PARLIAMENT
OF THE REPUBLIC OF SOUTH AFRICA

Electricity generation technology choice: Costs and considerations

Parliamentary Budget Office

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This report has been compiled in response to a request from the Chairperson of the Standing Committee on Appropriations in Parliament. The Committee asked the PBO to investigate the costs of energy generation technology.

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1. Introduction

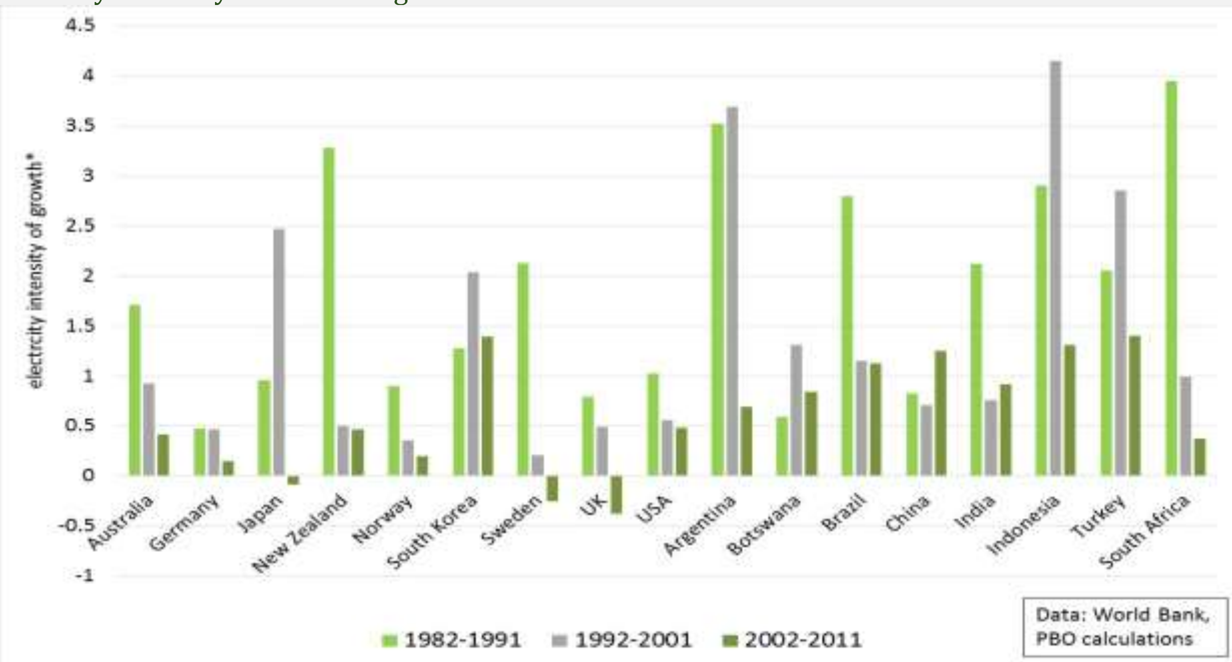
South Africa will add additional electricity generation capacity to meet both future demand and replace its ageing fleet. It is critical that the technology-mix chosen is optimal in terms of the effect on public finances and growth. This study presents the key factors that need to be considered by Members of Parliament concerned with public finances in considering technology choice, and compares different technologies according to the identified factors.

1.1. Electricity and economic growth

An adequate and reliable supply of electricity is essential for economic growth and development. The amount of electricity consumed by an economy varies according to its population size, the size and nature of its economy, and its level of economic growth.

Box 1: Electricity-intensity of economic growth
Economies vary in their reliance on electricity for economic growth. The electricity-intensity of growth presents the change in electricity consumed by an economy relative to the change in the size of the economy, over a specific period. It reflects the economy's reliance on electricity for economic growth. The figure below presents the electricity-intensity of growth for a range of developed and emerging-market economies. The energy-intensity of growth of an economy is not constant, but instead changes over time. Most countries have experienced declining electricity-intensity of growth over the last three decades. Some highly-developed economies have even experienced negative electricity-intensity of growth, as overall electricity consumed declined while their economies grew. South Africa has experienced a significant decline in its electricity-intensity of growth. Over the period 2002-2011 the country's electricity-intensity of growth was the lowest compare to comparator developing countries. This was in part due to constrained electricity supply since 2008.

Electricity-intensity of economic growth 1982-2015



As economies develop from low-income, dependent on subsistence agriculture towards secondary and tertiary sectors, and as populations urbanize, the demand for electricity increases. As developing and advanced economies move away from heavy-manufacturing, and as fertility rates decrease, the electricity-intensity of growth slows down.

The relationship between growth and electricity consumption is bi-directional. The increase in economic activity increases demand for electricity, and the increase in electricity supply (capacity) also enables economic growth. Countries with limited electricity supply/with supply constraints experience slower growth.

1.2. Energy planning

Given the importance of electricity for growth, countries place great emphasis on energy planning. Energy planning, of which electricity is a fundamental component, seeks to ensure that a country has an adequate supply of electricity to meet its needs (system adequacy). In attempting to meet a country's electricity needs, energy planning seeks to:

- **Ensure affordability of electricity infrastructure**. In the case of a public utility, whether the utility's balance sheet (with or without state support) can sustain the investment.

- **Ensure that electricity is affordable for households and business.** High electricity prices increase the cost of living and reduce poor households' ability to meet basic needs. High electricity prices also increase the costs of doing business and reduce a country's competitiveness. Higher prices may reduce demand as households and businesses move towards alternate sources of energy, increase efficiency, and the economy shifts towards less energy-intensive sectors.

- **Maintain a responsive electricity system.** As power plants can take anything from 2 to 25 years to construct and commission, countries cannot simply add more capacity as the need arises. It is therefore essential that countries plan for the future. Countries rely on regular projections of electricity demand to determine future generation requirements. However demand projections, like GDP growth projections, are inherently uncertain. Both insufficient and excess capacity are potentially harmful to an economy. Insufficient capacity restrains growth and may deter investment. Excess capacity still needs to be paid for, operated, and maintained. This results in higher electricity prices. In addition scarce resources dedicated to constructing unnecessary capacity could have been allocated to meet other social and economic needs.

- **Meet the country's environmental objectives.** As electricity-generation technologies vary in their impact on the environment, the choice of technology can contribute to realising environmental objectives. Internationally, there is increasing emphasis on the need for the electricity supply industry to reduce carbon emissions in an attempt to fight climate change.

- **Meet the country's industrial policy objectives.** As constructing electricity-infrastructure (generation, storage, transmission and distribution) entails significant investment over several years (undertaken by public or private utilities), domestic procurement can be used to develop and further the country's industrial capabilities and create employment opportunities.

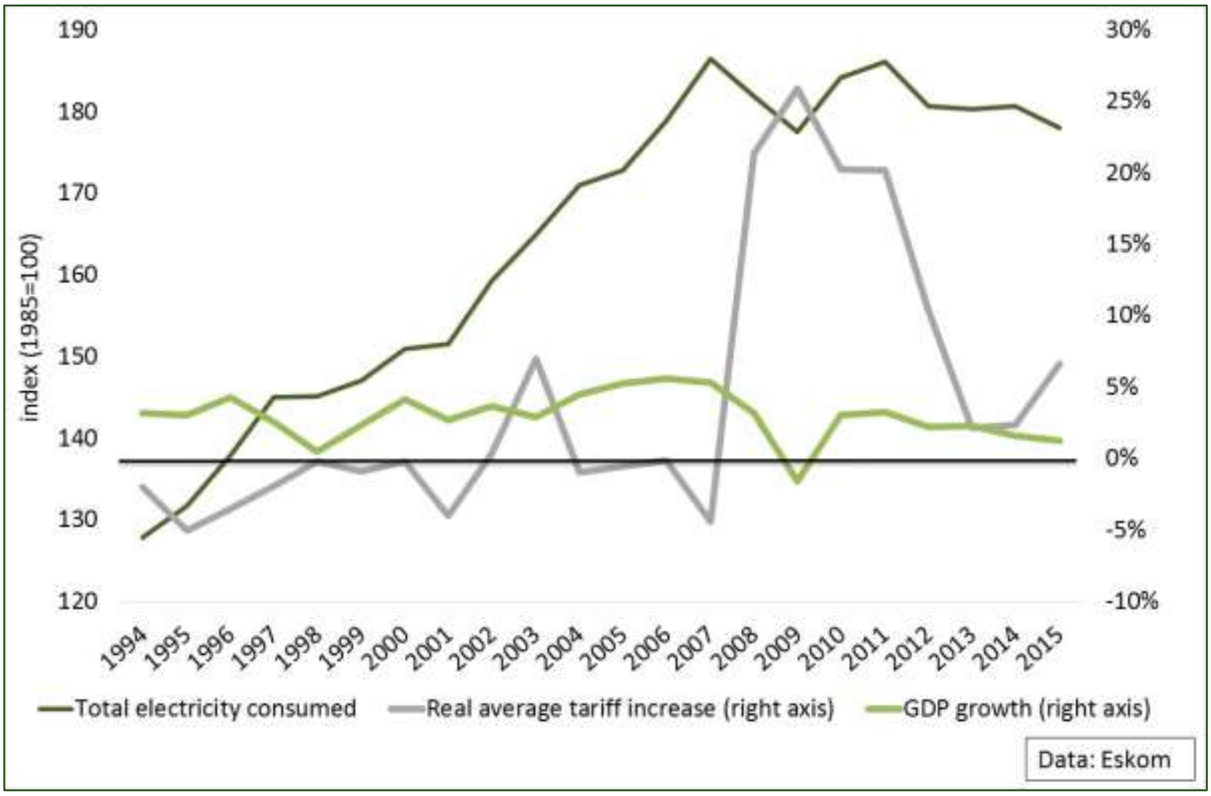
- **Meet the country's regional development objectives**. As neighbouring countries have varied electricity-generation capabilities and needs, countries are able to import and export electricity. Large regional energy projects may require regional cooperation and off-take from larger economies to be financially viable. However, while a country may have adequate supply through depending on other countries for electricity, fuel or technology to meet its own demand, this poses an energy-security risk. This risk could be reduced through greater self-reliance.

