Renewable Resources in SA
Smart Camp101 – A SAIEE Event

Crescent Mushwana, CSIR Energy Centre

Eskom Academy of Learning, Midrand, 22 February 2016
Crescent Mushwana  
Principal Engineer : Energy-system planning and operation

Professional Experience

• March 2015 – today: Principal Engineer: Energy-system planning and integration. Responsible for a team doing energy planning, grid planning, and system modelling & optimisation

• 2008– Feb 2015: Chief Engineer, Eskom Grid Planning (Strategic). Responsible for research, strategic planning studies, specialised studies/projects and planning database management

• 2005– 2008: Wires Executive, Eskom Key Sales and Customer Service. Responsible for technical input into contracts; technical investigations and audits; part of Distribution Code Industry Expert Team

• 2002 – 2004: Senior planner, Eskom Transmission System Planning. Responsible for power system planning studies (steady-state and dynamic); Business case development and technical/financial/ economic/environmental evaluation of grid projects.

Education

• M Eng. (Electrical), 2012, University of the Witwatersrand

• BSc Hons (Applied Science), 2004, University of Pretoria

• B Tech (Elec. Eng.), 1999, University of Johannesburg
Agenda

Resources for electricity generation

Renewables
- Renewables; what are they and myths around them
- International context
- Renewables in South Africa

Future South African economy with high shares of renewables
Conventional generation – a coal plant

Fuel source: Coal

Process: steam generation & emissions

Conversion: Mech. to Elec. power

Sources: Wikipedia; CSIR Analysis
## Resources for electricity generation

<table>
<thead>
<tr>
<th>Resource</th>
<th>Technology</th>
<th>Environmental impact</th>
<th>Infinite resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Thermal</td>
<td>Very High</td>
<td>No</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Thermal</td>
<td>Medium</td>
<td>No</td>
</tr>
<tr>
<td>Gas</td>
<td>Thermal</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Biomass</td>
<td>Thermal</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Wind</td>
<td>Kinetic - wind</td>
<td>Negligible</td>
<td>Yes</td>
</tr>
<tr>
<td>Solar Thermal (CSP)</td>
<td>Thermal</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Solar</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Hydro</td>
<td>Kinetic - water</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Geothermal</td>
<td>Thermal</td>
<td>Low</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Resources for electricity generation

Renewables

- Renewables; what are they and myths around them
- International context
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Future South African economy with renewables
What is Renewable Energy?

Energy derived from natural resources that are replenished at a faster rate than they are consumed, and thus cannot be depleted. Solar, wind, geothermal, hydro, and some forms of biomass are common sources of renewable energy.
Myths about renewable energy

1. **Renewables are too expensive**
   - Unsubsidised renewable (wind and PV) is now cheaper than new build convectional plants in South Africa (REBID Window 4). The same is true for other countries around the world; European Countries, Australia, India, etc.

2. **Renewable energy is a nice to have but not big enough**
   - International Energy Agency: Any country can reach high shares (approx. 60-80%) of wind, solar power cost-effectively.
   - Germany, Europe's biggest economy, already gets 35% of its electricity from renewables, and is aiming for 80% by 2050.
   - Renewables supplied 42% of mainland Spain’s electricity in 2013.
   - By 2050 almost all of global energy needs can be met with renewables.

3. **Renewable energy can’t supply electricity 24/7**
   - When a mix of sources spread over a wide area: solar and wind power, biogas, biomass and geothermal sources, the variability of renewables is greatly reduces and renewables can supply “base load”.
   - With high shares of renewables, smart grids and virtual power plants will be key of a reliable supply.

4. **The electricity grid can’t handle renewable energy**
   - The electricity grid must be designed for the purpose of handling high shares of renewables; smart grid, prosumers. Even with the existing grids built for centralised conventional plants, up to 30% shares of renewables can be accommodated without major changes.

5. **Renewable energy is bad for the environment**
   - Environmental Impact Assessments ensure that impact (birds & bats; noise; land use); land on wind farms is still available for farming and grazing.

