Least-cost electricity mix for South Africa by 2040
Scenarios for South Africa’s future electricity mix

CSIR Energy Centre

Cape Town, 3 November 2016
The Integrated Resource Plan (IRP) is the expansion plan for the South African power system.

In its most recent version, the IRP 2010 plans a doubling of power-generation capacity from 2010 to 2030.

Since the date of its release in early 2011, two main assumptions have changed:

- The demand forecast is now significantly lower than in IRP 2010.
- The costs of solar PV and wind are significantly lower than predicted in IRP 2010.

The CSIR has therefore conducted a study to re-optimise the South African power mix until 2040.

Two scenarios were defined to quantify two different ways of expanding the South African power system:

- “Re-Optimised” – least-cost re-optimisation of the demand/supply gap that widens from 2020-2040.

An hourly expansion and dispatch model (incl. unit commitment) using PLEXOS was run for both scenarios to test for adequacy and for economic feasibility.
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IRP 2010: expansion plan for South Africa’s power system until 2030

Installed capacity and electricity supplied from 2010 to 2030 as planned in the IRP 2010

**Business-as-Usual**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total installed net capacity in GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>35.9</td>
</tr>
<tr>
<td>2015</td>
<td>42.2</td>
</tr>
<tr>
<td>2020</td>
<td>85.7</td>
</tr>
<tr>
<td>2025</td>
<td>9.2</td>
</tr>
<tr>
<td>2030</td>
<td>41.1</td>
</tr>
</tbody>
</table>

**Re-Optimised**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total installed net capacity in GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>8.4</td>
</tr>
<tr>
<td>2015</td>
<td>9.2</td>
</tr>
<tr>
<td>2020</td>
<td>9.6</td>
</tr>
<tr>
<td>2025</td>
<td>1.8</td>
</tr>
<tr>
<td>2030</td>
<td>2.4</td>
</tr>
</tbody>
</table>

**Electricity supplied in TWh per year**

<table>
<thead>
<tr>
<th>Year</th>
<th>Electricity supplied in TWh per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>5%</td>
</tr>
<tr>
<td>2015</td>
<td>10%</td>
</tr>
<tr>
<td>2020</td>
<td>30%</td>
</tr>
<tr>
<td>2025</td>
<td>40%</td>
</tr>
<tr>
<td>2030</td>
<td>50%</td>
</tr>
</tbody>
</table>

**Renewables**

- Solar PV: 5% (12 TWh/yr)
- Wind: 14% (62 TWh/yr)
- Nuclear: 3% (90 TWh/yr)
- Coal: 24% (436 TWh/yr)
- Other: 15% (275 TWh/yr)

**Carbon free**

- 10% (25 TWh/yr)
- 34% (149 TWh/yr)

**CO2 emissions [Mt/yr]**

- 2010: 237
- 2030: 275

Note: Renewables include solar PV, CSP, wind, biomass, biogas, landfill and hydro (includes imports); CO2 emission intensity moves from 912 kgCO2/MWh (2010) to 600 kgCO2/MWh (2030)

Sources: DoE IRP 2010-2030; CSIR Energy Centre analysis
Link between planning and real world needs to be established
In-principle process of IRP planning and implementation

**Planning / simulation world**

- **Inputs**
  - Demand forecast
  - Technology costs assumptions
  - CO2 limits
  - Etc.

**IRP model**
(least-cost optimisation)

**Output**
- Capacity expansion plan

**Actuals / real world**

- **Inputs**
  - Ministerial Determinations based on capacity expansion plan

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

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

Currently, no feedback loop from procurement results to IRP planning assumptions institutionalised

Sources: CSIR Energy Centre analysis
Actual solar PV tariffs now well below cost assumptions of IRP 2010
First four bid windows’ results (solar PV) of Department of Energy’s REIPPPP

<table>
<thead>
<tr>
<th>Year</th>
<th>Assumptions: IRP2010 - high</th>
<th>Assumptions: IRP2010 - low</th>
<th>Actuals: REIPPPP (BW1-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>3.65</td>
<td>2.18</td>
<td>3.65</td>
</tr>
<tr>
<td>2012</td>
<td>2.18</td>
<td>1.17</td>
<td>2.18</td>
</tr>
<tr>
<td>2014</td>
<td>1.17</td>
<td>0.91</td>
<td>1.17</td>
</tr>
<tr>
<td>2016</td>
<td>0.91</td>
<td>0.62</td>
<td>0.91</td>
</tr>
</tbody>
</table>

∑ = 2.8 GW

Actual wind tariffs equally well below cost assumptions of IRP 2010
First four bid windows’ results (wind) of Department of Energy’s REIPPPP

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

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
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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 2040

Notes: MTSAO demand forecasts are extrapolated from 2025 to 2040 using CAGR; IRP 2016 under development is using High Growth Low Intensity (CSIR) demand forecast as base case.

