Energy modelling in South Africa for electricity generation or in the electricity sector

Presentation at the SAIPPA meeting

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Johannesburg, 20 October 2015

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The Context

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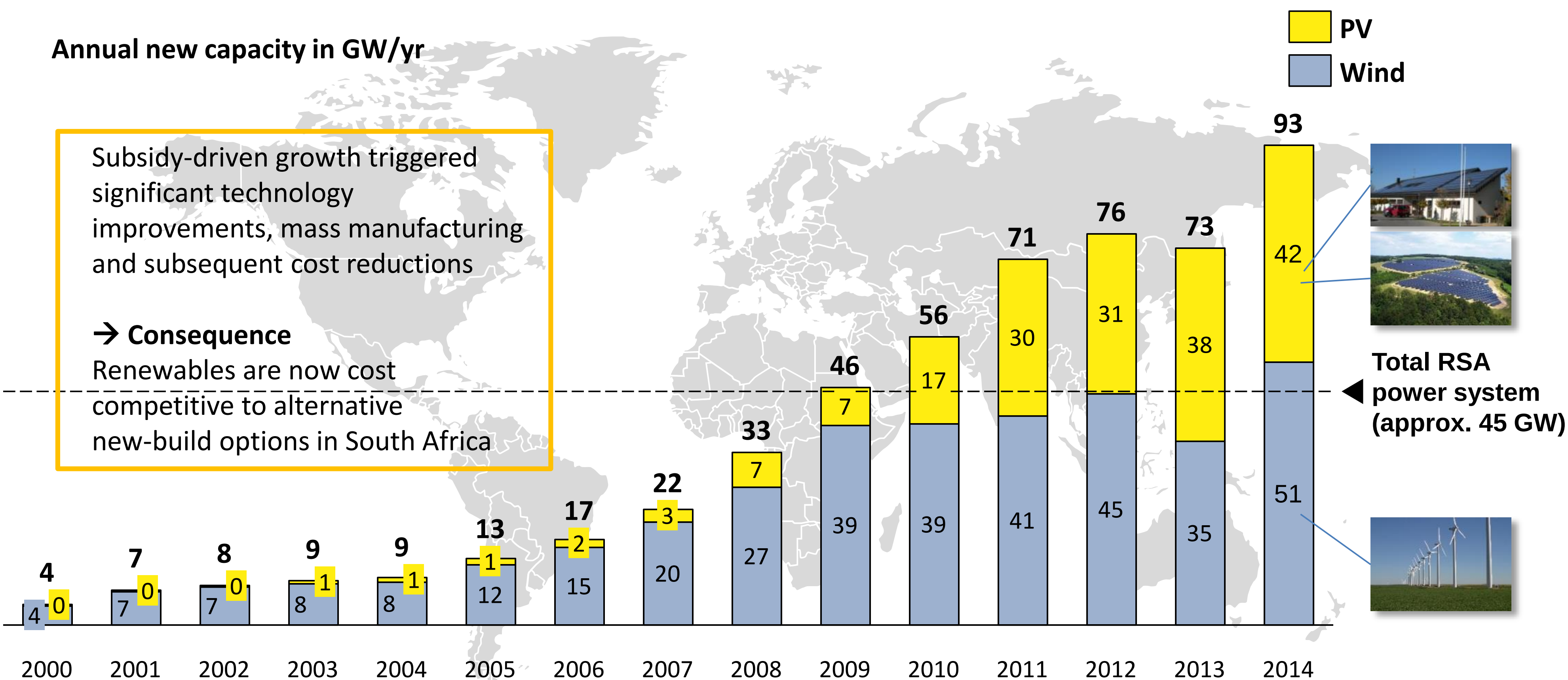
In 2014, 93 GW of wind and PV were newly installed globally



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

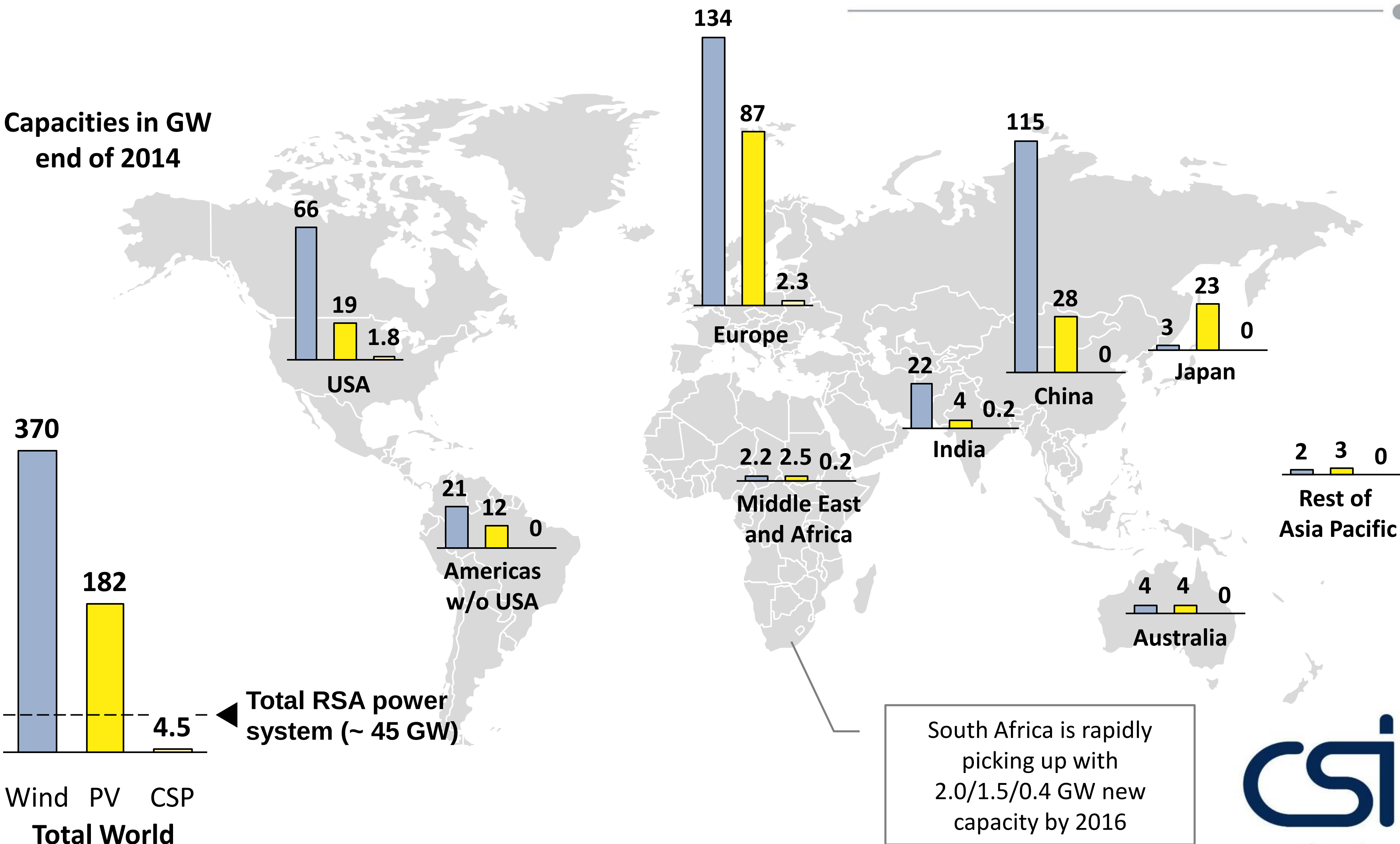
→ **Consequence**
Renewables are now cost competitive to alternative new-build options in South Africa

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

Sources: International Energy Outlook of the EIA; GWEC; EPIA; CSIR analysis

Renewables until today mainly driven by US, Europe and China

Globally installed capacities for three major renewables wind, PV and CSP end of 2014



South Africa is rapidly picking up with 2.0/1.5/0.4 GW new capacity by 2016

Sources: GWEC; EPIA; CSPToday; CSIR analysis

Phasing out of fossil fuels by 2100 – "greeny" or business sense?

G7 announcement on 8 June 2015

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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

G7 leaders, including Angela Merkel (in pink jacket), and invitees line up for the traditional group photo at the end of the summit. Photograph: Sven Hoppe/dpa/Corbis

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

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'You think you're

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France will phase out “10 Koebergs” by 2025 – replaced by renewables

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French energy transition bill adopted

23 July 2015

France's National Assembly yesterday gave final approval of the country's energy transition bill. Under the legislation, France's reliance on nuclear energy will be reduced to 50% of power generation by 2025.

Energy minister Royal speaks to the National Assembly following adoption of the energy transition bill (Image: French energy ministry)

French president Francois Hollande's 2012 election pledge was to limit nuclear's share of French generation at 50% by 2025, and the closure of France's oldest nuclear power plant, Fessenheim, by the end of 2016. In June last year, following a national energy debate, his government announced that the country's nuclear generating capacity would be capped at the current level of 63.2 GWe. It will also be limited to 50% of France's total output by 2025. Nuclear currently accounts for almost 75% of the country's electricity production, making closures of power reactors appear inevitable.

Debate about France's Energy Transition for Green Growth bill began in the lower house of parliament - the National Assembly - last October, with deputies agreeing on the overall objectives of the bill. These include: a 40% reduction in greenhouse gas emissions by 2030 and a 75% reduction by 2050, compared with 1990 levels; halving overall energy consumption by 2050 compared with 2012; increasing renewable energy's share of final energy consumption to 32%; and cutting the share of nuclear in electricity generation to 50% by 2025.