Sources: GreenCape; CSIR Analysis
A future energy system with high share of renewables

1. Storage includes battery, Hydrogen, and EV’s Charging and discharging

2. Central Power plants could be supplied by fossil-fuels or synthetic fuels produced by renewable energy

3. Transportation driven by synthetic fuels or hydrogen will be a key part of the integrated energy system

Sources: GreenCape; CSIR Analysis
Agenda

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Renewables
- Renewables; what are they and myths around them
- **International context**
- Renewables in South Africa

Future South African economy with renewables
In 2015, 120 GW of wind and solar PV newly installed globally

<table>
<thead>
<tr>
<th>Year</th>
<th>Wind</th>
<th>Solar PV</th>
<th>Total (approx. 45 GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>57</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>40</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>38</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>31</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>45</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>41</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>39</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>39</td>
<td>7</td>
<td></td>
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<tr>
<td>2007</td>
<td>27</td>
<td>17</td>
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<td>2006</td>
<td>20</td>
<td>7</td>
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<td>2005</td>
<td>15</td>
<td>2</td>
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<td>2004</td>
<td>12</td>
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<td>2003</td>
<td>8</td>
<td>1</td>
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<td>2002</td>
<td>7</td>
<td>0</td>
<td></td>
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<tr>
<td>2001</td>
<td>8</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>4</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Subsidy-driven growth triggered significant technology improvements, mass manufacturing and subsequent cost reductions.

→ Consequence

Renewables are now cost competitive to alternative new-build options in South Africa.

This is all very new: Almost 90% of the globally existing PV capacity was installed during the last five years alone!

Sources: GWEC; EPIA; BNEF; CSIR analysis
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

Operational capacities in GW end of 2015

- **Wind**: 432 GW
- **Solar PV**: 233 GW
- **CSP**: 4.8 GW

**Total RSA power system (45 GW)**

**Americas w/o USA/Canada**
- **USA**: 74 GW
- **Canada**: 26 GW
- **Middle East and Africa**: 26 GW

**Europe**
- **Europe**: 142 GW
- **West Europe**: 104 GW

**China**
- **China**: 145 GW
- **India**: 25 GW
- **Rest of Asia Pacific**: 38 GW

**South Africa**
- **South Africa**: 37 GW
- **Middle East and Africa**: 37 GW

South Africa is rapidly picking up with 4.0/2.8/1.1 GW new capacity by 2018-20

Sources: GWEC; EPIA; CSPToday; CSIR analysis
Phasing out of fossil fuels by 2100 – “greeny” or business sense?
G7 announcement on 8 June 2015

G7 leaders agree to phase out fossil fuel use by end of century

German chancellor Angela Merkel announces commitment to ‘decarbonise global economy’ and end extreme poverty and hunger.

The G7 leading industrial nations have agreed to cut greenhouse gases by phasing out the use of fossil fuels by the end of the century, the German chancellor, Angela Merkel, has announced, in a move hailed as historic by some environmental campaigners.

On the final day of talks in a Bavarian castle, Merkel said the leaders had committed themselves to the need to “decarbonise the global economy in the
France will phase out “10 Koebergs” by 2025 – replaced by renewables

France has by far the highest nuclear penetration of any country in the world, with 75% of its electricity coming from nuclear

France has passed a bill on 23 July 2015: mandates a reduction of the share of nuclear in the electricity mix to 50% by 2025

That’s a reduction by 140 TWh/yr of nuclear power generation, which is the same amount of energy produced by 10 Koebergs

This energy will be replaced by renewables

This emphasises again the recently achieved cost-competitiveness of renewables
Agenda

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Future South African economy with renewables

**Installed capacity**

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal</th>
<th>Gas</th>
<th>Peaking</th>
<th>Nuclear</th>
<th>Hydro</th>
<th>Wind</th>
<th>PV</th>
<th>CSP</th>
<th>Total installed net capacity in GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>35.9</td>
<td>1.8</td>
<td>2.4</td>
<td>1.8</td>
<td>41.1</td>
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<td></td>
<td>85.7</td>
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<tr>
<td>2015</td>
<td>42.2</td>
<td>2.1</td>
<td>2.4</td>
<td>2.4</td>
<td>41.1</td>
<td></td>
<td></td>
<td></td>
<td>85.7</td>
</tr>
<tr>
<td>2020</td>
<td>255</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td>436</td>
</tr>
<tr>
<td>2025</td>
<td>300</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td>436</td>
</tr>
<tr>
<td>2030</td>
<td>350</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td>436</td>
</tr>
</tbody>
</table>

**Energy mix**

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal</th>
<th>Gas</th>
<th>Peaking</th>
<th>Nuclear</th>
<th>Hydro</th>
<th>Wind</th>
<th>PV</th>
<th>CSP</th>
<th>Electricity supplied (TWh per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>255</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td>347</td>
</tr>
<tr>
<td>2015</td>
<td>300</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td>347</td>
</tr>
<tr>
<td>2020</td>
<td>350</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td>347</td>
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<tr>
<td>2025</td>
<td>400</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td></td>
<td></td>
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<td>400</td>
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<tr>
<td>2030</td>
<td>450</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td>450</td>
</tr>
</tbody>
</table>

Implementation of the IRP is done by Department of Energy through competitive tenders (“REIPPPP” for renewables)

Note: Hydro includes imports from Cahora Bassa
Sources: Integrated Resource Plan 2010, as promulgated in 2011; CSIR Energy Centre analysis
South Africa has almost 2-times the solar resource as Germany, where PV is close to cost competitiveness.

