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

Jarrad Wright
Dr Tobias Bischof-Niemz
Joanne Calitz
Crescent Mushwana

our future through science

Background

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

- "Business-as-Usual" – generally aligned with IRP 2010, updated demand forecast, no new optimisation
- "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

CSIR
our future through science

Agenda

Background

Approach and assumptions

Results

Conclusions

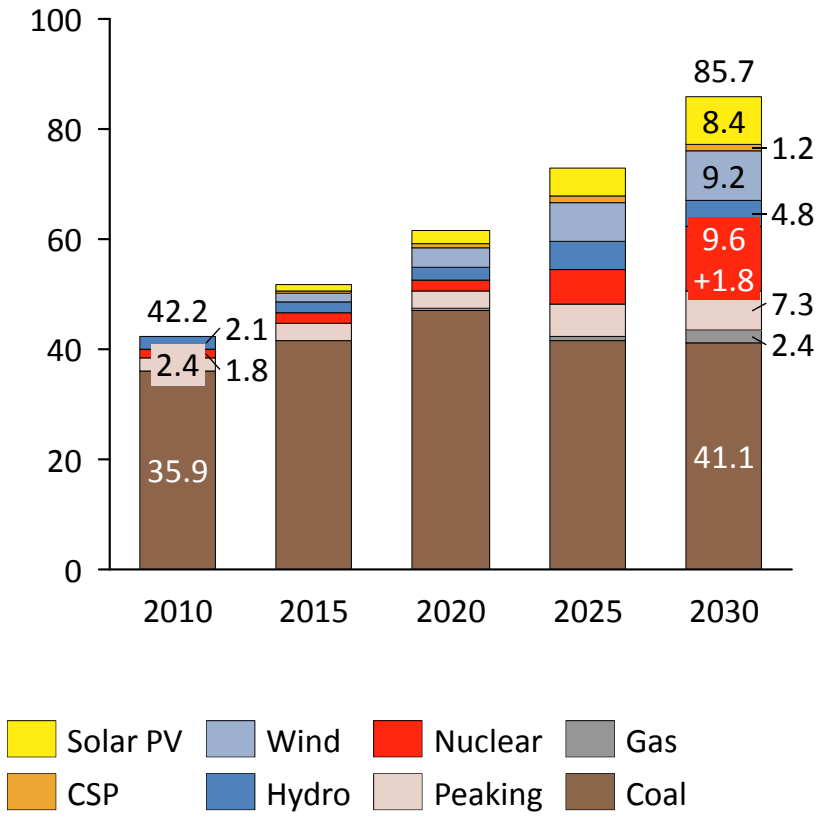
IRP 2010: expansion plan for South Africa's power system until 2030

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

Promulgated IRP 2010

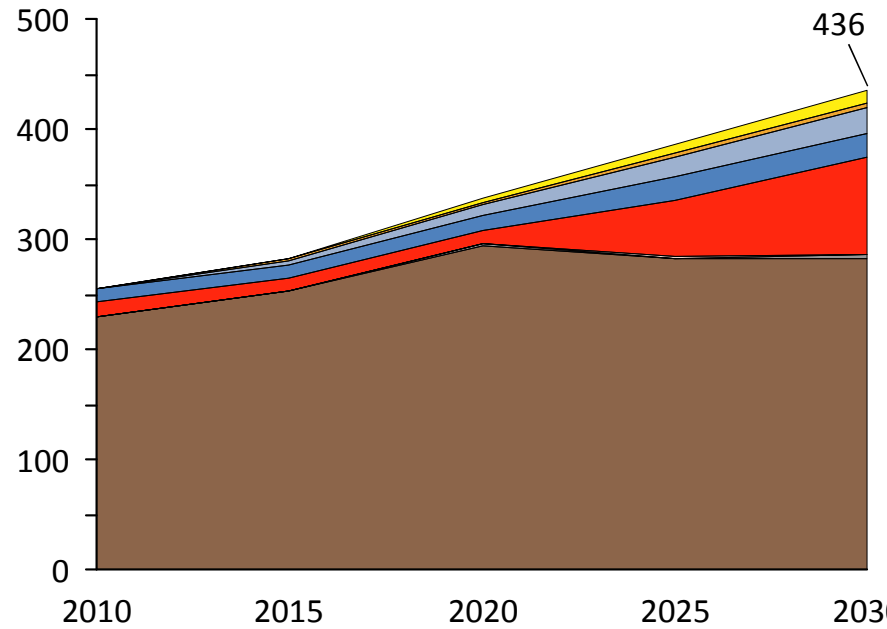
Business-as-Usual

Total installed net capacity in GW



Re-Optimised

Electricity supplied in TWh per year



	2010	2030
Renewables	**5%** (12 TWh/yr)	**14%** (62 TWh/yr)
Carbon free	**10%** (25 TWh/yr)	**34%** (149 TWh/yr)
CO2 emissions [Mt/yr]	**237**	**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

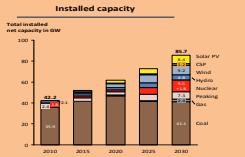
Currently, no feedback loop from procurement results to IRP planning assumptions institutionalised

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

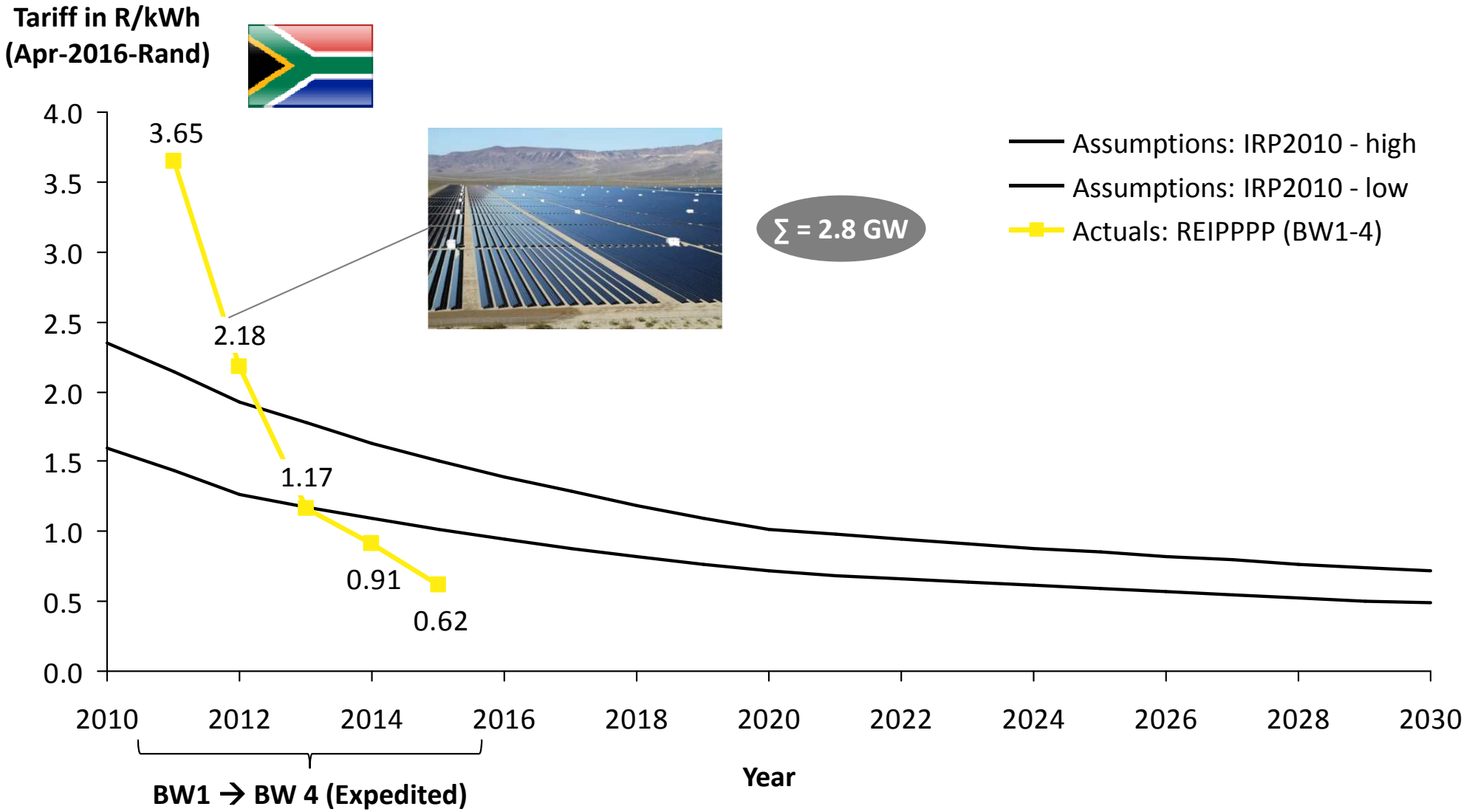
Procurement
(competitive tender e.g. REIPPPP, coal IPPPP)

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

Sources: CSIR Energy Centre analysis

Actual solar PV tariffs now well below cost assumptions of IRP 2010

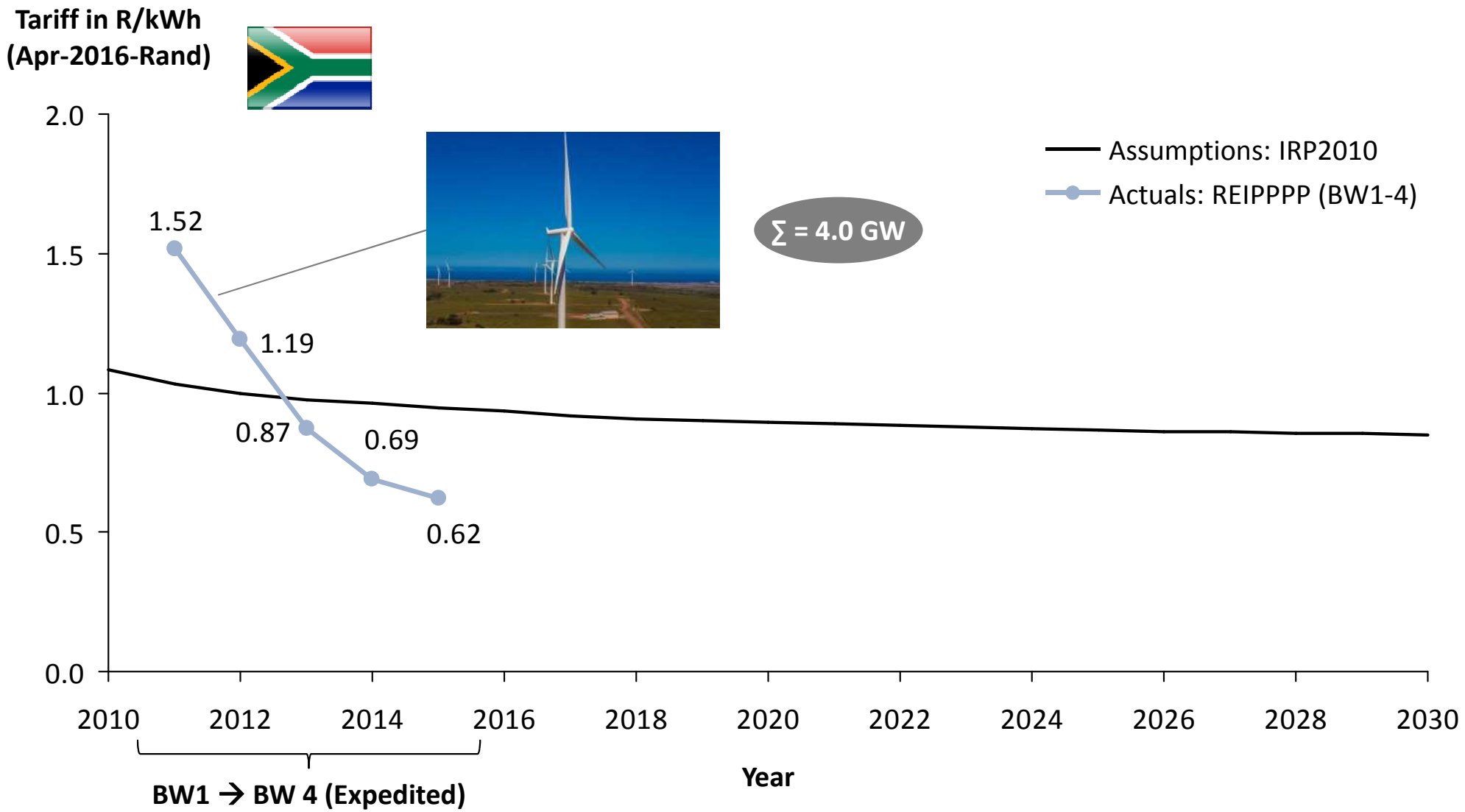
First four bid windows' results (solar PV) of Department of Energy's REIPPPP



