Least Cost Electricity Mix for South Africa

Optimisation of the South African power sector until 2050

CSIR Energy Centre

Status: 16 January 2017

Dr Tobias Bischof-Niemz

Chief Engineer

Jarrad Wright	+27 79 527 6002	JWright@csir.co.za
Dr Tobias Bischof-Niemz	+27 83 403 1108	TBischofNiemz@csir.co.za
Robbie van Heerden	+27 82 803 0961	RPvHeerden@csir.co.za
Crescent Mushwana	+27 82 310 2142	CMushwana@csir.co.za

CSIR

our future through science

Agenda

Expertise of Commentators

Comments on IRP Assumptions

IRP Results and Least-cost Scenario

Proposal / Next Steps

our future through science

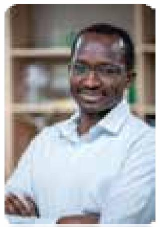
Commentators have significant expertise to give feedback on IRP & its implementation, from planning, system operation and grid perspective

Dr Tobias Bischof-Niemz

- Head of CSIR's Energy Centre
- Member of Ministerial Advisory Council on Energy (MACE)
- Member of IRP2010/IRP2013 teams at Eskom, energy planning in Europe for large utilities

Robbie van Heerden

- Senior Specialist: Energy Systems at the CSIR's Energy Centre
- Former General Manager and long-time head of System Operations at Eskom



Crescent Mushwana

- Research Group Leader: Energy Systems at the CSIR's Energy Centre
- Former Chief Engineer at Eskom strategic transmission grid planning

Jarrad Wright

- Principal Engineer: Energy Planning at the CSIR's Energy Centre
- Energy Commissioner in the National Planning Commission
- Former Africa manager of PLEXOS (software package used for the IRP)

CSIR
our future through science

Same software package as per the IRP was used to determine the least-cost expansion path of the South African power system to 2050

The Integrated Resource Plan (IRP) is the expansion plan for the South African power system until 2050

The IRP 2016 has a significant self-imposed limitation: The amount of wind and solar PV capacity that the model is allowed to build per year is limited, which is not technically/economically justified in the plan

The CSIR has therefore conducted a study to re-optimise the South African power mix until 2050

- First and most important deviation from IRP2016: no new-build limits on renewables (wind/solar PV)
- Additional deviation: relative costing for solar PV and wind aligned with latest relative IPP tariff results

Two scenarios from the draft IRP 2016 are compared with the re-optimisation

- “Draft IRP 2016 Base Case” – new coal, new nuclear
- “Draft IRP 2016 Carbon Budget” – significant new nuclear
- “CSIR Re-Optimised” – least-cost without constraints

An hourly capacity expansion and dispatch model (incl. unit commitment) using PLEXOS was run for all scenarios to test for technical adequacy à same software platform as IRP

CSIR
our future through science

Sources: CSIR analysis

Agenda

Expertise of Commentators

Comments on IRP Assumptions

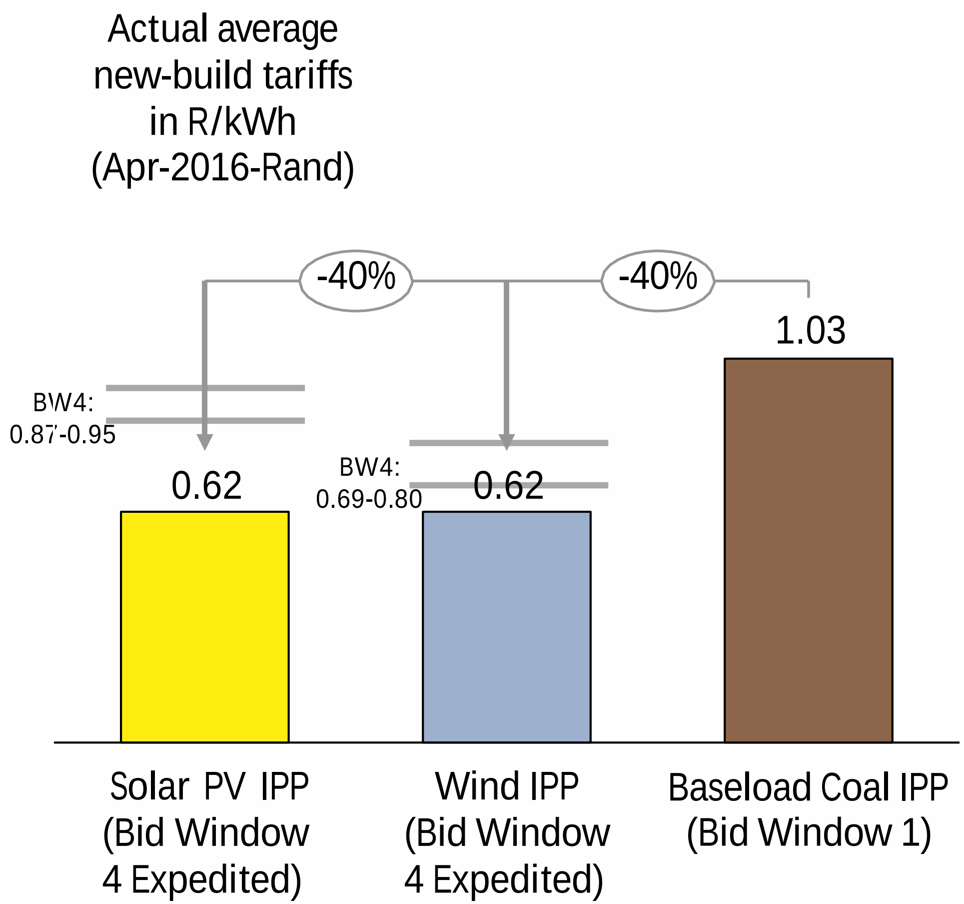
IRP Results and Least-cost Scenario

Proposal / Next Steps

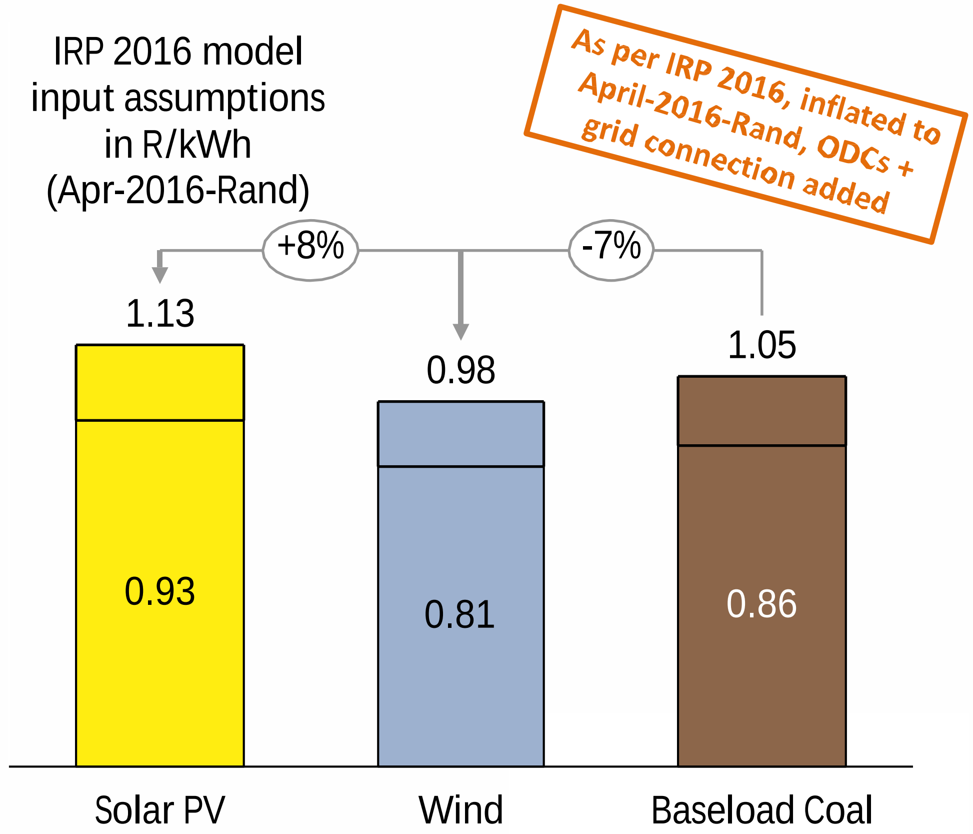
our future through science

Actual tariffs for new solar PV and wind are 40% cheaper than new baseload coal, whereas IRP 2016 assumes similar LCOE for all three

Actual tariffs from RE IPP and Coal IPP Procurement Programme



IRP 2016 cost input assumptions

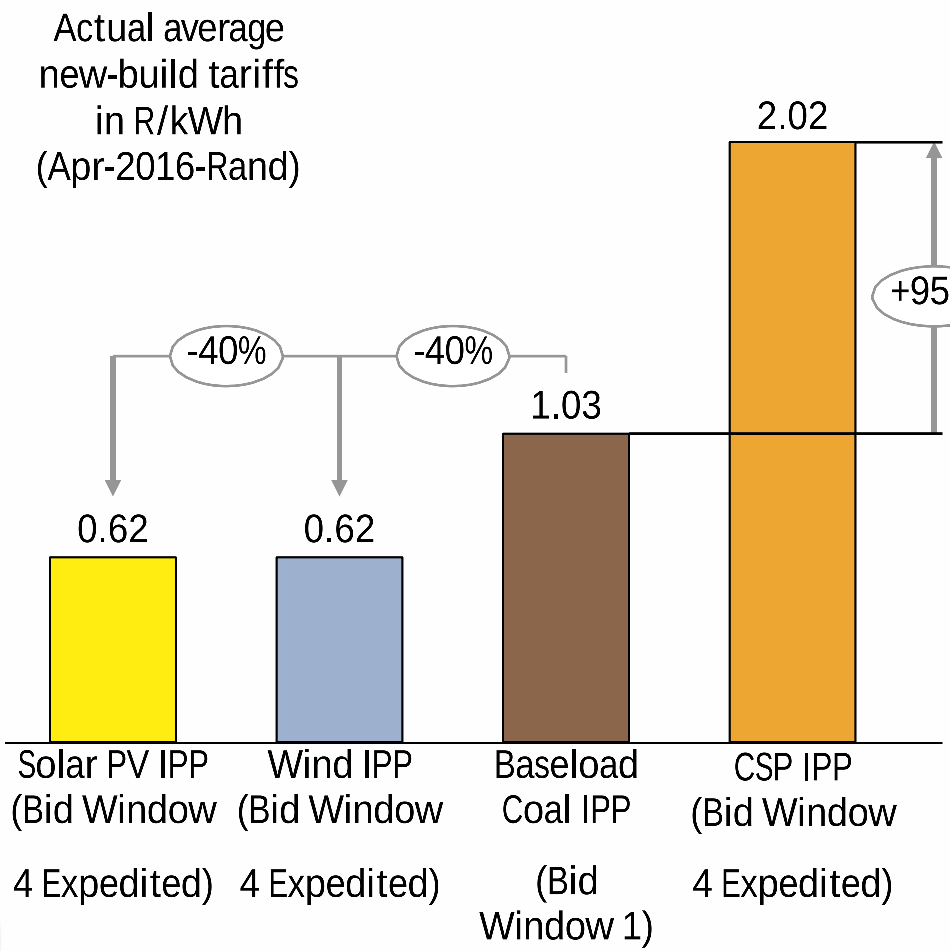


Sources: South African Department of Energy IPP Office's publications on results of IPP Bid Windows; IRP 2016 Draft; StatsSA on CPI; CSIR analysis

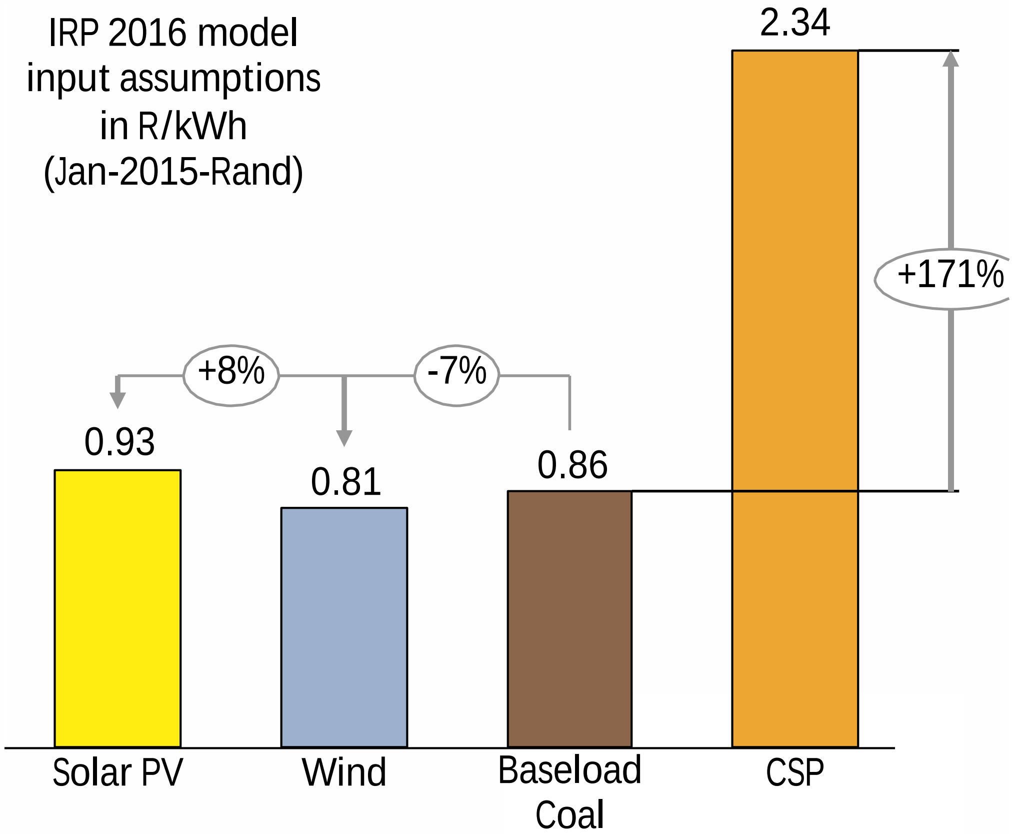
Actual tariffs for new solar PV and wind are 40% cheaper than new baseload coal, whereas IRP 2016 assumes similar LCOE for all three

As per IRP 2016, inflated to April-2016-Rand, ODCs + grid connection added

Actual tariffs from RE IPP and Coal IPP Procurement Programme

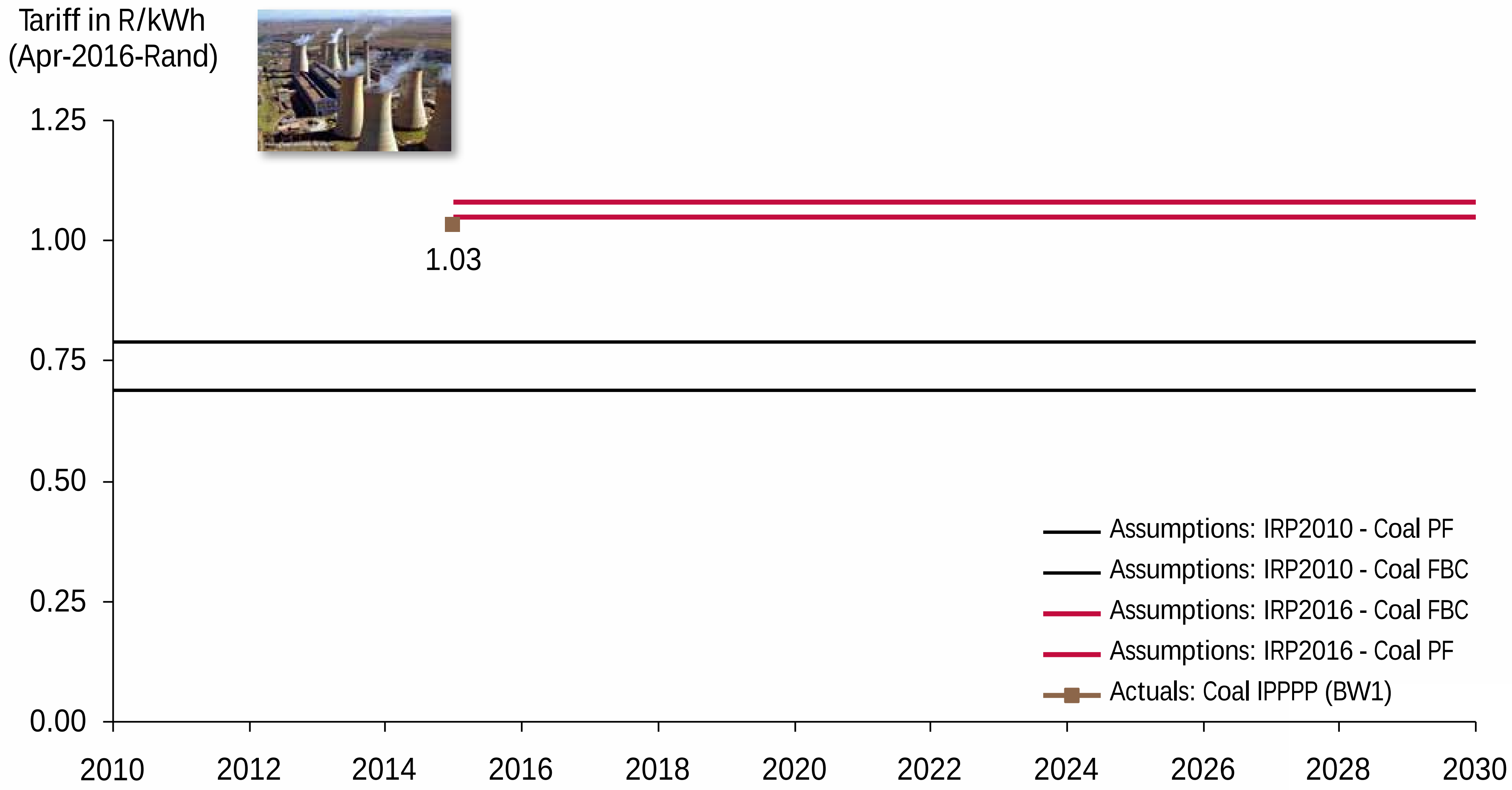


IRP 2016 cost input assumptions



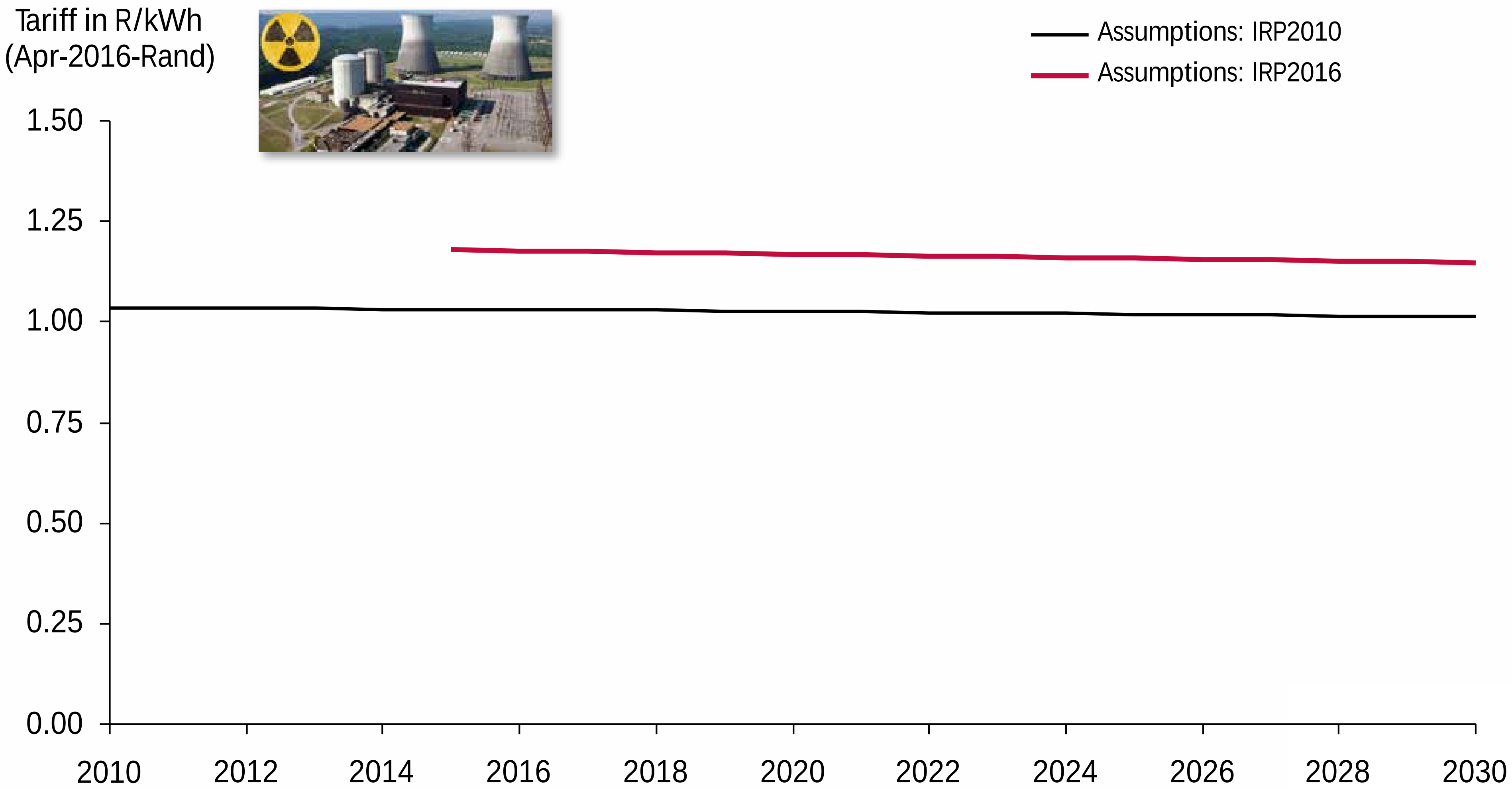
Sources: South African Department of Energy IPP Office's publications on results of IPP Bid Windows; IPP Office on Bid Window 4 expedited; StatsSA on CPI; CSIR analysis