Solar resource in South Africa…

SA’s planned PV capacity by 2030: 8.4 GW target too low

… as compared to Germany

Germany’s status today: almost 40 GW PV installed capacity (roughly one Eskom)
PV makes sense across South Africa: CSIR’s first 560 kW PV system in Pretoria can compete with 75 000 kW PV systems in the Northern Cape

Four bid windows’ results of Department of Energy’s IPP Procurement Programme and CSIR’s first own PV

Notes: For CSP Bid Window 3, the weighted average of base and peak tariff is indicated, assuming 50% annual load factor
Consequence of renewables’ cost reduction: PV and wind are cost-efficient fuel-savers for CCGTs already today

Lifetime cost per energy unit

<table>
<thead>
<tr>
<th>R/kWh (May-2015-R)</th>
<th>Renewables</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuals: Cost as per Bid Windows 3 &amp; 4</td>
<td>3.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Assumptions: Cost as per IRP with fuel updates</td>
<td>2.5</td>
<td>0.7</td>
</tr>
<tr>
<td>PV</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>Wind</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>CSP</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Baseload Coal</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Nuclear</td>
<td>1.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Mid-merit Coal</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Gas (OCGT)</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Diesel (OCGT)</td>
<td>0.8</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Fuel cost @ 110 R/GJ

Assumed load factor:
- PV: 85%
- Wind: 92%
- CSP: 50%
- Baseload Coal: 50%
- Nuclear: 10%
- Gas (CCGT): 10%
- Mid-merit Coal: 10%
- Gas (OCGT): 10%
- Diesel (OCGT): 10%

Note: Changing full-load hours for conventionalists drastically changes the fixed cost components per kWh (lower full-load hours → higher capital costs and fixed O&M costs per MWh);
Assumptions: average efficiency for CCGT = 50%, OCGT = 35%; coal = 37%; nuclear = 33%; IRP cost from Jan 2012 escalated with CPI to May 2015; assumed EPC CAPEX inflated by 10% to convert EPC/LCOE into tariff; CSP: 50% annual load factor and full utilisation of the five peak-tariff hours per day assumed to calculate weighted average tariff from base and peak tariff.
Sources: IRP Update; REIPPPP outcomes; StatsSA for CPI; Eskom financial reports on coal/diesel fuel cost; CSIR analysis.
Wind and PV stand for 2% of the electricity sent out from Jan-Jun 2015
Actual energy captured in wholesale market (i.e. without self-consumed energy of embedded plants)

Sources: Eskom; CSIR Energy Centre analysis
From Jan-Jun 2015, OCGTs on average used during the entire daytime
Actual monthly average diurnal courses of the total power supply in RSA for the months from Jan-Jun 2015

Note: Design as per Fraunhofer ISE
Sources: Eskom; CSIR Energy Centre analysis
CSIR-defined methodology:
In any hour, wind/PV can have one of three effects on the existing fleet

A. Saving coal fuel
   - ... output from OCGTs = 0 MWh

B. Saving diesel fuel
   - ... output from OCGTs > 0 MWh

C. Avoiding “unserved energy”
   - ... output from OCGTs > 0 MWh and (reserves of OCGTs and Pumped Hydro) < (wind and PV)

Applicable if ...