Notes: REIPPPP = Renewable Energy Independant 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 wind tariffs equally well below cost assumptions of IRP 2010

First four bid windows' results (wind) of Department of Energy's REIPPPP



Notes: REIPPPP = Renewable Energy Independant 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

Agenda

Background

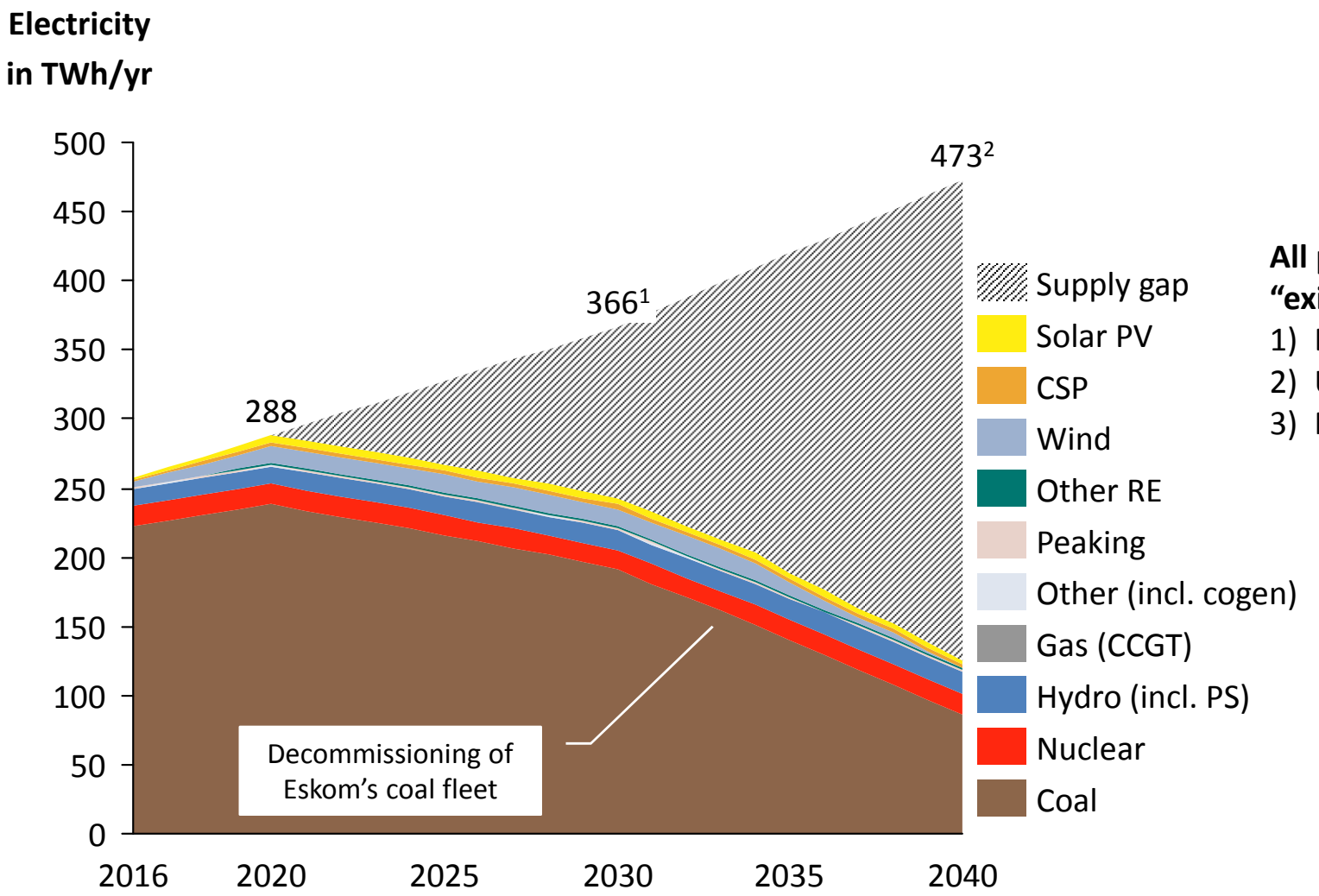
Approach and assumptions

Results

Conclusions

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



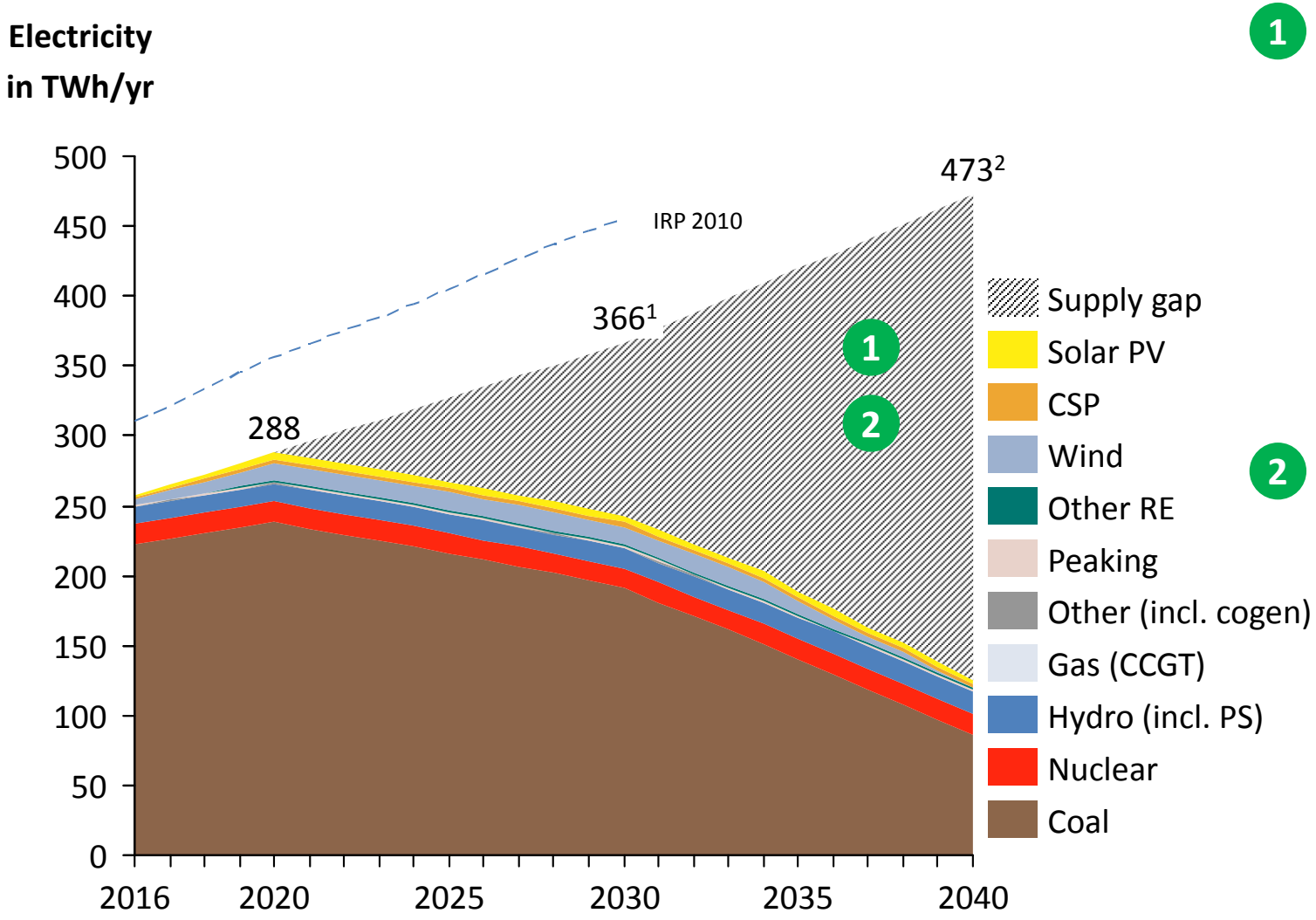
All power plants considered for "existing fleet" that are either:

1) Existing in 2016
2) Under construction
3) Procured (preferred bidder)

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

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



1 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)

2 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

CSIR
our future through science

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
Solar PV	Same as IRP 2010 by 2030	Slightly lower until 2030
Wind	Bid Window 4 Expedited tariff kept constant until 2040	Lower
CSP	Same as IRP 2013	Slightly higher
Coal	Coal IPP	Higher
Nuclear	as per IRP with Rosatom low-estimate CAPEX	Similar
Gas	as per IRP with fuel updates	Higher

