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ABBREVIATIONS

AsgiSA  Accelerated and Shared Growth Initiative for South Africa
CCGT  Closed Cycle Gas Turbine
CO₂  Carbon Dioxide
COUE  Cost of Unserved Energy
CSIR  Council for Scientific and Industrial Research
CSP  Concentrating Solar Power
DoE  Department of Energy
DSM  Demand Side Management
EEDSM  Energy Efficiency Demand Side Management
EIA  Environmental Impact Assessment
EPRI  Electric Power Research Institute
FGD  Flue Gas Desulphurisation
FBC  Fluidised Bed Combustion
GDP  Gross Domestic Product
GHG  Greenhouse Gas
GJ  Gigajoules
GW  Gigawatt (One thousand Megawatts)
GWh  Gigawatt hour
IDTTTe  Inter-Departmental Task Team
IGCC  Integrated Gasification Combined Cycle
IMC  Inter-Ministerial Committee on energy
IPP  Independent Power Producer
IRP  Integrated Resource Plan
kW  Kilowatt (One thousandth of a Megawatt)
LNG  Liquefied Natural Gas
LTMS  Long Term Mitigation Strategy
MCDM  Multi-criteria Decision Making
MTPPP  Medium Term Power Purchase Programme
MW  Megawatt
MWh  Megawatt hour
MYPD  Multi-Year Price Determination
NERSA  National Energy Regulator of South Africa; alternatively the Regulator
NOx  Nitrogen Oxide
OCGT  Open Cycle Gas Turbine
O&M  Operating and Maintenance (cost)
PF  Pulverised Fuel
PV  Present Value; alternatively Photo-Voltaic
PWR  Pressurised Water Reactor
RAB  Regulatory Asset Base
REFIT  Renewable Energy Feed-in Tariff
RTS  Return to Service
SOx  Sulphur Oxide
TW  Terawatt (One million Megawatts)
TWh  Terawatt hour
GLOSSARY

“Base-load plant” refers to energy plant or power stations that are able to produce energy at a constant, or near constant, rate, i.e. power stations with high capacity factors.

“Capacity factor” refers to the expected output of the plant over a specific time period as a ratio of the output if the plant operated at full rated capacity for the same time period.

“Cost of Unserved Energy” refers to the opportunity cost to electricity consumers (and the economy) from electricity supply interruptions.

“Demand Side” refers to the demand for, or consumption of, electricity.

“Demand Side Management” refers to interventions to reduce energy consumption.

“Discount rate” refers to the factor used in present value calculations that indicates the time value of money, thereby equating current and future costs.

“Energy efficiency” refers to the effective use of energy to produce a given output (in a production environment) or service (from a consumer point of view), i.e. a more energy-efficient technology is one that produces the same service or output with less energy input.

“Gross Domestic Product” refers to the total value added from all economic activity in the country, i.e. total value of goods and services produced.

“Integrated Resource Plan” refers to the co-ordinated schedule for generation expansion and demand-side intervention programmes, taking into consideration multiple criteria to meet electricity demand.

“Integrated Energy Plan” refers to the over-arching co-ordinated energy plan combining the constraints and capabilities of alternative energy carriers to meet the country’s energy needs.

“Levelised cost of energy” refers to the discounted total cost of a technology option or project over its economic life, divided by the total discounted output from the technology option or project over that same period, i.e. the levelised cost of energy provides an indication of the discounted average cost relating to a technology option or project.

“Peaking plant” refers to energy plant or power stations that have very low capacity factors, i.e. generally produce energy for limited periods, specifically during peak demand periods, with storage that supports energy on demand.

“Present value” refers to the present worth of a stream of expenses appropriately discounted by the discount rate.

“Reserve margin” refers to the excess capacity available to serve load during the annual peak.

“Scenario” refers to a particular set of assumptions that indicate a set of future circumstances, providing a mechanism to observe outcomes from these circumstances.

“Screening curve” refers to a graph that indicates the levelised cost of technology options relative to potential capacity factors for these technologies. These can be used to screen out clearly inferior technologies from a cost perspective.

“Supply side” refers to the production, generation or supply of electricity.
EXECUTIVE SUMMARY

While long-term planning is essential, it is fraught with uncertainty. This is particularly true today, given the pace of global change on political, economic, social, technological and environmental fronts.

The biggest challenge for all long term plans is to find a sensible balance which takes into account the divergent views and expectations put forward by the different parties involved. These views fall broadly into two categories: desired/wished for outcomes, and required inputs or outputs which are subject to various constraints. Such “could be” and “must be” parameters are the interdependent variables of planning.

Scenario planning is an effective tool to find this balance. A scenario is not a plan but rather a glimpse of a future where a particular outcome or input is amplified in a modelling process in order to observe the effect this has on the other interdependent variables. The balanced scenario is created by an assessment of all scenarios to establish a balance between desired future outcomes and the realities of known constraints. The balanced scenario is the basis for the ultimate government approved risk/policy adjusted plan.

The primary objective of the Integrated Resource Plan (IRP 2010) is to determine the long-term electricity demand and detail how this demand should be met in terms of generating capacity, type, timing and cost. However, the IRP 2010 also serves as input to other planning functions, inter alia economic development, funding, environmental and social policy formulation. The accuracy of the IRP is improved by regular reviews and updates as and when things change or new information becomes available. For this reason, all long-term plans should be considered as indicative rather than “cast in concrete” plans.

The proposed policy-adjusted IRP 2010 aims to achieve a balance between an affordable electricity price to support a globally competitive economy, a more sustainable and efficient economy, the creation of local jobs, the demand on scarce resources such as water and the need to meet nationally appropriate emission targets in line with global commitments. It supports the development of the Southern and Central African region by stimulating the development of hydro and other power projects in Africa. This serves as a catalyst for further economic development due to increased energy security.

The IRP 2010 supports a gross domestic product (GDP) growth trajectory averaging 4.5% over the next 20 years. It requires 41346 MW of new capacity (excluding capacity required to replace decommissioned plant) in order to meet the projected demand and provide adequate reserves. It assumes at least 3420 MW of demand side management (DSM) programmes, as well as a gradual reduction in electricity intensity due to increased efficiency and a diversification to secondary and tertiary sectors in the economy. It still assumes a significant primary sector, however, built on the extraction and beneficiation of the natural resources with which the country is blessed.

The scenario evaluation process confirmed that the “Revised Balanced Scenario” represents a fair and acceptable balance considering the divergence in stakeholder expectations and key constraints and risks, including:

- Affordability
- Reducing carbon emissions
- New technology uncertainties such as costs, operability, lead time to build etc.
- Water usage
- Job creation
- Security of supply

The least-cost Base Case would provide for alternative options other than coal such as the construction of imported hydro, liquefied natural gas (LNG)-fuelled combined cycle gas turbines (CCGTs) and some fluidised bed combustion (FBC) coal to meet the demand following Kusile’s completion. However these options are constrained by the availability of fuel or the capacity to
build. This results in the bulk of the demand (for base-load power) over the planning horizon being met by coal-fired power stations, with open cycle gas turbines (OCGT) providing peaking energy. This outcome is not surprising given the relatively low direct cost of coal-fired power stations and the relatively high domestic reserves of coal to meet future demand, and given that the externalities relating to coal are not included in the Base Case.

While the Base Case Scenario indicates the least-cost alternative, these costs do not include the inherent externalities involved in coal-fired electricity production, in particular greenhouse gas (GHG) emissions and the impact on the environment as well as the security of supply imperative in diversifying the national energy base.

Scenarios were developed around the targets for GHG emissions, as well as policy objectives relating to regional development and increasing demand-side interventions. These scenarios, alongside the Base Case, were assessed in terms of cost, emissions, water consumption, localisation potential and regional development objectives, as well as discounting for additional risk to the system.

The balanced scenarios (the original Balanced Scenario and the Revised Balanced Scenario) were developed from workshops with government departments considering the results of the assessment of these criteria and balancing the objectives to converge on the proposed IRP 2010.

The proposed IRP 2010 is presented in the table below as the plan that best meets the stakeholder criteria and the policy requirements of government.

In summary the plan includes:

- The continuation of Eskom’s committed build programme (including the return to service of Grootvlei and Komati power stations, and the construction of Medupi (4332 MW), Kusile (4338 MW) and Ingula (1332 MW) power stations).
- The construction of the Sere power station (100 MW wind farm).
- Phase 1 of the Renewable Energy power purchase programme linked to the National Energy Regulator of South Africa (NERSA) Renewable Energy Feed-In Tariff (REFIT1) programme amounting to 1025 MW (made up from wind, concentrated solar power (CSP), landfill and small hydro options).
- Phase 1 of the Medium Term Power Purchase programme of 390 MW (made up from co-generation and own build options).
- The Open Cycle Gas Turbine (OCGT) Independent Power Producer (IPP) programme of the Department of Energy (DoE) of 1020 MW.
- A nuclear fleet strategy, commencing in 2023, contributing at least 9,6 GW by 2030. The nuclear costs included in the IRP are generic values as for the other technologies and are not intended to tie the IRP to a specific technology.
- A wind programme in addition to the REFIT1 wind capacity, commencing in 2014, of a minimum 3,8 GW.
- A solar programme in addition to the REFIT1 solar capacity, commencing in 2016, of a minimum 400 MW. This does not include solar water heating, which is included in the DSM programme (to the extent of 1617 MW).
- A renewable programme from 2020, incorporating all renewable options, inclusive of wind, concentrating solar power (CSP), solar photo-voltaic, landfill, and hydro, amongst others) of an additional 7,2 GW.
- Imported hydro options from the region totalling 3349 MW from 2020 to 2023.
- CCGT capacity, fuelled with imported LNG, totalling 1896 MW from 2019 to 2021.
- Own generation or co-generation options of 1253 MW as identified in the Medium Term Risk Assessment study.
- Up to 5 GW of generic coal-based power generation from 2027 to 2030 (in addition to Medupi and Kusile). The choice of technology could be traditional pulverised fuel or clean coal technologies. The builder of the capacity could be Eskom, South African IPPs or regional IPPs. The choice of technology will be based on current assessments of carbon capture and storage sites and the impact of climate change mitigation targets. With the commercialisation of carbon sequestration technologies, additional coal options
could become viable. However for this IRP it was assumed that such technologies are not sufficiently developed to be included. Further iterations of the IRP could revisit this.

- Up to 5750 MW of peaking OCGT. This option could also be provided by demand response programmes.
- Eskom’s DSM programme as stipulated in the multi-year price determination (MYPD) application has been incorporated. The breakdown of associated technologies for DSM is included in Appendix B, indicating the expected savings from the various constituent programmes.

A number of critical assumptions were included in the development of the proposed IRP. These include:

- The development of a nuclear strategy to provide low emission base-load alternatives to coal-fired generation from 2023;
- The development of a renewable strategy to support a low carbon energy future, specifically developing local industries that support a significant rollout of wind, solar and other renewable technologies;
- The development of infrastructure to support the importation of liquefied natural gas;
- Continued investment in the maintenance and refurbishment of existing Eskom (and non-Eskom) plant to ensure generator performance at assumed levels;
- Continued investment in DSM initiatives to improve energy efficiency and delay additional capacity requirements. This includes the expected load reduction stemming from the Department of Energy’s one million solar water geyser target.
| Year | RTS Capacity | Medupi | Kusile | Ingula | DOE OCGT IPP | Cogeneration, own build | Wind | CSP | Landfill, hydro | Sere | Decommissioning | Committed build | New build options | Total system capacity | Demand Side Management | Reserve Margin | Reliable capacity Reserve Margin |
|------|-------------|--------|--------|--------|-------------|------------------------|------|-----|---------------|------|----------------|----------------|------------------|-----------------|---------------------|----------------------|----------------|--------------------------|
| 2010 | 380         | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0              | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2011 | 679         | 0      | 0      | 0      | 0           | 130                    | 200  | 0   | 0             | 0    | 0              | 103             | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2012 | 303         | 0      | 0      | 0      | 0           | 0                      | 0    | 200| 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2013 | 101         | 722    | 0      | 0      | 0           | 0                      | 333  | 1020| 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2014 | 0           | 722    | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2015 | 0           | 1444   | 0      | 0      | 0           | 0                      | 0    | 100| 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2016 | 0           | 722    | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2017 | 0           | 722    | 1446   | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2018 | 0           | 723    | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2019 | 0           | 1446   | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2020 | 0           | 723    | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2021 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2022 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2023 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2024 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2025 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2026 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2027 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2028 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2029 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
| 2030 | 0           | 0      | 0      | 0      | 0           | 0                      | 0    | 0   | 0             | 0    | 0              | 0               | 0                | 0               | 0                   | 0                   | 0                   | 0                   |
1. INTRODUCTION

The Integrated Resource Plan (IRP 2010) is a long-term electricity capacity plan which defines the need for new generation capacity for the country.

This document outlines the concepts and development behind the integrated resource plan for the electricity industry in South Africa as well as the strategic objectives of the IRP, including the policy and technical parameters that drive the planning process.

A number of scenarios have been developed to inform debate on specific issues relating to future generation capacity, dealing with climate change, regional integration and the benefits of demand side initiatives, especially regarding energy efficiency. The final proposed IRP 2010 is derived from the debate arising from these scenarios.

2. PLANNING OBJECTIVES AND SCOPE OF WORK

The Energy Act of 2008 obliges the Minister of Energy to develop and publish an integrated energy plan. As electricity forms a sub-component of the energy sector, this IRP for electricity needs to be integrated into the outlook for energy. The Minister derives the power to determine and publish the IRP from the Electricity Regulations on New Generation Capacity, August 2009, which in turn are promulgated pursuant to the Electricity Regulation Act, 2006. The System Operations and Planning Division of Eskom has been mandated by the Department of Energy (DoE) to produce the integrated resource plan for electricity in consultation with the Department and the National Energy Regulator of South Africa (NERSA).

The objective of the IRP 2010 is to develop a sustainable electricity investment strategy for generation capacity and supporting infrastructure for South Africa over the next 20 years. The investment strategy includes implications arising from demand-side management (DSM) and pricing, as well as capacity provided by all generators (Eskom and independent producers).

The IRP is intended to:

- Improve the long term reliability of electricity generation through meeting adequacy criteria over and above keeping pace with economic growth and development;
- Ascertain South Africa’s capacity investment needs for the medium term business planning environment;
- Consider environmental and other externality impacts and the effect of renewable energy technologies; and
- Provide the framework for Ministerial determination of new generation capacity (inclusive of the required feasibility studies) as envisaged in the New Generation Capacity regulations.

2.1. Governance

The regulations for New Generation Capacity assign governance of the IRP to different parties. The regulations state that the process for developing the IRP shall include:

a) Adoption of the planning assumptions;

b) Determination of the electricity load forecast;

c) Modelling scenarios based on the planning assumptions;

d) Determination of the base plan derived from a least-cost generation investment requirement;

e) Risk adjustment of the base plan, which shall be based on:
   i. The most probable scenarios, and
   ii. Government policy objectives for a diverse generation mix, including renewable and alternative energies, demand side management and energy efficiency; and

f) Approval and gazetting of the integrated resource plan.
While the IRP includes current policy imperatives into the planning process, the outputs can and will have an impact on further policy directions and strategies of other Ministries. This impact is particularly evident in the discussion on climate change mitigation strategies. The IRP process is a dynamic and iterative process, subject to ongoing review and update. However the long lead times required for expansion mean that vacillation on choice will lead to delays in capacity being built, with a subsequent impact on economic growth and jobs.

For the current revision of the IRP, the following forums, committees and Government initiatives have been established to govern its development:

a. The Inter-Ministerial Committee on energy (IMC);

b. The Inter-Departmental Task Team (IDTTe);

c. Work Group 2 (an IMC working group) on the IRP (WG2); and

d. The IRP Technical Task Team (IRP TTT) whose role is to advise the DoE on technical IRP matters.

Much of this governance is an interim arrangement with the IMC, due to be disbanded shortly. A long-term (permanent) governance and decision-making framework, including industry, civil society and trade unions, must be established with clear assignment of roles and responsibility. This must be accompanied by a framework to ensure allocation of build programmes to Eskom and independent power producers (IPPs).

Consultation and the IRP 2010 Development Process

The Department of Energy undertook to launch a proactive stakeholder consultation process to ensure that critical input could be sourced from a diverse constituency during the development of the plan, rather than post the publication of the plan. This process was a two-phased intervention:

- Consultation on input parameters to the IRP 2010 modelling; and
- Consultation on the Balanced Scenario and draft IRP 2010.

The final input parameter values that were used in the modelling of the scenarios were based on a consolidation of both government and broader stakeholder desired outcomes and constraints, as prescribed by legal, physical or moral limitations. The Balanced Scenario was developed based on the balancing of government policy objectives, including objectives for a diverse generation mix, renewable technologies, demand side management and energy efficiency, and sustainability.

Given the inherent uncertainty in long-term planning, the scenarios also considered sensitivities such as different demand forecasts.

2.2. Scope

The IRP covers the expansion of supply-side capacity to meet future electricity demand, including demand-side interventions to compete with supply-side options. The IRP deals only with the electricity industry, specifically the electricity supply industry, and does not integrate extensively with other energy industries or markets. Thus it is not an integrated energy plan (catering for all energy sources and uses), but deals specifically with the integration of resources for electricity production and consumption. This would form a subset of the overall Energy Plan produced by the DoE.

The IRP is developed for the period 2010 to 2030. While the load forecast is provided for 25 years (to 2034), the last four years of the expansion plan are not presented as these represent “end effects” relating to modelling concerns.

A reference plan (or base plan) is produced as an optimal plan, considering only the direct costs of all capacity options. Thereafter specific policy objectives and risk mitigation considerations are included in the planning to determine a risk-adjusted plan.

