for a just transition of the energy system are further outlined in Chapter 7, Section 3.

Energy consumption profile in the industrial sector

Industrial operations typically need a constant energy supply and hence do not exhibit peak daily consumption periods as is seen in the residential or commercial sectors. As a result, the industrial sector needs more careful consideration when integrating renewable energy into its operations. Supply interruptions are particularly harmful for industrial production processes that run on a continuous basis. Hence, each industrial company needs to assess how renewable energies are able to make a contribution to their specific industrial process given the temporal load profile as well as the form of energy required for the industrial process (*i.e.* electricity, heat or cooling).

Co-location with renewable energy primary resource

The falling costs of renewable energy in South Africa are well documented, particularly in terms of the prices seen under the REIPPPP. An important ingredient for achieving low costs is the location of renewable energy projects; they must be located in areas with very good primary resource (*e.g.* solar irradiation, wind speeds, biomass, etc). However, the major industrial areas in South Africa (*i.e.* in Gauteng and the South East Coast Durban area) are generally outside the locations with the best solar and wind resources (*i.e.* Northern Cape and Eastern Cape provinces). Over the short term, this may delay the deployment of renewables because the LCOE levels that may be reached in these locations are not as favourable as those offered by the best renewable energy sites in the country. This barrier is, however, expected to be temporary as costs for renewables keep decreasing while tariffs for conventional electricity supplies continue to rise. If these overall cost trends continue, renewable energy will certainly offer more favourable energy supply costs in time, even outside locations that have the best primary energy resources in the country.

Financial assessment of renewables as an investment

Energy supply through renewable energy carriers requires substantial investment, and this is particularly true in terms of electricity generation. The long-term PPAs that allow for investments to be recouped over many years are a key component of successful renewable energy projects. Within an industrial operation or company, potential investments in renewable energy supply are assessed in comparison to other capital projects. Such "projects" may include upgrades or refurbishments. These competing investment options are often assessed with a view to achieving the shortest possible payback period. As a result, renewable energy supply often does not emerge as the most attractive investment option. This is steadily changing, however, as energy costs continue to increase and become a larger share of the overall costs in industrial sector companies. Therefore, renewable energy supply needs to be seen as a long-term investment in the framework of the overall financial sustainability of the company, rather than a short-to-medium term investment.

Opportunities in the industrial sector

One of South Africa's unique competencies is in the chemicals and liquid fuels industries. With very competitive renewable energy tariffs and a strong chemicals sector, South Africa is in an opportune position to develop a domestic Power-to-X sector. Power-to-X turns surplus electricity into hydrogen, chemicals, heat and other useful products. This would be particularly useful as penetration of renewable energy increases, and there is a higher chance of surplus generation from renewables. With cheap surplus renewables-based electricity, South Africa can use electrolysis to split water into hydrogen and oxygen. The hydrogen can then be used in fuel cells, gas turbines or engines, as well as being a feedstock in synthetic gas. Such products can be exported to other markets and contribute to the targets for climate change mitigation, especially in terms of liquid fuels.

Energy efficiency for energy-intensive processes

The national industry is very energy-intensive. The Energy Intensive User Group of South Africa comprises only 28 companies, but these account for about 40% of all electricity consumption in the country (and 20% of national GDP) (EUIG, 2019). Energy efficiency is a major opportunity for making quick inroads for a more sustainable energy sector in the country. Although there is a national strategy for energy efficiency and initiatives already underway in South Africa to address industrial energy efficiency (*e.g.* through the National Cleaner Production Centre), there is still a lot of scope for expanding the programmes and thereby to realise significant savings from energy efficiency measures.

Renewables for low-temperature heat supply

Much of the energy demand in South Africa's industrial sector is in the form of process heat. Solar irradiation can be harnessed through relatively simple technologies such as evacuated tube collector and flat plate collector solar water heaters. A comprehensive approach for deploying renewables for low-temperature heat would require a mapping of heat demand for the entire country. Once this is completed, electricity for heating purposes may be replaced by water heating where low-temperature heat is required.