The above policy considerations have different implications for policy makers concerned with public finances. Promoting economic competitiveness, ensuring affordable electricity, and ensuring prudent use of state resources typically requires the lowest-cost electricity generation technology. Reducing the country's carbon emissions, promoting domestic industry and employment creation means higher costs options. The challenge faced by policy-makers regarding energy choice is how to balance these considerations. Placing emphasis on some considerations while ignoring others comes at a cost (financial, economic, environmental or other). Critical in these considerations are the country's level of development and short and medium-term economic outlook.

2. Energy choice in South Africa

South Africa is in the process of adding significant additional electricity generation capacity to its fleet. Over-investment during apartheid, followed by poor planning and insufficient investment after 1994 resulted in electricity prices being low by international standards with several years of real price decreases[1]. This incentivised an energy-intensive industrial base. Economic growth, which averaged 3.6 per cent a year between 1994 and 2008 increased demand for electricity across the economy. The demands on South Africa's electricity sector further increased with the country's social policies of household electrification and free basic electricity (FBE). By 1999 access to electricity was provided to an additional 2.5 million households, with additional connections to rural clinics and schools increasing the electrification level from about 36 per cent in 1994 to about 75 per cent at the end of 1998 (DME, 2001). South Africa's total electricity demand increased by 43 per cent between 1994 and 2004, by 2007 electricity demand increased by 63 per cent.

Figure 1: Electricity demand, prices and growth 1994-2015



The lack of investment in generation capacity resulted in the country's electricity supply struggling to meet the rapidly rising demand. In 2004 government had agreed to finance the building of new generation capacity, however this was too late to avert the growing pressure on the demand-supply balance. The situation culminated in country-wide blackouts from December 2007 to May 2008.

[1] The capital cost component of electricity tariffs in this period was negligible due to most power stations already been fully paid for. Excess capacity meant that new projects were not being financed.

2.1. New investment

In response to the dire need to increase supply, the country embarked on a massive investment program. Eskom refurbished old stations that were previously mothballed when the country had excess capacity. Eskom undertook significant investment in two large coal-fired power stations (Medupi and Kusile), a pumped storage plant, and the Sere wind farm. The country also commissioned the addition of 3725 MW of renewable capacity in the first three windows of the renewable energy independent power producer programme (REIPPP), and the subsequent 1121 MW in the fourth window.

Table 1: Recent electricity generation projects

Plant	Type of station	Project	Total future installed capacity (MW)	Addition to existing installed capacity*	Commenced	Completed
Grootvlei	Coal station	Refurbishing	1180	2.7%	2008	2013
Komati	Coal station	Refurbishing	1000	2.3%	2009	2012
Sere	Wind farm	New build	100	0.2%	2013	2015
Ingula	Pumped storage	New build	1332	3.0%	2005	underway
Medupi	Coal station	New build	4764	10.8%	2007	underway
Kusile	Coal station	New build	4800	10.9%	2007	underway
REIPPP BW1-3	various renewables	New build	3725	8.4%	2012	-
REIPPP BW4	various renewables	New build	1121	2.5%	2015	-
Total			**18022**	**40.9%**		

*Existing installed capacity excludes mothballed pl   Data: Eskom and Department of Energy

Despite these measures, the electricity demand-supply balance has remained tight. Limited capacity has forced Eskom to run plants for longer, with less time available for maintenance. This has reduced plant efficiency. In addition, Eskom has had to also run its diesel-powered peaking plants (open cycle gas turbines) to meet demand and avoid load-shedding. As the open cycle gas turbines are expensive to operate, this has further increased the cost of producing electricity, which has, to an extent, been passed on to the consumers.

The significant investment, a change in pricing methodology necessary to finance the investment, and additional costs incurred by Eskom to “keep the lights on” have also resulted in large increases to the electricity tariffs. Between 2007 and 2015 average electricity tariffs increased by over 170 per cent in real terms (nominal: 324%), compared to the period 1999 to 2007 where tariffs only increased by 38 per cent (nominal: 38.6%). Electricity prices are likely to increase further as Eskom moves toward fully cost-reflective tariffs.

2.2. Energy technology choice in SA

South Africa, like many other countries, determines its electricity generation capacity path through an Integrated Resources Plan (IRP). An IRP is a capacity expansion plan that covers total electricity demand requirements for the country. Integrated Resource Plans attempt to determine the optimal mix of electricity generation plants for the future in a transparent manner. This is based on assumptions about the country’s growth outlook, electricity needs, the costs and efficiencies of different technologies, coupled with the country’s commitment to reduce Co_2 emissions and other economic, social and environmental considerations. However, as inputs and assumptions, as well as the policy environment informing an IRP change, it is necessary to update an IRP for it be relevant and applicable. Countries therefore regularly update their Integrated Resource Plans.

South Africa's IRP is a subset of its Integrated Energy Plan, which is broader plan that covers all the country's energy needs. The Electricity Regulation Act (Act 4 of 2006) established the necessary powers for the Department of Energy to conduct an open IRP process. The IRP process is intended to allow for more transparent determination of the country's electricity generation path, and is intended to involve cabinet and stakeholders. In addition to the IRP, The Minister of Energy, in consultation with the National Energy Regulator, may also make Ministerial Determinations for new generation capacity if she/he believes that it is required to secure the continued uninterrupted supply of electricity. The Ministerial Determinations may also outline the generation technology. This is contained in Section 34(1)(a) of the Electricity Regulation Act.

The first IRP was completed in 2010. However it was published without consultation with only a month for comment. It was only three pages long, covering 2010 to 2013. This was followed by the IRP 2010, also known as the "policy-adjusted IRP". The IRP 2010 covered the period 2010 – 2030 (Baker, Burton, Godinho, & Trollip, 2015). It included different scenarios with a range of base-load and peaking plant technologies, with a schedule to come on-line. It also considered the country's Co_2 emissions targets. The Department of Energy later attempted to update the IRP 2010 by releasing its 2013 update. This was however not approved by the legislature. A new IRP is expected in 2016.

2.3. Changes since the last Integrated Resources Plan

The (current) official capacity expansion plan for electricity generation in South Africa (IRP 2010) is based on assumptions that are out-of-date. Its update (2013), although not official, is also based on out-of-date assumptions. Using an out-of-date IRP will result in sub-optimal-mix of generation plants and higher electricity prices.

