Submitted to DoE on 31 March 2017

Formal comments on the Integrated Resource Plan (IRP) Update Assumptions, Base Case and Observations 2016

CSIR Energy Centre

Pretoria, 31 March 2017

Jarrad G. Wright	*JWright@csir.co.za*	**Dr Tobias Bischof-Niemz**	*TBischofNiemz@csir.co.za*
Joanne Calitz	*JRCalitz@csir.co.za*	**Crescent Mushwana**	*CMushwana@csir.co.za*
Robbie van Heerden	*RPvHeerden@csir.co.za*	**Mamahloko Senatla**	*MSenatla@csir.co.za*

our future through science

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EXECUTIVE SUMMARY

our future through science

Executive Summary: A mix of solar PV, wind and flexible power generators is least cost

The CSIR determined the least cost, unconstrained electricity mix by 2050 as input into the IRP 2016

- Conservative approach: pessimistic assumptions for new technologies, optimistic for established ones

Result: It is least cost for any new investment in the power sector to be solar PV, wind or flexible power

- Solar PV, wind & flexible power generators (e.g. gas, CSP, hydro, biogas) are the cheapest new-build mix
- There is no technical limitation to solar PV and wind penetration over the planning horizon until 2050
- >70% renewable energy share by 2050 is cost optimal, replacing all old plants with the new optimal mix

South Africa can de-carbonise its electricity sector without pain: clean & cheap are no trade-offs anymore

- The "Least Cost" mix is the cheapest, it emits less CO_2 emissions, it consumes less water, and it creates more jobs in the electricity sector than both Draft IRP 2016 Base Case & Draft IRP 2016 Carbon Budget

Deviations from Least Cost have been quantified to inform policy adjustments. Compared to Least Cost:

- IRP 2016 Base Case: >R70 billion more costly, 2x more CO_2, 2.5x more water, 10-20% less jobs by 2050
- IRP 2016 Carbon Budget: R60 billion more costly, 15% more CO_2, 20% more water, 20% less jobs by 2050
- Decarbonised: R50 billion more costly, 95% decarbonised, 30% less water, 5% more jobs by 2050

Additionally: Least Cost is adaptable and therefore robust against unforeseen changes in demand and cost

Conservative RE/battery costing:
Least Cost: R75 billion/yr cheaper than Draft IRP 2016 Base Case (-10%)

Conservative cost inputs

- Conventional technologies (coal, nuclear, gas CAPEX): as per IRP 2016
- Battery technologies: as per IRP 2016 (10 000 R/kWh)
- Gas fuel: more expensive than IRP 2016 (150 R/GJ)
- Solar PV: aligned with original IRP 2010 cost assumptions (by 2030/2040/2050: 0.56/0.52/0.49 R/kWh)
- Wind: kept constant at latest South African auction result for study period (2016-2050: 0.62 R/kWh)

Conservative job number inputs

- Utilising job creation numbers from McKinsey study commissioned by the Department of Energy in the context of the Integrated Energy Plan
- Adjusting the numbers upwards for coal power generation and coal mining (McKinsey numbers assume more efficient / automated coal mining process and coal-power-station operations than current RSA)

Results (presented on next three slides)

- Least Cost is R60-75 billion/yr cheaper by 2050 than Draft IRP 2016 Base Case/Carbon Budget (-10%)
- By 2050, Least Cost emits 55% less CO_2 than Draft IRP 2016 Base Case & consumes 65% less fresh water
- By 2050, Least Cost creates 10-20% more jobs in the electricity sector than Draft IRP 2016 Base Case

Sources: http://www.energy.gov.za/files/IEP/2016/IEP-AnnexureB-Macroeconomic-Assumptions.pdf, pages 23-38

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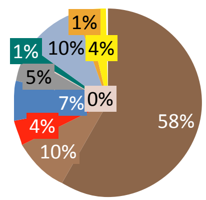
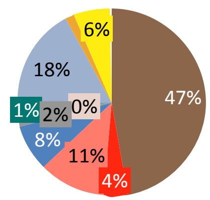
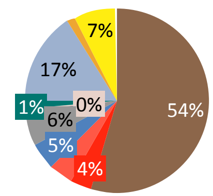
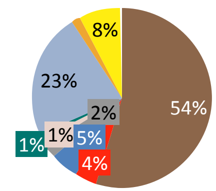
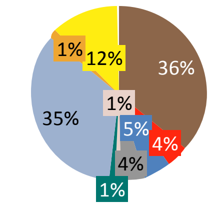
Least Cost is ≈R20-40 billion/yr cheaper by 2030 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

2030		IRP 2016 Base Case	IRP 2016 Carbon Budget	Unconstrained Base Case	Least Cost	Decarbonised
		As per Draft IRP 2016	As per Draft IRP 2016	As per DoE		
Energy Mix in 2030	**Demand: 343 TWh** 					
Cost in 2030	**Total system cost**[1] (R-billion/yr)	384	403	374	367	370
	Average tariff (R/kWh)	1.12	1.17	1.09	1.07	1.08
Environ-ment in 2030	**CO_2 emissions** (Mt/yr)	251	176	214	204	141
	Water usage (billion-litres/yr)	216	167	204	196	142
Jobs[2] in 2030	**Direct & supplier** ('000)	93-153	100-142	96-146	101-149	112-144

Because of lack of data, zero jobs for biomass/-gas assumed (affects Decarbonised)

■ Coal ■ Coal (new) ■ Nuclear ■ Nuclear (new) ■ Hydro+PS ■ Gas ■ Peaking ■ Biomass/-gas ■ Other storage ■ Wind ■ CSP ■ Solar PV

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

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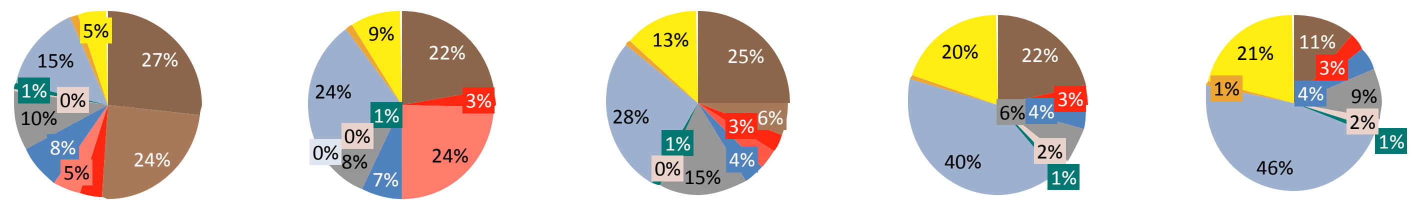
Least Cost is ≈R45-60 billion/yr cheaper by 2040 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

As per Draft IRP 2016 | As per DoE

Energy Mix in 2040 — Demand: 428 TWh



2040		IRP 2016 Base Case	IRP 2016 Carbon Budget	Unconstrained Base Case	Least Cost	Decarbonised
Cost in 2040	**Total system cost**[1] (R-billion/yr)	535	530	511	495	498
	Average tariff (R/kWh)	1.25	1.24	1.19	1.15	1.16
Environ-ment in 2040	**CO_2 emissions** (Mt/yr)	251	176	214	113	141
	Water usage (billion-litres/yr)	216	167	204	66	142
Jobs[2] in 2040	**Direct & supplier** ('000)	185-241	191-216	199-234	234-258	242-254

Because of lack of data, zero jobs for biomass/-gas assumed (affects Decarbonised)

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

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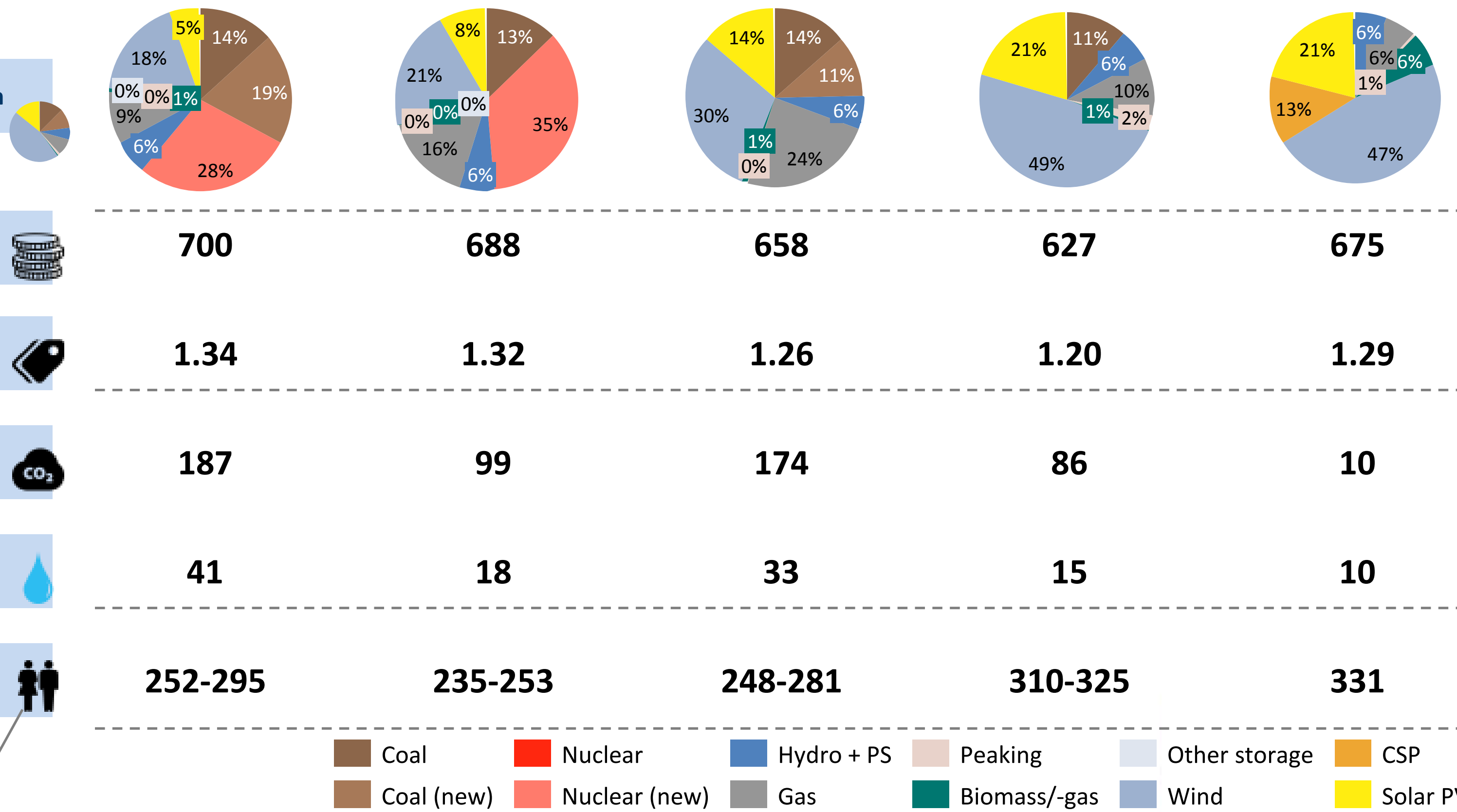
Least Cost is ≈R60-75 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