New manufacturing opportunities

Several manufacturing plants have been established in South Africa since the launch of the REIPPPP. These facilities built upon the strong manufacturing capabilities found in South Africa and created new competencies. Examples of this include manufacturing of wind towers, inverters, solar panels, tracking systems for solar PV and mounting structures. Delays in the most recent rounds of the REIPPPP have harmed some of these operations, but the skills and competence in the country remain.

With the increasing deployment of renewables in South Africa and in the overall SADC region, these national manufacturing industries could also be strengthened and expanded. As outlined in Chapter 7, Section 3, locating new industries in current coal mining regions can facilitate a just transition to renewables.

Technology development

Renewable energy technologies are still showing decreasing costs due to technology improvements and economies of scale in manufacturing (see Chapter 6 for further information). These decreasing costs indicate that there is still room for improvement in terms of technology development.

The most pertinent examples for South Africa may include battery storage, high-temperature heat storage media and systems, new generation biofuels, as well as Power-to-X (*i.e.* using low-cost renewables as an energy input to production process for chemicals, synthetic fuels, etc). (See Box 5 for an overview of some renewable energy technologies possibly upcoming in South Africa.)

The contribution to these developments gives South African companies the opportunity to have intellectual property and export South African-based innovation to other markets. The opportunity to take part in innovation and development of these technologies may have a limited associated time window because once technologies reach full maturity and cost reductions become incremental, there is only limited scope for further technological improvements that South Africa may achieve and commercialise.

9 RECOMMENDATIONS FOR AN ACCELERATED ENERGY TRANSITION IN SOUTH AFRICA

South Africa has vast potential for renewable energy deployment and energy efficiency, including in end-use sectors. Chapter 7 identifies the concrete technology options that exist in different sectors. To realise the available technology options and the associated benefits, South Africa needs to address the central barriers and challenges faced by the national energy sector. The opportunities identified by sector in Chapter 8 point to suggested ways to enhance the enabling framework and conditions for increased renewable energy and energy efficiency. This chapter translates the analysis into a set of concrete recommendations for the national energy transition, along the following seven central themes:

- Realign the national energy sector structure.
- Enhance investments in national power sector infrastructure.
- Clarify and simplify the regulatory environment (particularly for SSEG) and ensure consistent implementation of polices.
- Support targeted research and development on innovative renewable energy (enabling) technologies, undertake research on a just transition for the energy sector and devise corresponding measures.
- Increase sector coupling to exploit opportunities for renewables-based power to underpin other end-use demand sectors such as transportation and industry.
- Widen the use of private-public partnerships in the deployment of renewable energy.
- Fully realise the potential of embedded generation.

The specific recommendations under these seven central themes are further explained in the following sections.

9.1 Realignment of the national energy sector structure

The energy sector structure in South Africa has served the country well for several decades. Over recent years, renewable energy has become increasingly cost-competitive, particularly as a distributed small-scale solution. This development has challenged the suitability of the current energy sector structure. In light of this, certain restructuring options for the national energy sector should be investigated and selected for implementation.[39]

They may include an institutional realignment to adapt to a power sector with higher shares of variable renewables. The realignment needs to enable the application of new business models and maintain the financial sustainability of the institutions facing emerging trends such as:

- generation for self-consumption (*i.e.* prosumers)
- increase embedded generation, with a targeted focus on improving energy access (especially, at a small scale)
- energy trading
- digitisation
- increased flexibility of power systems, including increased ramping of large fossil plants, improved renewable resource forecasts, demand response and storage technologies (*e.g.* battery storage)
- demand for a range of new and more diverse energy-related municipal services (rather than just on-selling of power from the wholesale market).

39 As outlined in Chapter 3, Box 2 of this study, President Ramaphosa in February 2019 announced the unbundling of Eskom into three separate entities – Generation, Transmission and Distribution – under Eskom Holdings. Since the news emerged after the writing of this study, it was not reflected in the present findings.

9.2 Enhanced investments in national power sector infrastructure

Over recent years, South Africa repeatedly faced periods of load-shedding. The power cuts are imposed to prevent a collapse of the national electricity grid. Especially national industries that rely on stable supplies for maintaining smooth operations are negatively affected by rolling outages, which lead to reduced output and contribute to suppressed economic growth in South Africa.