Figure 2: Expected and actual growth 2011-2020

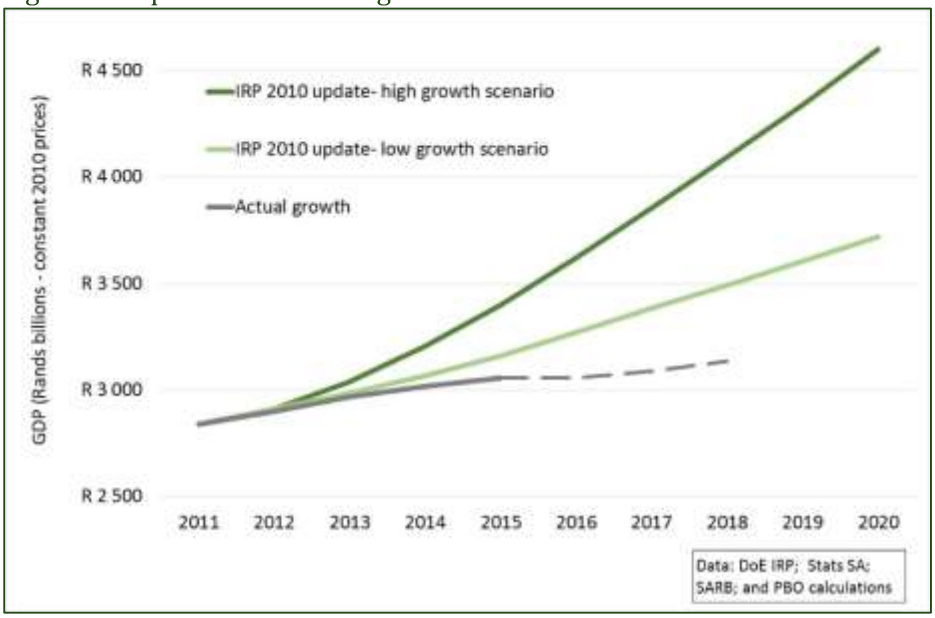
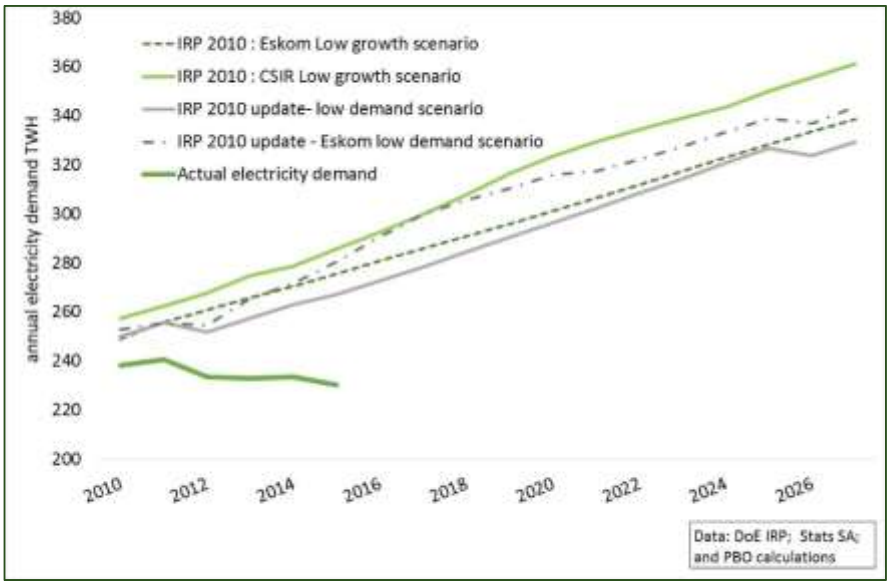


Figure 3: Expected and actual electricity demand 2010-2026



Economic growth has been much slower than assumed in the IRP 2010 and the IRP update, even when compared to the IRP's low growth scenarios. Slow economic growth, limited electricity supply, and higher electricity tariffs have reduced growth in demand for electricity. Since 2011, demand for electricity has been about 12 per cent lower than expected in the Integrated Resource Plans. Annual electricity demand is yet to recover to pre-2008 levels. The slow growth outlook, and lower energy-intensity of growth imply a significantly reduced energy demand outlook for the country. This necessitates an adjustment to the country's electricity generation capacity plans and careful consideration over any new procurement.

Since the IRP 2010 and the 2013 update, there have been several other developments related to electricity generation which necessitate a reconsideration of the optimal generation technology level and mix. These include:

- Technology costs and efficiencies (including carbon emissions, fuel and water requirements) have changed (see sec 3.5 and 3.6).
- There have been significant changes in the price and availability of fuels.
- South Africa's recent experience with large electricity generation infrastructure projects (Medupi and Kusile), and smaller projects (REIPPs, Sasolburg, Sere wind farm) have provided insights and local-benchmarking into South Africa specific lead-times and costs, allowing for more accurate cost and time estimates for future projects.
- Energy-intensive sectors have reduced their demand.
- Eskom's finances, and consequently its ability to raise debt and finance major projects without the support of the state, has worsened.
- Slow growth, rising national debt and increased guarantees issued to state owned entities, have reduced the state's room to provide guarantees and direct support to state owned entities.
- The country's credit ratings have deteriorated and its borrowing costs have increased.

These developments warrant careful consideration over energy technology choice for the country.

3. Electricity generation choice – costs and considerations

This section presents the main considerations for policy makers concerned with the procurement of electricity generation capacity as it relates to the use and allocation of public resources. It discusses potential implications for the economy and public finances resulting from the identified considerations. It provides recent estimates of costs and other considerations based on independent studies.

3.1. Data and limitations

Country-specifics significantly influence the cost of generating electricity. While international estimates by organisations such as the International Energy Agency allow for the comparison of the cost of producing electricity across different technologies, it is more accurate to compare cost estimates that reflect country specifics. This report therefore uses cost estimates and technical specifications for the range of technologies from the Department of Energy's IRP 2010 and the IRP update, as well as the Electric Power Research Institute's 2012 and 2015 estimates prepared for the IRP.

Box 2: EPRI cost estimates
The Electric Power Research Institute (EPRI) is a non-profit organisation that conducts research on the generation, delivery and use of electricity for the benefit of the public. The organisation's vast network of scientists, engineers and experts enables it to provide objective counter-viewpoints to government and industry. EPRI regularly conducts cost of generation studies to support better technology choice.

In addition to independence and expertise, EPRI is able to provide cost estimates that more accurately reflect country specifics – critical for appropriate technology choice. This is possible through linkages with national utilities and other local experts (Eskom is a member of EPRI). EPRI recently undertook two cost of generation studies (2012 and 2015) to inform South Africa's Integrated Resources Plan. The 2015 study is the most recent and detailed cost estimate of electricity generation technologies available for South Africa.

Despite using the most recent estimates reflective of the cost of constructing power plants and producing electricity within South Africa, the cost estimates are based on assumptions regarding several of variables. A change in one variable, such as the price of fuel or the country's credit rating, will have a significant impact on the actual cost. In addition, and noted in the EPRI reports, the cost estimates are for generation technologies within South Africa, and do not include the additional costs and considerations surrounding specific projects within a country. For example, constructing a 1000MW coal power plant far from a city and transmission infrastructure will be more expensive than if the same plant were to be located closer to a city and transmission infrastructure. Cost estimates for particular projects rather than technologies therefore present more accurate estimates.

3.2. Technologies considered

The specific technologies compared in this section are derived from the technologies included in the IRP 2010 and the IRP 2010 update. They include base-load and intermediate technologies. Hydro-electric options are only available in the IRP update, more recent estimates are not available.

Table 2: Technologies considered

	Technology	Type	Rating
conventional technology	Coal 1	Pulverized Coal with FGD	6x750MW
	Coal 2	Pulverized Coal with CCS	6x750MW
	Coal 3	Fluidized Bed Combustion with FGD	1x250MW
	Coal 4	Fluidized Bed Combustion with FGD and CCS	1x250MW
	Coal 5	Integrated Gasification Combined Cycle	2x644MW (IRP 2010: 125MW)
	Coal 6	Integrated Gasification Combined Cycle with CCS	2x644MW
	Nulcear 1	Areva EPR	1X1600MW
	Nuclear fleet	Areva EPR - multiple nuclear units with the same commercial service date	6X1600MW
	Gas 1	Combined Cycle Gas Turbine	711MW (EPRI 2015: 732MW)
	Gas 2	Combined Cycle Gas Turbine with CCS	591MW (EPRI 2015: 635MW)
renewable technology	Wind	Farm	2x50MW (IRP 2010: 200MW)
	Solar 1	Concentrated Solar Power - Parabolic trough - 6 hours storage	125MW
	Solar 2	Concentrated Solar Power - Parabolic trough - 9 hours storage	125MW
	Solar 3	Concentrated Solar Power - Central receiver - 6 hours storage	125MW
	Solar 4	Concentrated Solar Power - Central receiver - 9 hours storage	125MW
	Solar 5	Concentrated photovoltaic (PV)	10MW
	Biomass 1	Forestry residue	25MW
	Biomass 2	Municipal solid waste	25MW
	Hydro 1	Imported hydro - Mozambique	1500MW
	Hydro 2	Imported hydro - Mozambique	850MW
	Hydro 3	Imported hydro - Zambia	250MW
	FGD: Flue Gas Desulfurization, CCS: Carbon Capture and Storage		Data: DoE IRP and EPRI

Box 3: Hydro-electric options

While South Africa is a water-scarce country with limited hydro-electric potential within its borders, the region has significant hydro-electric potential. The IRP update included regional hydro-electric import options from Mozambique and Zambia. The cost estimates from these are included in the analysis. Significant hydro-electric potential also exists with the proposed development of the Grand Inga on the Congo River in the Democratic Republic of Congo. If developed, the Grand Inga will offer the region more than 40 000 MW of capacity - more than South Africa's current installed capacity- and will be the largest hydro-electric scheme in the world. For the project to be feasible, several countries would need to be involved, with South Africa as the greatest electricity consumer in the region, having to off-take future output. The International Energy Agency notes, that to achieve low-carbon electricity, electricity markets will have to become more flexible and better integrated across borders in order. This requires governments to work together to integrate their regulatory frameworks regarding security of electricity supply, and the deeper integration of electricity markets (IEA-OECD, 2013). The Grand Inga could alter the carbon-intensity of the country's electricity supply industry.