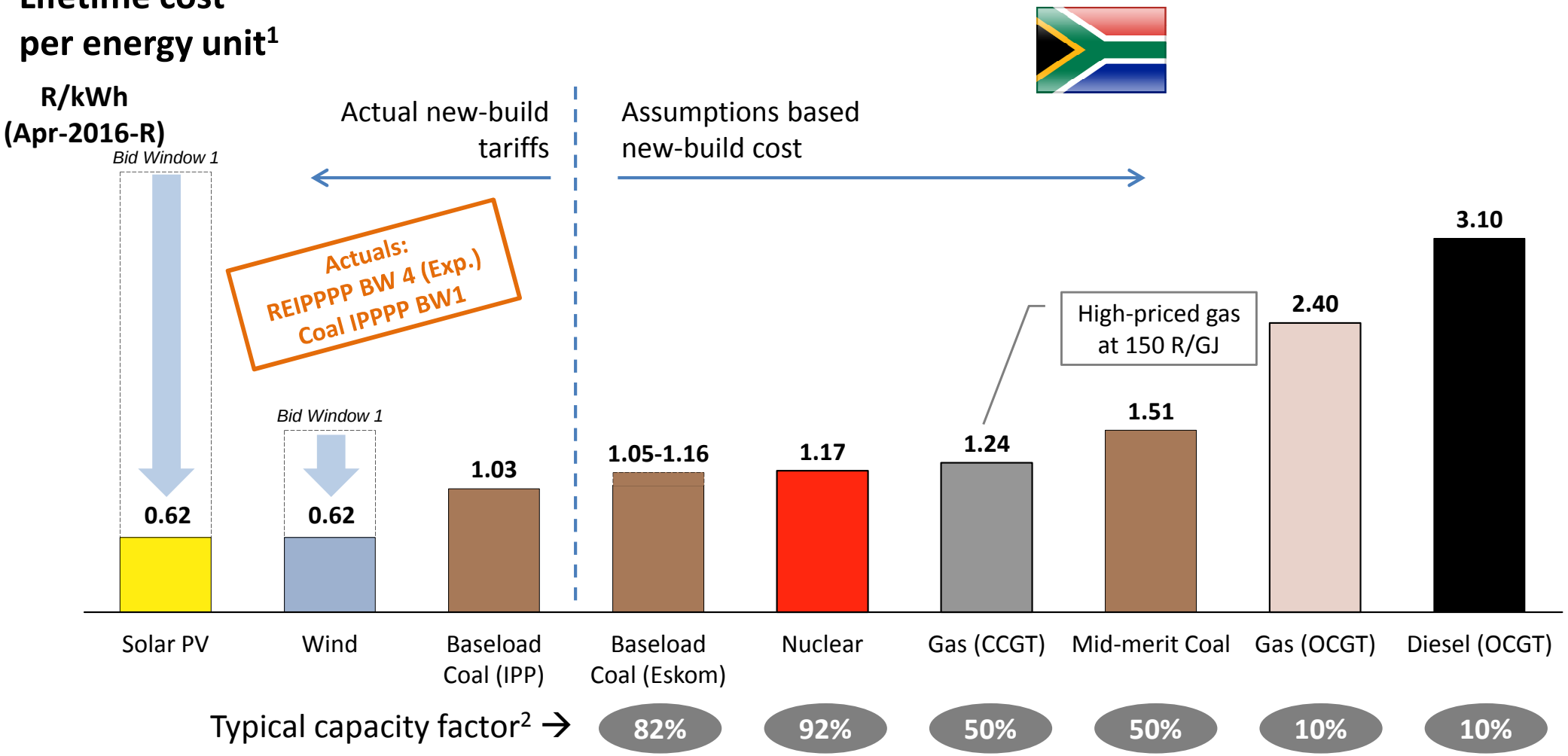
All other assumptions and methodology fully aligned with IRP 2010, for example:

- 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

CSIR
our future through science

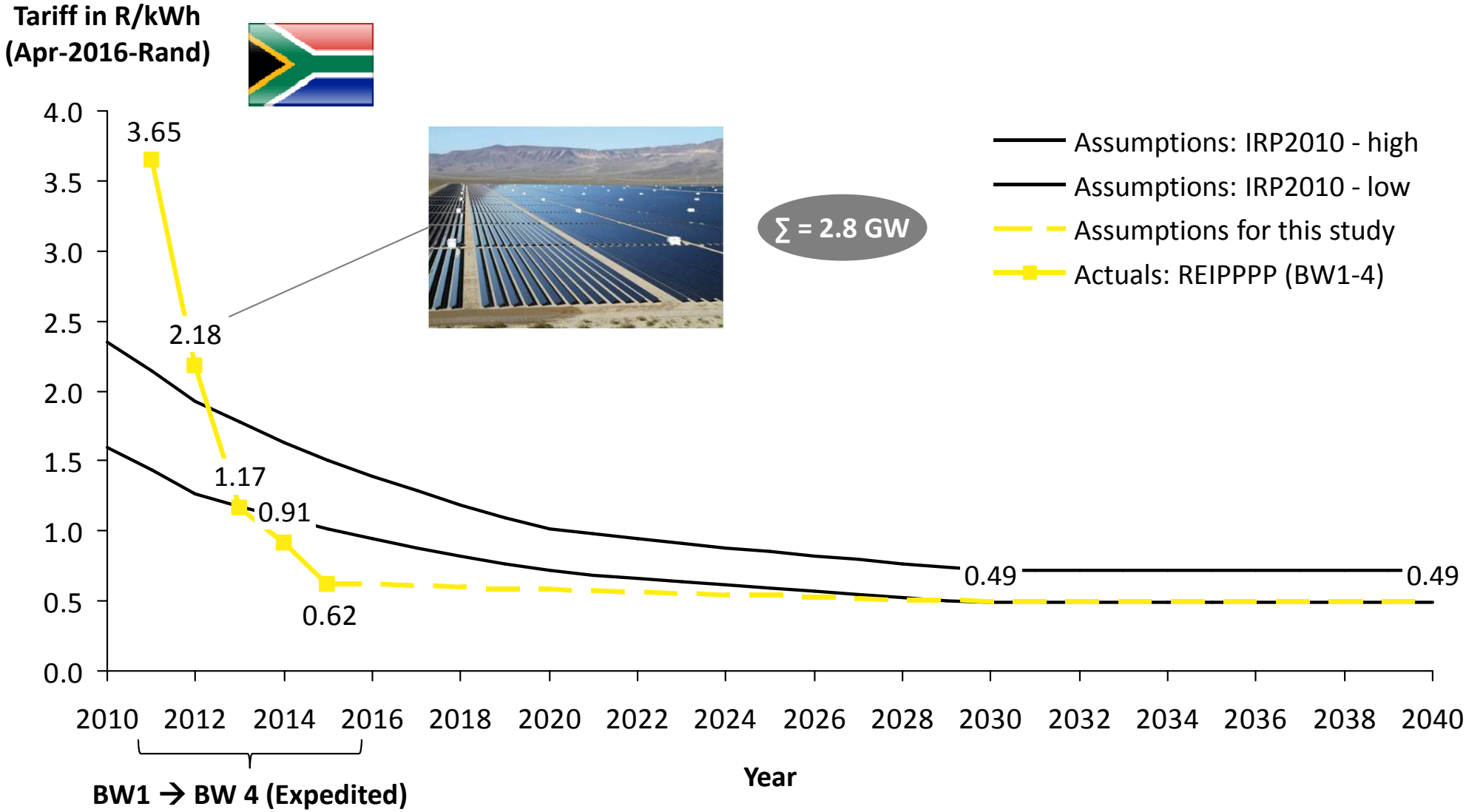
Key input cost assumptions for new supply technologies

Lifetime cost per energy unit[1]



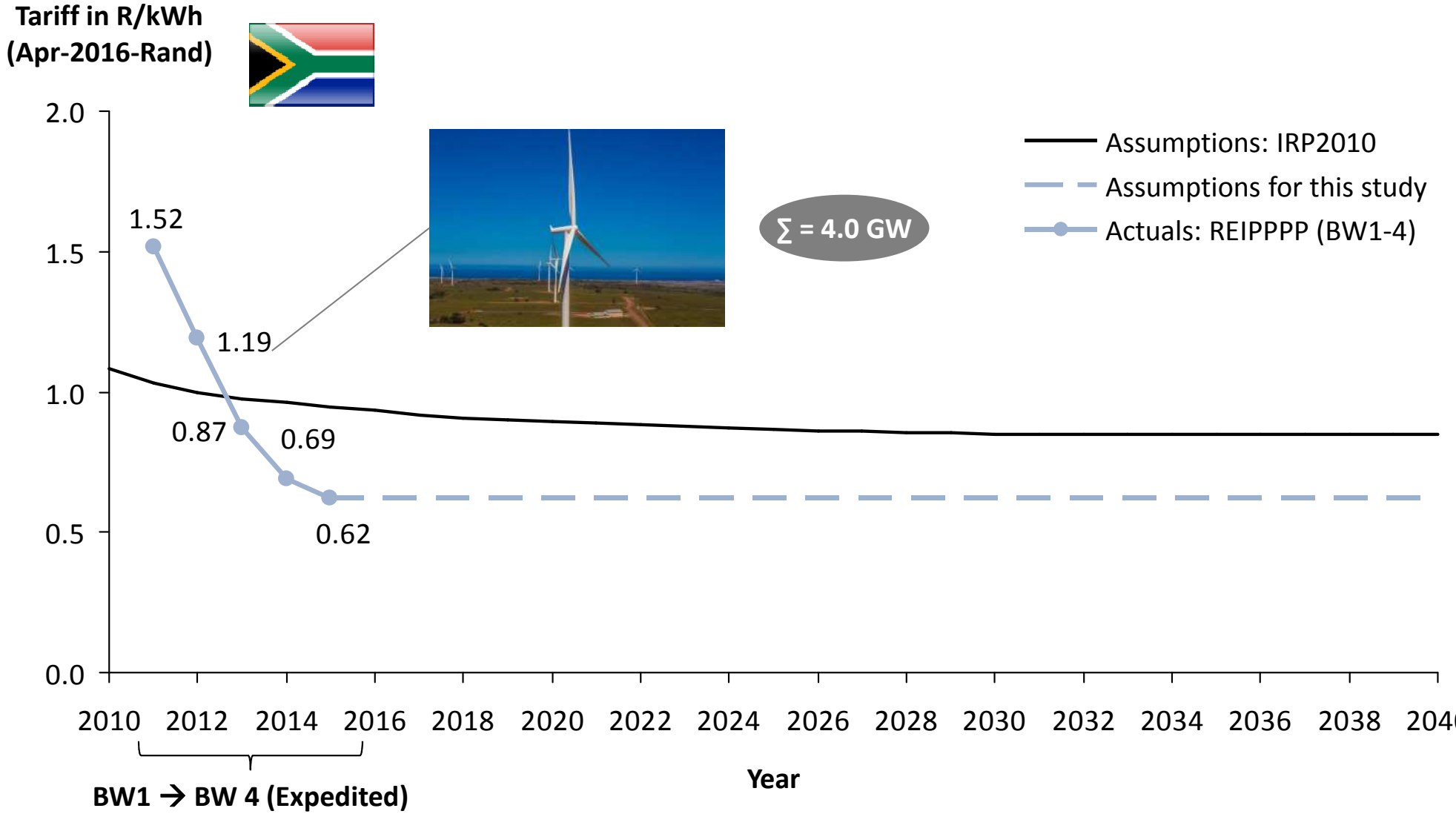
[1] Lifetime cost per energy unit is only presented for brevity. The model inherently includes the specific cost structures of each technology i.e. capex, Fixed O&M, variable O&M, fuel costs etc.
[2] Changing full-load hours for conventional new-build options drastically changes the fixed cost components 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



Notes: REIPPPP = Renewable Energy Independant 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