1. Peak demand = 53.2 GW    2. Peak demand = 68.7 GW    Sources: DoE (IRP 2010); DoE (IRP 2013); Eskom MTSAO 2016-2021; StatsSA; World Bank; CSIR analysis

All power plants considered for “existing fleet” that are either:
1) Existing in 2016
2) Under construction
3) Procured (preferred bidder)
Two scenarios defined to fill the supply/demand gap until 2040
Forecasted supply and demand balance for the South African electricity system from 2016 to 2040

Scenario: "Business-as-Usual"
• Generally aligned with IRP 2010, but demand shifted
• Nuclear as per briefing to Portfolio Committee on Energy (11 October 2016)
• New coal, nuclear, some RE
• New capacities fixed as per IRP 2010 (no optimisation)

Scenario: "Re-Optimised"
• Coal, nuclear, gas, RE are all available as supply options
• Supply candidates chosen by least cost optimisation to meet energy and capacity requirement

Notes: MTSAO demand forecasts are extrapolated from 2025 to 2040 using CAGR; IRP 2016 under development is using High Growth Low Intensity (CSIR) demand forecast as base case.
1. Peak demand = 53.2 GW  2. Peak demand = 68.7 GW  Sources: DoE (IRP 2010); DoE (IRP 2013); Eskom MTSAO 2016-2021; StatsSA; World Bank; CSIR analysis
### Key assumptions: pessimistic regarding solar PV and wind cost, optimistic regarding nuclear cost

#### Technology Costing Logic Compared to IRP 2010

<table>
<thead>
<tr>
<th>Technology</th>
<th>Costing Logic</th>
<th>Compared to IRP 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV</td>
<td>Same as IRP 2010 by 2030</td>
<td>Slightly lower until 2030</td>
</tr>
<tr>
<td>Wind</td>
<td>Bid Window 4 Expedited tariff kept constant until 2040</td>
<td>Lower</td>
</tr>
<tr>
<td>CSP</td>
<td>Same as IRP 2013</td>
<td>Slightly higher</td>
</tr>
<tr>
<td>Coal</td>
<td>Coal IPP</td>
<td>Higher</td>
</tr>
<tr>
<td>Nuclear</td>
<td>as per IRP with Rosatom low-estimate CAPEX</td>
<td>Similar</td>
</tr>
<tr>
<td>Gas</td>
<td>as per IRP with fuel updates</td>
<td>Higher</td>
</tr>
</tbody>
</table>

All other assumptions and methodology fully aligned with IRP 2010, for example:

- Discount rate of 8% (real)
- PLEXOS software package used for long-term optimisation & production cost modelling
- Decommissioning schedule of existing Eskom fleet
- Demand forecast using MTSAO 2016-2021 (extrapolated until 2040), reaches the IRP 2010 assumed 2030 level just before 2040
### Key input cost assumptions for new supply technologies

#### Lifetime cost per energy unit

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Actual new-build tariffs</th>
<th>Assumptions based new-build cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV</td>
<td>0.62 R/kWh</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>0.62 R/kWh</td>
<td></td>
</tr>
<tr>
<td>Coal (IPP)</td>
<td>1.03 R/kWh</td>
<td>1.05-1.16 R/kWh</td>
</tr>
<tr>
<td>Coal (Eskom)</td>
<td>1.05-1.16 R/kWh</td>
<td>1.17 R/kWh</td>
</tr>
<tr>
<td>Nuclear</td>
<td>1.17 R/kWh</td>
<td>1.24 R/kWh</td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>1.24 R/kWh</td>
<td>1.51 R/kWh</td>
</tr>
<tr>
<td>Mid-merit Coal</td>
<td>1.51 R/kWh</td>
<td>2.40 R/kWh</td>
</tr>
<tr>
<td>Gas (OCGT)</td>
<td>2.40 R/kWh</td>
<td>3.10 R/kWh</td>
</tr>
<tr>
<td>Diesel (OCGT)</td>
<td>3.10 R/kWh</td>
<td></td>
</tr>
</tbody>
</table>

### Typical capacity factor

- Solar PV: 82%
- Wind: 92%
- Coal (IPP): 50%
- Coal (Eskom): 50%
- Nuclear: 10%
- Gas (CCGT): 10%
- Mid-merit Coal: 10%
- Gas (OCGT): 10%
- Diesel (OCGT): 10%

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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 conventional 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; 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.
Future cost assumptions for solar PV aligned with IRP 2010

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

- **Assumptions:** IRP2010 - low
- **Assumptions:** IRP2010 - high
- **Assumptions for this study**
- **Actuals:** REIPPPP (BW1-4)


Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis

Σ = 2.8 GW
Future cost assumptions for wind aligned with results of Bid Window 4

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

Assumptions for this study

Assumptions: IRP2010

Actuals: REIPPPP (BW1-4)

Σ = 4.0 GW


Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE IPP Office; CSIR analysis
CO2 emissions constrained by RSA’s Peak-Plateau-Decline objective

PPD that constrains CO2 emission from electricity sector

CO2 emissions (electricity sector) [Mt/yr]

Sources: DoE (IRP 2010-2030 Update); StatsSA; CSIR own analysis
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Least-cost: 70% RE energy in South African electricity sector by 2040
Comparison of energy supply for Business-as-Usual and a Re-Optimised scenario