Actual coal tariff of Bid Window 1 is significantly above IRP 2010 assumptions and almost exactly on the Coal PF assumption of IRP 2016



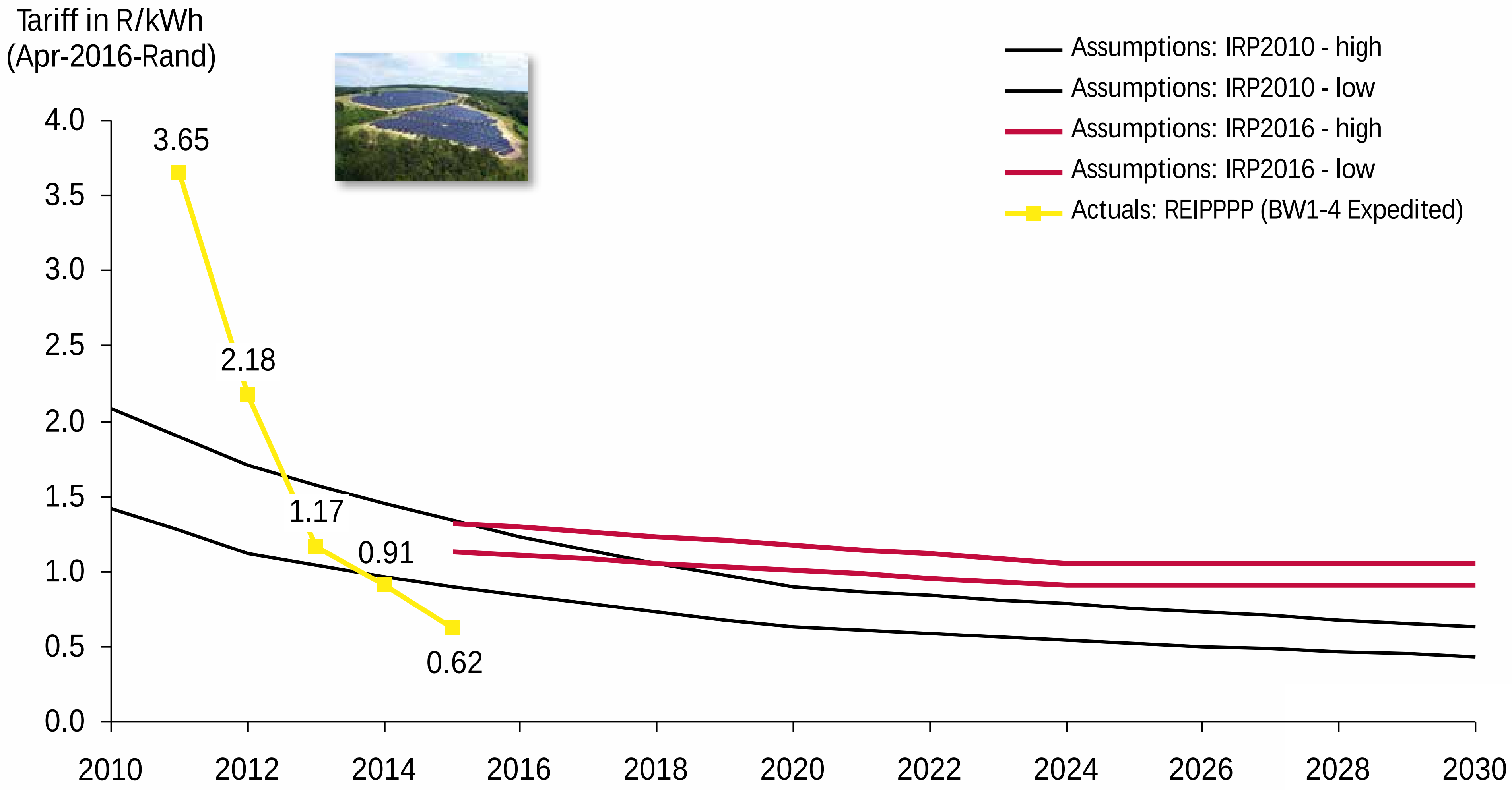
Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 30 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document; “IRP Tariff” then calculated assuming 90% of total tariff to be LCOE EPC costs, i.e. divide the LCOE by 0.9 to derive at the “IRP Tariff”
Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; https://www.ipp-projects.co.za/Home/GetPressRelease?fileid=228bdd35-e18e-e611-9455-2c59e59ac9cd&fileName=PressRelease-Coal-based-Independent-Power-Producer-programme-announcement-10Oct2016.pdf; CSIR analysis

Nuclear cost assumptions increased slightly from IRP 2010 to IRP 2016



Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 60 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document; "IRP Tariff" then calculated assuming 90% of total tariff to be LCOE EPC costs, i.e. divide the LCOE by 0.9 to derive at the "IRP Tariff"
Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; https://www.ipp-projects.co.za/Home/GetPressRelease?fileid=228bdd35-e18e-e611-9455-2c59e59ac9cd&fileName=PressRelease-Coal-based-Independent-Power-Producer-programme-announcement-10Oct2016.pdf; CSIR analysis

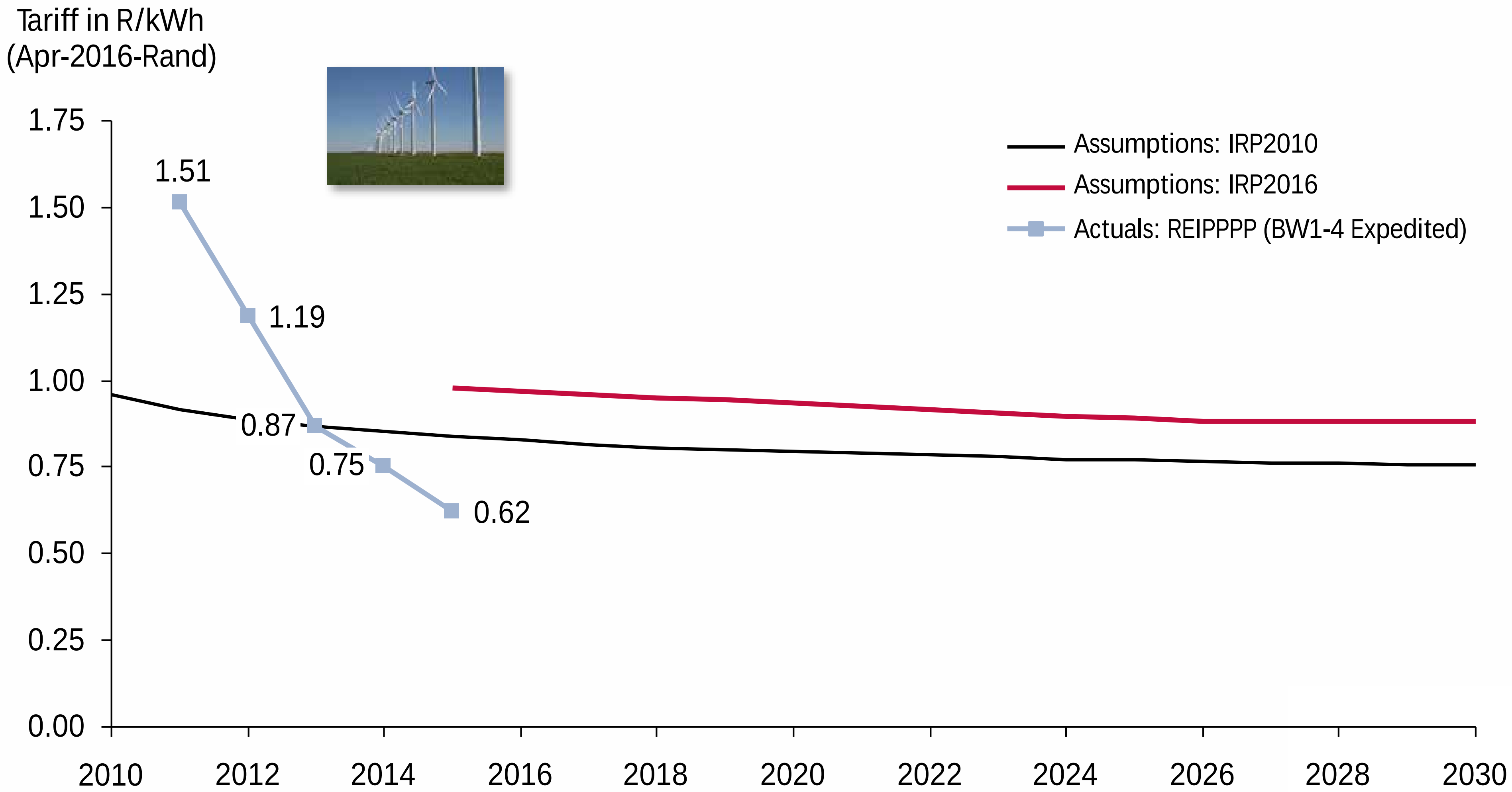
Actual solar PV tariffs quickly approached IRP 2010 assumptions in first four bid windows and are now well below cost assumption funnel



Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 25 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document; “IRP Tariff” then calculated assuming 90% of total tariff to be LCOE EPC costs, i.e. divide the LCOE by 0.9 to derive at the “IRP Tariff”

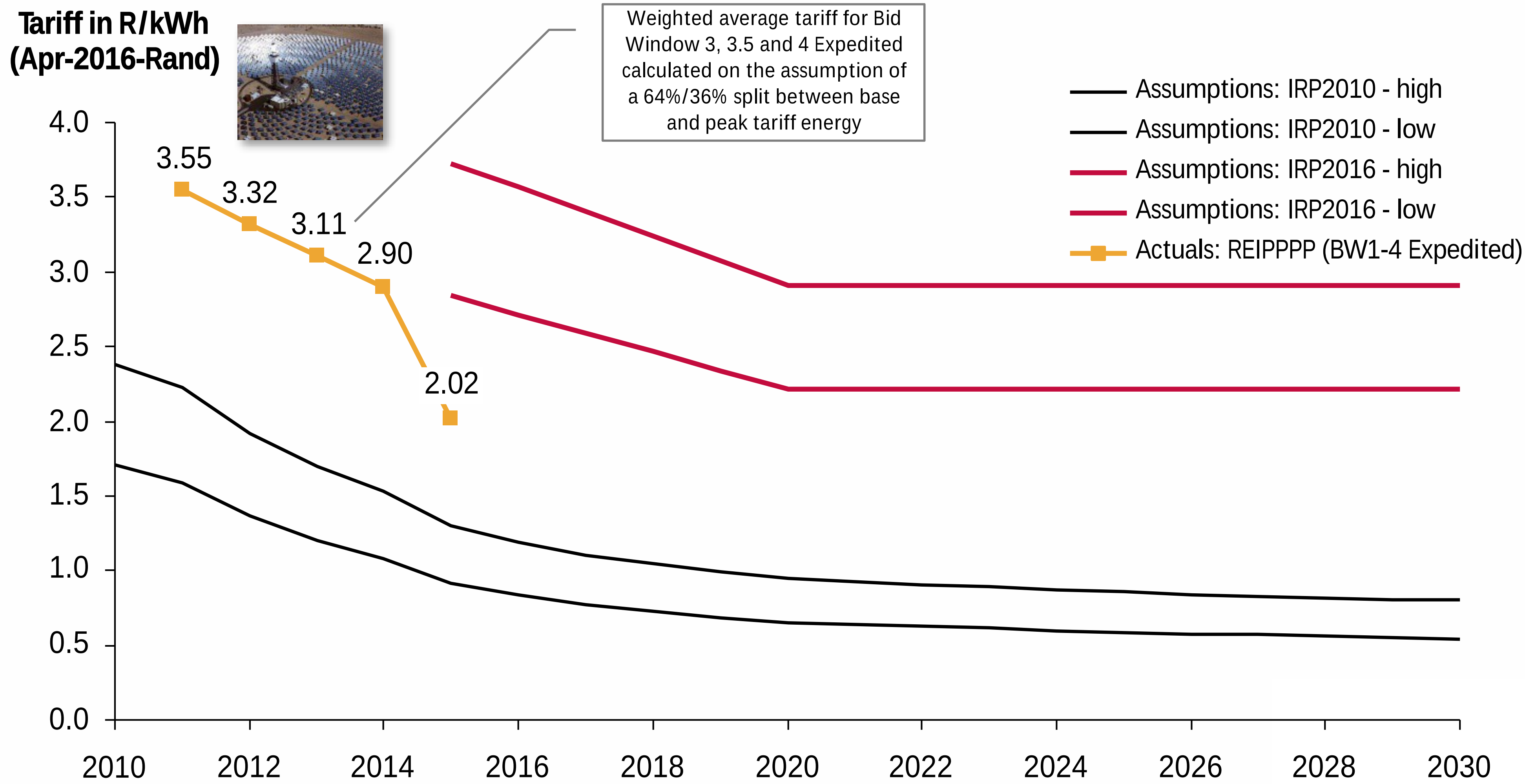
Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

Actual wind tariffs in bid window four were below the level that was assumed for 2030 in IRP 2010, BW 4 Expedited is significantly below



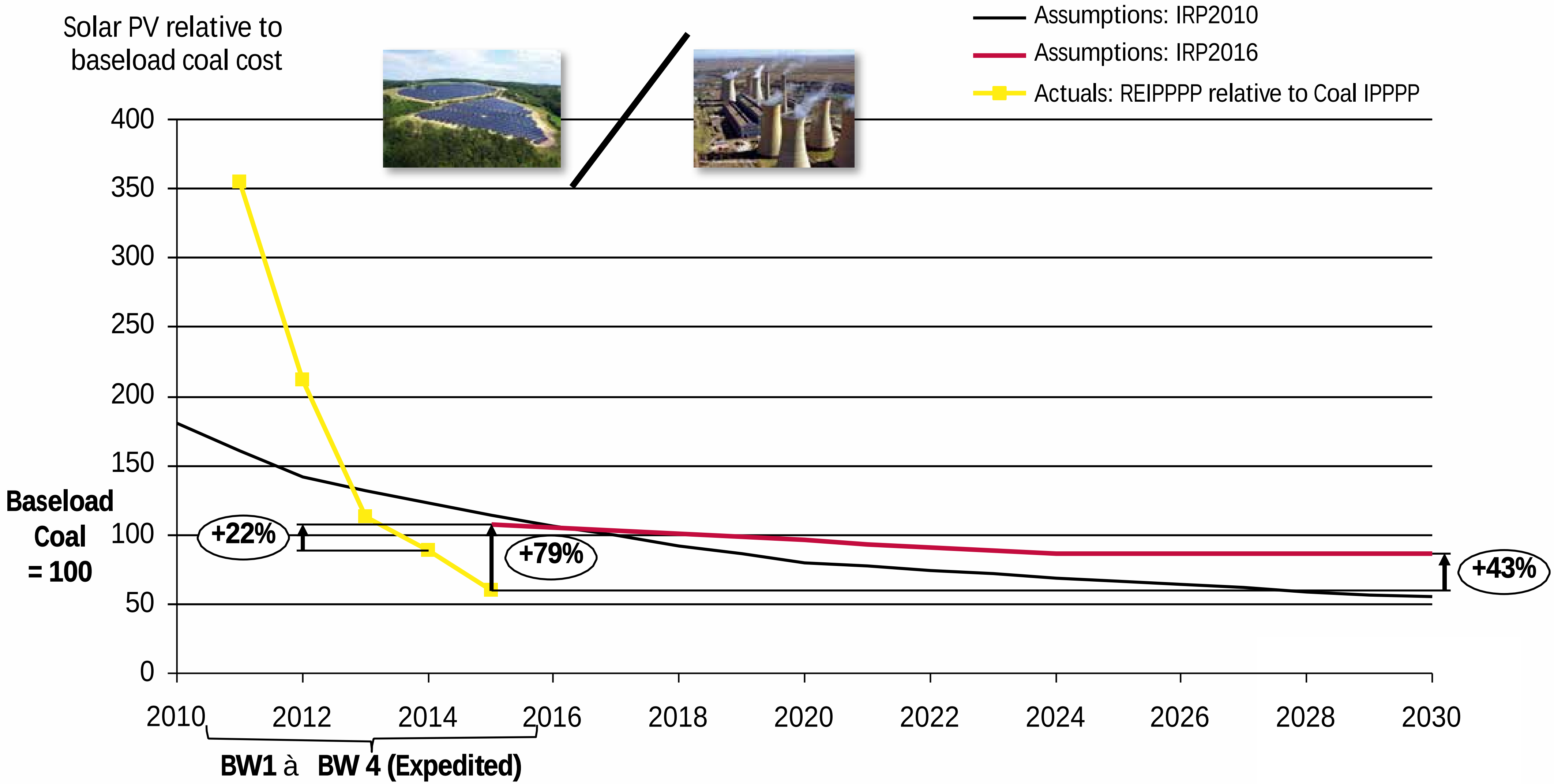
Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 20 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document; “IRP Tariff” then calculated assuming 90% of total tariff to be LCOE EPC costs, i.e. divide the LCOE by 0.9 to derive at the “IRP Tariff”
Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

Actual CSP tariffs are declining from bid window 1 to 4 Expedited, and are now close to the upper boundary of IRP 2013 cost assumptions



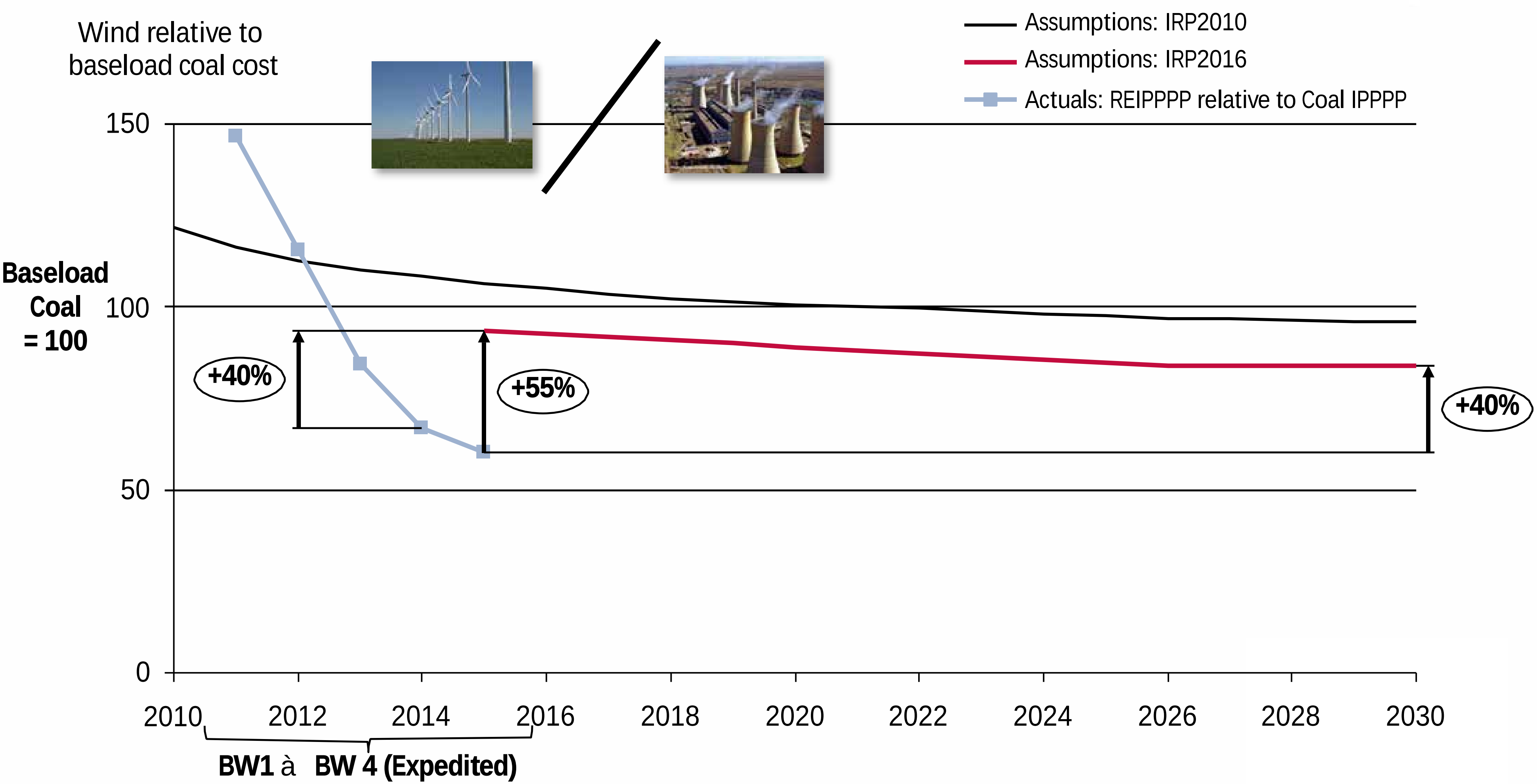
Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 30 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document; “IRP Tariff” then calculated assuming 90% of total tariff to be LCOE EPC costs, i.e. divide the LCOE by 0.9 to derive at the “IRP Tariff”
Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

IRP 2016 Solar PV cost assumptions relative to baseload coal much higher than in IRP 2010 – despite actual PV/coal ratio is much lower