	As per Draft IRP 2016		As per DoE		
2050	**IRP 2016 Base Case**	**IRP 2016 Carbon Budget**	**Unconstrained Base Case**	**Least Cost**	**Decarbonised**

Energy Mix in 2050 — Demand: 522 TWh



		IRP 2016 Base Case	IRP 2016 Carbon Budget	Unconstrained Base Case	Least Cost	Decarbonised
Cost in 2050	**Total system cost**[1] (R-billion/yr)	700	688	658	627	675
	Average tariff (R/kWh)	1.34	1.32	1.26	1.20	1.29
Environ-ment in 2050	**CO_2 emissions** (Mt/yr)	187	99	174	86	10
	Water usage (billion-litres/yr)	41	18	33	15	10
Jobs[2] in 2050	**Direct & supplier** ('000)	252-295	235-253	248-281	310-325	331

Because of lack of data, zero jobs for biomass/-gas assumed (affects Decarbonised)

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

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Expected RE/battery costing:
Least Cost: R145 bn/yr cheaper than Draft IRP 2016 Base Case (-20%)

Expected cost inputs

- Conventional technologies (coal, nuclear, gas CAPEX): as per IRP 2016
- Battery technologies: expected cost reductions applied (2030/2040/2050: 2 000/1 000/800 R/kWh)
- Gas fuel: more expensive than IRP 2016 (150 R/GJ)
- Solar PV: 50% further cost reductions until 2050 assumed (by 2030/2040/2050: 0.46/0.38/0.30 R/kWh)
- Wind: 20% further cost reductions until 2050 assumed (by 2030/2040/2050: 0.56/0.53/0.50 R/kWh)

Conservative job number inputs

- Utilising job creation numbers from McKinsey study commissioned by the Department of Energy in the context of the Integrated Energy Plan
- Adjusting the numbers upwards for coal power generation and coal mining (McKinsey numbers assume more efficient / automated coal mining process and coal-power-station operations than current RSA)

Results (presented on next three slides)

- Least Cost is R135-145 billion/yr cheaper by 2050 than Draft IRP 2016 Base Case/Carbon Budget (-20%)
- By 2050, Least Cost emits 70% less CO_2 than Draft IRP 2016 Base Case & consumes 75% less fresh water
- By 2050, Least Cost creates 30-50% more jobs in the electricity sector than Draft IRP 2016 Base Case

Sources: http://www.energy.gov.za/files/IEP/2016/IEP-AnnexureB-Macroeconomic-Assumptions.pdf, pages 23-38

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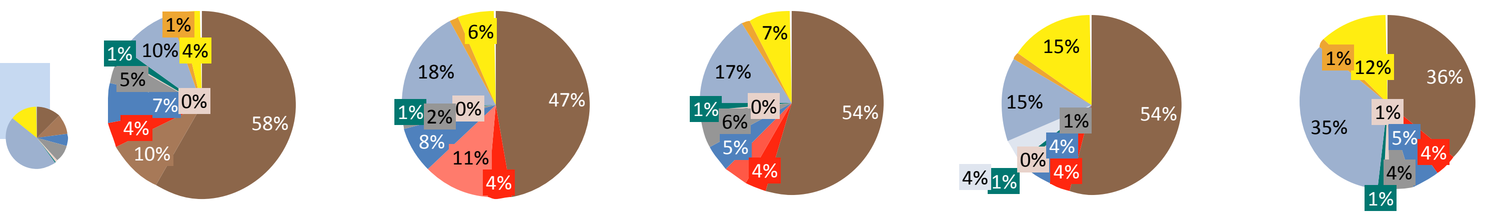
Least Cost is ≈R30-50 billion/yr cheaper by 2030 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

2030		As per Draft IRP 2016: IRP 2016 Base Case ("Expected" costs)	As per Draft IRP 2016: IRP 2016 Carbon Budget ("Expected" costs)	As per DoE: Unconstrained Base Case ("Expected" costs)	Least Cost ("Expected" costs)	Decarbonised ("Expected" costs)
Energy Mix in 2030	**Demand: 343 TWh**	(see chart)	(see chart)	(see chart)	(see chart)	(see chart)
Cost in 2030	**Total system cost**[1] (R-billion/yr)	382	399	369	353	355
	Average tariff (R/kWh)	1.11	1.16	1.08	1.03	1.03
Environ-ment in 2030	**CO_2 emissions** (Mt/yr)	251	176	214	206	141
	Water usage (billion-litres/yr)	216	167	204	193	142
Jobs[2] in 2030	**Direct & supplier** ('000)	93-153	100-142	96-146	106-156	112-144



Coal | Coal (new) | Nuclear | Nuclear (new) | Hydro+PS | Gas | Peaking | Biomass/-gas | Other storage | Wind | CSP | Solar PV

Because of lack of data, zero jobs for biomass/-gas assumed (affects Decarbonised)

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

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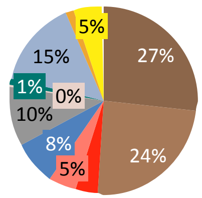
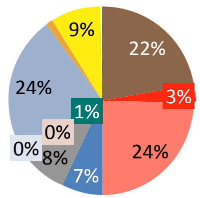
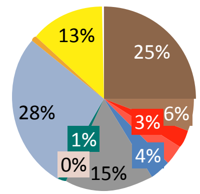
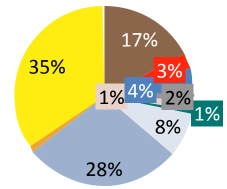
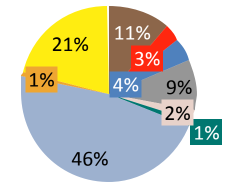
Least Cost is ≈R80-105 billion/yr cheaper by 2040 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

2040		As per Draft IRP 2016: IRP 2016 Base Case ("Expected" costs)	As per Draft IRP 2016: IRP 2016 Carbon Budget ("Expected" costs)	As per DoE: Unconstrained Base Case ("Expected" costs)	Least Cost ("Expected" costs)	Decarbonised ("Expected" costs)
Energy Mix in 2040	**Demand: 428 TWh** 					
Cost in 2040	**Total system cost[1]** (R-billion/yr)	548	526	489	444	465
	Average tariff (R/kWh)	1.28	1.23	1.14	1.04	1.09
Environ-ment in 2040	**CO_2 emissions** (Mt/yr)	251	176	214	91	141
	Water usage (billion-litres/yr)	216	167	204	53	142
Jobs[2] in 2040	**Direct & supplier** ('000)	185-241	191-216	199-234	273-294	242-254

Legend: Coal, Coal (new), Nuclear, Nuclear (new), Hydro+PS, Gas, Peaking, Biomass/-gas, Other storage, Wind, CSP, Solar PV

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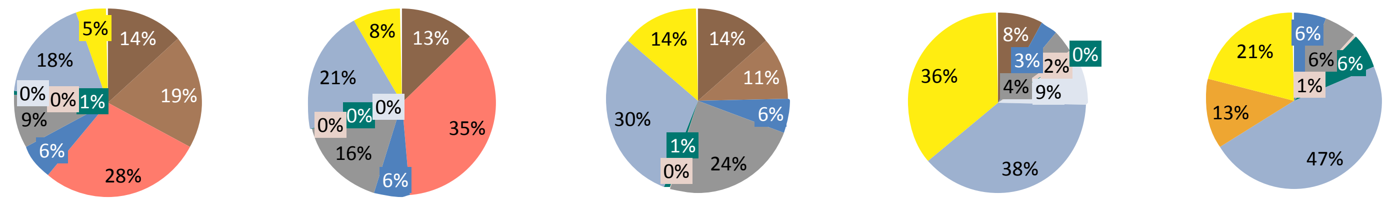
Least Cost is ≈R135-145 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

2050		As per Draft IRP 2016: IRP 2016 Base Case ("Expected" costs)	As per Draft IRP 2016: IRP 2016 Carbon Budget ("Expected" costs)	As per DoE: Unconstrained Base Case ("Expected" costs)	Least Cost ("Expected" costs)	Decarbonised ("Expected" costs)
Energy Mix in 2050	**Demand: 522 TWh** 					
Cost in 2050	**Total system cost**[1] (R-billion/yr)	675	664	596	529	579
	Average tariff (R/kWh)	1.29	1.27	1.14	1.01	1.11
Environ-ment in 2050	**CO_2 emissions** (Mt/yr)	187	99	174	60	10
	Water usage (billion-litres/yr)	41	18	33	10	10
Jobs[2] in 2050	**Direct & supplier** ('000)	252-295	235-253	248-281	380-392	331

Legend: Coal, Coal (new), Nuclear, Nuclear (new), Hydro + PS, Gas, Peaking, Biomass/-gas, Other storage, Wind, CSP, Solar PV

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IRP PLEXOS model only optimises for cost of power generation (Gx) – two additional key aspects considered: system stability and grid cost