Yesterday, following 150 hours of parliamentary debate - during which 5034 amendments were discussed in open session and 970 amendments were passed - the National Assembly adopted the

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http://www.world-nuclear-news.org/NP-French-energy-transition-bill-adopted-2307155.html

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 <u>reduction</u> 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

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Agenda

IRP Assumptions and Actuals

Cost-competitiveness of Renewables

The Baseload Argument

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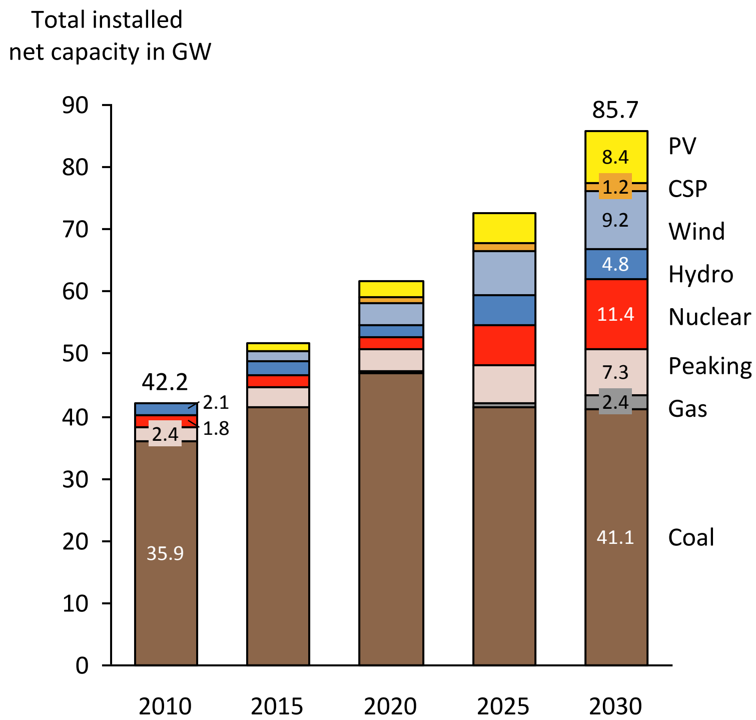
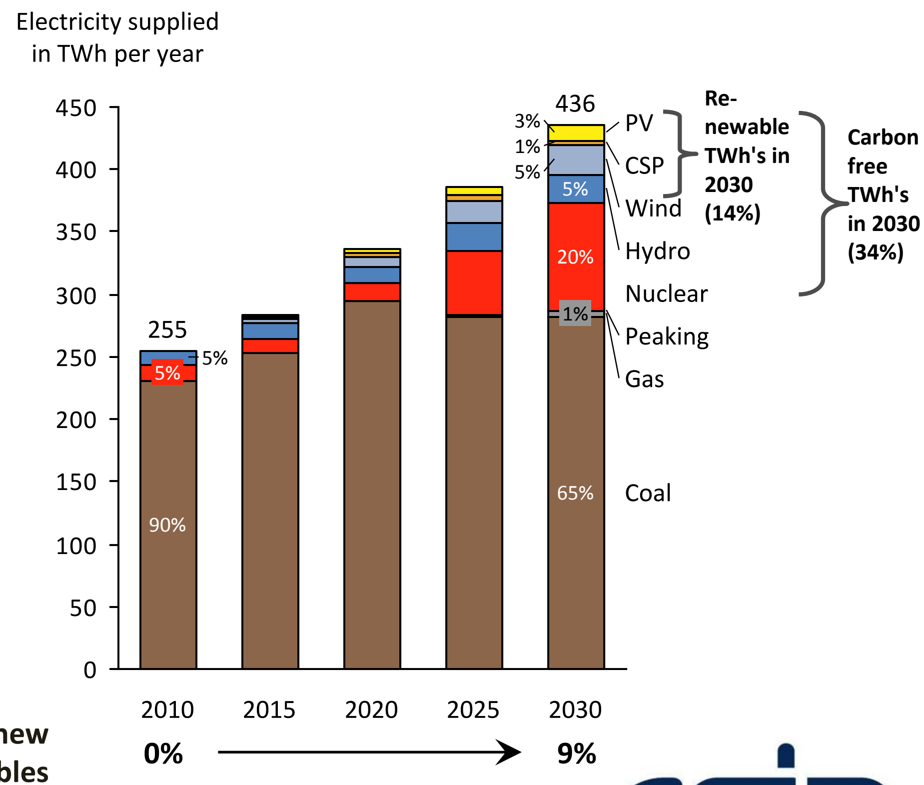
Integrated Resource Plan 2010 (IRP 2010): Plan of the power generation mix for South Africa until 2030

Installed capacity



Energy mix



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

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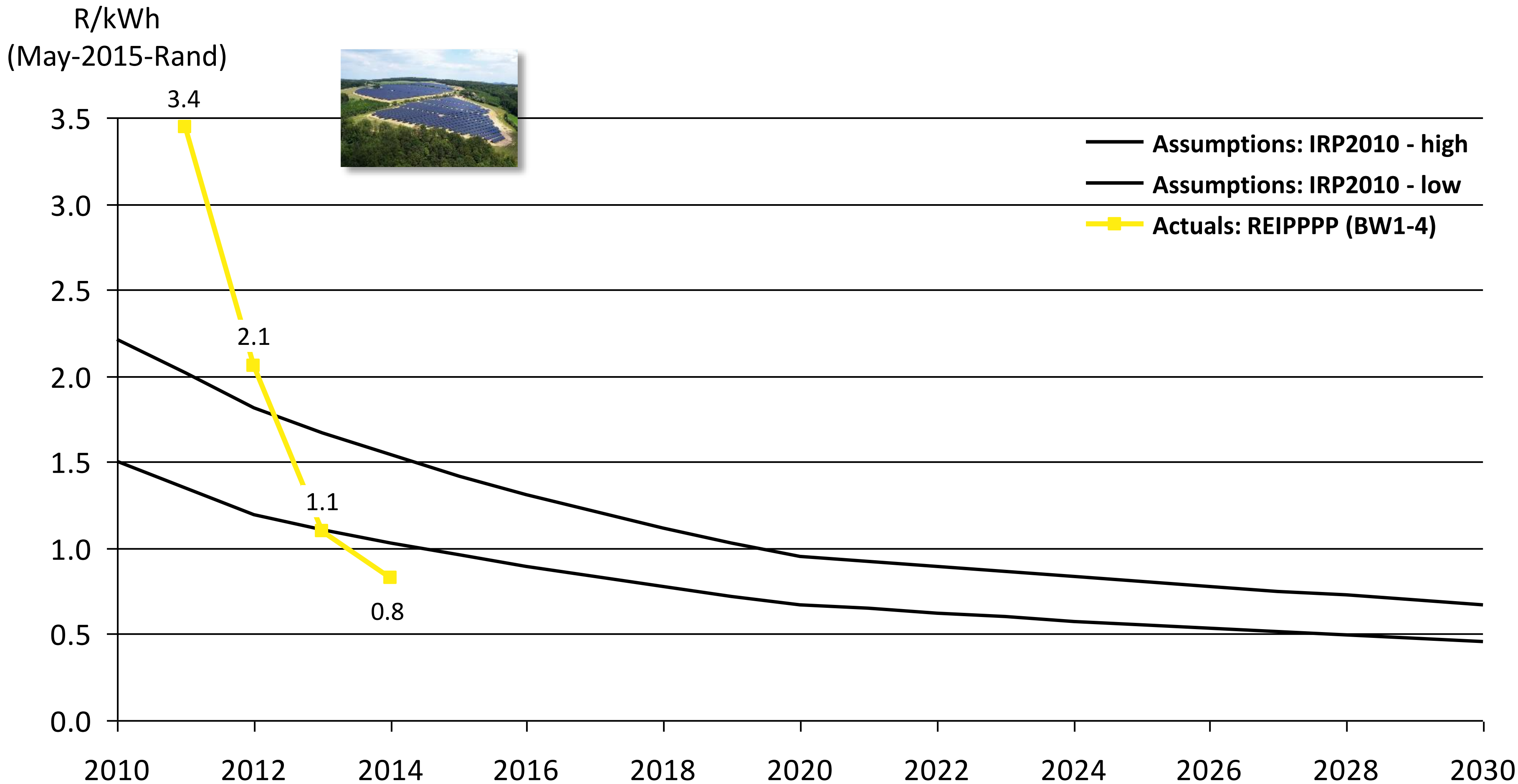
Note: hydro includes imports from Cahora Bassa

Sources: Integrated Resource Plan 2010, as promulgated in 2011; CSIR Energy Centre analysis

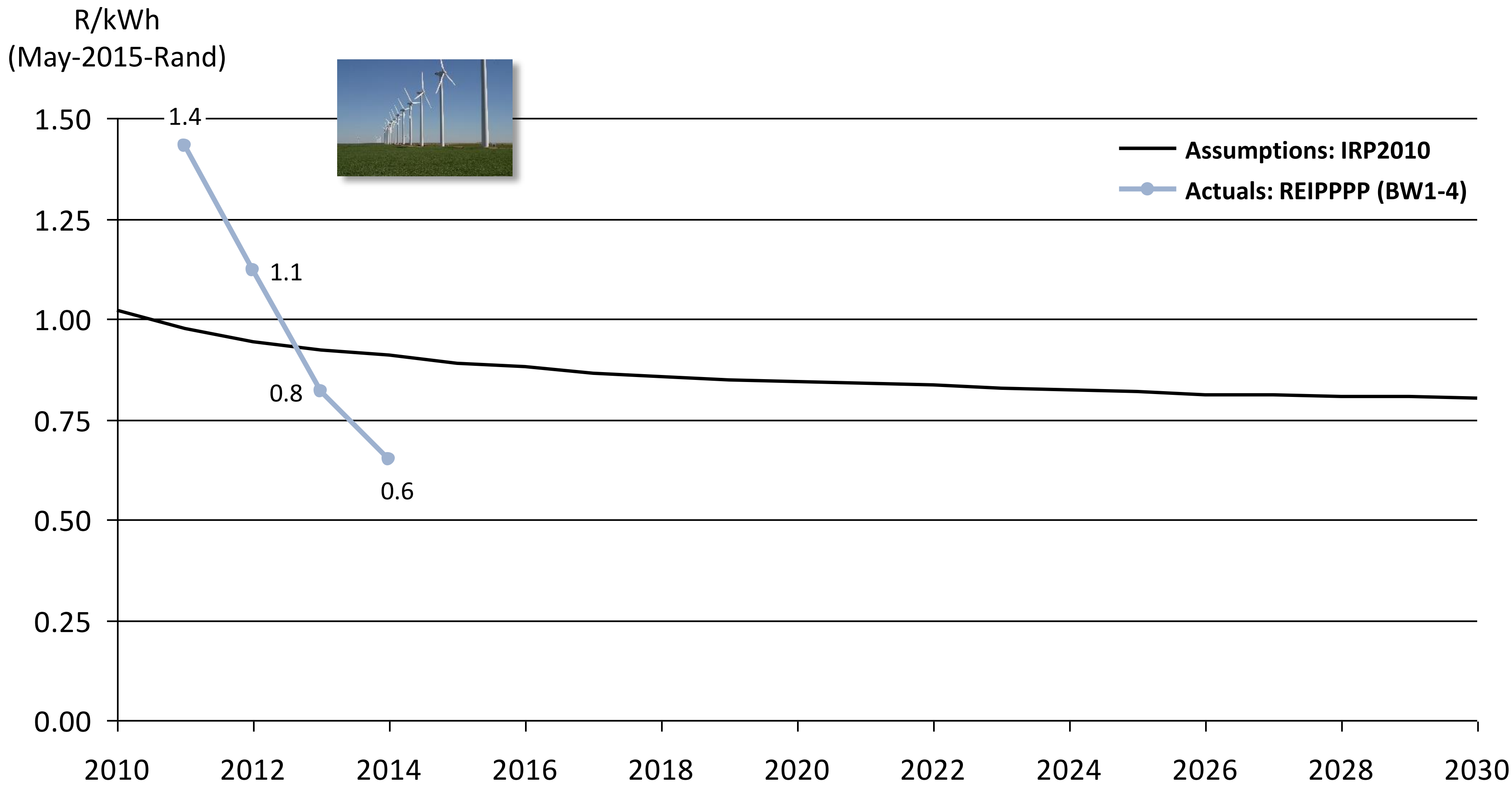
Actual PV tariffs quickly approached IRP cost assumptions in first four bid windows and are now below the lowest cost assumptions of IRP