3.3. Costs

Ensuring stable and healthy public finances, and promoting economic growth in the consideration of electricity generation technology, necessitates careful consideration of the costs of the range of technologies available to meet the country's electricity needs. The technology-mix adopted should supply the country's electricity demand while efficiently allocating scare public resources. This requires selecting the lowest-cost technically viable option.

3.4. Cost comparisons

As a country considers a range of potential technologies, it is necessary to standardise cost estimates to allow for comparison. The most commonly used measures are; the levelised cost of electricity (LCOE) and; the overnight capital cost.

It is important to note that while the LCOE and the overnight capital cost are useful summary measures of the overall competiveness of different generating technologies, actual plant investment decisions are affected by the specific technological and regional characteristics of a project, which involve numerous other factors.

3.5. Overnight capital cost

A common measure to compare different electricity generation technologies is the capital cost. The capital cost presents the total capital cost to construct a power plant, and is standardised (divided by the capacity of the plant) to allow for comparison of economic feasibility across plants with different capacities. It is expressed in terms of cost (Rands) per kilowatt (of capacity). It is also referred to as the overnight capital cost as it does not take into account financing costs or cost escalations. It therefore is not a final cost of total construction. The overnight capital cost estimate indicates a general affordability of a technology, and is thus useful as a "first hurdle" in technology consideration. If the capital cost is too high, the technology simply cannot be afforded.

Figure 4: Overnight capital costs – conventional technology (constant 2015 prices)

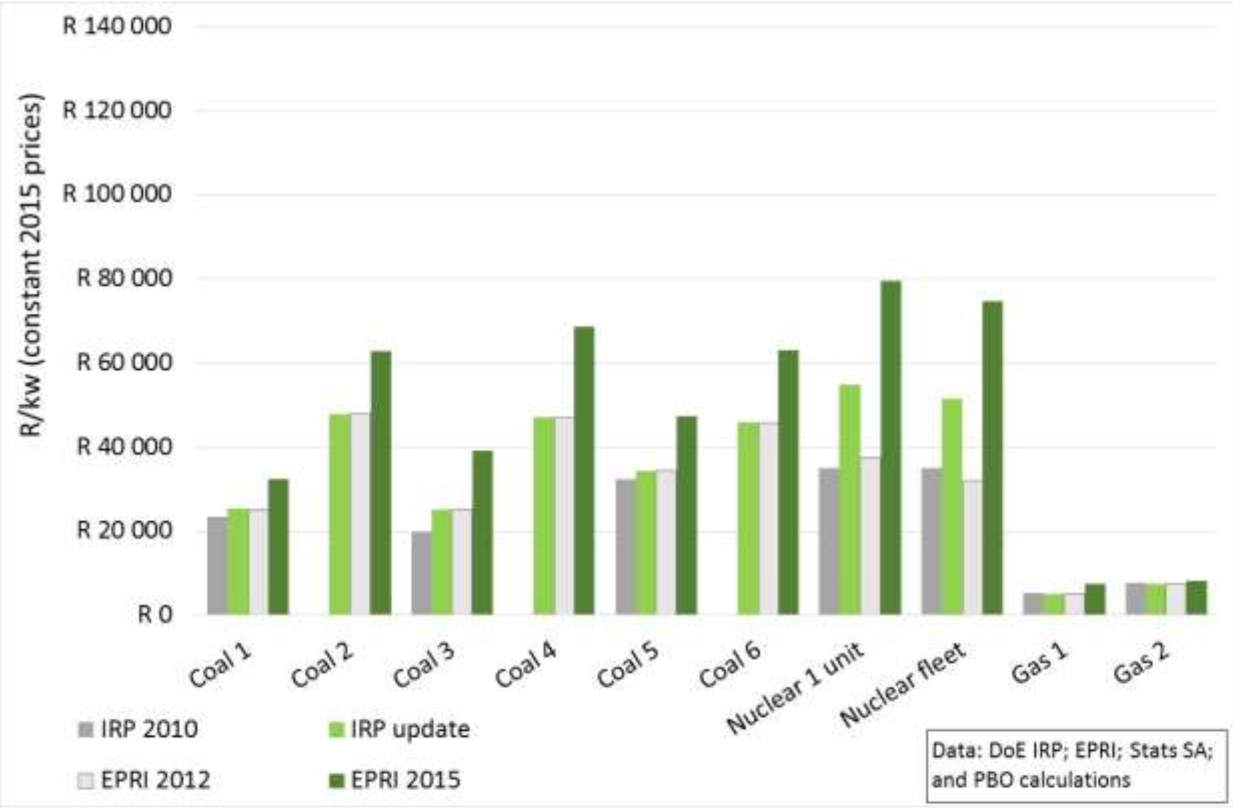
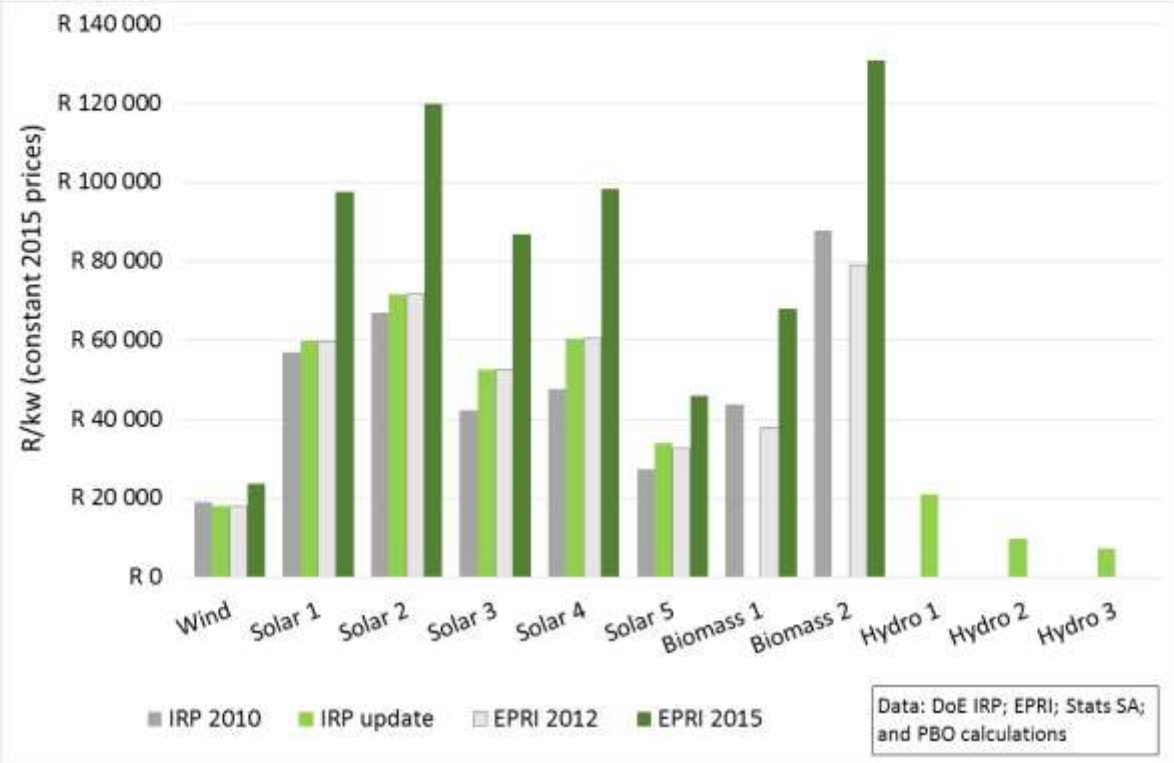


Figure 5: Overnight capital costs – renewable technology (constant 2015 prices)



Figures 4 and 5 show capital costs estimates for conventional and renewable technologies in constant 2015 prices. The most recent cost estimates, from the Electric Power Research Institute 2015 study, are significantly higher than the previous estimates. This highlights the necessity for the country to update its electricity generation capacity path. On an overnight capital cost basis, renewable technologies – with the exception of wind and hydro – are more expensive than conventional technologies. On an overnight capital cost basis, gas technology is the cheapest technology across both conventional and renewable energy options, followed by hydro, wind and Coal (1 and 3). Within the range of conventional technologies considered, nuclear energy is the most expensive – 16 per cent more than the most expensive coal option (coal 4) and 67 per cent more expensive than the most expensive gas option (gas 2).