Snapshot of supply structure in a particular hour

- Actuals
- What if wind/PV hadn’t been there

Sources: CSIR Energy Centre analysis

Note: Only applicable in the short run to assess effect of wind/PV on the existing fleet. Not applicable to assess additional value of renewables in new-build scenarios.
On an unconstrained day, wind and PV replace mainly coal fuel
Actual South African supply structure for a summer day, 2 January 2015 (Friday)

Sources: Eskom; CSIR Energy Centre analysis
On a constrained day, both wind and PV replace mainly diesel fuel
Actual South African supply structure for an autumn day, 9 April 2015 (Thursday)

Sources: Eskom; CSIR Energy Centre analysis
On 9 January, PV even prevented unserved energy between 8h-11h00
Actual South African supply structure for a summer day, the 9 January 2015 (Friday)
Agenda

Resources for electricity generation

Renewables
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A future South African power system & economy with high shares of renewables
Extreme scenario: Prerequisites for a 40% renewables share by 2030

40% of the South African electricity demand by 2030 (450 TWh/yr as per IRP2010) from renewables
• 25-30 GW of wind turbines (2-3 GW/yr)
• 25-30 GW of solar PV (2-3 GW/yr)
• 4-5 GW of biomass, biogas and CSP (300 MW/yr)

Prerequisites for a cost-efficient integration
• Possibility to connect medium-sized wind and solar PV farms (approx. 1-30 MW per project) to the existing grid
• Possibility to connect embedded generators behind customers’ meters to the grid
• Creation of a procurement platform that allows cost-efficient procurement of energy/capacity, as well as reserves from a wide range of distributed sources through aggregators/Virtual Power Plants

Prerequisites for successful technical integration
• Widespread spatial distribution of wind & PV to reduce short-term volatility of the aggregated profile
• Investments into grid infrastructure to unlock potential for wind integration in windy areas with no grid
• Flexibilisation of the existing conventional fleet to cater for increasing fluctuations of the residual load
• 4-5 GW of flexible power generators from the biomass/biogas/CSP fleet in addition to the flexible gas fleet that is already planned in the IRP 2010 are sufficient to provide the required flexibility

Further cost reduction of electricity storage in form of batteries will be an added bonus to provide flexibility, is however not a necessary pre-condition for achieving a 40% renewables share by 2030
Producing carbon-neutral synthetic fuels from cheap renewable power could be a business case for South Africa ...

**Inputs**
- Renewable electricity
- H₂O
- CO₂

**Electrolysis**
- Electrolyser
- H₂

**Fuel Production**
- Reverse Water Gas Shift Reactor
- Syngas (CO, H₂)
- Fischer-Tropsch Reactor
- Synfuel (Diesel, petrol, kerosene)

**Outputs**
- H₂O

Sources: CSIR Energy Centre analysis
... because the main cost driver is cost of renewable electricity input.

South Africa’s competitive advantage: more sun and wind means cheaper renewable electricity.

The PtL concept will be piloted and demonstrated on the CSIR campus in Pretoria, with the goal of commercialisation.

Sources: CSIR Energy Centre analysis
Already at today’s renewable electricity cost in South Africa, PtL is not far from competitiveness with production cost of biofuels.

<table>
<thead>
<tr>
<th>Actual average wind/solar PV tariff in South Africa today</th>
<th>Pure electricity cost of PtL plant fed with South African wind/PV power</th>
<th>Total PtL production cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR-ct/kWh 5.1</td>
<td>EUR-ct/kWh 8.5</td>
<td>EUR-ct/kWh 12.7</td>
</tr>
<tr>
<td>Solar/wind cost</td>
<td>PtL electricity cost component</td>
<td>Total PtL cost</td>
</tr>
</tbody>
</table>

60% efficiency (realistically)

Electricity approx. 2/3 of total cost

Approx. 1 EUR/litre

Sources: CSIR Energy Centre analysis
New principle approach for long-term capacity expansion planning?

**Solar PV and wind are cost competitive to alternative new-build options today**
- Solar PV and wind are the cheapest bulk electricity sources per kWh in South Africa already today
- Costs will further decrease, especially on the side of solar PV

**The technical potential for solar PV and wind can be considered to be “unlimited” in most countries**

**At the same time, solar PV and wind are so called variable renewables**
- Both technologies are however dispatched by the weather and not by the owner or system operator
- They are “must run” technologies in any market setting, because marginal costs are zero

**That has implications for long-term energy planning**
- As a rule of thumb, solar PV and wind should be deployed up to the maximum technically needed level
- The mix of solar PV and wind should be optimised to reduce the “behaviour” of the residual load
- Widespread spatial aggregation of solar PV and wind will reduce fluctuations of the combined profile
- The residual load then needs to be supplied cost optimally by flexible dispatchable power generators (CSP, hydro, natural gas, biogas, biomass, pumped hydro, other storage, etc.)
- Additionally, the flexibilisation of the dispatchable part of the load will help to balance supply and demand instantaneously
- Introduction of Power-to-Liquid is a very flexible demand-side intervention and a “pressure valve” for power systems
Thank you!