The IRP 2010 Revision 2 was developed following public participation in the inputs to the model as well as a review of the inputs and model used in determining Revision 1 (the first four years of which were promulgated in January 2010). Some of the key differences between Revision 2 and Revision 1 are:
The expected energy consumption (and demand profile) for the next 20 years has been revised, based on the realised impact of the recent economic downturn and revised expectations based on the approved MYPD price increases;

- Generic costs for supply-side technologies have been used in Revision 2 as opposed to the Eskom-based costs in Revision 1;
- The DSM programme is not included in the demand forecast, but separately identified as a mandatory programme for the model;
- Additional information arising from the public participation was included, in particular the sugar cane fibre biomass options, future liquefied natural gas (LNG) prices, and additional scenario suggestions.

### 2.3. Planning parameters

#### Adequacy criteria

Inadequate reliability of South Africa’s generation, transmission and distribution system may lead to interruptions of the supply of electricity to customers; either randomly selected or specifically selected on account of their load management contracts with the System Operator.

Reserve, redundancy and reliability standards, criteria and targets, were selected primarily to minimise the sum of the cost to the country of the energy supplied and of the cost to the customer of the energy ‘unsupplied’ as a result of equipment failure or system inadequacies. The economic evaluation of investments affecting the reliability of supply takes into account the cost to the customer of unsupplied energy, and its probability of occurrence.

This method can be applied in two ways: either through determining a specific reserve margin outside the expansion planning model, which is then entered as a constraint to the model; or alternatively, allowing the expansion planning model to optimise the level itself (based on the cost of unserved energy and the supply-side costs) and to determine the appropriate mix of plant to meet this optimised level.

The optimisation inherent in the IRP 2010 model determines the appropriate generation adequacy for the system, based on the cost of unserved energy (COUE). If this is correctly modelled (with an appropriate value for the COUE) the optimal expansion plan would incorporate the negative impacts of not meeting demand. This should suffice to negate the need for explicit adequacy criteria, along with appropriate sensitivity studies to accommodate uncertainties in the underlying assumptions.

The reserve margin is published as an indicator, both with and without adjustment for the capacity credits (or firm capacity) provided by variable technologies (especially wind). The COUE is set at R75/kWh, with a sensitivity test on a lower COUE of R10/kWh.

The COUE of R75/kWh is derived from the cost impact on consumers in the marginal sector (where the worst impact of supply interruptions took place). At the lower end the R10/kWh is determined from the electricity intensity (as the value of economic production for each kWh of electricity consumed to produce it).

#### Discount rate

The discount rate is set at a real (after inflation) rate of 8% per annum before tax. Sensitivities have been calculated at 3% and 13% using the screening curves, indicating the impact of discount rates on technology levelised costs. The screening curves are discussed further in Appendix C.

The discount rate serves as a proxy for the financing of projects. Any reduction in the discount rate (either overall or for specific technologies) implies a subsidy by government, which needs to be accommodated in the fiscus.

The 8% real discount rate reflects the rate approved by NERSA for state-owned enterprises (Eskom, Transnet).
Exchange rate
The exchange rate was used as per the Electric Power Research Institute (EPRI) report, using R7.40/USD (as at beginning January 2010).

Since the IRP deals with real values over the period of the study, exchange rate fluctuations would be inconsistent with this approach. With significant changes to the modelling inputs, allowance can be made for varying exchange rates, but no significant benefit is derived from this change.

Technical assumptions
Appendix A covers assumptions and parameters for expected energy consumption.
Appendix B covers assumptions and parameters for demand-side interventions (including energy efficiency initiatives).
Appendix C covers assumptions and parameters for supply side options (including renewable energy technologies).

2.4. Modelling
Each of the scenarios determined below (including the Base Case) has been modelled with the objective of minimising the direct costs of the expansion plan (including capital, fuel and operating costs). When certain constraints have been imposed, including emission constraints in specific scenarios, these are always constraints on the cost optimisation objective.

For modelling efficiency purposes the calendar year is converted into a load duration curve with time slices representing periods of similar demand. This mechanism is used for the expansion plan optimisation. For the robustness check in the sensitivity analysis, a full production optimisation is executed on the chronological calendar year, ensuring that the pumping cycle, amongst other considerations, is accurately reflected.

Planned outage co-ordination is modelled by allowing the system to optimise planned outages according to capacity availability. In addition, unplanned outages are modelled by adjusting the load duration curve to an effective load duration which incorporates the probability of plant failure. However, for the purposes of the scenarios, which include emission limits and other output related indicators, an alternative methodology is used, since the effective load duration methodology would result in additional total generation (to meet the higher effective demand calculated from the plant failure probability). The alternative methodology uses reserve requirements on generators to emulate the additional capacity for outages, thus generator output is more realistic and emissions and other constraints relating to this output can be more accurately modelled.

3. SCENARIOS
All the scenarios were modelled based on the cost assumptions for potential supply-side projects, assumptions for demand-side interventions as well as the underlying expected demand. All known, feasible projects were included in each scenario, which included:

- Eskom and non-Eskom committed generation projects;
- IPP programmes;
- Decommissioning programmes; and
- Mandated demand-side interventions.

The demand forecast used is as per Appendix A with the committed DSM programme indicated in Appendix B.

Capacity requirements
Figure 1 provides a simplistic view of the capacity required in each year from 2010 to 2020 to meet three different forecasts as discussed in Appendix A. An assumed 15% reserve margin is added to

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1 In the case of Koeberg, the actual maintenance schedule determined by Eskom is incorporated as it contains the considerations for refuelling outages.
each of the three forecasts (high, moderate, low). The requirement in each case is the demand required (with reserve margin) less the existing South African generation capacity (43 895 MW), net of planned decommissioning. The projects currently under development are indicated. These include the return to service (RTS); the base-load capacity under construction at Medupi and Kusile as well as the peaking capacity under construction at Ingula; the IPP programmes represented by the DoE OCGT, the REFIT and the Medium Term Power Purchase Programme (MTPPP) programmes; and the funded Eskom DSM programme. These programmes (in various stages of commitment) fill the gap to some extent, but the graph highlights the shortfall in meeting a 15% reserve margin on the high capacity requirement after 2017, and on a moderate capacity requirement after 2020, whereas the low growth is met with existing programmes until decommissioning of existing plant requires replacement from 2022. The Kusile capacity is indicated separately to identify the requirement should this capacity not materialise.

**Figure 1. System capacity requirement**

It should be noted that this view is overly simplistic in that it excludes the energy constraints applicable to generators such as OCGT, pumped storage and hydro plants. The energy requirement would accelerate the need for additional capacity to a point before that reflected in this graph.

Given the existing uncertainty regarding the Eskom build programme, in particular the funding of the Kusile power station, three Base Cases were developed: Base Case 0.0 (using the current committed Eskom build); Base Case 0.1 (excluding Kusile from the build completely) and Base Case 0.2 (with a 12 month delay in Medupi and a 24 month delay in Kusile). The purpose of this was to provide information to the debate regarding the future of Kusile, especially the impact of not continuing with the programme. Many of the scenarios were also developed to allow for a case inclusive of the Kusile capacity and another case excluding that capacity.

A number of scenarios have been developed to incorporate specified uncertainties or unknowns, including possible policy objectives that are as yet unclear. The results from these scenarios were assessed to determine a risk-adjusted IRP (as distinct from the least-cost Base Case) to accommodate the policy considerations and uncertainties.
Each scenario is based on the System Operator moderate forecast, with no learning curves for technologies.

**Table 1. Scenarios for the IRP**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Constraints</th>
<th>Kusile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case 0.0</td>
<td>Limited regional development options</td>
<td>Committed</td>
</tr>
<tr>
<td></td>
<td>No externalities (incl. carbon tax) or climate change targets</td>
<td></td>
</tr>
<tr>
<td>Base Case 0.1</td>
<td>As above</td>
<td>Excluded</td>
</tr>
<tr>
<td>Base Case 0.2</td>
<td>As above</td>
<td>Committed, but 24 month delay; and 12 month delay for Medupi</td>
</tr>
<tr>
<td>Emission Limit 1.0 (EM1)</td>
<td>Annual limit imposed on CO₂ emissions from electricity industry of 275 MT CO₂-eq</td>
<td>Committed</td>
</tr>
<tr>
<td>Emission Limit 1.1</td>
<td>As above</td>
<td>Excluded</td>
</tr>
<tr>
<td>Emission Limit 2.0 (EM2)</td>
<td>Annual limit imposed on CO₂ emissions from electricity industry of 275 MT CO₂-eq, imposed only from 2025</td>
<td>Committed</td>
</tr>
<tr>
<td>Emission Limit 2.1</td>
<td>As above</td>
<td>Excluded</td>
</tr>
<tr>
<td>Emission Limit 3.0 (EM3)</td>
<td>Annual limit imposed on CO₂ emissions from electricity industry 220 MT CO₂-eq, imposed from 2020</td>
<td>Committed</td>
</tr>
<tr>
<td>Emission Limit 3.1</td>
<td>As above</td>
<td>Excluded</td>
</tr>
<tr>
<td>Carbon Tax 0.0 (CT)</td>
<td>Imposing carbon tax as per Long Term Mitigation Strategy (LTMS) values (escalated to 2010 ZAR)</td>
<td>Committed</td>
</tr>
<tr>
<td>Carbon Tax 0.1</td>
<td>As above</td>
<td>Excluded</td>
</tr>
<tr>
<td>Regional Development 0.0 (RD)</td>
<td>Inclusion of additional regional projects as options</td>
<td>Committed</td>
</tr>
<tr>
<td>Regional Development 0.1</td>
<td>As above</td>
<td>Excluded</td>
</tr>
<tr>
<td>Enhanced DSM 0.0 (EDSM)</td>
<td>Additional DSM committed to extent of 6 TWh energy equivalent in 2015</td>
<td>Committed</td>
</tr>
<tr>
<td>Enhanced DSM 0.1</td>
<td>As above</td>
<td>Excluded</td>
</tr>
<tr>
<td>Balanced Scenario</td>
<td>Emission constraints as with EM 2.0, Coal costs at R200/ton; LNG cost at R80/GJ, Import Coal with FGD, forced in Wind earlier with a ramp-up (200 MW in 2014; 500 MW in 2015; 800 MW in 2016; 1200 MW in 2017; 1600 MW annual limit on options thereafter)</td>
<td>Committed, but 24 month delay; and 12 month delay for Medupi</td>
</tr>
<tr>
<td>Revised Balanced Scenario</td>
<td>As with Balanced Scenario, with the additional requirement of a solar programme of 100 MW in each year from 2016 to 2019 (and a delay in the REFIT solar capacity to 100 MW in each of 2014 and 2015). CCGT forced in from 2019 to 2021 to provide backup options. Additional import hydro as per the Regional Development scenario</td>
<td>Committed, but 24 month delay; and 12 month delay for Medupi</td>
</tr>
</tbody>
</table>

The detailed results for each case are provided in Appendix D. The key aspects of each scenario are discussed here.

**Base Case**

The Base Case (with Kusile and Medupi as per the original committed schedule) provides for imported hydro as the first base-load capacity in 2020 (after the committed programmes), followed by combined cycle gas turbines (CCGT) (fuelled by liquefied natural gas, or LNG), then imported coal and fluidised bed combustion (FBC) coal, before pulverised coal which forms the basis of all further base-load capacity. Additional peaking capacity is exclusively provided by open-cycle gas turbines (OCGT), fuelled by diesel.

CO₂ emissions continue to grow (albeit at a lower rate due to more efficient power stations replacing decommissioned older ones) to a level of 381 million tons at the end of the period (2030). Water usage drops from 336 420 million litres in 2010 to 266 721 million litres in 2030 (due to replacing older wet-cooled coal power stations with newer dry-cooled ones).

The cancellation of the Kusile project would require alternative capacity to be built in 2017, in this case FBC coal and CCGT, with additional projects brought on at least a year earlier in each case. This increases the cost to the economy from R789bn to R840bn (in present value terms), but does not include the net impact of the cost saving on the cancelled project and penalties relating to this cancellation. The present value costs indicated do not include capital costs for committed projects.
A delay in building Medupi and Kusile causes some projects to be brought forward, for example an FBC coal unit in 2015 and CCGT units in 2017/18, to cover the reduced capacity over the medium term, but other options are pushed further out in time as the last unit of Kusile is only commissioned by 2020. Security of supply is not dramatically impacted by the delay, as long as the identified mitigating projects can be built in the periods required.

**Emission Limit 1**

Imposing a limit on emissions (at 275 million tons of CO₂ throughout the period) shifts the base-load alternatives away from coal (in particular pulverised coal) to nuclear and gas. Wind capacity is also favoured to meet the energy requirements over the period, especially as the emission constraint starts to bite in 2018. As the nuclear programme is restricted in terms of its build rate (one unit every 18 months starting in 2022) wind is required to reduce emissions in the interim. CCGT provides a strong mid-merit alternative until nuclear is commissioned, especially providing higher load factors than wind, with some dispatchability. The total cost to the economy (excluding capital costs of committed projects) is R860bn, compared with R789bn for the Base Case, but with significantly lower water consumption (241 785 million litres in 2030).

The scenarios with the cancellation of Kusile allow for additional pulverised coal generation to be built later (in 2028) with more wind capacity before 2022. CCGT capacity is brought forward to fill the gap left by Kusile’s cancellation.

**Emission Limit 2**

The emission limit is retained at 275 million tons but is only imposed from 2025. Under these conditions the nuclear and wind build is delayed (nuclear by one year, wind by five years). The other capacity is similar to the Base Case until 2022, when low carbon capacity is required to ensure that the constraint can be met in 2025. Decommissioning of older power stations (6654 MW by 2025) provides an opportunity to return to the constrained level of emissions. The cost to the economy is lower than the Emission Limit 1 scenario at R835bn with a slightly higher average annual emission of 275 million tons (as opposed to 266 million tons).

**Emission Limit 3**

The tighter emission limit of 220 million tons is imposed from 2020. This requires a significant amount of wind capacity (17600 MW starting in 2015) and solar capacity (11250 MW commissioned between 2017 and 2021) to meet the constraint. In total 17,6 GW of wind, 11,3 GW of solar and 9,6 GW of nuclear are built, with no coal capacity included. CCGT is constructed as a lower emission mid-merit capacity along with 6,5 GW of OCGT peakers.

The cost to the economy is significantly higher at R1250bn with much lower average annual emissions (235 million tons) and water consumption (218 970 million litres in 2030).

**Carbon Tax**

The carbon tax scenario includes a carbon tax at the level of that discussed in the Long Term Mitigation Strategy (LTMS) document, starting at R165/MWh in 2010 rands, escalating to R332/MWh in 2020 until the end of the period (2030) before escalating again to R995/MWh in 2040. This level of carbon tax causes a switch in generation technology to low carbon emitting technologies, in particular the nuclear fleet (starting in 2022) and wind capacity of 17,6 GW starting in 2020. The remainder is provided by imported hydro (1959 MW), OCGT (4255 MW) and CCGT (4266 MW) with some FBC coal after 2028 (1750 MW).

The cost to the economy (excluding the tax itself, which would be a transfer to the fiscus) arising from the changed generation portfolio is R852bn, with average annual emissions at 269 million tons and water consumption declining to 238 561 million litres in 2030.

**Regional Development**

While the Base Case only includes some import options (limited import hydro (Mozambique) and import coal (Botswana)), the regional development scenario considers all listed projects from the Imports parameter input sheet. These additional options provide good alternatives to local supply options at lower generation costs (but require additional transmission capacity to transport the energy).
Including these options brings the total cost to the economy (excluding the transmission backbone requirement for these projects) to R783bn (R6bn cheaper than the Base Case). The import coal and hydro options are preferred to local options, but imported gas is not preferred to local gas options.

**Enhanced DSM**
A test case scenario was run to see what the impact of additional DSM would be on the IRP. For this scenario an additional 6 TWh of DSM energy was forced by 2015. The resulting reduction in cost was R12,8bn  (R789,5bn of the Base Case less R776,7bn for the Enhanced DSM scenario) on a PV basis, indicating that if a 6 TWh programme could be run for less than this cost it would be beneficial to the economy.

**Balanced Scenarios**
Two balanced scenarios were created considering divergent stakeholder expectations and key constraints and risks. The balanced scenarios represent the best trade-off between least-investment cost, climate change mitigation, diversity of supply, localisation and regional development. The CO₂ emission targets are similar to those in the Emissions 2 scenario.

The balanced scenarios include the Eskom committed build programme plus the MTPPP and REFIT commitments. A significant amount of wind is built, as this is the cheapest renewable energy option. Care is taken to ensure a steady and consistent build up in wind capacity in order to stimulate localisation of manufacturing and job creation. A consistent, although more modest, commitment is given to the more expensive concentrated solar option (CSP) in order to develop local experience with this technology as well as costs. The renewable energy options continue after 2020, but are not specified according to technology type at this stage. These choices will be made when there is more local knowledge and experience with both wind and solar energy. Nuclear energy comes in as a base-load option from 2023 – but because this is 13 years away, this decision does not yet have to be made. The scenario also provides for substantial diversity with gas, regional hydro, and coal options also included. In addition, allowance is made for some short to medium term co-generation and self-build options to bolster security of supply concerns.