The load-shedding is the result of a severe backlog for electricity infrastructure maintenance, rehabilitation and strengthening. In addition, the new mega coal plants are years behind schedule, significantly over budget and not properly functioning due to technical problems. Eskom is therefore unable to generate enough electricity for reliably meeting national demand. South Africa needs to considerably increase investment in the national power infrastructure to address the current backlog and strengthen national generation capacity and grids. The effect of such investments can be further enhanced through realignment of the national energy sector structure (see Chapter 9, Section 1).

9.3 Enhanced regulatory process and consistent policy implementation

The energy sector regulatory environment is still evolving in South Africa as new technologies and generation options influence actors in the market. Creating a supportive environment for renewable energy needs to include a regulatory regime that is simple, clear and easy to understand. This also implies that, once policy decisions are taken, there should be an effort to minimise retrospective changes to those policies in order to create policy stability and certainty.

Key elements to consider within the regulatory environment include:

- treatment of embedded generation in jurisdictions where grid infrastructure is owned by Eskom, by metro municipalities, and by smaller municipalities, respectively.
- clarity on how different associated regulatory rules relate and link to one another (*e.g.* rules and regulations on embedded generation, wheeling, trading, procurement, etc).
- improved communication with energy sector actors regarding the progress of regulatory processes.

Certain issues that are inherently complex will require lengthy deliberation between multiple government departments. In such instances, it is especially important to increase transparency and communication to maintain the confidence of all interested and affected parties.

In addition, South Africa already has a range of policies and programmes that are well designed for supporting its national objectives. Examples in the energy sector include the REIPPPP and the INEP. A key element of success, besides formulating good policies, lies in ensuring their effective and consistent implementation. There are several instances where inconsistent implementation has harmed the perception around the national energy sector. Examples of inconsistency may include:

- delays in procurement programmes where prior commitments and timelines are not observed.
- retraction of promulgated policy, regulatory rules or instruments.
- the promulgation of policies from different government departments where there is poor alignment.
- differentiated treatment of sector stakeholders under the same policy or regulatory environment.

For a successful national energy transition, such instances should be avoided.

9.4 Targeted research on innovative technologies and key aspects of the "just transition"

South Africa should support research and development for innovative technologies to be able to leapfrog certain technologies and participate in major growth markets. This includes renewable energy technologies (ocean energy, etc) and renewables-enabling technologies (storage, smart grids, etc). For these potential future technology options, further work needs to focus on understanding their potential and the research and development required to achieve maturity and commercialisation. See Box 5 of this study for a more detailed overview.

However, the gradual transition to an energy sector with higher shares of renewable energy does not only involve new technologies, market players, and power system operations – it also involves people, jobs and communities. The South African energy sector has relied on coal and other fossil fuels for decades, and this sector provides many jobs. At least part of the resistance against renewables seen from some stakeholders originates from a concern about the impact on jobs in the coal and broader fossil fuels sectors – concerns that are reasonable in a country with very high unemployment. To ensure an inclusive and just energy transition and fair prospects for renewables, there should be a clear understanding and roadmap to outline the implications of such a transition as well as how exactly it will be executed. Such clarity will require further targeted research on the following aspects:

- the impact on jobs in the coal mining sector and related sectors (*i.e.* coal processing, coal transportation).
- prospects for re-skilling workers from fossil fuel-based industries and repositioning these people for a future in renewables, as well as for establishing new clean industries in coal mining regions.
- clarity of the national job creation potential of renewable energy projects and along the entire renewable energy value chain (see IRENA [2018b] for further information).
- understanding how the transition to higher shares of renewable energy impacts the developmental path of the country, looking not only at renewables as an enabler for supply of low-cost energy but also for lower pollution, overall environmental protection, and improved public health (especially in communities around heavy coal mining and power generation; see, for example, the Co-Benefits project in South Africa described in Chapter 7, Section 3).
- the extent to which renewables can provide opportunities for micro and small-scale enterprise development.

As outlined in Chapter 7, Section 3, it will be crucial to manage an inclusive, gradual process and foster social acceptance for the renewable energy transition. For this purpose, and to address the above-listed aspects in an integrated manner, South Africa could set up a national commission to foster a dialogue between key role-players and to jointly develop a comprehensive coal phase-out plan and associated measures for cushioning impacts on workers and communities.

