
CSIR Energy Centre

Pretoria, 31 March 2017
EXECUTIVE SUMMARY
Executive Summary:
A mix of solar PV, wind and flexible power generators is least cost

The CSIR determined the least cost, unconstrained electricity mix by 2050 as input into the IRP 2016
• Conservative approach: pessimistic assumptions for new technologies, optimistic for established ones

Result: It is least cost for any new investment in the power sector to be solar PV, wind or flexible power
• Solar PV, wind & flexible power generators (e.g. gas, CSP, hydro, biogas) are the cheapest new-build mix
• There is no technical limitation to solar PV and wind penetration over the planning horizon until 2050
• >70% renewable energy share by 2050 is cost optimal, replacing all old plants with the new optimal mix

South Africa can de-carbonise its electricity sector without pain: clean & cheap are no trade-offs anymore
• The “Least Cost” mix is the cheapest, it emits less CO₂ emissions, it consumes less water, and it creates more jobs in the electricity sector than both Draft IRP 2016 Base Case & Draft IRP 2016 Carbon Budget

Deviations from Least Cost have been quantified to inform policy adjustments. Compared to Least Cost:
• IRP 2016 Base Case: >R70 billion more costly, 2x more CO₂, 2.5x more water, 10-20% less jobs by 2050
• IRP 2016 Carbon Budget: R60 billion more costly, 15% more CO₂, 20% more water, 20% less jobs by 2050
• Decarbonised: R50 billion more costly, 95% decarbonised, 30% less water, 5% more jobs by 2050

Additionally: Least Cost is adaptable and therefore robust against unforeseen changes in demand and cost
Conservative RE/battery costing:

Least Cost: R75 billion/yr cheaper than Draft IRP 2016 Base Case (-10%)

Conservative cost inputs

- Conventional technologies (coal, nuclear, gas CAPEX): as per IRP 2016
- Battery technologies: as per IRP 2016 (10 000 R/kWh)
- Gas fuel: more expensive than IRP 2016 (150 R/GJ)
- Solar PV: aligned with original IRP 2010 cost assumptions (by 2030/2040/2050: 0.56/0.52/0.49 R/kWh)
- Wind: kept constant at latest South African auction result for study period (2016-2050: 0.62 R/kWh)

Conservative job number inputs

- Utilising job creation numbers from McKinsey study commissioned by the Department of Energy in the context of the Integrated Energy Plan
- Adjusting the numbers upwards for coal power generation and coal mining (McKinsey numbers assume more efficient / automated coal mining process and coal-power-station operations than current RSA)

Results (presented on next three slides)

- Least Cost is R60-75 billion/yr cheaper by 2050 than Draft IRP 2016 Base Case/Carbon Budget (-10%)
- By 2050, Least Cost emits 55% less CO₂ than Draft IRP 2016 Base Case & consumes 65% less fresh water
- By 2050, Least Cost creates 10-20% more jobs in the electricity sector than Draft IRP 2016 Base Case

Least Cost is ≈R20-40 billion/yr cheaper by 2030 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

<table>
<thead>
<tr>
<th>2030</th>
<th>IRP 2016 Base Case</th>
<th>IRP 2016 Carbon Budget</th>
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</tr>
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<td>Cost in 2030</td>
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</tr>
<tr>
<td>Total system cost (R-billion/yr)</td>
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<td>403</td>
<td>374</td>
<td>367</td>
<td>370</td>
</tr>
<tr>
<td>Average tariff (R/kWh)</td>
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<td>1.17</td>
<td>1.09</td>
<td>1.07</td>
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1 Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today’s average cost for these items)
2 Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Because of lack of data, zero jobs for biomass/gas assumed (affects Decarbonised)
# Least Cost is $\approx$R45-60 billion/yr cheaper by 2040 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

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<td>511</td>
<td>495</td>
<td>498</td>
</tr>
<tr>
<td>Average tariff (R/kWh)</td>
<td>1.25</td>
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<td>191-216</td>
<td>199-234</td>
<td>234-258</td>
<td>242-254</td>
</tr>
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- **Coal**
- **Nuclear**
- **Hydro+PS**
- **Peaking**
- **Other storage**
- **CSP**
- **Coal (new)**
- **Nuclear (new)**
- **Gas**
- **Biomass/gas**
- **Wind**
- **Solar PV**

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Least Cost is ≈R60-75 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

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<td><strong>Demand: 522 TWh</strong></td>
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### Cost in 2050

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<tbody>
<tr>
<td><strong>Total system cost</strong> (R-billion/yr)</td>
<td>700</td>
<td>688</td>
<td>658</td>
<td>627</td>
<td>675</td>
</tr>
<tr>
<td><strong>Average tariff</strong>  (R/kWh)</td>
<td>1.34</td>
<td>1.32</td>
<td>1.26</td>
<td>1.20</td>
<td>1.29</td>
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### Environment in 2050

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<tr>
<td><strong>Water usage</strong>     (billion-litres/yr)</td>
<td>41</td>
<td>18</td>
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### Jobs in 2050

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**Notes:**
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2. Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

*Because of lack of data, zero jobs for biomass/gas assumed (affects Decarbonised)*
Expected RE/battery costing:
Least Cost: R145 bn/yr cheaper than Draft IRP 2016 Base Case (-20%)

Expected cost inputs
- Conventional technologies (coal, nuclear, gas CAPEX): as per IRP 2016
- Battery technologies: expected cost reductions applied (2030/2040/2050: 2 000/1 000/800 R/kWh)
- Gas fuel: more expensive than IRP 2016 (150 R/GJ)
- Solar PV: 50% further cost reductions until 2050 assumed (by 2030/2040/2050: 0.46/0.38/0.30 R/kWh)
- Wind: 20% further cost reductions until 2050 assumed (by 2030/2040/2050: 0.56/0.53/0.50 R/kWh)

Conservative job number inputs
- Utilising job creation numbers from McKinsey study commissioned by the Department of Energy in the context of the Integrated Energy Plan
- Adjusting the numbers upwards for coal power generation and coal mining (McKinsey numbers assume more efficient / automated coal mining process and coal-power-station operations than current RSA)

Results (presented on next three slides)
- Least Cost is R135-145 billion/yr cheaper by 2050 than Draft IRP 2016 Base Case/Carbon Budget (-20%)
- By 2050, Least Cost emits 70% less CO$_2$ than Draft IRP 2016 Base Case & consumes 75% less fresh water
- By 2050, Least Cost creates 30-50% more jobs in the electricity sector than Draft IRP 2016 Base Case

Least Cost is $\approx$R30-50 billion/yr cheaper by 2030 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

### As per Draft IRP 2016

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<td>Total system cost¹ (R-billion/yr)</td>
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<tr>
<td>382</td>
</tr>
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<td>Average tariff (R/kWh)</td>
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<tr>
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¹ Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as $\approx$0.30 R/kWh (today’s average cost for these items)

² Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

### As per DoE

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<td>1.16</td>
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<td>Water usage (billion-litres/yr)</td>
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<td>Direct &amp; supplier ('000)</td>
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<tr>
<td>100-142</td>
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1 Because of lack of data, zero jobs for biomass/gas assumed (affects Decarbonised)

2 Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com
Least Cost is \( \approx \) R80-105 billion/yr cheaper by 2040 than IRP 2016 Base Case and IRP 2016 Carbon Budget case.

### 2040

#### Energy Mix in 2040
- **Demand:** 428 TWh

#### Cost in 2040
- **Total system cost** \((\text{R-billion/yr})\)
  - IRP 2016 Base Case ("Expected" costs): 548
  - IRP 2016 Carbon Budget ("Expected" costs): 526
  - Unconstrained Base Case ("Expected" costs): 489
  - Least Cost ("Expected" costs): 444
  - Decarbonised ("Expected" costs): 465

- **Average tariff** \((\text{R/kWh})\)
  - IRP 2016 Base Case ("Expected" costs): 1.28
  - IRP 2016 Carbon Budget ("Expected" costs): 1.23
  - Unconstrained Base Case ("Expected" costs): 1.14
  - Least Cost ("Expected" costs): 1.04
  - Decarbonised ("Expected" costs): 1.09

#### Environment in 2040
- **CO\(_2\) emissions** \((\text{Mt/yr})\)
  - IRP 2016 Base Case ("Expected" costs): 251
  - IRP 2016 Carbon Budget ("Expected" costs): 176
  - Unconstrained Base Case ("Expected" costs): 214
  - Least Cost ("Expected" costs): 91
  - Decarbonised ("Expected" costs): 141

- **Water usage** \((\text{billion-litres/yr})\)
  - IRP 2016 Base Case ("Expected" costs): 216
  - IRP 2016 Carbon Budget ("Expected" costs): 167
  - Unconstrained Base Case ("Expected" costs): 204
  - Least Cost ("Expected" costs): 53
  - Decarbonised ("Expected" costs): 142

#### Jobs\(^2\) in 2040
- **Direct & supplier** \(('000)\)
  - IRP 2016 Base Case ("Expected" costs): 185-241
  - IRP 2016 Carbon Budget ("Expected" costs): 191-216
  - Unconstrained Base Case ("Expected" costs): 199-234
  - Least Cost ("Expected" costs): 273-294
  - Decarbonised ("Expected" costs): 242-254

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\(^1\) Only power generation \((\text{Gx})\) is optimised while cost of transmission \((\text{Tx})\), distribution \((\text{Dx})\) and customer services is assumed as \(\approx 0.30\) R/kWh (today’s average cost for these items).

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Because of lack of data, zero jobs for biomass/gas assumed (affects Decarbonised).
Least Cost is $\approx$R135-145 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case.

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<td>Demand: 522 TWh</td>
<td>18% Coal (new) 19% Nuclear (new) 6% Gas 28% Other storage</td>
<td>16% Coal (new) 6% Nuclear (new) 0% Gas 35% Other storage</td>
<td>11% Coal (new) 6% Nuclear (new) 4% Gas 38% Other storage</td>
<td>6% Coal (new) 4% Nuclear (new) 9% Gas 36% Other storage</td>
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<tr>
<td>Total system cost (R-billion/yr)</td>
<td>675</td>
<td>664</td>
<td>596</td>
<td>529</td>
</tr>
<tr>
<td>Average tariff (R/kWh)</td>
<td>1.29</td>
<td>1.27</td>
<td>1.14</td>
<td>1.01</td>
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Because of lack of data, zero jobs for biomass/gas assumed (affects Decarbonised)
IRP PLEXOS model only optimises for cost of power generation (Gx) – two additional key aspects considered: system stability and grid cost

System Stability (inertia): worst case below 1% of Gx cost

- Connecting nuclear/coal via HVDC and/or solar PV/wind to the grid reduces the “system inertia”
- This reduces the inherent stabilising effect of synchronous inertia during contingency events
- Many technical solutions to operate low-inertia system
- In this study the “worst case” was costed
  - State-of-the-art technology (very high costs assumed, no further tech/cost advancements)
  - No further increase in engineering of how to deal with low-inertia systems
- In all scenarios, the worst-case-cost are well below 1% of the total cost of power generation (Gx) by 2050, cost differences between scenarios are much lower than 1%

Transmission grid cost: Gx Least Cost also cheapest for Tx

- High-level cost estimate for shallow and deep grid connection cost for all scenarios was developed
- Least Cost (Gx) case is additionally R20-30 billion/yr cheaper compared to Draft IRP 2016 Base Case and Carbon Budget case on transmission grid side
BACKGROUND
Agenda

The IRP process

CSIR mandate
Agenda

The IRP process

CSIR mandate
The IRP is South Africa’s long-term electricity capacity expansion plan

Integrated resource planning (IRP) for electricity is a long-term capacity expansion planning process typically applying least-cost planning principles to meet expected future demand reliably taking into account all existing and future supply resources to a city, province/state or country.

In South Africa, an IRP is performed periodically at a country level with the Department of Energy (DoE) being the custodian of the process – the current iteration of the IRP is the IRP 2016 (draft)

• Starting point of the IRP Base Case: pure techno-economic analysis to determine least-cost way to supply electricity
• Later process: least-cost mix is policy adjusted to cater for aspects not captured in IRP model and/or policy objectives
• These adjustments are typically country level priorities and policy objectives e.g. emissions trajectories, water usage, localisation potential, regional development, etc.

Due to it’s wide ranging implications for a broad range of stakeholders – it is typically made a consultative process where inputs are sought from various entities

The IRP 2016 is the electricity expansion plan for South Africa until 2050

Sources: CSIR analysis
Last promulgated IRP is IRP 2010, update currently ongoing (IRP 2016)

The enforceable IRP in South Africa is still the IRP 2010 as promulgated in 2011

A number of changes since IRP 2010 (demand forecast and confirmation of wind/solar PV cost decrease)

The IRP 2016 currently released for public consultation is the latest update to South Africa’s IRP and is the electricity system expansion plan to 2050

Public comments are invited by the Department of Energy to be submitted by 31 March 2017
Integrated Resource Plan (IRP): Process for power generation capacity expansion in South Africa

**Inputs**

1) Demand Forecast
2) Existing Supply Forecast:
   - Plants under construction
   - Preferred bidders
   - Decommissioning
   - Plant performance
3) New Supply Options:
   - Technology costs
   - Technology technical characteristics
4) Constraints:
   - CO₂ limits
   - Security/adequacy of supply level

**Outputs**

**IRP modelling framework (PLEXOS®)**

- LT¹ techno-economic least-cost optimisation
- MT/ST² production cost testing system adequacy (security of supply)

**After policy adjustment:**
- Final “IRP” for promulgation
- Key questions answered:
  - What to build (MW)?
  - When to build it (timing)?

**Procurement**

- (competitive tender e.g. REIPPPP, coal IPPPP)

**Outcomes**

- Preferred bidders
- MW allocation
- Technology costs actuals (Ø IPP tariffs)

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¹ LT = Long-term
² MT/ST = Medium-term/Short-term

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IRP process as described in the Department of Energy’s Draft IRP 2016 document: least-cost Base Case is derived from technical planning facts

### Least Cost Base Case

#### Planning Facts

- **Scenario 1**
  - Constraint: RE limits
  - Constraint: e.g. forcing in of nuclear, CSP, biogas, hydro, others

- **Scenario 2**
  - Constraint: Advanced CO$_2$ cap decline

- **Scenario 3**

#### Case vs. Cost

<table>
<thead>
<tr>
<th>Case</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>Base</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>Base + Rxx bn/yr</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Base + Ryy bn/yr</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Base + Rzz bn/yr</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

1. Public consultation on costed scenarios
2. Policy adjustment of Base Case
3. Final IRP for approval and gazetting

Reminder: IRP 2010 planned the electricity mix only until 2030
Installed capacity and electricity supplied from 2010 to 2030 as planned in the IRP 2010

Note: Installed capacity and electricity supplied excludes pumped storage; Renewables include solar PV, CSP, wind, biomass, biogas, landfill and hydro (includes imports).
Sources: DoE IRP 2010-2030; CSIR Energy Centre analysis
Currently under discussion: Draft IRP 2016 Base Case plans until 2050
Installed capacity and electricity supplied from 2016 to 2050 as planned in the Draft IRP 2016 Base Case

### Installed capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>Total installed net capacity in GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>49.8</td>
</tr>
<tr>
<td>2030</td>
<td>82.5</td>
</tr>
<tr>
<td>2040</td>
<td>108.7</td>
</tr>
<tr>
<td>2050</td>
<td>135.7</td>
</tr>
</tbody>
</table>

### Energy mix

- **Installed capacity**
  - Solar PV
  - CSP
  - Wind
  - Peaking
  - Gas
  - Hydro+PS
  - Coal (new)
  - Nuclear (new)
  - Coal

- **Energy mix**
  - Renewable (RE) (10%)
  - CO2 free (10%)
  - Other (29%)
  - Peaking (57%)

Note: Installed capacity and electricity supplied includes pumped storage; Renewables include solar PV, CSP, wind, biomass, biogas, landfill and hydro (includes imports).
Sources: DoE Draft IRP 2016; CSIR Energy Centre analysis.
Agenda

The IRP process

CSIR mandate
The DoE has asked for public comments and CSIR are mandated as a scientific body to contribute to key areas affecting all South Africans.

The DoE has requested for the inputs from the public in provincial roadshows as part of wider consultations (in addition to inter-departmental consultations and NEDLAC).

CSIR has already provided oral inputs (early Dec 2016), written inputs on 31 Mar 2017 (this document).

The CSIR is mandated by the Scientific Research Council Act section (3):

> The objects of the CSIR are, through directed and particularly multi-disciplinary research and technological innovation, to foster, in the national interest and in fields which in its opinion should receive preference, industrial and scientific development, either by itself or in co-operation with principals from the private or public sectors, and thereby to contribute to the improvement of the quality of life of the people of the Republic, and to perform any other functions that may be assigned to the CSIR by or under this Act.

CSIR has the capabilities to provide the scientific fact base for South Africa’s energy planning.

As part of the contribution to the IRP 2016 public participation process – CSIR performed power-system analyses for a range of scenarios and submit a complete package of data, models, report and slide deck.
Energy Research at the CSIR covers the entire energy value chain, from technologies, systems, market design to implementation

Challenge
• The global energy industry is in a restructuring phase, driven by the need for more efficient use of energy, renewable energies & new technologies (eVehicles, hydrogen, batteries)
• The CSIR’s energy research responds to global megatrends while addressing national research priorities

Objectives
• The objective is to make CSIR the leading research institution on the African continent in energy, globally recognised
• Significant HCD pipeline with long-term target of 200+ staff

Outputs generated so far
• Strong teams around hydrogen storage, batteries, energy systems, solar PV and wind technology testing & development

2017/18 Plans
• Accelerated recruitment in areas hydrogen generation, energy efficiency and demand response technologies

The feedback on the IRP is part of the research on “Energy Systems”
CSIR team has significant expertise from power system planning, system operation and grid perspective

Dr Tobias Bischof-Niemz
- Head of the CSIR Energy Centre
- Member of the Ministerial Advisory Council on Energy (MACE)
- Member of IRP2010/2013 team at Eskom, energy planning in Europe for large utilities

Joanne Calitz
- Senior Engineer: Energy Planning (CSIR Energy Centre)
- Previously with Eskom Energy Planning
- Medium-Term Outlook and IRP for RSA

Robbie van Heerden
- Senior Specialist: Energy Systems (CSIR Energy Centre)
- Former General Manager and long-time head of System Operations at Eskom

Mamahloko Senatla
- Researcher: Energy Planning (CSIR Energy Centre)
- Previously with the Energy Research Centre at University of Cape Town

Crescent Mushwana
- Research Group Leader: Energy Systems (CSIR Energy Centre)
- Former Chief Engineer at Eskom strategic transmission grid planning

Jarrad Wright
- Principal Engineer: Energy Planning (CSIR Energy Centre)
- Commissioner: National Planning Commission (NPC)
- Former Africa Manager of PLEXOS
GLOBAL AND DOMESTIC VIEW OF SUPPLY TECHNOLOGIES
Agenda

Global electricity sector generation mix

Coal

Nuclear

Natural gas

Solar PV, Wind, CSP, Biogas
Agenda

Global electricity sector generation mix

Coal

Nuclear

Natural gas

Solar PV, Wind, CSP, Biogas
2000: South Africa’s electricity sector is fuelled by coal (92%)
Structure of electricity generation for selected countries