**Figure 2. Net new generation capacity (Base Case 0.0)**

![Graph showing net new generation capacity](image)
Adequacy
While the reserve margin is a weak indicator of generation adequacy for the system, it provides a useful snapshot for the annual peak. In this case each scenario meets (or at least approaches) a 15% reserve margin, adjusted for capacity credits for variable generation sources. Scenarios with high penetration from variable generation sources, in particular wind generation, have significantly higher unadjusted, or full, reserve margins, due to the higher capacity required to provide an equivalent “predictable” capacity.
Emissions

With the imposition of specific carbon emission constraints the model ensures that the limit will be reached and coal-fired generation is adjusted to this target. This includes the possibility of limiting generation at older, less efficient power stations to the point that they may be “stranded” ahead of their expected end-of-life. This impact is indicated in the price curves below, especially in the cases where Kusile is constructed as per the Eskom build programme.

On the other hand, the carbon tax scenario imposes the tax as a cost of coal-fired generation and the emissions are an outcome of the optimisation process. Figure 5 shows how the carbon tax scenario exceeds the targets imposed in EM1.0 and EM2.0.

Figure 5. Expected CO₂ emissions
Apart from the reduction in absolute emissions in the emission constrained and carbon tax scenarios, all the scenarios also indicate an improvement in the relative emissions (or emission rates) for the electricity sector. While the Base Case has only a marginal improvement (due to the replacement of older power stations with newer, more efficient capacity) the emission constrained scenarios indicate a significant drop in the relative emissions of the electricity sector, as reflected in Figure 6.

Figure 6. Expected CO₂ emission rates

![Figure 6. Expected CO₂ emission rates](image)

Figure 7 indicates the trade-off between the total cost of a scenario portfolio and the emissions relating to that portfolio. The “low cost” scenario (Base Case) has a high emission rate (of 0.84 CO₂ tons/MWh) but has a low direct cost of R789bn. The other extreme of the “low carbon” scenario (Emission 3) provides a much lower emission rate (of 0.48 CO₂ tons/MWh) but the total direct cost increases to R1250bn. The Revised Balanced Scenario, as a balance between the two extremes, provides an emission rate of 0.59 CO₂ tons/MWh at a cost of R856bn.

This result suggests that there is a diminishing marginal return for each decrease in the emission rate, since the Revised Balanced Scenario is able to reduce the emission rate at a smaller increase in cost, but the increase in cost from the Revised Balanced Scenario to Emission 3 is significant at only a marginal improvement in emission rate.

Figure 7. Returns on carbon reduction

![Figure 7. Returns on carbon reduction](image)
Costs
The costs of each scenario are calculated by summing the total capital, operating and maintenance (O&M) and fuel costs for all options and then discounting these to determine the total Present Value (PV) cost for the scenario. The discount rate of 8% is applied to the present value calculation. The capital costs of the committed plant (in particular Medupi, Kusile and Ingula) are not included in the calculation as these are common across all scenarios.

The cumulative present value cost is shown in Figure 8, highlighting the large disparity between the Emission 3 scenario and the other scenarios.

Figure 8. Cumulative PV costs for each scenario

Price Curves
An alternative expression of the cost associated with each scenario is the price impact on consumers resulting from the expansion plan indicated by the scenario.

Price curves are calculated using the regulatory pricing rules as summarised in the Electricity Regulation Act (Act 4 of 2006) that allows for electricity prices to recover the full efficiently incurred cost plus a reasonable return. The annual costs in the calculations are based on the MYPD2 submission to NERSA, which is a public document, with inflationary escalation of cost buckets after the first five year period. A reasonable return was estimated using the NERSA determined cost of capital of 8.17% per annum and with the capital expenditure of the industry adjusted by the results of the IRP scenario being priced.

It is important to note that the IRP optimises the expansion plan using levelised cost calculations, while the pricing rules are different. The pricing rules allow for Operating and Maintenance (O&M) costs to be included in revenue requirements for the year they are expended, with capital expenses recovered through depreciation over 25 years after the date of commissioning for the capital portion. The financing cost is recovered by the return calculation at the real cost of capital from date of expense, allowing Work under Construction to earn a return even if no depreciation is allowed.

The price curve thus allows the MYPD2 price path of 25% nominal increases until 2012/13, which is called “2012” in this exercise because the calendar year 2012 and the financial year 2012/13 overlap by 75% and 2012 is the best approximation. After 2012 the price curve is allowed to return to the pricing rules curve with no further intervention. See curves below for the Base Case and three scenarios. The prices are shown in real 2010 rand per kWh.

Appendix F contains a more detailed explanation of the pricing model with important sensitivities.
Capital spending, operating costs and primary energy costs have been adjusted to reflect the different generation expansion plans in the future years, to calculate the price curves for the scenarios. This was achieved by assuming that the Base Case capex, primary energy and O&M costs correspond with the MYPD2 submission, and then adding the differences to the model for other scenarios, to give a relative difference which is reflected in the price curves above.

Thus the absolute price levels are less important than the difference in the price curves for various scenarios. In the above graph, the emission constrained scenario would have a price premium above the other scenarios after 2020.

The carbon tax price curve does not include the cost of the actual tax itself, only the impact of the generation choices driven by the carbon tax. This is for the benefit of comparison with the other scenarios.

4. CRITERIA

A methodology has been developed to deal with identifying the key criteria from stakeholders against which to weigh the results of the scenarios. The criteria apply to each scenario in order to provide additional inputs to the debate regarding the preferred IRP. While the scenarios are not intended as implementable plans in themselves, they provide an indication of the impact of specific policy choices. The scoring for the scenarios, based on the criteria and the evaluation thereof, is not intended to provide a definitive preferred plan from the scenario but to indicate preferences.

Once the scoring has been completed, it is expected that the benefits and costs of each scenario are discussed to drive the determination of the preferred expansion plan as the basis of the proposed IRP 2010.

A set of criteria were proposed and discussed at a series of inter-departmental workshops against which to assess a number of key parameters identified. These include:

a) Water
   The usage of water is quantified for each technology, according to the independent EPRI report and information from existing Eskom plant. The cost of water for existing plant and approved future plant is known and quantified. For plant that is recommended to be built in the proposed IRP 2010 only the usage of water is quantified, given that the location of the plant is not known at this stage of the IRP.
b) Cost
Each scenario involves the construction of new generation capacity over the study period. For the current and approved projects the costs from the existing owner (Eskom, municipality or private supplier) is used. For potential new projects the approved data set of option costs will be used. The criteria applied for this dimension should cover the direct costs associated with new generation capacity built under each scenario (including capital, operating and fuel costs) as well as existing plant (but excluding capital costs for committed plant) and summed to determine the total cost of the plan. This will be discounted to determine the present value of the plan and used as a comparator between the different scenarios.

An alternative approach is to look at the future electricity price curves required to meet the generation costs incurred by the scenario portfolio. This model, similar to that applied in the Eskom MYPD decision by NERSA, provides an indicator of future costs to consumers for the electricity industry from each scenario portfolio.

c) Climate change mitigation
The Department of Environmental Affairs “Long Term Mitigation Strategy” (LTMS) provides guidance on the extent to which greenhouse gas (GHG) emissions should be restricted over time. For the purposes of the IRP the GHG emissions from existing and planned generation capacity can be quantified in the model and compared between scenarios. While certain scenarios may impose a specific limit to emissions, this criterion compares the actual emissions between all scenarios.

d) Portfolio risk or uncertainty
An approach has been developed to identify and model the risks associated with each of the scenario portfolios. There are different dimensions or sources of risk between the scenario portfolios, including (but not limited to):

- The validity of the cost assumptions for each technology;
- The validity of the lead time assumptions for each technology;
- The maturity of each technology;
- The security of fuel supplies for each technology; and
- Operational risks associated with each technology (including secondary life cycle effects), such as waste management, pollution and contamination.

Ideally these risks would carry cost elements which would enable incorporation into the IRP optimisation (through monetisation of the risk elements). However given the time constraints and dearth of data to support this process, this is not feasible at present. The second best approach would be to identify a probability distribution associated with the risks, use the standard deviation as a measure of risk, and apply these across the identified dimensions. While this can be done for some of the risk dimensions, there is again a lack of information and time to produce such measures for every dimension. The third approach is to apply subjective expert judgement to each technology for every dimension and derive a risk factor for each technology (and consequently a capacity weighting for each scenario portfolio). This methodology was used for the IRP 2010, with the resulting risk factor compared between the different scenarios.

e) Localisation benefit
A rating has been given to each scenario portfolio to indicate the extent to which this portfolio supports localisation of specific technologies and supporting industries. It is expected that the earlier a technology construction programme is triggered, and the more steadily such technology capacity is added, the higher the potential to localise the technology industry. Thus a wind industry is supported by a regular build profile, starting earlier, and consequently a portfolio that incorporates such a build profile would have a higher score in this criterion. The application is however subjective.

f) Regional development
Workshops with government departments indicated that this is an important criterion for the portfolios and that those portfolios that support increased import from regional options should
receive a higher score. Thus the portfolio with the higher percentage of imports (to the total capacity) scores higher on the regional development criterion. Technically speaking the total capacity is replaced in this calculation by the demand that must be met, so as not to penalise portfolios that build significant wind (which requires more capacity for each unit of demand due to the capacity credits applied to wind).

For the first three criteria (emissions, cost of plan and water) and the regional development criterion the measurement is provided by the optimisation results. The average domestic emissions figure is determined based on the emission contribution of each of the proposed projects and its expected output in each year. Similarly the cost of the plan is determined based on the capital, operating and fuel costs of each project (discounted to 2010 rands), but specifically excludes the capital costs associated with existing power stations and the committed Eskom build. The water criterion is measured by summating the water requirements for the scenario portfolio for the entire study period.

The uncertainty factor criterion is measured using uncertainty factors for each technology, which is then applied based on the relative capacity of each technology in the portfolio. The localisation criterion is based on a subjective score applied to the portfolios based on their perceived potential for localisation.

**RATING THE SCENARIOS**

Each of the scenarios provides the same reliability, since the model optimises between the cost of new generation and unserved energy. Thus security of supply is not treated as a criterion.

The criteria and associated metrics provide a framework in which the balanced scenario can be assessed for “goodness of fit”. The principle is to achieve the best fit considering the divergent stakeholders’ objectives. The table below contains the criteria metric values for each of the scenarios.

**Table 2. Criteria metric scores for each scenario**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Av. annual CO₂ emissions (million tons)</th>
<th>Price path peak (cents/kWh)</th>
<th>Av. water consumption (million litres)</th>
<th>Uncertainty factor</th>
<th>Localisation potential</th>
<th>Regional development (% capacity imports in 2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case 0.0</td>
<td>303</td>
<td>100</td>
<td>327</td>
<td>6.87</td>
<td>2</td>
<td>6.87</td>
</tr>
<tr>
<td>Emission 1.0</td>
<td>266</td>
<td>114</td>
<td>310</td>
<td>6.12</td>
<td>4</td>
<td>6.87</td>
</tr>
<tr>
<td>Emission 2.0</td>
<td>276</td>
<td>105</td>
<td>319</td>
<td>6.12</td>
<td>4</td>
<td>6.87</td>
</tr>
<tr>
<td>Emission 3.0</td>
<td>236</td>
<td>172</td>
<td>283</td>
<td>5.21</td>
<td>4</td>
<td>3.85</td>
</tr>
<tr>
<td>Carbon Tax 0.0</td>
<td>269</td>
<td>115</td>
<td>316</td>
<td>5.34</td>
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<td>5.1</td>
</tr>
<tr>
<td>Regional Development 0.0</td>
<td>301</td>
<td>101</td>
<td>326</td>
<td>6.99</td>
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<td>10.4</td>
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<tr>
<td>Enhanced DSM</td>
<td>299</td>
<td>104</td>
<td>324</td>
<td>6.86</td>
<td>2</td>
<td>6.87</td>
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<tr>
<td>Balanced</td>
<td>272</td>
<td>107</td>
<td>318</td>
<td>6.05</td>
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<td>4.68</td>
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<tr>
<td>Revised Balance</td>
<td>271</td>
<td>111</td>
<td>318</td>
<td>6.11</td>
<td>8</td>
<td>8.63</td>
</tr>
</tbody>
</table>

**SCORING THE SCENARIOS**

Using a rigorous multi-criteria decision making framework (MCDF) it is possible to describe, numerate and score the preferences and values of the stakeholders with respect to each of the criteria. This provides a foundation to assist in choosing a single portfolio as the preferred option. In addition it is possible to identify next-best alternates that can undergo additional stress testing to incorporate concerns regarding robustness to sensitivities.

An important step in the MCDF process is to determine weightings for each of the criterion. This provides the mechanism to score the scenario portfolios across the different criteria. Applying the
agreed weighting for each criterion and value function returned the results contained in the table below.

Table 3. Score for each criteria

<table>
<thead>
<tr>
<th>Plans</th>
<th>CO₂ emissions</th>
<th>Price</th>
<th>Water</th>
<th>Uncertainty</th>
<th>Localisation potential</th>
<th>Regional development</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case 0.0</td>
<td>-</td>
<td>21.74</td>
<td>-</td>
<td>2.73</td>
<td>-</td>
<td>6.08</td>
<td>30.54</td>
</tr>
<tr>
<td>Emission 1.0</td>
<td>12.41</td>
<td>18.61</td>
<td>5.24</td>
<td>16.14</td>
<td>6.47</td>
<td>6.08</td>
<td>64.94</td>
</tr>
<tr>
<td>Emission 2.0</td>
<td>9.43</td>
<td>20.61</td>
<td>2.53</td>
<td>16.14</td>
<td>6.47</td>
<td>6.08</td>
<td>61.25</td>
</tr>
<tr>
<td>Emission 3.0</td>
<td>21.74</td>
<td>-</td>
<td>10.87</td>
<td>19.57</td>
<td>6.47</td>
<td>-</td>
<td>58.65</td>
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<tr>
<td>Carbon Tax 0.0</td>
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<td>18.41</td>
<td>3.50</td>
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<td>6.47</td>
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<td>61.91</td>
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<tr>
<td>Region Development 0.0</td>
<td>0.67</td>
<td>21.53</td>
<td>0.37</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>33.44</td>
</tr>
<tr>
<td>Enhanced DSM</td>
<td>1.54</td>
<td>20.85</td>
<td>0.94</td>
<td>3.04</td>
<td>-</td>
<td>6.08</td>
<td>32.45</td>
</tr>
<tr>
<td>Balanced</td>
<td>10.46</td>
<td>20.24</td>
<td>2.74</td>
<td>16.71</td>
<td>11.02</td>
<td>1.85</td>
<td>63.01</td>
</tr>
<tr>
<td>Revised Balance</td>
<td>11.01</td>
<td>19.33</td>
<td>2.92</td>
<td>16.32</td>
<td>15.22</td>
<td>8.85</td>
<td>73.66</td>
</tr>
</tbody>
</table>

The MCDF scores clearly demonstrate the extent to which the Revised Balanced Scenario represents a fair and acceptable balance across the key criteria. The MCDF also serves as a basis for debate on policy choices.

5. RECOMMENDED EXPANSION PLAN

The balanced scenarios (the original Balanced Scenario and the Revised Balanced scenario) were developed from workshops with government departments considering the results of all scenarios and the MCDF analysis.

The initial balanced scenario was based on the Emission 2 scenario which combined the interests of affordability (or least-cost) with an emission target that complied with LTMS requirements. It was decided, however, that the wind build programme started too late and was not sufficient to ensure a local industry to support this. Thus the wind programme was forced to start in 2014 (following the initial outlays from the renewable feed-in mechanism) at a steady construction for each year. In addition, the build programme for Eskom’s new coal-fired power stations was delayed – by 12 months for Medupi and by 24 months for Kusile. Costs for future coal were decreased from R300 a ton to R200 a ton, while LNG prices were increased to R80/GJ. Import coal costs were changed from the generic costs of pulverised fuel without flue gas desulphurisation (FGD) to those inclusive of FGD.

Following discussions with government stakeholders it was decided firstly, that the emissions from import coal should be excluded from domestic emissions accounting, and secondly, that a solar build programme was required alongside wind at a lower level initially considering the fact that this technology is relatively new and still evolving. The current solar programme (as part of the renewable feed-in mechanism) was moved one year later to lay the foundation for this new programme which will continue at 100 MW for each year. After 2020 the renewable programme continues as a proxy for either wind, solar or other renewable technologies which are viable at that point. Additional regional options were included as per the Regional Development scenario, and some CCGT capacity was forced to allow for a domestic contingency for import and renewable options.
## Table 4. Proposed IRP (Revised Balance Scenario)

<table>
<thead>
<tr>
<th>RTS Capacity</th>
<th>Medupi</th>
<th>Kurule</th>
<th>Ingula</th>
<th>Medupi OCGT</th>
<th>IPP Cogeneration, own build</th>
<th>Coal (PF, FBC, Imports)</th>
<th>Gas CCGT</th>
<th>Cogeneration, own build</th>
<th>Coal (PF, FBC, Imports)</th>
<th>Gas CCGT</th>
<th>Cogeneration, own build</th>
<th>Coal (PF, FBC, Imports)</th>
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The MCDF process confirmed that this Revised Balanced Scenario represents an appropriate balance between the different stakeholder expectations considering a number of key constraints and risks, for example:

- Affordability/Funding availability;
- Reducing carbon emissions;
- New technology uncertainties such costs, operability, lead time to build etc;
- Water usage;
- Localisation and job creation;
- Southern African regional development and integration; and
- Security of supply.

Another consideration included in the Revised Balanced Scenario is the support for the development of a local industry for renewable technologies, in particular wind and solar. By bringing the construction programme for these technologies forward and maintaining a stable roll-out programme, an opportunity is provided for localisation, not only in the construction of the equipment, but in the development of skills to support the renewable programme. By not specifically categorising the renewable technologies after 2020 a window is provided for government to direct alternative renewable technology development to meet government objectives.
The total wind capacity added by 2019 is 4500 MW (inclusive of REFIT1 wind), solar capacity by 2019 is 600 MW, and the total renewable capacity added from 2019 to 2030 is 7200 MW. By forcing the earlier adoption of renewable technologies the country is able to achieve a lower GHG emission peak (296 million tons in 2022, as opposed to 315 million tons in the Emission 2 scenario) at only a marginal increase in cost to the economy.