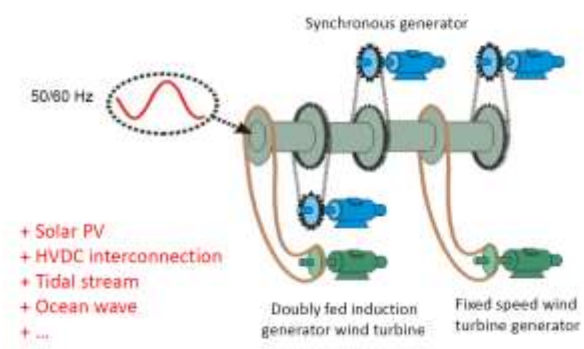
System Stability (inertia): <u>worst case</u> below 1% of Gx cost

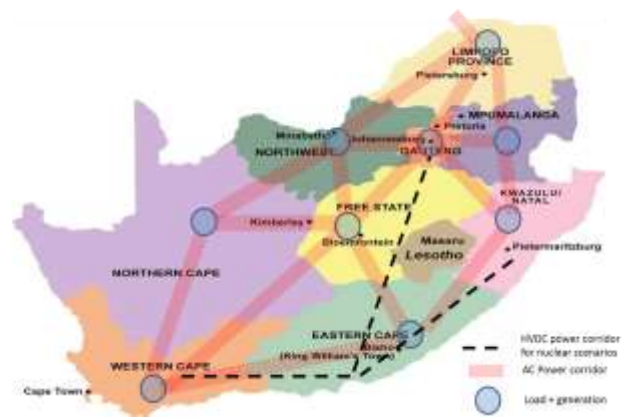
- Connecting nuclear/coal via HVDC and/or solar PV/wind to the grid reduces the "system inertia"
- This reduces the inherent stabilising effect of synchronous inertia during contingency events
- Many technical solutions to operate low-inertia system
- In this study the "worst case" was costed
  - State-of-the-art technology (very high costs assumed, no further tech/cost advancements)
  - No further increase in engineering of how to deal with low-inertia systems
- In all scenarios, the worst-case-cost are well below 1% of the total cost of power generation (Gx) by 2050, cost differences between scenarios are much lower than 1%

Transmission grid cost: Gx Least Cost also cheapest for Tx

- High-level cost estimate for shallow and deep grid connection cost for all scenarios was developed
- Least Cost (Gx) case is additionally R20-30 billion/yr cheaper compared to Draft IRP 2016 Base Case and Carbon Budget case on transmission grid side

Load Balancing (Frequency Control)





BACKGROUND

Agenda

The IRP process

CSIR mandate

our future through science

Agenda

The IRP process

CSIR mandate

The IRP is South Africa's long-term electricity capacity expansion plan

Integrated resource planning (IRP) for electricity is a long-term capacity expansion planning process typically applying least-cost planning principles to meet expected future demand reliably taking into account all existing and future supply resources to a city, province/state or country

In South Africa, an IRP is performed periodically at a country level with the Department of Energy (DoE) being the custodian of the process – the current iteration of the IRP is the IRP 2016 (draft)

- Starting point of the IRP Base Case: pure techno-economic analysis to determine least-cost way to supply electricity
- Later process: least-cost mix is policy adjusted to cater for aspects not captured in IRP model and/or policy objectives
- These adjustments are typically country level priorities and policy objectives e.g. emissions trajectories, water usage, localisation potential, regional development, etc.

Due to it's wide ranging implications for a broad range of stakeholders – it is typically made a consultative process where inputs are sought from various entities

The IRP 2016 is the electricity expansion plan for South Africa until 2050

Sources: CSIR analysis

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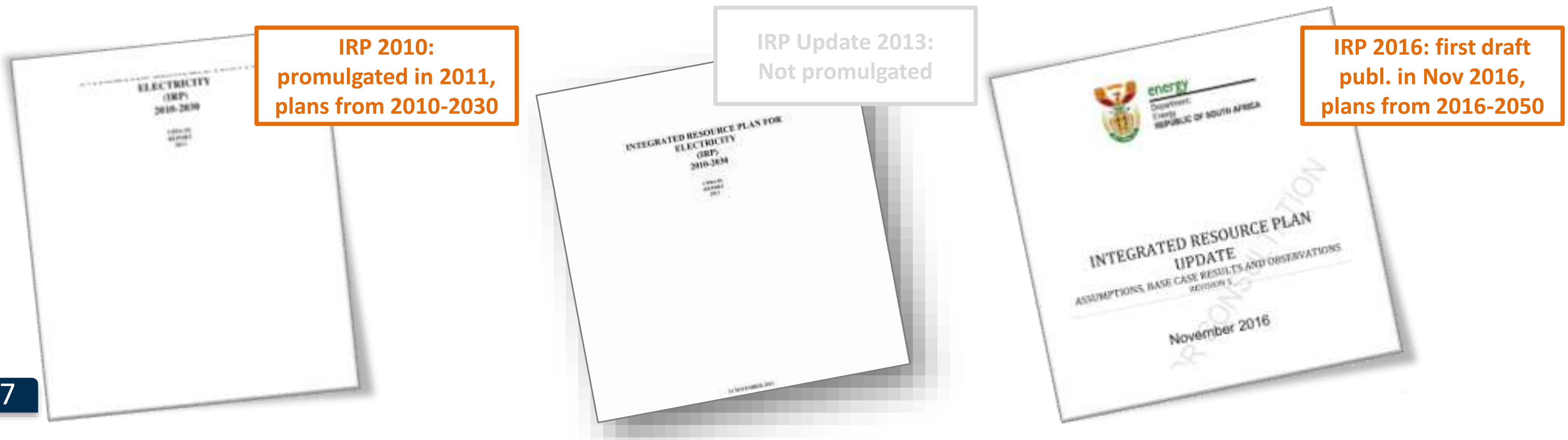
Last promulgated IRP is IRP 2010, update currently ongoing (IRP 2016)

The enforceable IRP in South Africa is still the IRP 2010 as promulgated in 2011

A number of changes since IRP 2010 (demand forecast and confirmation of wind/solar PV cost decrease)

The IRP 2016 currently released for public consultation is the latest update to South Africa's IRP and is the electricity system expansion plan to 2050

Public comments are invited by the Department of Energy to be submitted by 31 March 2017



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Integrated Resource Plan (IRP): Process for power generation capacity expansion in South Africa

Planning / simulation world

Inputs
1) Demand Forecast
2) Existing Supply Forecast:
- Plants under construction
- Preferred bidders
- Decommissioning
- Plant performance

3) New Supply Options:
- Technology costs **assumptions**
- Technology technical characteristics

4) Constraints:
- CO_2 limits
- Security/adequacy of supply level

IRP modelling framework (PLEXOS®)

LT[1] techno-economic least-cost optimisation

MT/ST[2] production cost testing system adequacy (security of supply)

Output
Per scenario:
- Total system costs
- Capacity expansion (GW)
- Energy share (TWh)
- CO_2 emissions
- Water usage
- Jobs in the electricity sector

After policy adjustment:
- Final “IRP” for promulgation
- Key questions answered:
  - What to build (MW)?
  - When to build it (timing)?

Actuals / real world

Inputs
- Ministerial Determinations for new technology specific generation capacity

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

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

[1] LT = Long-term
[2] MT/ST = Medium-term/Short-term

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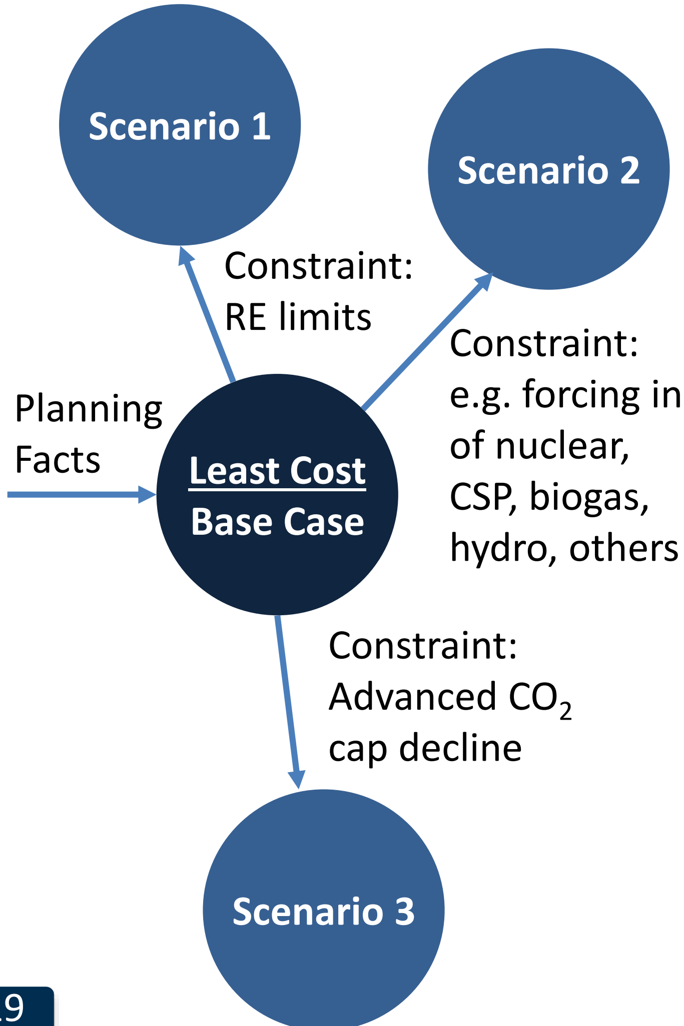
IRP process as described in the Department of Energy's Draft IRP 2016 document: least-cost Base Case is derived from technical planning facts



Case	Cost
Base Case	Base
Scenario 1	Base + Rxx bn/yr
Scenario 2	Base + Ryy bn/yr
Scenario 3	Base + Rzz bn/yr
…	…

1. Public consultation on costed scenarios
2. Policy adjustment of Base Case
3. Final IRP for approval and gazetting

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Sources: based on Department of Energy's Draft IRP 2016, page 7; http://www.energy.gov.za/IRP/2016/Draft-IRP-2016-Assumptions-Base-Case-and-Observations-Revision1.pdf