9.5 Sector coupling and end-use sector debarbonisation

Productive end-uses in other sectors are often reliant on fossil fuels. The most prominent example is the dominance of petroleum-based fuels in transportation. Also, in many instances, biomass and fossil fuels are used for heating purposes in South Africa. To achieve deep carbon emission reductions, the use of renewables-based power as a substitute for fossil fuels may prove to be a very useful option.

Technology options for supplying a range of end-uses with electricity exist, as outlined in Chapters 7 and 8. Besides the transport sector, sector coupling could also be done between the power sector and the heating/cooling sector. For example, instead of curtailing excess renewable energy, it may be used for water heating in the residential sector and hence substitute some of the fossil fuel-based electricity that is used for water heating in South Africa – particularly in the residential sector. Coupling of the power and heating sectors can thereby increase the flexibility of the power system (essentially creating variable and dispatchable demand) and enhance the ability of the power system to accommodate higher shares of variable renewables. Proper analysis of the South African power system should be conducted to see whether the more valuable option is using renewables for water heating (*i.e.* solar water heating) or coupling water heating to power generation such that there is flexible demand to accommodate increased deployment of variable renewable energy.

9.6 Development of public-private partnerships in the energy sector

In recent years, South Africa has rolled out major infrastructure projects using the public-private partnership model. Two of the most prominent existing examples of such an approach in South Africa are the Gautrain project (the largest public-private partnership project in South Africa's history) and the REIPPPP in which the South Africa Government created a procurement programme that attracted investment from the private sector. The partnership between the public and private sector took place not only at the programme level (with government setting up the REIPPPP and industry responding to this) but also at the project level, where public sector investment firms (*i.e.* IDC, DBSA, PIC, and others) took equity shares in projects alongside private sector investors. This model proved effective and led to the unlocking of over USD 15 billion in direct investment into the renewable energy sector alone. The applicability of this model should be explored in other areas as well, particularly:

- In a potential programme centred on municipalities procuring energy for demand within their jurisdiction. Such a programme is currently being explored by Ekurhuleni Municipality and, with national government backing, other municipalities may be able to also explore this possibility.
- Setting up manufacturing facilities where risk is shared between both public and private sector investment firms. This has been attempted for the manufacture of wind turbine towers in the Coega Industrial Development Zone where the IDC together with DCD Wind Tower entered into a joint venture.
- Although the results of this joint venture were somewhat mixed. This was primarily due to delays in the REIPPPP procurement rounds, which led to unsteady demand for the production of wind towers and affected the profitability of the manufacturing facility.

In principle, however, the use of public-private partnerships can allow for optimal risk sharing and for the unlocking of investment for further deployment of renewables, thereby creating employment at the same time.

9.7 Realising the full potential of SSEG

In recent years, embedded generation has accelerated in South Africa. This development has been more the result of market forces and the performance of the national utility rather than of active policy support. These developments outside of a comprehensive government programme are having negative effects on all incumbent electricity suppliers (*i.e.* both the national utility and municipalities). These effects include revenue losses from decreased electricity sales, grid defections and under-recovery of costs for electricity distribution.

To mitigate against these effects and guide the further growth of this sector for the benefit of the country, a more proactive approach should be adopted. In encouraging the further development of embedded generation, attention should be given to:

- Potential financial savings due to decreased maximum notifiable demand as a result of localised generation from solar PV.
- Possibilities for municipalities to diversify their offering into energy services supporting small-scale installations (and thereby safeguarding their financial sustainability). At the same time, municipalities and Eskom need to adopt new business models to engage in new service offerings.
- Job creation potential and small, medium and micro-sized enterprise development with regard to installation and maintenance of small-scale generation units.

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ANNEX: LIST OF STAKEHOLDERS

In the development of this study, national stakeholder meetings and consultations were held jointly by the Department of Energy (DoE), the South African National Energy Development Institute (SANEDI) and IRENA, with support and significant inputs from CSIR and UCT.

As part of those meetings, the REmap project team distributed a stakeholder questionnaire. IRENA, the DoE and SANEDI thank the following organisations and individuals for their inputs during the meetings and consultations.

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