The Revised Balanced Scenario provides ample opportunity for private investment in electricity generation from the renewable programmes to the CCGT and regional options. The decision as to who builds this capacity must still be made as part of the feasibility assessment after the finalisation of the IRP 2010.

As part of the medium term business mitigation strategy a number of own generation or co-generation options have been identified before 2017. These options have been included in the Revised Balanced Scenario as additional capacity forced in as per the medium-term schedule, in order to maintain some continuity between the plans. However these options have not been included in the calculations on water, prices or emissions.

The Revised Balanced Scenario follows the original decision that transmission infrastructure would not be included in the cost determination for different projects. However it is clear that the regional options are significantly impacted by the transmission infrastructure required to transport the power to South Africa. While there are debates regarding the actual costs for this infrastructure and what proportion would be met by domestic consumers, it is evident that options further from South Africa’s borders should be penalised relative to closer options. In this regard, the import hydro options identified in the Balanced Revised Scenario could end up being more expensive than import coal options which are not built in this scenario. Thus it is possible that the latter option should be favoured over the other regional projects purely on the basis of transmission infrastructure costs, and because South Africa is not penalised by carbon emissions as these do not count toward the domestic target. This would require a modification to the scenario (with regional hydro being delayed accordingly). There is potential for additional import hydro but these projects have not been identified with sufficient costs or capacity to include. Future iterations of the IRP should include these options as better information becomes available.

6. RISKS AND UNCERTAINITIES

6.1. Sensitivity studies

Even with the policy and growth uncertainties catered for to some extent in the scenarios listed above, there are a number of other uncertainties that need to be considered. The models have been tested against changes in the underlying assumptions regarding the following, in particular:

a) Changes in the energy forecast

Since all the scenarios were modelled on the moderate forecast, a test was carried out on the high and low forecasts produced by the System Operator (see Appendix A). The impact of the high forecast is shown in Table 35 in Appendix D. The higher forecast results in the earlier commissioning of the options chosen in the Base Case where possible. A total of 28,5 GW of new pulverised coal is required (as opposed to 16,5 GW in the Base Case with the moderate forecast).

The low forecast allows for a delay in new capacity until 2022 and a significantly lower new coal capacity requirement (to 5,2 GW by 2030). The details for this case are shown in Table 36 in Appendix D.

b) Uncertain and prolonged lead times for building new plant, in particular:

- A twelve month delay in commissioning of Medupi, and a 24 month delay in the commissioning of Kusile.
This sensitivity has been determined for the Base Case (see Table 19 in Appendix D). The clearest impact of the delay in the Eskom build programme is the lower reserve margins from 2013 to 2018 and the bringing forward of some CCGT capacity in 2018.

- The cancellation of the Kusile project.
  The result for the Base Case is captured in Table 18 in Appendix D. For the purposes of debate each scenario has also been developed with a case excluding the Kusile project.

c) The impact of a lower assumed cost of unserved energy (at R10/kWh)
This sensitivity is included in Table 34 in Appendix D. The decrease in the cost of unserved energy tilts the balance in favour of less supply-side capacity (a net new build of 29403 MW as opposed to 31878 MW in the equivalent Base Case), with an increase in unserved energy over the period, especially after the committed programme has been completed. The first new capacity required is only in 2020, a year later than in the equivalent Base Case.

d) Discount rates
Screening curves have been developed based on the cost assumptions for each technology option, indicating the variation in levelised cost for each option based on different assumed capacity factors. These curves are also useful in testing sensitivity to other variables, in particular the impact of a higher or lower discount rate. Figure 10 indicates the impact of the choice of discount rate on the levelised cost for different technologies. Clearly technologies with a higher component of capital costs (relative to other costs) are more impacted by the choice of discount rate, for example the parabolic trough concentrated solar, wind and nuclear. In particular it is noteworthy that at an 8% discount rate pulverised coal is cheaper than nuclear for full lifecycle costs, whereas at a 3% discount rate nuclear is cheaper than pulverised coal.

Figure 10. Sensitivity on levelised costs
e) Cost of technologies

The assumed costs for nuclear capacity have elicited much debate. There is a strong probability that the costs could be higher than those assumed. The impact of this higher cost is indicated in Figure 11 which shows the higher tariff arising from an increase in capital costs of 40%.

Figure 11. Sensitivity of higher nuclear costs

6.2. Key risks in the IRP

The proposed IRP 2010 envisages a dramatic transition from a traditional coal-based electricity industry toward a low carbon environment. This transition carries some risks for the operations of the integrated power system, especially the introduction of variable generation technologies such as wind. The supporting infrastructure, in the form of transmission and distribution networks, and water infrastructure, amongst others, will also be impacted, especially after decommissioned coal power stations are replaced by nuclear and renewable resources which are geographically positioned away from the traditional generation sources in Mpumalanga.

However the improved diversification from reliance on coal toward numerous fuel sources reduces the inherent risk in the electricity sector.

While the risk factor criterion provides a mechanism to evaluate the potential plans for the inherent risks of each plan, it is worth highlighting the risks to provide focus for possible mitigation:

1. Execution of the energy efficiency demand side management (EEDSM) programme
   i. Either through funded Eskom programme, or
   ii. Standard offer, or
   iii. Alternative mechanisms;

2. Execution of the Eskom build programme – highlighted in sensitivities above (dependent on the funding of Kusile, while ensuring no significant slippage in Medupi and Ingula timelines);

3. Liquefied natural gas infrastructure, timelines and costs;
4. Practical execution of wind capacity expansion at the assumed rate in the IRP
   • Supporting infrastructure would be required to make the wind build rate possible, particularly in terms of sufficient equipment to hoist the wind masts across the country;

5. Impact of wind on system operations and grid stability, including the possibility of additional storage to provide back-up supply
   • The IRP 2010 assumed that the wind load factor provides a sufficient proxy for the capacity credit or firm capacity provided by wind. However, experience from other countries, in particular Germany, indicates that at higher wind penetrations the capacity credit from wind is reduced. Initial suggestions are that this should be 25% in winter and 21% in summer (as opposed to the assumed 33%), but studies are continuing to provide further input on this. Critically for the IRP results however, it is possible that the reserve margin indicated is over-stated by using the load factor as the capacity contribution from wind;

6. Practicality of the nuclear fleet build programme, including funding concerns; and

7. Realisation of the expected demand forecast
   • The demand forecast includes an assumption on the changing energy intensity of the economy. If the industrial policy is successful in promoting the regeneration of the industrial base it is possible that the decline in energy intensity may be much slower than that suggested.
   • The lack of distribution and reticulation infrastructure investment over the past decade may have constrained current consumption patterns which, with possible investment in the future, could increase the total demand for electricity beyond that anticipated. Similarly network expansion could release unrealised or “suppressed” demand and increase total demand on the system.

Another approach to these risks is to consider the critical decision points for the relevant technologies and the impact on the plan if these decisions are not made.

Table 5. Mitigation actions for IRP programmes

<table>
<thead>
<tr>
<th>Programme</th>
<th>Decision point</th>
<th>Programme fails</th>
<th>Delay of one year</th>
<th>Delay of two years</th>
</tr>
</thead>
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<tr>
<td><strong>Nuclear programme</strong></td>
<td>Early 2011</td>
<td>Replace 10 GW of nuclear capacity with: 38 GW of wind; 19 GW of solar; 10 GW of import base-load (hydro, coal or gas); 10 GW of “cleaner coal” (with consequences for emissions); Combinations of above, with some CCGT</td>
<td>Replace 1.6 GW of capacity in 2023 with: 6.4 GW of wind; 3.2 GW of solar; 1.6 GW of import base-load; 1.6 GW of “cleaner coal”; Combinations of above, with some CCGT</td>
<td>Replace 3.2 GW of capacity in 2022/3 with: 13 GW of wind; 6.4 GW of solar; 3.2 GW of import base-load; 3.2 GW of &quot;cleaner coal&quot;; Combinations of above, with some CCGT</td>
</tr>
<tr>
<td><strong>LNG infrastructure</strong></td>
<td>Early 2011</td>
<td>Replace 2 GW of CCGT capacity with: 2 GW of import base-load options; 2 GW of “cleaner coal” options. (3)</td>
<td>Replace 500 MW of capacity in 2019 with: 500 MW of import base-load; 500 MW of “cleaner coal”</td>
<td>Replace 1.2 GW of capacity in 2019/20 with: 1.2 GW of import base-load; 1.2 GW of “cleaner coal”</td>
</tr>
<tr>
<td><strong>Execution of EEDSM</strong></td>
<td>Late 2010</td>
<td>Replace 3.5 GW of DSM capacity with: Own generation or co-generation options in the medium term; CCGT, wind or solar options in the longer term (preferably low carbon options)</td>
<td>Replace 750 MW of capacity in 2011 with: Nothing – there being no viable options in the near term until own generation options become viable.</td>
<td>Replace 1.5 GW of capacity in 2011/2 with: Nothing – there being no viable options in the near term until own generation options become viable</td>
</tr>
<tr>
<td><strong>Wind programme beyond REFIT (1)</strong></td>
<td>Late 2011</td>
<td>From a security of supply point of view there is a limited impact, but from a carbon reduction point of view the capacity must be replaced by low carbon sources (solar, imports, additional EEDSM)</td>
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</table>
Solar programme beyond REFIT (1,2)

From a security of supply point of view there is a limited impact, but from a carbon reduction point of view the capacity must be replaced by low carbon sources (wind, imports, additional EEDSM).

Import hydro options

Early 2011
- Replace 3.5 GW of hydro capacity with:
  - 3.5 GW of alternative import options (including coal);
  - 14 GW of wind;
  - 7 GW of solar;
  - 7 GW of mid-merit CCGT;
  - 7 GW of “cleaner coal” Combinations of the above

Early 2012
- Replace 360 MW of hydro capacity with:
  - 360 MW of alternative import options (including coal);
  - 1.4 GW of wind;
  - 720 MW of solar;
  - 360 MW of mid-merit CCGT;
  - 360 MW of “cleaner coal” Combinations of the above

- Replace 1,1 GW of hydro capacity with:
  - 1.1 GW of alternative import options (including coal);
  - 4.4 GW of wind;
  - 2.2 GW of solar;
  - 1.1 GW of mid-merit CCGT;
  - 1.1 GW of “cleaner coal” Combinations of the above

Note: (1) Wind and solar capacity can be procured via staggered tranches. Unlike CCGT there is less supporting infrastructure required to make this happen.
(2) The solar capacity can be supported through the solar park concept which provides a co-ordinated approach to supporting transmission and water infrastructure and other development requirements.
(3) CCGT provides operating reserve support for variable output technologies and thus these do not provide appropriate alternatives to CCGT capacity. Small-scale coal could be possible by 2019 (especially via FBC or similar technology).

### 6.3. IRP projects

Figure 12 provides a summary of the proposed capacities per technology in the draft IRP and the necessary decision points for each of the “programmes” or generic options identified in the draft IRP. The programmes highlighted in RED are those for which the decision point has already passed. If decisions have not been taken by the relevant stakeholders these options may not materialise as expected. The expected lags, or implementation times, required for the programmes are based on assumptions regarding the time taken for environmental assessments, business case approval, procurement processes (for independent power producers or equipment) and the construction of the plant and supporting infrastructure (transmission, water, or other as required).

Programmes highlighted in ORANGE have imminent decision points and should receive higher priority. Those highlighted in YELLOW still have some leeway before the decisions are required. If the feasibility study and allocation decision highlighted above is delayed, this could jeopardise the success of these programmes. The decision period indicated does not at this stage include the full feasibility and allocation programme, thus programmes in ORANGE are already at risk unless the feasibility process is by-passed by a Ministerial determination outside the current regulations.

The RED programmes require immediate determination and execution. These include:

a) Own generation and co-generation: There are already processes under way where certain electricity consumers are developing their own projects. A potential bottleneck for this process could be a national third party access (or wheeling) framework, which supports generators being able to supply Eskom or municipal customers via the existing transmission and distribution networks. This is something Eskom is focusing on.

b) Department of Energy Open Cycle Gas Turbine (OCGT) IPP: If the IPP is required by 2013 as proposed, the procurement process must now be finalised and financial closure reached by early 2011.

c) Renewable Energy Feed-in Tariff (REFIT) options: The procurement process must now be finalised and executed in order to achieve the requirements in the IRP 2010. We are already late in meeting the expectations for wind, small hydro and landfill from this programme as proposed in the IRP and this must be expedited.

d) Wind (after REFIT): If the decision is taken to go the full procurement path (i.e. IPPs) then a procurement process must be followed, leading to financial closure in time to allow three years for environmental impact assessments (EIAs) and construction. There is no time for a full procurement process at the proposed build rate in the IRP. Since wind projects are not essential to the security of supply during this period, slippage is possible without jeopardising the system, but priority must be given to fulfil this programme.
Decisions are imminent for the ORANGE programmes:

a) The nuclear fleet: A decision on the execution of the programme will be required in early 2011 in order to ensure the supporting infrastructure and mechanisms are put in place in time, as well as to ensure that financing and commercial mechanisms are explored to support the fleet deployment. The existing regulations do not require an allocation decision for nuclear, therefore the Minister can make an immediate determination to expedite the process; and

b) The solar fleet: A decision will also be required during 2011 to support the development of a fleet as expected in the IRP.

While it may appear that some decisions can be delayed, i.e. YELLOW programmes, this is not necessarily the case given the need for a feasibility study and allocation. In particular:

a) The Combined Cycle Gas Turbine (CCGT) deployment requires supporting liquefied natural gas (LNG) importing infrastructure, which would be on critical path if delayed beyond early 2011. This decision would be required, regardless of who is allocated the responsibility for the build. This process could be mitigated by asking PetroSA or another entity to start investigating the development of this infrastructure.

b) The import hydro options do not require an allocation decision since these involve IPPs and require an immediate assignment by the Minister of the Single Buyer Officer as the designated Buyer to kick off the programmes. The transmission infrastructure is critical to the success of these programmes and should be initiated immediately; specifically the decisions around infrastructure required in neighbouring countries and the risk allocation for the financing of this infrastructure.
Figure 12. Decision points for IRP projects or programmes

<table>
<thead>
<tr>
<th>Non Committed Build</th>
<th>Committed Build</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New coal options</strong></td>
<td><strong>DOE OCGT IPP</strong></td>
</tr>
<tr>
<td>Key Decision</td>
<td>Key Decision</td>
</tr>
<tr>
<td>Balanced</td>
<td>Balanced</td>
</tr>
<tr>
<td>Revised</td>
<td>Revised</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RFQ = Request for Qualification (for commercial tender to supply energy)</td>
<td>B-Case or B/C = Business Case development</td>
</tr>
<tr>
<td>Proc = Procurement process</td>
<td>EIA = Environmental Impact Assessment</td>
</tr>
<tr>
<td>App = Project approval</td>
<td>Cons = Construction</td>
</tr>
<tr>
<td>MOU = Inter-governmental memorandum of understanding</td>
<td></td>
</tr>
</tbody>
</table>
7. CONCLUSION

The Revised Balanced Scenario provides a solid basis on which to construct the proposed IRP as it combines the main elements that meet the criteria determined by government stakeholders. This plan includes:

- The continuation of Eskom’s committed build programme (including the return to service of Grootvlei and Komati power stations, and the construction of Medupi (4332 MW), Kusile (4338 MW) and Ingula (1332 MW) power stations);
- The construction of the Sere power station (100 MW wind farm);
- Phase 1 of the Renewable Energy power purchase programme linked to the National Energy Regulator of South Africa (NERSA) Renewable Energy Feed-in Tariff (REFIT1) programme amounting to 1025 MW (made up of wind, concentrated solar power (CSP), landfill and small hydro options);
- Phase 1 of the Medium Term Power Purchase programme of 390 MW (made up of co-generation and own build options);
- The Department of Energy’s Open Cycle Gas Turbine (OCGT) IPP programme of 1020 MW;
- A nuclear fleet strategy, commencing in 2023, of at least 9.6 GW by 2030. The nuclear costs included in the IRP are generic values as for the other technologies and are not intended to tie the IRP to a specific technology;
- A wind programme in addition to the REFIT1 wind capacity, commencing in 2014, of a minimum 3.8 GW;
- A solar programme in addition to the REFIT1 solar capacity, commencing in 2016, of a minimum 400 MW. This does not include solar water heating, which is included in the DSM programme (to the extent of 1617 MW);
- A renewable programme from 2020, incorporating all renewable options, inclusive of wind, solar CSP, solar photo-voltaic, landfill, and hydro, amongst others) of an additional 7.2 GW;
- Imported hydro options from the region totalling 3349 MW from 2020 to 2023;
- CCGT capacity, fuelled with imported LNG, totalling 1896 MW from 2019 to 2021;
- Own generation or co-generation options of 1253 MW as identified in the Medium Term Risk Assessment study;
- Up to 5 GW of generic coal based power generation from 2027 to 2030 (in addition to Medupi and Kusile). The choice of technology could be traditional pulverised fuel or clean coal technologies. The builder of the capacity could be Eskom, South African IPPs or regional IPPs. The choice of technology will be based on current assessments of carbon capture and storage sites and the impact on climate change mitigation targets. With the commercialisation of carbon sequestration technologies, additional coal options could become viable. However for this IRP it was assumed that such technologies are not sufficiently developed to be included. Further iterations of the IRP could revisit this;
- Up to 5750 MW of peaking OCGT. This option could also be provided by demand response programmes; and
- Eskom’s current demand-side management (DSM) programme as stipulated in the multi-year price determination (MYPD) application has been incorporated. The breakdown of associated technologies for DSM is included in Appendix B indicating the expected savings from the various constituent programmes.