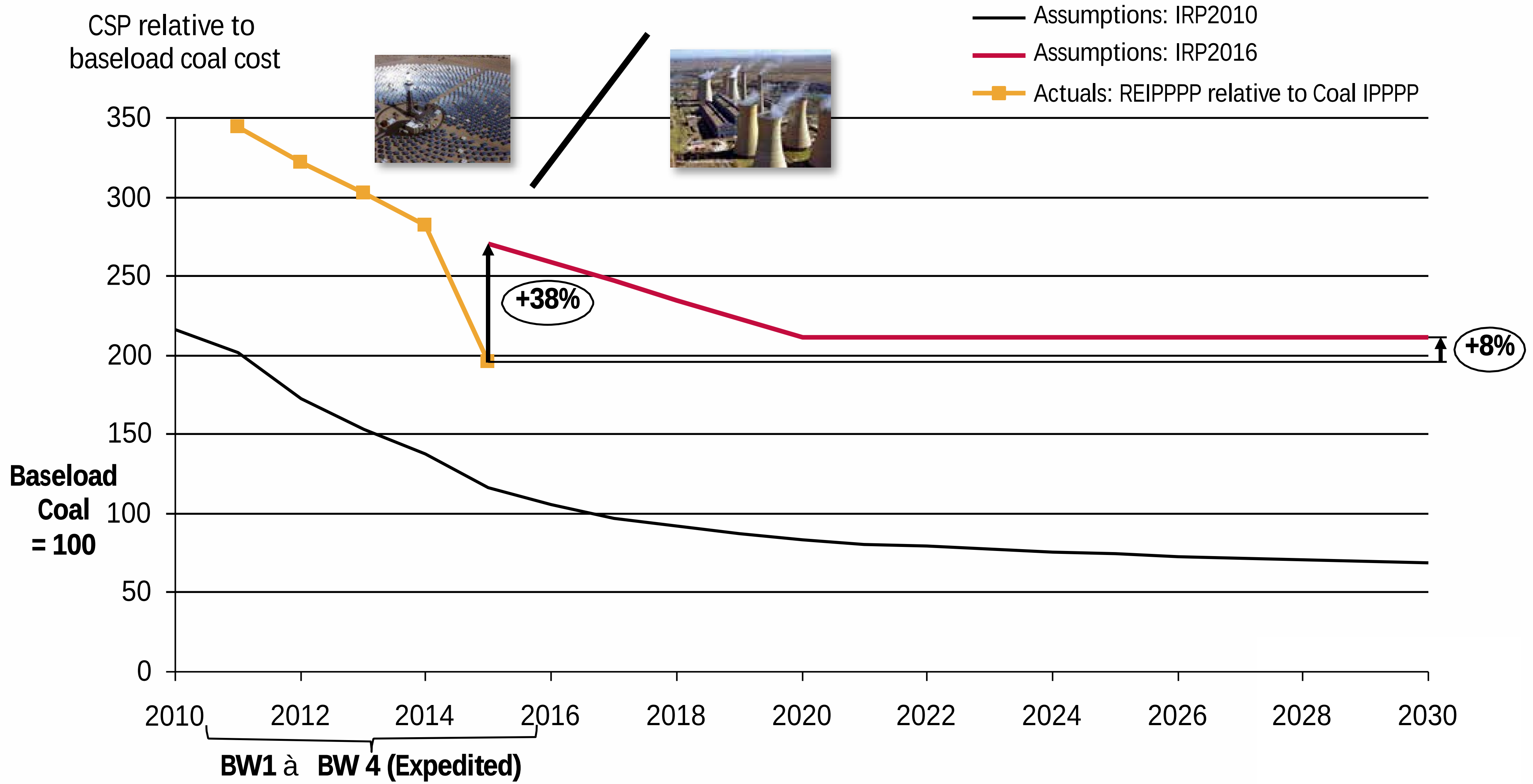
Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 25 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

IRP 2016 wind cost assumptions relative to baseload coal lower than in IRP 2010 – but actual ratios from IPP Programmes being even lower



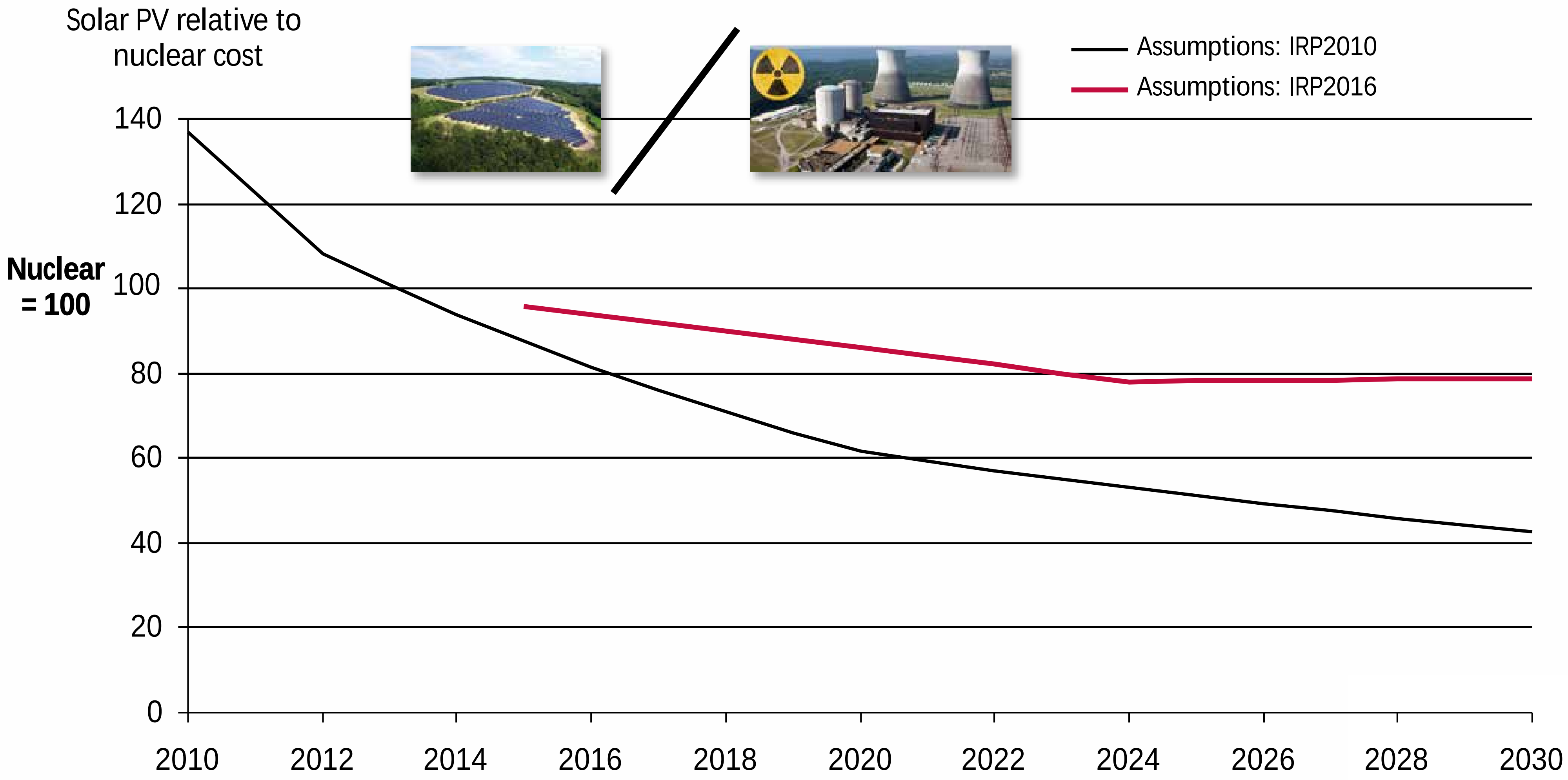
Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 20 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

IRP 2016 CSP cost assumptions relative to baseload coal higher than in IRP 2010 – actual ratios from IPP Programmes lie between IRP2010/16



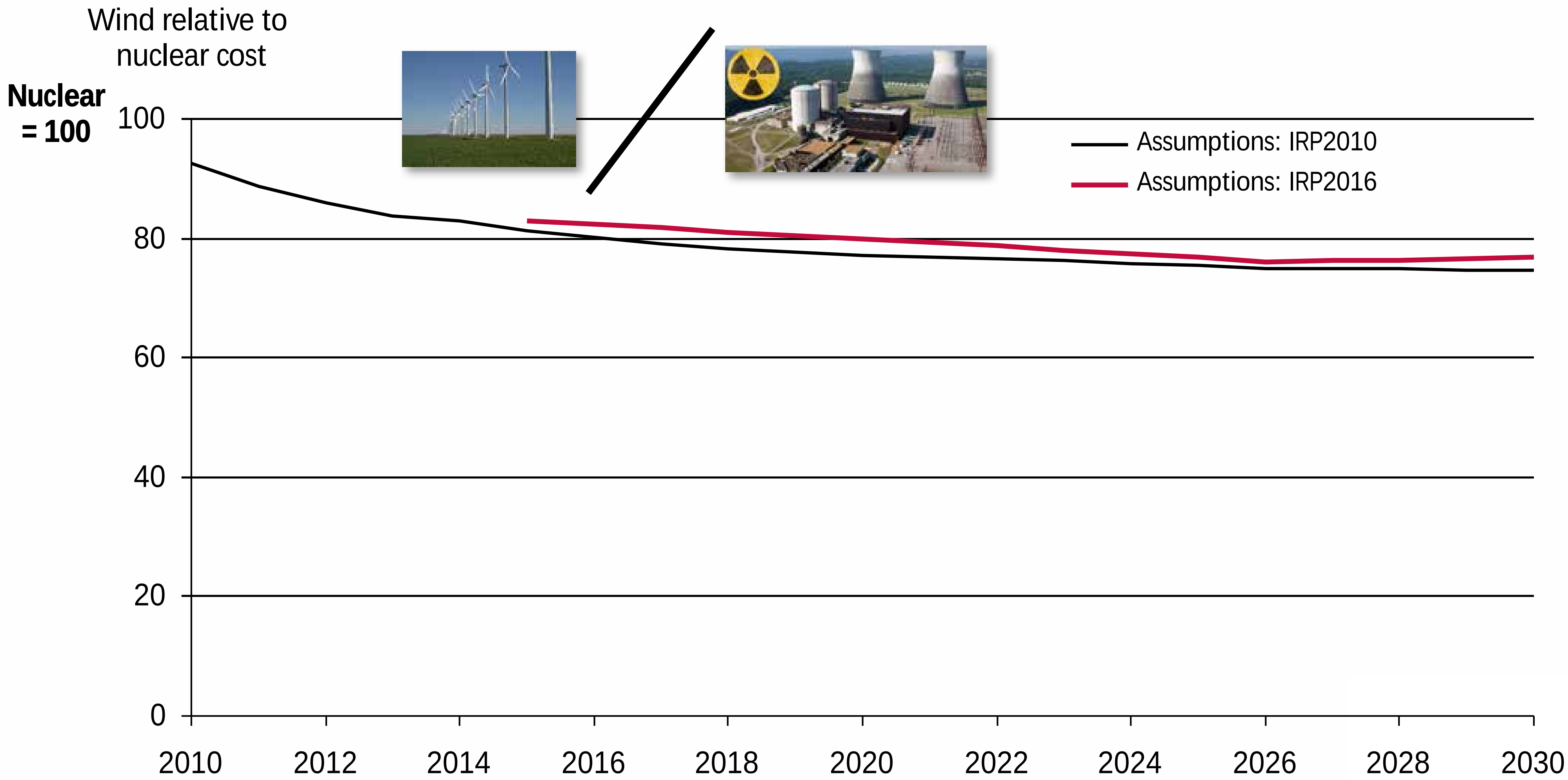
Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 25 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

IRP 2016 Solar PV cost assumptions relative to nuclear much higher than in IRP 2010



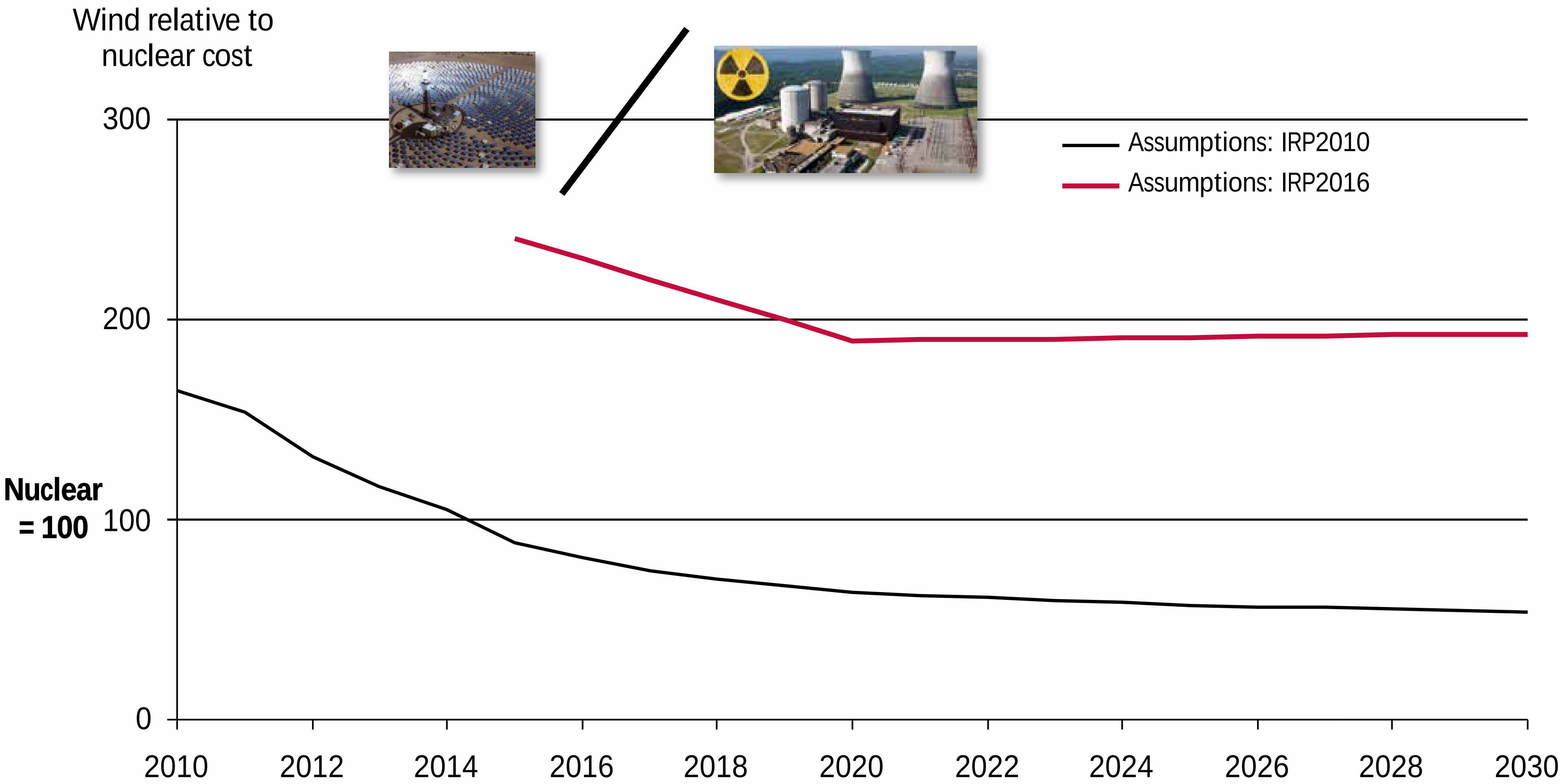
Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 25 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

IRP 2016 wind cost assumptions relative to nuclear kept constant compared to IRP 2010



Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 20 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document   Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

IRP 2016 CSP cost assumptions relative to nuclear significantly higher than in IRP 2010



Assumptions: CPI used for normalisation to Apr-2016-Rand; LCOE calculated for IRP 2010 and 2013 with 8% discount rate (real), 20 yrs lifetime, cost and load factor assumptions as per relevant IRP document; LCOE for IRP 2016 straight from IRP document Sources: IRP 2010; IRP 2013; IRP 2016 draft as of November 2016; http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; CSIR analysis

Logic to derive “IRP Tariff” curves

Calculate the IRP LCOE path for each technology based on

- Cost development path for CAPEX in R/kW and for O&M in R/kW/yr as per IRP 2010 / IRP 2013
- Discount rate of 8%
- Lifetime of 25/20/30 years for PV/wind/CSP
- Load factors as per the profiles used in IRP 2010 / IRP 2013
- For IRP 2016, use straight the reported LCOE (i.e. without own LCOE calculation)

Adjust all resulting IRP LCOE numbers to Apr 2016 via CPI table

- http://www.statssa.gov.za/keyindicators/CPI/CPIHistory.pdf

Translate all Apr-2016-based IRP LCOE numbers into an “IRP Tariff”

- The IRP-assumed costs (CAPEX and O&M) reflect only the costs within the battery limit of the EPC contract. Owner’s development costs (ODCs) and grid connection costs are not considered
- Assume that for an IPP the pure EPC CAPEX plus O&M stands for 90% of the total costs that lead to the tariff
- Therefore, divide “IRP LCOE” numbers by 90% to derive at the “IRP Tariff”
- This tariff is logically comparable to the tariffs that IPPs bid for in the REIPPPP

CSIR
our future through science

Sources: CSIR analysis

IRP 2016: Annual new-build limits for solar PV and wind are constant in absolute terms but decrease relative to the size of the power system

Draft IRP 2016 Base Case

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

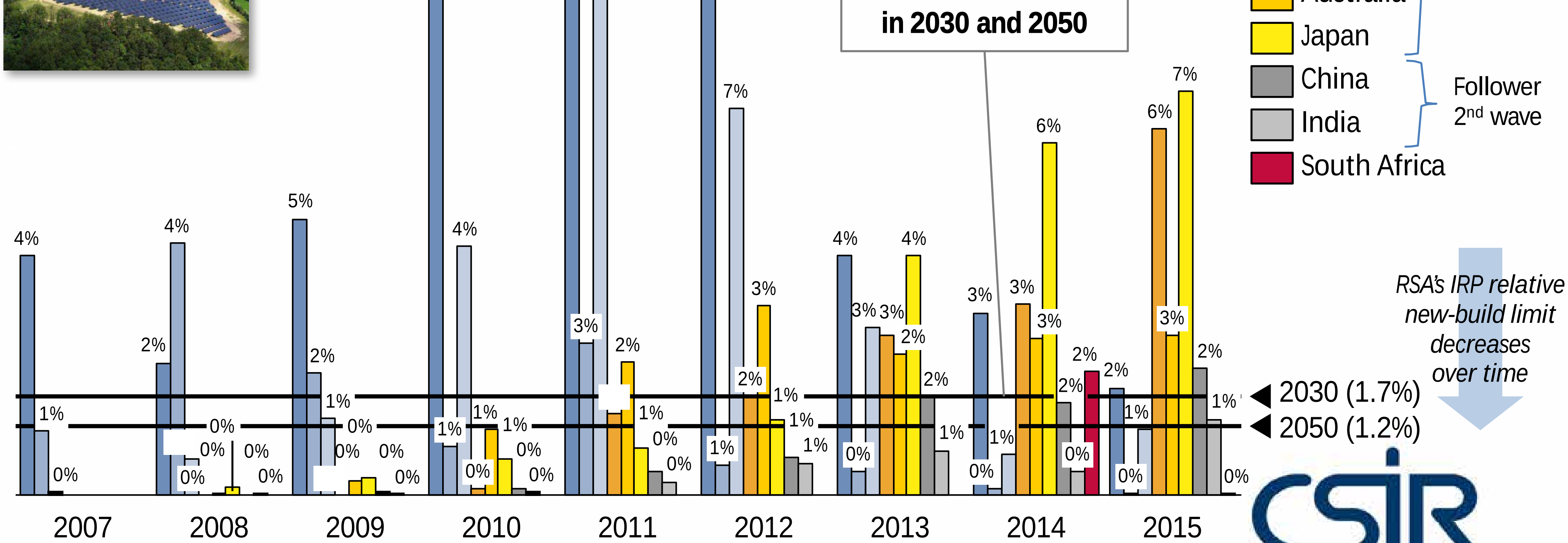
No such limits are applied for any other technology. No technical justification is provided for these limits. No explanation is given why these limits are constant over a 30-year period while the power system grows.