While overnight capital costs, are simple to estimate and understand, and are used internationally to provide a useful measure of affordability between competing options, they exclude other important considerations that affect the overall cost of generation technology. These include:

- Financing costs
- Plant life
- Plant load-factor
- Operation and maintenance costs
- Fuel costs

While the exclusion of these factors allows for less variability in cost estimates, it also results in cost estimates that are not fully reflective of the costs and risks associated with the particular technology. The IRP 2013 update and the IRP 2010 focus on overnight cost of capital, and only include LCOE in the appendix to the document.

Box 4: Cost over-runs

Internationally, most major infrastructure projects exceed the original time and cost estimates. Electricity-generation projects are no exception. Significant cost escalations increase the cost a country and consumers have to pay for electricity. Large-scale electricity generation build programmes are generally always completed even if they turn out to be more expensive to build, operate and maintain than initially estimated. Inaccurate cost estimates, and technologies more likely to incur cost-escalations, therefore have the potential to lock the country into higher than budgeted for/affordable expenditure for several decades. This has been the case with both Medupi and Kusile. It is critical that cost estimates are as accurate as possible, and technology choice is cognisant of the cost escalation potential of different technologies.

Cost and time over-run across different technologies

	Hydro	Nuclear	Thermal (including coal)	Wind	Solar
Number of projects in sample	61	180	36	35	39
Projects with cost over-run (%)	77	92.2	66.7	57.1	41
Average cost escalation (%)	70.6	117.3	12.6	7.7	1.3
Average cost over-run (US$ million)	2437	1282	168.5	32.8	-4.2
*Time over-run (%)	63.7	64	10.4	9.5	-0.2

*Applies only to a smaller subsample N = 33 for hydro, 175 for nuclear, 24 for thermal, 18 for wind, 23 for solar

Source: Sovacool, Gilbert and Nugent, 2014

A study by Sovacool, Gilbert and Nugent (2014) investigating cost and time overruns in electricity projects find that cost escalations are not the same for all electricity generation technologies. Their findings, which are based on 401 electricity projects built between 1936 and 2014 in 57 countries, indicate that nuclear and hydro-electric power projects have the highest occurrence of cost over-runs, and the highest cost and time escalations.

3.6. Levelised cost of electricity (LCOE)

An alternate measure of the overall competiveness of different generating technologies is the levelised cost of electricity (LCOE). The LCOE is a summary measure that represents the per-kilowatt hour cost of building and operating a generating plant over an assumed financial life. It is intended to be used as financial tool in comparing the costs of electricity generators.

Box 5: Estimating the levelised cost of electricity (LCOE)

To determine the LCOE, the total cost of building an electricity generator is first calculated by accounting for the projected capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilisation rate for each plant type. Each cost component is then adjusted for inflation to account for the likely change in nominal costs over time and discounted back to today. The importance of each factor in calculating total cost varies among technologies. For example, for technologies such as solar and wind generation that have no fuel costs and relatively small variable O&M costs, LCOE is mostly determined by the estimated capital costs. Once the discounted total lifetime cost of a generator has been calculated, it is then divided by the system's lifetime expected power output – measured in kilowatts per hour (kWh), generating the LCOE.

Figure 6: Components of LCOE

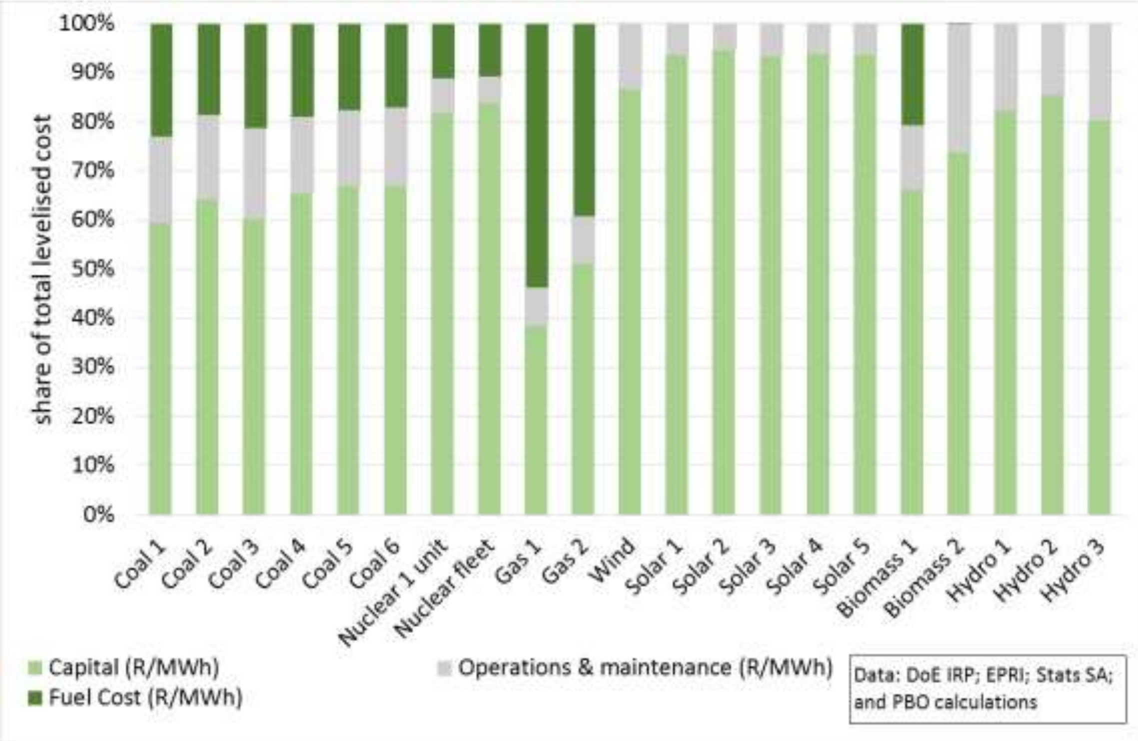
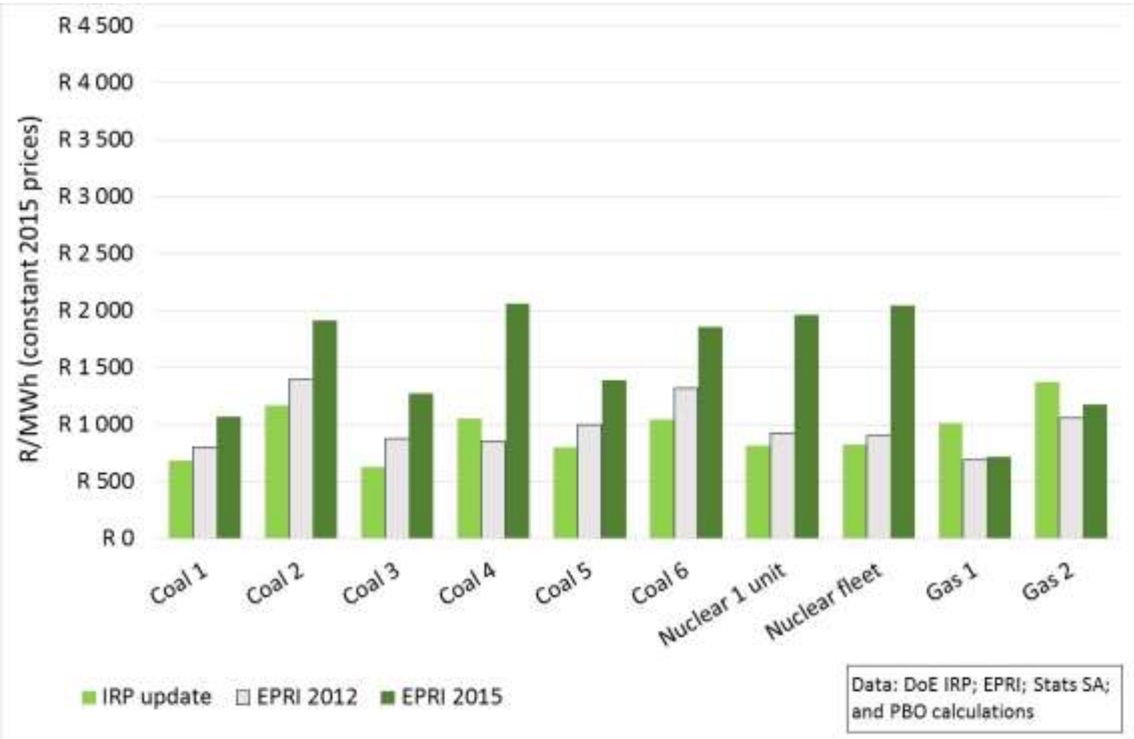
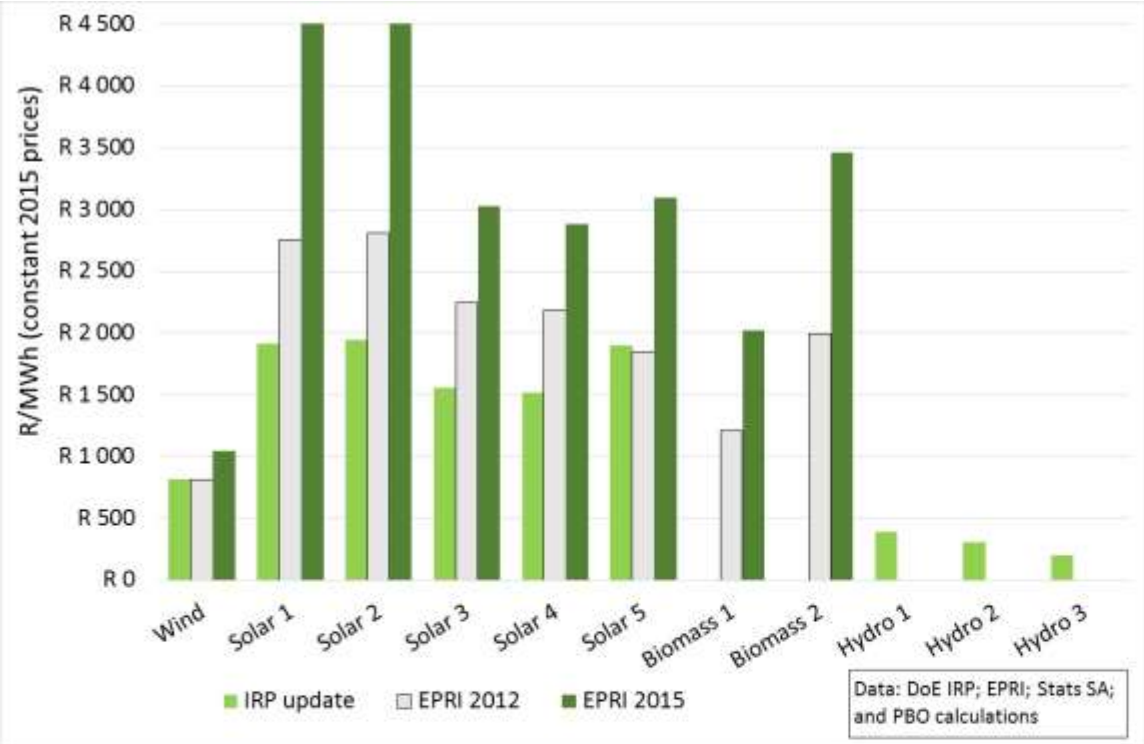