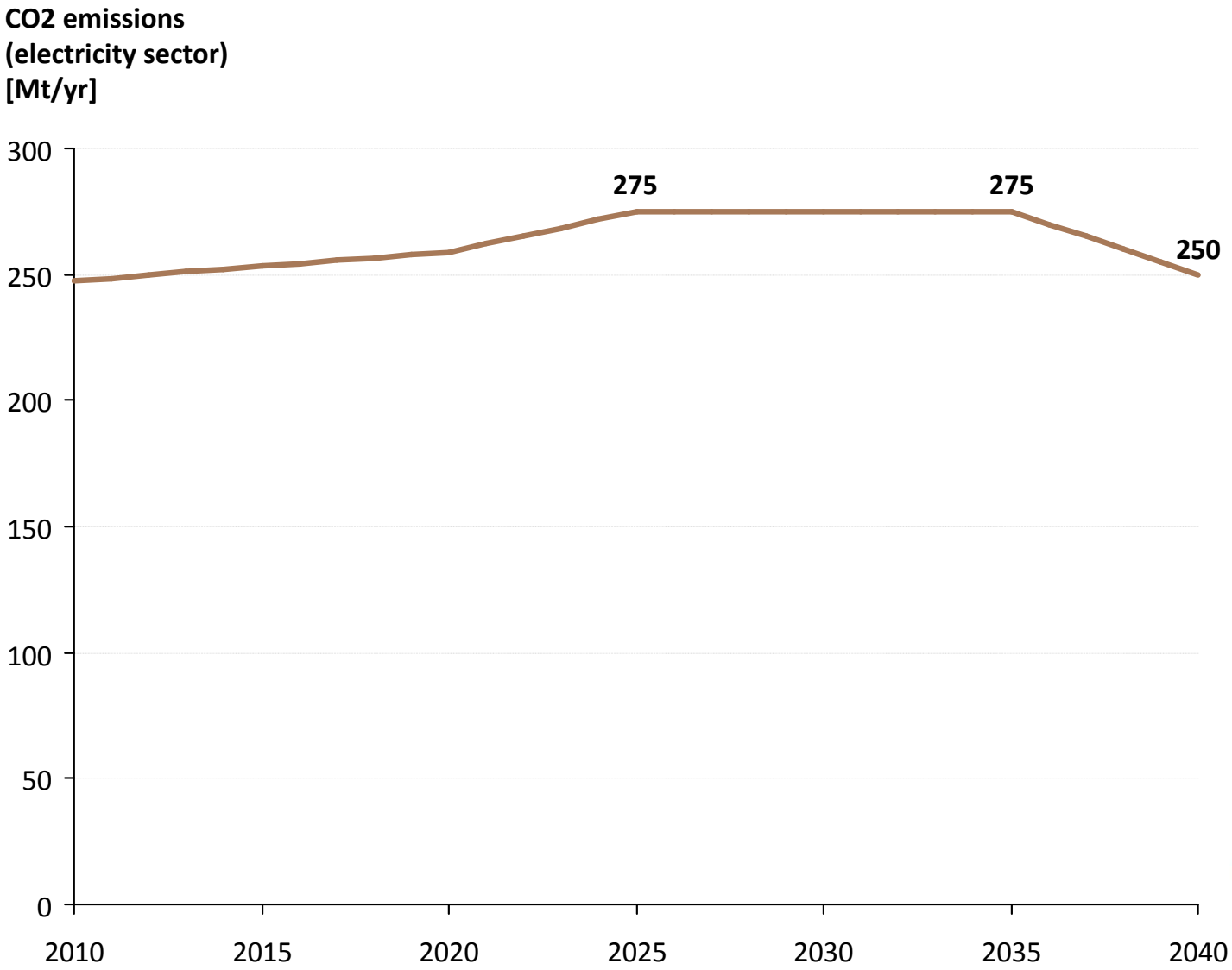
Future cost assumptions for wind aligned with results of Bid Window 4



Notes: REIPPPP = Renewable Energy Independant 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

CO2 emissions constrained by RSA's Peak-Plateau-Decline objective

PPD that constrains CO2 emission from electricity sector



PPD = Peak Plateau Decline

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

Agenda

Background

Approach and assumptions

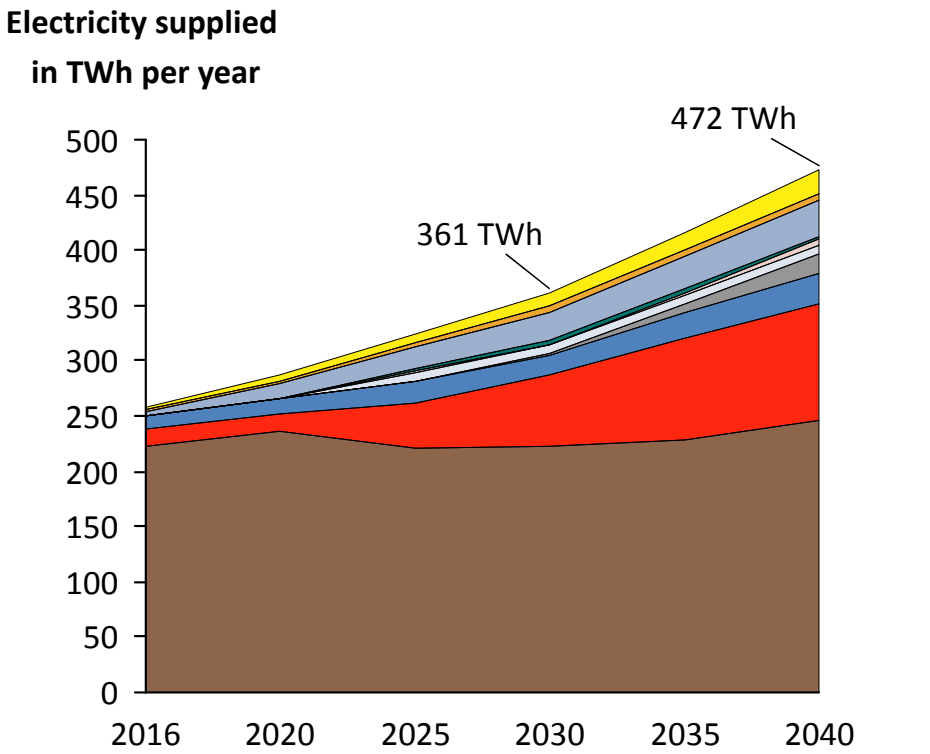
Results

Conclusions

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



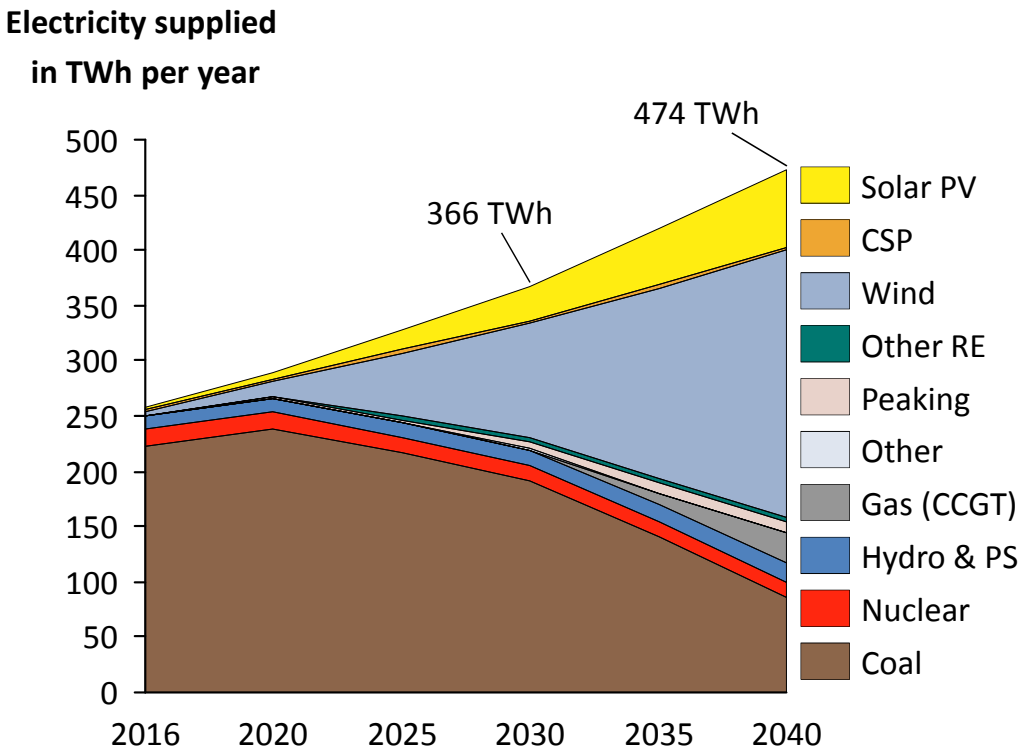
7% (18 TWh/yr) → **18%** (64 TWh/yr) → **19%** (91 TWh/yr)

Renewables

217 Mt/yr → **250 Mt/yr**

CO2

2 Re-Optimised



7% (18 TWh/yr) → **40%** (146 TWh/yr) → **71%** (332 TWh/yr)