Year	System Peak Load in MW	New-build limit Solar PV in MW/yr	Relative new-build limit Solar PV	New-build imit Wind in MW/yr	Relative new-build limit Wind
2020	44 916	1 000	2.2%	1 600	3.6%
2025	51 015	1 000	2.0%	1 600	3.1%
2030	57 274	1 000	1.7%	1 600	2.8%
2035	64 169	1 000	1.6%	1 600	2.5%
2040	70 777	1 000	1.4%	1 600	2.3%
2045	78 263	1 000	1.3%	1 600	2.0%
2050	85 804	1 000	1.2%	1 600	1.9%

Note: Relative new-build limit = New-build limit / system peak load
Sources: IRP 2016 Draft; CSIR analysis

Today: Both leading and follower countries install much more new solar PV capacity per year than what South Africa's limit is in 2030

Annual new solar PV capacity relative to system peak load

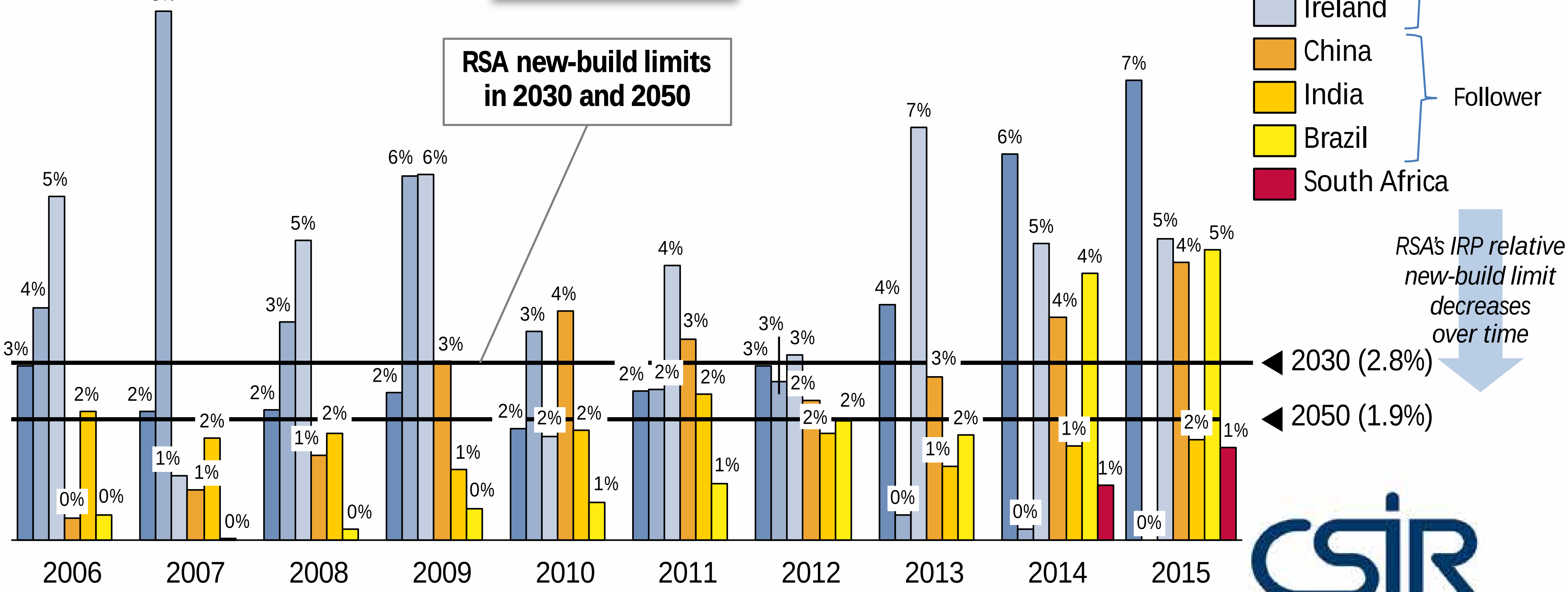


CSIR
our future through science

Sources: SolarPowerEurope; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis

Today: Both leading and follower countries install much more new wind capacity per year than what South Africa's limit is in 2050

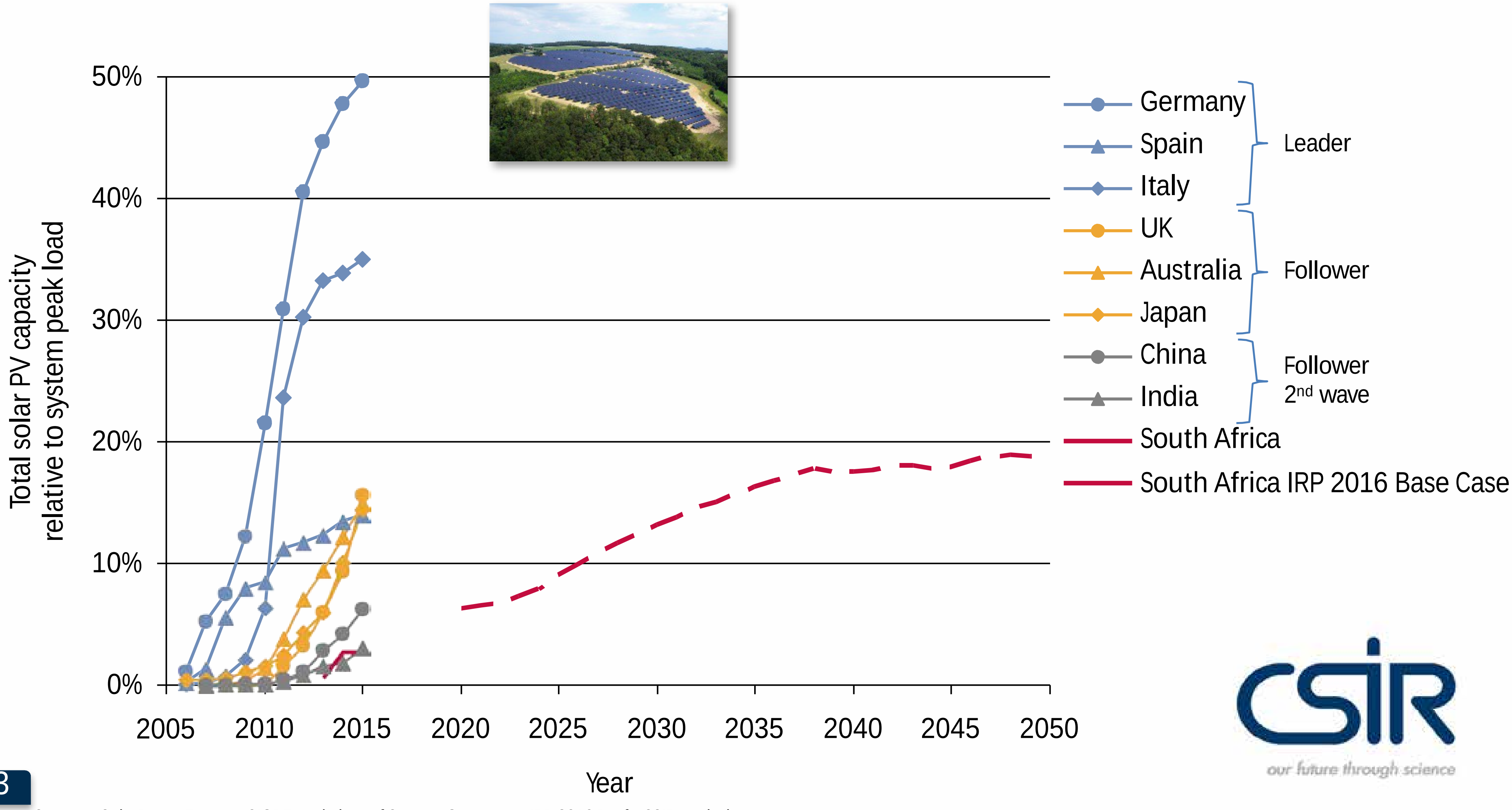
Annual new wind capacity relative to system peak load



CSIR
our future through science

Sources: GWEC; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis

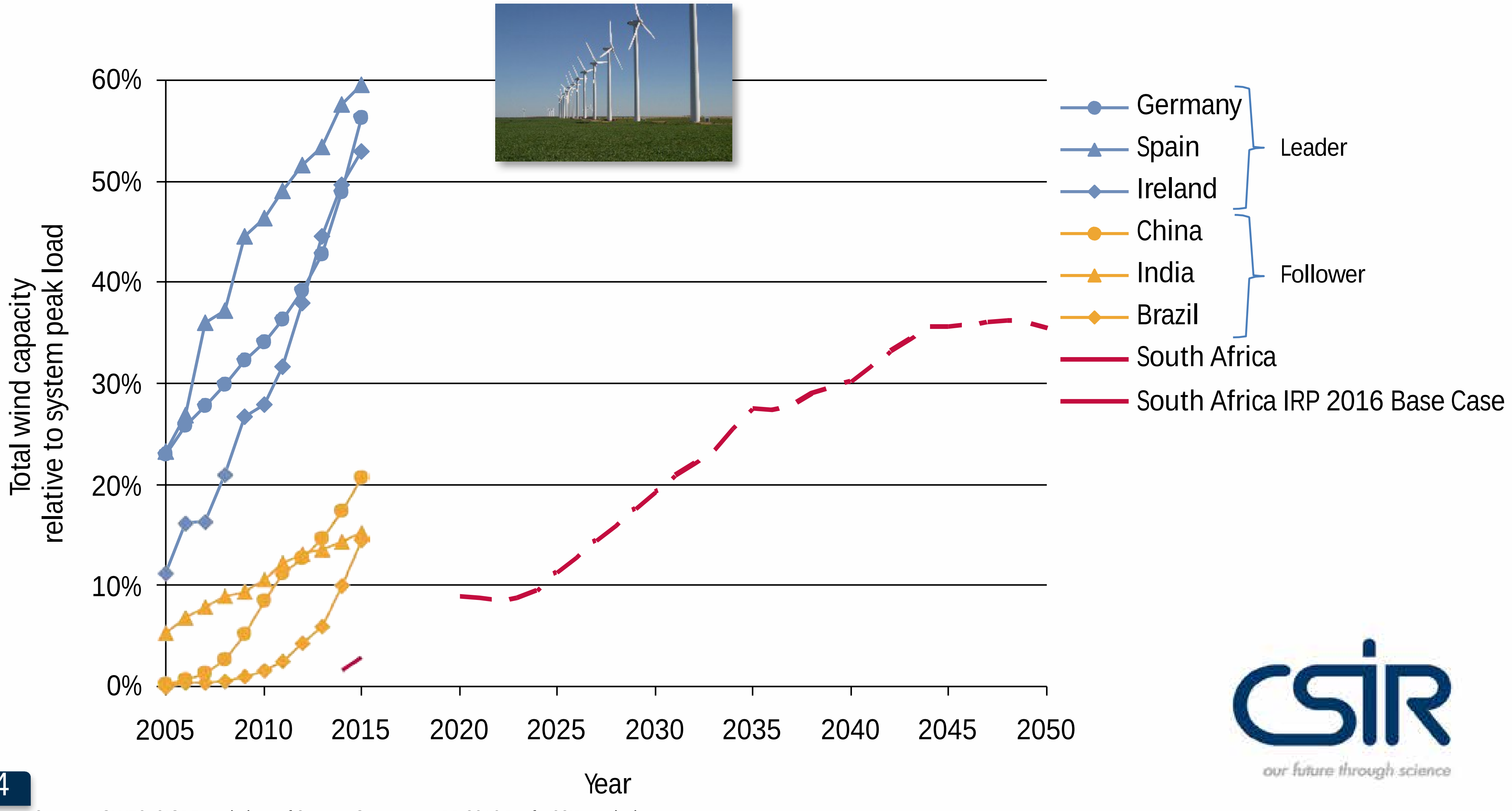
Today: Solar PV penetration in leading countries 2.5 times RSA's plan for 2050 – follower countries already today almost at RSA's 2050 level



Sources: SolarPowerEurope; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis

CSIR our future through science

Today: Wind penetration in leading countries almost twice RSA's plan for 2050 – follower countries already today at 60% of RSA's 2050 level



Sources: GWEC; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis

Agenda

Expertise of Commentators

Comments on IRP Assumptions

IRP Results and Least-cost Scenario

Proposal / Next Steps

CSIR
our future through science

The CSIR conducted a Wind and Solar PV Resource Aggregation Study

CSIR, SANEDI, Eskom and Fraunhofer IWES conducted a joint study to holistically quantify

- the wind-power potential in South Africa and
- the portfolio effects of widespread spatial wind and solar power aggregation in South Africa

Wind Atlas South Africa (WASA) data was used to simulate wind power across South Africa

Solar Radiation Data (SoDa) was used to simulate solar PV power across South Africa

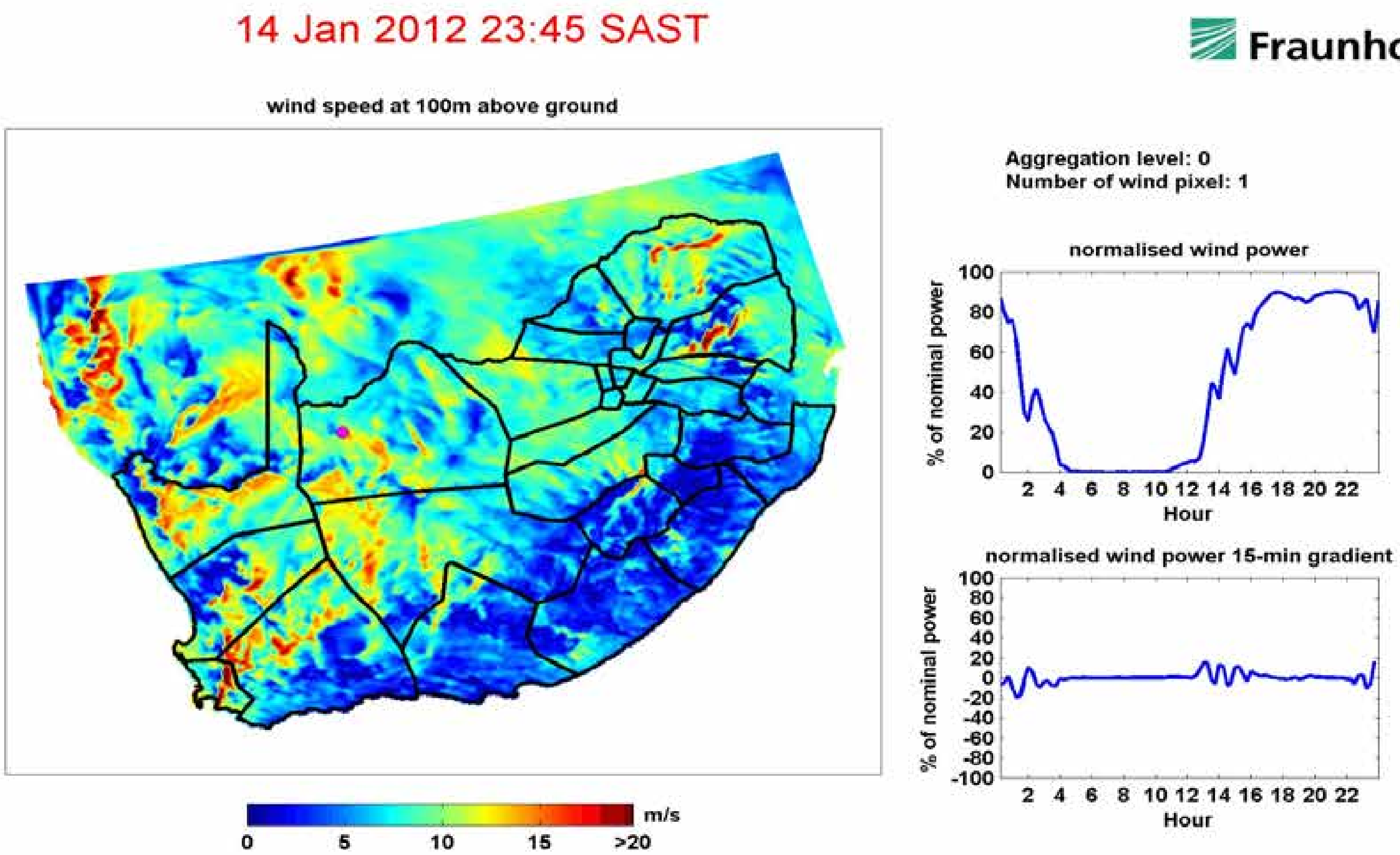
Output: Simulated time-synchronous solar PV and wind power production time-series

- 5 km x 5 km spatial resolution
- Almost 50,000 pixels covering entire South Africa
- 15-minute temporal resolution
- 5 years temporal coverage (2009-2013)

Sources: www.csir.co.za/Energy_Centre/wind_solarpv.html

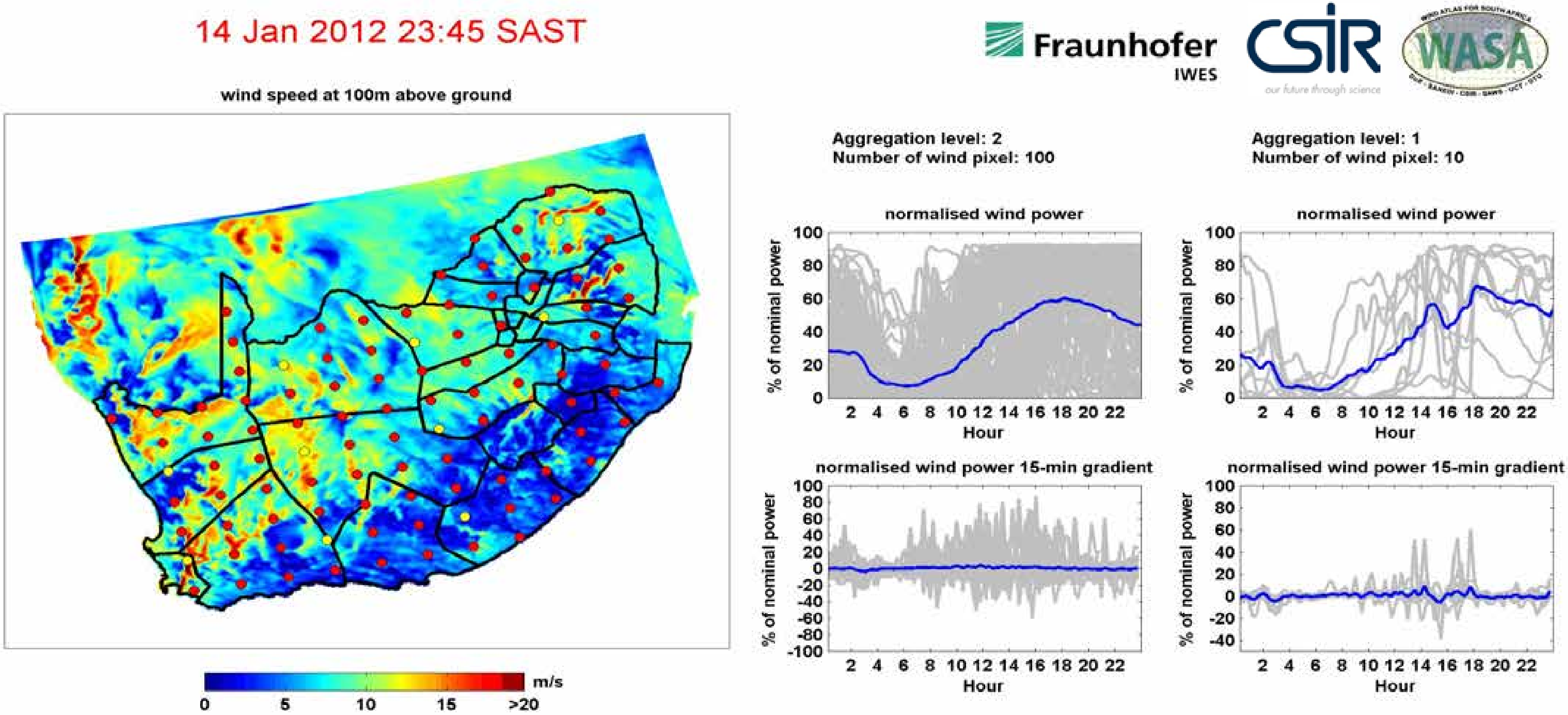
A single wind farm changes its power output quickly

Simulated wind-speed profile and wind power output for 14 January 2012

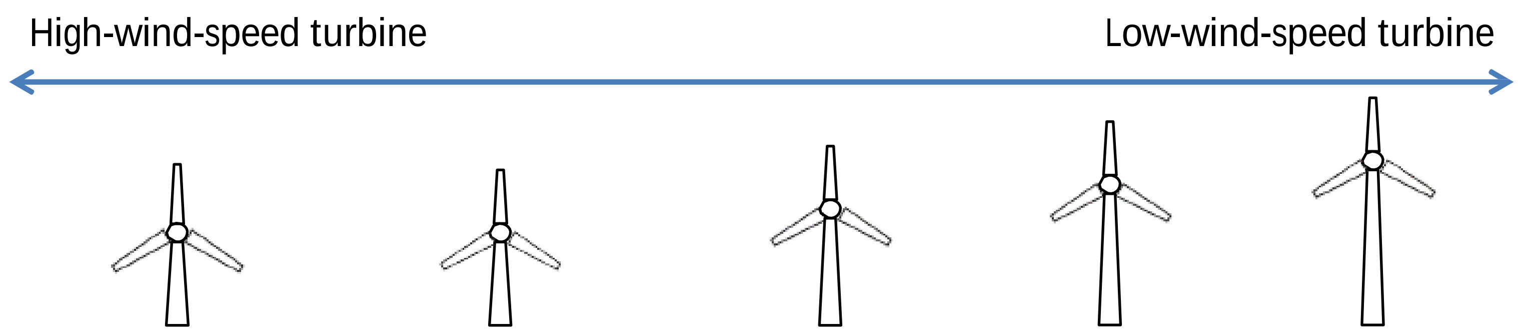


Aggregating 100 wind farms: 15-min gradients almost zero

Simulated wind-speed profile and wind power output for 14 January 2012



Five different generic wind turbine types defined for simulation of wind power output per 5x5 km pixel in South Africa (~50 000 pixels)