**1 Business-as-Usual**

<table>
<thead>
<tr>
<th>Year</th>
<th>Electricity supplied in TWh per year</th>
<th>Carbon Dioxide (Mt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>217</td>
<td>217</td>
</tr>
<tr>
<td>2020</td>
<td>290</td>
<td>268</td>
</tr>
<tr>
<td>2025</td>
<td>350</td>
<td>295</td>
</tr>
<tr>
<td>2030</td>
<td>404</td>
<td>323</td>
</tr>
<tr>
<td>2035</td>
<td>447</td>
<td>357</td>
</tr>
<tr>
<td>2040</td>
<td>472</td>
<td>390</td>
</tr>
</tbody>
</table>

**2 Re-Optimised**

<table>
<thead>
<tr>
<th>Year</th>
<th>Electricity supplied in TWh per year</th>
<th>Carbon Dioxide (Mt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>217</td>
<td>217</td>
</tr>
<tr>
<td>2020</td>
<td>250</td>
<td>266</td>
</tr>
<tr>
<td>2025</td>
<td>300</td>
<td>295</td>
</tr>
<tr>
<td>2030</td>
<td>348</td>
<td>325</td>
</tr>
<tr>
<td>2035</td>
<td>390</td>
<td>355</td>
</tr>
<tr>
<td>2040</td>
<td>474</td>
<td>390</td>
</tr>
</tbody>
</table>

**Sources:** CSIR analysis
Significant solar PV and wind capacities rolled out until 2040

Comparison of generation capacity for Business-as-Usual and a Re-Optimised path to 2040

1. Business-as-Usual

- Total installed net capacity in GW

2. Re-Optimised

- Total installed net capacity in GW

Sources: CSIR analysis
1 Business-as-Usual: Coal and nuclear dominate the 2040 energy mix

Demand and Supply in GW

Exemplary Week under Business-as-Usual in 2040

Sources: CSIR analysis
Re-Optimised: Wind and solar PV dominate the 2040 energy mix

Exemplary Week under Re-Optimised in 2040

Sources: CSIR analysis
Re-Optimised scenario creates a steady, significant & increasing market
Roadmap of investment for wind and solar PV to 2040

1 Business-as-Usual

- **2020-2030**
  - Wind: 0.4 GW/yr
  - Solar PV: 0.4 GW/yr

2 Re-Optimised

- **2020-2030**
  - Wind: 2.8 GW/yr
  - Solar PV: 1.5 GW/yr

- **2030-2040**
  - Wind: 4.5 GW/yr
  - Solar PV: 2.5 GW/yr

Sources: CSIR analysis

BW1 → BW 4 (Expedited)
Re-Optimised R87 billion/year cheaper by 2040 (without cost of CO2)

Total cost of power generation in bR/yr (constant 2016)

- Business-as-Usual
- Re-optimised
- Delta (BAU - Re-optimised)

Total Present Value of Delta = R330 billion in 2016 Rand
Business-as-Usual incurs large cost from building new coal and nuclear.

Comparison of total electricity system costs average electricity tariff of BAU and Re-Optimised mix.

1. Business-as-Usual

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

- 314 (w/o CO2)
- 488 (w/o CO2)
- 517 (w/ CO2)

2. Re-Optimised

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

- 292 (w/o CO2)
- 401 (w/o CO2)
- 412 (w/ CO2)

Sources: CSIR
Sensitivity on cost difference: Even if RE were 50% more expensive than assumed, Re-Optimised is still cheaper than Business-as-Usual.

Sources: CSIR analysis
Unit cost of power generation: Re-Optimised case is almost 20 cents/kWh cheaper than BAU by 2040
Factoring in cost of CO2 emissions: Re-Optimised case is 23 cents/kWh cheaper than BAU by 2040.
Re-Optimised: CO2 emissions and water use significantly lower

Comparison of CO2 emissions and water use for BAU and a Re-Optimised scenario to 2040

Electricity sector CO2 emissions in MtCO2/yr

-150 Mt/yr (-60%)

Electricity sector water use in billion litres/yr

-40 billion litres/yr (-60%)

Sources: CSIR analysis
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South Africa can get 70% renewable energy share by 2040 at least cost

Solar PV, wind and natural gas is the cheapest new-build mix for the South African power system

It is the cost-optimal expansion to aim for a 70% renewable energy share by 2040

This “Re-Optimised” mix is almost R90 billion per year cheaper by 2040 than the Business-as-Usual scenario (without factoring in cost of CO2 emissions – difference is > R100 billion per year with CO2)

The Re-Optimised mix will furthermore reduce South Africa’s CO2 emissions by 60% compared to BAU

Avoiding CO2 emissions and least-cost is not a trade-off anymore – South Africa can de-carbonise its electricity sector at negative carbon-avoidance cost

Building out the required capacities until 2040 will provide a steady anchor offtake for a South African solar PV and wind manufacturing industry
Thank you

Ha Khensa

Siyathokoza

Re a leboha

Enkosi

Ro livhuha

Siyabonga

Dankie

Re a leboga