A number of critical assumptions were included in the development of the proposed IRP 2010. These include:

- The development of a nuclear strategy to provide low emission base-load alternatives to coal-fired generation from 2023;
- The development of a renewable strategy to support a low carbon energy future, specifically developing local industries that support a significant rollout of wind, solar and other renewable technologies;
- The development of infrastructure to support the importation of liquefied natural gas;
- Continued investment in the maintenance and refurbishment of existing Eskom (and non-Eskom) plant to ensure generator performance at assumed levels; and
• Continued investment in DSM initiatives to improve energy efficiency and delay additional capacity requirements. This includes the expected load reduction stemming from the Department of Energy’s one million solar water geyser target.
APPENDIX A – ENERGY AND DEMAND FORECAST

A.1. ASSUMPTIONS

Although the IRP 2010 has a time horizon of 20 years, the load forecast covers the period 2010 to 2035.

The IRP 2010 Revision 2 load forecast covers the total requirement for electricity generation to meet the needs of South Africa, including the needs of neighbouring states and international customers (assuming existing contracts continue at current export volumes). The forecast includes the total energy requirements of all consumers, irrespective of the source of this generation (which may be a result of self-generation or co-generation).

Demand-side management initiatives that are planned (i.e., not yet realised) are excluded from the forecast, since these are included in the planning process to be treated similarly to supply-side options.

Economic growth
A strong correlation exists between the GDP growth and the electricity sales growth, and the electricity sales forecast is based to a large extent on this relationship. The two assumptions underlying this relationship are the forecast GDP and the electricity intensity.

The AsgiSA targeted growth of 6% GDP growth by 2014 is currently used as a base for the high GDP growth forecast. The intention of this target was also to halve unemployment by about 2014. The model assumes an adjustment to the target date (delaying to 2016) to compensate for the impact of the global economic recession. Although this might be seen as an optimistic target, GDP growth rates of close to 6% were achieved in the recent past. While the growth is expected at 6% per annum for a large portion of the forecast period, this is expected to gradually decline over time to 5.3% in 2035. Thus the average annual growth rate of the high GDP growth forecast over the period of 2010 to 2035 is 5.5% per annum.

The moderate GDP growth forecast is similar to the average historical GDP growth over the last few years. The latter is also seen as the potential growth if the AsgiSA targets are not achieved, and are also close to the potential growth of the South African economy as seen by the South African Reserve Bank. This is also in line with the forecasts made by many institutions over the medium term. The average annual GDP growth of this forecast is approximately 4.5% between 2010 and 2035.

The low GDP growth forecast is about 1% lower, on an average annual basis, than the moderate GDP forecast. This is also in line with low growth scenarios which were part of the scenario exercise referred to above. During the past twenty years a narrow cone of ± 1% growth was found very realistic and appropriate for long term planning and therefore the values assumed for the GDP growth rates are as per the table below.
Table 6. Assumptions for GDP growth rates 2010-2035

<table>
<thead>
<tr>
<th>Year</th>
<th>Moderate</th>
<th>High</th>
<th>Low</th>
<th>Year</th>
<th>Moderate</th>
<th>High</th>
<th>Low</th>
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<td>3.68</td>
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<td>-1.70</td>
<td>-1.70</td>
<td>2023</td>
<td>4.80</td>
<td>5.80</td>
<td>3.80</td>
</tr>
<tr>
<td>2010</td>
<td>2.50</td>
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</tr>
<tr>
<td>2011</td>
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<td>4.70</td>
<td>2.70</td>
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<td>5.80</td>
<td>3.80</td>
</tr>
<tr>
<td>2012</td>
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<td>5.00</td>
<td>3.00</td>
<td>2026</td>
<td>4.70</td>
<td>5.70</td>
<td>3.70</td>
</tr>
<tr>
<td>2013</td>
<td>4.00</td>
<td>5.00</td>
<td>3.00</td>
<td>2027</td>
<td>4.70</td>
<td>5.70</td>
<td>3.70</td>
</tr>
<tr>
<td>2014</td>
<td>4.00</td>
<td>5.00</td>
<td>3.00</td>
<td>2028</td>
<td>4.70</td>
<td>5.70</td>
<td>3.70</td>
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<td>2015</td>
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<td>5.50</td>
<td>3.50</td>
<td>2029</td>
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<td>5.60</td>
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<td>2031</td>
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<td>2018</td>
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<td>6.00</td>
<td>4.00</td>
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<td>5.50</td>
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<td>6.00</td>
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<td>4.00</td>
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<td>2021</td>
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<td>5.90</td>
<td>3.90</td>
<td>2035</td>
<td>4.30</td>
<td>5.30</td>
<td>3.30</td>
</tr>
</tbody>
</table>

Electricity intensity

This parameter is not a specific input to the demand forecast model, but is used as a check to determine the correct trajectory for electricity demand (relative to economic growth).

Figure 13. Electricity intensity for South Africa

The electricity intensity of the economy is a measure of the ratio of electricity energy consumption relative to the Gross Domestic Product (GDP). This can be expressed at basic prices and market prices.

The recent historic trend is indicated in the graph above (comparing total South African consumption, including losses, to gross value added at basic prices in blue (constant 2005 prices)), with the intensity at 2009 sitting at 0,16kWh/R of gross value added. The intensity based on the gross value added at market prices (constant 2005 prices) is indicated by the purple line with the intensity at 2009 sitting at 0,129kWh/R of gross value added. The energy intensity will gradually decline from the 0,16kWh/R in 2009 to 0,1kWh/R in 2034 at basic prices.

It is expected that, following the trend of developed countries, the tertiary sector of the economy (which is less energy intensive) should grow at a faster rate than the primary or secondary sectors. High price increases for electricity should also induce a certain amount of substitution to alternative sources.
energy sources, or increased energy efficiency, which should reduce the electricity intensity in the economy.

The decline in energy intensity also provides an indication of the expected improvement in energy efficiency. If the economy grows as per the expected economic growth without any change in energy intensity the expected demand should be significantly higher (at 770 TWh by 2034). Due to the expected shift from energy intensive industries to less intensive economic activity, coupled with efficiency improvements caused by higher prices, the efficiency savings brings the expected demand down to 496TWh, a saving of 35%.

**Figure 14. Improved efficiencies in the IRP 2010 demand forecast**

**Price elasticity of demand**

The forecasting models do not include this parameter at present. Price increases in electricity will have two separate impacts on electricity demand: through income effects which will impact on GDP growth (price increases may reduce income and expenditure through the impact on disposable income) and through substitution effects which will have a direct impact on electricity demand. The former is captured in the assumptions on GDP growth, the latter in the future electricity intensity.

**Forecasting peak demand**

The long-term forecast for electrical energy is the key input from which the long-term demand forecast (i.e. the forecast for the annual demand profile) is derived. The long-term energy forecast and the long-term demand forecast determine the energy and capacity requirements respectively, which must be met through the IRP for 2010. The demand forecast was calculated based on the energy forecast.

**A.2. MODELS**

The System Operator used an in-house developed methodology for the energy forecast, called the Sectoral Model. The Sectoral Model uses Eskom sales categories as the basis for developing the forecast, and is closely aligned to the Eskom MYPD sales forecast for the first 5 years. The model is a combination of statistical analysis, tracking of historical trends and applying expert knowledge. It is further expanded to include individual forecasts for all of the Eskom key customers. The other Eskom
categories are developed per customer service area and the model enables a geographical view per Eskom category.

The CSIR was requested to provide an independent energy forecast. The CSIR used a statistical model which they developed. The model is essentially a multiple regression model forecasting technique, used to forecast the annual consumption within the individual electricity sectors by relating various conditions (or “drivers”) to the demand in each sector.

### A.3. RESULTS

The figure below shows the proposed forecasts for the period up to 2035 using three different GDP assumptions: High – 5.51%, Moderate – 4.51% and Low – 3.51%. These result in electricity growths from the System Operator model of 3.65%, 2.84% and 1.85% respectively. The CSIR model for the same economic growth suggests 2.18%, 2.02% and 1.76% respectively.

#### Table 7. Expected annual energy requirement 2010-2034

<table>
<thead>
<tr>
<th>Year</th>
<th>CSIR Low</th>
<th>CSIR Mod</th>
<th>CSIR High</th>
<th>SO Low</th>
<th>SO Mod</th>
<th>SO High</th>
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<tbody>
<tr>
<td>2010</td>
<td>249,051</td>
<td>249,422</td>
<td>249,626</td>
<td>257,601</td>
<td>259,685</td>
<td>261,769</td>
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<td>2011</td>
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<td>256,744</td>
<td>257,693</td>
<td>262,394</td>
<td>266,681</td>
<td>270,969</td>
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<tr>
<td>2012</td>
<td>261,031</td>
<td>262,376</td>
<td>263,682</td>
<td>267,784</td>
<td>274,403</td>
<td>281,022</td>
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<td>2013</td>
<td>265,790</td>
<td>267,694</td>
<td>269,169</td>
<td>274,788</td>
<td>283,914</td>
<td>293,041</td>
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<td>2014</td>
<td>270,630</td>
<td>272,964</td>
<td>274,497</td>
<td>278,880</td>
<td>290,540</td>
<td>302,201</td>
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<td>2015</td>
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<td>278,589</td>
<td>280,341</td>
<td>285,920</td>
<td>300,425</td>
<td>314,930</td>
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<td>2016</td>
<td>281,051</td>
<td>284,450</td>
<td>286,545</td>
<td>292,728</td>
<td>310,243</td>
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<td>2017</td>
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<td>289,983</td>
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<td>299,991</td>
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<td>2018</td>
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<td>298,548</td>
<td>308,036</td>
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<td>323,498</td>
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<td>2021</td>
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<td>317,996</td>
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<td>2022</td>
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<td>324,928</td>
<td>334,587</td>
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<td>2023</td>
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<td>2024</td>
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<td>343,634</td>
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<td>2025</td>
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<td>346,399</td>
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<td>2030</td>
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<td>2031</td>
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<td>397,937</td>
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<td>2033</td>
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<td>399,384</td>
<td>415,456</td>
<td>386,404</td>
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<td>598,677</td>
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**Note:** CSIR Low, Moderate and High reflect the three economic trajectories, as with the System Operator (SO) Low, Moderate and High.
Figure 15. Expected annual energy requirement 2010-2034

Peak demand

The initial observations were that the load factor was increasing over the forecasted period. This is because the high load factor sectors are dominant in the customer mix of the energy forecast. The energy forecast of the smelters sector is almost constant whereas the industrial sector as a whole is increasing. This led to the load factor being over-stated as the load factor for smelters is very high and it forms a significant portion of the industrial sector. To rectify this, the smelters sector was separated from the industrial sector. Two new profiles, i.e. "new" industrial and smelters sector, were then formed and used in the new forecast. The load factor then gradually decreased towards the end of the forecast period.

The actual profiles for 2007 to 2009 did not provide appropriate indicators for future profiles as these years contain abnormalities caused by supply constraints (in particular interruptions and load shedding). To rectify this, "corrected" profiles were used instead.

Using the sector mix from the energy forecast and confirmed by the model calculations, indications are that the system will remain at a high load factor for a considerable number of years. The current dominating sectors for electricity consumption have very high load factors, and are expected to remain dominant for some time to come. In-depth research needs to be undertaken on these sectors to quantify how issues like beneficiation will impact the load factor.
Table 8. Annual maximum demand 2010-2034

<table>
<thead>
<tr>
<th>Year</th>
<th>High Maximum Demand (MW)</th>
<th>Low Maximum Demand (MW)</th>
<th>Moderate Maximum Demand (MW)</th>
<th>2010 IRP Rev1 Maximum Demand (MW)</th>
<th>CSIR_Moderate (MW)</th>
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<tbody>
<tr>
<td>2010</td>
<td>39216</td>
<td>38587</td>
<td>38885</td>
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</tr>
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<td>2013</td>
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APPENDIX B – DEMAND SIDE INTERVENTIONS

B.1. MANDATORY PROGRAMMES

The Eskom DSM programme, as submitted by Eskom in the 2010 MYPD, is included in the IRP 2010 as a committed programme. While historic results (from previous demand-side management programmes) are locked into the demand forecast, future DSM initiatives are not included in the demand forecast, but are included in the IRP 2010 model as committed programmes.

Table 9. Eskom DSM programme

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<tr>
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<td>38</td>
<td>68</td>
<td>68</td>
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<td>Energy (GWh)</td>
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<td>275</td>
<td>492</td>
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<td>Process Optimisation</td>
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<td>210</td>
<td>293</td>
<td>384</td>
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<td>78</td>
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<td>287</td>
<td>556</td>
<td>910</td>
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<td>Energy (GWh)</td>
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<td>227</td>
<td>360</td>
<td>838</td>
<td>1,622</td>
<td>2,656</td>
<td>3,689</td>
<td>4,722</td>
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<tr>
<td>Total</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Capacity (MW)</td>
<td>254</td>
<td>496</td>
<td>811</td>
<td>1,313</td>
<td>1,969</td>
<td>2,597</td>
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Note: The capacity indicated here is the adjusted capacity to meet the system peak (as opposed to the peak capacity saving from each individual programme)

Research conducted by Eskom indicates that this programme may only scratch the surface of the potential market for EEDSM (which has been estimated at 12933 MW of total market potential). The approved Eskom programme, which is included in the IRP, has been developed based on the most likely options in the medium term.

Energy efficiency (as a separate concept to DSM) covers the use of electricity by consumers. The effect of the price increases would impact on energy efficiency and has been catered for in the electricity intensity parameter sheet. DSM will include specific programmes (or interventions) which may target energy efficiency. These are included above.

While the public participation process provided good direction and ideas on future programmes, there remains little additional information to test these programmes. Thus for this iteration of the IRP the Eskom DSM programme has had to be relied on.
The energy conservation scheme (ECS) is not included in the IRP 2010 as this is seen as a medium term measure to deal with the current shortfall in capacity until 2015 when new generation capacity can provide the required demand.

**B.2. OPTIONS**

In the long run it is expected that additional EEDSM options, with correct costs and anticipated energy savings, should compete with supply-side options, to the extent that new capacity is delayed by the introduction of new EEDSM programmes. The enhanced DSM scenario tests the impact of additional DSM programmes but without programme costs it is only possible to indicate the potential savings from such programmes.
APPENDIX C – SUPPLY-SIDE OPTIONS

C.1. TECHNOLOGY CHOICES

The IRP 2010 starts off with the existing fleet of power stations available in South Africa, together with existing import contracts, to define the existing supply of electricity which is available for distribution from second to second to electricity users. Committed projects to expand existing facilities or to build new facilities are added to the fleet at the expected dates of completion of the projects to ensure the IRP 2010 will reflect a realistic situation in the medium term. For future years the software modelling tool is allowed to choose the appropriate supply options to satisfy demand in the most cost effective way, while satisfying different constraints as defined in various scenarios. These future supply options are contained in a data base where the capital cost of facilities as well as the fuel and operational cost of each option is specified. This chapter intends to describe the supply options used in the IRP 2010 development process.

Existing Fleet of Power Stations

Eskom has 22 operational power stations with a combined capacity of 40 635 MW. The oldest power station (Komati) started production in 1961 and was fully operational by 1966. After being fully mothballed in 1990 Komati was brought back into service and should be fully operational again in 2011. Camden and Grootvlei were also mothballed in the early 1990s and were brought back to service in the last few years.

Table 10. Existing South African generation capacity assumed for IRP

<table>
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<tr>
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<th>Capacity (MW)</th>
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<tbody>
<tr>
<td>Eskom</td>
<td>40635</td>
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<tr>
<td>Camden</td>
<td>1520</td>
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<tr>
<td>Grootvlei</td>
<td>372</td>
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<tr>
<td>Komati</td>
<td>202</td>
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<tr>
<td>Arnott</td>
<td>2280</td>
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<tr>
<td>Hendrina</td>
<td>1870</td>
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<tr>
<td>Kriel</td>
<td>2850</td>
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<tr>
<td>Duvha</td>
<td>3450</td>
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<tr>
<td>Maltab</td>
<td>3450</td>
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<tr>
<td>Kendel</td>
<td>3840</td>
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<td>Lethabo</td>
<td>3558</td>
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<td>Matimba</td>
<td>3690</td>
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<tr>
<td>Tutuka</td>
<td>3510</td>
</tr>
<tr>
<td>Majuba</td>
<td>3843</td>
</tr>
<tr>
<td>Koeberg</td>
<td>1800</td>
</tr>
<tr>
<td>Gariep</td>
<td>960</td>
</tr>
<tr>
<td>Vanderkloof</td>
<td>240</td>
</tr>
<tr>
<td>Drakensberg</td>
<td>1000</td>
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<tr>
<td>Palmiet</td>
<td>400</td>
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<tr>
<td>Acacia and Port Rex</td>
<td>342</td>
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<tr>
<td>Ankerlig and Gourikwa</td>
<td>2058</td>
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<tr>
<td>Non-Eskom</td>
<td>3280</td>
</tr>
<tr>
<td>TOTAL</td>
<td>43895</td>
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</table>

Two pump storage power stations (Drakensberg and Palmiet) are being used as peaking supplies together with four gas turbine power stations, of which two are small and more than 30 years old (Acacia and Port Rex) and the other two are bigger and less than 5 years old (Ankerlig and Gourikwa). Two hydro power stations in the Orange River (Gariep and Vanderkloof) are in operation,
and one nuclear power station (Koeberg) is used for base-load generation. The remaining ten power stations are coal fired base-load power stations.