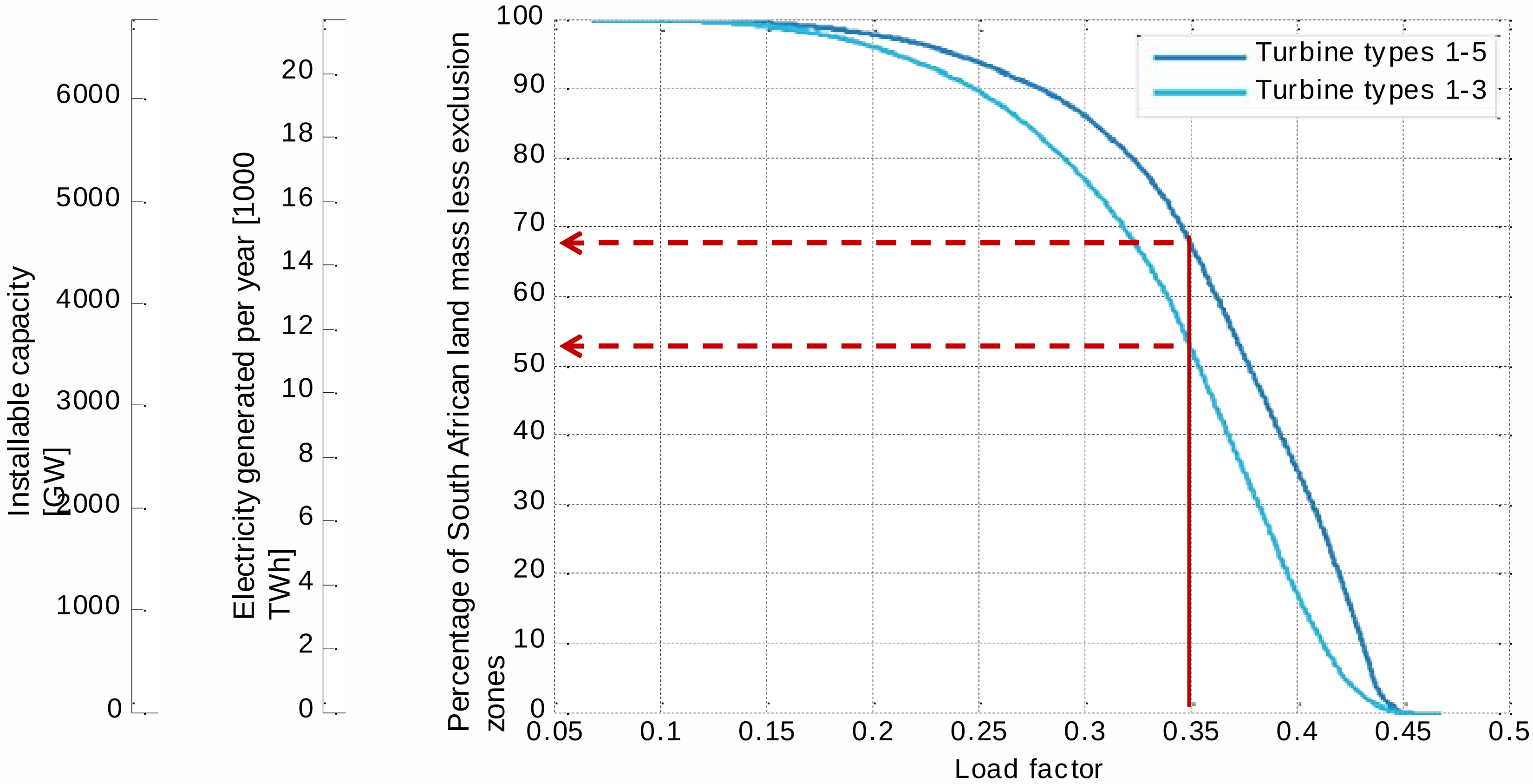
Turbine type no.	1	2	3	4	5
Nominal power [MW]	3	2.2	2.4	2.4	2.4
Selection criterion	$\bar{v}_{80m} > 8.5\frac{m}{s}$	$\bar{v}_{80m} < 8.5\frac{m}{s}$ and $\bar{v}_{100m} > 7.5\frac{m}{s}$	$\bar{v}_{100m} < 7.5\frac{m}{s}$	$\bar{v}_{120m} < 7.5\frac{m}{s}$	$\bar{v}_{140m} < 7.5\frac{m}{s}$
Blade diameter [m]	90	95	117	117	117
Hub height [m]	80	80	100	120	140

Space requirement 0.1km²/MW
à max. 250 MW per pixel

CSIR
our future through science

On almost 70% of suitable land area in South Africa a 35% capacity factor or higher can be achieved (>50% for turbines 1-3)

Share of South African land mass less exclusion zones with capacity factors to be reached accordingly

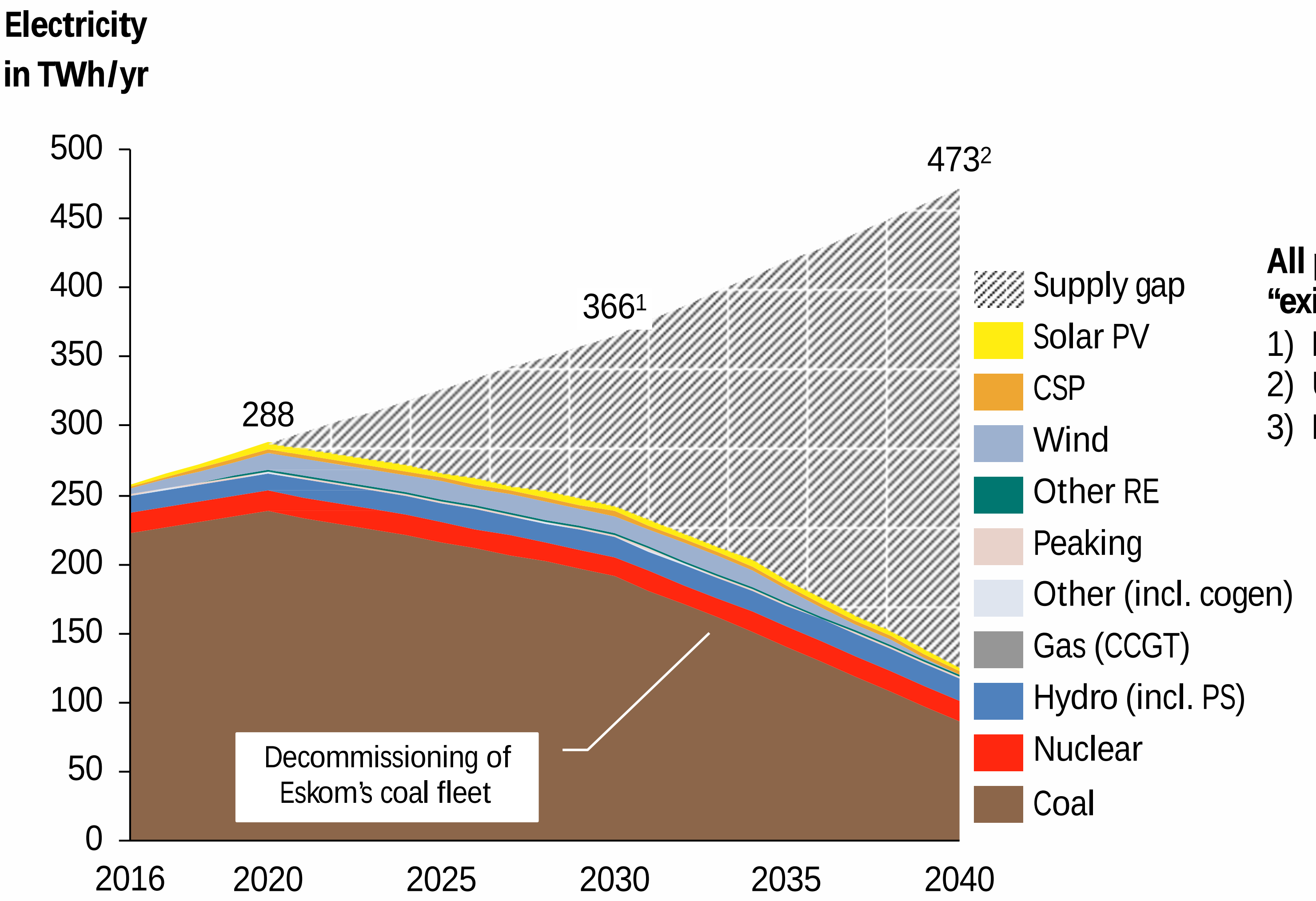


à Installing turbine type 4 and 5 will cause higher costs but also increase capacity factors and electricity yield whilst consuming the same area

our future through science

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



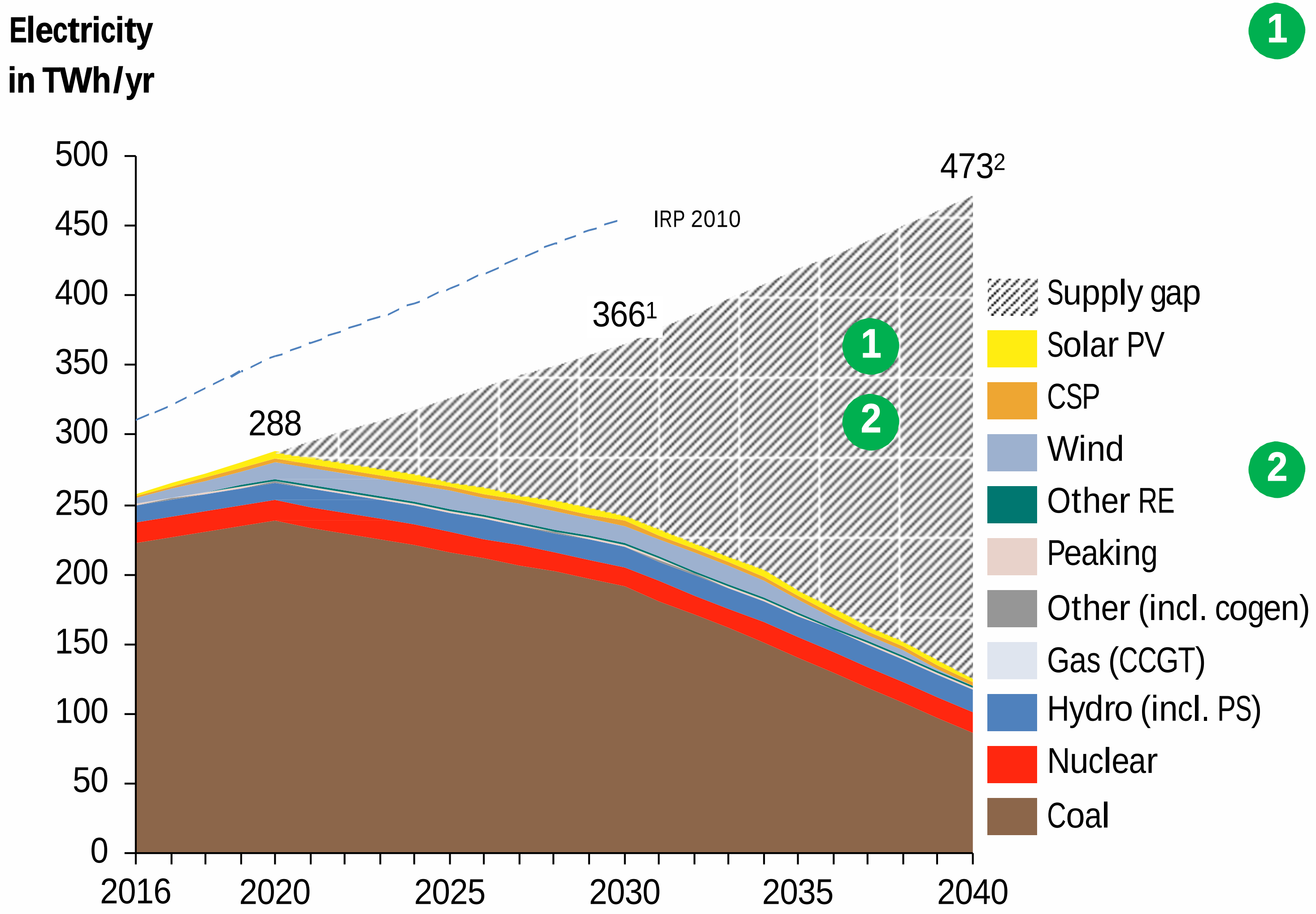
All power plants considered for "existing fleet" that are either:

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"

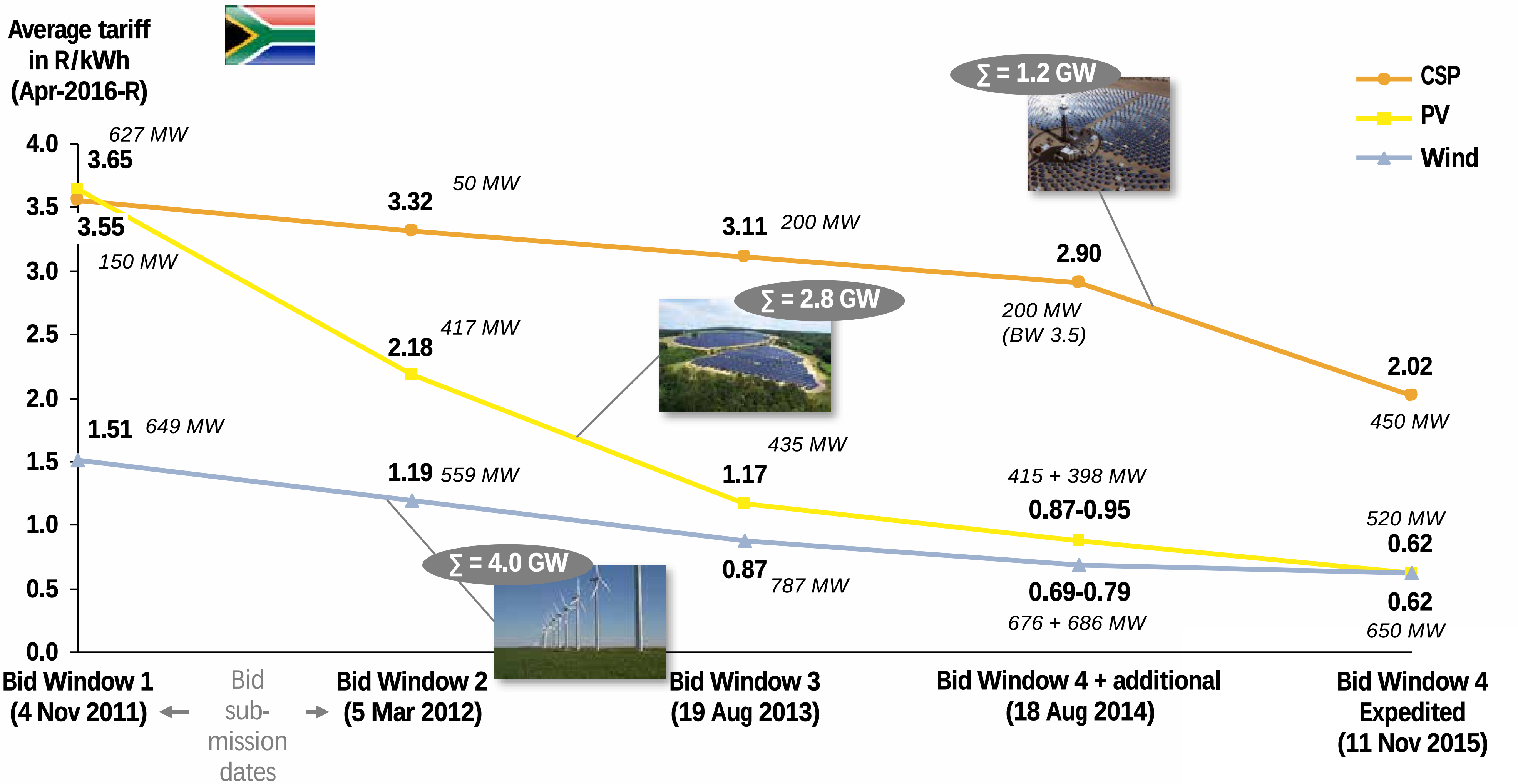
- Coal, nuclear, gas, RE are all available as supply options
- Supply candidates chosen by least cost optimisation to meet energy and capacity requirement

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

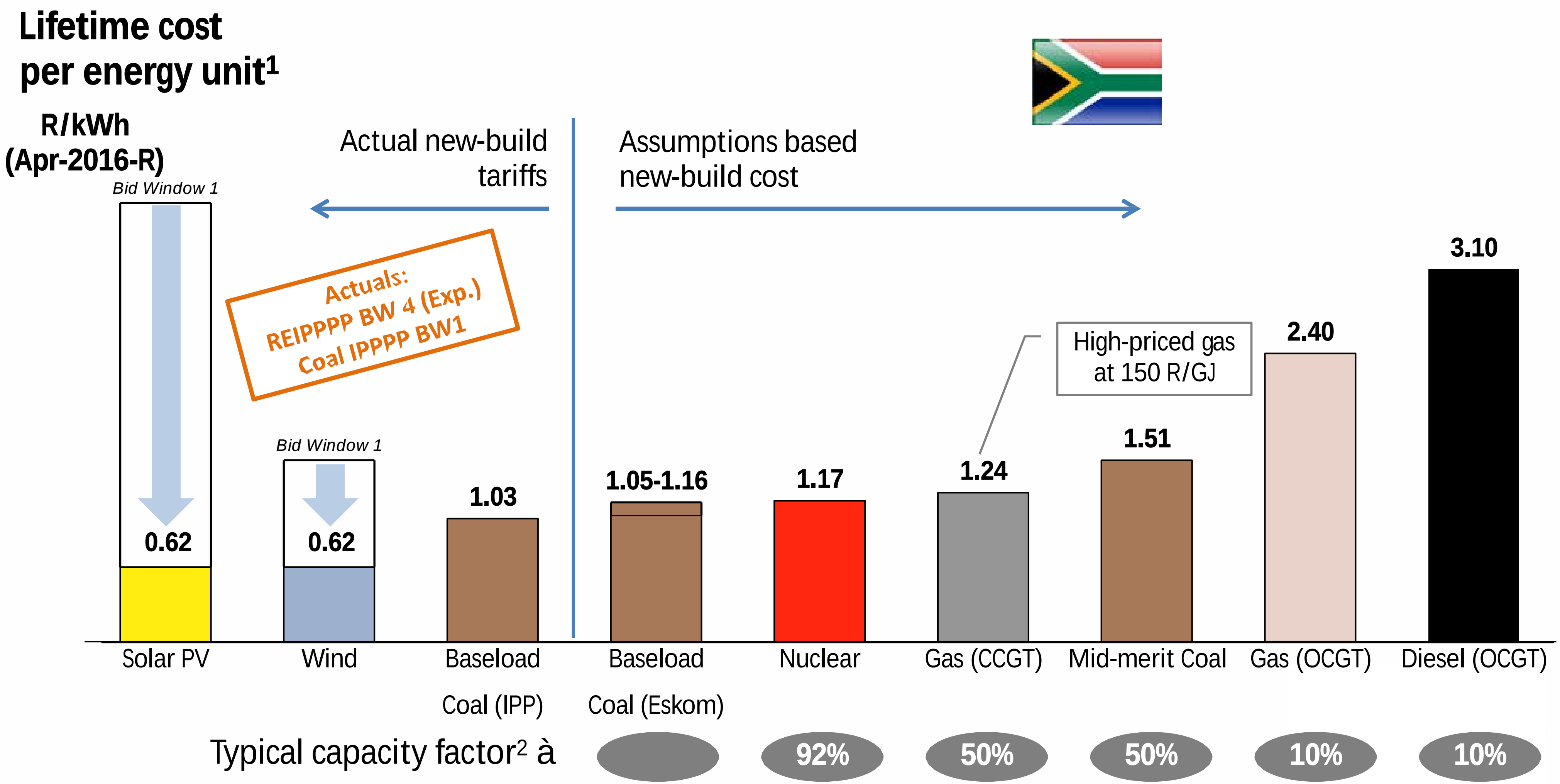
Actual tariffs: new renewables projects much cheaper than first ones

First four Bid Windows' results of Department of Energy's RE IPP Procurement Programme (REIPPPP)



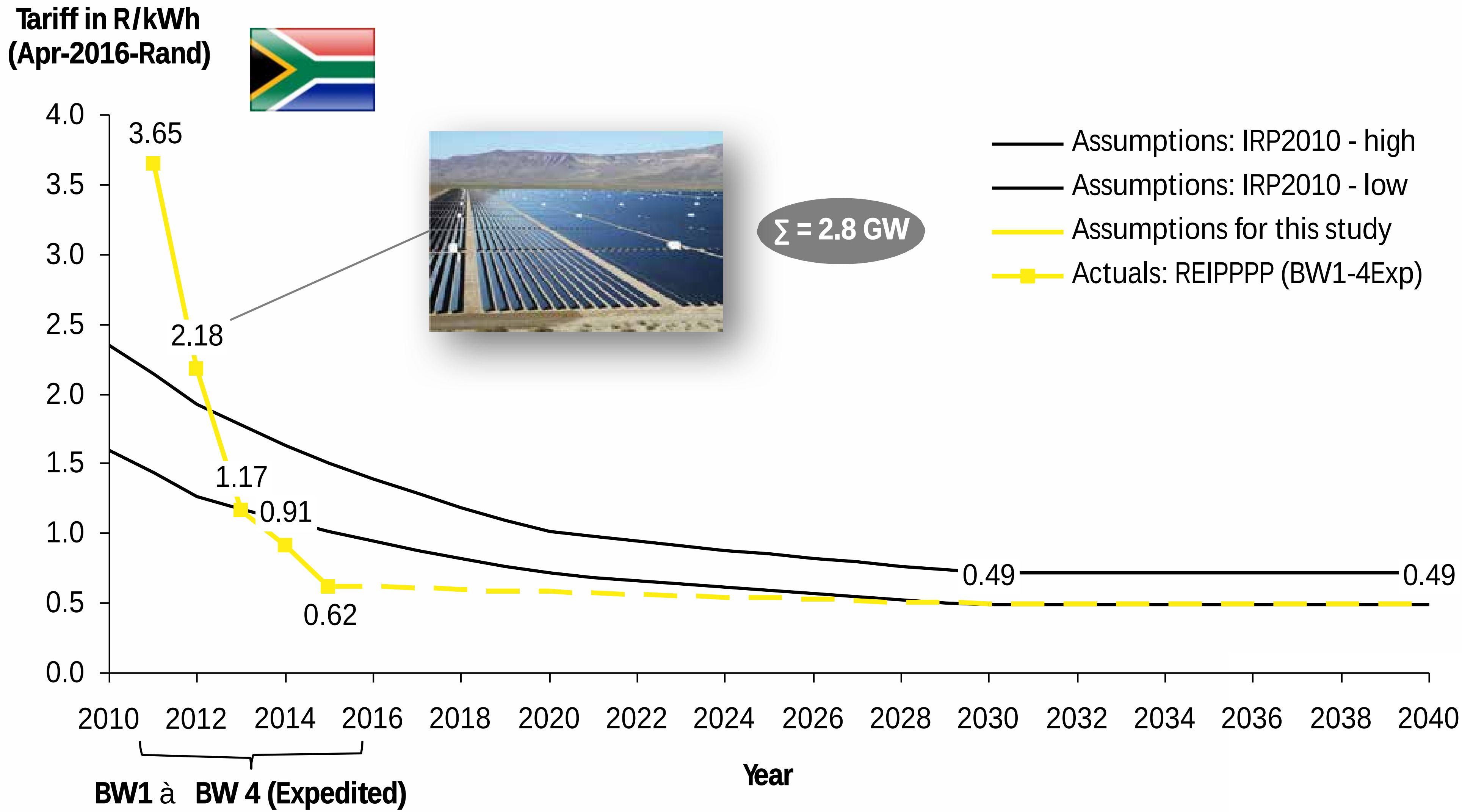
Notes: For CSP Bid Window 3, 3.5 and 4 Expedited, the weighted average of base and peak tariff is indicated, assuming 64%/36% split between base and peak tariff; BW = Bid Window; Sources: Department of Energy's publications on results of first four bidding windows http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; IPP Office on BW4 Expedited; StatsSA on CPI; CSIR analysis