Structure of Electricity Generation in 2000

<table>
<thead>
<tr>
<th>Country</th>
<th>World</th>
<th>France</th>
<th>Ukraine</th>
<th>Spain</th>
<th>USA</th>
<th>United Kingdom</th>
<th>Russia</th>
<th>Germany</th>
<th>South Africa</th>
<th>India</th>
<th>Brazil</th>
<th>China</th>
<th>Japan</th>
<th>Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWh</td>
<td>15552</td>
<td>540</td>
<td>171</td>
<td>224</td>
<td>4053</td>
<td>377</td>
<td>878</td>
<td>577</td>
<td>211</td>
<td>570</td>
<td>349</td>
<td>1356</td>
<td>1100</td>
<td>277</td>
</tr>
<tr>
<td>Renewables (non-hydro)</td>
<td>2%</td>
<td>1%</td>
<td>7%</td>
<td>2%</td>
<td>1%</td>
<td>2%</td>
<td>3%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>2%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Hydro</td>
<td>17%</td>
<td>13%</td>
<td>17%</td>
<td>14%</td>
<td>7%</td>
<td>7%</td>
<td>19%</td>
<td>5%</td>
<td>19%</td>
<td>13%</td>
<td>2%</td>
<td>3%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Oil</td>
<td>8%</td>
<td>6%</td>
<td>10%</td>
<td>16%</td>
<td>39%</td>
<td>3%</td>
<td>9%</td>
<td>10%</td>
<td>1%</td>
<td>13%</td>
<td>5%</td>
<td>3%</td>
<td>16%</td>
<td>18%</td>
</tr>
<tr>
<td>Gas</td>
<td>39%</td>
<td>30%</td>
<td>9%</td>
<td>22%</td>
<td>53%</td>
<td>42%</td>
<td>53%</td>
<td>92%</td>
<td>68%</td>
<td>87%</td>
<td>16%</td>
<td>3%</td>
<td>1%</td>
<td>31%</td>
</tr>
<tr>
<td>Coal</td>
<td>39%</td>
<td>36%</td>
<td>32%</td>
<td>32%</td>
<td>20%</td>
<td>29%</td>
<td>53%</td>
<td>92%</td>
<td>68%</td>
<td>87%</td>
<td>78%</td>
<td>23%</td>
<td>21%</td>
<td>37%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>17%</td>
<td>77%</td>
<td>30%</td>
<td>20%</td>
<td>23%</td>
<td>15%</td>
<td>15%</td>
<td>6%</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>3%</td>
<td>2%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Sources: IEA; CSIR analysis
2014: South Africa’s electricity sector is fuelled by coal (92%)  
Structure of electricity generation for selected countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Coal</th>
<th>Gas</th>
<th>Oil</th>
<th>Nuclear</th>
<th>Renewables (non-hydro)</th>
<th>Hydro</th>
<th>Total (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>92%</td>
<td>5%</td>
<td>2%</td>
<td>1%</td>
<td>15%</td>
<td></td>
<td>23,904</td>
</tr>
<tr>
<td>France</td>
<td>22%</td>
<td>41%</td>
<td>17%</td>
<td>5%</td>
<td>1%</td>
<td>6%</td>
<td>563</td>
</tr>
<tr>
<td>Ukraine</td>
<td>21%</td>
<td>78%</td>
<td>5%</td>
<td>1%</td>
<td>15%</td>
<td>7%</td>
<td>183</td>
</tr>
<tr>
<td>Spain</td>
<td>16%</td>
<td>39%</td>
<td>5%</td>
<td>26%</td>
<td>1%</td>
<td>6%</td>
<td>279</td>
</tr>
<tr>
<td>USA</td>
<td>19%</td>
<td>45%</td>
<td>18%</td>
<td>2%</td>
<td>10%</td>
<td>5%</td>
<td>4,339</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>19%</td>
<td>30%</td>
<td>30%</td>
<td>2%</td>
<td>10%</td>
<td>17%</td>
<td>339</td>
</tr>
<tr>
<td>Russia</td>
<td>15%</td>
<td>50%</td>
<td>17%</td>
<td>1%</td>
<td>4%</td>
<td>1%</td>
<td>1,064</td>
</tr>
<tr>
<td>Germany</td>
<td>17%</td>
<td>50%</td>
<td>24%</td>
<td>1%</td>
<td>5%</td>
<td>5%</td>
<td>628</td>
</tr>
<tr>
<td>South Africa</td>
<td>92%</td>
<td>1%</td>
<td>17%</td>
<td>19%</td>
<td>19%</td>
<td>2%</td>
<td>253</td>
</tr>
<tr>
<td>India</td>
<td>10%</td>
<td>72%</td>
<td>19%</td>
<td>4%</td>
<td>2%</td>
<td>5%</td>
<td>591</td>
</tr>
<tr>
<td>Brazil</td>
<td>34%</td>
<td>6%</td>
<td>14%</td>
<td>3%</td>
<td>3%</td>
<td>0%</td>
<td>5,679</td>
</tr>
<tr>
<td>China</td>
<td>40%</td>
<td>72%</td>
<td>19%</td>
<td>8%</td>
<td>0%</td>
<td>7%</td>
<td>1,041</td>
</tr>
<tr>
<td>Japan</td>
<td>23%</td>
<td>33%</td>
<td>11%</td>
<td>22%</td>
<td>5%</td>
<td>0%</td>
<td>280</td>
</tr>
<tr>
<td>Italy</td>
<td>17%</td>
<td>22%</td>
<td>2%</td>
<td>7%</td>
<td>5%</td>
<td>1%</td>
<td>30</td>
</tr>
</tbody>
</table>

Sources: IEA; CSIR analysis
From 2000 to 2014, renewables and gas grew most, followed by coal.

Global Electricity Generation in TWh/yr

<table>
<thead>
<tr>
<th>Year</th>
<th>Renewables (non-hydro)</th>
<th>Hydro</th>
<th>Oil</th>
<th>Gas</th>
<th>Coal</th>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>15,552 (17%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>15,671 (17%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>16,284 (19%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>16,879 (20%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>17,649 (22%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>18,409 (23%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>19,113 (24%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>19,937 (25%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>20,310 (26%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>20,231 (26%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>21,582 (28%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>22,279 (30%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>22,777 (31%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>23,454 (32%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>23,904 (33%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: IEA; CSIR analysis
Global demand growth from 2000-2014 was supplied by coal, gas & RE

Electricity generation in Germany in TWh/yr

Change from 2000 to 2014

Sources: IEA; CSIR analysis
Globally from 2000-2014: Renewables & gas grew by 4%-points each, coal by 2%-points, nuclear declined by 6%-points and oil by 4%-points
Agenda

Global electricity sector generation mix

Coal

Nuclear

Natural gas

Solar PV, Wind, CSP, Biogas
2000: South Africa produced 92% of its electricity from coal

Structure of electricity generation for selected countries

<table>
<thead>
<tr>
<th>Country</th>
<th>TWh</th>
<th>Non-coal</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>15 552</td>
<td>61%</td>
<td>39%</td>
</tr>
<tr>
<td>South Africa</td>
<td>211</td>
<td>92%</td>
<td>8%</td>
</tr>
<tr>
<td>India</td>
<td>1 356</td>
<td>68%</td>
<td>32%</td>
</tr>
<tr>
<td>China</td>
<td>570</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td>Germany</td>
<td>577</td>
<td>47%</td>
<td>53%</td>
</tr>
<tr>
<td>USA</td>
<td>4 053</td>
<td>47%</td>
<td>53%</td>
</tr>
<tr>
<td>Ukraine</td>
<td>171</td>
<td>70%</td>
<td>30%</td>
</tr>
<tr>
<td>Japan</td>
<td>1 100</td>
<td>79%</td>
<td>21%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>377</td>
<td>68%</td>
<td>32%</td>
</tr>
<tr>
<td>Italy</td>
<td>277</td>
<td>89%</td>
<td>11%</td>
</tr>
<tr>
<td>Spain</td>
<td>224</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Russia</td>
<td>878</td>
<td>64%</td>
<td>36%</td>
</tr>
<tr>
<td>Brazil</td>
<td>349</td>
<td>97%</td>
<td>3%</td>
</tr>
<tr>
<td>France</td>
<td>540</td>
<td>94%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Sources: IEA; CSIR analysis
2014: South Africa produced 92% of its electricity from coal

Structure of electricity generation for selected countries

Sources: IEA; CSIR analysis
Total global electricity generation from coal increased by 60% since 2000, its share in global electricity generation stayed constant at ~40%.
South Africa’s energy system relies on domestic coal and imported oil

Simplified energy-flow diagram (Sankey diagram) for South Africa in 2014 in PJ

Primary Energy

- Oil: 897 PJ
- Coal: 6,200 PJ
- Nuclear: 151 PJ
- Renewables: 661 PJ
- Natural Gas: 161 PJ

Conversion

- Liquefaction: 709 PJ
- Power Plants: 2,829 PJ

End Use

- Non-energy: 179 PJ
- Transport: 749 PJ
- Electricity: 700 PJ
- Heat: 1,503 PJ
- Export: 1,935 PJ

Sources: IEA; CSIR analysis
China is by far the largest electricity producer from coal – with declining contribution and planned reduction in new-build capacities

China is the largest producer of electricity from coal in absolute terms globally

- It produced 4 115 TWh of electricity from coal-fired power stations in 2014 (18x South Africa)
- After a rapid growth from 1 060 TWh in 2000

The relative contribution of coal in the Chinese electricity mix has however reduced

- 78% in 2000
- 72% in 2014

China recently announced the cancellation of 100 GW of planned new coal-fired power stations

- To achieve CO₂ reduction targets
- To reduce air pollution (smog) in urban areas

Sources: http://ceenews.info/en/china-cancels-more-than-100-gw-of-coal-plants; IEA; CSIR analysis
Agenda

Global electricity sector generation mix

Coal

Nuclear

Natural gas

Solar PV, Wind, CSP, Biogas
2000: South Africa produced 6% of its electricity from nuclear
Structure of electricity generation for selected countries

Structure of Electricity Generation in 2000

<table>
<thead>
<tr>
<th>Country</th>
<th>TWh</th>
<th>Non-nuclear</th>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>1552</td>
<td>83%</td>
<td>17%</td>
</tr>
<tr>
<td>France</td>
<td>540</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>Ukraine</td>
<td>171</td>
<td>72%</td>
<td>28%</td>
</tr>
<tr>
<td>Spain</td>
<td>224</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>USA</td>
<td>4053</td>
<td>77%</td>
<td>23%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>377</td>
<td>85%</td>
<td>15%</td>
</tr>
<tr>
<td>Russia</td>
<td>878</td>
<td>71%</td>
<td>29%</td>
</tr>
<tr>
<td>Germany</td>
<td>577</td>
<td>94%</td>
<td>6%</td>
</tr>
<tr>
<td>South Africa</td>
<td>211</td>
<td>97%</td>
<td>3%</td>
</tr>
<tr>
<td>India</td>
<td>570</td>
<td>98%</td>
<td>2%</td>
</tr>
<tr>
<td>Brazil</td>
<td>349</td>
<td>99%</td>
<td>1%</td>
</tr>
<tr>
<td>China</td>
<td>1356</td>
<td>71%</td>
<td>29%</td>
</tr>
<tr>
<td>Japan</td>
<td>1100</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Italy</td>
<td>277</td>
<td>71%</td>
<td>29%</td>
</tr>
</tbody>
</table>

Sources: IEA; CSIR analysis
2014: South Africa produced 5% of its electricity from nuclear

Structure of electricity generation for selected countries

Sources: IEA; CSIR analysis
Total global nuclear electricity generation stayed constant since 2000, its share in global electricity generation decreased from 17% to 11%.

Global Electricity Generation in TWh/yr

<table>
<thead>
<tr>
<th>Year</th>
<th>Non-nuclear</th>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>15 552 (83%)</td>
<td>2 591 (17%)</td>
</tr>
<tr>
<td>2001</td>
<td>15 671 (83%)</td>
<td>2 638 (17%)</td>
</tr>
<tr>
<td>2002</td>
<td>16 284 (84%)</td>
<td>2 661 (16%)</td>
</tr>
<tr>
<td>2003</td>
<td>16 879 (84%)</td>
<td>2 635 (16%)</td>
</tr>
<tr>
<td>2004</td>
<td>17 649 (84%)</td>
<td>2 738 (15%)</td>
</tr>
<tr>
<td>2005</td>
<td>18 409 (85%)</td>
<td>2 768 (15%)</td>
</tr>
<tr>
<td>2006</td>
<td>19 113 (86%)</td>
<td>2 791 (14%)</td>
</tr>
<tr>
<td>2007</td>
<td>19 937 (87%)</td>
<td>2 719 (13%)</td>
</tr>
<tr>
<td>2008</td>
<td>20 310 (87%)</td>
<td>2 733 (13%)</td>
</tr>
<tr>
<td>2009</td>
<td>20 231 (89%)</td>
<td>2 696 (13%)</td>
</tr>
<tr>
<td>2010</td>
<td>21 582 (89%)</td>
<td>2 756 (13%)</td>
</tr>
<tr>
<td>2011</td>
<td>22 279 (89%)</td>
<td>2 583 (12%)</td>
</tr>
<tr>
<td>2012</td>
<td>22 777 (89%)</td>
<td>2 460 (11%)</td>
</tr>
<tr>
<td>2013</td>
<td>23 454 (89%)</td>
<td>2 479 (11%)</td>
</tr>
<tr>
<td>2014</td>
<td>23 903 (89%)</td>
<td>2 535 (11%)</td>
</tr>
</tbody>
</table>

Sources: IEA; CSIR analysis
31 countries worldwide have operational nuclear power plants

Map of countries with operational nuclear reactors for commercial electricity production

Sources: World Nuclear Association - Reactor data base, CSIR analysis
In the last decade, 60% of nuclear capacity additions came from China

New nuclear capacity commissioned per year since 1950s

New nuclear capacity (year of first commercial operation) in GW/yr

Sources: World Nuclear Association – Reactor database; CSIR analysis
After global ramp-up from 1970-1990, nuclear installed capacity stable

Global installed capacity end of year for nuclear, wind and solar PV (1970-2016) in GW (net)

Operational capacity end of year in GW

Sources: World Nuclear Association – Reactor database; EPIA; GWEC; CSIR analysis
Nuclear power has been part of South Africa since 1970s

History of key decisions and milestones related to nuclear for power generation in South Africa

Sources:
Gen III+ nuclear reactors can be sourced from various vendors

Reactors name, size, vendor and representative country likely available for South Africa’s nuclear procurement

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Vendor</th>
<th>Vendor countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP1000 Pressurised Water Reactor (PWR)</td>
<td>1,100 (4,590/1,200)</td>
<td>Westinghouse(^2)</td>
<td><img src="https://via.placeholder.com/15" alt="Japan" /> <img src="https://via.placeholder.com/15" alt="United States" /></td>
</tr>
<tr>
<td>Evolutionary Power Reactor (EPR)</td>
<td>1,650 (3,400/1,770)</td>
<td>Areva/EDF</td>
<td><img src="https://via.placeholder.com/15" alt="France" /></td>
</tr>
<tr>
<td>Water-Water Energetic Reactor (VVER)(^1)</td>
<td>1,082 (3,200/1,170)</td>
<td>Rosatom</td>
<td><img src="https://via.placeholder.com/15" alt="Russia" /></td>
</tr>
<tr>
<td>Advanced Boiling Water Reactor (ABWR)</td>
<td>1,350 (3,926/1,420)</td>
<td>GE-Hitachi (and Toshiba)</td>
<td><img src="https://via.placeholder.com/15" alt="United States" /> <img src="https://via.placeholder.com/15" alt="Japan" /></td>
</tr>
<tr>
<td>Advanced Power Reactor (APR) 1400</td>
<td>1,400 (3,983/1,455)</td>
<td>Korea HNP (KHNP)</td>
<td><img src="https://via.placeholder.com/15" alt="South Korea" /></td>
</tr>
<tr>
<td>Hualong One (HPR 1000)</td>
<td>1,100 (3,050/1,150)</td>
<td>CNNC/CGN</td>
<td><img src="https://via.placeholder.com/15" alt="China" /></td>
</tr>
</tbody>
</table>

\(^1\) RU: Vodo-Vodyanoi Energetichesky Reaktor (VVER); \(^2\) Owned by Toshiba

Hinkley Point C will be the first nuclear power plant built on the back of a Power Purchase Agreement with an Independent Power Producer

The 3.2 GW Hinkley Point C nuclear power station is to be built by Electricité de France (EDF) under a Power Purchase Agreement (PPA) and is planned to be operational by 2025.

The power plant will be jointly owned by French Electricité de France (EDF) and Chinese China General Nuclear CGN (China).

This is the first time ever that a nuclear power plant is built on the basis of a PPA (all project risks with the plant owner).

The resultant tariff in the PPA is hence the most transparent cost of nuclear so far, as it is reflective of the project risks.

Catastrophic risks are excluded (i.e. borne by the state).

Known Hinkley Point C PPA parameters:
- **35 years** PPA lifetime
- **Tariff indexed to inflation** (CPI)
- Initial tariff: 92.5 GBP/MWh (2012) i.e. **1.53 ZAR/kWh**

---

1 Annual average GBP/ZAR exchange rate for 2012 (13.0) and ZAR-CPI inflation from 2012 to 2016

Nuclear decommissioning costs generally not included in an IRP: the long asset lifetime makes the costs negligible in present value

The International Energy Agency (IEA) said that 200 of the 434 reactors in operation around the globe would be retired by 2040 with de-commissioning costs >$500 million per reactor\(^1\)

The US Nuclear Regulatory Commission (NRC) estimates in the range of $350-500 per kW of net installed capacity ($300-400 million per reactor)

France’s nuclear safety authority (ASN\(^2\)) estimates costs at between $600-700 per kW of net installed capacity ($550-650 million per reactor)

Germany made provisions of $1,500 per kW of net installed capacity ($1.1 billion per reactor)

Japanese government estimates around $800 per kW of net installed capacity ($625 million per reactor)

Russia’s costs are estimated to range from $800-1,500 per kW of net installed capacity ($500 million to $1 billion per reactor)

Long asset lifetime makes present value of costs negligible – real cash provision needs to be made though

---

\(^1\) These costs do not include waste disposal and long-term fuel storage  
\(^2\) ASN - Autorite de Surete Nucleaire  
In Germany, waste management and storage costs were recently transferred by private operators to the government for EUR24 billion.

Nuclear plant operators in Germany have agreed to pay EUR 24 billion into a German government fund to transfer risk/liability of waste storage/handling. This is equivalent to additional “CAPEX” of EUR 1,100 per kW of net capacity, i.e. ≈ $1,200 per kW.

Global electricity sector generation mix

Coal

Nuclear

Natural gas

Solar PV, Wind, CSP, Biogas
2000: South Africa produced 3% of its electricity from natural gas

Structure of electricity generation for selected countries

Structure of Electricity Generation in 2000

<table>
<thead>
<tr>
<th>Country</th>
<th>Gas TWh</th>
<th>Non-gas TWh</th>
<th>Total TWh</th>
<th>Gas %</th>
<th>Non-gas %</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>82%</td>
<td>18%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>42%</td>
<td>58%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>23%</td>
<td>77%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>37%</td>
<td>63%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>39%</td>
<td>61%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>16%</td>
<td>84%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>9%</td>
<td>91%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>1%</td>
<td>99%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>17%</td>
<td>83%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ukraine</td>
<td>10%</td>
<td>90%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>3%</td>
<td>97%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>2%</td>
<td>98%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>0%</td>
<td>100%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>0%</td>
<td>100%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: IEA; update for RSA with StatsSA(Sasol gas generation); CSIR analysis
2014: South Africa produced 3% of its electricity from natural gas

Structure of electricity generation for selected countries

Structure of Electricity Generation in 2014

<table>
<thead>
<tr>
<th>Country</th>
<th>TWh</th>
<th>Non-gas</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>23,903</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td>Russia</td>
<td>1,064</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Japan</td>
<td>1,041</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>Italy</td>
<td>280</td>
<td>67%</td>
<td>33%</td>
</tr>
<tr>
<td>UK</td>
<td>339</td>
<td>70%</td>
<td>30%</td>
</tr>
<tr>
<td>USA</td>
<td>4,339</td>
<td>73%</td>
<td>27%</td>
</tr>
<tr>
<td>Spain</td>
<td>279</td>
<td>83%</td>
<td>17%</td>
</tr>
<tr>
<td>Brazil</td>
<td>591</td>
<td>86%</td>
<td>14%</td>
</tr>
<tr>
<td>Germany</td>
<td>628</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td>Ukraine</td>
<td>183</td>
<td>93%</td>
<td>7%</td>
</tr>
<tr>
<td>India</td>
<td>1,287</td>
<td>95%</td>
<td>5%</td>
</tr>
<tr>
<td>South Africa</td>
<td>253</td>
<td>97%</td>
<td>3%</td>
</tr>
<tr>
<td>France</td>
<td>563</td>
<td>98%</td>
<td>2%</td>
</tr>
<tr>
<td>China</td>
<td>5,679</td>
<td>98%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Sources: IEA; update for RSA with StatsSA(Sasol gas generation); CSIR analysis
Total global electricity generation from natural gas increased by 90% since 2000, its share in global electricity generation rose by 4%-points.