Assumptions: CPI used for normalisation to May-2015-Rand; LCOE calculated for IRP with 8% discount rate (real), 25 yrs lifetime, cost and load factor assumptions as per relevant IRP document; "IRP Tariff" then calculated assuming 80% of total project costs to be EPC costs, i.e. divide the LCOE by 0.8 to derive at the "IRP Tariff"

Sources: IRP 2010; IRP Update; http://www.ipprenewables.co.za/gong/widget/file/download/id/279; CSIR Energy Centre analysis

Actual wind tariffs in bid window three were already at the level that was assumed for 2030 in the IRP, bid window four is significantly below



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IRP Assumptions and Actuals

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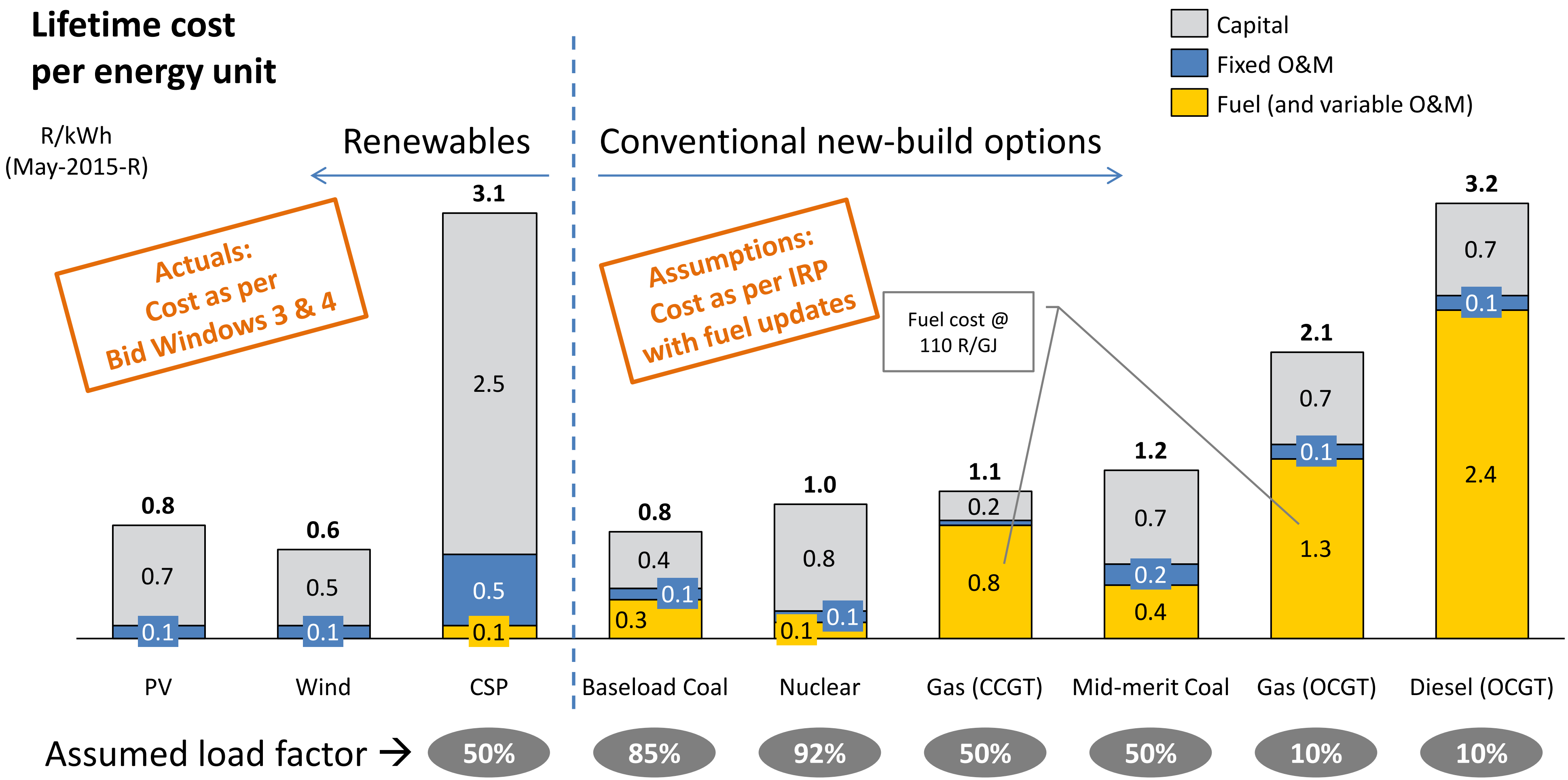
Consequence of renewables' cost reduction: PV and wind are cost-efficient fuel-savers for CCGTs already today

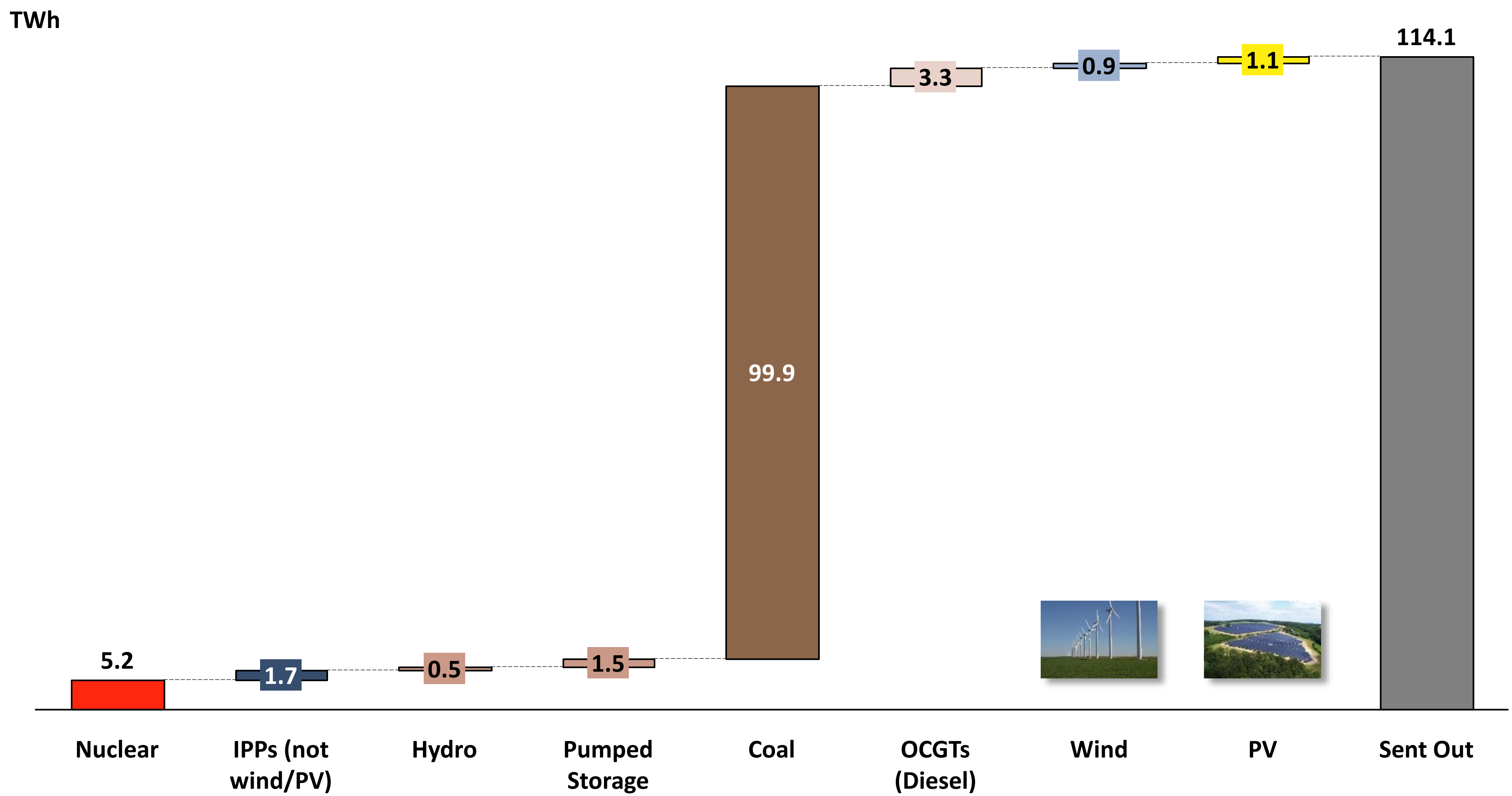


Note: Changing full-load hours for conventionals drastically changes the fixed cost components per kWh (lower full-load hours → higher capital costs and fixed O&M costs per MWh);
Assumptions: average efficiency for CCGT = 50%, OCGT = 35%; coal = 37%; nuclear = 33%; IRP cost from Jan 2012 escalated with 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