Key input cost assumptions for new supply technologies



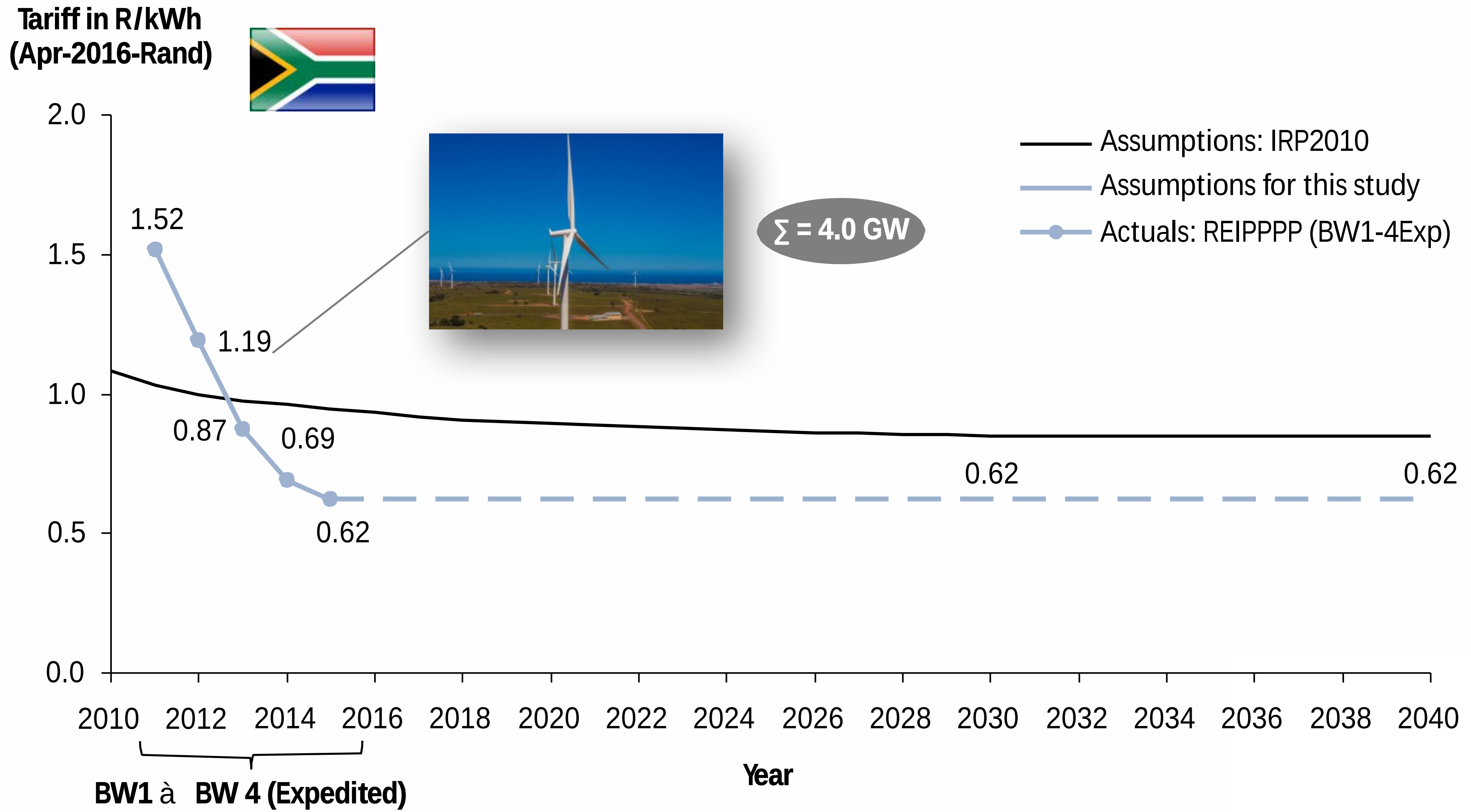
1 Lifetime cost per energy unit is only presented for brevity. The model inherently includes the specific cost structures of each technology i.e. capex, Fixed O&M, variable O&M, fuel costs etc.
2 Changing full-load hours for conventional new-build options drastically changes the fixed cost components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



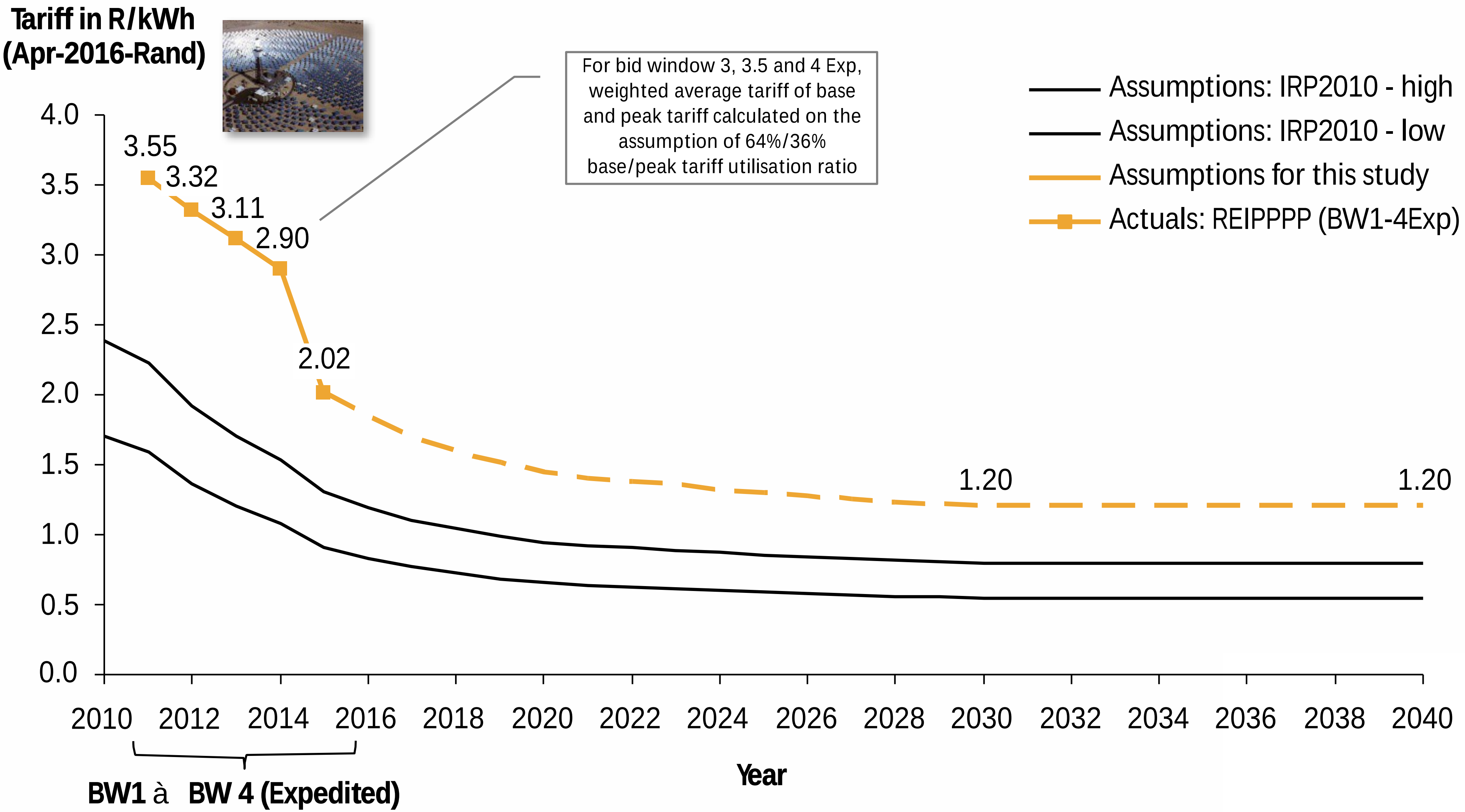
Notes: REIPPPP = Renewable Energy Independant Power Producer Programme; BW = Bid Window; bid submissions for the different BWs: BW1 = Nov 2011; BW2 = Mar 2012; BW 3 = Aug 2013; BW 4 = Aug 2014; BW 4 (Expedited) = Nov 2015 Sources: StatsSA for CPI; IRP 2010; South African Department of Energy (DoE); DoE 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

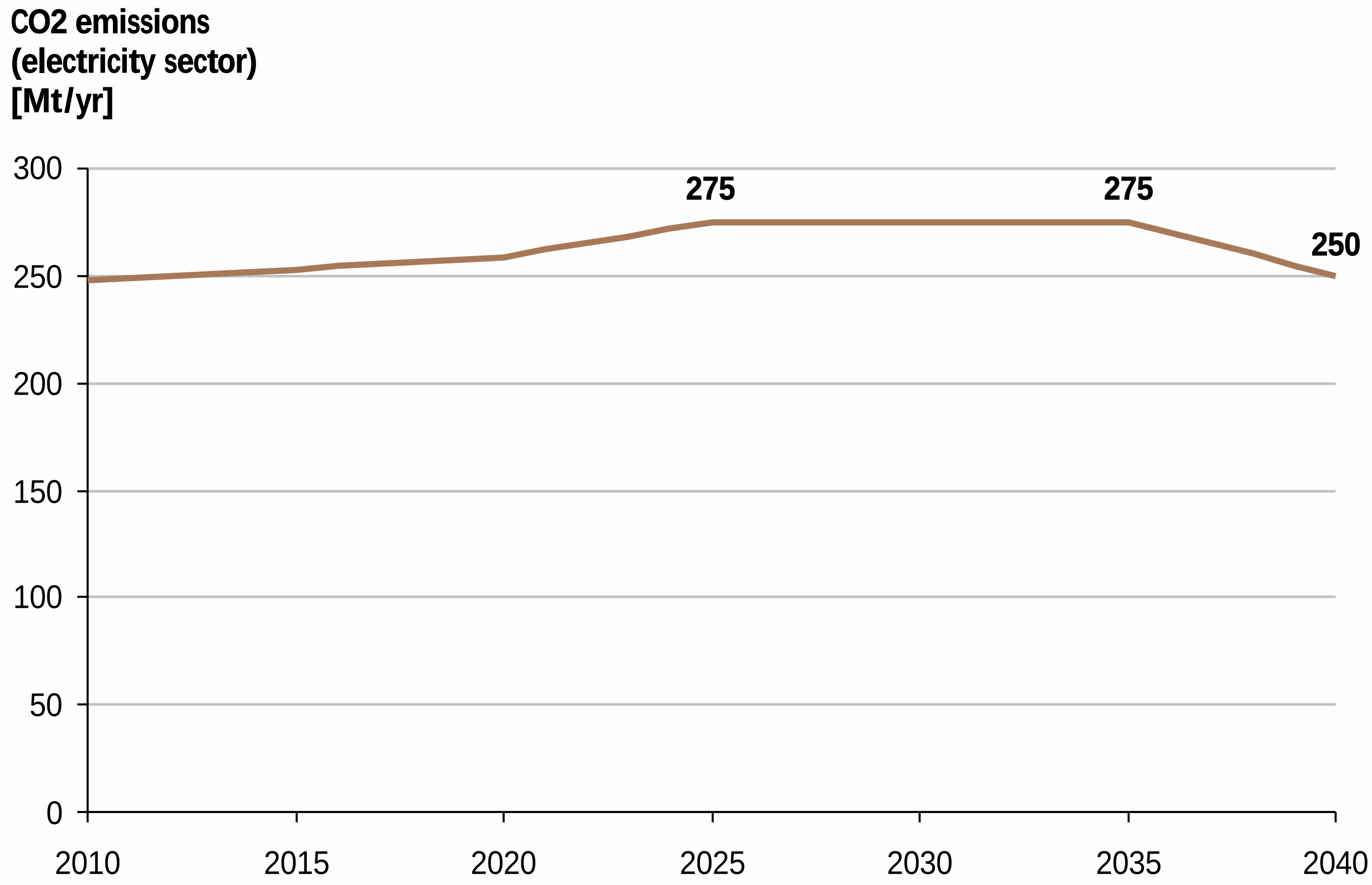
Actual CSP tariffs are declining from bid window 1 to 4 Expedited, and are now close to the upper boundary of IRP 2013 cost assumptions



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



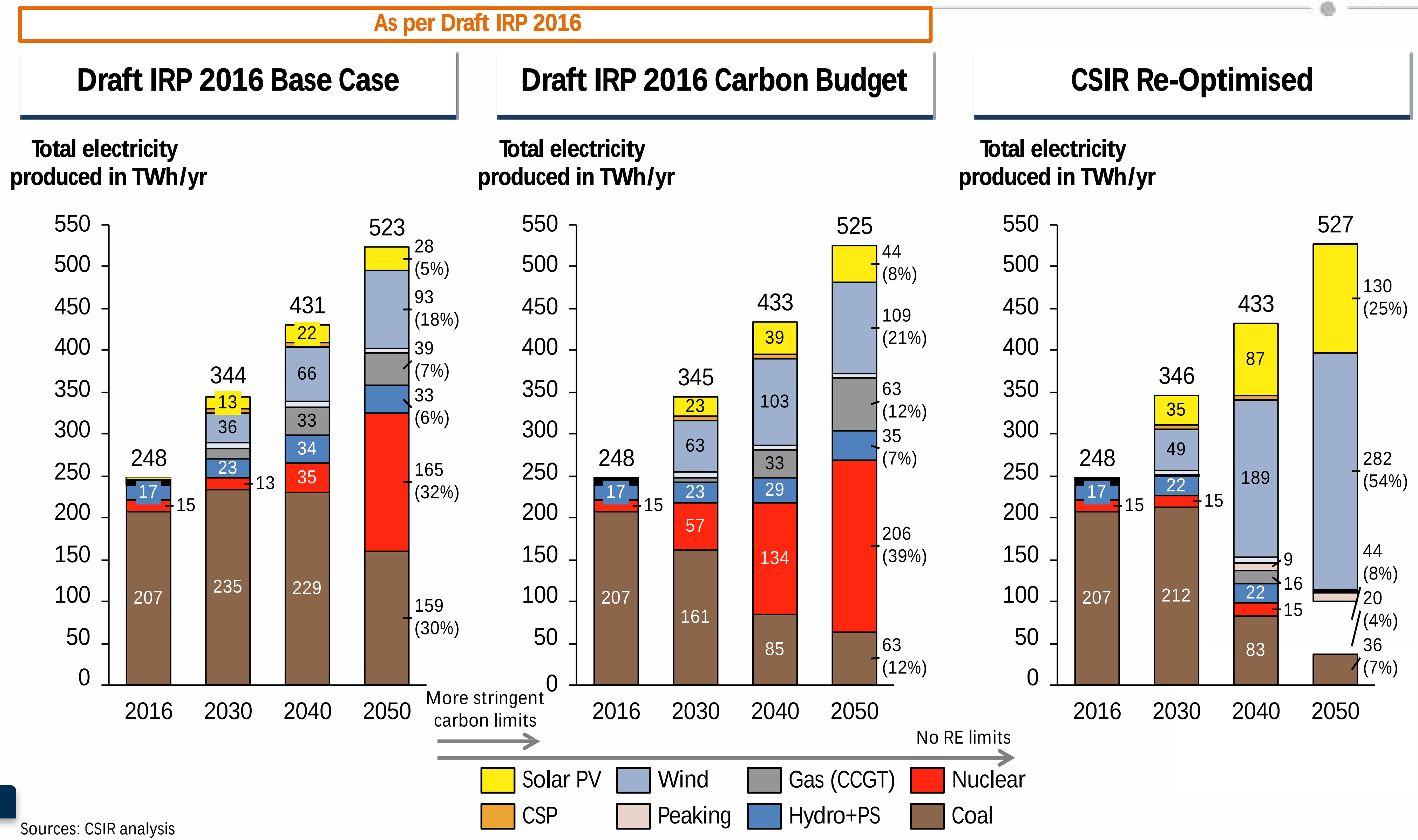
CO2 cap implemented as a hard constraint into the model (i.e. must not be exceeded)

Only in post-processing to calculate cost of CO2, cost of 120 R/t assumed

PPD = Peak Plateau Decline

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

Least-cost "CSIR Re-Optimised" case is largely based on wind and PV

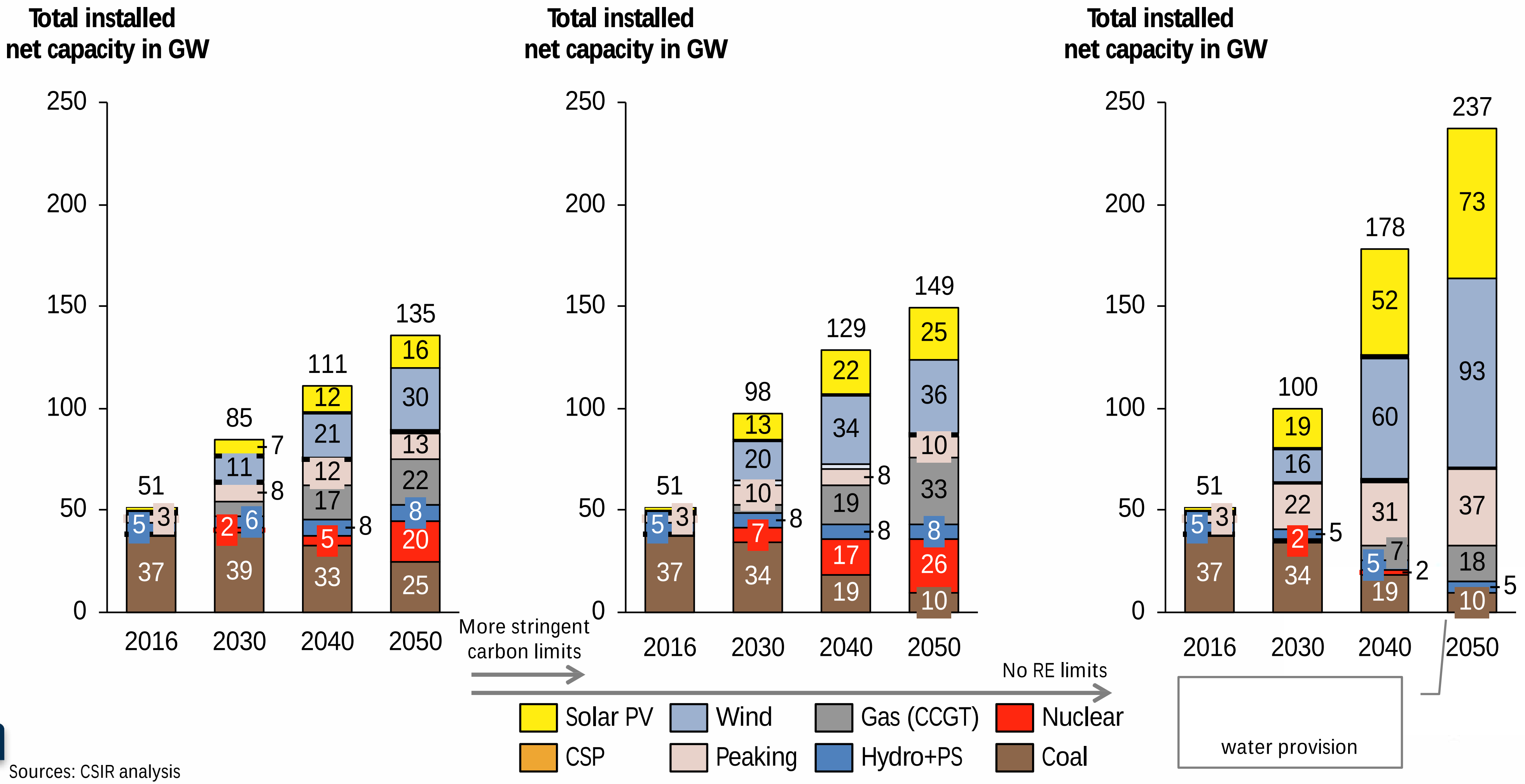


Sources: CSIR analysis

In the CSIR Re-Optimised case, 100 GW of wind & 60 GW of PV by 2050

As per Draft IRP 2016

Draft IRP 2016 Base Case	Draft IRP 2016 Carbon Budget	CSIR Re-Optimised



Sources: CSIR analysis

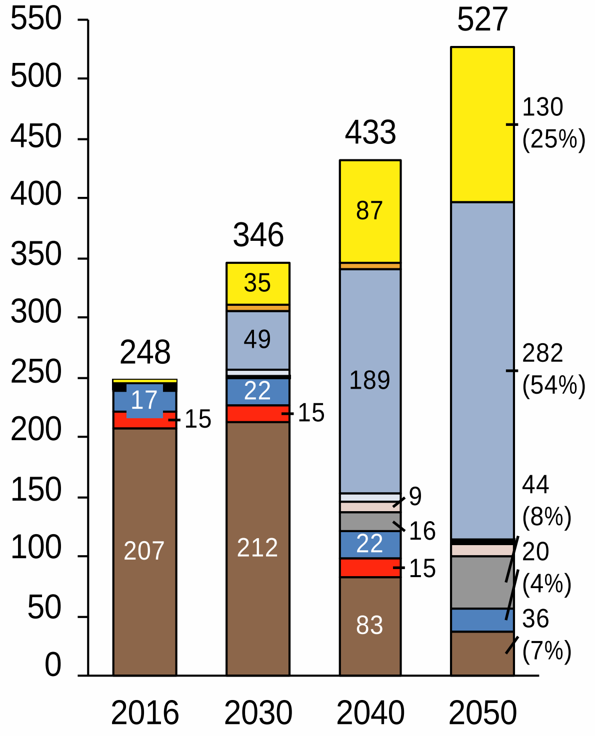
CSP sensitivity: CSP < 1.4 R/kWh and at 20% CF is cost competitive