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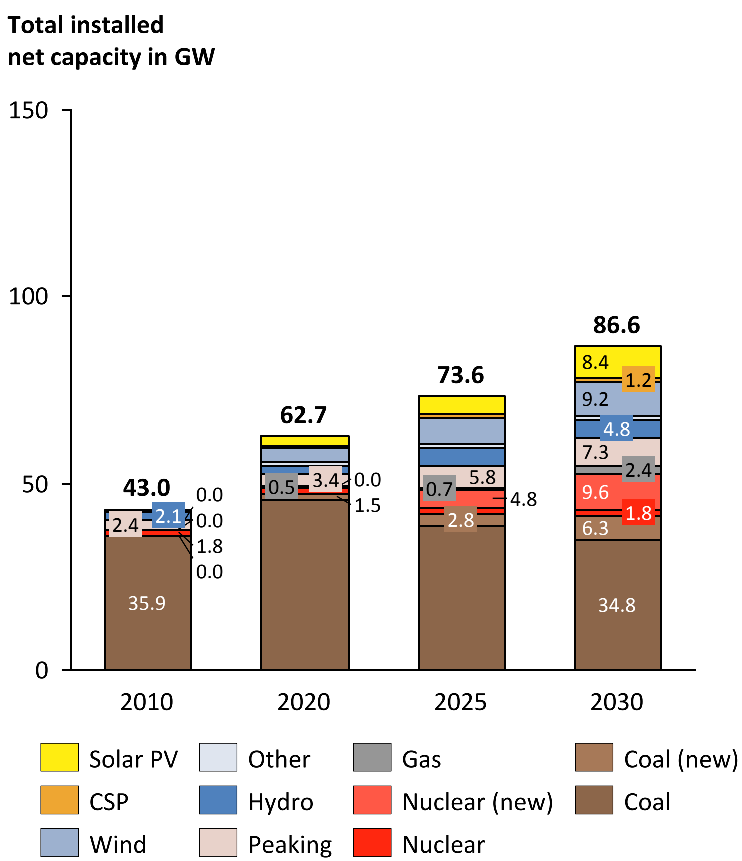
Reminder: IRP 2010 planned the electricity mix only until 2030

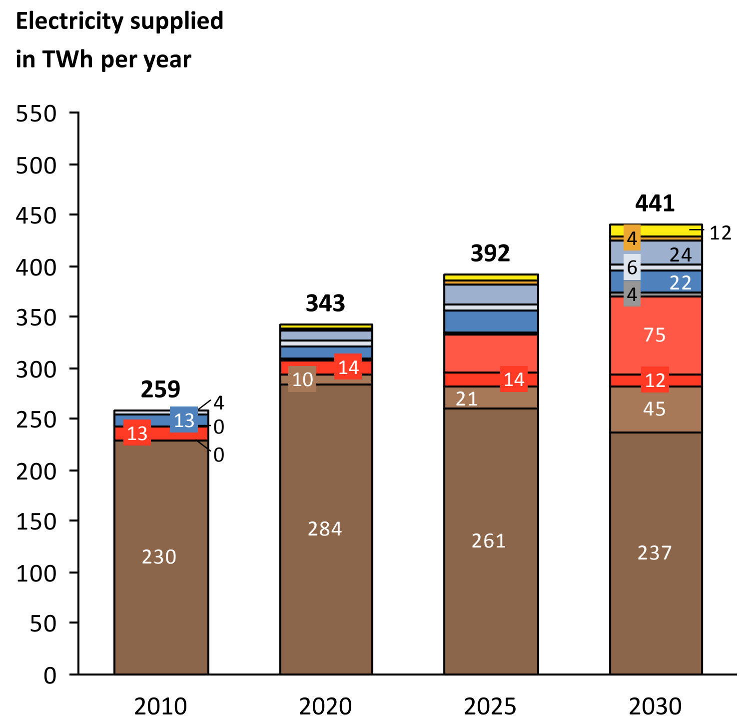
Installed capacity and electricity supplied from 2010 to 2030 as planned in the IRP 2010

Promulgated IRP 2010

Installed capacity



Energy mix



RE — **5%** (12 TWh/yr) → **14%** (62 TWh/yr)

CO_2 free — **10%** (25 TWh/yr) → **34%** (149 TWh/yr)

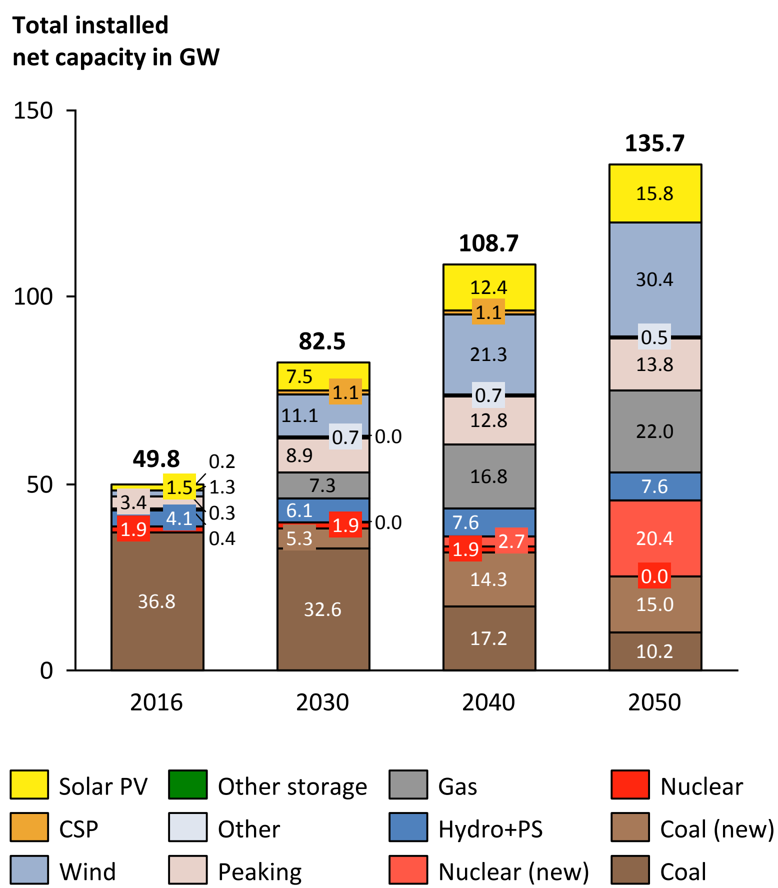
Note: Installed capacity and electricity supplied <u>excludes</u> pumped storage; Renewables include solar PV, CSP, wind, biomass, biogas, landfill and hydro (includes imports).
Sources: DoE IRP 2010-2030; CSIR Energy Centre analysis

Currently under discussion: Draft IRP 2016 Base Case plans until 2050

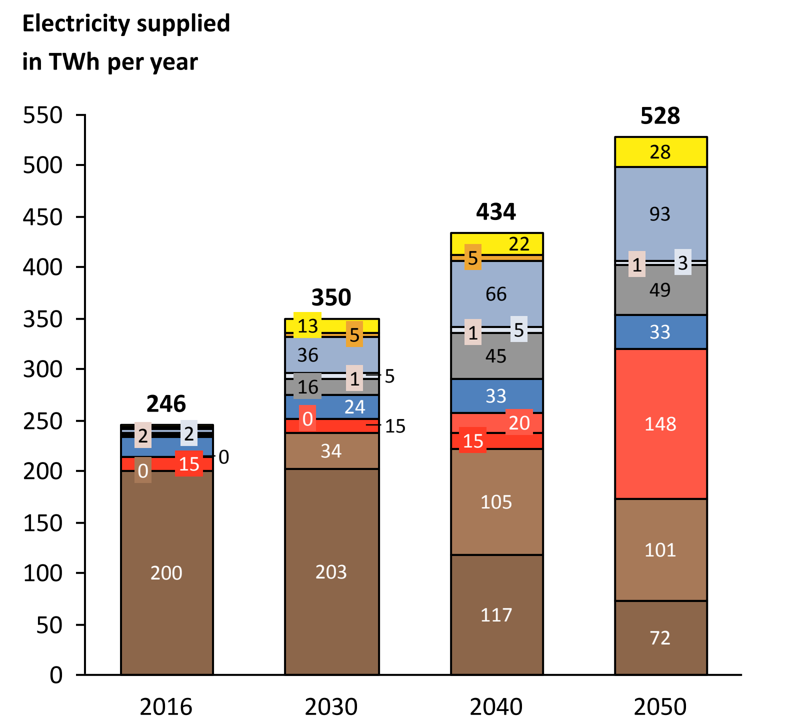
Installed capacity and electricity supplied from 2016 to 2050 as planned in the Draft IRP 2016 Base Case

Current Draft IRP 2016 Base Case

Installed capacity



Energy mix



Note: Installed capacity and electricity supplied includes pumped storage; Renewables include solar PV, CSP, wind, biomass, biogas, landfill and hydro (includes imports).
Sources: DoE Draft IRP 2016; CSIR Energy Centre analysis

Agenda

The IRP process

CSIR mandate

our future through science

The DoE has asked for public comments and CSIR are mandated as a scientific body to contribute to key areas affecting all South Africans

The DoE has requested for the inputs from the public in provincial roadshows as part of wider consultations (in addition to inter-departmental consultations and NEDLAC)

CSIR has already provided oral inputs (early Dec 2016), written inputs on 31 Mar 2017 (this document)

The CSIR is mandated by the Scientific Research Council Act section (3):

> *The objects of the CSIR are, through directed and particularly multi-disciplinary research and technological innovation, to foster, in the national interest and in fields which in its opinion should receive preference, industrial and scientific development, either by itself or In co-operation with principals from the private or public sectors, and thereby to contribute to the improvement of the quality of life of the people of the Republic, and to perform any other functions that may be assigned to the CSIR by or under this Act.*

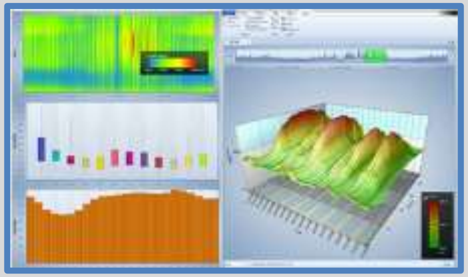
CSIR has the capabilities to provide the scientific fact base for South Africa's energy planning