17

Wind and PV stand for 2% of the electricity sent out from Jan-Jun 2015

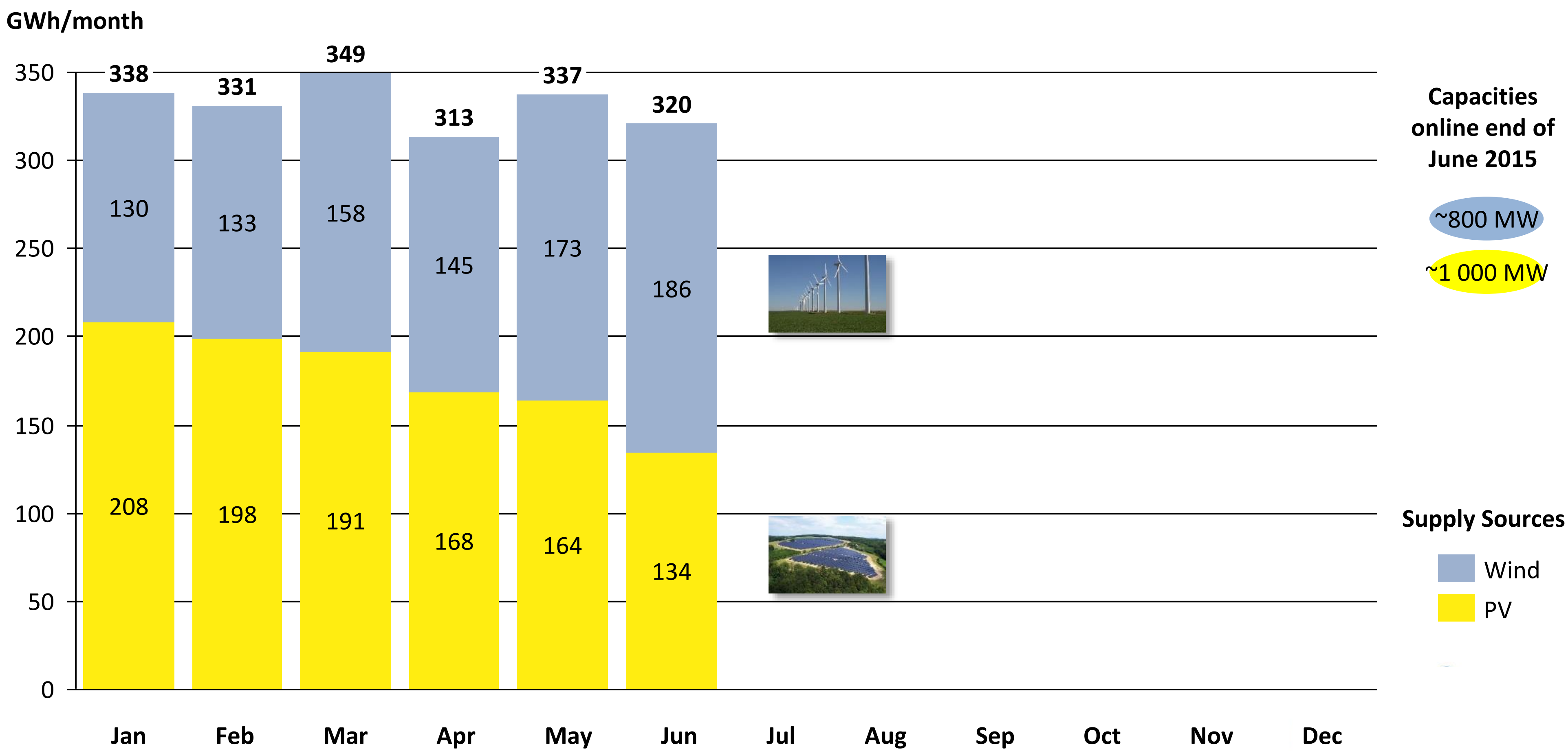
Actual energy captured in wholesale market (i.e. without self-consumed energy of embedded plants)



Sources: Eskom; CSIR Energy Centre analysis

The combined wind/PV fleet supplied 310-350 GWh per month in 2015

Actual monthly production from large-scale PV and wind plants under the REIPPPP in RSA from Jan-Jun 2015

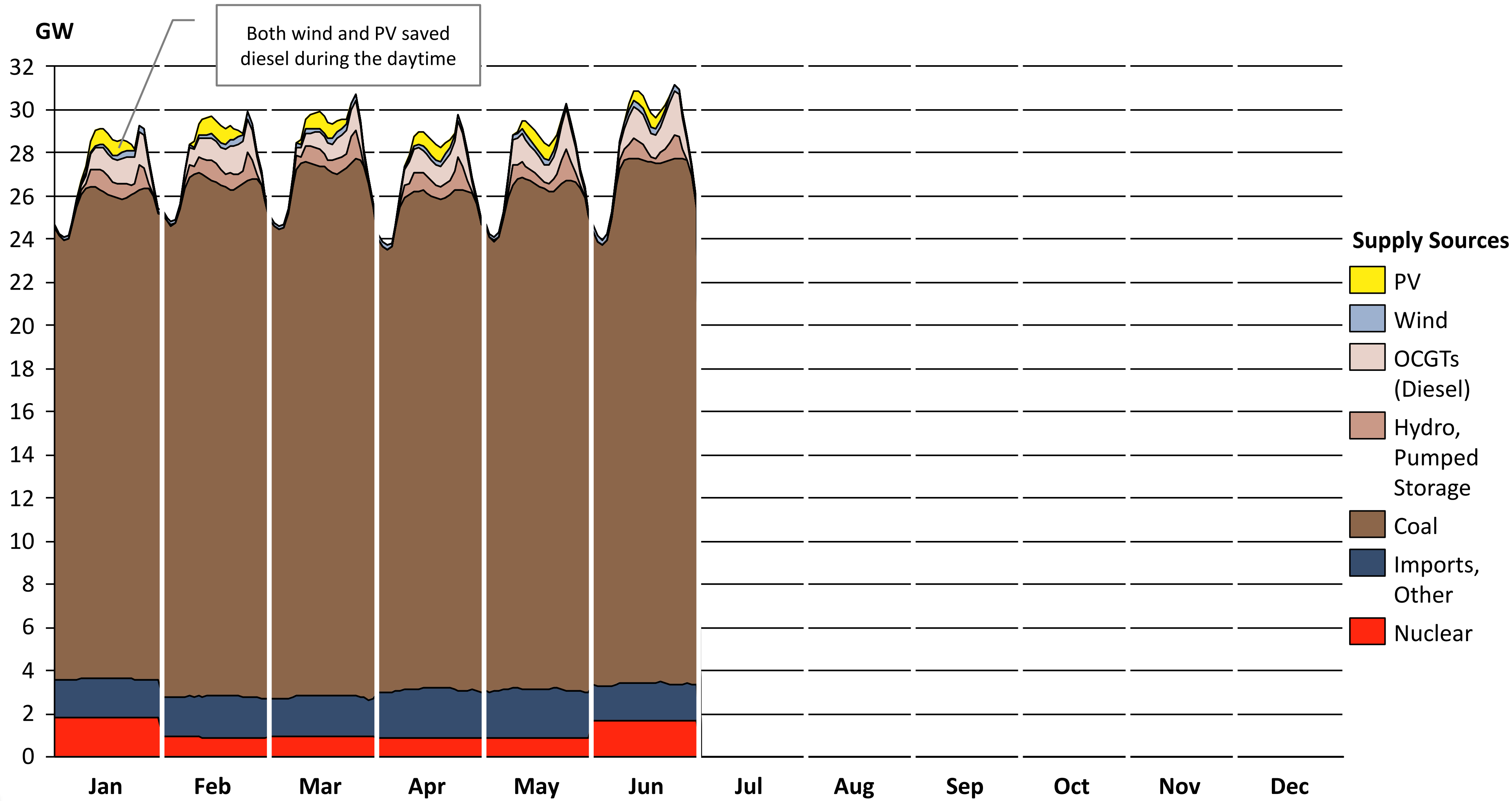


Note: Wind generation excludes Eskom's 100 MW Sere wind farm which came online in 2014 and was fully commissioned by 31 March 2015