Comparison of energy supply for Re-Optimised base scenario and Re-Optimised with low CSP cost

CSP annual CF @ 20%, cost @ 1.32 R/kWh

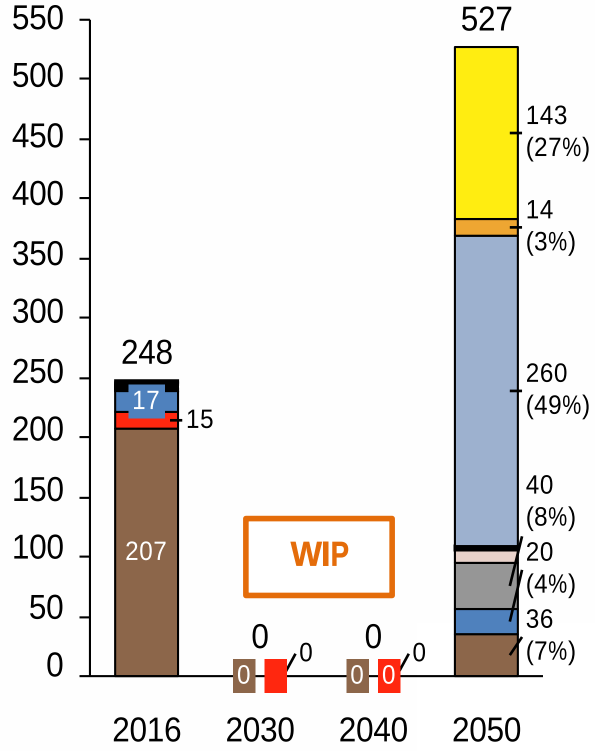
CSIR Re-Optimised (base)

Total electricity produced in TWh/yr



Re-Optimised, CSP Sensitivity

Total electricity produced in TWh/yr



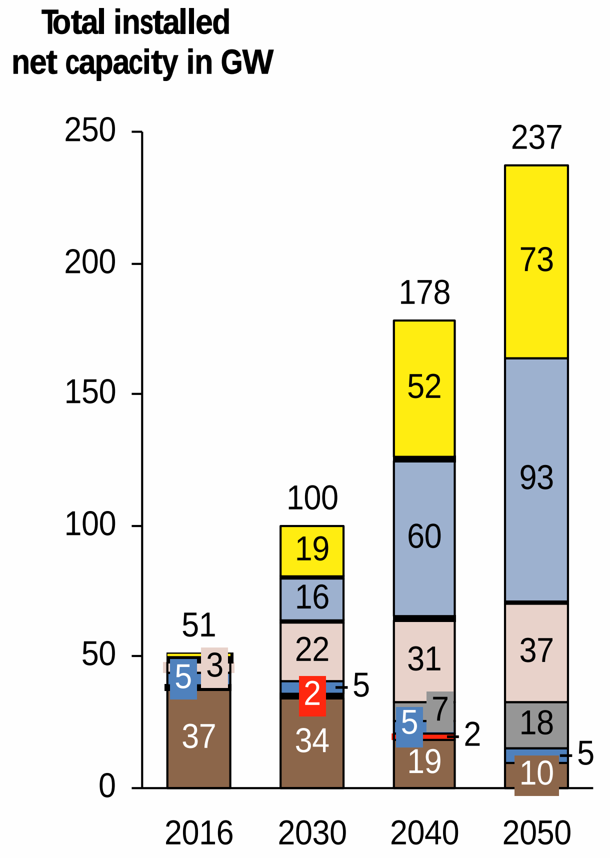
Sources: CSIR analysis

CSP sensitivity: CSP < 1.4 R/kWh and at 20% CF is cost competitive

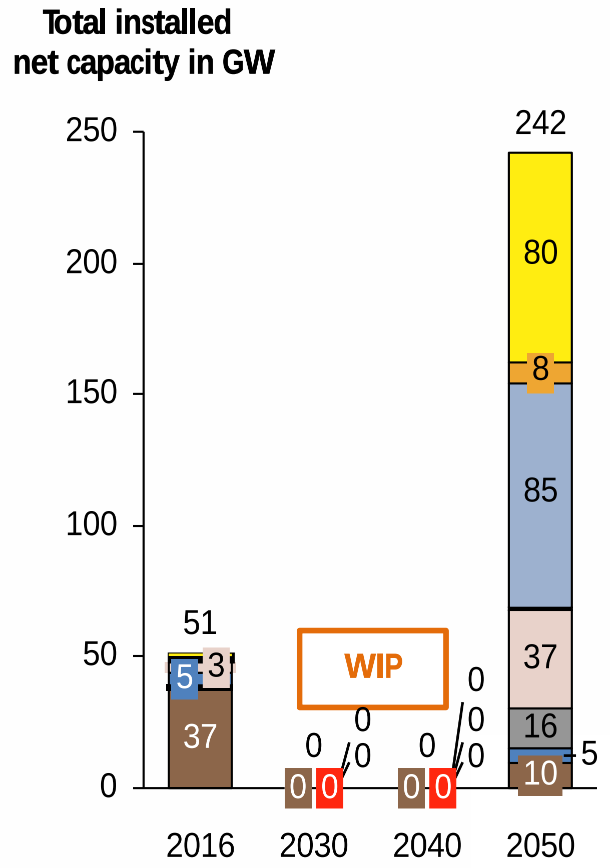
Comparison of energy supply for Re-Optimised base scenario and Re-Optimised with low CSP cost

CSP annual CF @ 20%,
cost @ 1.32 R/kWh

CSIR Re-Optimised (base)



Re-Optimised, CSP Sensitivity



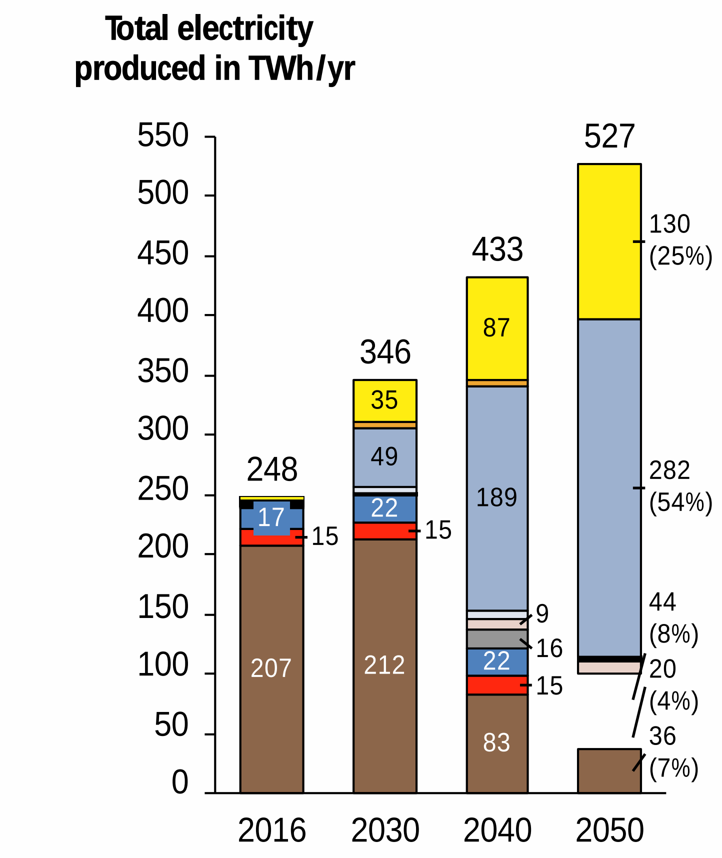
Sources: CSIR analysis

CSP sensitivity: CSP < 0.9 R/kWh and at 60% CF is cost competitive

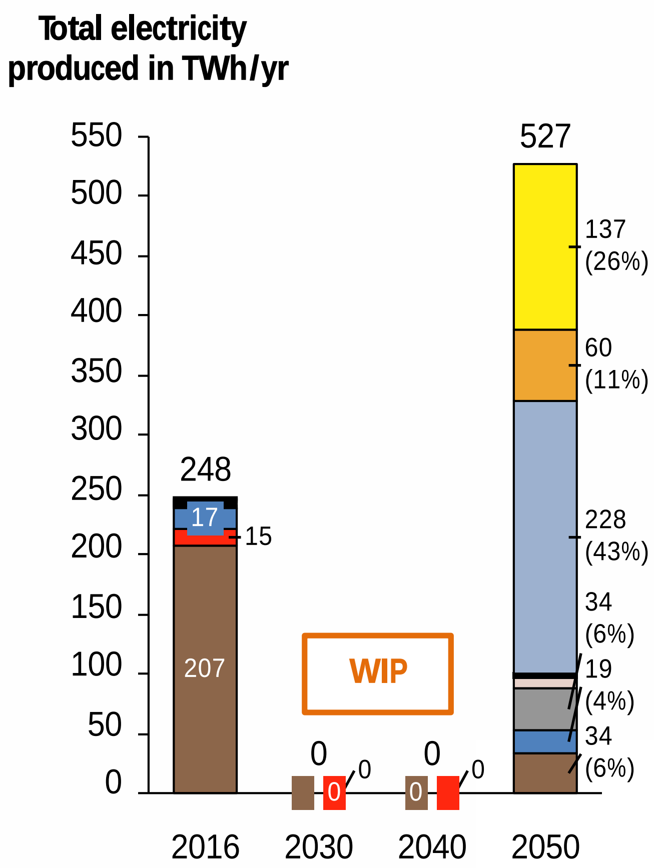
Comparison of energy supply for Re-Optimised base scenario and Re-Optimised with low CSP cost

CSP annual CF @ 60%, cost @ 0.82 R/kWh

CSIR Re-Optimised (base)



Re-Optimised, CSP Sensitivity



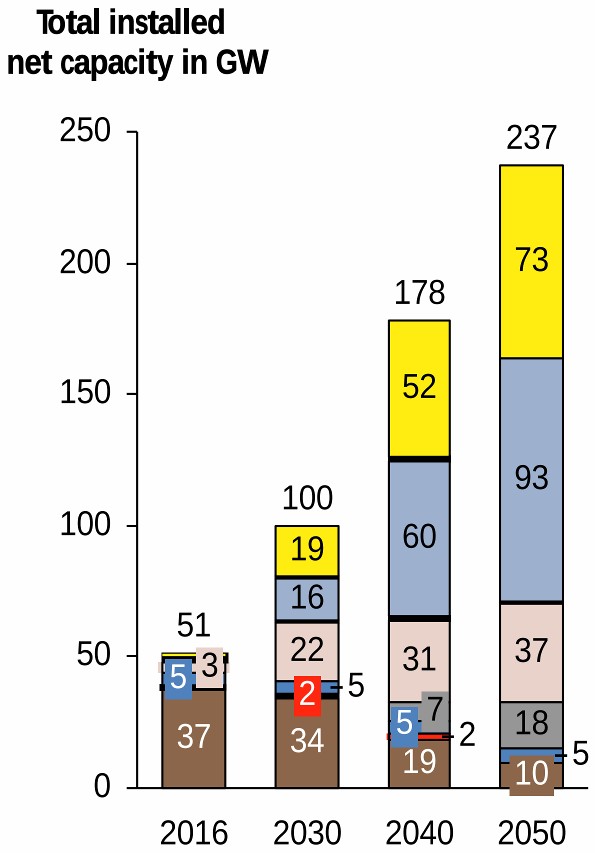
Sources: CSIR analysis

CSP sensitivity: CSP < 0.9 R/kWh and at 60% CF is cost competitive

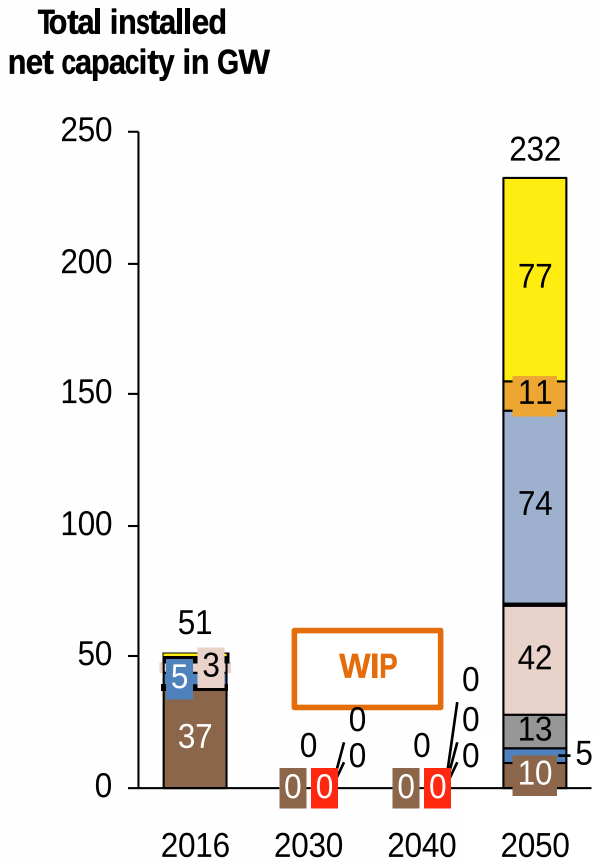
Comparison of energy supply for Re-Optimised base scenario and Re-Optimised with low CSP cost

CSP annual CF @ 60%, cost @ 0.82 R/kWh

CSIR Re-Optimised (base)



Re-Optimised, CSP Sensitivity



Sources: CSIR analysis

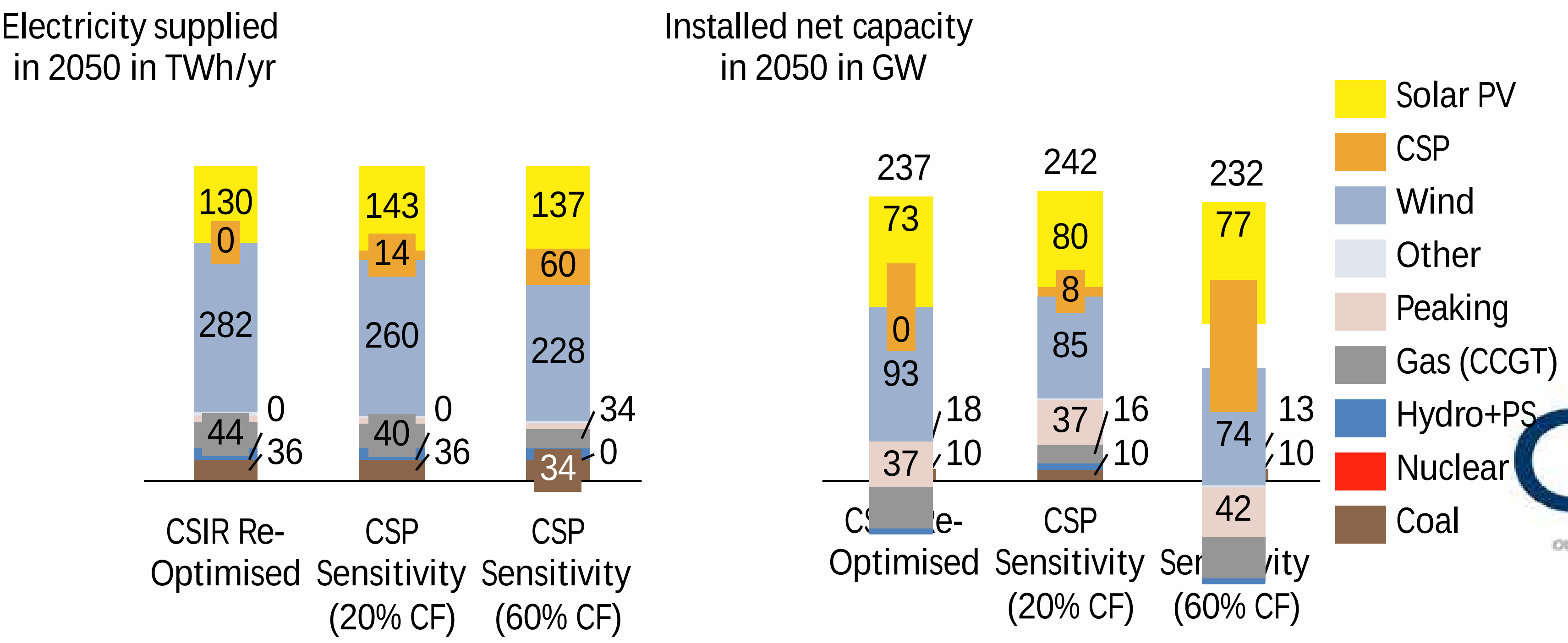
CSP sensitivity: CSP cost below 1.4 R/kWh makes it a gas fuel saver

Sensitivity with below benchmark CSP cost

Two pre-conditions for CSP to be a cost-efficient contributor in the energy mix in 2050

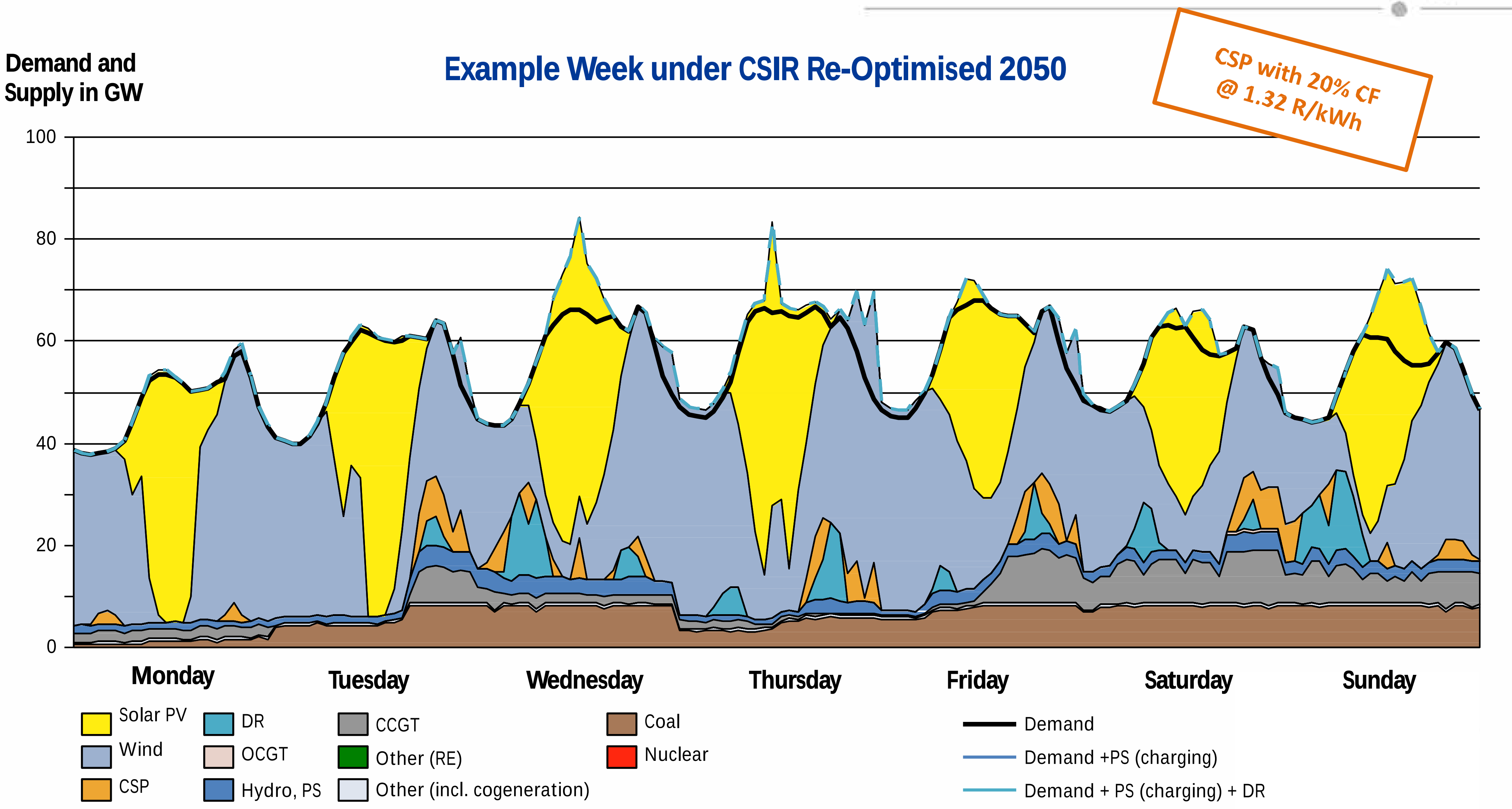
- 1) CSP cost below 1.4 R/kWh @ 20% CF à today RSA: 2.0 R/kWh @ 50-60% CF, or
- 2) CSP cost below 0.9 R/kWh @ 60% CF à today RSA: 2.0 R/kWh @ 50-60% CF
- CSP fully dispatchable within a certain daily energy budget (i.e. CSP energy budget can be distributed by the System Operator as required into the 24 hours of the day, within the maximum of installed capacity)

If these two conditions are met, then CSP can play the role of a gas fuel saver and displaces wind in 2050