Figure 7: LCOE - conventional technologies (constant 2015 prices)



Figures 7 and 8 show LCOE estimates for the different base load and intermediate technologies from the IRP update, and the EPRI 2012 and 2015 studies, in constant 2015 prices. The IRP 2010 does not present LCOEs for the technologies considered. With the exception of gas technology, all LCOEs are higher (in real terms) than previously estimated. On an LCOE basis, hydro, gas (1) and coal (1) are the cheapest options across conventional and renewables technologies. According to the 2015 EPRI study, nuclear technology and coal 4 (Fluidized Bed Combustion with FGD and CCS) are the most expensive conventional technologies. On an LCOE basis, renewable technologies are, on average, more expensive than the conventional technology.

Figure 8: LCOE - renewable technologies (constant 2015 prices)



3.7. Financial and economic affordability

The lowest financial cost option may not adequately take account of policy goals and externality costs, such as environmental and health costs. Therefore, the lowest financial cost option may not have the highest economic benefits or have the lowest economic cost (when taking into account externalities) to the country. It is important that the additional financial cost, relative to the lowest-financial cost viable option, be compared to the (potential) benefit to the country arising from targeting other policy goal(s).

The country incurs costs from more expensive technologies through two direct and indirect channels. Firstly, the increase in average electricity tariffs is proportional to the cost of producing electricity (including capital, fuel and O&M). Investing in expensive electricity generation technology will increase tariffs more relative to an investment in cheaper technology. This represents a direct cost. Higher electricity tariffs may reduce overall economic activity and national revenue as households reduce spending and business responds to the increase in input costs, eroding competitiveness. Lower growth and revenue reduce the fiscal room available for the state to meet important social and economic goals. This represents an indirect cost for the economy.

Secondly, in the case of a state owned utility investing in electricity generating capacity, the utility may require assistance from the state in the form of guarantees, loans and capital injections, as is currently the case with Eskom. While these measures may be necessary to reduce the financing cost for the state-owned utility and allow for lower and smoother overall increases in electricity tariffs, it contributes to the country's liabilities and reduces room to borrow to meet other socio-economic objectives. The Government has to take account of uncertainty in its investment decisions because of the current difficult economic environment. It may be prudent in situations of high uncertainty to avoid very large capital investments where the repayments of loans are certain but returns from the project are uncertain and possibly volatile. As mentioned elsewhere, most predictions of South African electricity demand had significantly overestimated demand. One reason is that they did not adequately take account of increased uncertainty in the slow global recovery, post-financial crisis era. Further uncertainty arises with very large projects that often take longer to complete and cost more than was initially budgeted.

Table 3: Comparing capital cost estimates

	Coal 1	Coal 2	Coal 3	Coal 4	Coal 5	Coal 6	Nuclear unit	Nuclear fleet	Gas 2	Gas 3	
Rated Capacity (MW Net)	4500	4500	250	500	1288	1288	1600	9600	732	635	
Capital cost estimate* - Rands billion	R 145.89	R 282.20	R 9.78	R 34.30	R 60.93	R 81.31	R 127.09	R 716.28	R 6.01	R 11.45	
Ovenight capital cost - R/Kw	R 32 420	R 62 712	R 39 133	R 68 600	R 47 308	R 63 132	R 79 432	R 74 612	R 8 205	R 18 030	
	Wind	Solar 1	Solar 2	Solar 3	Solar 4	Solar 5	Biomass 1	Biomass 2	Hydro 1	Hydro 2	Hydro 3
Rated Capacity (MW Net)	100	125	125	125	125	10	25	25	1125	850	750
Capital cost estimate* - Rands billion	R 2.37	R 12.20	R 14.97	R 10.85	R 12.29	R 0.46	R 1.70	R 3.27	R 23.50	R 8.30	R 8.94
Ovenight capital cost - R/Kw	R 23 690	R 97 624	R 119 762	R 86 766	R 98 297	R 46 052	R 68 062	R 130 733	R 20 888	R 9 767	R 11 916

Capital cost estimates do not consider financing and related costs, full project costs are generally higher

Apart from hydro, all figures are from the EPRI 2015 study. Hydo figures are from the IRP update, and have been converted to reflect 2015 prices

Data: EPRI 2015 and IRP update, PBO calculations

Table 3 presents capital cost estimates for the technologies considered in this report. Several conventional technology options entail significant capital investment, which may require state support, and significantly higher average electricity tariffs. This large upfront financial commitment is of particular concern in the context of both the country and Eskom experiencing financial challenges. The 2016 Budget set a course of fiscal consolidation in response to deteriorating economic outlook and heightened risk of external shocks. The aim of the fiscal consolidation is to restore public finances to a sustainable path. In order to achieve this goal, Government has expressed its commitment to actively manage fiscal risks emanating from state-owned companies. Government's current fiscal course requires a circumspect approach to the size of guarantees and direct financial support to state-owned entities, particularly given the country's precarious credit-rating.