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

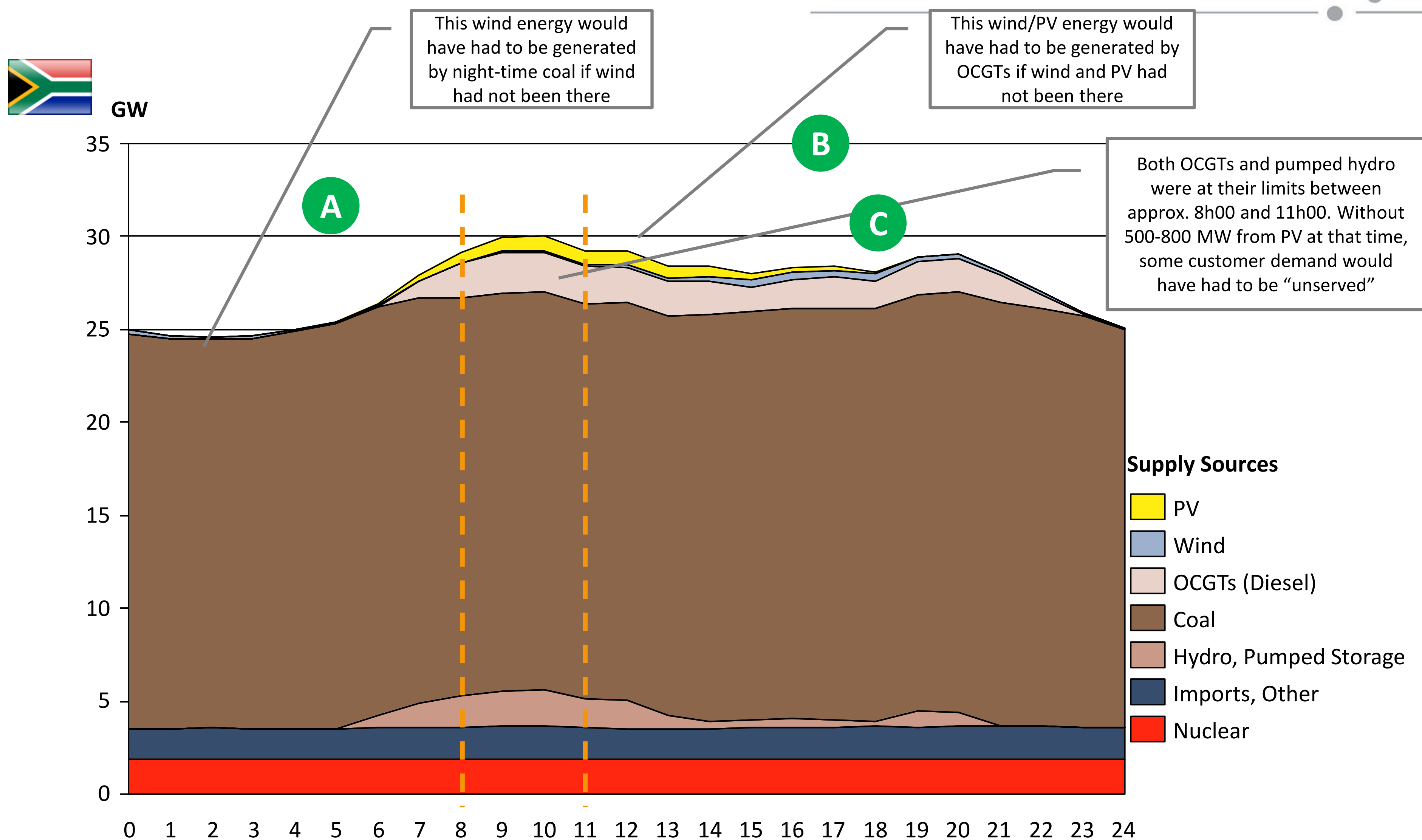


Note: Design as per Fraunhofer ISE

Sources: Eskom; CSIR Energy Centre analysis

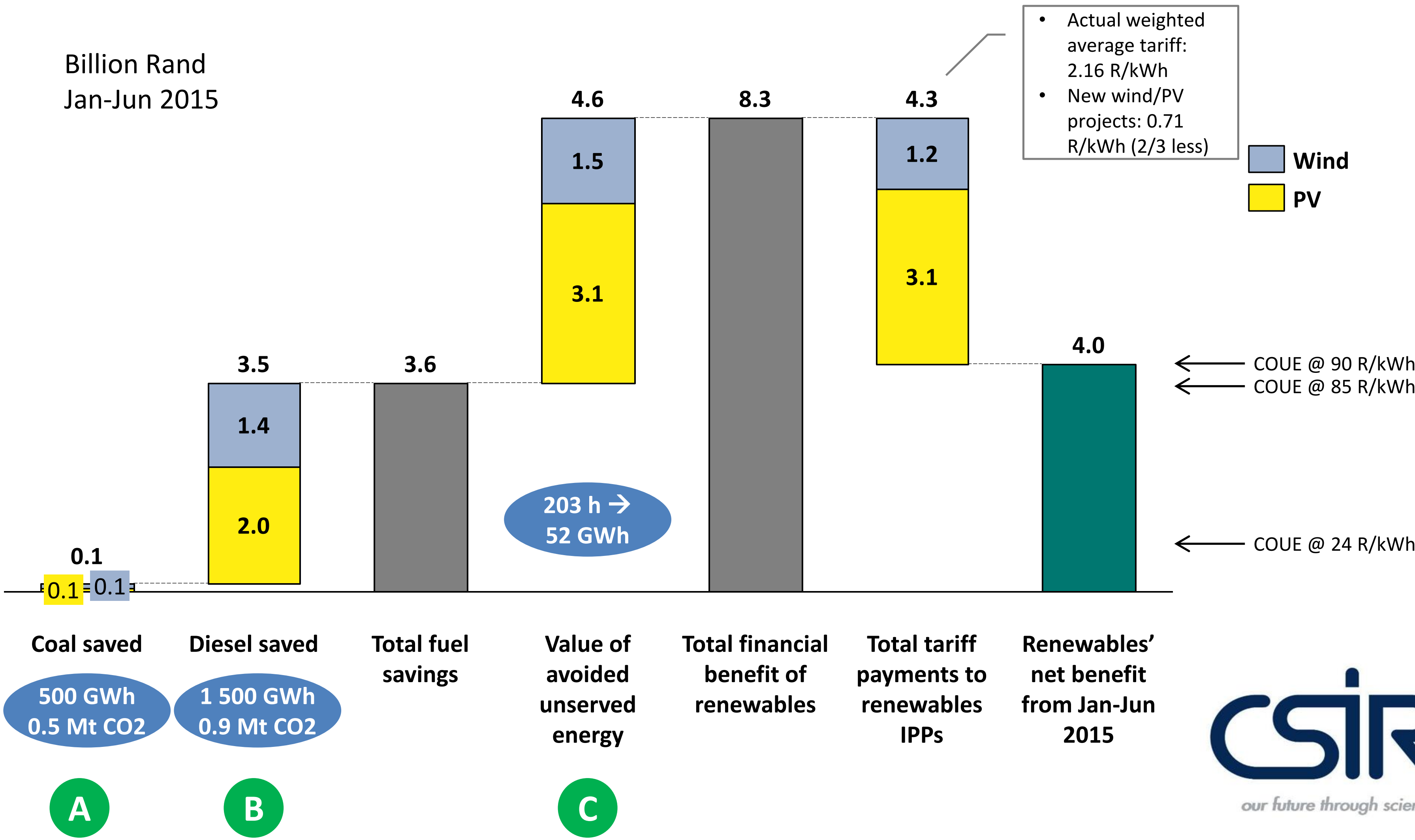
CSIR-defined methodology:
In any hour, wind/PV can have one of three effects on the existing fleet

Actual South African supply structure for a summer day, the 9 January 2015 (Friday)



Sources: Eskom; CSIR Energy Centre analysis

In summary (Jan-Jun 2015): Renewables generated a net benefit for the economy of R4.0 bn



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Sources: CSIR Energy Centre analysis

In addition:
On 15 days wind/PV avoided load shedding entirely or a higher stage

There were 15 days where avoided unserved energy exceeded 1 000 MWh, of which

- 4 days where wind and PV avoided load shedding entirely
- 5 days where wind and PV delayed the initiation of Stage 1 load shedding for a number of hours
- 4 days where wind and PV avoided the need to move from Stage 1 to Stage 2 load shedding for a number of hours
- 2 days where wind and PV avoided the need to move from Stage 2 to Stage 3 load shedding for a number of hours

Plus: environmental benefit CO2 avoidance

- Wind and solar PV in H1 2015 avoided 1.4 million tonnes of CO2 emissions

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Notes: If on a day avoided unserved energy was greater 1 000 MWh and on that day the avoided unserved energy occurred during at least four consecutive hours, or avoided unserved energy was greater than 1 500 MWh, then on that day either stage 1 load shedding was avoided or an additional stage of load shedding was avoided   Sources: CSIR Energy Centre analysis

Common perceptions and paradigms

IRP Assumptions and Actuals

Cost-competitiveness of Renewables

The Baseload Argument

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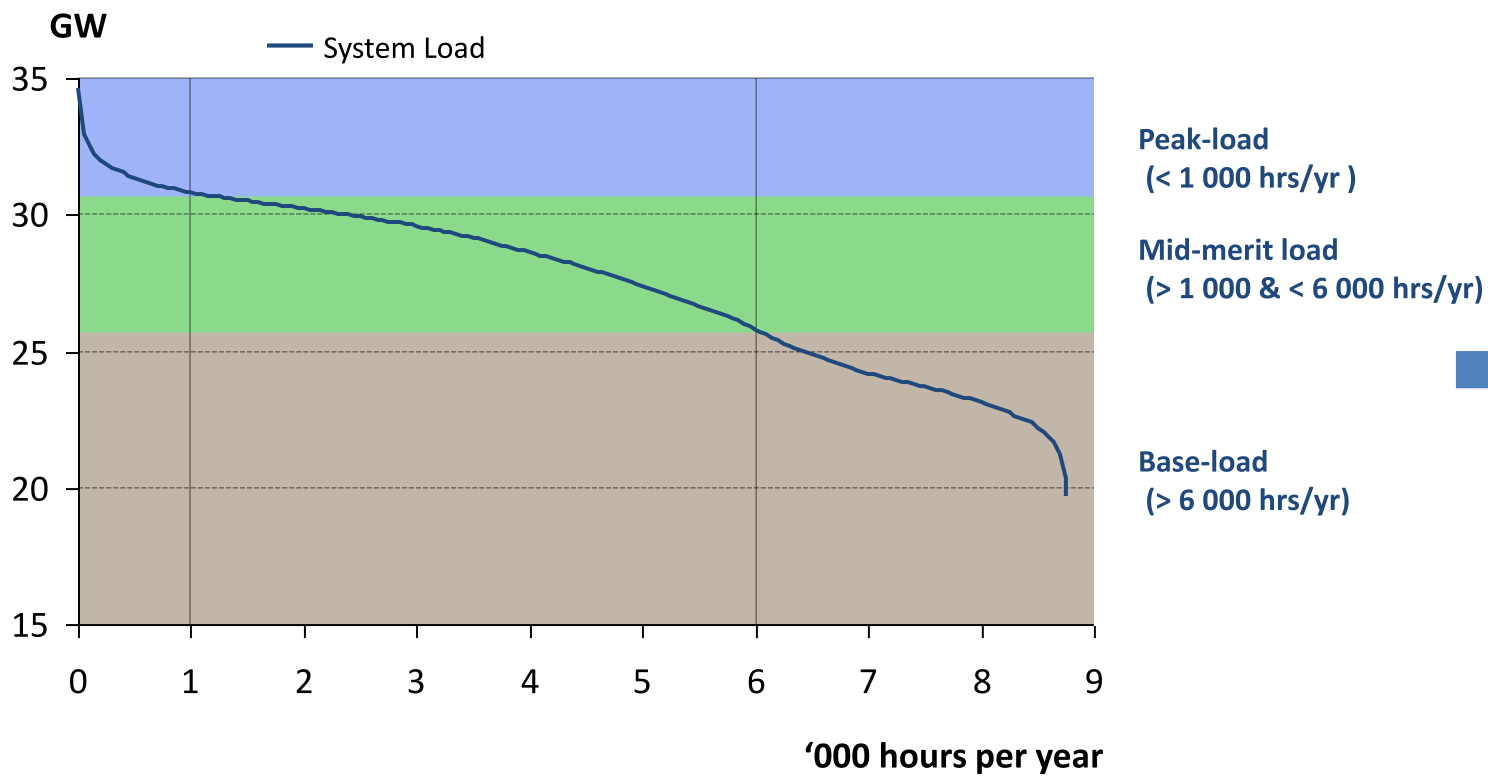
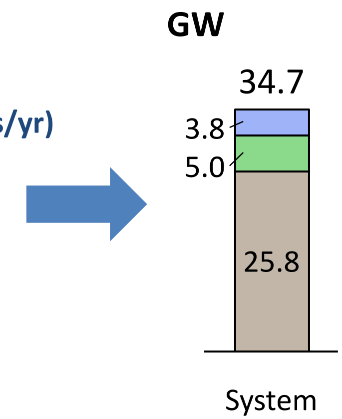
The system load from August 2014 to July 2015 had a peak demand of 3.8 GW, mid-merit of 5.0 GW, and base-load demand of 25.8 GW