Source: IEA; CSIR analysis
LNG supply chain from natural gas field over liquefaction and ocean shipping to regasification at the destination, where the gas is used.
Liquefied Natural Gas (LNG) high-level overview

LNG is natural gas that has been super-cooled into a liquid that is one six hundredth of its original volume: storage and transport of imported LNG is made easier by this significant reduction in volume

Fair price of LNG today: 7-9 $/MMBtu; this is an ex-ship price

Re-gasification adds 0.5–1 $/MMBtu

Storage plus transport add another 0.2-0.8 $/MMBtu if the power plant is far away from the LNG landing terminal

FSRUs (Floating Storage and Re-gasification Unit) can be used for regasification without building a full-scale land-based LNG terminal

Minimum size for land-based LNG terminal is around 2–3 bcm p.a. sent out; most big ones are around 10 bcm p.a.
## Properties of different types of gas storage

### Natural Gas Storage

<table>
<thead>
<tr>
<th>Porous storage and caverns (under-ground)</th>
<th>Tube (in-ground)</th>
<th>Sphere (on-ground)</th>
<th>Gas holder (on-ground)</th>
</tr>
</thead>
</table>

### Liquefied Natural Gas (LNG) Storage

<table>
<thead>
<tr>
<th>Large-scale tanks (in-ground)</th>
<th>Standard-sized tanks (on-ground)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Operating temperature</th>
<th>Ambient</th>
<th>Ambient</th>
<th>Ambient</th>
<th>Ambient</th>
<th>-162°C</th>
<th>-162°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating pressure</td>
<td>High: 60-190 bar (above atmospheric)</td>
<td>High: 100 bar (above atmospheric)</td>
<td>Medium: 5 to 20 bar (above atmospheric)</td>
<td>Low: 15 to 150 mbar (above atmospheric)</td>
<td>Low: 100-250 mbar (above atmospheric)</td>
<td>Low to medium: 0.3-16 bar (above atmospheric)</td>
</tr>
<tr>
<td>Withdrawal rate</td>
<td>0.6-2.3 million m³/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working gas storage capacity</td>
<td>60-100 million m³ (norm) = 600 to 1 000 GWh th (per cavern)</td>
<td>0.5-0.7 million m³ (norm) = 5 to 7 GWh th (per 20 tubes, 200 m each)</td>
<td>30-170 thsd m³ (norm) = 0.3 to 1.7 GWh th</td>
<td>30-170 thsd m³ (norm) = 0.3 to 1.7 GWh th</td>
<td>130-250 thsd m³ (LNG) = 800 to 1 500 GWh th</td>
<td>60-700 m³ (LNG) = 0.4 to 4 GWh th</td>
</tr>
<tr>
<td>Invest</td>
<td>R 0.1 to 1 million / GWh th (depends on geology)</td>
<td>R 20 to 30 million / GWh th</td>
<td>R 20 to 30 million / GWh th</td>
<td>R 20 to 30 million / GWh th</td>
<td>R 1 to 1.5 million / GWh th</td>
<td>R 2 to 6 million / GWh th</td>
</tr>
</tbody>
</table>

Sources: websites of operators of gas storages, research institutes, CSIR analysis
Underground natural gas storage typically only in countries with substantial heating demand and large seasonal variations.

US, UK, China, Spain have significant LNG storage capacity (not captured here).

Note: Japan and Korea have very large LNG storage capacities (but no underground natural gas storage).

Sources: Magazine “Erdoel, Erdgas, Kohle”; LNG Report 2011; CSIR analysis.
Gas conversions

**LNG parameters**
- Heat value of LNG: 45 MJ/kg = 12.5 kWh/kg (note: 1 MMBtu = 1.05587 GJ)
- Mass density of LNG: 450 kg/m$^3$
- Typical storage size of an FSRU: 170 000 m$^3$
- Energy stored in a typical FSRU: 3.44 PJ = 0.96 TWh$_{th}$ (per 170 000 m$^3$)

**Gas throughput for one FSRU**
- Typical recharging cycle of the FSRU: Monthly $\rightarrow$ 12 re-charges per year, 150 000 m$^3$ each
- Typical amount of LNG per year: 1 800 000 m$^3$/a (for one FSRU with 12 re-charges per year) $\rightarrow$ 810 000 t/a = 0.8 mmtpa $\rightarrow$ 36.5 PJ/a = 10.1 TWh$_{th}$/a

**Electricity generation from one FSRU**
- Typical electricity production: 5.1 TWh$_{el}$/a from 1 FSRU that supplies a 50% efficient gas plant

**Comparisons**
- Sasol produces approx. 7 TWh$_{el}$/a from its gas-fired power plants in South Africa
- South Africa (Sasol and PetroSA) converts > 100 PJ/a into liquid fuels today
- South Africa imports approx. 200 PJ/a today from Mozambique through a pipeline
Annual electricity production and LNG offtake from a gas fleet

Annual electricity production in TWh/yr from a gas fleet of size A, operating at a capacity factor B

<table>
<thead>
<tr>
<th>A: Size of the gas fleet in GW</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>2.2</td>
<td>4.4</td>
<td>6.6</td>
<td>8.8</td>
<td>11.0</td>
<td>13.1</td>
<td>15.3</td>
<td>17.5</td>
<td>19.7</td>
</tr>
<tr>
<td>5.0</td>
<td>4.4</td>
<td>8.8</td>
<td>13.1</td>
<td>17.5</td>
<td>21.9</td>
<td>26.3</td>
<td>30.7</td>
<td>35.0</td>
<td>39.4</td>
</tr>
<tr>
<td>7.5</td>
<td>6.6</td>
<td>13.1</td>
<td>19.7</td>
<td>26.3</td>
<td>32.9</td>
<td>39.4</td>
<td>46.0</td>
<td>52.6</td>
<td>59.1</td>
</tr>
<tr>
<td>10.0</td>
<td>8.8</td>
<td>17.5</td>
<td>26.3</td>
<td>35.0</td>
<td>43.8</td>
<td>52.6</td>
<td>61.3</td>
<td>70.1</td>
<td>78.8</td>
</tr>
<tr>
<td>12.5</td>
<td>11.0</td>
<td>21.9</td>
<td>32.9</td>
<td>43.8</td>
<td>54.8</td>
<td>65.7</td>
<td>76.7</td>
<td>87.6</td>
<td>98.6</td>
</tr>
<tr>
<td>15.0</td>
<td>13.1</td>
<td>26.3</td>
<td>39.4</td>
<td>52.6</td>
<td>65.7</td>
<td>78.8</td>
<td>92.0</td>
<td>105.1</td>
<td>118.3</td>
</tr>
</tbody>
</table>

Note: Assumption of an average 50% electrical efficiency of the gas fleet

Annual LNG offtake in mmtpa from a gas fleet of size A, operating at a capacity factor B

<table>
<thead>
<tr>
<th>A: Size of the gas fleet in GW</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>0.4</td>
<td>0.7</td>
<td>1.1</td>
<td>1.4</td>
<td>1.8</td>
<td>2.1</td>
<td>2.5</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>5.0</td>
<td>0.7</td>
<td>1.4</td>
<td>2.1</td>
<td>2.8</td>
<td>3.5</td>
<td>4.2</td>
<td>4.9</td>
<td>5.6</td>
<td>6.3</td>
</tr>
<tr>
<td>7.5</td>
<td>1.1</td>
<td>2.1</td>
<td>3.2</td>
<td>4.2</td>
<td>5.3</td>
<td>6.3</td>
<td>7.4</td>
<td>8.4</td>
<td>9.5</td>
</tr>
<tr>
<td>10.0</td>
<td>1.4</td>
<td>2.8</td>
<td>4.2</td>
<td>5.6</td>
<td>7.0</td>
<td>8.4</td>
<td>9.8</td>
<td>11.2</td>
<td>12.6</td>
</tr>
<tr>
<td>12.5</td>
<td>1.8</td>
<td>3.5</td>
<td>5.3</td>
<td>7.0</td>
<td>8.8</td>
<td>10.5</td>
<td>12.3</td>
<td>14.0</td>
<td>15.8</td>
</tr>
<tr>
<td>15.0</td>
<td>2.1</td>
<td>4.2</td>
<td>6.3</td>
<td>8.4</td>
<td>10.5</td>
<td>12.6</td>
<td>14.7</td>
<td>16.8</td>
<td>18.9</td>
</tr>
</tbody>
</table>
Agenda

Global electricity sector generation mix

Coal

Nuclear

Natural gas

Solar PV, Wind, CSP, Biogas
World:
In 2016, 124 GW of new wind and solar PV capacity installed globally

Global annual new capacity in GW/yr

This is all very new: Roughly 80% of the globally existing solar PV capacity was installed during the last five years

Sources: GWEC; EPIA; BNEF; CSIR analysis
World:
Significant cost reductions materialised in the last 5-8 years

Global annual new capacity in GW/yr

Sources: IEA; GWEC; EPIA; BNEF; CSIR analysis

Subsidies
Cost competitive
Renewables until today mainly driven by US, Europe, China and Japan
Globally installed capacities for three major renewables wind, solar PV and CSP end of 2015

Source: GWEC; EPIA; CSPToday; CSIR analysis
South Africa:
From 2013 to 2016, 3.1 GW of wind, solar PV and CSP commissioned

Capacity online in MW (end of year)

Supply Sources
- Solar PV
- Wind
- CSP

Notes: RSA = Republic of South Africa. Solar PV capacity = capacity at point of common coupling. Wind includes Eskom’s Sere wind farm (100 MW)
Sources: Eskom; DoE IPP Office
South Africa:
In 2016, almost 7 TWh electricity produced from wind, solar PV & CSP

Notes: Wind includes Eskom’s Sere wind farm (100 MW)
Sources: Eskom; DoE IPP Office
2016: Wind, solar PV and CSP supplied 3% of the total RSA system load
Actuals captured in wholesale market for Jan-Dec 2016 (i.e. without self-consumption of embedded plants)

Annual electricity in TWh

<table>
<thead>
<tr>
<th>Residual Load</th>
<th>Wind</th>
<th>Solar PV</th>
<th>CSP</th>
<th>System Load (domestic and export load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>231.3</td>
<td>3.7</td>
<td>2.6</td>
<td>0.5</td>
<td>238.2</td>
</tr>
</tbody>
</table>

Notes: Wind includes Eskom’s Sere wind farm (100 MW)
Sources: Eskom; DoE IPP Office
Actual tariffs: new wind/solar PV 40% cheaper than new coal in RSA

Results of Department of Energy’s RE IPP Procurement Programme (REIPPPP) and Coal IPP Proc. Programme

Significant reductions in actual tariffs ...

Actual average tariffs in R/kWh (Apr-2016-R)

-59%
-83%

-40%

METHODOLOGY AND APPROACH
Agenda

Electricity sector expansion planning

Modelling framework

System cost of electricity

Scenarios

Sensitivities

What-If analysis
Electricity sector expansion planning

Modelling framework

System cost of electricity

Scenarios

Sensitivities

What-If analysis
The existing fleet of power generators phases out until 2050

Decommissioning schedule for the South African electricity system from 2016 to 2050

All power plants considered for “existing fleet” that are either:
1) Existing in 2016
2) Under construction
3) Procured (preferred bidder)

Sources: DoE (IRP 2016); Eskom MTS AO 2016-2021; StatsSA; World Bank; CSIR analysis
Demand grows, existing fleet phases out – gap needs to be filled
Forecasted supply and demand balance for the South African electricity system from 2016 to 2050

The IRP model fills the supply gap in the least-cost manner, subject to any constraints imposed on the model.

Note: All power plants considered for “existing fleet” that are either Existing in 2016, Under construction, or Procured (preferred bidder)
Sources: DoE (IRP 2016); Eskom MTSAO 2016-2021; StatsSA; World Bank; CSIR analysis
Definition of residual load

Power [GW]

- System Load
- Solar PV
- Wind
- Residual Load

Δ Load

Δ Time

Hour
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What-If analysis
CSIR uses an industry standard software package for expansion planning of the power system – same package as used by DoE/Eskom

Commercial software used by DoE & CSIR …

Co-optimisation of long-term investment & operational decisions in hourly time resolution from today to 2050

- What mix to build?
- How to operate the mix once built?
- Objective function: Least Cost, subject to an adequate (i.e. reliable) power system

Key technical limitations of power generators covered

- Maximum ramp rates (% of installed capacity/h)
- Minimum operating levels (% of installed capacity)
- Minimum up & down times (h btw start/stop)
- Start-up and shut-down profiles

… covers all key cost drivers of a power system

Costs covered in the model include

- All capacity-related costs of all power generators
  - CAPEX of new power plants (R/kW)
  - Fixed Operation and Maintenance (FOM) cost (R/kW/yr)
- All energy-related costs of all power generators
  - Variable Operation and Maintenance (VOM) cost (R/kWh)
  - Fuel cost (R/GJ)
- Efficiency losses due to more flexible operation
- Reserves provision (included in capacity costs)
- Start-up and shut-down costs

Costs not covered in the model currently used are

- Any grid-related costs (note: transmission-level grid costs typically ~10-15% of generation costs)
- Costs related to add. system services (e.g. inertia requirements, black-start and reactive power)

Sources: CSIR analysis
The IRP currently only optimises for the generation cost component of total system cost (this is the dominant component)

Costs included in Gx optimisation model:
- CAPEX (plant level)
- FOM\(^1\)
- VOM\(^2\)
- Fuel

Costs excluded in Gx optimisation model:
- Externalities e.g. CO\(_2\) emissions costs
- Decommissioning costs
- Waste management and/or rehabilitation
- Major mid-life overhaul
- Shallow grid connection costs

Not optimised in PLEXOS modelling framework (CSIR assumption for all scenarios = 0.30 R/kWh)
- Qualitatively discussed (quantified for system inertia)
- Not considered

Optimised in PLEXOS model

High-level costing applied to PLEXOS outcomes

Other (metering, billing, customer services, overheads)

Total system cost

---

\(^1\) FOM = Fixed Operations and Maintenance costs; \(^2\) VOM = Variable Operations and Maintenance costs; \(^3\) Typically referred to as Ancillary Services includes services to ensure frequency stability, transient stability, provide reactive power/voltage control, ensure black start capability and system operator costs.
Common reporting layout applied to all scenarios by DoE and by CSIR

IRP scenarios as published by the DoE ...

... are analysed with respect to total installed capacity (GW) and energy balance (TWh/yr)

Determine total operational capacity per year
- Add existing fleet & its decommissioning schedule
- Decommission new plants at the end of their economic life e.g. wind = 20, solar PV = 25 years

Determine energy balances for different technologies and calibrate with IRP outputs

Scenarios of the Draft IRP 2016 show the annual new installed capacity per year per technology

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PLEXOS actual inputs are individual cost items that together with the utilisation of the plant (a model output) allow to calculate LCOE.

Note: Start-up and shut-down costs are an additional cost item that PLEXOS models. Input is the cost in R/start.
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What-If analysis
# Overview of scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Source</th>
<th>Difference to Draft IRP 2016 Base Case</th>
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<tr>
<td>Draft IRP 2016 Base Case</td>
<td>Department of Energy Draft IRP 2016 as of November 2016</td>
<td>N/A</td>
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<tr>
<td>Draft IRP 2016 Carbon Budget</td>
<td>Department of Energy Draft IRP 2016 as of November 2016</td>
<td>Tighter carbon reduction targets</td>
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<tr>
<td>Draft IRP 2016 “Unconstrained Base Case”</td>
<td>Department of Energy Scenario run by DoE/Eskom as per request of the Ministerial Advisory Council on Energy (MACE)</td>
<td>No constraints on new build technologies</td>
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<tr>
<td>Least Cost</td>
<td>CSIR</td>
<td>No constraints on new build technologies</td>
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</table>

- **Difference to Draft IRP 2016 Base Case**
  - Tighter carbon reduction targets
  - No constraints on new build technologies
  - No constraints on new build technologies
  - RE costing aligned with latest REIPPPP
  - Demand shaping from residential EWHs
Overview of scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Source</th>
<th>Difference to Draft IRP 2016 Base Case</th>
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<tr>
<td>Decarbonised</td>
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<td>No constraints on new build technologies</td>
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<td></td>
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<td>95% CO₂ emissions reduction in the electricity sector compared to 2016</td>
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<td>Early coal fleet decommissioning</td>
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<td></td>
<td>Medupi and coal IPPs decommissioned from 2045</td>
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<tr>
<td></td>
<td></td>
<td>Kusile is not commissioned</td>
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<tr>
<td>Least-cost (“Expected” costs)</td>
<td>CSIR</td>
<td>No constraints on new build technologies</td>
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<tr>
<td></td>
<td></td>
<td>Expected realistic further cost reductions for solar PV, wind, CSP &amp; batteries applied</td>
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<td>Electric vehicle uptake</td>
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<td>Low demand (EIUG)</td>
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<tr>
<td>“Unconstrained Base Case”</td>
<td>CSIR</td>
<td>Low demand (EIUG)</td>
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<td>CSIR</td>
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<td>RE costing aligned with latest REIPPPP</td>
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<td>Demand shaping from residential EWHs</td>
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<td>Supply technology tipping points</td>
<td>CSIR</td>
<td>Least cost scenario input assumptions</td>
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<td>Lower costs for supply technologies not in least cost scenario e.g. nuclear, CSP etc</td>
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Submitted to DoE on 31 March 2017
Overview of sensitivities

<table>
<thead>
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<th>Sensitivity</th>
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<td>Delay Medupi and Kusile by 1 year per unit</td>
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<td></td>
<td>Follow Eskom’s low plant performance path</td>
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</table>

- CSIR

**Source:**
Least cost scenario input assumptions
Delay Medupi and Kusile by 1 year per unit
Follow Eskom’s low plant performance path

**Difference to Draft IRP 2016 Base Case:**

- Least cost scenario input assumptions
- Delay Medupi and Kusile by 1 year per unit
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**Overview of sensitivities**

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What-If analysis
## Overview of What-If analyses

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<tr>
<th>What-If</th>
<th>Source</th>
<th>Difference to Draft IRP 2016 Base Case</th>
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<tbody>
<tr>
<td>Draft IRP 2016 Base Case (over-investment)</td>
<td>CSIR</td>
<td>Least cost scenario input assumptions&lt;br&gt;Low demand (EIUG)&lt;br&gt;Hard-coded installed capacity from this scenario but with lower demand forecast</td>
</tr>
<tr>
<td>Draft IRP 2016 Carbon Budget (over-investment)</td>
<td>CSIR</td>
<td>Least cost scenario input assumptions&lt;br&gt;Low demand (EIUG)&lt;br&gt;Hard-coded installed capacity from this scenario but with lower demand forecast</td>
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<td>Draft IRP 2016 “Unconstrained Base Case” (over-investment)</td>
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<tr>
<td>Least Cost (over-investment)</td>
<td>CSIR</td>
<td>Least cost scenario input assumptions&lt;br&gt;Low demand (EIUG)&lt;br&gt;Hard-coded installed capacity from this scenario but with lower demand forecast</td>
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INPUT ASSUMPTIONS
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Supply technologies (technical characteristics)

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IRP 2010 forecasted steep cost decline for solar PV from 2010 to 2030

Tariff in R/kWh (Apr-2016-Rand)

- Assumptions: IRP 2010 - high
- Assumptions: IRP 2010 - low

Year

2010 2015 2020 2025 2030 2035 2040 2045 2050

Notes: REIPPPP = Renewable Energy Independent Power Producer Programme; BW = Bid Window; bid submissions for the different BWs: BW1 = Nov 2011; BW2 = Mar 2012; BW 3 = Aug 2013; BW 4 = Aug 2014; BW 4 (Expedited) = Nov 2015   Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
Actual solar PV tariffs quickly moved below IRP 2010 cost assumptions

Tariff in R/kWh (Apr-2016-Rand)

- Assumptions: IRP 2010 - high
- Assumptions: IRP 2010 - low
- Actuals: REIPPPP (BW1-4Exp)

∑ = 2.8 GW


Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
IRP 2016 increases cost assumptions for solar PV compared to IRP 2010

Tariff in R/kWh (Apr-2016-Rand)

- Assumptions: IRP 2010 - high
- Assumptions: IRP 2010 - low
- Assumptions: IRP 2016 - high
- Assumptions: IRP 2016 - low
- Actuals: REIPPPP (BW1-4Exp)

∑ = 2.8 GW

Notes: REIPPPP = Renewable Energy Independent Power Producer Programme; BW = Bid Window; bid submissions for the different BWs: BW1 = Nov 2011; BW2 = Mar 2012; BW 3 = Aug 2013; BW 4 = Aug 2014; BW 4 (Expedited) = Nov 2015  Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
CSIR study cost input assumptions for solar PV:
Future cost assumptions for solar PV aligned with IRP 2010

Tariff in R/kWh (Apr-2016-Rand)

Year

2010  2015  2020  2025  2030  2035  2040  2045  2050

BW1 → BW 4 ( Expedited )

Assumptions: IRP2010 - high
Assumptions: IRP2010 - low
Assumptions: IRP 2016 - high
Assumptions: IRP 2016 - low
Assumptions for this study
Actuals: REIPPPP (BW1-4Exp)

∑ = 2.8 GW

Notes: REIPPPP = Renewable Energy Independent Power Producer Programme; BW = Bid Window; bid submissions for the different BWs: BW1 = Nov 2011; BW2 = Mar 2012; BW 3 = Aug 2013; BW 4 = Aug 2014; BW 4 ( Expedited ) = Nov 2015 Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
Solar PV:
Cost input and supply profile assumptions

Technology-specific inputs

- **CAPEX**: 9 240 R/kW
- **FOM**: 200 R/kW/a
- **VOM**: 0 R/kWh
- **Fuel price**: N/A
- **Heat rate**: N/A
- **Lifetime**: 25 a

General input across all technologies

- **Discount rate**: 8.2%

Utilisation

- **Capacity factor**: 25%
  (a model output for all technologies other than wind/PV)

Resulting cost per energy unit

- **LCOE**: 0.62 R/kWh
IRP 2010 forecasted small cost decline for wind from 2010 to 2030.