Renewables

217 Mt/yr → **100 Mt/yr**

CO2

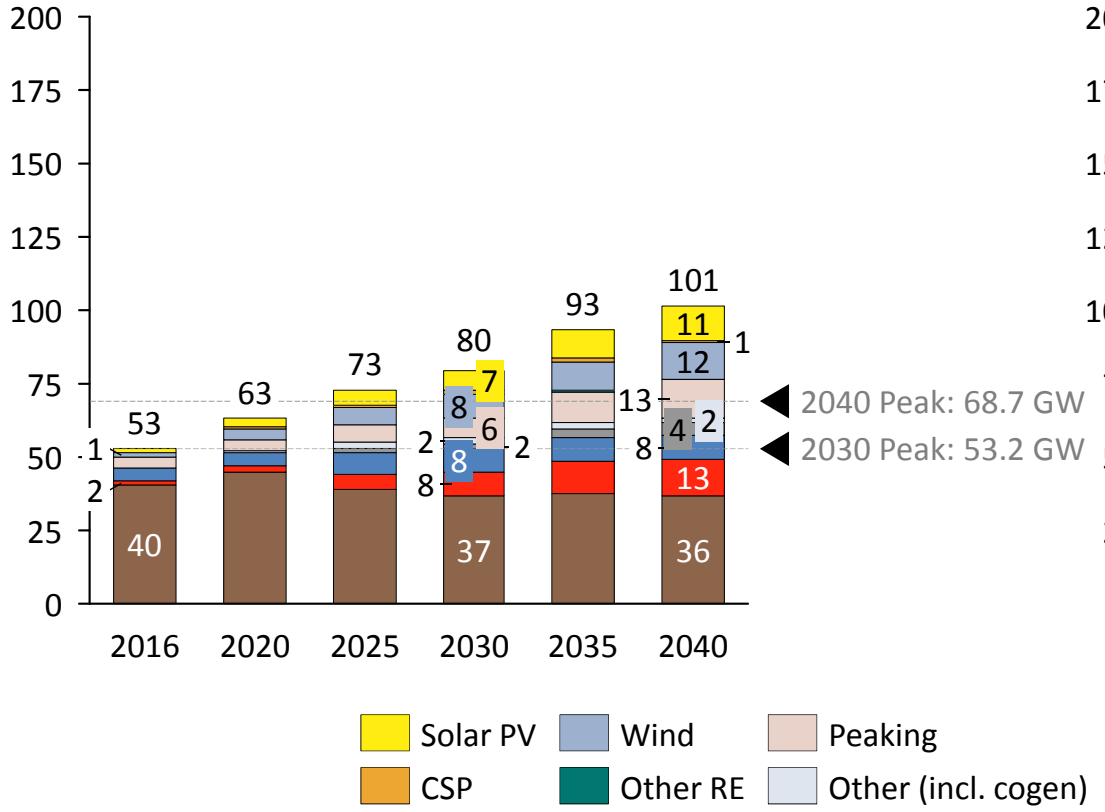
Sources: CSIR analysis

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

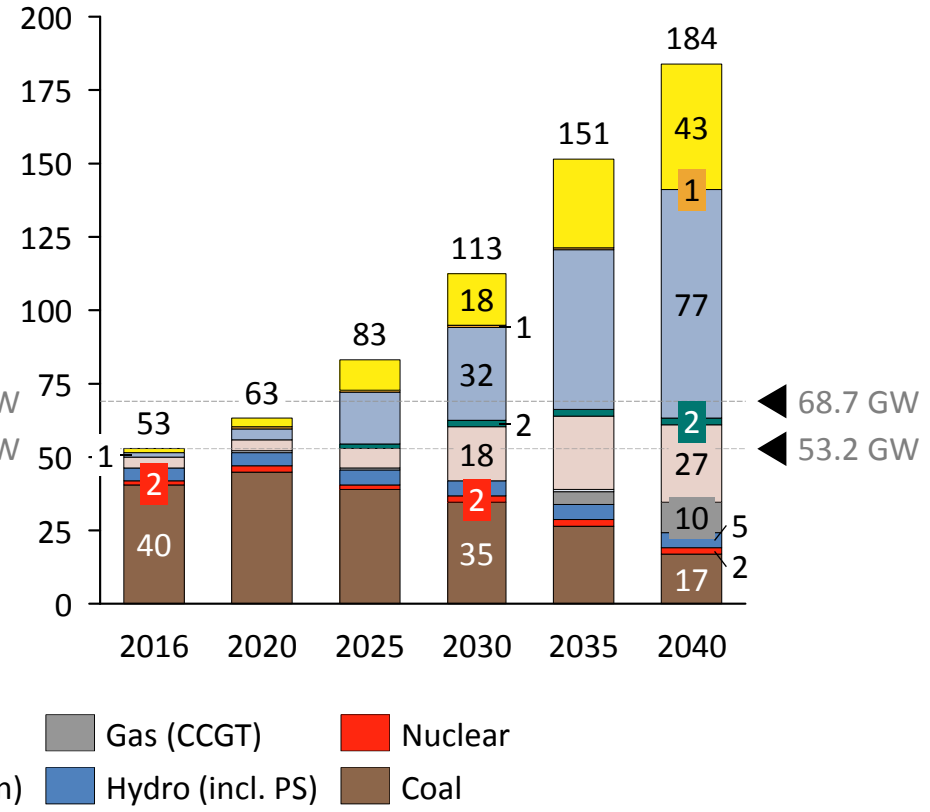
1 Business-as-Usual

Total installed net capacity in GW



2 Re-Optimised

Total installed net capacity in GW

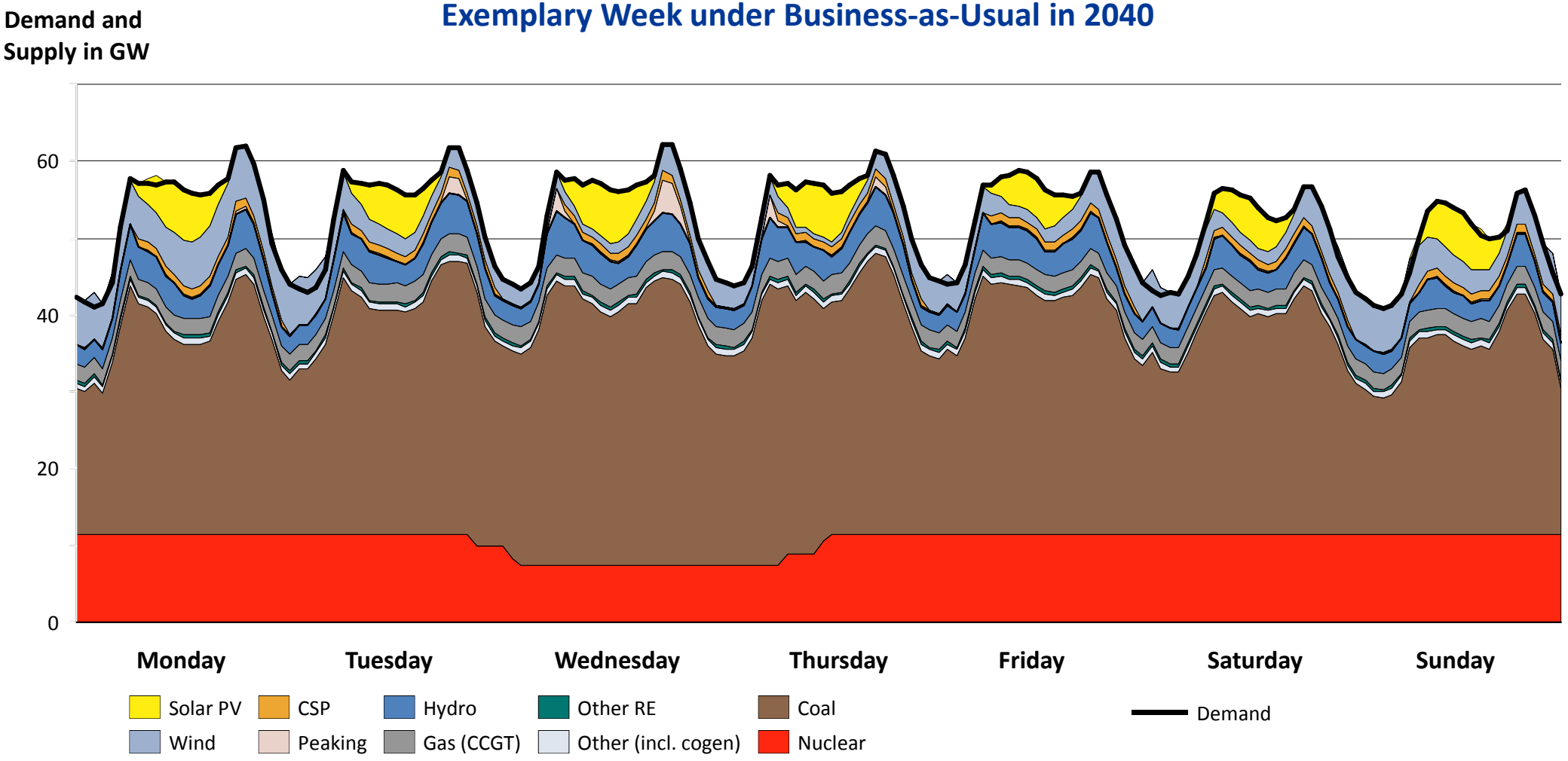


Solar PV · Wind · Peaking · Gas (CCGT) · Nuclear
CSP · Other RE · Other (incl. cogen) · Hydro (incl. PS) · Coal

Sources: CSIR analysis

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

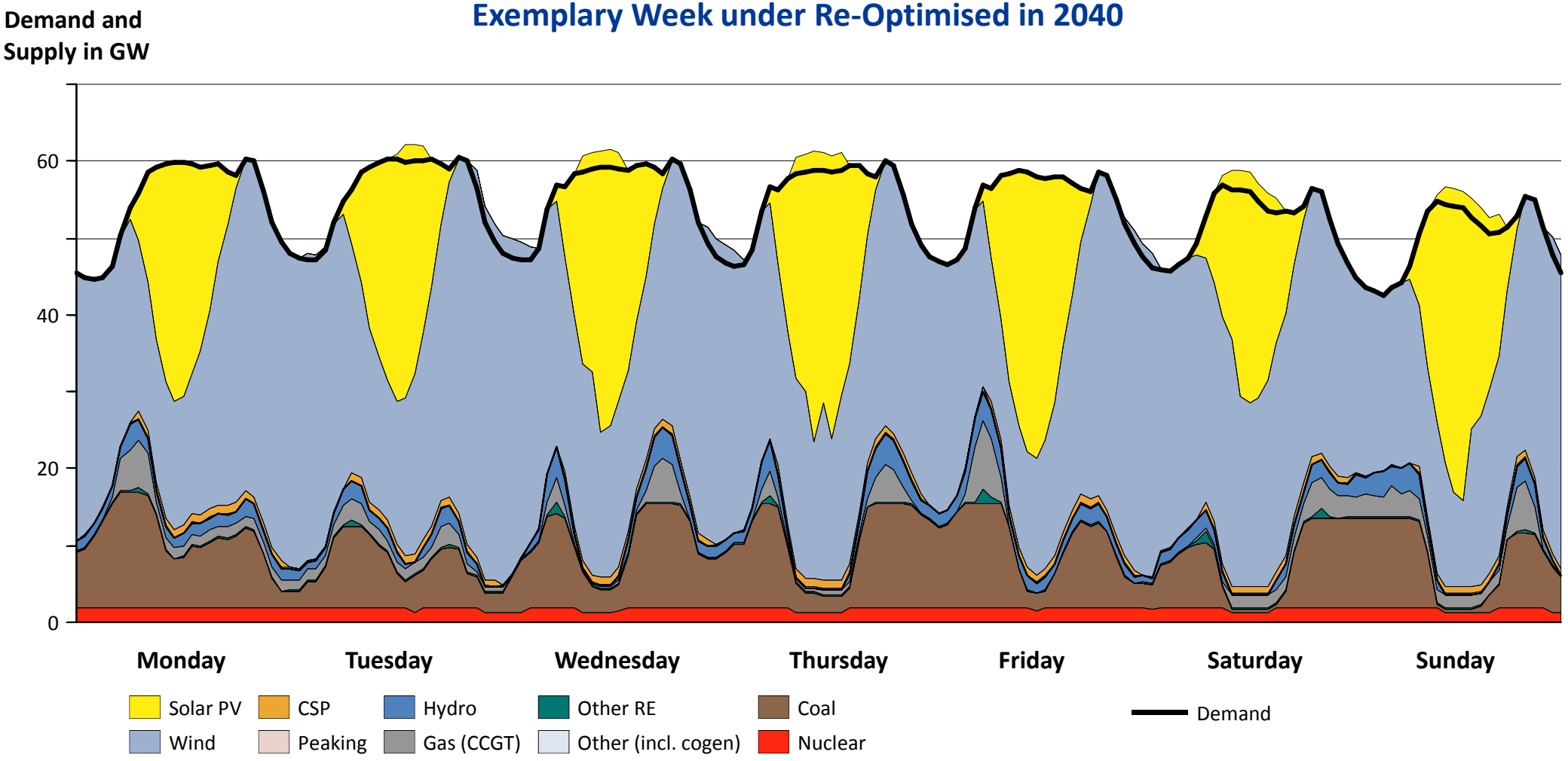
Exemplary Week under Business-as-Usual in 2040