Load Duration Curve for Aug 2014 to Jul 2015 as per actual data

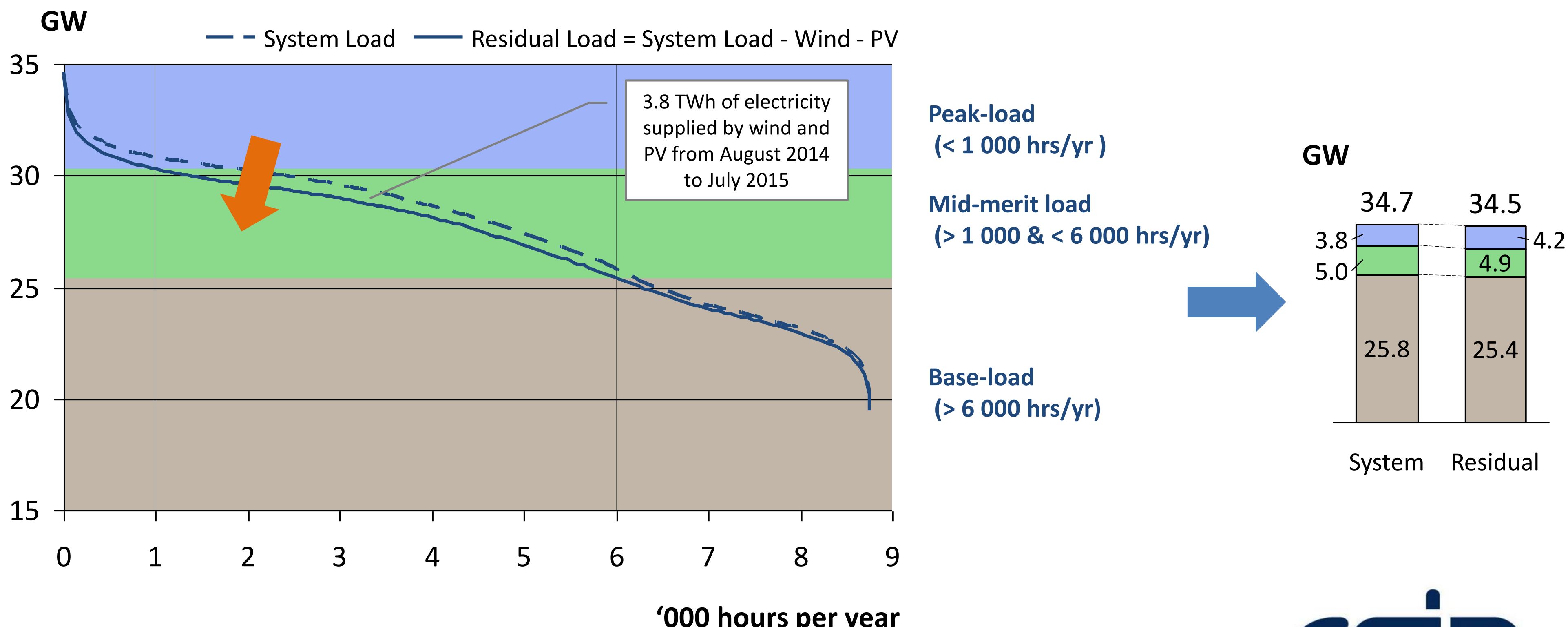




Sources: CSIR Energy Centre analysis

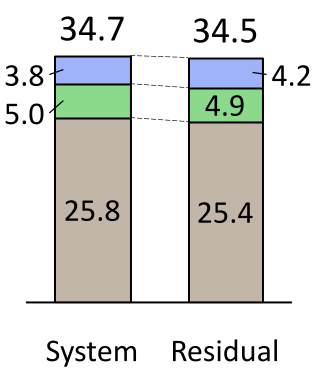
Wind/PV changed the shape of residual load: new peak-demand goes up to 4.2 GW, mid-merit & base-load demand go down to 4.9/25.4 GW

Load Duration Curve for Aug 2014 to Jul 2015 as per actual data



Sources: CSIR Energy Centre analysis

Additional effect CAPEX savings:
Wind & PV change shape of the load and allow for cheaper new-builds



Type	Delta for required new-builds	Assumed cost of new capacity in R/kW
Peak	+400 MW	8 000
Mid-merit	-100 MW	12 000
Base	-400 MW	25 000

Last year, wind and PV changed the residual load such that cheaper new conventional power stations can be built: Annualised R9 billion CAPEX savings translates into additional value of R0.2 per kWh of renewable energy

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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 potential for solar PV and wind is almost "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 instanteneously

Today, supply side is dispatched to instantaneously balance demand

Today

Supply	Demand
Diesel Gas Hydro Coal Nuclear	Residential Commercial Industry Mining

Dispatchable | Not dispatchable

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In future, a flexible dispatchable supply fleet and dispatchable load together will balance supply and demand

Today

Supply

- Diesel
- Gas
- Hydro
- Coal
- Nuclear

Demand

- Residential
- Commercial
- Industry
- Mining

Future

Supply

- Solar PV
- Wind

- Hydro
- (Bio)gas
- CSP
- Storage
- Etc.

Demand

- Non-dispatch-able Load

- Dispatch-able Load (water heating, space heating / cooling, industrial heat, eVehicles, pumping, etc.)

Dispatchable | Not dispatchable

Thought experiment: Build a new power system from scratch

Annual demand: **11.1 TWh/yr (4-5% of today's South African demand)**

Base load: **1 GW**

Day load: **1.3 GW in summer**
1.5 GW in winter

What is cheaper to supply that profile?

1) Base and mid-merit coal?
2) A blend of wind and solar PV, mixed with gas to fill the gaps?

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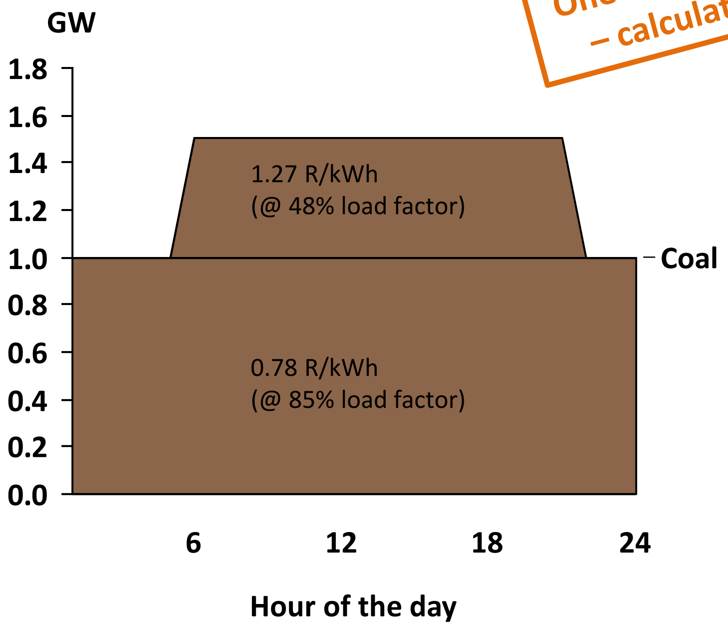
A mix of new baseload-operated coal and new mid-merit coal costs 0.88 R/kWh for the pure cost of power generation

One illustrative winter day in display – calculations done for a full year



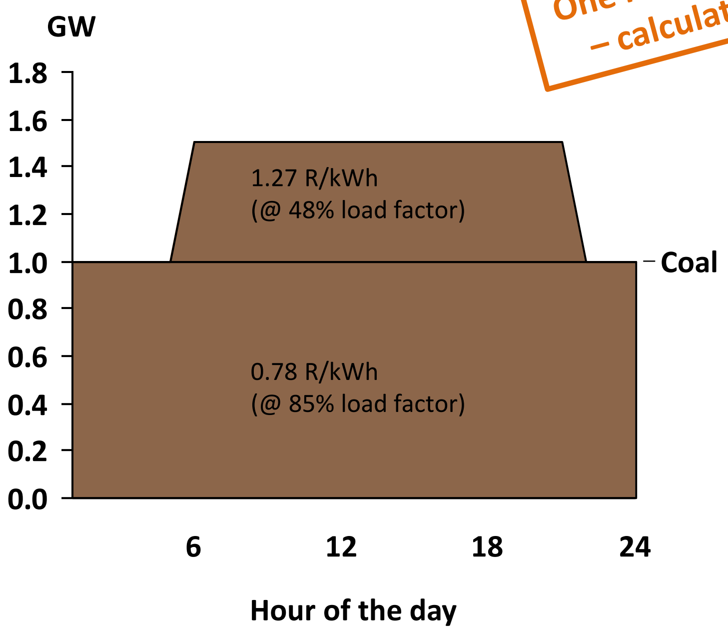
Technology: Coal base / coal mid-merit
Size: 1.18 / 0.56 GW
Energy: 11.1 TWh/yr

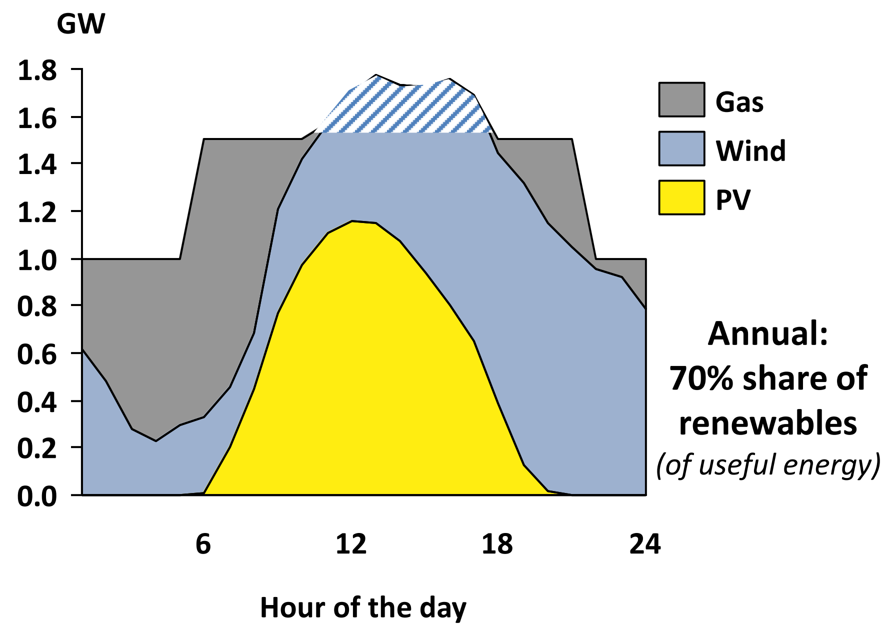
Weighted cost: **0.88 R/kWh**

CO2: ~0.95 kg/kWh

A fully dispatchable mix of PV, wind and flexible gas can supply the demand similarly in the same reliable manner as the coal mix

One illustrative winter day in display – calculations done for a full year





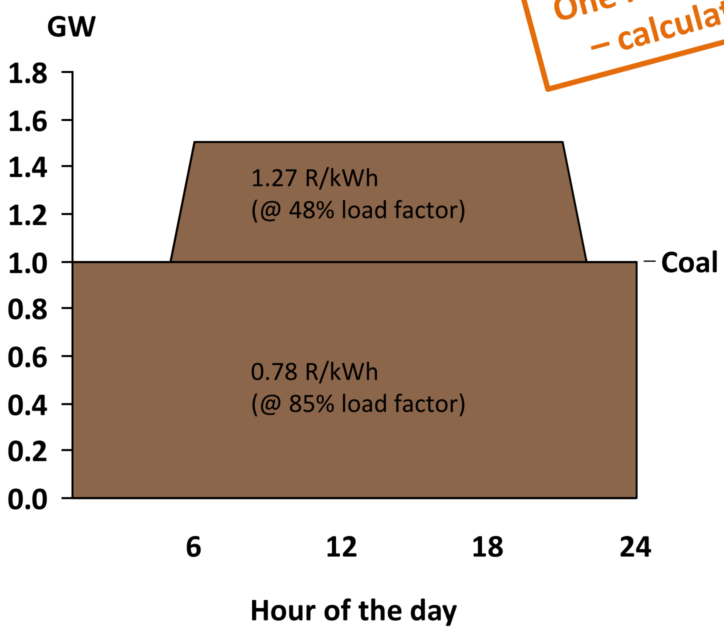
Technology:	Coal base / coal mid-merit
Size:	1.18 / 0.56 GW
Energy:	11.1 TWh/yr