Tariff in R/kWh (Apr-2016-Rand)

Year

Assumptions: IRP 2010

Actual wind tariffs quickly moved below IRP 2010 assumptions

IRP 2016 increases cost assumptions for wind compared to IRP 2010

Tariff in R/kWh (Apr-2016-Rand)

- Assumptions: IRP 2010
- Assumptions: IRP 2016 - high
- Assumptions: IRP 2016 - low
- Actuals: REIPPPP (BW1-4Exp)

CSIR study cost input assumptions for wind:
Future cost assumptions for wind aligned with results of Bid Window 4

Tariff in R/kWh (Apr-2016-Rand)

Year

BW1 → BW 4 (Expedited)

Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
Wind: Cost input and supply profile assumptions

**Technology-specific inputs**
- CAPEX: 13 250 R/kW
- FOM: 500 R/kW/a
- VOM: 0 R/kWh
- Fuel price: N/A
- Heat rate: N/A
- Lifetime: 20 a

**General input across all technologies**
- Discount rate: 8.2%

**Utilisation**
- Capacity factor: 36%
  (a model output for all technologies other than wind/PV)

**Resulting cost per energy unit**
- LCOE: 0.62 R/kWh
CSIR study cost input assumptions for CSP:
Today’s latest tariff as starting point, same cost decline as per IRP 2010

For bid window 3, 3.5 and 4 Exp, weighted average tariff of base and peak tariff calculated on the assumption of 64%/36% base/peak tariff utilisation ratio.
Inputs as per IRP 2016:  
Key resulting LCOE from cost assumptions for new supply technologies

Lifetime cost per energy unit\(^1\)  
(LCOE) in R/kWh  
(Apr-2016-R)  

<table>
<thead>
<tr>
<th>Technology</th>
<th>LCOE (R/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV</td>
<td>0.62</td>
</tr>
<tr>
<td>Wind</td>
<td>0.62</td>
</tr>
<tr>
<td>Baseload Coal (PF)</td>
<td>1.00</td>
</tr>
<tr>
<td>Nuclear</td>
<td>1.09</td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>1.41</td>
</tr>
<tr>
<td>Mid-merit Coal</td>
<td>1.41</td>
</tr>
<tr>
<td>Gas (OCGT)</td>
<td>2.89</td>
</tr>
<tr>
<td>Diesel (OCGT)</td>
<td>3.69</td>
</tr>
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</table>

Assumed capacity factor\(^2\)  

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capacity Factor</th>
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</thead>
<tbody>
<tr>
<td>Solar PV</td>
<td>82%</td>
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<tr>
<td>Wind</td>
<td>90%</td>
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<tr>
<td>Baseload Coal (PF)</td>
<td>50%</td>
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<tr>
<td>Nuclear</td>
<td>50%</td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>10%</td>
</tr>
<tr>
<td>Mid-merit Coal</td>
<td>10%</td>
</tr>
<tr>
<td>Gas (OCGT)</td>
<td></td>
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<tr>
<td>Diesel (OCGT)</td>
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</tbody>
</table>

\(\text{CO}_2\) in kg/MWh  

<table>
<thead>
<tr>
<th>Technology</th>
<th>CO(_2) (kg/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV</td>
<td>0</td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
</tr>
<tr>
<td>Baseload Coal (PF)</td>
<td>1 000</td>
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<td>Nuclear</td>
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<td>Gas (CCGT)</td>
<td>400</td>
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<td>Mid-merit Coal</td>
<td>1 000</td>
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<td>Gas (OCGT)</td>
<td>600</td>
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<tr>
<td>Diesel (OCGT)</td>
<td>600</td>
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</tbody>
</table>

\(^1\) Lifetime cost per energy unit is only presented for brevity. The model inherently includes the specific cost structures of each technology i.e. capex, Fixed O&M, variable O&M, fuel costs etc.

\(^2\) Changing full-load hours for new-build options drastically changes the fixed cost components per kWh (lower full-load hours \(\rightarrow\) higher capital costs and fixed O&M costs per kWh).

Assumptions: Average efficiency for CCGT = 55%; OCGT = 35%; nuclear = 33%; IRP costs from Jan-2012 escalated to May-2016 with CPI; assumed EPC CAPEX inflated by 10% to convert EPC/LCOE into tariff; Sources: IRP 2013 Update; Doe IPP Office; StatsSA for CPI; Eskom financial reports for coal/diesel fuel cost; EE Publishers for Medupi/Kusile; Rosatom for nuclear capex; CSIR analysis
Sensitivity: 50% reduction of capacity factor hits capital-intensive power generators most

Lifetime cost per energy unit¹ (LCOE) in R/kWh (Apr-2016-R)

- Solar PV: 0.62
- Wind: 0.62
- Baseload Coal (IPP): 1.65
- Nuclear: 2.06
- Gas (CCGT): 1.69
- Mid-merit Coal: 2.47
- Gas (OCGT): 4.06
- Diesel (OCGT): 4.86

Fixed (Capital, O&M) vs Variable (Fuel)

CO₂ in kg/MWh
- Solar PV: 0
- Wind: 0
- Baseload Coal (IPP): 1000
- Nuclear: 400
- Gas (CCGT): 1000
- Mid-merit Coal: 600
- Gas (OCGT): 600
- Diesel (OCGT): 600

Assumed capacity factor² → 41%, 45%, 25%, 25%, 5%, 5%

¹ Lifetime cost per energy unit is only presented for brevity. The model inherently includes the specific cost structures of each technology i.e. capex, Fixed O&M, variable O&M, fuel costs etc.
² Changing full-load hours for new-build options drastically changes the fixed cost components per kWh (lower full-load hours → higher capital costs and fixed O&M costs per kWh);
Assumptions: Average efficiency for CCGT = 55%, OCGT = 35%; nuclear = 33%; IRP costs from Jan-2012 escalated to May-2016 with CPI; assumed EPC CAPEX inflated by 10% to convert EPC/LCOE into tariff;
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PLEASE REFER TO REPORT AND TO EXCEL SPREADSHEETS
FOR FULL SET OF COST INPUT ASSUMPTIONS FOR ALL TECHNOLOGIES
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Supply technologies (technical characteristics)

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Electricity sector CO₂ emissions trajectories

Jobs per technology
Supply technologies (technical characteristics)

All relevant generators were modelled with appropriate technical constraints as stylised above

Sources: CSIR Estimates; GE; Wartsila; EPRI
Supply technologies (technical characteristics)

Similar to the IRP 2016 - wind and solar PV profiles for 27 supply areas (with exclusion masks) were used

NOTE: These profiles were then aggregated into one profile that defines expected new wind and solar PV profiles

Sources: CSIR Wind and solar Aggregation Study
Wind: supply profile assumptions

Utilisation
Annual capacity factor = 36%
Solar PV: supply profile assumptions

Utilisation
Annual capacity factor = 20.4%
Supply technologies (technical characteristics)

Duration curve

Sources: CSIR Wind and solar Aggregation Study
Supply technologies (technical characteristics)

Aggregated wind power profile [p.u.]

Day of month

Sources: CSIR Wind and solar Aggregation Study
Supply technologies (technical characteristics)

Aggregated Solar PV power profile [p.u.]

Sources: CSIR Wind and solar Aggregation Study
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Jobs per technology
Decommissioning schedule (IRP 2016)

Installed capacity [GW]

Sources: CSIR analysis
Three EAF scenarios defined in the IRP 2016

Energy Availability Factor (EAF) [%]

- Low
- Moderate
- High

Sources: DoE Draft IRP 2016
In IRP 2016 and in Least Cost case the moderate EAF is used.

Energy Availability Factor (EAF) [%]

Sources: DoE Draft IRP 2016
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Supply technologies (technical characteristics)

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Jobs per technology
Reserve requirements initially defined by Eskom Ancillary Services requirements and extrapolated forward after 2022

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<td>2200</td>
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<tr>
<td>Summer</td>
<td>Peak</td>
<td>3800</td>
<td>4400</td>
<td>4400</td>
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<td>4400</td>
<td>5600</td>
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Sources: Eskom; CSIR assumptions

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<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
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<tbody>
<tr>
<td><strong>Peak</strong></td>
<td>3800</td>
<td>5600</td>
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<tr>
<td><strong>Off-peak</strong></td>
<td>4400</td>
<td>5600</td>
</tr>
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</table>

MTST assumptions

LT assumptions
Agenda

Supply technologies (cost characteristics)

Supply technologies (technical characteristics)

Existing fleet

Reserve requirements

**Electrical energy demand forecast**

Demand shaping - domestic Electric Water Heaters (EWHs)

Electricity sector CO$_2$ emissions trajectories

Jobs per technology
Demand forecasts

Electrical energy demand [TWh]

Note: There is no spatial context for this demand forecast i.e. it is at a national level. Some level of spatial context is given in the analysis performed by CSIR on network infrastructure.
Agenda

Supply technologies (cost characteristics)

Supply technologies (technical characteristics)

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Jobs per technology
Demand shaping as a demand side resource - domestic electric heaters (EWHs)

Many opportunities for demand shaping in a number of end-use sectors (domestic, commercial, industrial).

In the scenarios assessed by CSIR - the intention of including one particular demand shaping opportunity (domestic electric water heating) is to demonstrate the significant impact this can have on the power system.

Modelled as a resource with intra-day controllability (can be dispatched as needed on any given day) based on power system needs.

Key input parameters to estimate potential demand shaping via EWH:

- South African population (to 2050)
- Number of households (current)
- Number of persons per household (future)
- EWHs (current)
- EWHs per household (future)
- Adoption rate of demand shaping via EWHs (future)
- Calibration for power (MW) and energy (TWh) used for electric water heating (existing)
- Movement to EWH technologies i.e. heat pumps vs electric geysers (future)
Demand shaping can provide ~24 GW/3 GW (demand increase/decrease) with ~70 GWh/d of dispatchable energy by 2050

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>2016-2019</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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<tr>
<td>Population</td>
<td>[mln]</td>
<td>55.7 - 57.5</td>
<td>58.0</td>
<td>61.7</td>
<td>64.9</td>
<td>68.2</td>
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<td>[mln]</td>
<td>16.9 - 18.1</td>
<td>18.5</td>
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<td>Residents per HH</td>
<td>[ppl/HH]</td>
<td>3.29 - 3.17</td>
<td>3.13</td>
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<td>2.50</td>
<td>2.50</td>
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<td>HHs with EWH</td>
<td>[%]</td>
<td>28 - 33</td>
<td>34</td>
<td>50</td>
<td>75</td>
<td>100</td>
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<tr>
<td>HHs with EWH</td>
<td>[mln]</td>
<td>4.7 - 5.9</td>
<td>6.3</td>
<td>11.2</td>
<td>19.5</td>
<td>27.3</td>
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<tr>
<td>Demand shaping adoption</td>
<td>[%]</td>
<td>-</td>
<td>2</td>
<td>25</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Demand shaping</td>
<td>[TWh/a]</td>
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<td>5.4</td>
<td>28.3</td>
<td>26.4</td>
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<td>[GWh/d]</td>
<td>-</td>
<td>1.1</td>
<td>14.9</td>
<td>77.4</td>
<td>72.3</td>
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<td>Demand shaping (demand increase)</td>
<td>[MW]</td>
<td>-</td>
<td>371</td>
<td>4 991</td>
<td>25 970</td>
<td>24 265</td>
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<td>Demand shaping (demand decrease)</td>
<td>[MW]</td>
<td>-</td>
<td>46</td>
<td>620</td>
<td>3 226</td>
<td>3 015</td>
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</table>

Sources: CSIR estimates; StatsSA; AMPS survey; Statista; Eskom; Draft IRP 2016
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Supply technologies (cost characteristics)

Supply technologies (technical characteristics)

Existing fleet

Reserve requirements

Electrical energy demand forecast

Demand shaping - domestic Electric Water Heaters (EWHs)

Electricity sector CO$_2$ emissions trajectories

Jobs per technology
**CO₂ emissions constrained by RSA’s Peak-Plateau-Decline objective**

PPD that constrains CO₂ emission for the whole country and from the electricity sector

---

**CO₂ Emissions [Mt/yr]**

- **RSA PPD Upper**
- **IRP 2016 Moderate Decline**
- **RSA PPD Lower**
- **IRP 2016 Advanced Decline**

---

**Sources:** DoE (IRP 2010-2030 Update); StatsSA; CSIR analysis
Moderate Decline applied in IRP 2016 and in Least Cost

CO₂ Emissions [Mt/yr]

- RSA PPD Upper
- IRP 2016 Moderate Decline
- RSA PPD Lower
- IRP 2016 Advanced Decline

Sources: DoE (IRP 2010-2030 Update); StatsSA; CSIR analysis
Agenda

Supply technologies (cost characteristics)

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Demand shaping - domestic Electric Water Heaters (EWHs)

Electricity sector CO₂ emissions trajectories

Jobs per technology
Localised job creation per technology is a function of capital (build-out) as well as operations (utilisation) for each technology

A study was commissioned by the DoE and undertaken by McKinsey & Company as part of the IEP:

- “Potential for Job Creation and Localisation of the electricity generating technologies”
  
  
  — IEP 2016 Annexure B: macroeconomic parameters

As part of this work, job creation for each major technology was determined on the following basis:

- Direct jobs: For “capex” (job-years/GW) and “opex” (annual jobs/TWh)
- Supplier jobs: For “capex” (job-years/GW) and “opex” (annual jobs/TWh)
- Multipliers for indirect and induced jobs

These jobs were further classified into 5 categories (for localisation potential).

- The CSIR has assumed that all categories constitute localised jobs except the “Global demand required” category

The CSIR has also only included direct and supplier jobs. The analysis performed by CSIR calculates the number of jobs in each scenario as a result of the capacity build-out (MW) and energy utilisation (TWh)
Localised job creation per technology is a function of capital (build-out) as well as operations (utilisation) for each technology.

### Capex

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capex</th>
<th>Suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (incl. coal mining)</td>
<td>25 570</td>
<td>5 990</td>
</tr>
<tr>
<td>Nuclear (incl. Uranium mining)</td>
<td>14 750</td>
<td>8 450</td>
</tr>
<tr>
<td>Gas (excl. shale gas extraction)</td>
<td>4 680</td>
<td>800</td>
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<tr>
<td>Solar PV</td>
<td>6 400</td>
<td>4 400</td>
</tr>
<tr>
<td>CSP</td>
<td>26 000</td>
<td>9 000</td>
</tr>
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<td>Wind</td>
<td>8 720</td>
<td>4 920</td>
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### Opex

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<th>Technology</th>
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<td>Coal (incl. coal mining)</td>
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<tr>
<td>Gas (excl. shale gas extraction)</td>
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<td>Solar PV</td>
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<td>CSP</td>
<td>130</td>
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<tr>
<td>Wind</td>
<td>110</td>
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</table>

Note: It seems like the McKinsey study (appendix of IEP) under-estimates direct/supply job numbers in the coal industry. Thus, CSIR have assumed more jobs in the coal industry than in the McKinsey study. 

Sources: DoE IEP 2016 Annexure B: Macroeconomic parameters
LONG-TERM EXPANSION PLAN RESULTS
(SCENARIOS)
Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost ("Expected" costs)

Scenario comparison and summary
## Overview of scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Source</th>
<th>Difference to Draft IRP 2016 Base Case</th>
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<tr>
<td>Draft IRP 2016 Base Case</td>
<td>Department of Energy Draft IRP 2016 as of November 2016</td>
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<td>Draft IRP 2016 Carbon Budget</td>
<td>Department of Energy Draft IRP 2016 as of November 2016</td>
<td>Tighter carbon reduction targets</td>
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<tr>
<td>Draft IRP 2016 “Unconstrained Base Case”</td>
<td>Department of Energy Scenario run by DoE/Eskom as per request of the Ministerial Advisory Council on Energy (MACE)</td>
<td>No constraints on new build technologies</td>
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<tr>
<td>Least Cost</td>
<td>CSIR</td>
<td>No constraints on new build technologies</td>
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<td></td>
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<td>No constraints on new build technologies</td>
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<tr>
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<td>Demand shaping from residential EWHs</td>
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</table>
Overview of scenarios

<table>
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<td>Decarbonised</td>
<td>CSIR</td>
<td>Cost assumptions of Least-cost scenario</td>
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<td>No constraints on any new build technologies</td>
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<td></td>
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<td>95% reduction of CO₂ by 2050)</td>
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<tr>
<td></td>
<td></td>
<td>Early coal fleet decommissioning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medupi and coal IPPs decommission 2045</td>
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<td></td>
<td></td>
<td>No Kusile</td>
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<td>Least cost (“Expected” costs)</td>
<td>CSIR</td>
<td>No constraints on any new build technologies</td>
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<td>More realistic learning rates for solar PV and wind i.e. more aggressive</td>
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<td>Learning rates for storage</td>
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<tr>
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<td>Electric vehicle uptake</td>
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Demand forecasts

Electrical energy demand [TWh]

- **Historical**
- **High (IRP 2016 Base Case)**
- **Low (IRP 2016)**
- **EIUG**
- **IRP 2010**

**Note:** There is no spatial context for this demand forecast i.e. it is at a national level. Some level of spatial context is given in the analysis performed by CSIR on network infrastructure.

Sources: IRP 2016; EIUG; CSIR analysis
Same demand forecast as per IRP 2016 Base Case applied

Electrical energy demand [TWh]

Note: There is no spatial context for this demand forecast i.e. it is at a national level. Some level of spatial context is given in the analysis performed by CSIR on network infrastructure.
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Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost (“Expected” costs)

Scenario comparison and summary
Scenario: Draft IRP 2016 Base Case
1/3 coal, 1/3 nuclear, 1/3 solar PV/wind/gas, ≈R690 bn/yr cost in 2050

As per Draft IRP 2016

Installed Capacity

Energy Produced

System cost and average tariff

Difference to Draft IRP 2016 Base Case

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; 2 Direct and supplier jobs only; Sources: CSIR; Eskom; DoE
Draft IRP 2016 Base Case: Nuclear and coal dominate the supply mix in 2050

Exemplary Week under Draft IRP 2016 Base Case (2050)

Sources: CSIR analysis, based on DoE’s Draft IRP 2016
Agenda

Draft IRP 2016: Base Case

**Draft IRP 2016: Carbon Budget**

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost (“Expected” costs)

Scenario comparison and summary
Scenario: Draft IRP 2016 Carbon Budget
Nuclear, renewables and gas replace coal, ≈R690-billion/yr cost in 2050

Installed Capacity

Energy Produced

System cost and average tariff

CO₂ Emissions [Mt/yr]

Water Usage [bl/yr]

Jobs² [‘000]

Difference to Draft IRP 2016 Base Case

• Tighter carbon reduction targets

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; ² Direct and supplier jobs only; Sources: CSIR; Eskom; DoE
Draft IRP 2016 Carbon Budget: Nuclear dominates with additional RE means additional flexibility required from gas

Exemplary Week under Draft IRP 2016 Base Case (2050)

Sources: CSIR analysis, based on DoE’s Draft IRP 2016
Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost (“Expected” costs)

Scenario comparison and summary
Draft IRP 2016 limits the annual build-out rates for solar PV and wind

The imposed new-build limits for solar PV and wind mean that the IRP model is not allowed in any given year to add more solar PV and wind capacity to the system than these limits.