As part of the contribution to the IRP 2016 public participation process – CSIR performed power-system analyses for a range of scenarios and submit a complete package of data, models, report and slide deck

Sources: CSIR analysis

Submitted to DoE on 31 March 2017

Energy Research at the CSIR covers the entire energy value chain, from technologies, systems, market design to implementation



Challenge

- The global energy industry is in a restructuring phase, driven by the need for more efficient use of energy, renewable energies & new technologies (eVehicles, hydrogen, batteries)
- The CSIR's energy research responds to global megatrends while addressing national research priorities

Objectives

- The objective is to make CSIR the leading research institution on the African continent in energy, globally recognised
- Significant HCD pipeline with long-term target of 200+ staff

Energy Demand → Energy Supply → Energy Storage → Energy Systems → Energy Market Design

Energy-Autonomous Campus Programme *(real-world implementation)*

Outputs generated so far

- Strong teams around hydrogen storage, batteries, energy systems, solar PV and wind technology testing & development

2017/18 Plans

- Accelerated recruitment in areas hydrogen generation, energy efficiency and demand response technologies

The feedback on the IRP is part of the research on "Energy Systems"

CSIR team has significant expertise from power system planning, system operation and grid perspective

Dr Tobias Bischof-Niemz

- Head of the CSIR Energy Centre
- Member of the Ministerial Advisory Council on Energy (MACE)
- Member of IRP2010/2013 team at Eskom, energy planning in Europe for large utilities

Joanne Calitz

- Senior Engineer: Energy Planning (CSIR Energy Centre)
- Previously with Eskom Energy Planning
- Medium-Term Outlook and IRP for RSA

Robbie van Heerden

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

Mamahloko Senatla

- Researcher: Energy Planning (CSIR Energy Centre)
- Previously with the Energy Research Centre at University of Cape Town

Crescent Mushwana

- Research Group Leader: Energy Systems (CSIR Energy Centre)
- Former Chief Engineer at Eskom strategic transmission grid planning

Jarrad Wright

- Principal Engineer: Energy Planning (CSIR Energy Centre)
- Commissioner: National Planning Commission (NPC)
- Former Africa Manager of PLEXOS

GLOBAL AND DOMESTIC VIEW OF SUPPLY TECHNOLOGIES

Agenda

Global electricity sector generation mix

Coal

Nuclear

Natural gas

Solar PV, Wind, CSP, Biogas

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Global electricity sector generation mix

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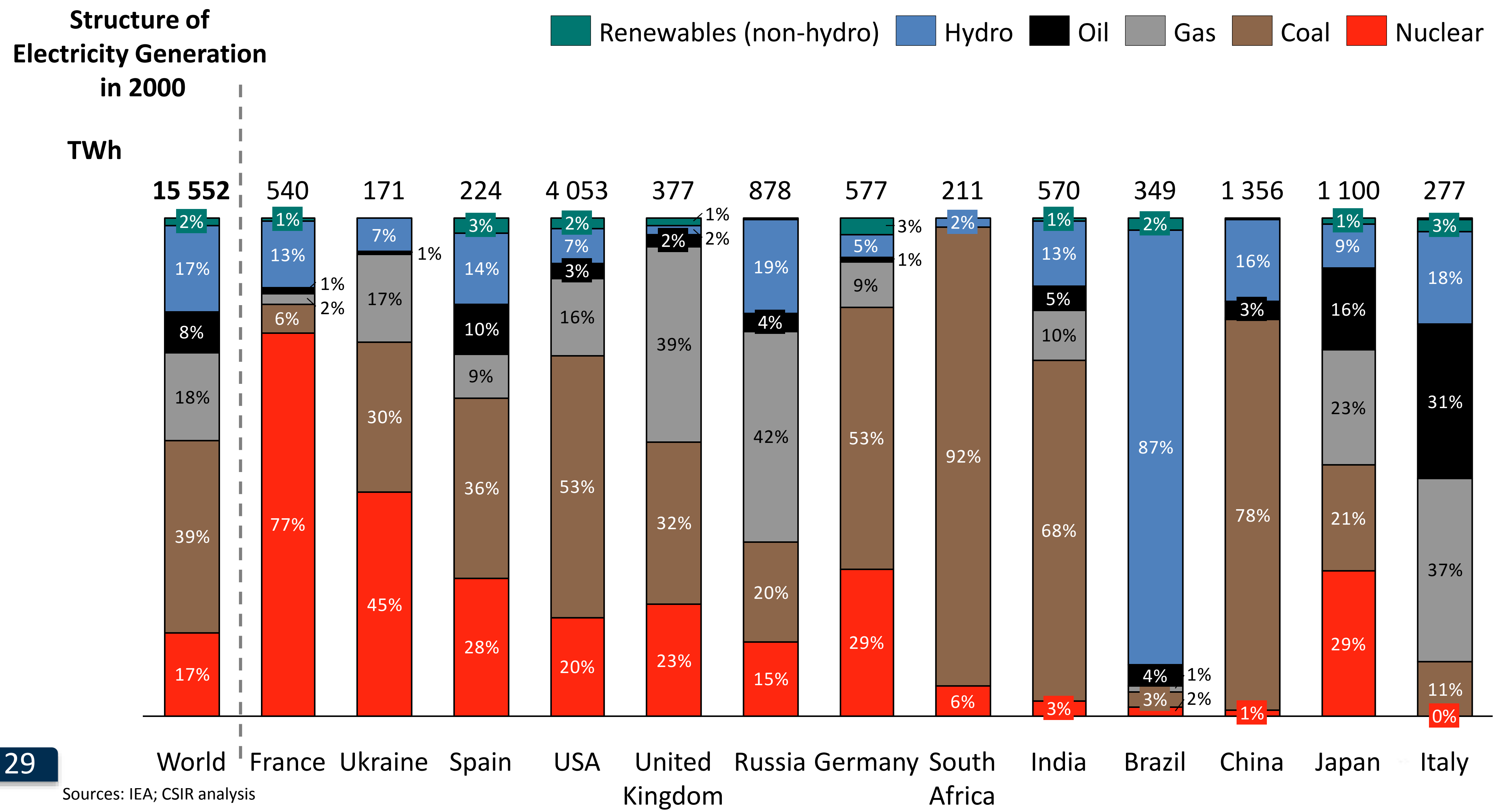
our future through science

2000: South Africa's electricity sector is fuelled by coal (92%)

Structure of electricity generation for selected countries



Sources: IEA; CSIR analysis

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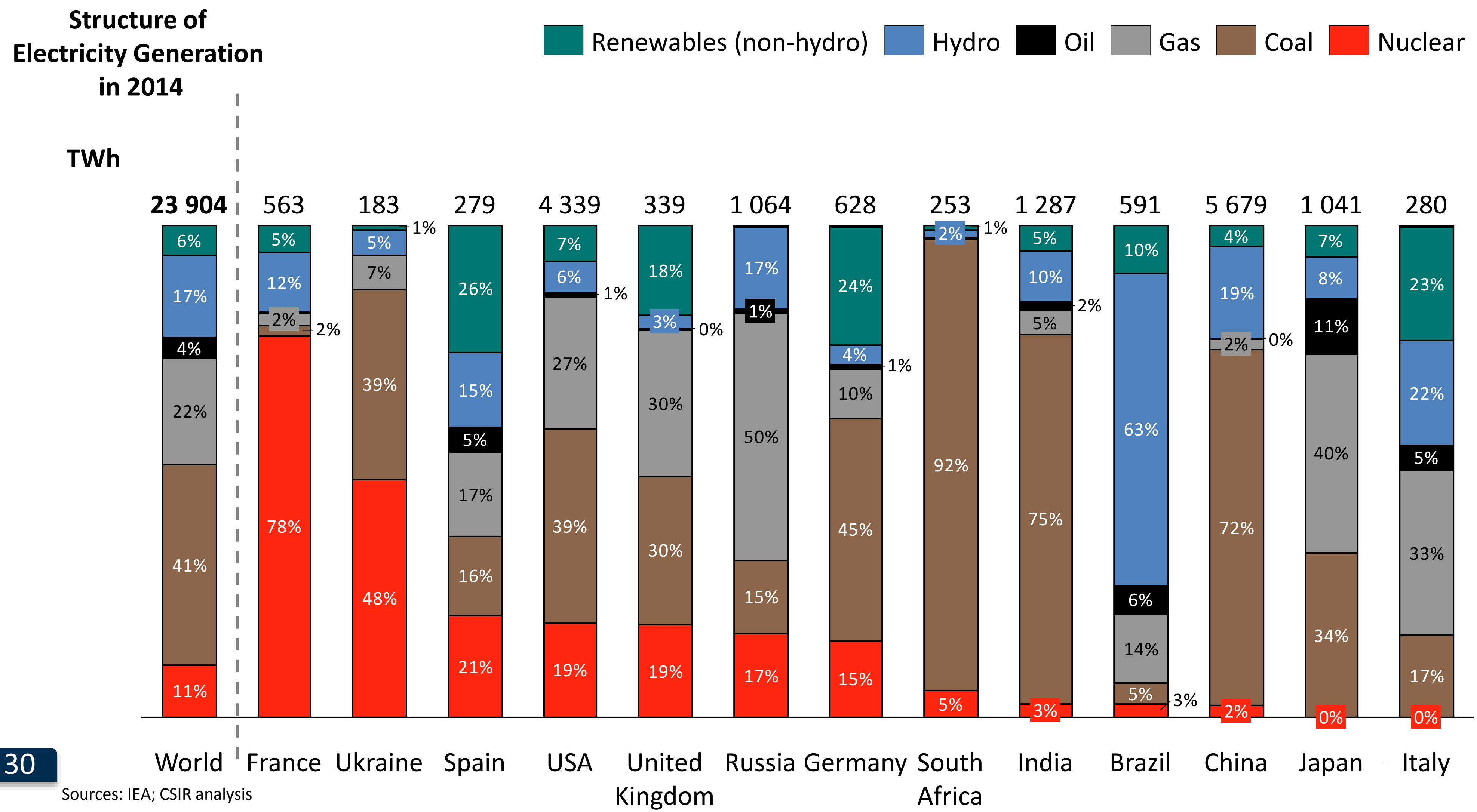
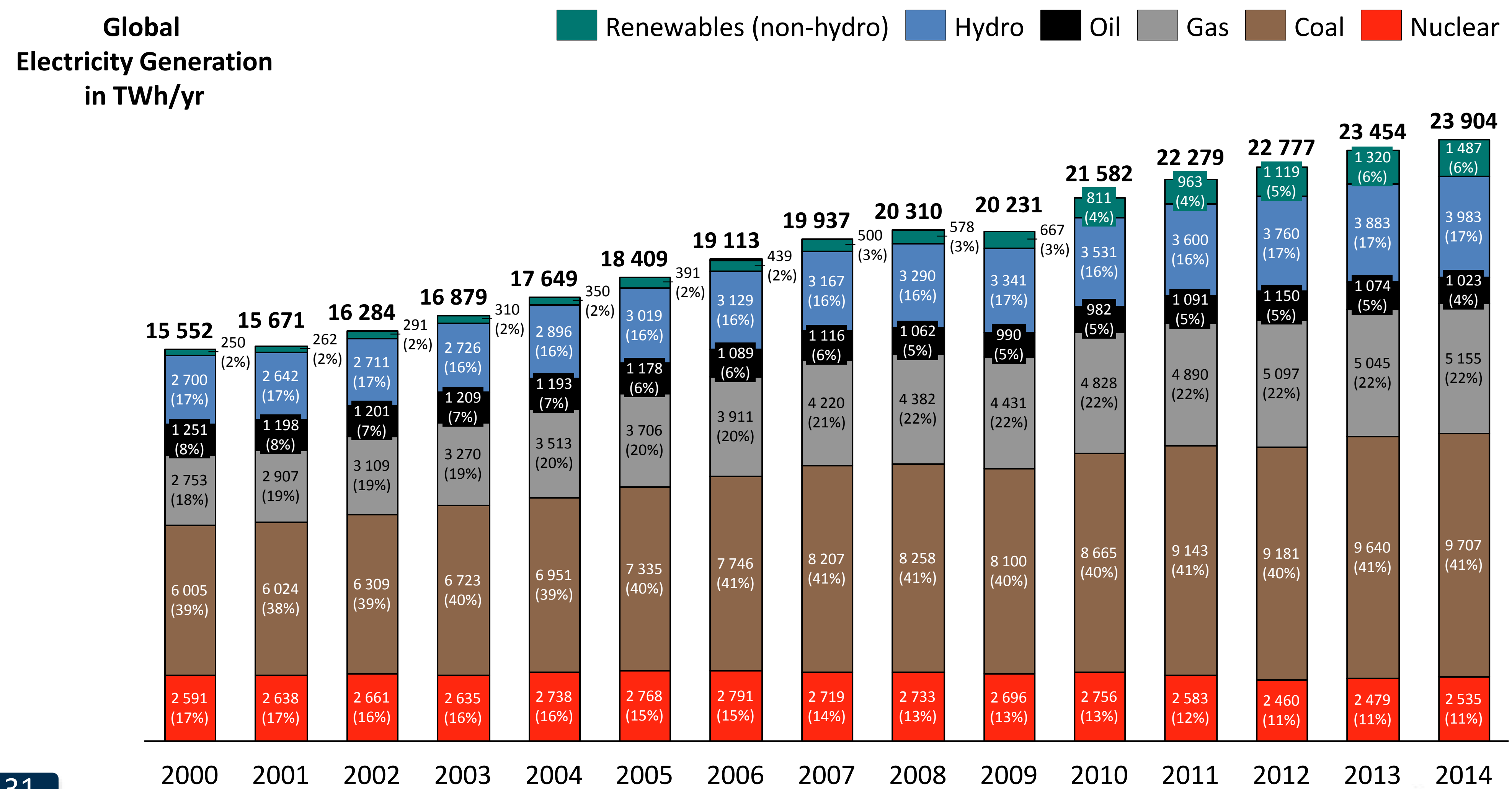