Sources: CSIR analysis

2 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

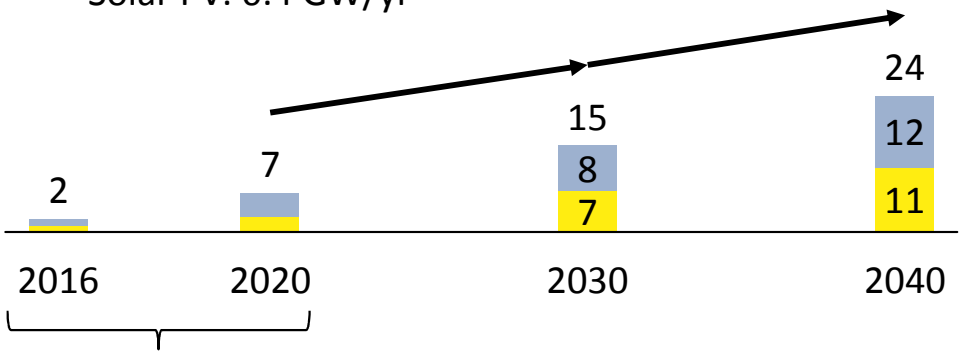
Wind: 0.4 GW/yr

Solar PV: 0.4 GW/yr

2030-2040

Wind: 0.4 GW/yr

Solar PV: 0.4 GW/yr



BW1 → BW 4 (Expedited)

2 Re-Optimised

2020-2030

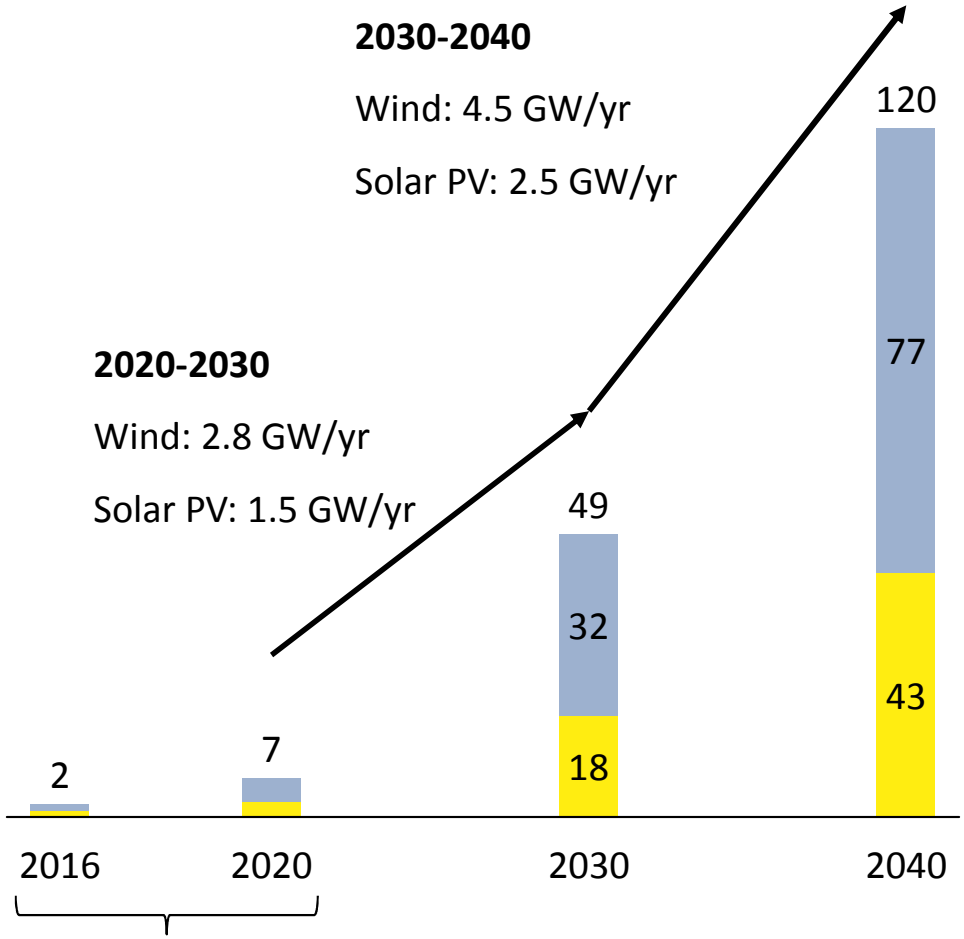
Wind: 2.8 GW/yr

Solar PV: 1.5 GW/yr

2030-2040

Wind: 4.5 GW/yr

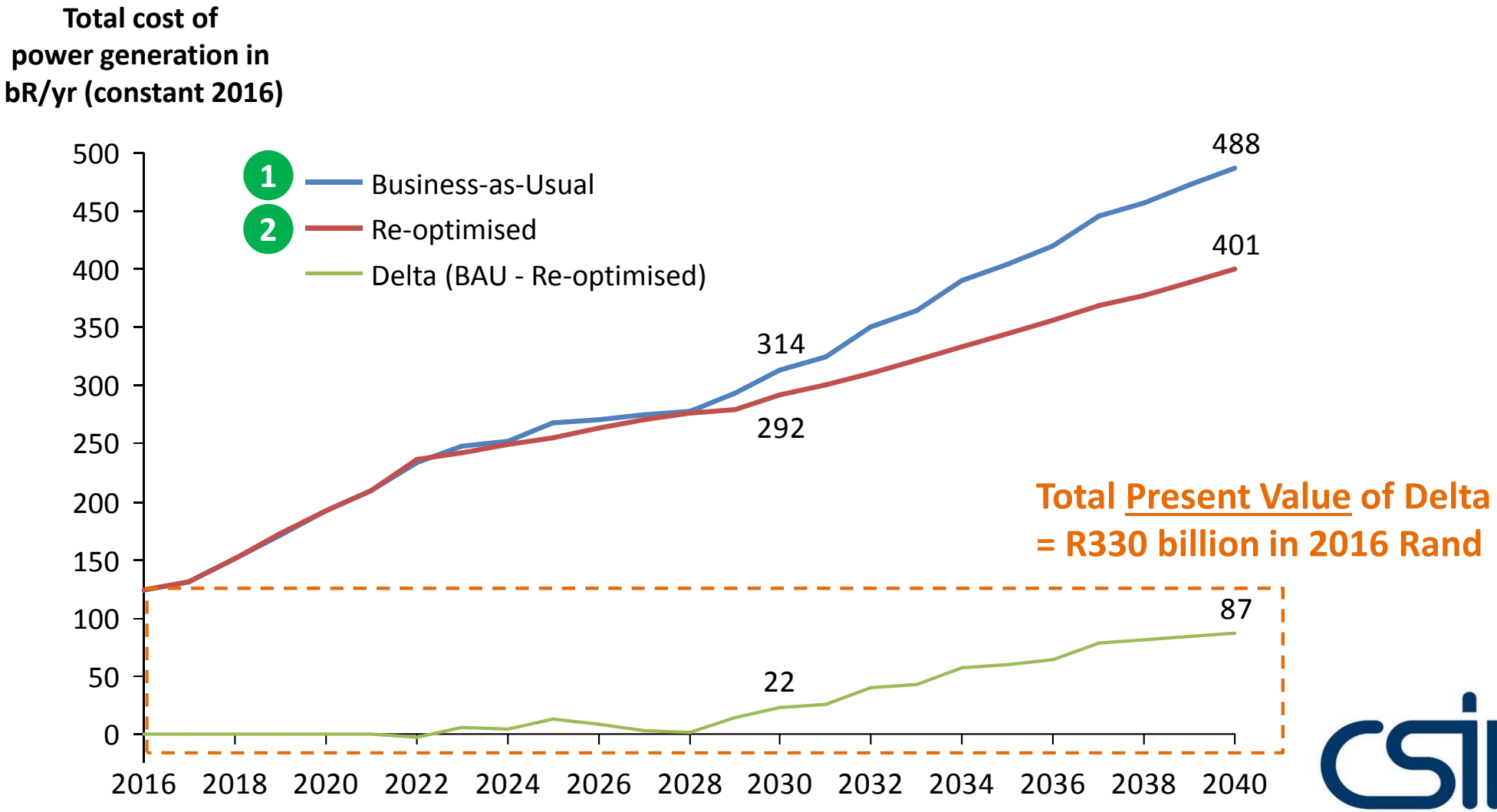
Solar PV: 2.5 GW/yr



BW1 → BW 4 (Expedited)

Sources: CSIR analysis

Re-Optimised R87 billion/year cheaper by 2040 (without cost of CO2)



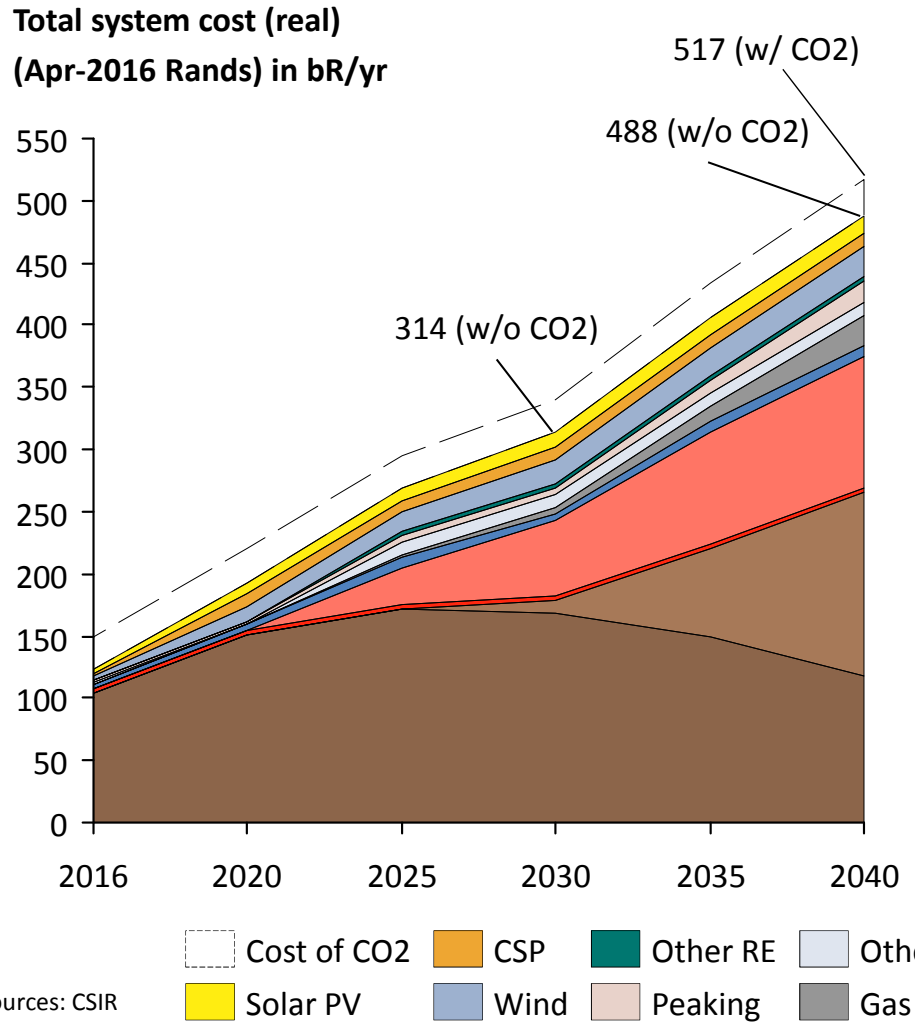
Total Present Value of Delta = R330 billion in 2016 Rand