No such limits are applied for any other technology. No techno-economical reason/justification is provided for these limits. No explanation given why the limits are constant until 2050 while the power system grows.

<table>
<thead>
<tr>
<th>Year</th>
<th>System Peak Load in MW (as per Draft IRP)</th>
<th>New-build limit Solar PV in MW/yr (as per Draft IRP)</th>
<th>Relative new-build limit Solar PV (derived from IRP)</th>
<th>New-build limit Wind in MW/yr (as per Draft IRP)</th>
<th>Relative new-build limit Wind (derived from IRP)</th>
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</thead>
<tbody>
<tr>
<td>2020</td>
<td>44 916</td>
<td>1 000</td>
<td>2.2%</td>
<td>1 800</td>
<td>4.0%</td>
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<td>2025</td>
<td>51 015</td>
<td>1 000</td>
<td>2.0%</td>
<td>1 800</td>
<td>3.5%</td>
</tr>
<tr>
<td>2030</td>
<td>57 274</td>
<td>1 000</td>
<td>1.7%</td>
<td>1 800</td>
<td>3.1%</td>
</tr>
<tr>
<td>2035</td>
<td>64 169</td>
<td>1 000</td>
<td>1.6%</td>
<td>1 800</td>
<td>2.8%</td>
</tr>
<tr>
<td>2040</td>
<td>70 777</td>
<td>1 000</td>
<td>1.4%</td>
<td>1 800</td>
<td>2.5%</td>
</tr>
<tr>
<td>2045</td>
<td>78 263</td>
<td>1 000</td>
<td>1.3%</td>
<td>1 800</td>
<td>2.3%</td>
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<tr>
<td>2050</td>
<td>85 804</td>
<td>1 000</td>
<td>1.2%</td>
<td>1 800</td>
<td>2.1%</td>
</tr>
</tbody>
</table>

Note: Relative new-build limit = New-build limit / system peak load
Sources: IRP 2016 Draft; CSIR analysis
Today: Both leading and follower countries are installing more new solar PV capacity per year than South Africa’s IRP limits for 2030/2050

Annual new solar PV capacity relative to system peak demand

RSA’s IRP relative new-build limit decreases over time

Sources: SolarPowerEurope; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis
Today: Both leading and follower countries are installing more new wind capacity per year than South Africa’s IRP limits for 2030/2050

Annual new wind capacity relative to system peak demand

RSA new-build limits in 2030 and 2050

Sources: GWEC; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis
Solar PV penetration in leading countries today is 2.5 times that of South Africa’s Draft IRP 2016 Base Case for the year 2050.

Sources: SolarPowerEurope; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis
Wind penetration in leading countries today is 1.7-1.8 times that of South Africa’s Draft IRP 2016 Base Case for the year 2050.

Sources: GWEC; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis
Scenario: Unconstrained Base Case
No new nuclear, some new coal, PV/wind/gas – R660 bn/yr by 2050

As per DoE

Installed Capacity

Energy Produced

System cost and average tariff

Difference to Draft IRP 2016 Base Case

• No build-out constraints on any technology

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; 2 Direct and supplier jobs only; Sources: CSIR; Eskom
Unconstrained Base Case: Solar PV, wind and gas with some new coal in the supply mix in 2050

Exemplary Week under Least Cost (2050)

Sources: CSIR analysis
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Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost ("Expected" costs)

Scenario comparison and summary
Scenario: Least Cost
No new nuclear, no new coal, 75% RE by 2050, R630 billion/yr in 2050

**Installed Capacity**

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar PV</th>
<th>CSP</th>
<th>Hydro+PS</th>
<th>Wind</th>
<th>Nuclear (new)</th>
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<th>Coal (new)</th>
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**Energy Produced**

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**System cost and average tariff**

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<td>2050</td>
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**Jobs**

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Difference to Draft IRP 2016 Base Case

- No build-out constraints on any technology
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHPs

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; 2 Direct and supplier jobs only; Sources: CSIR; Eskom
Scenario: Least Cost - Solar PV and wind dominate supply mix in 2050, with curtailment and variability managed by flexible gas.

Exemplary Week under Least Cost (2050)

- Customer demand
- Demand (incl pumping, DR, storage)

Sources: CSIR analysis
Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost (“Expected” costs)

Scenario comparison and summary
Assumption: 95% decarbonisation of the South African power sector by 2050 compared to 2016, which means down to 10 Mt/yr of CO2

PPD = Peak Plateau Decline
Sources: DoE (IRP 2010-2030 Update); StatsSA; CSIR analysis
No “smart decommissioning” is performed for now\(^1\). Instead, no coal fired generation by 2050, achieved by:

- All Eskom coal decommissions 5 years earlier from 2030
- Medupi decommissions from 2045
- Kusile is not commissioned
- Coal IPPs decommission from 2045

\(^1\) Optimising if/when to decommission existing coal fleet is not performed (Eskom, coal IPPs, Sasol)

Sources: CSIR analysis
### Scenario: Decarbonised

>90% RE by 2050 mostly PV & wind with biomass/-gas and CSP

#### Installed Capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar PV</th>
<th>CSP</th>
<th>Wind</th>
<th>Hydro+PS</th>
<th>Nuclear</th>
<th>Other storage</th>
<th>Biomass/-gas</th>
<th>Peaking</th>
<th>Coal (new)</th>
<th>Total</th>
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#### Energy Produced

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#### System cost and average tariff

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<td>0.60</td>
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<td>331</td>
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</table>

#### Difference to Draft IRP 2016 Base Case

- Cost assumptions of Least-cost scenario
- No constraints on new build technologies
- 95% reduction of CO₂ by 2050
- Early coal fleet decommissioning
- Medupi and coal IPPs decommission 2045
- No Kusile

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; 2 Direct and supplier jobs only; Sources: CSIR; Eskom
Scenario: Decarbonised - Solar PV and wind dominate supply mix in 2050, with curtailment and variability managed by flexible gas
Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost ("Expected" costs)

Scenario comparison and summary
CSIR study cost input assumptions for solar PV:
Realistic future cost assumptions for solar PV

Tariff in R/kWh (Apr-2016-Rand)

Year

2010 2015 2020 2025 2030 2035 2040 2045 2050

Assumptions: IRP2010 - high
Assumptions: IRP2010 - low
Assumptions: IRP 2016 - high
Assumptions: IRP 2016 - low
Assumptions for this study
Actuals: REIPPPP (BW1-4Exp)

Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
CSIR study cost input assumptions for wind: Realistic future cost assumptions for wind

Tariff in R/kWh (Apr-2016-Rand)

- Assumptions: IRP 2010
- Assumptions: IRP 2016 - high
- Assumptions: IRP 2016 - low
- Assumptions for this study
- Actuals: REIPPPP (BW1-4Exp)


**For Least Cost ("Expected" costs)**
CSIR study cost input assumptions for CSP:
Today’s latest tariff as starting point, same cost decline as per IRP 2010

Tariff in R/kWh (Apr-2016-Rand)

For bid window 3, 3.5 and 4 Exp, weighted average tariff of base and peak tariff calculated on the assumption of 64%/36% base/peak tariff utilisation ratio

Assumptions:
- IRP2010 - high
- IRP2010 - low
- IRP2016 - high
- IRP2016 - low

Assumptions for this study
- Actuals: REIPPPP (BW1-4Exp)

Notes:
- Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
Storage technology (from IRP 2016) with assumed learning rates

High level assumptions (for now) on learning rates for storage:

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<td>Capacity</td>
<td>Capex(^1)</td>
<td>FOM(^2)</td>
<td>Capex(^1)</td>
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<td>(Apr-2016 ZAR)</td>
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<td>[R/kWh]</td>
<td>[R/kW/yr]</td>
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<td>Lithium-ion (1 hrs)</td>
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<td>618</td>
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<td>Lithium-ion (3 hrs)</td>
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<td>618</td>
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<tr>
<td>CAES (8 hrs)</td>
<td>180</td>
<td>3 459</td>
<td>212</td>
<td>3 459</td>
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</table>

\(^1\) Capex = Capital expenditure (including IDC); \(^2\) FOM = Fixed Operations and Maintenance Costs
Electric vehicle usage for demand side flexibility

Inclusion of a demand side flexibility resource in the form of mobile storage (electric motor vehicles) demonstrates impact on the power system as adoption increases.

Modelled similar to EWH demand shaping as a resource with intra-day controllability (can be dispatched as needed on any given day) based on power system needs.

Key input parameters to estimate potential demand shaping via electric motor vehicles:

- Current population
- Expected population growth to 2050
- Current number of motor vehicles
- Expected motor vehicles per capita
- Adoption rate of electric vehicles to 2050
- Electric vehicle fleet capacity (MW)
- Electric vehicle energy requirement (GWh/d)
- Proportion of electric vehicle fleet connected simultaneously
Electric vehicle demand shaping can provide ~48 GW/1.7 GW (demand increase/decrease) with ~40 GWh/d of dispatchable energy by 2050

<table>
<thead>
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<th>Property</th>
<th>Unit</th>
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<th>2020</th>
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<td>700</td>
<td>1 700</td>
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Sources: CSIR estimates; StatsSA; eNaTis
Scenario: Least cost (Expected costs)
If solar PV, wind and battery cost drop as expected

**Installed Capacity**

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar PV</th>
<th>Gas</th>
<th>Hydro+PS</th>
<th>Nuclear (new)</th>
<th>Wind</th>
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<th>Coal (new)</th>
<th>Total</th>
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**Energy Produced**

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<th>Year</th>
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<th>Gas</th>
<th>Hydro+PS</th>
<th>Nuclear (new)</th>
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**System cost and average tariff**

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</table>

**Difference to Draft IRP 2016 Base Case**

- No constraints on new build technologies
- More realistic learning rates for PV and wind
- Learning rates for storage
- Demand shaping via EWHs
- Electric vehicle uptake

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; 2 Direct and supplier jobs only; Sources: CSIR; Eskom
Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost (“Expected” costs)

Scenario comparison and summary

- Conservative RE/battery cost
- Expected RE/battery cost
Total system cost: Draft IRP 2016 Base Case ≈R70 bn/year more expensive by 2050 than Least Cost (without cost of CO₂)

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)
Total system cost: Draft IRP 2016 Base Case ≈R85 bn/year more expensive by 2050 than Least Cost (with cost of CO\(_2\))

Total system cost in bR/yr
(Apr-2016 Rand)

- Draft IRP 2016 Base Case
- IRP 2016 Carbon Budget
- IRP 2016 Unconstrained Base Case
- Least Cost
- Decarbonised

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)

Sources: Eskom on Tx, Dx cost; CSIR analysis
Average tariff (without cost of CO₂):
Draft IRP Base Case tariff 12 cents/kWh higher than Least Cost by 2050

Average tariff in R/kWh
(Apr-2016 Rand)

- Draft IRP 2016 Base Case
- IRP 2016 Carbon Budget
- IRP 2016 Unconstrained Base Case
- Least Cost
- Decarbonise

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)

Sources: Eskom on Tx, Dx cost; CSIR analysis
Average tariff (with cost of CO₂):
Draft IRP Base Case tariff 16 cents/kWh higher than Least Cost by 2050

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items)   Sources: Eskom on Tx, Dx cost; CSIR analysis


**CO₂ emissions trajectories and water usage summary**

**CO₂ emissions**

- **[Mt/yr]**
  - Draft IRP 2016 Base Case
  - IRP 2016 Unconstrained Base Case
  - Decarbonise
  - IRP 2016 Carbon Budget
  - Least Cost
  - PPD Moderate

**Water consumption**

- **[bl/yr]**

Source: CSIR analyses
The Least-Cost and Decarbonised scenarios install significantly more wind and solar PV as well as more flexible peaking capacity.
Least Cost is ≈ R20-40 billion/yr cheaper by 2030 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

**2030**

<table>
<thead>
<tr>
<th></th>
<th>As per Draft IRP 2016</th>
<th>As per DoE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Mix in 2030</strong></td>
<td>IRP 2016 Base Case</td>
<td>IRP 2016 Carbon Budget</td>
</tr>
<tr>
<td>Demand: 343 TWh</td>
<td>58%</td>
<td>47%</td>
</tr>
<tr>
<td><strong>Cost in 2030</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total system cost (R-billion/yr)</td>
<td>384</td>
<td>403</td>
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<tr>
<td>Average tariff (R/kWh)</td>
<td>1.12</td>
<td>1.17</td>
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<tr>
<td><strong>Environment in 2030</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ emissions (Mt/yr)</td>
<td>251</td>
<td>176</td>
</tr>
<tr>
<td>Water usage (billion-litres/yr)</td>
<td>216</td>
<td>167</td>
</tr>
<tr>
<td><strong>Jobs in 2030</strong></td>
<td>93-153</td>
<td>100-142</td>
</tr>
<tr>
<td>Direct &amp; supplier ('000)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today’s average cost for these items)
2. Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com
Least Cost is \(\approx R45-60\) billion/yr cheaper by 2040 than IRP 2016 Base Case and IRP 2016 Carbon Budget case.

### 2040

#### Energy Mix in 2040
- **Demand:** 428 TWh

#### Cost in 2040
- **Total system cost** (R-billion/yr)
  - IRP 2016 Base Case: 535
  - IRP 2016 Carbon Budget: 530
  - Unconstrained Base Case: 511
  - Least Cost: 495
  - Decarbonised: 498
- **Average tariff** (R/kWh)
  - As per Draft IRP 2016: 1.25
  - As per DoE: 1.16

#### Environment in 2040
- **CO₂ emissions** (Mt/yr)
  - IRP 2016 Base Case: 251
  - IRP 2016 Carbon Budget: 176
  - Unconstrained Base Case: 214
  - Least Cost: 113
  - Decarbonised: 141
- **Water usage** (billion-litres/yr)
  - IRP 2016 Base Case: 216
  - IRP 2016 Carbon Budget: 167
  - Unconstrained Base Case: 204
  - Least Cost: 66
  - Decarbonised: 142

#### Jobs in 2040
- **Direct & supplier** ('000)
  - IRP 2016 Base Case: 185-241
  - IRP 2016 Carbon Budget: 191-216
  - Unconstrained Base Case: 199-234
  - Least Cost: 234-258
  - Decarbonised: 242-254

---

1. Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as \(=0.30\) R/kWh (today’s average cost for these items).
2. Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com
Least Cost is \( \approx \) R60-65 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case.

<table>
<thead>
<tr>
<th>2050</th>
<th>IRP 2016 Base Case</th>
<th>IRP 2016 Carbon Budget</th>
<th>Unconstrained Base Case</th>
<th>Least Cost</th>
<th>Decarbonised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand: 522 TWh</td>
<td><img src="chart" alt="Energy Mix" /></td>
<td><img src="chart" alt="Energy Mix" /></td>
<td><img src="chart" alt="Energy Mix" /></td>
<td><img src="chart" alt="Energy Mix" /></td>
<td><img src="chart" alt="Energy Mix" /></td>
</tr>
<tr>
<td>Total system cost (R-billion/yr)</td>
<td>700</td>
<td>688</td>
<td>658</td>
<td>627</td>
<td>675</td>
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<td>Average tariff (R/kWh)</td>
<td>1.34</td>
<td>1.32</td>
<td>1.26</td>
<td>1.20</td>
<td>1.29</td>
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<tr>
<td>CO(_2) emissions (Mt/yr)</td>
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<td>99</td>
<td>174</td>
<td>86</td>
<td>10</td>
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<tr>
<td>Water usage (billion-litres/yr)</td>
<td>41</td>
<td>18</td>
<td>33</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Direct &amp; supplier ('000)</td>
<td>252-295</td>
<td>235-253</td>
<td>248-281</td>
<td>310-325</td>
<td>331</td>
</tr>
</tbody>
</table>

1. Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as \( \approx \)0.30 R/kWh (today’s average cost for these items).
2. Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com
Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost ("Expected" costs)

Scenario comparison and summary
  • Conservative RE/battery cost
  • Expected RE/battery cost
Total system cost: Draft IRP 2016 Base Case ≈R155 bn/year more expensive by 2050 than Least Cost (without cost of CO₂)

Sources: CSIR analysis

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)
Total system cost: Draft IRP 2016 Base Case ≈R170 bn/year more expensive by 2050 than Least Cost (with cost of CO₂)

Total system cost in bR/yr (Apr-2016 Rand)

- Draft IRP 2016 Base Case
- IRP 2016 Carbon Budget
- IRP 2016 Unconstrained Base Case
- Least-cost ("Expected" costs)" Expected" costs
- Decarbonised

Costs applied: “Expected” costs

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)

Sources: CSIR analysis
Average tariff (without cost of CO₂): Draft IRP Base Case tariff 30 cents/kWh higher than Least Cost by 2050

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)
Average tariff (with cost of CO₂):
Draft IRP Base Case tariff 33 cents/kWh higher than Least Cost by 2050

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)

Sources: Eskom on Tx, Dx cost; CSIR analysis
Least Cost is \(\approx\) R30-50 billion/yr cheaper by 2030 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

### Energy Mix in 2030

<table>
<thead>
<tr>
<th>Energy Mix in 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand: 343 TWh</td>
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</table>

### Cost in 2030

<table>
<thead>
<tr>
<th>Cost in 2030</th>
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<tbody>
<tr>
<td>Total system cost (R-billion/yr)</td>
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<td>382</td>
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</table>

<table>
<thead>
<tr>
<th>Cost in 2030</th>
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<tbody>
<tr>
<td>Average tariff (R/kWh)</td>
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<td>1.11</td>
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### Environment in 2030

<table>
<thead>
<tr>
<th>Environment in 2030</th>
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<tbody>
<tr>
<td>CO₂ emissions (Mt/yr)</td>
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<td>251</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment in 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water usage (billion-litres/yr)</td>
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<tr>
<td>216</td>
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</tbody>
</table>

### Jobs in 2030

<table>
<thead>
<tr>
<th>Jobs in 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct &amp; supplier ('000)</td>
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<tr>
<td>93-153</td>
</tr>
</tbody>
</table>

---

1. Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as \(\approx\)0.30 R/kWh (today’s average cost for these items).
2. Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Because of lack of data, zero jobs for biomass/gas assumed (affects Decarbonised).
Least Cost is ≈R80-105 billion/yr cheaper by 2040 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

<table>
<thead>
<tr>
<th>2040</th>
<th>IRP 2016 Base Case (“Expected” costs)</th>
<th>IRP 2016 Carbon Budget (“Expected” costs)</th>
<th>Unconstrained Base Case (“Expected” costs)</th>
<th>Least Cost (“Expected” costs)</th>
<th>Decarbonised (“Expected” costs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Mix in 2040</td>
<td>Total system cost (R-billion/yr)</td>
<td>Average tariff (R/kWh)</td>
<td>CO₂ emissions (Mt/yr)</td>
<td>Water usage (billion-litres/yr)</td>
<td>Jobs^2 (‘000)</td>
</tr>
<tr>
<td>Demand: 428 TWh</td>
<td>548</td>
<td>1.28</td>
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<td>185-241</td>
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<tr>
<td></td>
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<td>214</td>
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<td>141</td>
<td>142</td>
<td>242-254</td>
</tr>
</tbody>
</table>

^1 Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today’s average cost for these items)

^2 Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Because of lack of data, zero jobs for biomass/-gas assumed (affects Decarbonised)
Least Cost is ≈R135-145 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

<table>
<thead>
<tr>
<th>2050</th>
<th>IRP 2016 Base Case (“Expected” costs)</th>
<th>IRP 2016 Carbon Budget (“Expected” costs)</th>
<th>Unconstrained Base Case (“Expected” costs)</th>
<th>Least Cost (“Expected” costs)</th>
<th>Decarbonised (“Expected” costs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand: 522 TWh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Mix in 2050</td>
<td>675</td>
<td>664</td>
<td>596</td>
<td>529</td>
<td>579</td>
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<tr>
<td>Cost in 2050</td>
<td>1.29</td>
<td>1.27</td>
<td>1.14</td>
<td>1.01</td>
<td>1.11</td>
</tr>
<tr>
<td>Environment in 2050</td>
<td>187</td>
<td>99</td>
<td>174</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Water usage (billion-litres/yr)</td>
<td>41</td>
<td>18</td>
<td>33</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Jobs² in 2050</td>
<td>252-295</td>
<td>235-253</td>
<td>248-281</td>
<td>380-392</td>
<td>331</td>
</tr>
<tr>
<td>Direct &amp; supplier (’000)</td>
<td>5%</td>
<td>14%</td>
<td>19%</td>
<td>9%</td>
<td>1%</td>
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<tr>
<td>IPCC assumptions:</td>
<td>9%</td>
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<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Hydro + PS</td>
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<td>6%</td>
<td>35%</td>
<td>36%</td>
<td>38%</td>
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<tr>
<td>Nuclear</td>
<td>13%</td>
<td>11%</td>
<td>14%</td>
<td>14%</td>
<td>8%</td>
</tr>
<tr>
<td>Nuclear (new)</td>
<td>13%</td>
<td>11%</td>
<td>14%</td>
<td>14%</td>
<td>0%</td>
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<tr>
<td>Coal</td>
<td>19%</td>
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<td>0%</td>
<td>0%</td>
<td>9%</td>
</tr>
<tr>
<td>Coal (new)</td>
<td>9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Biomass/gas</td>
<td>8%</td>
<td>36%</td>
<td>3%</td>
<td>4%</td>
<td>9%</td>
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<tr>
<td>Peaking</td>
<td>6%</td>
<td>6%</td>
<td>6%</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>Other storage</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Peaking</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>6%</td>
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<tr>
<td>CSP</td>
<td>6%</td>
<td>5%</td>
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<td>6%</td>
<td>47%</td>
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<td>Other storage</td>
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<td>6%</td>
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<td>1%</td>
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<tr>
<td>Wind</td>
<td>21%</td>
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<td>1%</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>Solar PV</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>4%</td>
</tr>
</tbody>
</table>

1. Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today’s average cost for these items)
2. Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Because of lack of data, zero jobs for biomass/gas assumed (affects Decarbonised)
Summary:
A mix of solar PV, wind and flexible power generators is least cost

It is cost-optimal to aim for >70% renewable energy share by 2050
- Solar PV, wind and flexible power generators (e.g. gas, CSP, hydro, biogas, demand response) are the cheapest new-build mix for the South African power system
- There is no technical limitation to solar PV and wind penetration over the planning horizon until 2050

“Clean” and “least-cost” is not a trade-off anymore: South Africa can de-carbonise its electricity sector at negative carbon-avoidance cost
- The “Least Cost” mix is >70 billion per year cheaper by 2050 than the current Draft IRP 2016 Base Case
- Additionally, Least Cost mix reduces CO₂ emissions by 55% (≈100 Mt/yr) over Draft IRP 2016 Base Case

The IRP and this analysis factor in all first-order cost drivers within the boundaries of the electricity system, but not external costs and benefits of certain electricity mixes that occur outside of the electricity system

Deviations from the Least Cost electricity mix can be quantified to inform policy adjustments (e.g. forcing in of certain technologies not selected by the least-cost mix like coal, nuclear, pumped storage, CSP, biogas, biomass, etc.)