Country	TWh	Renewables (non-hydro)	Hydro	Oil	Gas	Coal	Nuclear
World	23 904	6%	17%	4%	22%	41%	11%
France	563	5%	12%		2%	2%	78%
Ukraine	183	1%	5%		7%	39%	48%
Spain	279	26%	15%	5%	17%	16%	21%
USA	4 339	7%	6%	1%	27%	39%	19%
United Kingdom	339	18%	3%	0%	30%	30%	19%
Russia	1 064		17%	1%	50%	15%	17%
Germany	628	24%	4%	1%	10%	45%	15%
South Africa	253	1%	2%			92%	5%
India	1 287	5%	10%	2%	5%	75%	3%
Brazil	591	10%	63%	6%	14%	5%	3%
China	5 679	4%	19%	0%	2%	72%	2%
Japan	1 041	7%	8%	11%	40%	34%	0%
Italy	280	23%	22%	5%	33%	17%	0%

Sources: IEA; CSIR analysis

Submitted to DoE on 31 March 2017

From 2000 to 2014, renewables and gas grew most, followed by coal



Sources: IEA; CSIR analysis

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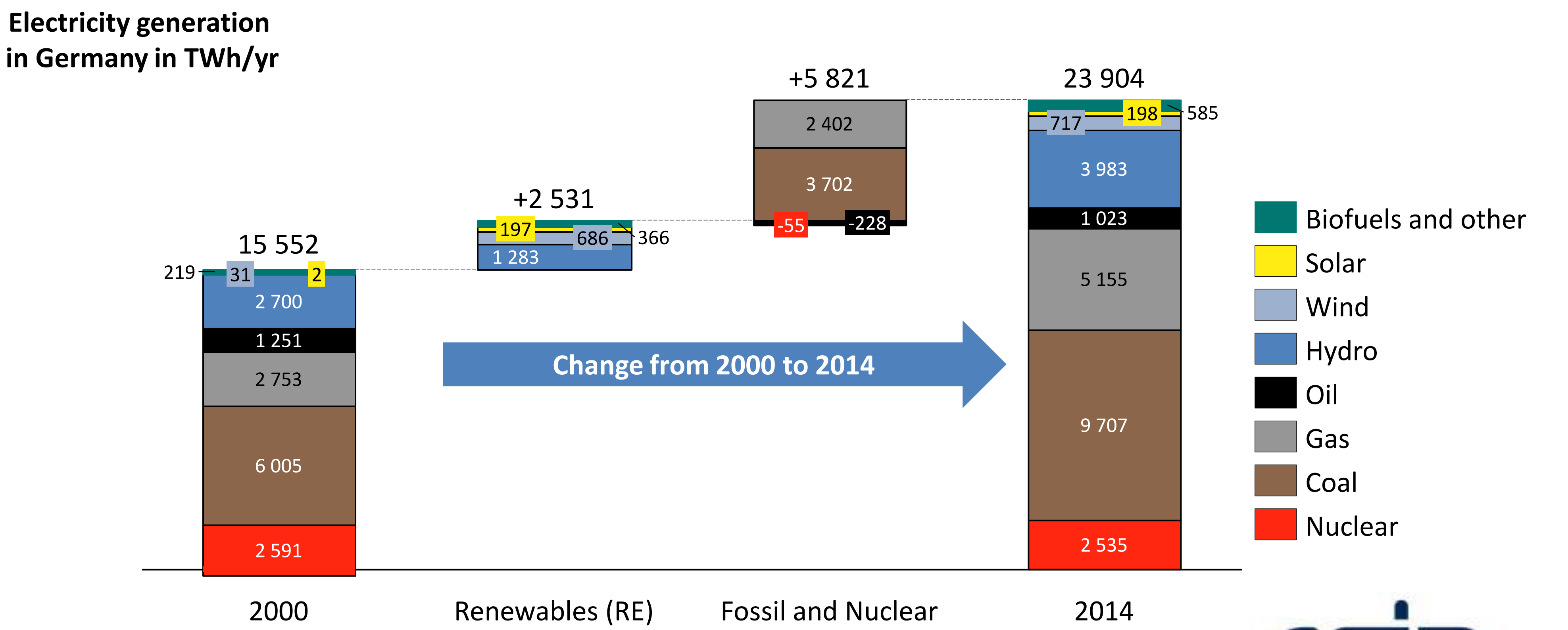
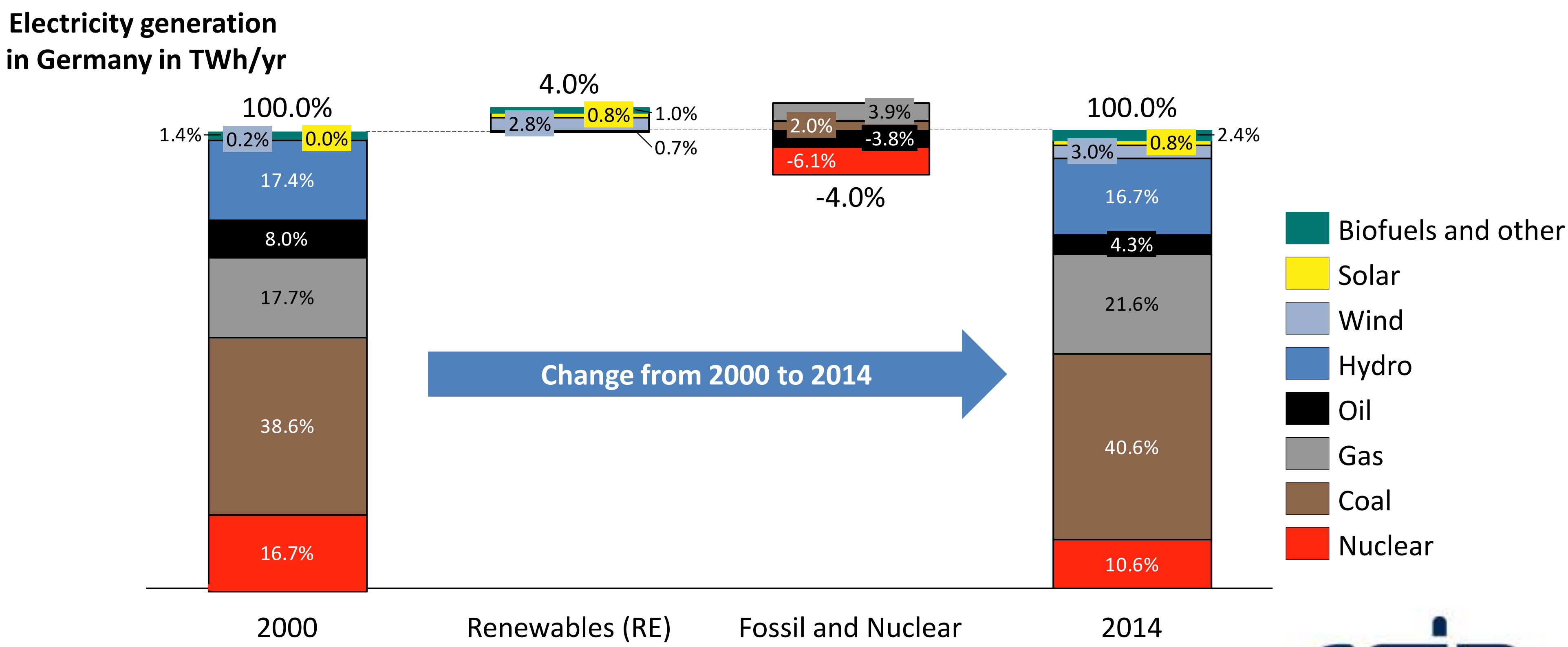
Global demand growth from 2000-2014 was supplied by coal, gas & RE