CSIR
our future through science

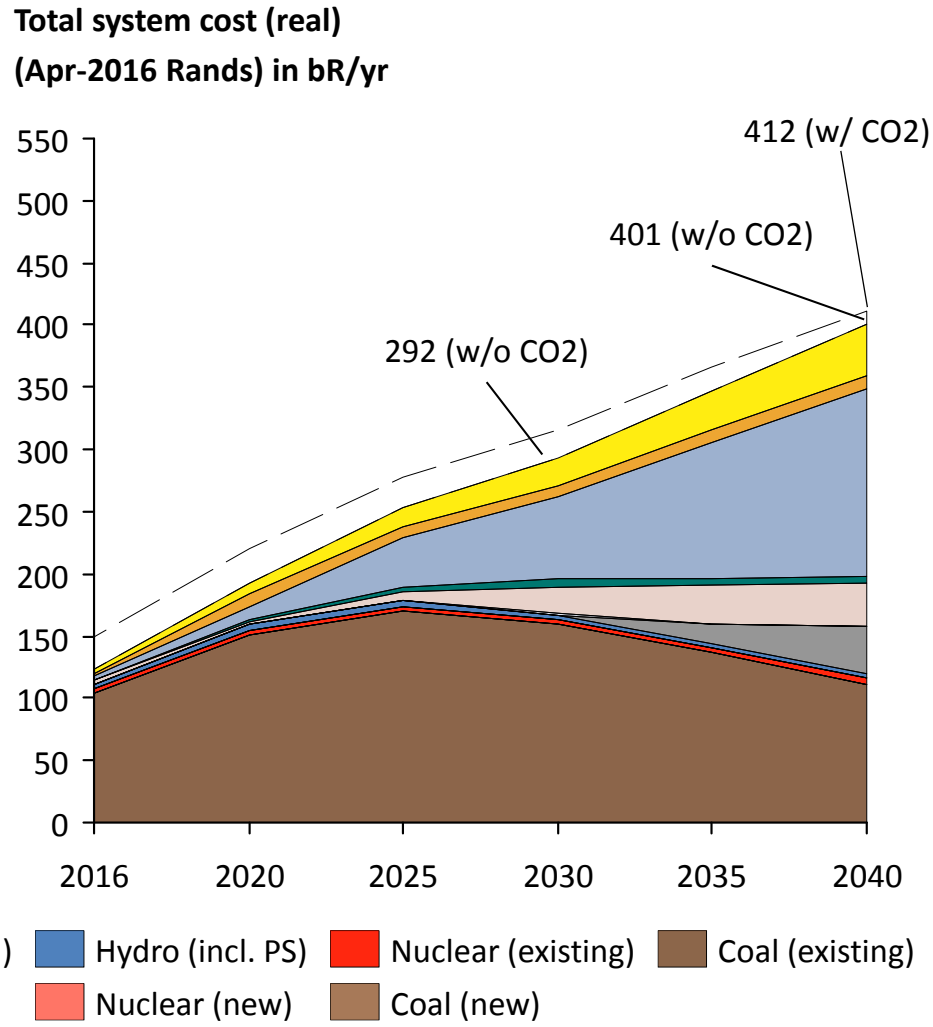
Business-as-Usual incurs large cost from building new coal and nuclear

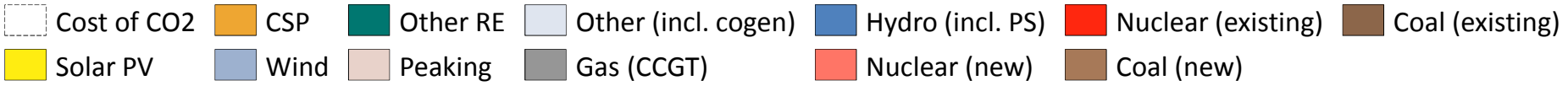
Comparison of total electricity system costs average electricity tariff of BAU and Re-Optimised mix