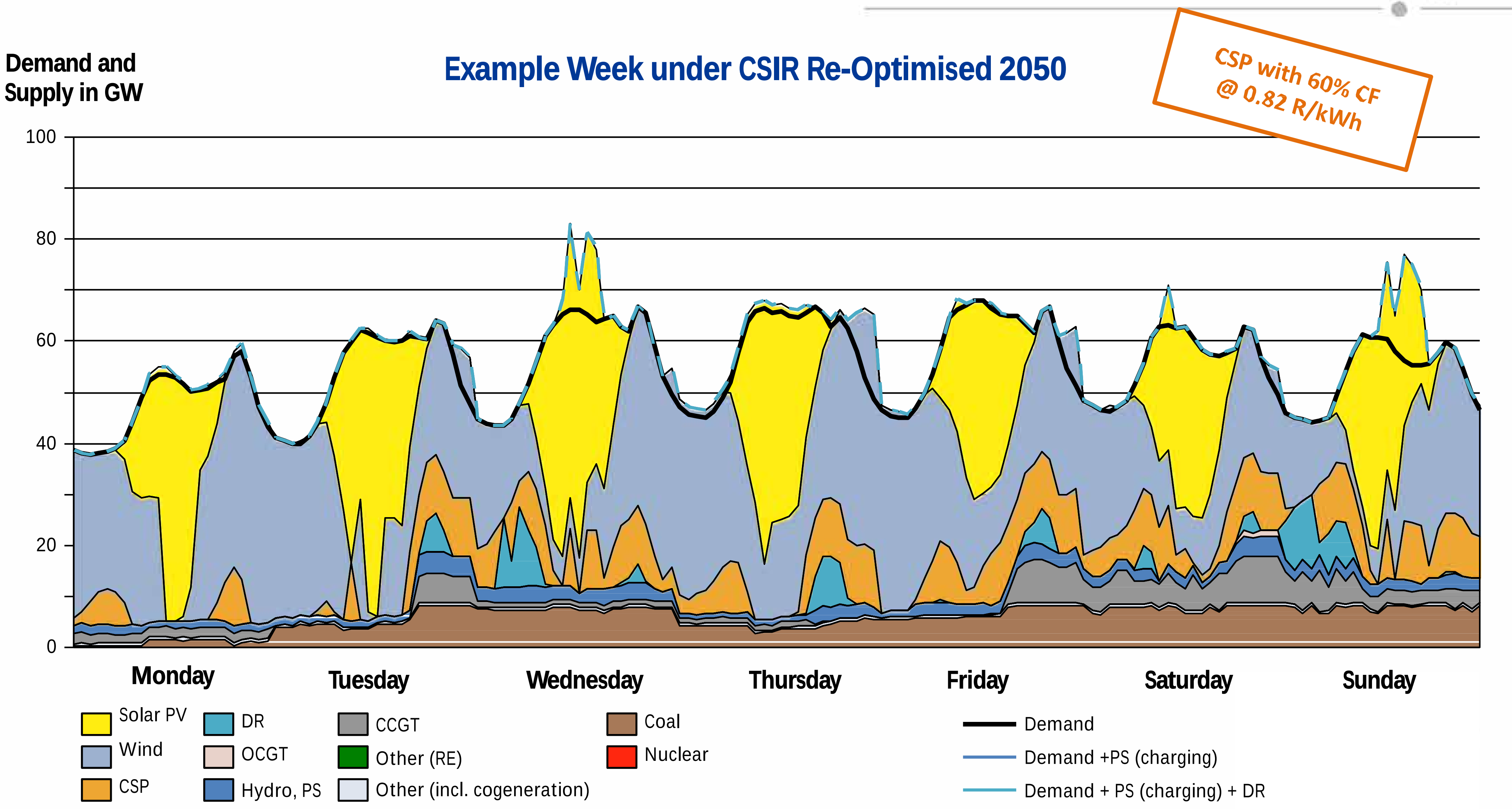
CSIR our future through science

IRP 2016 (DRAFT): CSIR Re-Optimised in 2050
CSP 20% CF



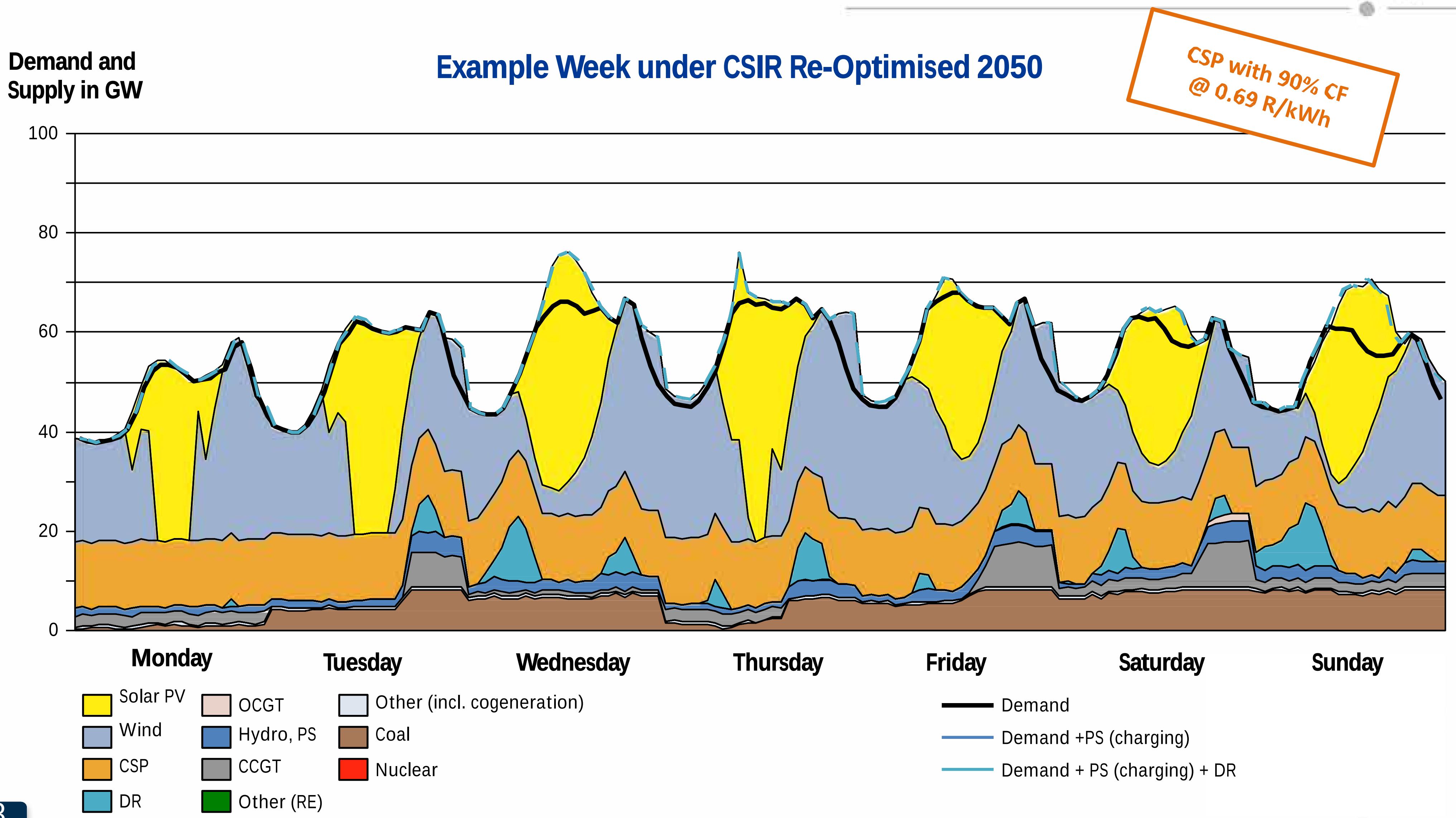
Sources: CSIR analysis

IRP 2016 (DRAFT): CSIR Re-Optimised in 2050
CSP 60% CF



Sources: CSIR analysis

IRP 2016 (DRAFT): CSIR Re-Optimised in 2050
CSP 90% CF



Sources: CSIR analysis

CSIR Re-Optimised case without renewables limits is R90 billion/yr cheaper than both IRP 2016 Base Case & IRP 2016 Carbon Budget case

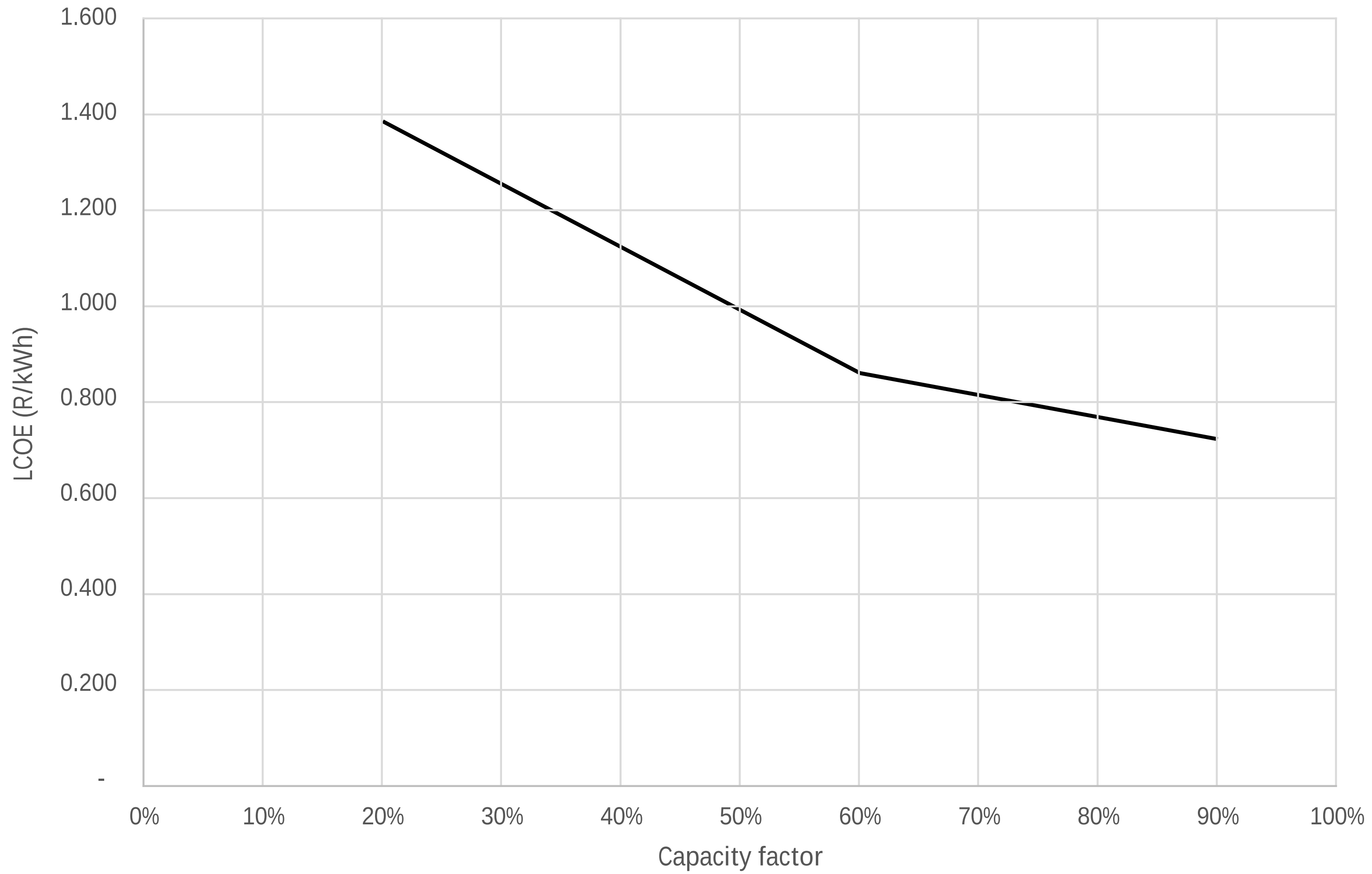
Preliminary
Year 2050

Draft IRP 2016 Base Case	Draft IRP 2016 Carbon Budget	CSIR Re-Optimised
27%	33%	80%
R580 billion/yr	R580 billion/yr	R490 billion/yr
200 Mt/yr	100 Mt/yr	70 Mt/yr
40 bn l/yr	16 bn l/yr	11 bn l/yr

CSIR
our future through science

Sources: CSIR analysis

Tipping point cost for CSP depends on annual average CF



our future through science

Agenda

Expertise of Commentators

Comments on IRP Assumptions

IRP Results and Least-cost Scenario

Proposal / Next Steps

our future through science

Recommendation:
The IRP Base Case should be least-cost, free of any artificial constraints

Solar PV, wind and flexibility is the cheapest new-build mix for the South African power system and it is the cost-optimal expansion to aim for a >70% renewable energy share by 2050

This "CSIR Re-Optimised" mix is <u>R90 billion per year</u> cheaper by 2050 than current Draft IRP Base Case

Also, CSIR Re-Optimised mix reduces CO_2 emissions by 65% (-130 Mt/yr) compared to Draft IRP Base Case

Avoiding CO_2 emissions and least-cost is not a trade-off anymore – South Africa can de-carbonise its electricity sector at <u>negative</u> carbon-avoidance cost

Recommendation: The IRP Base Case should be least-cost, free of any artificial constraints

- New-build limits for renewables should be lifted, relative costs of wind/PV updated, and the unconstrained re-run should form the Base Case of the IRP 2016
- Any cost increase due to deviations from the least-cost Base Case should be reported on

CSIR our future through science

Note: Wind and solar PV would have to be 60% more expensive than assumed before the IRP Base Case and the CSIR Re-Optimised case break even
Sources: CSIR analysis

Re a leboha

Ha Khensa

Enkosi

Siyathokoza

Thank you

Re a leboga

Ro livhuha

Dankie

Siyabonga

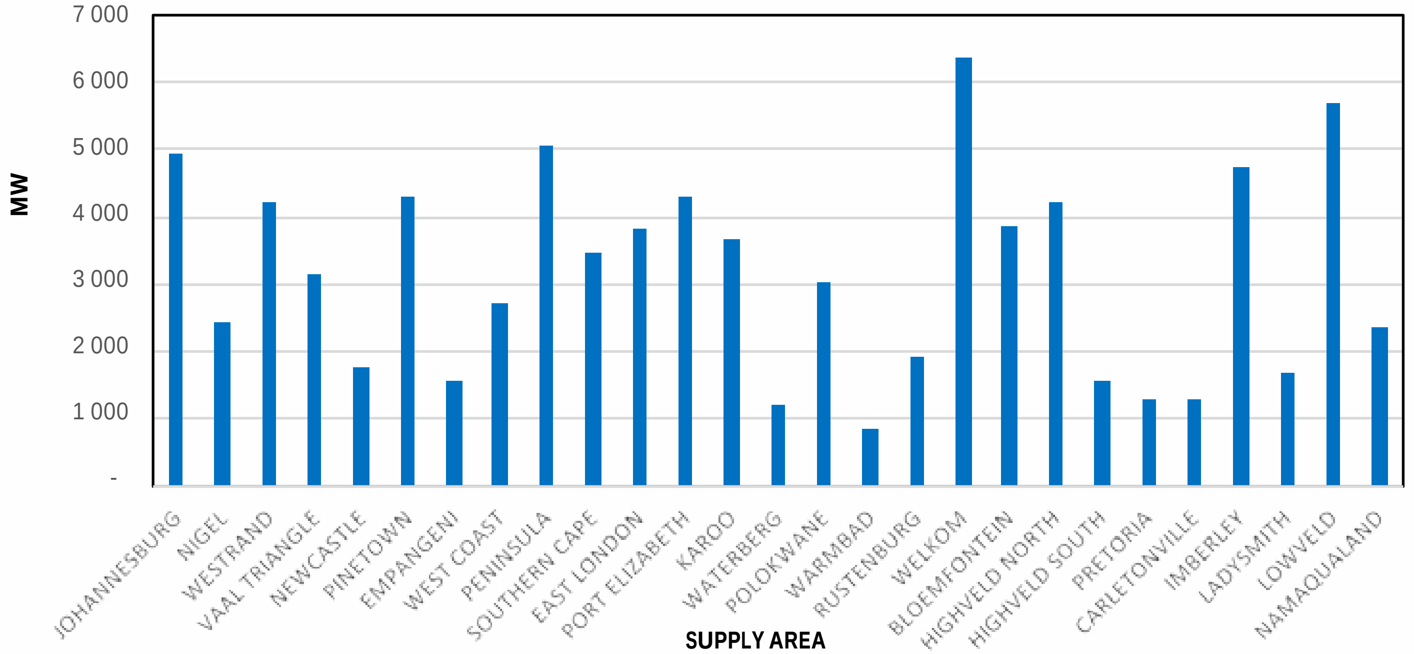
our future through science

Note: „Thank you“ in all official languages of the Republic of South Africa

BACKUP

REBID 1-4 amounts to only 6.8 GW of Wind and PV, the grid has more than enough capacity (≈85 GW) by year 2022

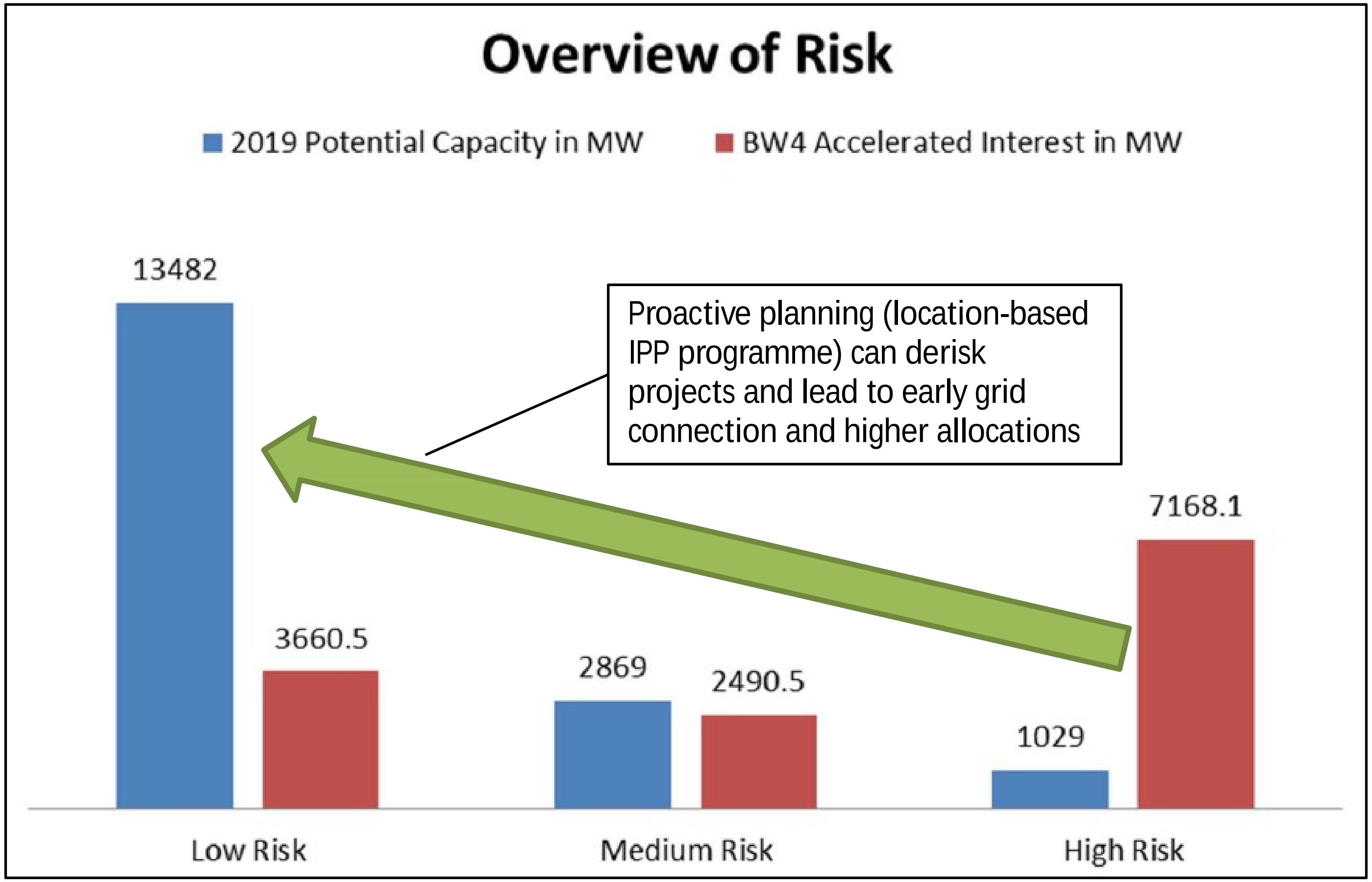
27 Supply areas' generation integration capacity ≈ 85 000 MW by year 2022
based on GCCA 2022 - using the grid designed for according to the 2014 TDP grid models



Additional studies (stability etc.) to quantity how much of the 85 GW can be comprised of wind and PV (with flexible generators) are warranted for managing the rollout plan

GCCA – Generation Connection Capacity Assessment
Sources:
- Transmission development plan 2016-2025: http://www.eskom.co.za/Whatweredoing/TransmissionDevelopmentPlan/Pages/Transmission_Development_Plans.aspx
- GCCA 2022: http://www.eskom.co.za/Whatweredoing/GCCAReport/Pages/Default.aspx
- CSIR analyses

Lack of location-based incentives for IPPs leads to interest in substations that are already constrained (e.g. RE Bid 4 Expedited)



Low risk:
Capacity available

Medium risk:
Minimal grid infrastructure required

High risk:
Extensive grid infrastructure required at Tx level

For Bid Window 4 Expedited, only 1170 MW was allocated for wind (650 MW) and PV (520 MW); more could have been allocated

Sources:
- Eskom Transmission Grid Planning - Expedited Bid Window Programme Access Risk Assessment
- CSIR analysis

Grid assessment/information to accompany the formal submission – all to be based publicly available information and data sets

- Grid capacity available at all busbars (66/88/132/275/400 kV) in transmission substations after RE Bid Windows 1-4
- Wind and solar PV correlation/aggregation impact on grid capacity assessment
- Location of wind and PV plants for the least-cost optimised electricity generation mix by 2050
- The estimated grid cost for the integration of new generation capacity for each scenario studies
- High-level assessment of the variable RE penetration levels for South Africa that will necessitate detailed stability and other studies associated with a South African system with low inertia

Actual experience from power systems globally indicate that > 50% instantaneous penetration of variable RE is possible before stability issues are a cause for concern