Sources: IEA; CSIR analysis

Submitted to DoE on 31 March 2017

Globally from 2000-2014: Renewables & gas grew by 4%-points each, coal by 2%-points, nuclear declined by 6%-points and oil by 4%-points



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Sources: IEA; CSIR analysis

Agenda

Global electricity sector generation mix

Coal

Nuclear

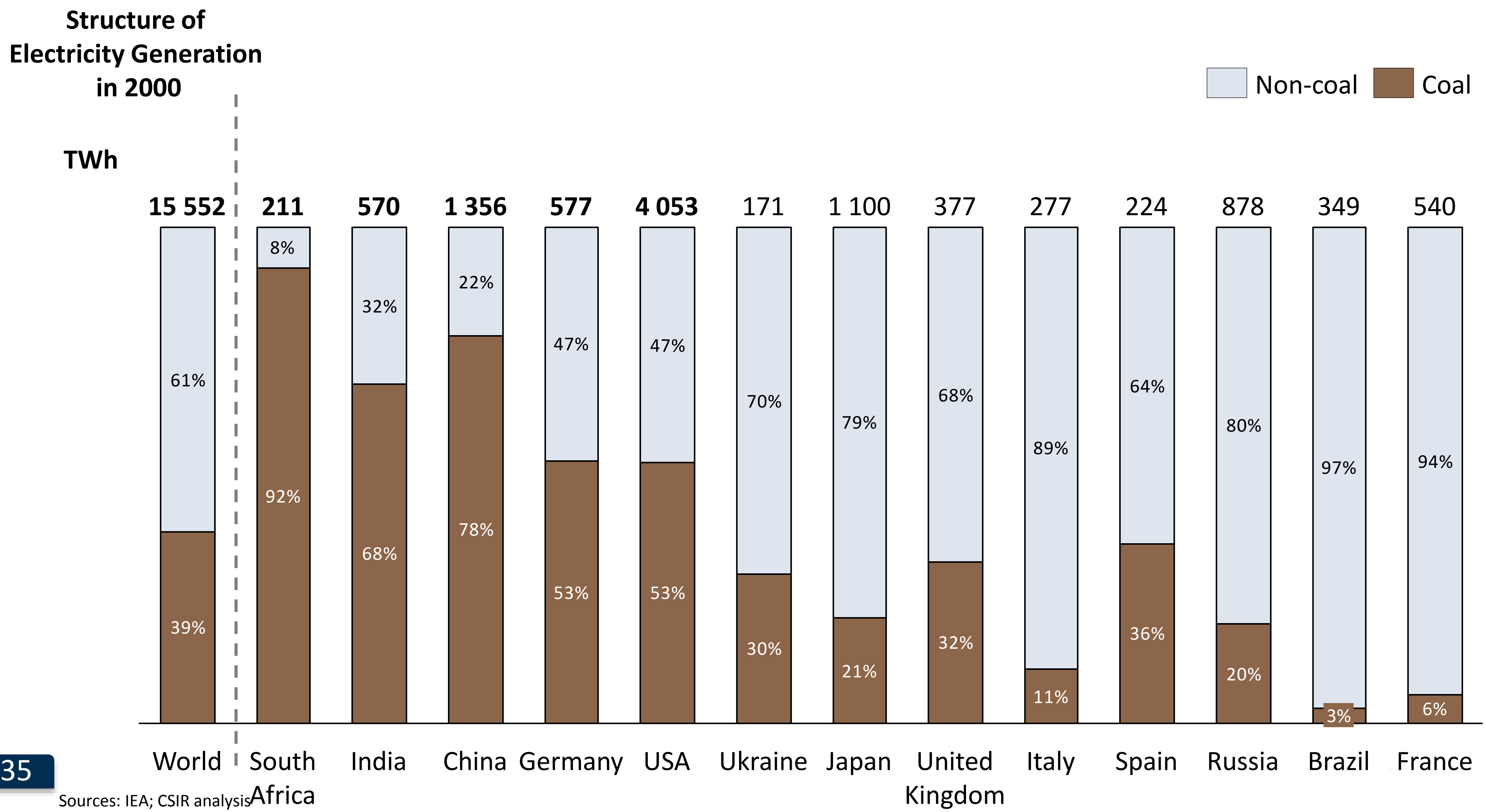
Natural gas

Solar PV, Wind, CSP, Biogas

Submitted to DoE on 31 March 2017

2000: South Africa produced 92% of its electricity from coal

Structure of electricity generation for selected countries



Sources: IEA; CSIR analysis

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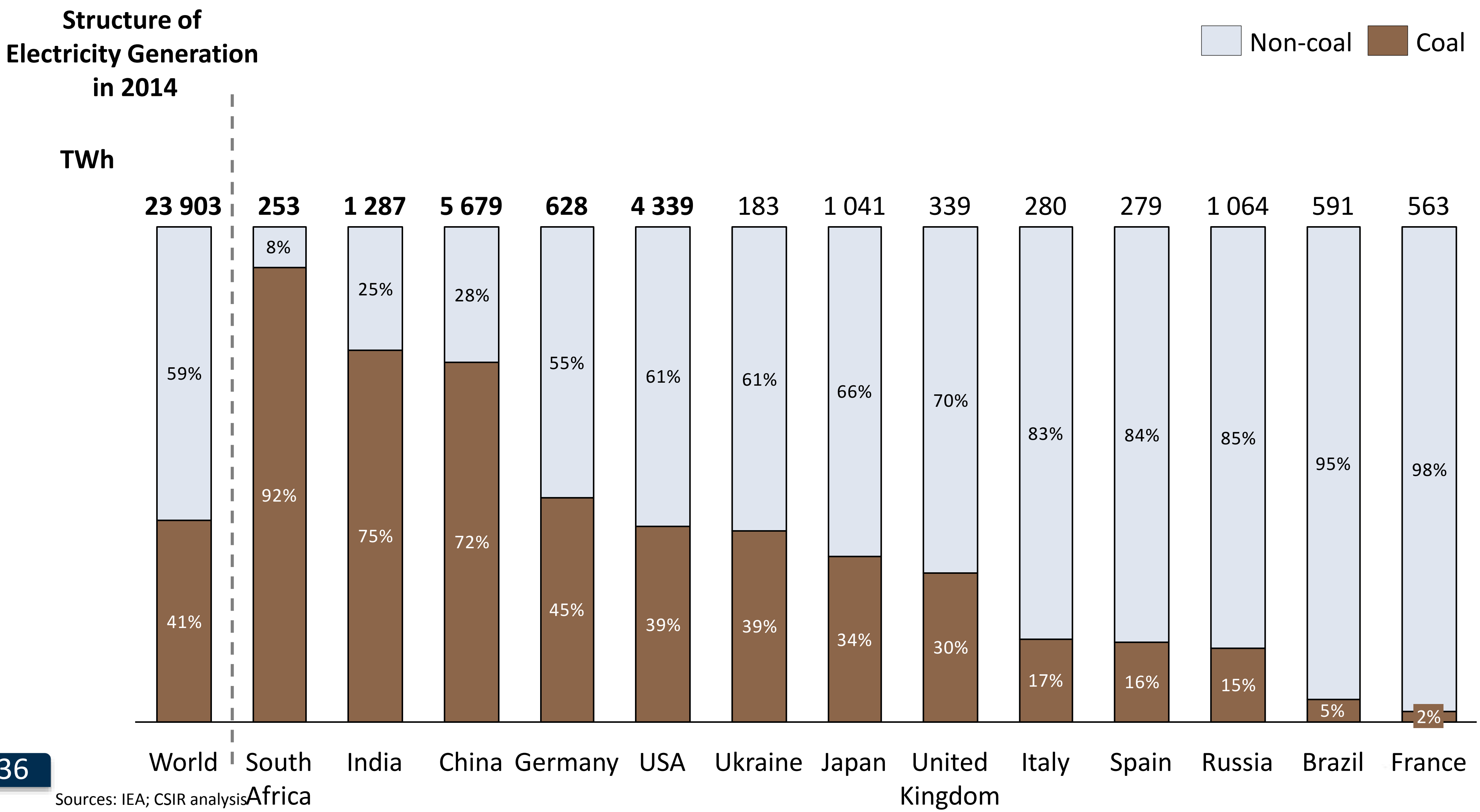
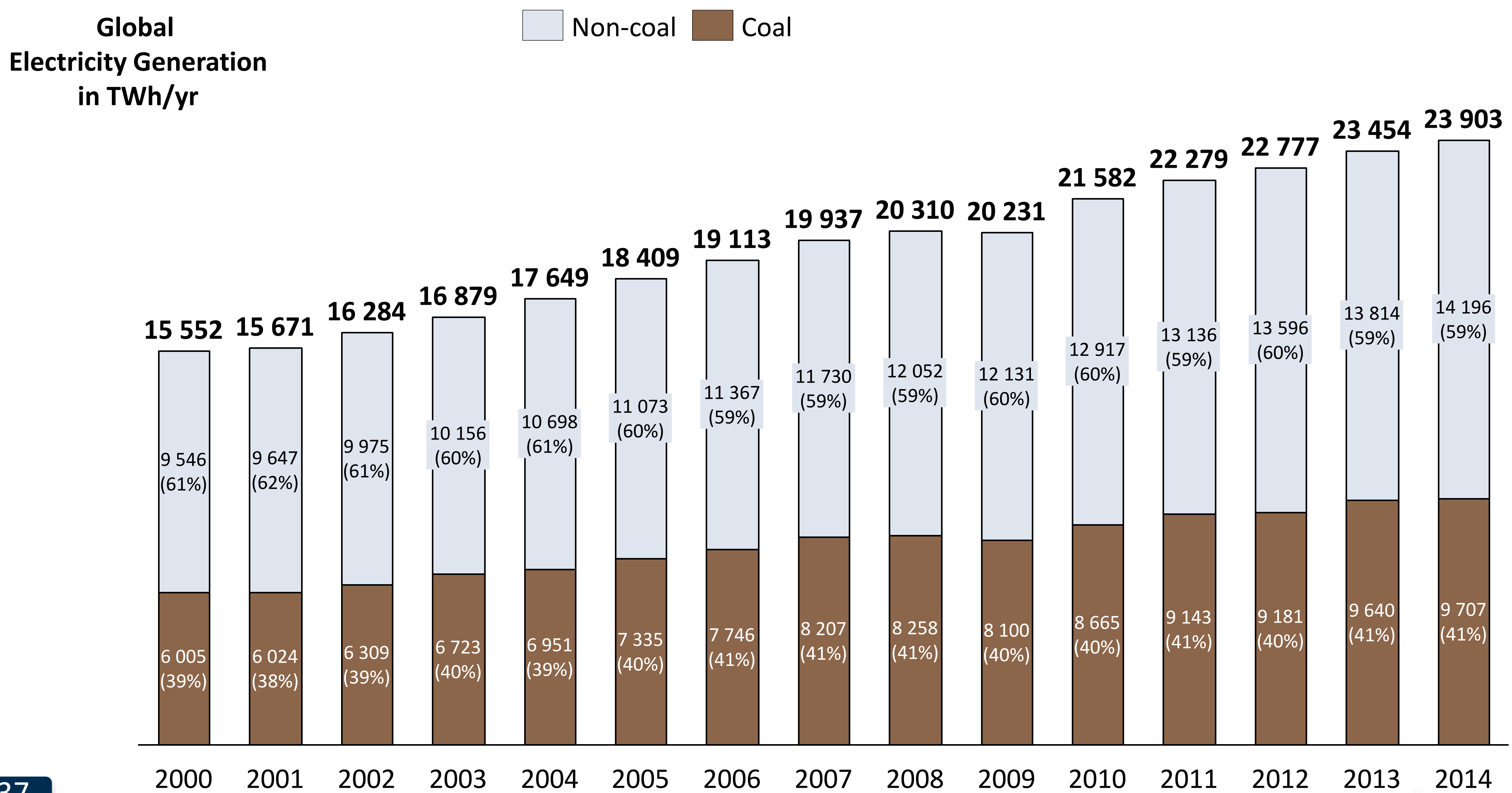