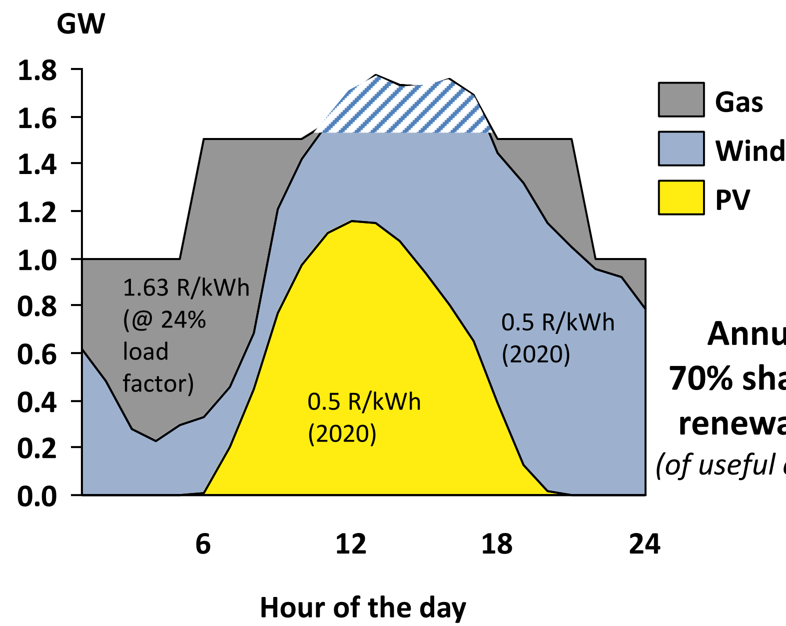
Weighted cost: **0.88 R/kWh**

CO2: ~0.95 kg/kWh

By 2020, a mix of PV, wind and flexible gas (LNG-based) is cheaper than coal, even without any value given to excess wind/PV energy

One illustrative winter day in display – calculations done for a full year





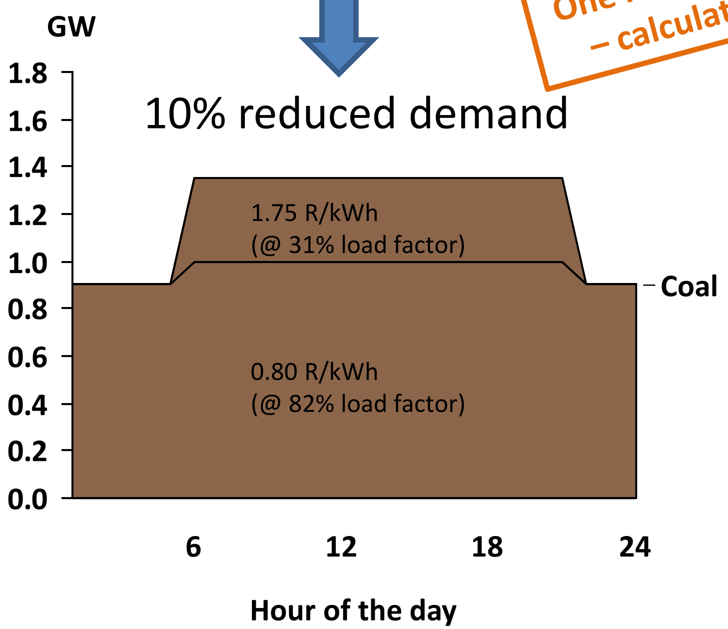
Annual:
70% share of renewables
(of useful energy)

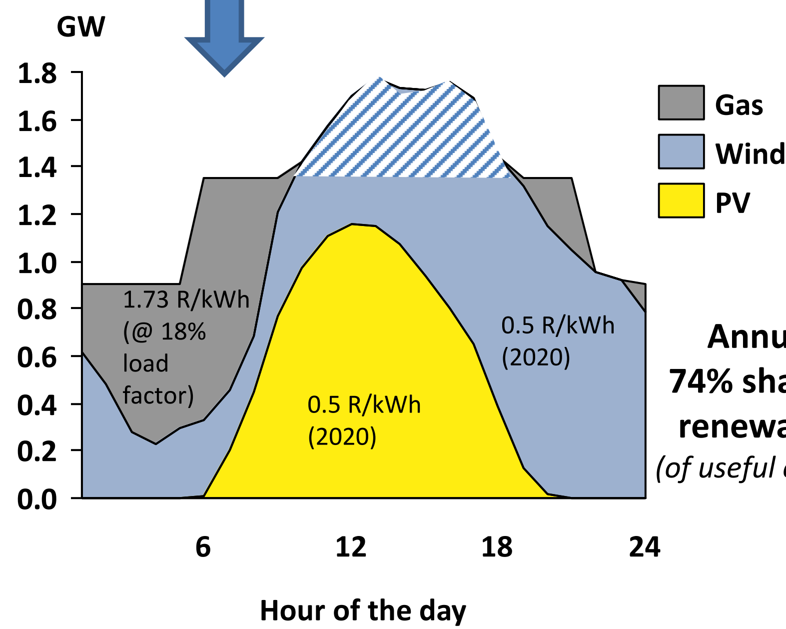
Technology:	Coal base / coal mid-merit
Size:	1.18 / 0.56 GW
Energy:	11.1 TWh/yr
Weighted cost:	**0.88 R/kWh**
CO2:	~0.95 kg/kWh

Technology:	PV / wind / gas
Size:	1.5 / 2.0 / 1.61 GW
Energy (useful):	11.1 TWh/yr
Energy (total):	3.6 / 5.3 / 3.2 TWh/yr = 12.1 TWh/yr
Weighted cost:	**0.87 R/kWh** *(per useful energy, i.e. no value given to excess)*
CO2:	~0.18 kg/kWh (per useful energy)

In addition, the cost of a PV / wind / gas power plant scale more with reduced demand and thus unit cost per kWh stay more or less constant

One illustrative winter day in display – calculations done for a full year





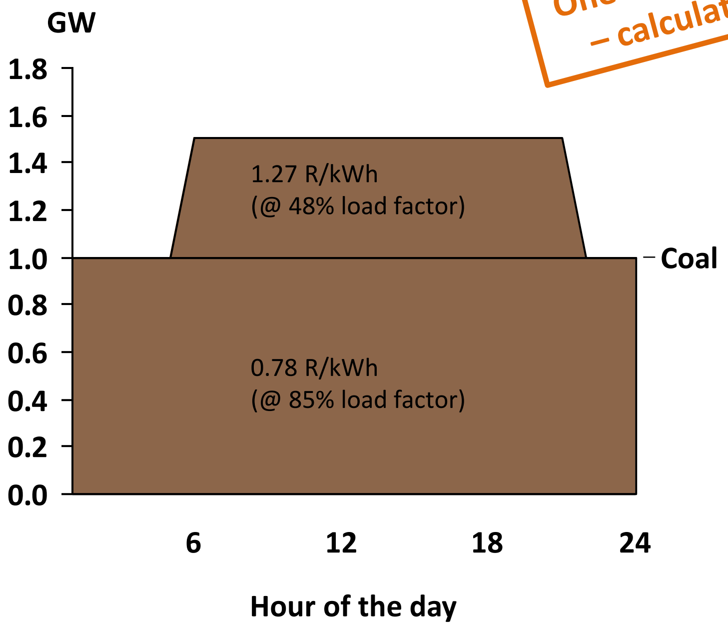
Annual:
74% share of renewables
(of useful energy)

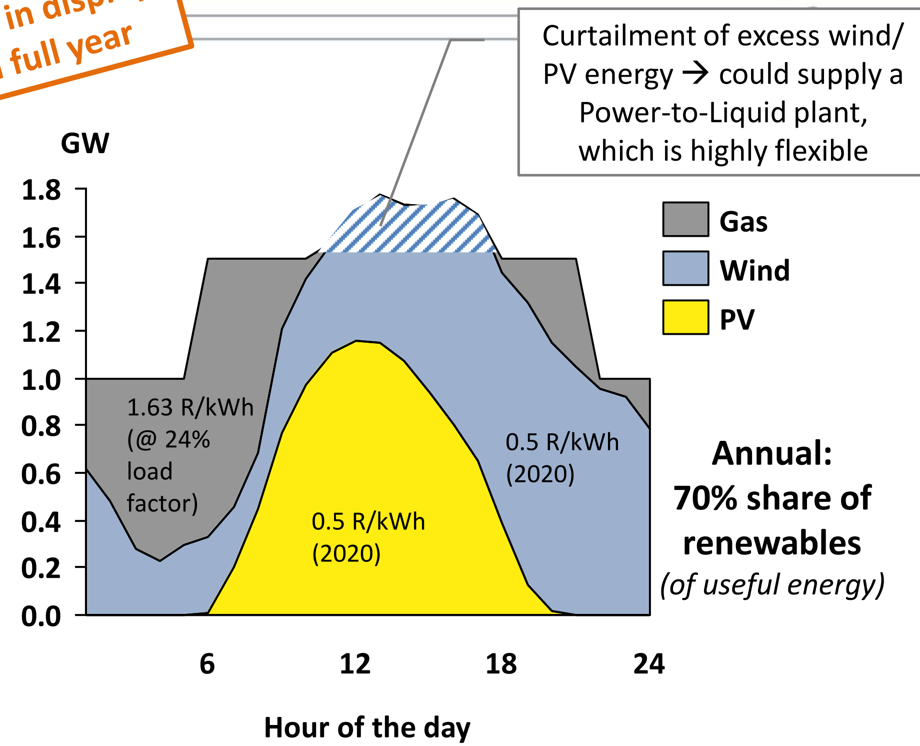
Technology:	Coal base / coal mid-merit
Size:	1.18 / 0.56 GW
Energy:	10.0 TWh/yr
Weighted cost:	**0.94 R/kWh (plus 7%)**
CO2:	~0.95 kg/kWh

Technology:	PV / wind / gas
Size:	1.5 / 2.0 / 1.61 GW
Energy (useful):	10.0 TWh/yr
Energy (total):	3.6 / 5.3 / 2.5 TWh/yr = 11.4 TWh/yr
Weighted cost:	**0.87 R/kWh (constant)** *(per useful energy, i.e. no value given to excess)*
CO2:	~0.16 kg/kWh (per useful energy)

In reality, flexible, dispatchable loads and/or storage would utilise the excess energy – if value is assigned to it, cost of useful energy go down