Note: Wind and solar PV would have to be 50% more expensive than assumed before the IRP Base Case and the Least Cost case break even
Sources: CSIR analysis
LONG-TERM EXPANSION PLAN RESULTS
(SENSITIVITIES)
Agenda

Low demand forecast
   Base Case
   Unconstrained Base Case
   Least Cost

Supply technology tipping points
Overview of sensitivities

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Source</th>
<th>Difference to Draft IRP 2016 Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Case</strong> (Low demand)</td>
<td>CSIR</td>
<td>Low demand (EIUG)</td>
</tr>
<tr>
<td><strong>“Unconstrained Base Case”</strong> (Low demand)</td>
<td>CSIR</td>
<td>Low demand (EIUG) No constraints on new build technologies</td>
</tr>
<tr>
<td><strong>Least Cost</strong> (Low demand)</td>
<td>CSIR</td>
<td>Low demand (EIUG) No constraints on new build technologies RE costing aligned with latest REIPPPP Demand shaping from residential EWHs</td>
</tr>
<tr>
<td><strong>Supply technology tipping points</strong></td>
<td>CSIR</td>
<td>Least cost scenario input assumptions Lower costs for supply technologies not in least cost scenario e.g. nuclear, CSP etc</td>
</tr>
</tbody>
</table>
Agenda

Low demand forecast
  - Base Case
  - Unconstrained Base Case
  - Least Cost

Supply technology tipping points
Demand forecasts

Electrical energy demand [TWh]

Note: There is no spatial context for this demand forecast i.e. it is at a national level. Some level of spatial context is given in the analysis performed by CSIR on network infrastructure.

Sources: CSIR analysis
Lower demand forecast as per EIUG applied

Note: There is no spatial context for this demand forecast i.e. it is at a national level. Some level of spatial context is given in the analysis performed by CSIR on network infrastructure.
Agenda

Low demand forecast

Base Case

Unconstrained Base Case
Least Cost

Supply technology tipping points
Scenario: Base Case (Low Demand)
Significant new coal, some wind/PV - ≈R480-bln/yr cost in 2050

### Installed Capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal (new)</th>
<th>Nuclear (new)</th>
<th>Peaking</th>
<th>CSP</th>
<th>Wind</th>
<th>Solar PV</th>
<th>Hydro+PS</th>
<th>Other storage</th>
<th>Biomass/gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>37</td>
<td>12</td>
<td>37</td>
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</tr>
<tr>
<td>2030</td>
<td>74</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>5</td>
<td>30</td>
<td>16</td>
<td>15</td>
<td>2</td>
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<td>2040</td>
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<td>10</td>
<td>2</td>
<td>10</td>
<td>8</td>
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### Energy Produced

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<tr>
<td>2016</td>
<td>246</td>
<td>200</td>
<td>217</td>
<td>79</td>
<td>1</td>
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<tr>
<td>2030</td>
<td>315</td>
<td>204</td>
<td>221</td>
<td>127</td>
<td>2</td>
</tr>
<tr>
<td>2040</td>
<td>359</td>
<td>195</td>
<td>192</td>
<td>156</td>
<td>3</td>
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<tr>
<td>2050</td>
<td>389</td>
<td>168</td>
<td>204</td>
<td>158</td>
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</table>

### System Cost and Average Tariff

<table>
<thead>
<tr>
<th>Year</th>
<th>[bR/yr]</th>
<th>[R/kWh]¹</th>
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<tbody>
<tr>
<td>2016</td>
<td>203</td>
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<tr>
<td>2030</td>
<td>345</td>
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<td>2040</td>
<td>452</td>
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<tr>
<td>2050</td>
<td>528</td>
<td>1.05</td>
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</tbody>
</table>

¹ Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; ² Direct and supplier jobs only; Sources: CSIR; Eskom

Difference to Draft IRP 2016 Base Case

- Low demand (EIUG)

---

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Submitted to DoE on 31 March 2017
Agenda

Low demand forecast

Base Case

Unconstrained Base Case

Least Cost

Supply technology tipping points
Scenario: Unconstrained Base Case (Low Demand)

Installed Capacity

Energy Produced

System cost and average tariff

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar PV</th>
<th>CSP</th>
<th>Wind</th>
<th>Hydro+PS</th>
<th>Gas</th>
<th>Nuclear (new)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
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<td>5</td>
<td>8</td>
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<table>
<thead>
<tr>
<th>Year</th>
<th>Installed Capacity [GW]</th>
<th>Energy Produced [TWh/yr]</th>
<th>System cost and average tariff [bR/yr]</th>
<th>[R/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>246</td>
<td>200</td>
<td>203</td>
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<tr>
<td>2030</td>
<td>315</td>
<td>197</td>
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<tr>
<td>2040</td>
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<tr>
<td>2050</td>
<td>390</td>
<td>51</td>
<td>470</td>
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</table>

Difference to Draft IRP 2016 Base Case

- Low demand (EIUG)
- No constraints on new build technologies

*CO₂ Emissions [Mt/yr]*

- 2016: 217 Mt/yr
- 2030: 212 Mt/yr
- 2040: 122 Mt/yr
- 2050: 104 Mt/yr

*Water Usage [bl/yr]*

- 2016: 282 bl/yr
- 2030: 204 bl/yr
- 2040: 73 bl/yr
- 2050: 22 bl/yr

*Jobs [‘000]*

- 2016: 79 000
- 2030: 127 000
- 2040: 182 000
- 2050: 227 000

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; 2 Direct and supplier jobs only; Sources: CSIR; Eskom
Agenda

Low demand forecast
  Base Case
  Unconstrained Base Case
  Least Cost

Supply technology tipping points
Scenario: Least Cost (Low Demand)

### Installed Capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar PV</th>
<th>CSP</th>
<th>Wind</th>
<th>Hydro+PS</th>
<th>Nuclear (new)</th>
<th>Coal (new)</th>
<th>Peaking</th>
<th>Other storage</th>
<th>Biomass/gas</th>
<th>Total</th>
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<tbody>
<tr>
<td>2016</td>
<td>50</td>
<td>15</td>
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### Energy Produced

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<th>Wind</th>
<th>Hydro+PS</th>
<th>Nuclear (new)</th>
<th>Coal (new)</th>
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</tr>
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### System cost and average tariff

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<th>Year</th>
<th>Tariff w/o CO2</th>
<th>Tariff w CO2</th>
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### CO₂ Emissions

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<th>Wind</th>
<th>Hydro+PS</th>
<th>Nuclear (new)</th>
<th>Coal (new)</th>
<th>Peaking</th>
<th>Other storage</th>
<th>Biomass/gas</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>2016</td>
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### Water Usage

<table>
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<tr>
<th>Year</th>
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<th>Wind</th>
<th>Hydro+PS</th>
<th>Nuclear (new)</th>
<th>Coal (new)</th>
<th>Peaking</th>
<th>Other storage</th>
<th>Biomass/gas</th>
<th>Total</th>
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<tbody>
<tr>
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<td>0</td>
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### Jobs

<table>
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<tr>
<th>Year</th>
<th>Solar PV</th>
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<th>Wind</th>
<th>Hydro+PS</th>
<th>Nuclear (new)</th>
<th>Coal (new)</th>
<th>Peaking</th>
<th>Other storage</th>
<th>Biomass/gas</th>
<th>Total</th>
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<tbody>
<tr>
<td>2016</td>
<td>79</td>
<td>132</td>
<td>211</td>
<td>248</td>
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<td>10</td>
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<td>400</td>
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</table>

### Difference to Draft IRP 2016 Base Case

- Low demand (EIUG)
- No constraints on new build technologies
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHs

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; 2 Direct and supplier jobs only; Sources: CSIR; Eskom
Total system cost: IRP 2016 Base Case (Low Demand) ≈R30 bn/year more expensive by 2050 than Least Cost (without cost of CO₂)

Total system costs in bR/yr (Apr-2016 Rand)

- Draft IRP 2016 Base Case (Low Demand)
- IRP 2016 Unconstrained Base Case (Low Demand)
- Least Cost (Low Demand)

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)

Sources: CSIR analysis
Total system cost: Draft IRP 2016 Base Case \(\approx\) R45 bn/year more expensive by 2050 than Least Cost (with cost of \(\text{CO}_2\))

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)
Average tariff (without cost of CO₂): Draft IRP Base Case tariff 7 cents/kWh higher than Least Cost by 2050

Average tariff in R/kWh (Apr-2016 Rand)

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)

Sources: Eskom on Tx, Dx cost; CSIR analysis
Average tariff (with cost of CO₂):
Draft IRP Base Case tariff 11 cents/kWh higher than Least Cost by 2050

Average tariff in R/kWh
(Apr-2016 Rand)

Note: Medium-term from 2016-2030 not the main focus of this long-term expansion study (investigated in more detail in the medium-term outlook)

Draft IRP 2016 Base Case
IRP 2016 Unconstrained Base Case
Least Cost

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items)  Sources: Eskom on Tx, Dx cost; CSIR analysis
CO₂ emissions trajectories and water usage summary

**CO₂ emissions**
- [Mt/yr]
- 2010: 217
- 2015: 275
- 2020: 275
- 2025: 210
- 2030: 204
- 2035: 104
- 2040: 77
- 2045: 66
- 2050: 46

**Water consumption**
- [Mt/yr]
- 2010: 282
- 2015: 197
- 2020: 15
- 2025: 66
- 2030: 46
- 2035: 22
- 2040: 15

Source: CSIR analyses

Draft IRP 2016 Base Case
IRP 2016 Unconstrained Base Case
Least Cost
PPD Moderate
The Least-Cost and Decarbonised scenarios install significantly more wind and solar PV as well as more flexible peaking capacity.
Low Demand: Least Cost is ~R5 billion/yr cheaper by 2030 than Base Case

### 2030

#### Energy Mix in 2030
Demand: 307 TWh

#### Cost in 2030
Total system cost\(^1\) (R-billion/yr)
Average tariff (R/kWh)

#### Environment in 2030
CO\(_2\) emissions (Mt/yr)
Water usage (billion-litres/yr)

#### Jobs\(^2\) in 2030
Direct & supplier ('000)

<table>
<thead>
<tr>
<th>Demand</th>
<th>Base Case (Low Demand)</th>
<th>Unconstrained Base Case (Low Demand)</th>
<th>Least Cost (Low Demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>307 TWh</td>
<td>2% 11% 65%</td>
<td>2% 16% 63%</td>
<td>2% 18% 61%</td>
</tr>
<tr>
<td>334</td>
<td>1.09</td>
<td>1.09</td>
<td>1.07</td>
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<tr>
<td>221</td>
<td>212</td>
<td>204</td>
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</tr>
<tr>
<td>212</td>
<td>76-127</td>
<td>78-127</td>
<td>84-132</td>
</tr>
</tbody>
</table>

\(^1\) Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today’s average cost for these items)

\(^2\) Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com
Low Demand: Least Cost is ~R25 billion/yr cheaper by 2040 than Base Case

<table>
<thead>
<tr>
<th>2040</th>
<th>Base Case (Low Demand)</th>
<th>Unconstrained Base Case (Low Demand)</th>
<th>Least Cost (Low Demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Mix in 2040</strong></td>
<td>Demand: 352 TWh</td>
<td><strong>Demand: 352 TWh</strong></td>
<td><strong>Demand: 352 TWh</strong></td>
</tr>
<tr>
<td><strong>Cost in 2040</strong></td>
<td>Total system cost (R-billion/yr)</td>
<td><strong>Total system cost (R-billion/yr)</strong></td>
<td><strong>Total system cost (R-billion/yr)</strong></td>
</tr>
<tr>
<td></td>
<td>Average tariff (R/kWh)</td>
<td><strong>Average tariff (R/kWh)</strong></td>
<td><strong>Average tariff (R/kWh)</strong></td>
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<td>CO₂ emissions (Mt/yr)</td>
<td><strong>CO₂ emissions (Mt/yr)</strong></td>
<td><strong>CO₂ emissions (Mt/yr)</strong></td>
</tr>
<tr>
<td></td>
<td>Water usage (billion-litres/yr)</td>
<td><strong>Water usage (billion-litres/yr)</strong></td>
<td><strong>Water usage (billion-litres/yr)</strong></td>
</tr>
<tr>
<td><strong>Jobs² in 2040</strong></td>
<td>Direct &amp; supplier ('000)</td>
<td><strong>Direct &amp; supplier ('000)</strong></td>
<td><strong>Direct &amp; supplier ('000)</strong></td>
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</table>

1. Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today’s average cost for these items).

2. Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com
Low Demand: Least Cost is ~R30 billion/yr cheaper by 2050 than Base Case

### 2050

#### Energy Mix in 2050
- Demand: 382 TWh
- Nuclear (24%), Coal (24%), Wind (18%), Solar PV (9%), Gas (8%), Peaking (7%), Hydro+PS (1%), Other storage (1%), CSP (1%), Biomass-gas (3%), Wind (3%), Other (1%)

#### Cost in 2050
- Total system cost: R487 billion/yr
- Average tariff: R1.27/kWh
- CO₂ emissions: 204 Mt/yr
- Water usage: 46 billion-litres/yr

#### Environment in 2050
- Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

#### Jobs in 2050
- Direct & supplier (‘000): 195-244

---

1. Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ~0.30 R/kWh (today’s average cost for these items).
2. Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com
Agenda

Low demand forecast
  Base Case
  Unconstrained Base Case
  Least Cost

Supply technology tipping points
CSIR study cost input assumptions for CSP:
Today’s latest tariff as starting point, same cost decline as per IRP 2010

For bid window 3, 3.5 and 4 Exp, weighted average tariff of base and peak tariff calculated on the assumption of 64%/36% base/peak tariff utilisation ratio

Notes: REIPPPP = Renewable Energy Independent Power Producer Programme; BW = Bid Window; bid submissions for the different BWs: BW1 = Nov 2011; BW2 = Mar 2012; BW 3 = Aug 2013; BW 4 = Aug 2014; BW 4 (Expedited) = Nov 2015 Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
CSP example sensitivity – CSP would need to be below the curve to be chosen

Latest CSP average tariff: 2.02 R/kWh

1 Weighted average tariff for bid window 3.5 calculated on the assumption of ~50% annual load factor and full utilisation of the 5 peak-tariff hours per day
CSP example sensitivity – CSP would need to be below the curve to be chosen

Latest CSP average tariff: 2.02 R/kWh

CSP would need to bring costs down to the point where it would offer more value to the system than it costs

Tariff by 2030

Similar approach should be applied to other technologies not included in the Least Cost capacity expansion plan

1 Weighted average tariff for bid window 3.5 calculated on the assumption of ~50% annual load factor and full utilisation of the 5 peak-tariff hours per day
MEDIUM TERM OUTLOOK
Agenda

Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
Linear build-out to 2030
Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment
## Overview of scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Source</th>
<th>Difference to Draft IRP 2016 Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft IRP 2016 Base Case</td>
<td>Department of Energy Draft IRP 2016 as of November 2016</td>
<td>N/A</td>
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<tr>
<td>Draft IRP 2016 Carbon Budget</td>
<td>Department of Energy Draft IRP 2016 as of November 2016</td>
<td>Tighter carbon reduction targets</td>
</tr>
<tr>
<td>Least Cost</td>
<td>CSIR</td>
<td>No constraints on any new build technologies</td>
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<tr>
<td></td>
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<td>RE costing aligned with latest REIPPPP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Demand shaping from residential EWHs</td>
</tr>
<tr>
<td>Linear build-out</td>
<td>CSIR</td>
<td>Spread wind and solar PV new build from 2030 Least Cost result linearly from 2021</td>
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<tr>
<td></td>
<td></td>
<td>Re-optimise other supply options around linear build</td>
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Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
Linear build-out to 2030
Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis
Over-investment
**Scenario: Draft IRP 2016 Base Case**

14% solar PV/wind energy share by 2030, R384 billion cost in 2030

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**Capacity Installed**

- **2016**: 50 [GW]
- **2020**: 7 [GW]
- **2025**: 11 [GW]
- **2030**: 33 [GW]

**Energy Produced**

- **2016**: 217 [TWh/yr]
- **2020**: 282 [TWh/yr]
- **2025**: 216 [TWh/yr]
- **2030**: 350 [TWh/yr]

**Cost and Tariff**

- **2016**: 1 [bR/yr]
- **2020**: 5 [bR/yr]
- **2025**: 15 [bR/yr]
- **2030**: 384 [bR/yr]

---

**As per Draft IRP 2016**

- **Earliest new build**
  - 2021: Solar PV
  - 2023: Wind
  - 2024: Peaking
  - 2025: Gas (CCGT)
  - 2028: Coal

---

1. Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016
Agenda

Scenarios

Draft IRP 2016: Base Case

**Draft IRP 2016: Carbon Budget**

- Least cost
- Linear build-out to 2030

Scenario comparison and summary

Sensitivities

- Least cost (low demand forecast)
- Linear build-out to 2030 (low demand forecast)
- Low supply (low plant performance and delayed new builds)
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment
Scenario: Draft IRP 2016 Carbon Budget
24% solar PV/wind energy share by 2030, R404 billion cost in 2030

Capable to Installed

Energy Produced

Cost and Tariff

Difference to Draft IRP 2016 Base Case

- Tighter carbon reduction targets

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016
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Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget

**Least cost**
Linear build-out to 2030
Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment
Scenario: Least Cost
31% solar PV/wind energy share by 2030, R367 billion cost in 2030

Cost and Tariff

<table>
<thead>
<tr>
<th>Year</th>
<th>[bR/yr]</th>
<th>[R/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>203</td>
<td>1.2</td>
</tr>
<tr>
<td>2020</td>
<td>282</td>
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<td>2025</td>
<td>196</td>
<td>0.4</td>
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<tr>
<td>2030</td>
<td>367</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Difference to Draft IRP 2016 Base Case

- No build-out constraints on any technology
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHs

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016
Agenda

Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
**Linear build-out to 2030**
Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment
Scenario: Linear build-out of wind and Solar PV to 2030
31% solar PV/wind energy share by 2030, R367 billion cost in 2030

**Capacity Installed**

- [GW]
  - Other storage
  - Gas
  - Solar PV
  - CSP
  - Wind
  - Biomass/gas
  - Peaking
  - Tariff w/o CO2
  - Tariff w CO2

**Energy Produced**

- [TWh/yr]
  - 2016:
    - Solar PV: 1,250 MW
    - Wind: 2,100 MW
  - 2020:
    - 246 TWh
  - 2025:
    - 304 TWh
  - 2030:
    - 351 TWh

**Cost and Tariff**

- [bR/yr]
  - 2016:
    - 203 TWh
  - 2020:
    - 273 TWh
  - 2025:
    - 346 TWh
  - 2030:
    - 367 TWh

- [R/kWh]
  - 2016:
    - 1.34 R/kWh
  - 2020:
    - 1.17 R/kWh
  - 2025:
    - 0.98 R/kWh
  - 2030:
    - 0.92 R/kWh

**Difference to Draft IRP 2016 Base Case**

- Same assumptions as Least Cost
- 2030 Wind and solar PV build from Least Cost scenario linearly built from 2021 to 2030

---

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016
Shifting wind and solar PV earlier increases system costs (without cost of CO$_2$) ≈ 1 - 6 R billion/yr between 2021 and 2030

Total system cost in bR/yr (Apr-2016 Rand)

Sources: CSIR analysis
Shifting wind and solar PV earlier increases system costs (with cost of CO$_2$) $\approx 1 - 4$ R billion/yr between 2021 and 2030

**Total system cost**

in bR/yr

(Apr-2016 Rand)

Sources: CSIR analysis
Average tariff (without cost of CO$_2$):
Linear build ≈ 1-2 cents/kWh higher than Least Cost from 2021 - 2027

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)  
Sources: Eskom on Tx, Dx cost; CSIR analysis
Average tariff (with cost of CO$_2$):
Linear build $\approx$ 1 cents/kWh higher than Least Cost from 2022 - 2025
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Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
Linear build-out to 2030

Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment
Scenario comparison: Total new installed capacity

**Draft IRP 2016 Base Case**

- Earliest new build
  - 2021 - Solar PV
  - 2023 - Wind
  - 2024 - Peaking
  - 2025 - Gas (CCGT)

**Draft IRP 2016 Carbon Budget**

- Earliest new build
  - 2020 - Solar PV
  - 2021 - Wind
  - 2025 - Peaking
  - 2026 - Nuclear
  - 2028 - Gas (CCGT)

**Least Cost**

- Earliest new build
  - 2023 - Peaking
  - 2024 - Solar PV
  - 2025 - Wind
  - 2028 - Gas (CCGT)
Scenario comparison: Annual new and decommissioned capacity

Draft IRP 2016 Base Case

Draft IRP 2016 Carbon Budget

Least Cost

[GW]

2016 2020 2025 2030

2016 2020 2025 2030

2016 2020 2025 2030

Other storage  CSP  Biomass/-gas  Gas  Nuclear (New)  Coal (New)
Solar PV  Wind  Peaking  Hydro+PS  Nuclear  Coal
The Least-Cost scenario installs significantly more wind and solar PV as well as more flexible peaking capacity.
Total system cost: Draft IRP 2016 Base Case ≈R17 bn/year more expensive by 2030 than Least Cost (without cost of CO₂)

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)
Sources: Eskom on Tx, Dx cost; CSIR analysis
Total system cost: Draft IRP 2016 Base Case ≈R23 bn/year more expensive by 2030 than Least Cost (with cost of CO₂)

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)   Sources: Eskom on Tx, Dx cost; CSIR analysis
Average tariff (without cost of CO₂):
Draft IRP Base Case tariff ≈5 cents/kWh higher than Least Cost by 2030

Average tariff in R/kWh
(Apr-2016 Rand)

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)  
Sources: Eskom on Tx, Dx cost; CSIR analysis
Average tariff (with cost of CO₂): Draft IRP Base Case tariff ≈7 cents/kWh higher than Least Cost by 2030

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)  Sources: Eskom on Tx, Dx cost; CSIR analysis
CO₂ emissions trajectories and water usage summary

**CO₂ emissions [Mt/yr]**

- Draft IRP 2016 Base Case
- Least Cost
- IRP 2016 Carbon Budget
- PPD Moderate

Source: CSIR analyses
Agenda

Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
Linear build-out to 2030
Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment
### Overview of sensitivities

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Source</th>
<th>Difference to Draft IRP 2016 Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Least Cost</strong> (Low demand)</td>
<td>CSIR</td>
<td>Low demand (EIUG) No constraints on any new build technologies RE costing aligned with latest REIPPPP Demand shaping from residential EWHs</td>
</tr>
<tr>
<td><strong>Linear build-out</strong> (Low demand)</td>
<td>CSIR</td>
<td>Spread wind and solar PV new build from 2030 Least Cost result linearly from 2021 Re-optimise other supply options around linear build</td>
</tr>
<tr>
<td><strong>Low Supply</strong></td>
<td>CSIR</td>
<td>Least cost scenario input assumptions Delay Medupi and Kusile by 1 year/unit Follow Eskom’s low plant performance path</td>
</tr>
<tr>
<td><strong>Low Supply</strong> (Low demand)</td>
<td>CSIR</td>
<td>Low demand (EIUG) Least cost scenario input assumptions Delay Medupi and Kusile by 1 year/unit Follow Eskom’s low plant performance path</td>
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</table>
Agenda

Scenarios
Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
Linear build-out to 2030
Scenario comparison and summary

Sensitivities
Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis
Over-investment
Scenario: Least Cost (low demand)
24% solar PV/wind energy share by 2030, R327 billion cost in 2030

Capacity Installed

Energy Produced

Cost and Tariff

Earliest new build
2025 - Solar PV & Peaking
2027 - Wind
2029 - Gas (CCGT)

Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016 Base Case

Difference to Draft IRP 2016 Base Case
• Low demand (EIUG)
• No build-out constraints on any technology
• RE costing aligned with latest REIPPPP
• Demand shaping from residential EWHs
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Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
Linear build-out to 2030
Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
**Linear build-out to 2030 (low demand forecast)**
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment
Scenario: Linear build-out of wind and Solar PV (low demand)
24% solar PV/wind energy share by 2030, R327 billion cost in 2030

Capacity Installed

Energy Produced

Cost and Tariff

Difference to Draft IRP 2016 Base Case

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016
Shifting wind and solar PV earlier increases system costs (without cost of CO\(_2\)) \(\approx 1 - 7\) R billion/yr between 2021 and 2029 with low demand.
Shifting wind and solar PV earlier increases system costs (with cost of CO$_2$) $\approx 1$ - 4 R billion/yr between 2021 and 2029 with low demand.

Total system cost in bR/yr (Apr-2016 Rand)

- Least Cost (Low Demand)
- Least Cost Linear Build (Low Demand)
- Difference

Sources: CSIR analysis
Average tariff (without cost of CO₂): Linear build ≈ 1-2 cents/kWh higher than Least Cost from 2021 - 2029 with low demand

### Average tariff in R/kWh (Apr-2016 Rand)

<table>
<thead>
<tr>
<th>Year</th>
<th>Least Cost (Low Demand)</th>
<th>Least Cost Linear Build (Low Demand)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>0.84</td>
<td>-</td>
<td>-</td>
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<tr>
<td>2017</td>
<td>1.02</td>
<td>1.02</td>
<td>0.00</td>
</tr>
<tr>
<td>2018</td>
<td>1.05</td>
<td>1.05</td>
<td>0.00</td>
</tr>
<tr>
<td>2019</td>
<td>1.03</td>
<td>1.03</td>
<td>0.00</td>
</tr>
<tr>
<td>2020</td>
<td>1.07</td>
<td>1.07</td>
<td>0.00</td>
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</table>

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)  
Sources: Eskom on Tx, Dx cost; CSIR analysis
Average tariff (with cost of CO₂): Linear build ≈ 1-2 cents/kWh higher than Least Cost from 2021 - 2026 with low demand

Average tariff in R/kWh (Apr-2016 Rand)

- Least Cost (Low Demand)
- Least Cost Linear Build (Low Demand)
- Difference

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)  
Sources: Eskom on Tx, Dx cost; CSIR analysis
Building wind and solar PV earlier shifts the peaking and gas requirements later.
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Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
Linear build-out to 2030
Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
**Low supply (low plant performance and delayed new builds)**
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment
Energy Availability Factor (EAF) [%]

Sources: DoE Draft IRP 2016
Energy Availability Factor (EAF) [%]

Sources: DoE Draft IRP 2016
Scenario: Low Supply
37% solar PV/wind energy share by 2030, R383 billion cost in 2030

Capacity Installed

Energy Produced

Cost and Tariff

Earliest new build
2020 - Solar PV & wind
2021 - Peaking
2025 - Gas (CCGT)

Supply shortage

[GW]

[TWh/yr]

[bR/yr]

[R/kWh]

1 includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016

2 No new build allowed due to short term lead time constraints. First solar PV & wind allowed from 2020, peaking & gas from 2021, coal from 2022 & nuclear from 2025

Scenario: Low Supply
37% solar PV/wind energy share by 2030, R383 billion cost in 2030

Difference to Draft IRP 2016 Base Case

• Same assumptions as Least Cost
• Delay Medupi and Kusile by 1 year per unit
• Follow Eskom’s low plant performance path
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Scenarios
- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
- Least cost
- Linear build-out to 2030
- Scenario comparison and summary

Sensitivities
- Least cost (low demand forecast)
- Linear build-out to 2030 (low demand forecast)
- Low supply (low plant performance and delayed new builds)
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis
- Over-investment
Scenario: Low Supply (low demand)
30% solar PV/wind energy share by 2030, R341 billion cost in 2030

### Capacity Installed

<table>
<thead>
<tr>
<th>Year</th>
<th>Other storage</th>
<th>Gas</th>
<th>Solar PV</th>
<th>Hydro+PS</th>
<th>Wind</th>
<th>Nuclear (new)</th>
<th>Nuclear</th>
<th>Biomass/gas</th>
<th>Coal (new)</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>50</td>
<td>1</td>
<td>33</td>
<td>16</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
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<td>2020</td>
<td>60</td>
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<td>42</td>
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<td>33</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>21</td>
<td>5</td>
</tr>
</tbody>
</table>

- Earliest new build: 2020 - Solar PV & wind
- 2021 - Peaking
- 2025 - Gas (CCGT)

### Energy Produced

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>217 TWh/yr</td>
</tr>
<tr>
<td>2020</td>
<td>282 TWh/yr</td>
</tr>
<tr>
<td>2025</td>
<td>316 TWh/yr</td>
</tr>
<tr>
<td>2030</td>
<td>341 TWh/yr</td>
</tr>
</tbody>
</table>

### Cost and Tariff

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost and Tariff</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>203 bR/yr</td>
</tr>
<tr>
<td>2020</td>
<td>282 bR/yr</td>
</tr>
<tr>
<td>2025</td>
<td>316 bR/yr</td>
</tr>
<tr>
<td>2030</td>
<td>341 bR/yr</td>
</tr>
</tbody>
</table>

### CO2 Emissions and Water Usage

- **CO2 Emissions [Mt/yr]**: 217 in 2016, 282 in 2020, 183 in 2025, 167 in 2030
- **Water Usage [bl/yr]**: 167 in 2016, 183 in 2020, 217 in 2025, 341 in 2030

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1. Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016
2. No new build allowed due to short term lead time constraints. First solar PV & wind allowed from 2020, peaking & gas from 2021, coal from 2022 & nuclear from 2025

---

Difference to Draft IRP 2016 Base Case

- EIUG Low demand forecast
- Same assumptions as Least Cost
- Delay Medupi and Kusile by 1 year per unit
- Follow Eskom’s low plant performance path
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Scenarios
- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
- Least cost
- Linear build-out to 2030
- Scenario comparison and summary

Sensitivities
- Least cost (low demand forecast)
- Linear build-out to 2030 (low demand forecast)
- Low supply (low plant performance and delayed new builds)
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis
- Over-investment
Overview of What-If analyses

### Sensitivity

<table>
<thead>
<tr>
<th>Draft IRP 2016 Base Case (over-investment)</th>
<th>Draft IRP 2016 Carbon Budget (over-investment)</th>
<th>Least Cost (over-investment)</th>
</tr>
</thead>
</table>

### Source

<table>
<thead>
<tr>
<th>Draft IRP 2016 Base Case</th>
<th>Draft IRP 2016 Carbon Budget</th>
<th>Least Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSIR</td>
<td>CSIR</td>
<td>CSIR</td>
</tr>
</tbody>
</table>

### Difference to Draft IRP 2016 Base Case

- Least cost scenario input assumptions
- Low demand (EIUG)
- Hard-coded installed capacity from this scenario but with lower demand forecast

Submitted to DoE on 31 March 2017
Overview of What-If analyses

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Source</th>
<th>Difference to Draft IRP 2016 Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel costs (Cheaper gas)</td>
<td>CSIR</td>
<td>Least cost scenario input assumptions Cheap natural gas</td>
</tr>
<tr>
<td>Fuel costs (More expensive coal)</td>
<td>CSIR</td>
<td>Least cost scenario input assumptions Higher coal fuel price</td>
</tr>
<tr>
<td>Resource availability (wind not available)</td>
<td>CSIR</td>
<td>Least cost scenario input assumptions Wind not available for extended periods</td>
</tr>
</tbody>
</table>
Agenda

Scenarios

Draft IRP 2016: Base Case
Draft IRP 2016: Carbon Budget
Least cost
Linear build-out to 2030
Decarbonise the electricity sector
Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)
Linear build-out to 2030 (low demand forecast)
Low supply (low plant performance and delayed new builds)
Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment
What-if: IRP 2016 Base Case (over-investment)
15% solar PV/wind energy share by 2030, R362 billion cost in 2030

<table>
<thead>
<tr>
<th>Capacity Installed</th>
<th>Energy Produced</th>
<th>Cost and Tariff</th>
</tr>
</thead>
<tbody>
<tr>
<td>[GW]</td>
<td>[TWh/yr]</td>
<td>[bR/yr]</td>
</tr>
<tr>
<td>Other storage</td>
<td>Solar PV</td>
<td>Gas</td>
</tr>
<tr>
<td>50</td>
<td>246</td>
<td>203</td>
</tr>
<tr>
<td>Gas</td>
<td>Hydro+PS</td>
<td>Wind</td>
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<tr>
<td>11</td>
<td>312</td>
<td>362</td>
</tr>
<tr>
<td>Wind</td>
<td>Biomass/gas</td>
<td>Nuclear</td>
</tr>
<tr>
<td>7</td>
<td>82</td>
<td>50</td>
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<td>Nuclear (new)</td>
<td>Peaking</td>
<td>Coal (new)</td>
</tr>
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<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Coal</td>
<td>Coal</td>
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<tr>
<td>9</td>
<td>14</td>
<td>0</td>
</tr>
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<td>Peaking</td>
<td>Coal</td>
<td>Coal</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Peaking</td>
<td>Coal</td>
<td>Coal</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Peaking</td>
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<tr>
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<tr>
<td>Peaking</td>
<td>Coal</td>
<td>Coal</td>
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<tr>
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</tr>
<tr>
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</table>
What-if: IRP 2016 Carbon Budget (over-investment)
27% solar PV/wind energy share by 2030, R382 billion cost in 2030

**Capacity Installed**

- [GW]
- 2016: 50
- 2020: 80
- 2025: 95
- 2030: 120

**Energy Produced**

- [TWh/yr]
- 2016: 246
- 2020: 310
- 2025: 310
- 2030: 310

**Cost and Tariff**

- [bR/yr]
- 2016: 203
- 2020: 282
- 2025: 381
- 2030: 381

- [R/kWh]

**Difference to Draft IRP 2016 Base Case**

- Low Demand (EIUG)
- Tighter carbon reduction targets
- Hard-coded installed capacity from this scenario but with lower demand forecast

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016
What-if: Least Cost (over-investment)
27% solar PV/wind energy share by 2030, R347 billion cost in 2030

Capacity Installed

Energy Produced

Cost and Tariff

Difference to Draft IRP 2016 Base Case

- Low Demand (EIUG)
- No build-out constraints on any technology
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHs

1 Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE’s Draft IRP 2016
Total system cost: IRP 2016 Base Case ≈R14 bn/year more expensive by 2030 than Least Cost (without cost of CO₂) if low demand materializes

Sources: CSIR analysis
Total system cost: IRP 2016 Base Case ≈R17 bn/year more expensive by 2030 than Least Cost (with cost of CO₂) if low demand materializes

Total system cost in bR/yr (Apr-2016 Rand)

Sources: CSIR analysis
Average tariff (without cost of CO$_2$): Draft IRP Base Case tariff $\approx$ 5 cents/kWh higher than Least Cost by 2030 if low demand materializes

Average tariff in R/kWh (Apr-2016 Rand)

- IRP 2016 Base Case (Over-investment)
- IRP 2016 Carbon Budget (Over-investment)
- Least Cost (Over-investment)

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today’s average cost for these items)  
Sources: Eskom on Tx, Dx cost; CSIR analysis
Average tariff (with cost of CO₂) Draft IRP Base Case tariff ≈ 6 cents/kWh higher than Least Cost by 2030 if the low demand materializes

Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items)  Sources: Eskom on Tx, Dx cost; CSIR analysis
**CO₂ emissions trajectories and water usage summary**

**CO₂ emissions**

- **Mt/yr**
- **2015:** 217
- **2020:** 214
- **2025:** 192
- **2030:** 138

**Water consumption**

- **bl/yr**
- **2015:** 282
- **2020:** 250
- **2025:** 214
- **2030:** 184

**Charts**

- **IRP 2016 Base Case**
  - (Over-investment)
- **IRP 2016 Carbon Budget**
  - (Over-investment)
- **Least Cost**
  - (Over-investment)
- **PPD Moderate**

Source: CSIR analyses
Network infrastructure

System services

- Reactive power and voltage control
- Power system stability (transient)
- Power system stability (frequency)
Agenda

Network infrastructure

System services

- Reactive power and voltage control
- Power system stability (transient)
- Power system stability (frequency)
Agenda

SA Grid Overview

Grid development plans

Provincial load location (2040 – spatial by Eskom) and 2050 (assumed)

Wind and solar PV resource location

Grid integration topology and costs – for direct connection
SA Grid overview by 2022
Agenda

SA Grid Overview

Grid development plans

Provincial load location (2040 – spatial by Eskom) and 2050 (assumed)

Wind and solar PV resource location

Grid integration topology and costs – for direct connection
## Plans for the development of a power system

### Integrated Resource Plan (IRP)
- The Department of Energy (Energy Planner) is accountable for the Country Electricity Plan, which is called the Integrated Resource Plan For Electricity (IRP 2010-2030).
- The Integrated Resource Plan (IRP) is intended to drive all new generation capacity development.
- Nersa licences new generators according to this determination.

### Strategic Grid Plan (SGP)
- The Strategic Grid Plan formulates long term strategic transmission corridor requirements
- The Plan is based on a range of generation scenarios and associated strategic network analysis
- Horizon date is 20 years
- Updated every 2 - 3 years

### Transmission Development Plan (TDP)
- The Transmission Development Plan (TDP) represents the transmission network infrastructure investment requirements
- The TDP covers a 10 year window
- Updated annually
- Indicates financial commitments required in the short to medium term

Sources: Eskom TDP 2016-2025: www.eskom.co.za/Whatweredoing/TransmissionDevelopmentPlan/
Transmission supply area generation connection capacity for simultaneous generation sources in an area

Grid capacity is available all over the country, therefore wind and PV projects should be incentivised to go where there is grid capacity in order to expedite time to connect to the grid.

_Focusing only on the Northern Cape for Wind and PV will result in unnecessary delay to connect new plants since wind and PV resource is good all over the country._
Transmission capacity for generation connection in the short term up year 2030 is not a limitation

<table>
<thead>
<tr>
<th>Supply areas' generation integration Capacity</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 Supply areas' generation integration Capacity</td>
<td>≈ 85 000 MW by year 2022 based on GCCA 2022 - using the grid designed for according to the TDP 2014-2024</td>
</tr>
</tbody>
</table>
Strategic plans are in place to unlock over 36 GW of generation connection interest, but timelines are too long for large integration.