3.8. Carbon-emission considerations

The energy sector is responsible for around two-thirds of global greenhouse gases (GHG) emissions. Electricity systems emit harmful pollutants such as SO2, NOx and particulates and greenhouse gas (Co2) when the technology involved uses fossil fuels. These emissions cause harm to humans and contribute to climate change.

South Africa has made several commitments to reducing its Co2 emissions. Choosing the appropriate policy instruments to achieve this, as well as the timing, is critical, given the country's high level of carbon emissions and low growth outlook. Such instruments should provide incentives for carbon-intensity reduction, encourage investment in energy saving measures, while being sensitive to the impact on the economy. To reduce the country's overall Co2 emissions and meet the country's climate change mitigation goals, National Treasury in 2013 proposed the introduction of carbon tax.

The domestic electricity sector, generating most of its output from coal-powered stations, is responsible for a significant Co2 emissions, and will be liable for the proposed carbon tax. To reduce carbon emissions from electricity generation, electricity generation technology with low carbon emissions will need to increase its share of the country's total electricity generation-mix.

The carbon emissions of different technologies can be compared based on Co2 emissions per kilowatt-hour of electricity generated. This reflects the total Co2 amount emitted throughout a plant's life must be calculated standardised by the expected electricity the plant will generate over its life.

Figure 9: Co2 emissions and LCOE across technologies (constant 2015 prices)

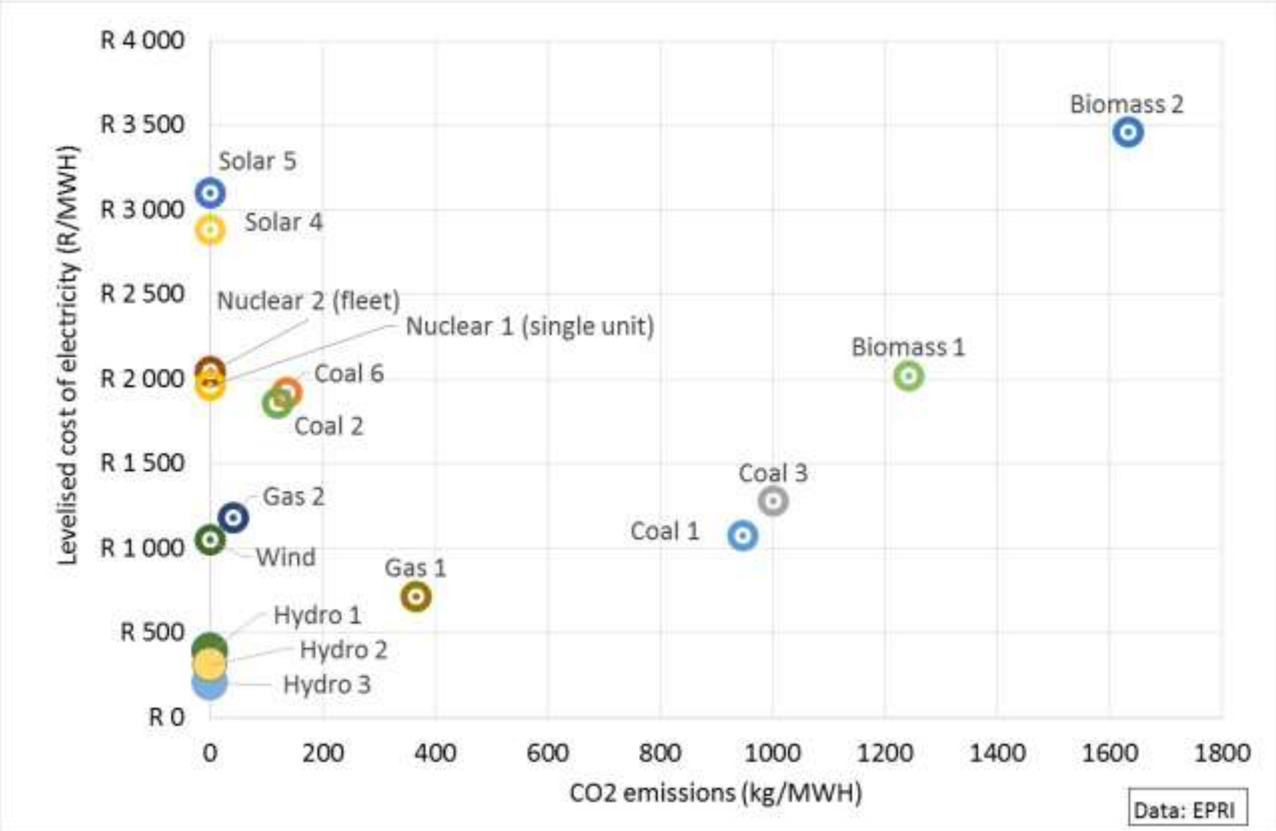


Figure 9 compares Co2 emissions per MWH and levelised cost of electricity across different technologies. Hydro, nuclear and renewable technologies have virtually no Co2 emissions, while technologies such as coal and biomass have comparatively high emissions. Cleaner technologies are generally more expensive. The introduction of carbon capture and storage for coal stations reduces the Co2 emissions, but not the extent where it is comparable to hydro, nuclear or renewables. Hydro and gas are the lowest cost – lowest Co2 emission technologies. Given the trade-off between cost and carbon emissions, it is important for Members of Parliament concerned with public finance to note the impact of cleaner technology on the economy and public finance.

3.9. Flexible capacity expansion

Uncertainty over future electricity demand requires an adaptable capacity expansion path. Investing in capacity based on the assumption of a high future demand presents the risk of over-investment. Over-investing results in generally higher-than-necessary electricity tariffs for the economy, as the additional costs spent on establishing these plants are paid-off over time. This risk is largest when electricity generation investment is lumpy and lacks flexibility. These risks can be reduced by adopting a more flexible approach to ensuring system adequacy. This entails adding generation capacity in smaller tranches – referred to as a modular approach – making the system more responsive to frequent updates to future electricity demand. This requires investment in small plants with shorter construction lead-times. Gas, wind, solar and biomass have the shortest construction times of the technologies considered in this report.

A further motivation for investing in several smaller plants, instead of a few larger plants, is the uncertainty due to changes in energy technology. The International Energy Agency (IEA-OECD, 2013) notes that the global energy sector is undergoing a major transformation, with renewable energy playing an increasingly larger role in national energy systems. This trends seems likely to continue as countries move towards low-carbon electricity, and renewable energy costs decline.

Table 4: Plant scale and construction lead times

	Coal 1	Coal 2	Coal 3	Coal 4	Coal 5	Coal 6	Nuclear-single	Nuclear- fleet	Gas 1	Gas 2	
Rated Capacity (MW Net)	4500	4500	250	500	1288	1288	1600	9600	732	635	
Capacity Factor (%)	85	85	85	85	85	85	90	60	50	50	
Lead-times and Project Schedule (years)	9	9	4	4	5	5	6	10	3	3	
Economic Life (years)	30	30	30	30	30	30	60	6814	30	30	
	Wind	Solar 1	Solar 2	Solar 3	Solar 4	Solar 5	Biomass 1	Biomass 2	Hydro 1	Hydro 2	Hydro 3
Rated Capacity (MW Net)	100	125	125	125	125	10	25	25	1125	850	750
Capacity Factor (%)	46	38	45.6	51	60.3	22.8	85	85	66.7	38	46
Lead-times and Project Schedule (years)	3 - 5	4	4	4	4	1	3.5 - 4	3.5 - 5	9	9	8
Economic Life (years)	20	30	30	30	30	25	30	30	60	60	60
	Source: Department of Energy and EPRI										

3.10. Localisation

Adding electricity generation capacity entails significant capital investment. This affords the domestic economy the opportunity to benefit from increased demand for a range of products and services required to construct, operate and maintain power stations and related infrastructure. In a semi-industrialised country like South Africa with established construction, manufacturing and steel industries, a significant share of the inputs and services will be sourced locally due to competitive local producers and lower transport costs – compared to importing. However, other inputs are likely to be sourced from outside the country as other countries may have more experience and expertise, and may be more competitive than South Africa at producing the some inputs. Opting for the lowest cost inputs, from domestic or foreign suppliers, is necessary to ensure the lowest impact on overall tariffs and on public finances.