1 Business-as-Usual



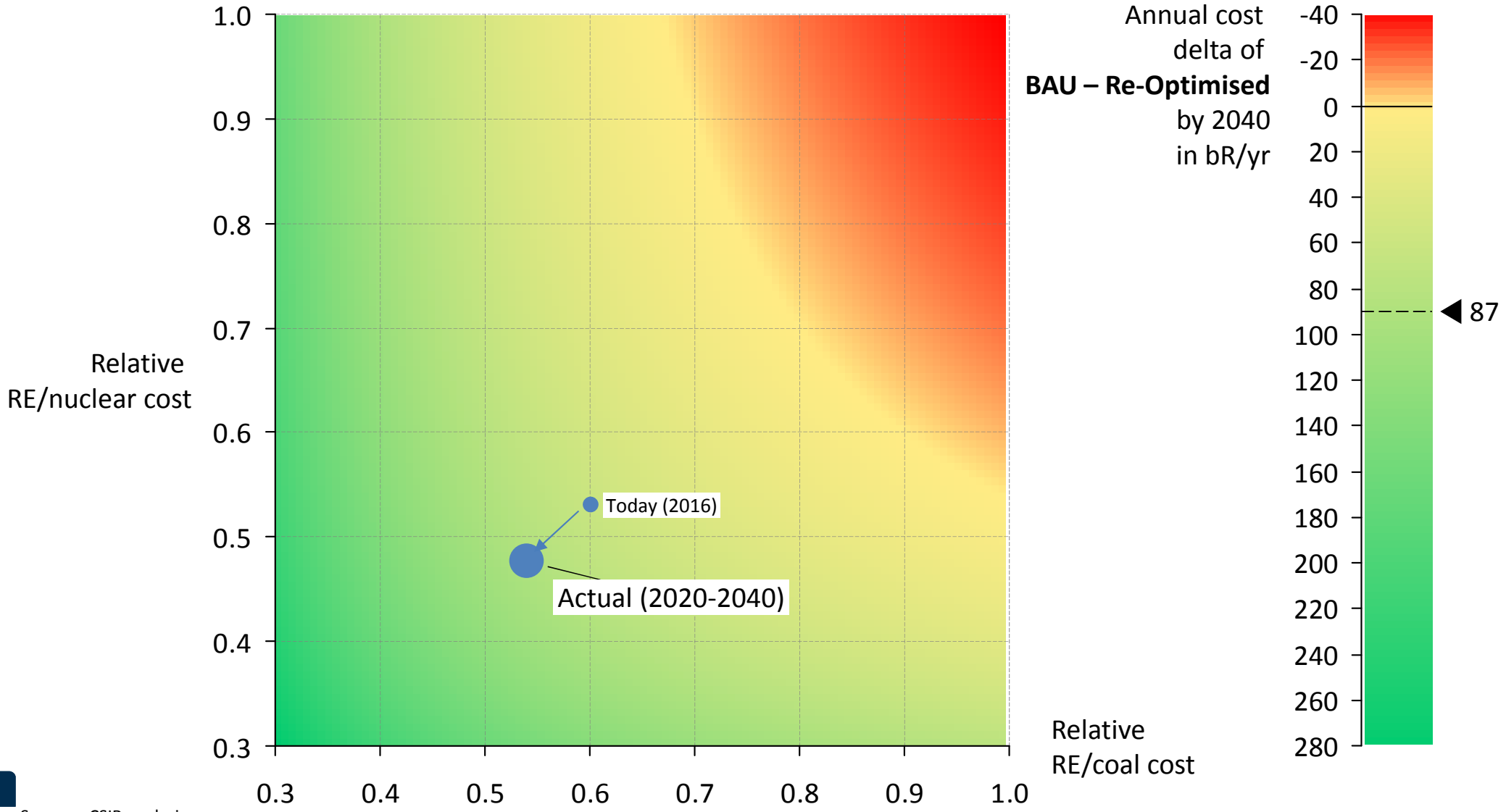
2 Re-Optimised





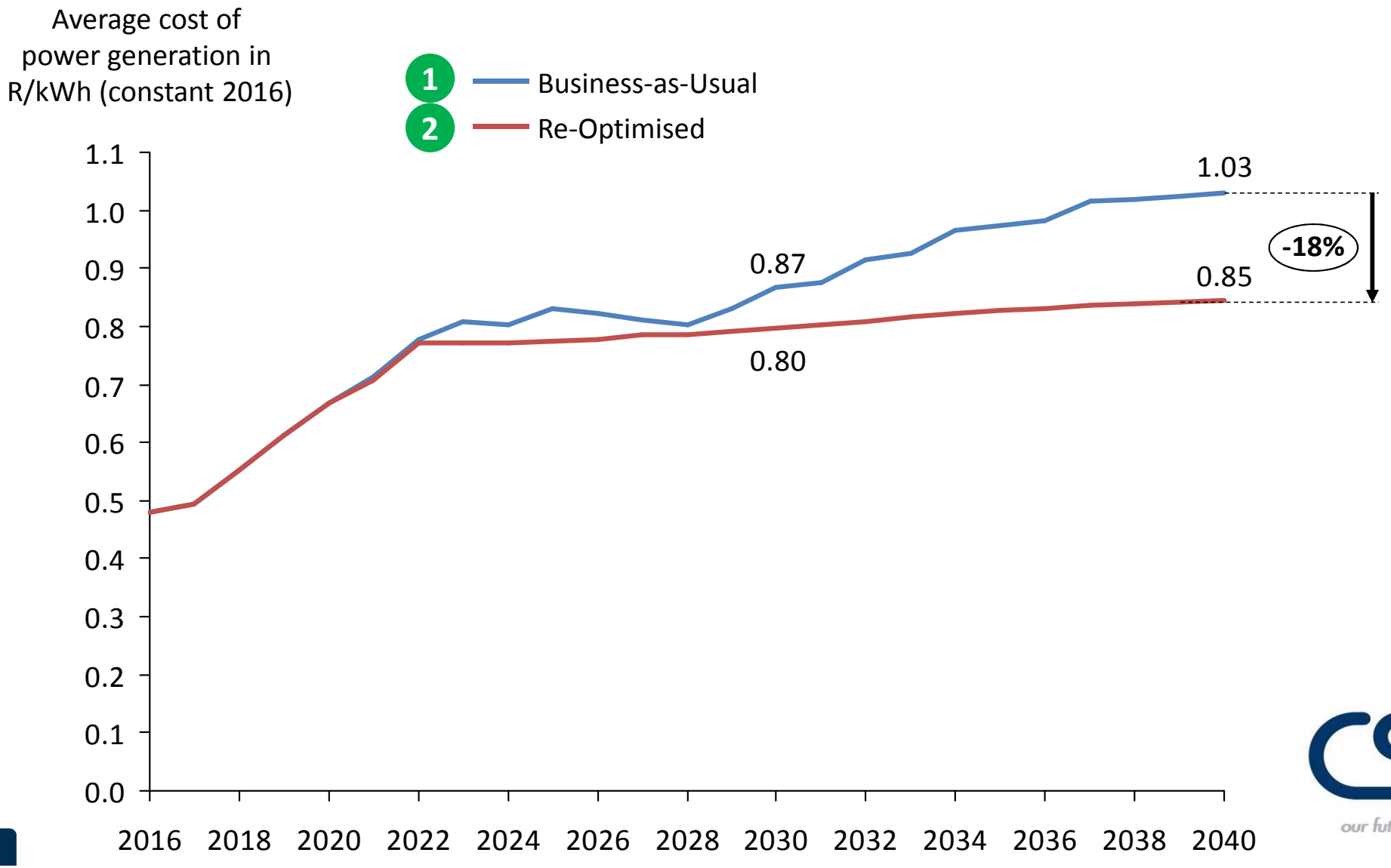
Sources: CSIR

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

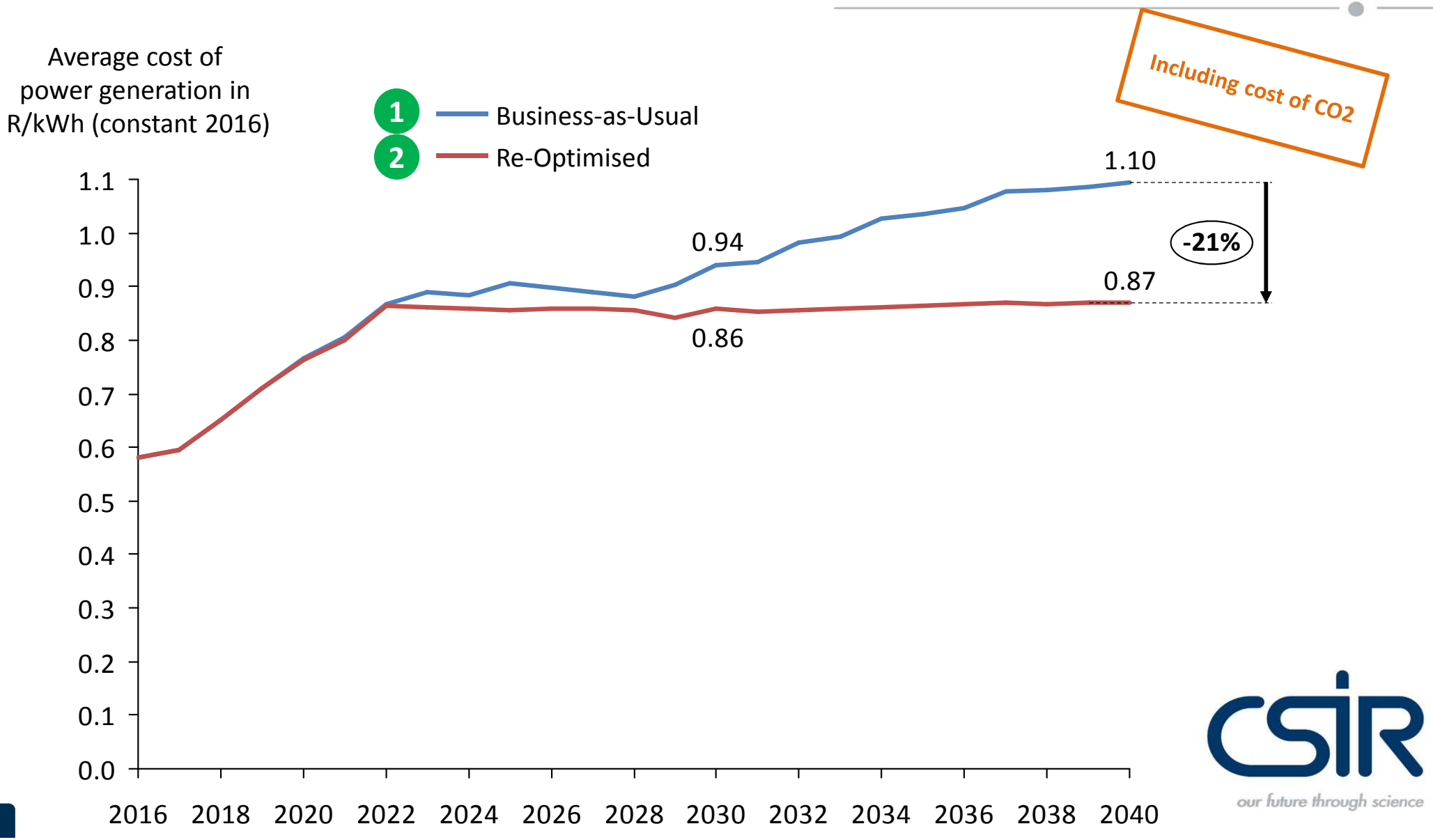


Sources: CSIR analysis

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

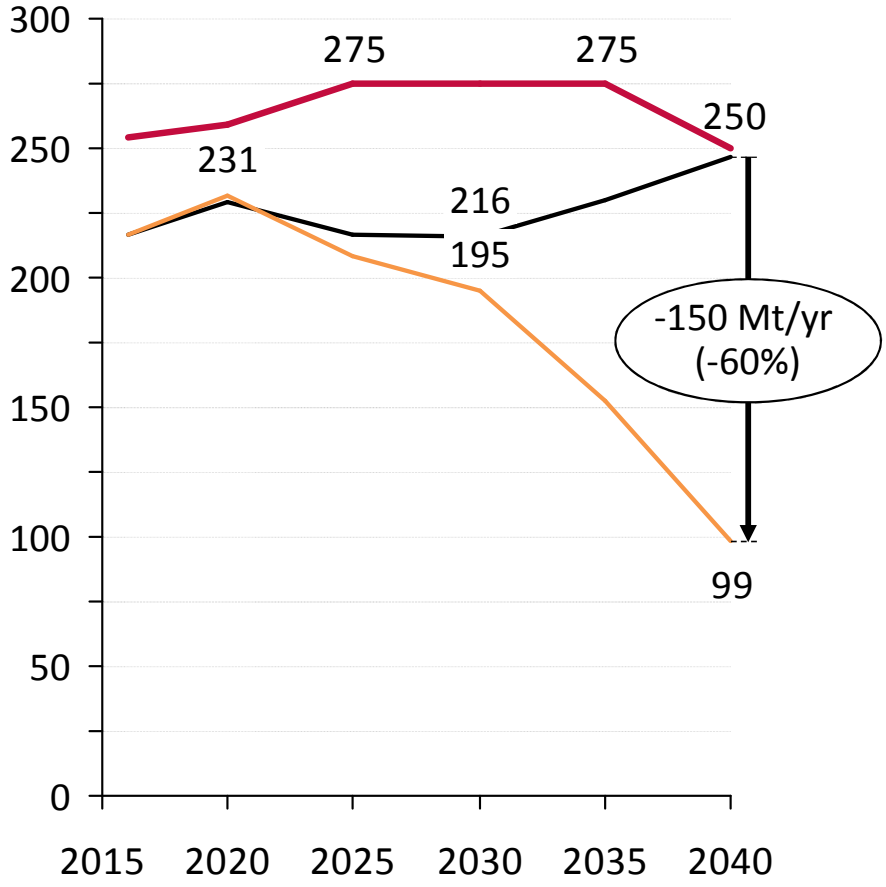


CSIR
our future through science

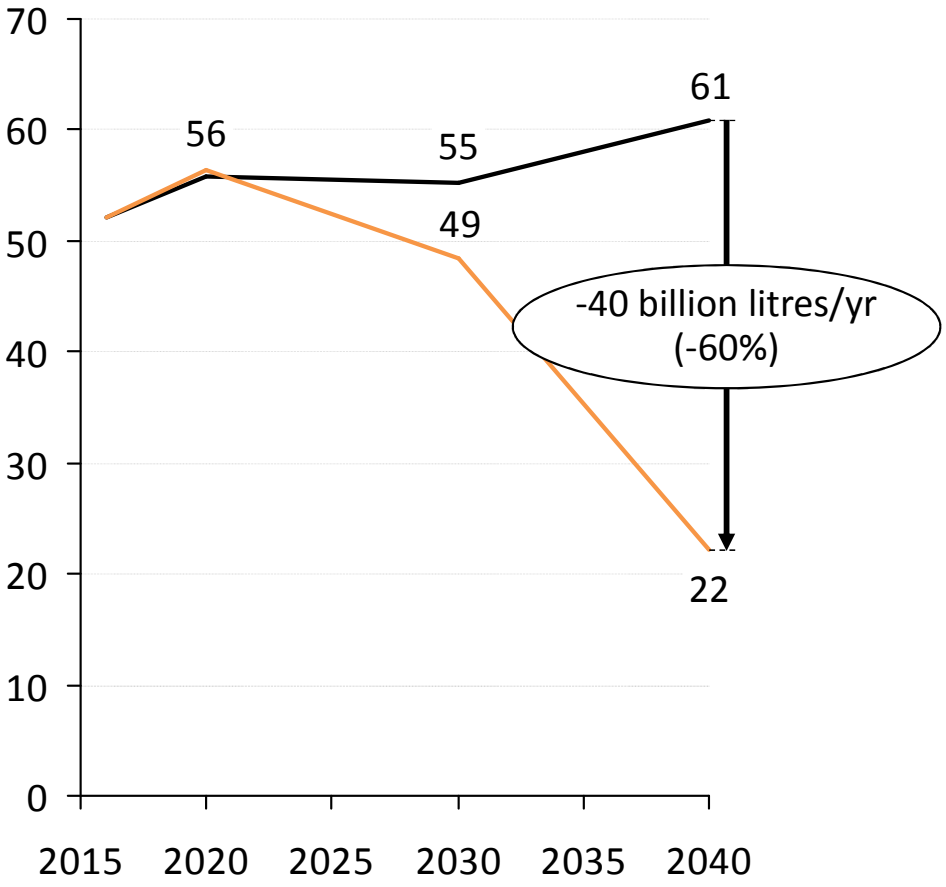
Re-Optimised: CO2 emissions and water use significantly lower

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

Electricity sector CO_2 emissions in MtCO2/yr



Electricity sector water use in billion litres/yr



BAU — Re-optimised — CO2 Cap

Sources: CSIR analysis

Agenda

Background

Approach and assumptions

Results

Conclusions

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

CSIR
our future through science

Re a leboha

Ha Khensa

Enkosi

Siyathokoza

Thank you

Re a leboga

Ro livhuha

Dankie

Siyabonga