Sources: Eskom Transmission development plan 2016-2025.
Agenda

SA Grid Overview

Grid development plans

Provincial load location (2040 – spatial by Eskom) and 2050 (assumed)

Wind and solar PV resource location

Grid integration topology and costs – for direct connection
Demand generation by 2040; generation for Base IRP 2010 scenario

Source: Eskom strategic grid plan
Load spatial location assumptions as per strategic grid plan

<table>
<thead>
<tr>
<th>No</th>
<th>Province</th>
<th>SGP Demand 2040 (GW)</th>
<th>IRP 2016 Year 2050 (GW)</th>
<th>% Total Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Eastern Cape</td>
<td>5.3</td>
<td>6.3</td>
<td>7%</td>
</tr>
<tr>
<td>2</td>
<td>Free State</td>
<td>3.4</td>
<td>4.1</td>
<td>5%</td>
</tr>
<tr>
<td>3</td>
<td>Gauteng</td>
<td>20.9</td>
<td>24.8</td>
<td>29%</td>
</tr>
<tr>
<td>4</td>
<td>Kwazulu-Natal</td>
<td>12.5</td>
<td>14.8</td>
<td>17%</td>
</tr>
<tr>
<td>5</td>
<td>Limpopo</td>
<td>6.7</td>
<td>8.0</td>
<td>9%</td>
</tr>
<tr>
<td>6</td>
<td>Mpumalanga</td>
<td>7.4</td>
<td>8.8</td>
<td>10%</td>
</tr>
<tr>
<td>7</td>
<td>North West</td>
<td>6.4</td>
<td>7.6</td>
<td>9%</td>
</tr>
<tr>
<td>8</td>
<td>Northern Cape</td>
<td>2.6</td>
<td>3.1</td>
<td>4%</td>
</tr>
<tr>
<td>9</td>
<td>Western Cape</td>
<td>7.3</td>
<td>8.6</td>
<td>10%</td>
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<tr>
<td></td>
<td>TOTAL</td>
<td>72.5</td>
<td>86</td>
<td>100%</td>
</tr>
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</table>
Agenda

SA Grid Overview

Grid development plans

Provincial load location (2040 – spatial by Eskom) and 2050 (assumed)

Wind and solar PV resource location

Grid integration topology and costs – for direct connection
The wind resource is good virtually all over the country, location of collector substation existing grid capacity should be prioritised

Collector substation and clustering allocation should prioritise:
- Areas with existing grid capacity (GCCA 2022 provides guidance)
- Areas with minimal environmental constraints (Data sets from the REDZs study provide guidance)

Sources:
Wind and solar resource aggregation study: http://www.csir.co.za/Energy_Centre/wind_solarpv.html
High potential for wind and solar PV, and space is no limitation

EIA applications: estimated Wind (89), PV(329); land use is roughly 1.21% of SA land
REDZ: estimated Wind (535 GW), PV (1782 GW); land use is roughly 4.4% of SA land
RE Rollout and Provincial Impact; the Cape area has been the focus, however, wind and solar resources are excellent in other provinces too.

<table>
<thead>
<tr>
<th>Province</th>
<th>Bid windows</th>
<th>Wind (MW)</th>
<th>PV (MW)</th>
<th>CSP (MW)</th>
<th>Total</th>
<th>% RE of Bid 1-4</th>
<th>Area (km²)</th>
<th>% of SA Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Cape</td>
<td>1,2,3,4</td>
<td>1440</td>
<td>70</td>
<td>0</td>
<td>1509</td>
<td>24%</td>
<td>168 966</td>
<td>14%</td>
</tr>
<tr>
<td>Free State</td>
<td>1,2,3,4</td>
<td>0</td>
<td>199</td>
<td>0</td>
<td>199</td>
<td>3%</td>
<td>129 825</td>
<td>11%</td>
</tr>
<tr>
<td>Gauteng</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>16 548</td>
<td>1%</td>
</tr>
<tr>
<td>Kwazulu-Natal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>94 361</td>
<td>8%</td>
</tr>
<tr>
<td>Lompopo</td>
<td>1,3</td>
<td>0</td>
<td>118</td>
<td>0</td>
<td>118</td>
<td>2%</td>
<td>125 755</td>
<td>10%</td>
</tr>
<tr>
<td>Mpumalanga</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>76 495</td>
<td>6%</td>
</tr>
<tr>
<td>North West</td>
<td>1,4</td>
<td>0</td>
<td>275</td>
<td>0</td>
<td>275</td>
<td>4%</td>
<td>106 512</td>
<td>9%</td>
</tr>
<tr>
<td>Northern Cape</td>
<td>1,2,3,3.5,4</td>
<td>1459</td>
<td>1497</td>
<td>600</td>
<td>3556</td>
<td>57%</td>
<td>372 889</td>
<td>31%</td>
</tr>
<tr>
<td>Western Cape</td>
<td>1,2,3,4</td>
<td>458</td>
<td>134</td>
<td>0</td>
<td>592</td>
<td>9%</td>
<td>129 462</td>
<td>11%</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>3357</td>
<td>2292</td>
<td>600</td>
<td>6249</td>
<td>100%</td>
<td>1 220 813</td>
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</table>
Agenda

SA Grid Overview

Grid development plans

Provincial load location (2040 – spatial by Eskom) and 2050 (assumed)

Wind and solar PV resource location

Grid integration topology and costs – for direct connection
Generation integration for topologies for distributed generation and bulk power or centralised generation

LEGEND
- EHV: 400 kV
- HV: 132 kV
- MV: 11/22/33 kV
- New grid for generation connection

Bulk Power Generation Plant with HV yard

Main Transmission System Substation
Grid connection costs are a small part of grid related costs associated with any generation integration.

*Grid-related cost include; grid connection capital cost, losses, location based costs (e.g. nodal/zonal pricing)
Grid connection assumptions

**Estimated direct connection costs**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Plant Capital R/kW</th>
<th>Estimated % Capital cost</th>
<th>Estimated grid connection R/kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>13 097</td>
<td>5%</td>
<td>655</td>
</tr>
<tr>
<td>PV</td>
<td>4 639</td>
<td>5%</td>
<td>232</td>
</tr>
<tr>
<td>Coal</td>
<td>45 103</td>
<td>10%</td>
<td>4510</td>
</tr>
<tr>
<td>Nuclear</td>
<td>84 420</td>
<td>12%</td>
<td>10130</td>
</tr>
<tr>
<td>Hydro + PS</td>
<td>63 299</td>
<td>10%</td>
<td>6330</td>
</tr>
<tr>
<td>CCGT</td>
<td>10 772</td>
<td>10%</td>
<td>1077</td>
</tr>
<tr>
<td>Bio</td>
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</table>

**Estimated backbone connection costs**

<table>
<thead>
<tr>
<th></th>
<th>R/kW</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC (excludes substations)</td>
<td>1600</td>
<td>Substations are cheaper that very long transmission lines</td>
</tr>
<tr>
<td>HVDC (excludes converter stations)</td>
<td>2900</td>
<td>Converter stations are the most expensive part of the HVDC system</td>
</tr>
</tbody>
</table>

**Key assumptions**

- Only direct grid connections considered, no backbone network considered; previous studies have shown that backbone grid is scenario neutral because it is largely load driven (but this can be revisited)

- **Connection costs based on nameplate capacity – a worst case connection**
  - Wind and PV distributed in all the provinces
  - All PV assumed to be grid connected – worst case scenario in term of connection costs; in reality 20-30% of PV will be embedded
  - HVDC costs for higher nuclear scenario not fully costed, assumption on costs is based on direction connection

Grid connection costs - supply scenarios for 2050

<table>
<thead>
<tr>
<th></th>
<th>Estimated Direct connection costs</th>
<th>Estimated Backbone Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capex (bR)</td>
<td>EAC (bR/yr)</td>
</tr>
<tr>
<td>IRP Base Case</td>
<td>436</td>
<td>39.5</td>
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<td>IRP Carbon Budget</td>
<td>433</td>
<td>39.2</td>
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<tr>
<td>Unconstrained Base Case</td>
<td>254</td>
<td>23.0</td>
</tr>
<tr>
<td>Least Cost</td>
<td>233</td>
<td>21.1</td>
</tr>
</tbody>
</table>

Notes

- Equivalent annual cost: Economic lifetime = 30 years, discount rate = 8.2%
- Backbone grid for all scenarios will be estimated, but will likely be similar for all scenarios since it is load driven, and the least cost scenario benefits from spatial aggregation, base case and carbon budget have less spatial benefits
- Backbone costs exclude HVDC converter station for the Base and Carbon budget scenarios; only HVDC lines assumed for the two scenarios.
Provincial grid node model – linear (dc) load flow

HVDC power corridor for nuclear scenarios
AC Power corridor
Load + generation
Network infrastructure

System services

- Reactive power and voltage control
- Power system stability (transient)
- Power system stability (frequency)
Synchronous generators inherently provide system stability through the direct, synchronous coupling of their physical inertia to the grid.

Load Balancing (Frequency Control)

- Solar PV
- HVDC interconnection
- Tidal stream
- Ocean wave
- ...
Averaging window is important – for frequency stability typically a 500 ms averaging window for RoCoF is considered.

The RocoF should not exceed a particular threshold within the pre-defined averaging window e.g. 500 ms.

Sources: EirGrid, SONI
System operators are already managing high non-synchronous penetration levels... today e.g. Ireland

\[
\text{SNSP [%]} = \frac{\text{System Non-Synchronous Penetration} = (\text{Wind} + \text{Imports})}{\text{Demand} + \text{Exports}}
\]

**Actuals for the week from 22/02/2017-03/03/2017**

Power in GW

Sources: EirGrid
System operators are already managing high non-synchronous penetration levels... today e.g. Ireland

\[
\text{SNSP [%]} = \frac{\text{System Non-Synchronous Penetration}}{\text{System Non-Synchronous Penetration}} = \frac{\text{Wind} + \text{Imports}}{\text{Demand} + \text{Exports}}
\]

Sources: EirGrid; CSIR analysis
The demand for system inertia is driven by two assumptions: the maximum allowable RoCoF & the largest assumed system contingency

Key assumptions:

- Maximum allowed RoCoF: 1 Hz/s
- Largest contingency ($P_{\text{cont}}$): 2 400 MW
- Kinetic energy lost in contingency event $E_{\text{kin(cont.)}}$: 5 000 MWs

\[ E_{\text{kin.(min)}} = P_{\text{cont}} \cdot \frac{f_n}{2(\text{RoCoF})} + E_{\text{kin}(\text{cont.})} \]

Term “inertia” is used a bit loosely to describe the amount of kinetic energy that is stored in the rotating masses of all synchronously connected power generators (and loads to be precise)

- $f_n$ = System frequency = 50 Hz

65 000 MWs of system inertia are required at any given point in time in order for RoCoF to stay below 1 Hz/s in the first 500 ms after the largest system contingency occurred

Sources: P. Kundur, Power System Stability and Control, 1994
As a starting point – we have assessed system inertia on an hourly basis via UCED in PLEXOS and some high level assumptions

Depending on what mix of power stations is operational at any given point in time, the total actual system inertia will be different.

For example, if 20 GW of old coal, 10 GW of new coal and 2 GW of nuclear are online, system inertia is:

\[ \approx 20 \text{ GW} \times 4 \text{ MWs/MVA} + 10 \text{ GW} \times 2 \text{ MWs/MVA} + 2 \text{ GW} \times 5 \text{ MWs/MVA} \]
\[ = 110 000 \text{ MWs} \]

If wind, PV and 5 GW of CCGTs are online, system inertia is only 47 000 MWs.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Inertia constant [MWs/MVA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (old)</td>
<td>4.0</td>
</tr>
<tr>
<td>Coal (new)</td>
<td>2.0</td>
</tr>
<tr>
<td>OCGT</td>
<td>6.0</td>
</tr>
<tr>
<td>CCGT</td>
<td>9.0</td>
</tr>
<tr>
<td>Biomass</td>
<td>2.0</td>
</tr>
<tr>
<td>Hydro/PS</td>
<td>3.0</td>
</tr>
<tr>
<td>Imports</td>
<td>0.0</td>
</tr>
<tr>
<td>Nuclear</td>
<td>5.0(^1)</td>
</tr>
<tr>
<td>Wind</td>
<td>0.0</td>
</tr>
<tr>
<td>PV</td>
<td>0.0</td>
</tr>
<tr>
<td>CSP</td>
<td>2.5</td>
</tr>
<tr>
<td>DR</td>
<td>0.0</td>
</tr>
<tr>
<td>ICE</td>
<td>2.0</td>
</tr>
</tbody>
</table>

\(^1\) Assumed in two cases:
1) At least half of the nuclear fleet is integrated via HVDC i.e. \( H = 2.5 \text{ MWs/MVA} \);
2) All of the nuclear fleet is integrated via HVDC i.e. \( H = 0 \text{ MW.s/MVA} \)

Sources: P. Kundur, Power System Stability and Control, 1994
The system would likely require additional system inertia by 2030 in the Carbon Budget and Least-cost scenarios.
The system would likely require additional system inertia by 2030 in the Carbon Budget and Least-cost scenarios.
Additional system inertia by 2030 would be required if the nuclear fleet is assumed to be integrated via HVDC.

2030
(All nuclear new-build via HVDC)

- Minimum synchronous energy
- Base Case
- Least Cost
- Carbon Budget
Additional inertia will be required by 2050 for all scenarios with the most being from the Least-cost scenario.

2050
(No nuclear new-build via HVDC)
Additional inertia will be required by 2050 for all scenarios with the most being from the Least-cost scenario

2050 (half of nuclear new-build via HVDC)
Similar additional inertia requirements in the Carbon Budget and Least-cost scenario by 2050 if nuclear is integrated fully via HVDC.

2050
(All of nuclear new build via HVDC)
Integrating a nuclear fleet via HVDC reduces intrinsic system inertia in a similar manner to that of solar PV and wind

<table>
<thead>
<tr>
<th></th>
<th>2030 Base Case</th>
<th>2030 Carbon Budget</th>
<th>2030 Least cost</th>
<th>2050 Base Case</th>
<th>2050 Carbon Budget</th>
<th>2050 Least cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum inertia needed [MW.s]</td>
<td>64 800</td>
<td>64 800</td>
<td>64 800</td>
<td>64 800</td>
<td>64 800</td>
<td>64 800</td>
</tr>
<tr>
<td>Minimum inertia (actual) [MW.s]</td>
<td>76 800</td>
<td>50 300</td>
<td>42 300</td>
<td>100 200</td>
<td>93 100</td>
<td>6 800</td>
</tr>
<tr>
<td>Additional inertia needed [MW.s]</td>
<td>-</td>
<td>14 500</td>
<td>22 500</td>
<td>-</td>
<td>-</td>
<td>58 000</td>
</tr>
<tr>
<td>Number of hours [hrs]</td>
<td>-</td>
<td>210</td>
<td>440</td>
<td>-</td>
<td>-</td>
<td>4 320</td>
</tr>
</tbody>
</table>

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<tr>
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</tr>
<tr>
<td>Minimum inertia (actual) [MW.s]</td>
<td>71 300</td>
<td>33 900</td>
<td>42 300</td>
<td>62 100</td>
<td>55 400</td>
<td>6 800</td>
</tr>
<tr>
<td>Additional inertia needed [MW.s]</td>
<td>-</td>
<td>30 900</td>
<td>22 500</td>
<td>2 700</td>
<td>9 400</td>
<td>58 000</td>
</tr>
<tr>
<td>Number of hours [hrs]</td>
<td>-</td>
<td>660</td>
<td>440</td>
<td>200</td>
<td>250</td>
<td>4 320</td>
</tr>
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</tr>
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<td>Minimum inertia (actual) [MW.s]</td>
<td>66 200</td>
<td>17 100</td>
<td>42 300</td>
<td>20 600</td>
<td>10 700</td>
<td>6 800</td>
</tr>
<tr>
<td>Additional inertia needed [MW.s]</td>
<td>-</td>
<td>47 700</td>
<td>22 500</td>
<td>44 200</td>
<td>54 100</td>
<td>58 000</td>
</tr>
<tr>
<td>Number of hours [hrs]</td>
<td>-</td>
<td>2 140</td>
<td>440</td>
<td>2 680</td>
<td>3 240</td>
<td>4 320</td>
</tr>
</tbody>
</table>
There are a number of options to increase system inertia

In principle, there are two ways to deal with lower system inertia
1) Conservative: Introduce additional intrinsic inertia (synchronous machines) to reduce RoCoF
2) Progressive: Introduce reactive measures and control algorithms to deal with an increased RoCoF

Here we will only outline the technical solutions in the conservative approach to increase intrinsic system inertia / reduce RoCoF (Option 1 above). These technical solutions are:

- Synchronous compensators (new purpose built devices and retro-fitting of decommissioned generators, with/without flywheels)
- Rotating stabiliser devices (typically a multi-pole device incorporating a flywheel, which can be based on a Doubly-Fed Induction Generator or a synchronous machine)
- Wind turbines with doubly-fed induction generator
- Pumped hydro (assuming synchronous machines are deployed)
- “Parking” of conventional generators i.e. operating generation plant at low MW output levels but with reduced/no capability to provide system services (e.g. operating reserve) at the lower output levels
- Reduction in the minimum MW generation thresholds of conventional generation while still leaving the plant with the capability to fully provide system services
- New flexible thermal power plant with high inertia constant

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### Additional costs for rotating stabilisers to ensure sufficient system inertia by 2050 – <1% in all scenarios

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<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Carbon Budget</th>
<th>Least cost</th>
<th>Base Case</th>
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<td>22 500</td>
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<td>440</td>
<td>-</td>
<td>200</td>
<td>250</td>
<td>-</td>
<td>4 320</td>
<td>22 500</td>
</tr>
<tr>
<td>Rotating stabilisers needed [MW]</td>
<td>-</td>
<td>770</td>
<td>560</td>
<td>-</td>
<td>70</td>
<td>240</td>
<td>-</td>
<td>1 450</td>
<td>-</td>
</tr>
<tr>
<td>Annual cost for rotating stabilisers [bR/yr]</td>
<td>-</td>
<td>2.4</td>
<td>1.7</td>
<td>-</td>
<td>0.2</td>
<td>0.7</td>
<td>-</td>
<td>4.5</td>
<td>-</td>
</tr>
<tr>
<td>(% of system costs) [%]</td>
<td>0.0%</td>
<td>0.6%</td>
<td>0.5%</td>
<td>0.0%</td>
<td>0.1%</td>
<td>0.7%</td>
<td>0.0%</td>
<td>0.3%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

Rotating stabiliser properties: CAPEX = 20 000 R/kW; FOM = 3% of CAPEX; all year operation; cost of electricity = 1 R/kWh; $H = 40$ MW.s/MVA
Thank you

Note: “Thank you” in all official languages of the Republic of South Africa
Wind:
Lifetime annual cash flow and annual energy production

Cash flow (cost) in $\text{b}/\text{GW}/\text{a}

Assumed capacity factor $\rightarrow 36$

Energy production in TWh/GW/a

Time in years

Time in years
Solar PV:
Lifetime annual cash flow and annual energy production

Cash flow (cost) in bR/GW/a

Energy production in TWh/GW/a

Assumed capacity factor → 25%
Nuclear:
Lifetime annual cash flow and annual energy production

Cash flow (cost)
in bR/GW/a

Time in years

Energy production
in TWh/GW/a

Time in years

Assumed capacity factor → 90%
Coal:
Lifetime annual cash flow and annual energy production

Assumed capacity factor → 82%
Gas (CCGT):
Lifetime annual cash flow and annual energy production

**Assumed capacity factor → 36%**

**Cash flow (cost)**
in bR/GW/a

<table>
<thead>
<tr>
<th>Time in years</th>
<th>Cash flow (cost)</th>
<th>CAPEX</th>
<th>Fixed O&amp;M</th>
<th>Variable O&amp;M</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.6</td>
<td>0.9</td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.5</td>
<td>0.9</td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.7</td>
<td>0.9</td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Energy production**
in TWh/GW/a

<table>
<thead>
<tr>
<th>Time in years</th>
<th>Energy production</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.2</td>
</tr>
<tr>
<td>1</td>
<td>3.2</td>
</tr>
<tr>
<td>2</td>
<td>3.2</td>
</tr>
<tr>
<td>3</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>3.2</td>
</tr>
<tr>
<td>5</td>
<td>3.2</td>
</tr>
<tr>
<td>6</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Submitted to DoE on 31 March 2017
Areas already applied for Environmental Impact Assessments have more capacity than what the current Least Cost case requires by 2050.

All EIAs (status early 2016)

Wind: 90 GW
Solar PV: 330 GW