Non-Eskom generation is dominated by the Cahora Bassa import of 1 500 MW. Other non-Eskom sources in South Africa consist of municipal generators and private generation under the medium term power purchase programme.

Table 11. Existing non-Eskom generation

<table>
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<th>Capacity (MW)</th>
<th>Load factor (%)</th>
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<td>Kelvin A</td>
<td>50 62.4</td>
</tr>
<tr>
<td>Kelvin B</td>
<td>155 62.4</td>
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<tr>
<td>Rooiwal</td>
<td>155 62.4</td>
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<tr>
<td>Pretoria West</td>
<td>75 62.4</td>
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<tr>
<td>Sasol SSF - Coal-fired PF</td>
<td>520 62.4</td>
</tr>
<tr>
<td>Sasol Infrachem - Coal-fired PF</td>
<td>130 62.4</td>
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<tr>
<td><strong>Pumped Storage</strong></td>
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<td>Steenbras</td>
<td>180 20</td>
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<tr>
<td><strong>Limited Energy Plant</strong></td>
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<td>Mini Hydro (First Falls, Second Falls, Mbashe and Ncore)</td>
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</tr>
<tr>
<td>Sappi Stanger</td>
<td>155 62.4</td>
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<tr>
<td>Mondi Merebank</td>
<td>50 62.4</td>
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<tr>
<td>Mondi Felixton</td>
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<tr>
<td>Mondi Umhlaluzi</td>
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<td>Methane Waste Gas</td>
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<td>Sugar Mills</td>
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<tr>
<td>Mossgas</td>
<td>90 62.4</td>
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</table>

Notes:
(1) Kelvin power station has had operational issues in the recent past – the power station capacity is limited to that used in IRP 2010 Rev 1 (205 MW, as above).
(2) No non-Eskom emergency gas turbine capacity is included in the IRP 2010 model.

Some of the older power stations will reach the end of their respective economic life during the planning period incorporated in this IRP. Some of the non-Eskom generators will be decommissioned from 2015 onwards, with substantial Eskom de-commissioning starting in 2022. Table 12 provides the expected decommissioned capacity.

In total, the existing installed capacity available to South Africa is 43895 MW. This capacity will be increased with a number of committed projects over the medium term. The following committed projects are included in this IRP development, with commissioning dates, as shown in the table below. The capacity is included if it is available before the peak of the year in question, for example no additional units are expected to be commissioned at Komati before the peak in 2010, however additional capacity commissioned after the peak will reflect in the following year.
### Table 12. Committed new capacity and decommissioning

<table>
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<th>Year</th>
<th>Grootevlei (RTS)</th>
<th>Komati (RTS)</th>
<th>Medupi</th>
<th>Kusile</th>
<th>DoE OCGT</th>
<th>Ingula</th>
<th>MTPPP 1</th>
<th>REFIT Wind</th>
<th>REFIT Other</th>
<th>Sere</th>
<th>Decommissioning</th>
<th>Net new capacity</th>
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<tr>
<td></td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
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After all these options are implemented, the IRP 2010 development process will start to bring new supply options into the plan. This will be done in a process that optimises the cost and any other factors that might constrain the plan, for example CO₂ emissions, or any government policy position that might specify targets for renewable energy production levels. The cost of available technologies is specified in the data input files, both for capital spending requirements as well as for production costs, be it fixed annual costs or variable production costs. The tables below give a reduced data sample for various supply options, using data from the final EPRI report on South African costs.
### Table 13. Generic supply-side option costs

<table>
<thead>
<tr>
<th>Pulverised Coal with FGD</th>
<th>Fluidised bed with FGD</th>
<th>Nuclear Area EPR</th>
<th>OCGT</th>
<th>CCGT</th>
<th>Wind</th>
<th>Concentrated PV</th>
<th>Forestry residue biomass</th>
<th>Municipal solid waste biomass</th>
<th>Pumped storage</th>
<th>Integrated Gasification Combined Cycle (IGCC)</th>
<th>CSP, parabolic trough, 3 hrs storage</th>
<th>CSP, parabolic trough, 6 hrs storage</th>
<th>CSP, parabolic trough, 9 hrs storage</th>
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<tbody>
<tr>
<td>Capacity, rated net</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>6X750 MW</td>
<td>6X250 MW</td>
<td>6X1600 MW</td>
<td>114,7 MW</td>
<td>711,3 MW</td>
<td>100X2 MW</td>
<td>10 MW</td>
<td>25 MW</td>
<td>25 MW</td>
<td>4X375 MW</td>
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<td>125 MW</td>
<td>125 MW</td>
<td>125 MW</td>
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<td>Life of programme</td>
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<td>60</td>
<td>30</td>
<td>30</td>
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<td>9</td>
<td>16</td>
<td>2</td>
<td>3</td>
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<td>2</td>
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<td>3.5-4</td>
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<td>4</td>
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<tr>
<td>Typical load factor (%)</td>
<td>85%</td>
<td>85%</td>
<td>92%</td>
<td>10%</td>
<td>50%</td>
<td>29% (7.8m/s wind @ 80m)</td>
<td>26.8%</td>
<td>85%</td>
<td>85%</td>
<td>20%</td>
<td>85%</td>
<td>31.2%</td>
<td>36.3%</td>
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<td>Variable O&amp;M (R/MWh)</td>
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<td>95.2</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>31.1</td>
<td>38.2</td>
<td>4</td>
<td>14.4</td>
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<td>Fixed O&amp;M (R/kW/a)</td>
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<td>-</td>
<td>70</td>
<td>148</td>
<td>266</td>
<td>502</td>
<td>972</td>
<td>2579</td>
<td>123</td>
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<td>513</td>
<td>562</td>
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<td>Variable Fuel costs (R/GJ)</td>
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<td>6.25</td>
<td>200</td>
<td>74.4</td>
<td>-</td>
<td>-</td>
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<td>19.5</td>
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<td>Fuel Energy Content, HHV, MJ/kg</td>
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<td>-</td>
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<td>11760</td>
<td>11390</td>
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<td>19220</td>
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<td>Heat Rate, kW/KWh, avg</td>
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<td>10760</td>
<td>11926</td>
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<td>14185</td>
<td>18580</td>
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<td>9758</td>
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<td>Overnight capital costs (R/kW)</td>
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<td>26575</td>
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<td>5780</td>
<td>14445</td>
<td>37225</td>
<td>33270</td>
<td>66900</td>
<td>7913</td>
<td>24670</td>
<td>37425</td>
<td>43385</td>
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<td>Phasing in capital spent (% per year) (*) indicates commissioning year of 1st unit</td>
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<td>2%, 6%, 13%, 17%, 16%, 15%, 11%, 3%</td>
<td>3%, 3%, 7%, 7%, 8%, 8%, 8%, 8%, 8%, 6%, 6%, 6%, 2%, 2%</td>
<td>90%, 10%</td>
<td>40%, 50%, 10%</td>
<td>2.5%, 2.5%, 5%, 15%, 75%</td>
<td>10%, 90%</td>
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<td>10%, 25%, 45%, 20%</td>
<td>3%, 16%, 17%, 21%, 20%, 14%, 7%, 2%, 10%</td>
<td>5%, 18%, 35%, 32%, 10%</td>
<td>10%, 25%, 45%, 20%</td>
<td>10%, 25%, 45%, 20%</td>
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<td>Equivalent Avail</td>
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<td>92.95</td>
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<td>88.8</td>
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<td>6000 (sea)</td>
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<td>256.8</td>
<td>250</td>
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<td>Sorbent usage, kg/MWh</td>
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<td>28.4</td>
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<td>CO2 emissions (kg/MWh)</td>
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<td>622</td>
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<td>Hg (kg/MWh)</td>
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<td>Particulates (kg/MWh)</td>
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<td>0</td>
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<td>-</td>
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<td>0.16</td>
<td>0.28</td>
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<td>Fly ash (kg/MWh)</td>
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<td>35.1</td>
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<td>-</td>
<td>-</td>
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<td>24.2</td>
<td>1226</td>
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<td>Bottom ash (kg/MWh)</td>
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<td>6.1</td>
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<td>Annual build limits</td>
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<td>1 unit every 18 months</td>
<td>2500 MW after 2017</td>
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<td>100 MW</td>
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Private generation options are included for 2014 and 2015 using the generic fluidised bed costs. The nuclear costs included here are generic values as for the other technologies and are not intended to tie the IRP to a specific technology.
### Table 14. Assumed project costs for import supply-side options

<table>
<thead>
<tr>
<th>Import hydro (Mozambique A)</th>
<th>Import hydro (Mozambique B)</th>
<th>Import coal (Botswana)</th>
<th>Import hydro (Mozambique C)</th>
<th>Import coal (Mozambique)</th>
<th>Import hydro (Zambia A)</th>
<th>Import coal (Zambia B)</th>
<th>Import hydro (Zambia C)</th>
<th>Import hydro (Namibia)</th>
<th>Import gas (Namibia)</th>
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<td>Capacity</td>
<td>1125 MW</td>
<td>850 MW</td>
<td>1200 MW</td>
<td>160 MW</td>
<td>1000 MW</td>
<td>750 MW</td>
<td>120 MW</td>
<td>360 MW</td>
<td>711 MW</td>
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<td>Life of programme</td>
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<td>30</td>
<td>60</td>
<td>30</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
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<tr>
<td>Lead time</td>
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<td>9</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Load factors (%)</td>
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<td>38%</td>
<td>85%</td>
<td>42%</td>
<td>N/A</td>
<td>46%</td>
<td>64%</td>
<td>38%</td>
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<td>Variable O&amp;M (R/MWh)</td>
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<td>18</td>
<td>12.1</td>
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<td>12.1</td>
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<td>Fixed O&amp;M (R/kW/a)</td>
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<td>69.8</td>
<td>379</td>
<td>69.8</td>
<td>160</td>
<td>69.8</td>
<td>69.8</td>
<td>69.8</td>
<td>168</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<td>7256</td>
<td>16880</td>
<td>15152</td>
<td>14400</td>
<td>6400</td>
<td>9464</td>
<td>4264</td>
<td>5780</td>
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<td>Phasing in capital spent (% per year)</td>
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<td>15%, 55%, 30%</td>
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<td>90</td>
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<td>90</td>
<td>91.7</td>
<td>90</td>
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<td>Maintenance</td>
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<td>4.8</td>
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<td>3.7</td>
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<td>3.7</td>
<td>5</td>
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<td>4.6</td>
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<td>-</td>
<td>100</td>
<td>-</td>
<td>-</td>
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<td>12.8</td>
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<td>Sorbent usage, kg/MWh</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>SO2 emissions (kg/MWh)</td>
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<tr>
<td>Fly ash (kg/MWh)</td>
<td>-</td>
<td>-</td>
<td>166.4</td>
<td>-</td>
<td>166.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Expected COD of 1st unit</td>
<td>-</td>
<td>-</td>
<td>0.12</td>
<td>-</td>
<td>0.12</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>

Regional projects are not treated as generic. Since many of these are either hydro or gas, there are local considerations that significantly change the costs of the plant (particularly hydro). Thus these options are identified specifically. The cost values used in the modelling are based on commercially sensitive negotiated prices, and thus will not be published. The results of the IRP will not identify specific projects, but assume a generic input from the region.

The costs and other parameters were derived from the SAPP Pool plan, which used 2006 USD. These costs were escalated by (an assumed) 8% to get to 2010 USD, and then R7.40/USD at Jan 2010. Some of these costs have been replaced with the EPRI generic numbers which are more up to date, and with Eskom project numbers where specific values were available.
Table 15. Sugar cane fibre biomass options

Sugar Cane Fibre Cost And Performance Summary (EPRI Executive Summary Format)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Cane Fibre</th>
<th>Cane Fibre (Felixton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Capacity MW net</td>
<td>52.5</td>
<td>49</td>
</tr>
<tr>
<td>Plant Operating Season per year - weeks</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Plant Cost Estimates (January 2010)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capex Rm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Plant Cost Overnight ZAR/kW</td>
<td>21,318</td>
<td>9,429</td>
</tr>
<tr>
<td>Lead Times and Project Schedule years</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Expense Schedule % of TPC per year</td>
<td>10%, 30%, 60%, 33%, 67%</td>
<td></td>
</tr>
<tr>
<td>Fuel Cost Estimates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First Year ZAR/GJ</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Expected Escalation</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Fuel Energy Content kJ/kg</td>
<td>6,850</td>
<td>6,343</td>
</tr>
<tr>
<td>Operation and Maintenance Cost Estimates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed O&amp;M ZAR/kW-yr</td>
<td>310</td>
<td>115</td>
</tr>
<tr>
<td>Variable O&amp;M ZAR/MWh</td>
<td>18</td>
<td>5.9</td>
</tr>
<tr>
<td>Availability Estimates (during season)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivalent Availability</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>3.8%</td>
<td>3.8%</td>
</tr>
<tr>
<td>Unplanned Outages</td>
<td>1.2%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Availability Estimates (for the year)</td>
<td></td>
<td></td>
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<tr>
<td>Equivalent Availability</td>
<td>66.0%</td>
<td>66.0%</td>
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<tr>
<td>Maintenance</td>
<td>33.0%</td>
<td>33.0%</td>
</tr>
<tr>
<td>Unplanned Outages</td>
<td>1.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Performance Estimates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic Life years</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Heat Rate kJ/kWh</td>
<td>19,327</td>
<td>26,874</td>
</tr>
<tr>
<td>Plant Load Factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical Capacity Factor during Season</td>
<td>71%</td>
<td>80%</td>
</tr>
<tr>
<td>Typical Capacity Factor overall</td>
<td>49%</td>
<td>55%</td>
</tr>
<tr>
<td>Maximum of Rated Capacity</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Minimum of Rated Capacity</td>
<td>22%</td>
<td>22%</td>
</tr>
<tr>
<td>Water Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per Unit of Energy L/MWh</td>
<td>217</td>
<td>217</td>
</tr>
<tr>
<td>Air Emissions kg/MWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2</td>
<td>2,129</td>
<td>2,807</td>
</tr>
<tr>
<td>CO2 Net of renewable CO2</td>
<td>88</td>
<td>115</td>
</tr>
<tr>
<td>SOx (as SO2)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NOx (as NO2)</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td>Particulates</td>
<td>0.45</td>
<td>0.8</td>
</tr>
<tr>
<td>Solid Wastes kg/MWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fly ash</td>
<td>81.7</td>
<td>113.6</td>
</tr>
<tr>
<td>Bottom ash</td>
<td>27.3</td>
<td>36.8</td>
</tr>
</tbody>
</table>

The costs for Felixton above are included as an option, but limited to this specific instance/project. The generic cane fibre costs are included as options in the IRP 2010 with a potential of 1000 MW as indicated by Tongaat in its submission.

Learning rates
None of the current scenarios include learning rates for technology options. A test case has yet to be run to determine the impact of learning rates on the optimal choices for the IRP. The following table includes some of the potential learning for specific technologies suggested by the International Energy Agency (IEA), based on the decrease in costs for each technology for every doubling in the global capacity for the technology.
Table 16. Potential learning rates

<table>
<thead>
<tr>
<th>Technology options</th>
<th>Learning rate for each doubling in capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind (onshore)</td>
<td>7</td>
</tr>
<tr>
<td>Photo-voltaics</td>
<td>18</td>
</tr>
<tr>
<td>CSP</td>
<td>10</td>
</tr>
<tr>
<td>Biomass</td>
<td>5</td>
</tr>
<tr>
<td>IGCC</td>
<td>3</td>
</tr>
<tr>
<td>Nuclear III</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: International Energy Agency, Energy Technology Perspectives 2008, Table 5.3. (p 207)

Figure 16. Screening curves for generation technologies (8% net discount rate)

Figure 16 provides an overview of the levelised costs for the generic options for the IRP 2010 based on the potential capacity factor for each technology. In most cases there is a wide range of possible load factors (for example, CCGT or forest waste biomass) whereas others, such as wind and other renewables, are limited to the assumed capacity factor in the IRP 2010 model. This can be significant in terms of the optimisation process in the model where certain technologies can offer capacity for operating reserves. This additional value is not indicated in the screening curve, which is a reflection of the energy dimension of each technology. Figure 17 offers an alternative view relating the levelised cost at an assumed capacity factor against the firm capacity (or capacity credit) offered by each capacity.

This suggests that even though certain technologies may be cheaper on a levelised cost basis the optimal plan would need to consider the capacity available to meet peak demand as well as reserves and the availability of each technology to offer this. Technologies will be limited by the capability to store the fuel, e.g. wind has no ability to store its fuel, concentrated solar has a limited capacity through the molten salts heat storage, pumped storage has the capacity through the water in the dams, and large base-load generators have capability through large fuel storage.

The selection of OCGT as a viable technology for the plan is based on the generation capacity provided at low capital cost to provide reserves and very limited peaking capability with a high degree
of certainty but at significant operating costs. This is preferable to pumped storage which has higher capital costs, but lower operating costs.

Figure 17. Capacity and energy dimension

![Capacity and Energy dimensions](image)

**Note:** The size of each bubble is based on the relative capital cost (per kW installed capacity) of each technology (in 2010 present value terms)

### C.2. TECHNOLOGY-SPECIFIC MODELLING ISSUES

**Wind**

In the absence of clear data on wind profiles across the country, a number of assumptions were made to generate such profiles for wind generation options. In order to accommodate the likelihood of diversity in wind profiles, four wind categories were developed using the same wind generation characteristics (load factor, costs, etc) but subject to different wind speed profiles.