However countries are not only concerned with minimising costs to the fiscus in the short run. Countries often use large public procurement as opportunities to stimulate domestic demand, and to develop local capabilities and industries. Developing local capabilities and industries can allow for the emergence of new industries with linkages to the industries providing inputs for power stations. This has the potential to lead to an overall increase in growth and employment.

However the potential benefit of developing local capabilities, increasing growth and employment must be compared to the higher cost of procuring electricity generation capacity. Higher cost considerations include:

- As the domestic country doesn't have existing capabilities in producing certain inputs, investment in capabilities is required. This has both a financial and lead-time components.
- A niche product, without broader industrial application, may require significant demand in the future to warrant the investment. This may lock the country into a particular technology choice in the future to ensure demand for the niche product/capabilities.
- Benefits from localisation may accrue to a narrow segment of society, while costs will be borne by overall society – in terms of opportunity cost of public finance, and higher electricity tariffs.

Table 5: EPRI local and import input assumptions

	Imported	**Local**		
	Total	Total	Materials	Labor
Coal 1 - 2	35%	65%	50%	50%
Coal 3 - 4	35%	65%	50%	50%
Coal 5	35%	65%	60%	40%
Nuclear	35%	65%	60%	40%
Gas 1 - 2	35%	65%	60%	40%
Wind	70%	30%	75%	25%
Solar 1 - 4	50%	50%	45%	55%
Solar 5	70%	30%	60%	40%
Biomass 1 - 2	35%	65%	50%	50%
				Source: EPRI 2015

Considering this, studies have investigated potential for localisation of new electricity generation procurement. A localisation study for the first two units of the South African nuclear new-build programme was initiated by the Department of Trade and Industry. The study concludes that approximately 40 per cent local content can be achieved and that South Africa should focus on establishing local capabilities to design, manage the project and deliver components and systems, not only manufacturing and construction for the new-build programme (Worley Parsons, 2011).

4. Conclusion

An adequate and reliable supply of electricity is essential for economic growth and development. South Africa will add additional electricity generation capacity to meet both future demand and replace its ageing fleet. It is critical that the technology-mix chosen is optimal in terms of the effect on public finances and growth.

Since the 2010 Integrated Resources Plan there have been several important developments affecting the electricity outlook for the country. Economic growth has been much slower than assumed in the IRP 2010 and the IRP update, even when compared to the IRP's low growth scenarios. Slow economic growth, limited electricity supply, and higher electricity tariffs have reduced growth in demand for electricity. A considerably slower growth outlook, and lower energy-intensity of growth imply a significantly reduced future electricity demand for the country. This necessitates an adjustment to the country's electricity generation capacity plans, and careful consideration over any new procurement.

The country's challenging economic situation, including a low growth outlook, high debt, increasing borrowing costs, and low revenue growth, necessitate that any decisions with fiscal implications to be sensitive to the potential effects on the economy and public finances.

This report presented key factors to be considered by Members of Parliament concerned with public finances in considering electricity generation technology choice.

In comparing costs, this report used the most recent cost estimates from the Electric Power Research Institute 2015 study. On an overnight capital cost basis, renewable technologies – with the exception of wind and hydro – are more expensive than conventional technologies. On an overnight capital cost basis, gas technology is the cheapest technology across both conventional and renewable energy options, followed by hydro, wind and Coal (1 and 3). Within the range of conventional technologies considered, nuclear energy is the most expensive – 16 per cent more than the most expensive coal option (Coal 4) and 67 per cent more expensive than the most expensive gas option (gas 2).

On a levelised cost of electricity (LCOE) basis, hydro, gas (1) and coal (1) are the cheapest options across conventional and renewables technologies. According to the 2015 EPRI study, nuclear technology and coal 4 (Fluidized Bed Combustion with FGD and CCS) are the most expensive conventional technologies. On an LCOE basis, renewable technologies are, on average, more expensive than the conventional technology.

Not opting for the lowest-cost option entails spending additional scarce resources than would have been necessary to meet the country's electricity needs. This may be necessary to realise other policy goals, including reducing carbon emissions, ensuring a flexible capacity expansion path, and developing local industrial capabilities. It is important that the additional cost, relative to the lowest-cost viable option, be compared to the (potential) benefit to the country arising from targeting other policy goal(s), and sensitive to the potential effect on the economy and public finances.

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6. Annexure

Table 6: Overnight capital costs (Rands/Kw)

Overnight capital costs - R/Kw	Coal 1	Coal 2	Coal 3	Coal 4	Coal 5	Coal 6	Nuclear 1	Nuclear 2	Gas 1	Gas 2	Wind	Solar 1	Solar 2	Solar 3	Solar 4	Solar 5	Biomass 1	Biomass 2	Hydro 1	Hydro 2	Hydro 3
nominal prices																					
IRP 2010	17785.0	-	14965.0	-	24670.0	-	26575.0	26575.0	-	5780.0	14445.0	43385.0	50910.0	32190.0	36225.0	20805.0	33270.0	66900.0			
IRP update	21572.0	40845.0	21440.0	40165.0	29282.0	39079.0	46841.0	44010.0	13223.0	6406.0	15394.0	51090.0	61176.0	44866.0	51604.0	28910.0	-	-	17834.4	8339.1	6159.0
EPRI 2012	21572.0	40845.0	21440.0	40165.0	29282.0	39079.0	32148.0	27326.0	13223.0	6406.0	15394.0	51090.0	61176.0	44866.0	51604.0	27743.0	32531.0	67505.0			
EPRI 2015	32420.0	62712.0	39133.0	68600.0	47308.0	63132.0	79432.0	74612.0	18030.0	8205.0	23690.0	97624.0	119762.0	86766.0	98297.0	46052.0	68062.0	130733.0			
constant 2015 prices																					
IRP 2010	23364.1		19659.5		32408.9		34911.5	34911.5		7593.2	18976.3	56994.7	66880.2	42287.9	47588.6	27331.4	43706.6	87886.2			
IRP update	25265.7	47838.7	25111.1	47042.3	34295.8	45770.3	54861.4	51545.6	15487.1	7502.9	18029.8	59837.9	71650.9	52548.2	60439.9	33860.1			20888.1	9767.0	7213.6
EPRI 2012	25265.7	47838.7	25111.1	47042.3	34295.8	45770.3	37652.6	32004.9	15487.1	7502.9	18029.8	59837.9	71650.9	52548.2	60439.9	32493.3	38101.1	79063.6			
EPRI 2015	32420.0	62712.0	39133.0	68600.0	47308.0	63132.0	79432.0	74612.0	18030.0	8205.0	23690.0	97624.0	119762.0	86766.0	98297.0	46052.0	68062.0	130733.0			

Source: Department of Energy and Electric Power Research Institute, PBO calculations

Table 7: Levelised cost of electricity (LCOE) (Rands/MWh)

Levelised cost of electricity - R/MWh	Coal 1	Coal 2	Coal 3	Coal 4	Coal 5	Coal 6	Nuclear 1	Nuclear 2	Gas 1	Gas 2	Wind	Solar 1	Solar 2	Solar 3	Solar 4	Solar 5	Biomass 1	Biomass 2	Hydro 1	Hydro 2	Hydro 3
nominal prices																					
IRP update	584.1	995.7	535.5	899.0	680.2	893.4	692.8	703.6	1173.4	861.0	693.9	1634.1	1659.9	1330.5	1292.0	1621.1	-	-	332.2	262.4	171.9
EPRI 2012	685.0	1190.8	746.5	723.3	852.7	1123.1	790.1	769.8	904.0	589.7	692.5	2353.5	2400.4	1916.1	1865.4	1580.7	1033.0	1699.3			
EPRI 2015	1071.8	1915.3	1276.3	2061.1	1390.9	1857.2	1959.6	2043.7	1175.8	712.2	1046.9	4547.5	4597.0	3024.1	2880.2	3096.7	2017.2	3456.7			
constant 2015 prices																					
IRP update	684.2	1166.2	627.2	1052.9	796.6	1046.4	811.5	824.1	1374.3	1008.4	812.7	1913.9	1944.1	1558.3	1513.2	1898.7			389.1	307.3	201.3
EPRI 2012	802.3	1394.7	874.3	847.1	998.7	1315.4	925.4	901.6	1058.8	690.7	811.1	2756.5	2811.4	2244.2	2184.8	1851.4	1209.9	1990.3			
EPRI 2015	1071.8	1915.3	1276.3	2061.1	1390.9	1857.2	1959.6	2043.7	1175.8	712.2	1046.9	4547.5	4597.0	3024.1	2880.2	3096.7	2017.2	3456.7			

Source: Department of Energy and Electric Power Research Institute, PBO calculations