One illustrative winter day in display – calculations done for a full year





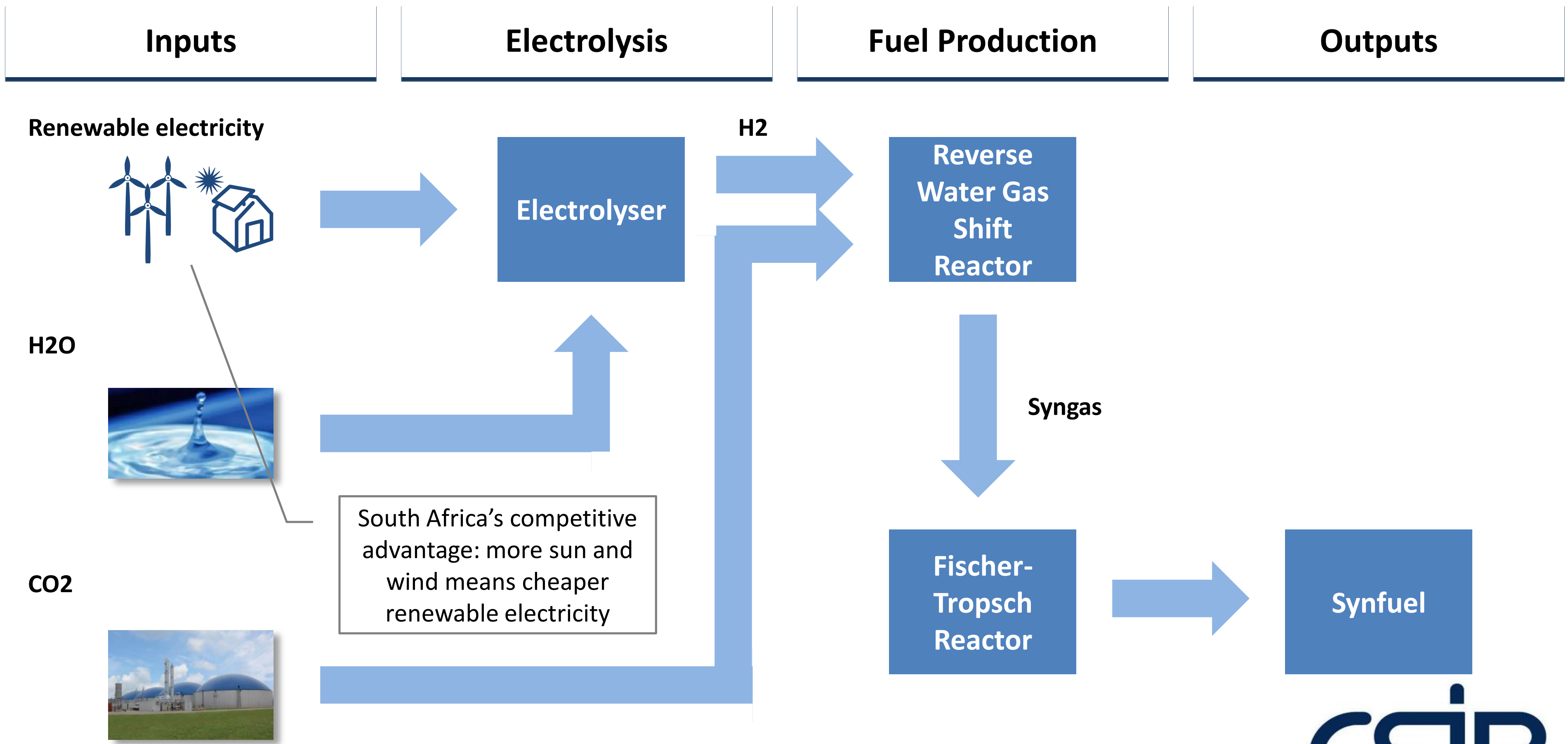
Technology: Coal base / coal mid-merit
Size: 1.18 / 0.56 GW
Energy: 11.1 TWh/yr

Weighted cost: **0.88 R/kWh**

Technology: PV / wind / gas
Size: 1.5 / 2.0 / 1.61 GW
Energy (useful): 11.1 TWh/yr
Energy (total): 3.6 / 5.3 / 3.2 TWh/yr = 12.1 TWh/yr

Weighted cost: **0.82~~7~~ R/kWh**
(0.87 R/kWh goes down to 0.82 R/kWh, even if only 0.5 R/kWh value is given to excess energy)

Producing carbon-neutral synthetic fuels from cheap renewable power could be a business case for South Africa …



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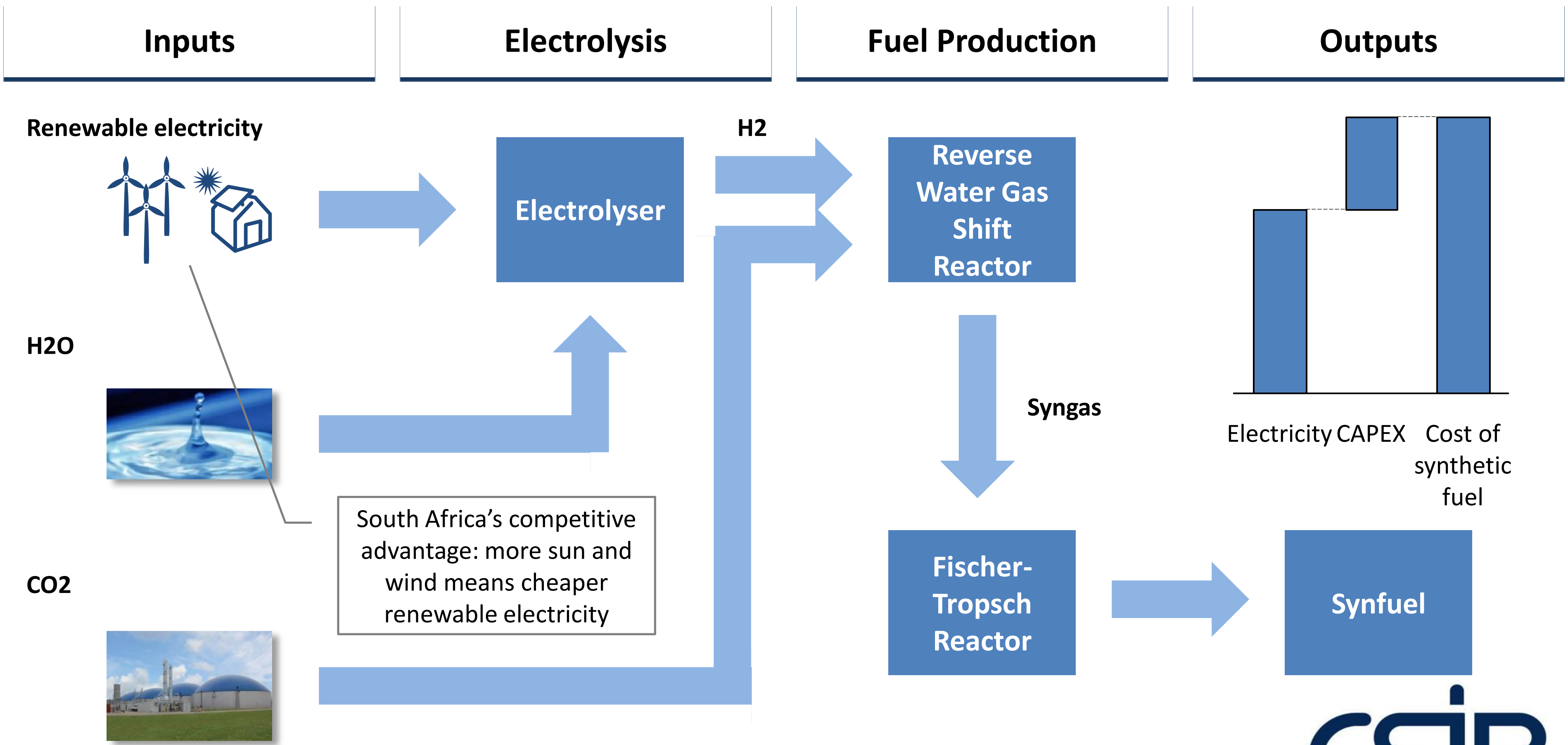
Sources: CSIR Energy Centre analysis

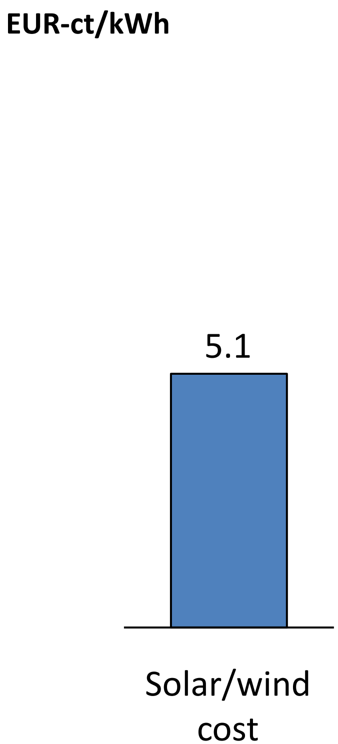
… because the main cost driver is cost of renewable electricity input



Sources: CSIR Energy Centre analysis

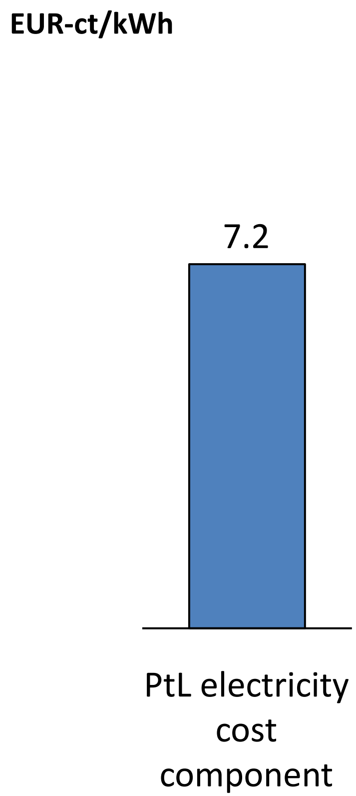
Already at today's renewable electricity cost in South Africa, PtL is not far from competitiveness with production cost of biofuels

Actual average wind/solar PV tariff in South Africa today



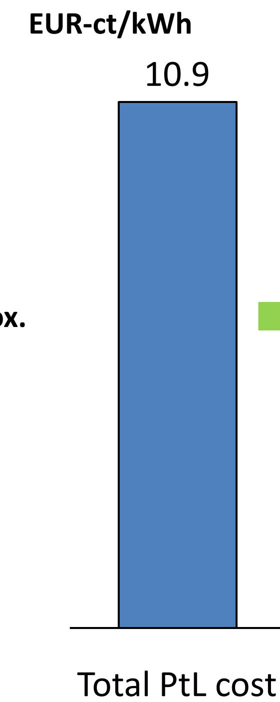
./. **70% efficiency (optimally)**

Pure electricity cost of PtL plant fed with South African wind/PV power



→ Electricity approx. 2/3 of total cost

Total PtL production cost



Below 1 EUR/litre

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Sources: CSIR Energy Centre analysis

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 <u>not a necessary pre-condition</u> for achieving a 40% renewables share by 2030

Thank you!

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