Each of these profiles was developed based on a four day cycle for wind speed. This assumption is based on findings by GTZ on the experience of wind in Germany. Within this four day cycle the distribution of wind speed is based on a Weibull distribution which caters for the non-normal distribution relating to wind speed. A random generator provided the wind speed in each hour within the constraints of the Weibull distribution and four day cycle. Each of the four profiles was generated randomly but independent of one another. No attempt was made to correlate the profiles with one another, providing some diversity but not generated in order to maximise this diversity.

The wind generation, a function of the wind speed in each hour, is then fixed at this profile over the period of the study. Since this generation is independent of the total system demand profile, the model would choose wind primarily for energy production and less for its contribution to the system capacity, especially where the profile does not closely match the system requirement.

The allocation of wind capacity was constrained to ensure that each of the profiles received an equal share of the capacity through the study period.
Solar
The final EPRI report on generation technology options for the development of the IRP\(^2\) provides profiles for solar generation based on storage options and technology choices. These profiles were used to indicate the generation profile for each solar technology based on a random indication of sunlit days (as opposed to overcast days with no generation). These profiles were developed to ensure that the assumed load factor from each option was met.

\(^2\) EPRI, Power Generation Technology Data for Integrated Resource Plan of South Africa, 2010
APPENDIX D DETAILED RESULTS

The optimal plans for each of the IRP scenarios are shown. The capacity required from each project in order to meet the annual peak is shown in each case.
### Table 17. Base Case 0.0 (Kusile in)

<table>
<thead>
<tr>
<th>Year</th>
<th>Committed Gas</th>
<th>Coal FBC</th>
<th>Import Coal</th>
<th>Gas CGGT</th>
<th>OCGT</th>
<th>Import Hydro</th>
<th>Coal PF + FGD</th>
<th>Total new build</th>
<th>Total system capacity</th>
<th>Peak demand (net sent-out) forecast</th>
<th>Peak demand Side Management</th>
<th>Reserve Margin</th>
<th>Reserve Margin</th>
<th>Annual energy (net sent-out) forecast</th>
<th>PV Total cost (cumulative)</th>
<th>Water</th>
<th>Total CO2 emissions</th>
<th>Capital expenditure (at date of commercial operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>640</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>640</td>
<td>44535</td>
<td>252</td>
<td>15.28</td>
<td>-</td>
<td>-</td>
<td>259,685</td>
<td>44,138</td>
<td>336,420</td>
<td>237</td>
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<td>2011</td>
<td>1009</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1009</td>
<td>45544</td>
<td>252</td>
<td>15.18</td>
<td>-</td>
<td>-</td>
<td>266,681</td>
<td>87,467</td>
<td>349,613</td>
<td>243</td>
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<tr>
<td>2012</td>
<td>1425</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1425</td>
<td>46969</td>
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<td>16.88</td>
<td>-</td>
<td>-</td>
<td>274,403</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2601</td>
<td>49570</td>
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<td>-</td>
<td>-</td>
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<td>347,830</td>
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<td>0</td>
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<td>-</td>
<td>295,629</td>
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<td>341,505</td>
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<td>0</td>
<td>0</td>
<td>1988</td>
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<td>-</td>
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<td>327,011</td>
<td>259</td>
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<td>0</td>
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<td>-</td>
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<td>346,282</td>
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<td>378,543</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>-</td>
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<td>72304</td>
<td>252</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>583,181</td>
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<td>430</td>
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<td>605,081</td>
<td>844,905</td>
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</tr>
</tbody>
</table>
## Table 18. Base Case 0.1 (Kusile out)

<table>
<thead>
<tr>
<th>Year</th>
<th>Committed</th>
<th>Coal FBC</th>
<th>Import Coal</th>
<th>Gas CC GT</th>
<th>OCGT</th>
<th>Import Hydro</th>
<th>Coal PF + FGD</th>
<th>Total new build</th>
<th>Total system capacity</th>
<th>Peak demand (net sent-out) forecast</th>
<th>Demand Side Management</th>
<th>Reserve Margin</th>
<th>Reserves</th>
<th>Unserved energy</th>
<th>Annual energy (net sent-out) forecast</th>
<th>PV Total cost (cumulative)</th>
<th>Water</th>
<th>Total CO₂ emissions</th>
<th>Capital expenditure (at date of commercial operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
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Table 26. Carbon Tax 0.0

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Note: The table includes columns for year, committed capacity, coal fired, imported coal, gas fired, oil, wind, nuclear fleet, coal fired with FGD, total new build, total system capacity, peak demand forecast, demand side management, reserve margin, reliable capacity, reserve margin, unserved energy, PV total cost, water, total CO2 emissions, and capital expenditure at date of commercial operation.
## Table 27. Carbon Tax 0.1

| Year  | Coal FBC | Import Coal | Gas CCGT | OCGT | Import Hydro | Wind | Nuclear Fleet | Coal PF + FGD | Total new build (MW) | Total system capacity (MW) | Peak demand (net sent-out) forecast (MW) | Demand Side Management Reserve Margin | Reliable capacity Reserve Margin | Annual energy (net sent-out) forecast (GWh) | PV Total cost (cumulative) Rm | Water | Total CO₂ emissions Rbn |
|-------|----------|-------------|----------|------|--------------|------|---------------|--------------|---------------------|-------------------------------|--------------------------------|----------------------------------------|----------------------------------|----------------------------------|--------------------------------|------------------------|----------------------|----------------------|
| 2010  | 640      | 0           | 0        | 0    | 0            | 0    | 0             | 0            | 640                 | 44535                         | 38885                          | 252                             | 15.28                              | 15.18                             | 259,685                        | 44,144                 | 336,986              | 237                 |
| 2011  | 1009     | 0           | 0        | 0    | 0            | 0    | 0             | 0            | 1009               | 45544                        | 39956                          | 494                             | 15.41                              | 14.74                             | 266,681                        | 87,480                 | 349,508              | 243                 |
| 2012  | 1425     | 0           | 0        | 0    | 0            | 0    | 0             | 0            | 1425               | 46969                        | 40995                          | 809                             | 16.88                              | 15.25                             | 274,403                        | 128,943                | 350,347              | 250                 |
| 2013  | 2601     | 0           | 0        | 0    | 0            | 0    | 0             | 0            | 2601               | 49570                        | 42416                          | 1310                            | 20.59                              | 17.84                             | 283,914                        | 168,796                | 348,884              | 252                 |
| 2014  | 2543     | 0           | 0        | 0    | 0            | 0    | 0             | 0            | 2543               | 52113                        | 43436                          | 1966                            | 25.66                              | 21.81                             | 290,540                        | 206,770                | 343,493              | 253                 |
| 2015  | 542      | 0           | 0        | 0    | 0            | 0    | 0             | 0            | 542                | 52655                        | 44865                          | 2594                            | 24.56                              | 19.58                             | 300,425                        | 243,973                | 335,139              | 260                 |
| 2016  | 632      | 0           | 0        | 0    | 0            | 0    | 0             | 0            | 632                | 53287                        | 45786                          | 3007                            | 24.56                              | 19.58                             | 310,243                        | 280,622                | 340,966              | 267                 |
| 2017  | 632      | 0           | 0        | 948  | 0            | 1600 | 0             | 0            | 2548               | 55835                        | 47870                          | 3420                            | 25.61                              | 17.87                             | 320,751                        | 331,915                | 350,621              | 272                 |
| 2018  | 0        | 0           | 948      | 0    | 1600         | 0    | 0             | 0            | 2548               | 58383                        | 49516                          | 3420                            | 26.66                              | 16.90                             | 332,381                        | 379,607                | 363,118              | 280                 |
| 2019  | 0        | 0           | 0        | 805  | 1110         | 1600 | 0             | 0            | 3515               | 61988                        | 51233                          | 3420                            | 29.46                              | 17.78                             | 344,726                        | 434,053                | 356,459              | 279                 |
| 2020  | 0        | 0           | 0        | 805  | 283          | 1600 | 0             | 0            | 2688               | 64586                        | 52719                          | 3420                            | 31.01                              | 17.52                             | 355,694                        | 477,052                | 363,889              | 286                 |
| 2021  | -75      | 0           | 237      | 805  | 0            | 1600 | 0             | 0            | 2567               | 67153                        | 54326                          | 3420                            | 31.91                              | 16.76                             | 365,826                        | 517,869                | 375,852              | 292                 |
| 2022  | -1870    | 0           | 250      | 0    | 0            | 1600 | 1600          | 0            | 2662               | 69815                        | 55734                          | 3420                            | 33.45                              | 16.67                             | 375,033                        | 579,388                | 351,030              | 281                 |
| 2023  | -2280    | 250         | 948      | 0    | 1600         | 1600 | 0             | 0            | 2118               | 71933                        | 57097                          | 3420                            | 30.41                              | 15.68                             | 383,914                        | 638,794                | 323,326              | 268                 |
| 2024  | -909     | 711         | 0        | 283  | 1600         | 0    | 0             | 0            | 2435               | 74368                        | 58340                          | 3420                            | 35.41                              | 15.54                             | 392,880                        | 678,957                | 314,781              | 271                 |
| 2025  | -1520    | 500         | 0        | 0    | 115          | 0    | 1600          | 0             | 2295               | 76663                        | 60150                          | 3420                            | 35.14                              | 14.05                             | 404,358                        | 730,261                | 289,238              | 262                 |
| 2026  | 0        | 0           | 0        | 0    | 1600         | 0    | 0             | 0            | 3200               | 79683                        | 61770                          | 3420                            | 36.87                              | 14.52                             | 415,281                        | 774,999                | 287,094              | 259                 |
| 2027  | 0        | 250         | 0        | 0    | 575          | 1600 | 0             | 0            | 2425               | 82288                        | 63404                          | 3420                            | 37.18                              | 13.68                             | 426,196                        | 804,312                | 288,875              | 264                 |
| 2028  | -2850    | 0           | 1200     | 0    | 690          | 1600 | 0             | 0            | 2240               | 84528                        | 64867                          | 3420                            | 37.56                              | 12.89                             | 436,761                        | 850,277                | 255,193              | 252                 |
| 2029  | -1128    | 0           | 345      | 0    | 1600         | 0    | 0             | 0            | 2417               | 86945                        | 66460                          | 3420                            | 37.92                              | 12.19                             | 445,888                        | 888,075                | 239,690              | 244                 |
| 2030  | 0        | 0           | 115      | 0    | 1600         | 0    | 750           | 2465          | 89410              | 67809                         | 3420                            | 38.86                              | 12.00                             | 454,357                        | 914,638                | 240,992              | 249                 |
Table 28. Regional development 0.0

<p>| Year | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | % | % | GWh | GWh | Rm | ML | MT | Rbn |
|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|-----|-----|----|----|----|-----|
| 2010 | 640 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 640 | 44535 | 38885 | 252 | 15.28 | 15.18 | - | 259,685 | 44,138 | 336,420 | 237 | - |
| 2011 | 1009 | 0  | 0  | 0  | 0  | 0  | 0  | 1009 | 45544 | 39956 | 494 | 15.41 | 14.74 | - | 266,681 | 87,467 | 349,613 | 243 | - |
| 2012 | 1425 | 0  | 0  | 0  | 0  | 0  | 0  | 1425 | 46969 | 40995 | 809 | 16.88 | 15.25 | - | 274,403 | 128,921 | 350,510 | 250 | - |
| 2013 | 2601 | 0  | 0  | 0  | 0  | 0  | 0  | 2601 | 49570 | 42416 | 1310 | 20.59 | 17.84 | - | 283,914 | 168,689 | 347,830 | 252 | - |
| 2014 | 2543 | 0  | 0  | 0  | 0  | 0  | 0  | 2543 | 52113 | 43436 | 1966 | 25.66 | 23.52 | - | 290,540 | 206,850 | 341,505 | 252 | - |
| 2015 | 1988 | 0  | 0  | 0  | 0  | 0  | 0  | 1988 | 54101 | 44865 | 2594 | 28.01 | 22.54 | - | 300,425 | 244,060 | 327,011 | 259 | - |
| 2016 | 1355 | 0  | 0  | 0  | 0  | 0  | 0  | 1355 | 55456 | 45786 | 3007 | 29.63 | 24.52 | - | 310,243 | 280,709 | 326,392 | 264 | - |
| 2017 | 1446 | 0  | 0  | 0  | 0  | 0  | 0  | 1446 | 56902 | 47870 | 3420 | 25.01 | 19.82 | - | 320,751 | 314,878 | 330,861 | 272 | - |
| 2018 | 723  | 0  | 0  | 0  | 0  | 0  | 0  | 723  | 57625 | 49516 | 3420 | 21.72 | 16.08 | - | 332,381 | 346,282 | 341,701 | 286 | - |
| 2019 | 0    | 0  | 0  | 0  | 0  | 0  | 575 | 0    | 575  | 58200 | 51233 | 3420 | 344,726 | 378,773 | 346,414 | 296 | 2.44 |
| 2020 | 0    | 0  | 0  | 0  | 0  | 0  | 805 | 480  | 1285 | 59485 | 52719 | 3420 | 355,694 | 411,154 | 360,645 | 306 | 6.08 |
| 2021 | -75  | 0  | 0  | 0  | 0  | 237 | 805 | 1183 | 2150 | 61635 | 54326 | 3420 | 365,826 | 449,227 | 369,814 | 313 | 23.38 |
| 2022 | -1870 | 750 | 0  | 0  | 948 | 805 | 1686 | 2319 | 63954 | 55734 | 3420 | 375,033 | 491,263 | 358,187 | 314 | 39.64 |
| 2023 | -2280 | 750 | 2200 | 474 | 690 | 0  | 1834 | 65788 | 57097 | 3420 | 22.56 | 18.14 | - | 383,914 | 539,596 | 330,000 | 319 | 61.67 |
| 2024 | -909  | 250 | 0  | 0  | 237 | 0  | 1500 | 1078 | 66866 | 58340 | 3420 | 21.75 | 17.45 | - | 392,880 | 577,374 | 318,869 | 325 | 37.95 |
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| 2026 | 0    | 0  | 0  | 0  | 0  | 230 | 1500 | 1730 | 70076 | 61770 | 3420 | 20.09 | 16.08 | - | 415,281 | 652,813 | 300,788 | 344 | 32.85 |
| 2027 | 0    | 0  | 0  | 0  | 0  | 0  | 1500 | 1500 | 71576 | 63404 | 3420 | 19.33 | 15.43 | - | 426,196 | 683,229 | 303,455 | 355 | 31.87 |
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| 2030 | 0    | 0  | 0  | 0  | 237 | 0  | 0  | 1500 | 1737 | 76729 | 67809 | 3420 | 19.17 | 15.54 | - | 454,357 | 783,120 | 262,911 | 376 | 33.39 |</p>
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Table 30. Enhanced Demand Side Management 0.0
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<td>6.11</td>
<td>366,289</td>
</tr>
<tr>
<td>2029</td>
<td>54917</td>
<td>3420</td>
<td>18.27</td>
<td>13.79</td>
<td>8.15</td>
<td>369,977</td>
</tr>
<tr>
<td>2030</td>
<td>55408</td>
<td>3420</td>
<td>18.60</td>
<td>14.15</td>
<td>4.41</td>
<td>372,920</td>
</tr>
</tbody>
</table>
APPENDIX E MEASURING AND SCORING THE CRITERIA

The criteria describe the dimensions in which the optimal scenario portfolios can be assessed for “goodness of fit”. The principle is to achieve the best outcome to meet stakeholders’ objectives, no matter how much in conflict these objectives may seem.

By following a rigorous multi-criteria decision making (MCDM) approach it is possible to describe, numerate and score the preferences and values of the stakeholders with respect to each of the criteria. This provides a solid foundation to assist in choosing a single portfolio as the preferred option. In addition it is possible to identify next-best alternates that can undergo additional stress testing to incorporate concerns regarding robustness to sensitivities.

PARTIAL VALUE FUNCTIONS

Having determined the metric results for each of the potential plans a partial value function is constructed to map these results to a value representing the preferences of decision-makers. The partial value function is important in providing a precise mechanism to rank the outcomes of the different plans in a particular criterion according to the decision-maker preferences. This process should include a broad range of stakeholders to capture all the preferences.

The partial value function provides a mechanism to map the metrics for each of the criterion to a value scale that reflects the group preferences. These preferences are by nature subjective, but by including numerous stakeholders in the workshops determining these preferences a broad and inclusive approach to the values can be determined.

For each criterion the range of result metrics is determined. Taking the cost criterion for illustrative purposes, the partial value curve can be determined according to the following method. Taking two fictional scenarios portfolios, Portfolios A and B, the worst performing portfolio on this criterion is Plan A (which, on the normalised scale, scores a 1.9), whereas the best performing scenario is Plan B (which scores a 1.00). In determining the value function the worst performer scores 0, while the best performer scores 100. This range is somewhat arbitrary, it could be 0..1 or 0..5 or 0..10. The choice of 0..100 is for conceptual ease.

The next step is to determine the marginal or relative importance of different points along the curve. Determining a piece-wise linear curve with four segments a good approximation of the non-linear aspect of the value function. It is therefore simple to split the domain of 1.00 to 1.9 into four equal segments. For these segments a priority ranking is determined to indicate whether, for example, reducing the PV cost from 1.9 to 1.67 is valued more than, less than or equal to a move from 1.67 to 1.45. Once these are ranked, the highest ranking is given a score of 10, and each of the other segments given a value in relation to this score.

The purpose of this approach is the show that the relationships between the different metric results and the corresponding values are not linear. The marginal value change resulting from a change in the metric is critical to the value function.

Once the ranking is determined and a score given to each segment, the value can be calculated for each segment based on the cumulative score from the first segment to the last. If the score for the four segments is, for example, 10, 8, 6, 5, then the value for the first segment is \(10/(10+8+6+5) \times 100 = 34\); for the second segment it is \((10+8)/(10+8+6+5) \times 100 = 62\); for the third \((10+8+6)/(10+8+6+5) \times 100 = 83\), and the last segment = 100.

This process should be repeated for each of the four criteria separately in order to identify preferences for each criterion.

WEIGHTINGS

A critical component of the MCDM process is to determine weightings for each of the criterion. This provides the mechanism to score the scenario portfolios across the different criteria.
In order to determine the weighting for the criteria a series of hypothetical cases are evaluated in which a portfolio scores best on each of the criteria and worst on all the others. Taking each of these hypothetical portfolios a preference ranking can be determined to indicate the extent to which one criterion is more important than others and how the other criteria relate in importance to one another. The highest priority gets an arbitrary weighting of 10 and the others are ranked in relation to the top score of 10.

Having calculated the importance weighting between the criteria and the partial value functions within each criterion a final value associated with each scenario portfolio was produced. This result is determined by multiplying the partial value result for each criterion by the weighting (as a percentage of the total weighting for all criteria).

The score from the process may indicate a preferred portfolio but this cannot be considered as the proposed IRP as the scenarios are not real-world constructs. The MCDM process may indicate a preference but the scenarios provide information to support debate on policy choices. The proposed IRP should consolidate the preferred portfolio with issues raised by the scenarios.

**UNCERTAINTY FACTOR**

As described in Chapter 4 each technology has inherent uncertainties relating to the assumptions made regarding future costs, lead times, operations and environmental impacts. These uncertainties and risks have not been monetised nor included in the other criteria, however a subjective factor is applied to each technology to partially account for these.

### Table 37. Uncertainty or risk factor

<table>
<thead>
<tr>
<th>Projects</th>
<th>Risk rating</th>
<th>Uncertainty in assumptions</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>No risk project</td>
<td>0</td>
<td>None</td>
<td>Scoring 0, future costs, lead times, security, operational risks</td>
</tr>
<tr>
<td>Pulverised coal with FGD</td>
<td>7</td>
<td>Low</td>
<td>Cost assumptions 1, lead times assumptions 3, security of supply risk 3, operational risks 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>Future coal costs could escalate to &gt;R15/GJ, EIA delays, infrastructure concerns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Environmental impact, water contamination, air pollution</td>
</tr>
<tr>
<td>OCGT</td>
<td>6</td>
<td>Low</td>
<td>Cost assumptions 1, lead times assumptions 3, security of supply risk 3, operational risks 2</td>
</tr>
<tr>
<td>Fluidised bed with FGD</td>
<td>6</td>
<td>Moderate</td>
<td>Future coal costs could escalate, EIA delays, infrastructure concerns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Some environmental impact, water contamination</td>
</tr>
<tr>
<td>CSP, parabolic trough</td>
<td>5</td>
<td>Low</td>
<td>Cost assumptions 1, lead times assumptions 1, security of supply risk 1, operational risks 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>Some uncertainty regarding future capital costs, Infrastructure concerns, local capability to be tested</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Some uncertainty regarding future capital costs, Availabilty concerns (issue of capacity credit)</td>
</tr>
<tr>
<td>Wind</td>
<td>2</td>
<td>Low</td>
<td>Cost assumptions 3, lead times assumptions 3, security of supply risk 3, operational risks 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>Actual capital costs could be significantly higher than assumed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Some availability concerns (capacity credit may not be correct)</td>
</tr>
<tr>
<td>Nuclear</td>
<td>10</td>
<td>Low</td>
<td>Cost assumptions 3, lead times assumptions 3, security of supply risk 1, operational risks 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>Significant EIA delays, opposition to development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Contamination, waste management</td>
</tr>
<tr>
<td>CCGT</td>
<td>6</td>
<td>Low</td>
<td>Cost assumptions 2, lead times assumptions 2, security of supply risk 2, operational risks 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>Uncertainty regarding future LNG costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Uncertainty on supporting LNG infrastructure</td>
</tr>
<tr>
<td>Import coal (Botswana)</td>
<td>8</td>
<td>Low</td>
<td>Cost assumptions 2, lead times assumptions 2, uncertainty assumed costs - fuel and capital</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>Some infrastructure concerns</td>
</tr>
<tr>
<td>Source</td>
<td>Security of supply risk</td>
<td>Operational risks</td>
<td>Risk of neighbouring domestic need</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------------------</td>
<td>-------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Import hydro</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Cost assumptions</td>
<td></td>
<td></td>
<td>Uncertain assumed costs</td>
</tr>
<tr>
<td>Lead time assumptions</td>
<td></td>
<td></td>
<td>Significant infrastructure requirements, specifically Moz</td>
</tr>
<tr>
<td>Security of supply risk</td>
<td></td>
<td></td>
<td>Risk of neighbouring domestic need</td>
</tr>
<tr>
<td>Operational risks</td>
<td>1</td>
<td></td>
<td>Environmental impact of dam</td>
</tr>
<tr>
<td>Import gas</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cost assumptions</td>
<td></td>
<td></td>
<td>Uncertain assumed costs</td>
</tr>
<tr>
<td>Lead time assumptions</td>
<td></td>
<td></td>
<td>Project uncertainty</td>
</tr>
<tr>
<td>Security of supply risk</td>
<td></td>
<td></td>
<td>Risk of neighbouring domestic need, resource supply risk</td>
</tr>
<tr>
<td>Operational risks</td>
<td>3</td>
<td></td>
<td>Environmental impact of infrastructure</td>
</tr>
</tbody>
</table>
APPENDIX F PRICING MODEL

Extended Pricing Model Description
The pricing curves for IRP2010 has been calculated using a forward looking pricing model based upon the regulatory pricing rules as used for the MYPD2 price review of Eskom. The pricing approach complies with the Electricity Regulation Act, Act 4 of 2006, which specifies that an efficient licensee should be awarded tariffs that recover the full cost of the business, and it should include a reasonable return. See paragraph (a) in the quote below.

From Electricity Regulation Act, Act 4 of 2006
Tariff principles
16. (I) A licence condition determined under section 15 relating to the setting or approval of prices, charges and tariffs and the regulation of revenues-
(a) must enable an efficient licensee to recover the full cost of its licensed activities, including a reasonable margin or return;
(b) must provide for or prescribe incentives for continued improvement of the technical and economic efficiency with which services are to be provided;
(c) must give end users proper information regarding the costs that their consumption imposes on the licensee’s business;
(d) must avoid undue discrimination between customer categories; and
(e) may permit the cross-subsidy of tariffs to certain classes of customers.

The pricing rules are based on a rate of return methodology, allowing the recovery of operational cost and depreciation for a financial year, with a return on the regulatory asset base (indexed with inflation) calculated using a real rate of return, currently set at 8.17% according to the MYPD2 determination of the Regulator.

The model uses the Eskom submission to the regulator, dated November 2009, as the source of data for the five year period from 2010/11 up to 2014/15. It also fixes the price increases to 25% nominal for the MYPD2 period, and then smoothly migrates to the price path based on the application of the pricing rules. Capital spending of the whole of Eskom was taken from this source, as well as all operational spending, primary energy spending, and depreciation and asset valuation. The economic variables (inflation, exchange rate) were also sourced from this Eskom submission.

To calculate the revenue requirements of Eskom the expenses were grouped into the following baskets: Employee benefits, Primary energy, Environmental levy, Other (including O&M), Depreciation, and Regulatory returns. Regulatory returns include the interest expenses, dividend payment to government if required, and tax liability. From the Rate of Return methodology, this return is a percentage of the regulatory asset base (RAB). Since the asset base is adjusted for the impact of inflation on an annual basis (the Electricity Pricing Policy of 2008 requires a replacement valuation of assets) the return percentage is a real cost of capital, and the Regulator calculated it to be 8.17% per annum. The opening balance of the RAB is also adjusted to reflect the real value of the assets, and the MYPD2 determination by the Regulator was used to obtain the asset base values for 2010, 2011 and 2012.

Annual capital spending was kept at 2015 levels up to 2019 to produce a stable long term electricity price for the Base Case. All operational spending was escalated with the long term inflation outlook of 6% per annum after 2015. The load forecast is aligned with the IRP assumptions.

The basic assumption was that the IRP Base Case aligned with the pricing model described above. This assumption allows for price comparison of all other plans and scenarios with the Base Case for the full study period from 2010 to 2030.

To simplify the calculations, the assumption was made that the MYPD2 submission for financial years could be converted to calendar years without any adjustments. This assumption could be challenged. However, the relative difference in electricity price of each plan or option compared to the Base Case price would be the important output of this exercise, thus the accuracy of the absolute price level is
not a priority. Even so, the absolute price levels calculated are a good indication of where prices are heading, though not 100% accurate.

The pricing rules allow for Eskom to earn a return on Work Under Construction (WUC) and the outputs of the IRP simulations are used in the pricing model to structure capital spending according to the EPRI S-curves to reflect this pricing rule. As a result of this rule, interest during construction would not be capitalised. The difference of annual capital spending in any scenario compared with the Base Case is factored into the pricing model to reflect the impact of the plan on prices.

**Capital Expenditure**

The capital expenditure for each scenario is calculated using the overnight cost of each technology chosen, and the S-curve that describes the phasing of expenditure and the lead time before commissioning of each unit, as recorded in the EPRI Report titled “Power Generation Technology Data for Integrated Resource Plan of South Africa, EPRI Member Specific Final Report, May 2010”. The capital spending is summated for all units under construction, and for all technologies chosen, to arrive at an annual real 2010 capital spending amount. This spending is then converted into a nominal rand value using the assumed inflation values per annum, and the difference with the Base Case capital spending amount is added into the model for each plan/scenario.

To ensure a more realistic termination of the price curve, the model compensates for a fall off in capital spending in the latter years of the plan when no WUC is added for new plant after the end of the study period, and the curves produced would represent a going concern past the end of the study period. After 2030 the model calculates the capital spending by calculating the amount of capacity needed to maintain a pre-selected reserve margin (15% in this case) multiplied by a rand per MW capital spending rate for the full Eskom business, estimated to be R27 000 per kW for this run. The accuracy of this technique could not be confirmed, though, and the prices in the later years should be seen as an approximation only.

**Operating, Maintenance and Primary Energy Expenditure**

The EPRI report is again used to determine these costs. It converts the fixed O&M, variable O&M, and fuel costs into annual expenditure by using the commissioning date of the plant and a realistic load factor determined from the IRP model output file to calculate the relevant MW and MWh figures for each technology. This is again added together to determine the annual O&M spending and primary energy spending in real 2010 rand terms. After conversion to nominal amounts, the difference in spending between a scenario and the Base Case is added into the model to produce the relevant price curve.

**General Operation of Model**

The model calculates the annual revenue required by the utility, using the cost baskets as described above. Using the appropriate load forecast, the revenue requirement is turned into an average selling price by dividing the annual revenue by the annual sales. The 2010 average price is the regulatory approved price, at 41.6 c/kWh. The output of the model used in the report is the 2010 rand value real average price curve from 2010 to 2030.

All current expenditure would be recovered in the period it is expended. The depreciation and regulatory return is supposed to compensate the utility for the capital spending, with depreciation recovering the capital cost and the returns responsible for the cost of the capital. The Base Case ends the study period with a debt: equity ratio close to 50:50 even though it starts at 65:35 in 2010 increasing to a worst ratio of 74:26 for the period 2012 to 2016, indicating that the regulatory pricing rules, if applied consistently, will be able to fund the expansion plan and the business over the long term.

To produce price curves up to 2030 it was necessary to make high level assumption regarding the capital spending past 2030. The pricing model does not, however, process any information regarding the decommissioning of existing power stations past 2030, and as a result the prices in the latter years of the study period are strictly indicative. All price curves start to show a declining trend in the later years to reflect the impact of reducing returns earned on depreciating assets, but the reality might be different for some of the plans. Caution should be exercised when interpreting the longer term pricing trends.
The model can be updated annually using the published Eskom financial statements to ensure the starting point of the calculations are sound.

RESULTS

Figure 18. Price curves for Base Case and Balanced Scenarios

All prices are assumed to have increased by 25% p.a. (nominal increases) during the MYPD2 period, and for an additional two years at the same rate. The real price of 70 c/kWh (2010 rand value) for 2013 becomes the starting price for all price curves, increasing to just more than 80 c/kWh in 2014. From 2014 the prices follow the price curve described by the pricing rules, given the MYPD2 RAB valuation and a real return of 8.17% on the RAB value.

From the above diagram it can be seen that the Base Case then increases to a maximum real 2010 rand value price of about R1.00 per kWh in 2020. If Medupi and Kusile is commissioned later than planned for according to the current project schedule, the maximum price is slightly higher, at about R1.02 c/kWh, but it reaches this peak after remaining below the bas case price curve until completion of the delayed projects. The slightly higher price represents the cost of mitigation during the delayed construction period of Medupi and Kusile.

With Medupi on time and Kusile cancelled, the maximum price is lower, peaking at 99 c/kWh, and it reaches the peak even later. With Kusile not built, the IRP software can optimise the capacity utilisation even further, using mid mer and peaking options more efficiently to obtain the lower electricity prices. The cost of penalties to cancel Kusile would be incurred during the MYPD2 (or perhaps MYPD3) period, and since the increases are limited to 25% nominal per year, the penalty would go into the debt:equity ratio and will not directly influence the price. A penalty of R50 billion would increase the medium term debt:equity ratio from 75:25 to 85:15 when using historic asset valuation index from 2005, as was the case previously, but with the new asset valuation rules the ratio goes from 50:50 to 55:45 if a R50 billion penalty is paid, with no impact on the price curve.

The “Balance” scenarios with more focus on renewable energy in the form of wind power shows a peak price around R1.07 per kWh with Medupi and Kusile on schedule, and slightly lower at R1.06/kWh with wind introduced at a slower rate. If, however, Medupi and Kusile is delayed by one to three years, and with the inclusion of solar, CCGT and nuclear technologies with the possibility of
more imports would result in slower price increases in the early years and a peak around R1.11 per kWh after 2020.

Figure 19. Price curves for Base Case and Emission control scenarios

Three emission control regimes were modelled, called Emissions 1, Emissions 2 and Emissions 3. Emissions 1 limits CO₂ emissions to 275 MT per year from present time, Emissions 2 imposes the same limit only after 2025, and Emissions 3 limits the CO₂ emissions to 220 MT per year after 2020. The two scenarios, with either Medupi and Kusile constructed on time, or Medupi on time and Kusile cancelled, were evaluated.

Limiting CO₂ emissions to 275 MT per year after 2025 does not present a major price penalty over the Base Case, adding perhaps five cent per kWh to the price after 2022. Imposing this limit from today adds about 15 c/kWh to the price after 2020, due to more expensive technologies being used to supply the required load, and with Kusile built there would be a slight over capacity in coal technology, leading to under-utilised assets. The limit of 220 MT of CO₂ emissions per year after 2020 appears to be an expensive option, increasing the price of electricity by more than 70% over the Base Case.

All options with Kusile cancelled show a delayed peak price, and also a reduced peak for the tighter cases. The IRP software can optimise the peaking, mid merit and base load plant better if Kusile is cancelled, resulting in the reduced electricity prices.
When focussing on DSM, and assuming the additional spending on DSM techniques amount to a real R10 billion per year, prices increase earlier than for the Base Case, but eventual prices would be about three to four c/kWh higher than the Base Case. DSM would cost more to implement, but has lower operating cost than generation options, and it also does not incur depreciation and returns in the books of the utility. The actual savings result per rand spent obtained could change the picture somewhat – the R10 billion spent per annum is not necessarily the correct assumption.

For the regional development plan, it was assumed that the cost of transmission outside South Africa would add about 15 c/kWh to the cost of the technology, and as a result the price of electricity would be around 1 c/kWh more expensive than the Base Case after 2020. The same relative margin in the price exists for both the cases where Kusile is either built or not built.
A scenario where the Cost of Unserved Energy (COUE) was reduced from R78 per kWh to R10 per kWh resulted in almost the same price curves, with only a slight benefit in later years with Kusile in operation. If Kusile was successfully implemented, the lower COUE resulted in almost exactly the same price curve. From the IRP results it would appear that no energy demand went unserved, though.

With a lower load to service, prices go up earlier than for the Base Case, with less sales to pay the same committed costs for Medupi, Kusile and Ingula. This continues as a detrimental impact on
prices which peak at about 5 c/kWh than for the Base Case before narrowing to less than 2 c/kWh in the later years. Over the longer term no price premium is expected.

A higher load forecast results in prices increasing more slowly after the MYPD2 period, with more sales to pay for committed projects, and better utilisation of the assets as a result. Prices remain lower than for the Base Case for the full study period due to this better utilisation of assets.

One would expect that prices would settle at LRMC for all cases over the longer term, and the deviation for the higher load forecast case perhaps highlights the shortcomings of the pricing model at the end of the study period, where prices remain lower in this case.

Figure 23. Base Case and Revised Balance Scenario with impact of carbon tax

The inclusion of the carbon tax to each price curve indicates the impact of the tax on a scenario with greater reliance on coal-fired generation. The Revised Balanced Scenario, which starts switching to low carbon resources throughout the period and more effectively after 2022, is less impacted by the tax after 2022 than the Base Case with its high reliance on coal-fired generation. The differential between the two scenarios (including the carbon tax) at the end of the study period is much narrower than the situation without the carbon tax and is reducing.

The assumed carbon tax was R150/ton CO2, escalating with inflation during the period. At this rate of taxation the consumer is still better off with the Base Case, but the marginal benefit reduces toward the end of the period.