Sources: IEA; CSIR analysis

Total global electricity generation from coal increased by 60% since 2000, its share in global electricity generation stayed constant at ~40%

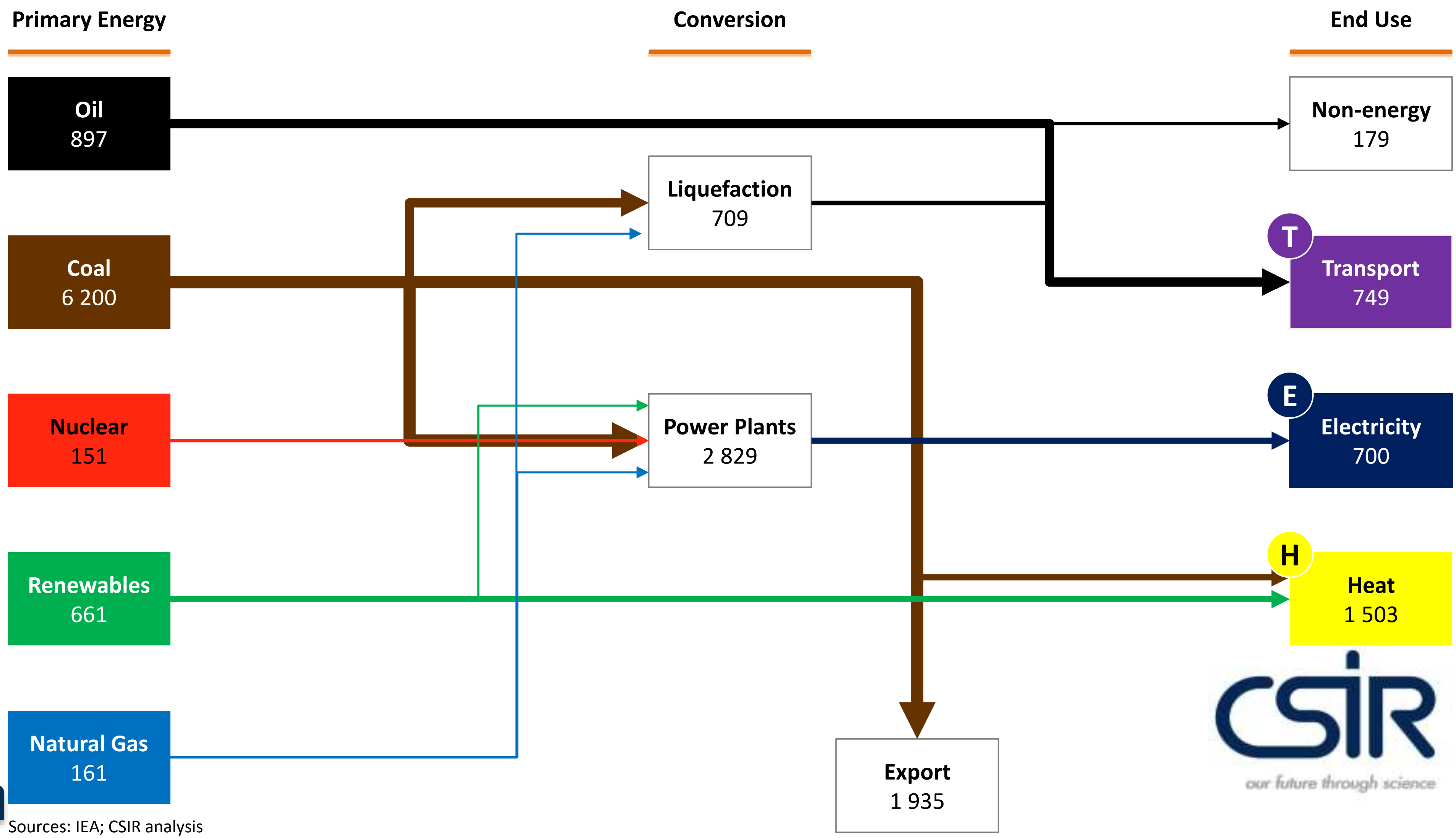


Sources: IEA; CSIR analysis

Submitted to DoE on 31 March 2017

South Africa's energy system relies on domestic coal and imported oil

Simplified energy-flow diagram (Sankey diagram) for South Africa in 2014 in PJ



Sources: IEA; CSIR analysis

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Submitted to DoE on 31 March 2017

China is by far the largest electricity producer from coal – with declining contribution and planned reduction in new-build capacities

China is the largest producer of electricity from coal in absolute terms globally

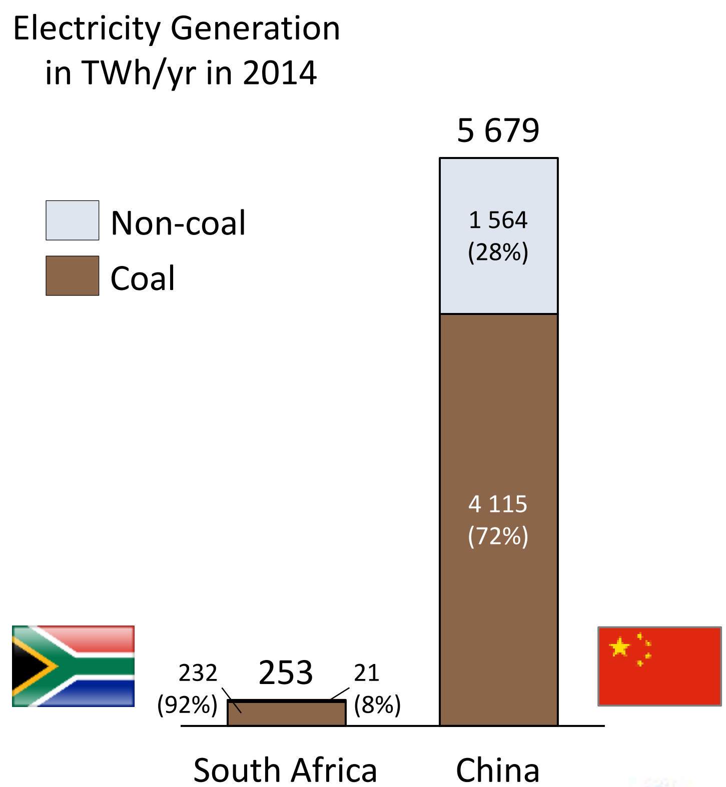
- It produced 4 115 TWh of electricity from coal-fired power stations in 2014 (18x South Africa)
- After a rapid growth from 1 060 TWh in 2000

The relative contribution of coal in the Chinese electricity mix has however reduced

- 78% in 2000
- 72% in 2014

China recently announced the cancellation of 100 GW of planned new coal-fired power stations

- To achieve CO_2 reduction targets
- To reduce air pollution (smog) in urban areas



Sources: http://ceenews.info/en/china-cancels-more-than-100-gw-of-coal-plants/; IEA; CSIR analysis

Agenda

Global electricity sector generation mix

Coal

Nuclear

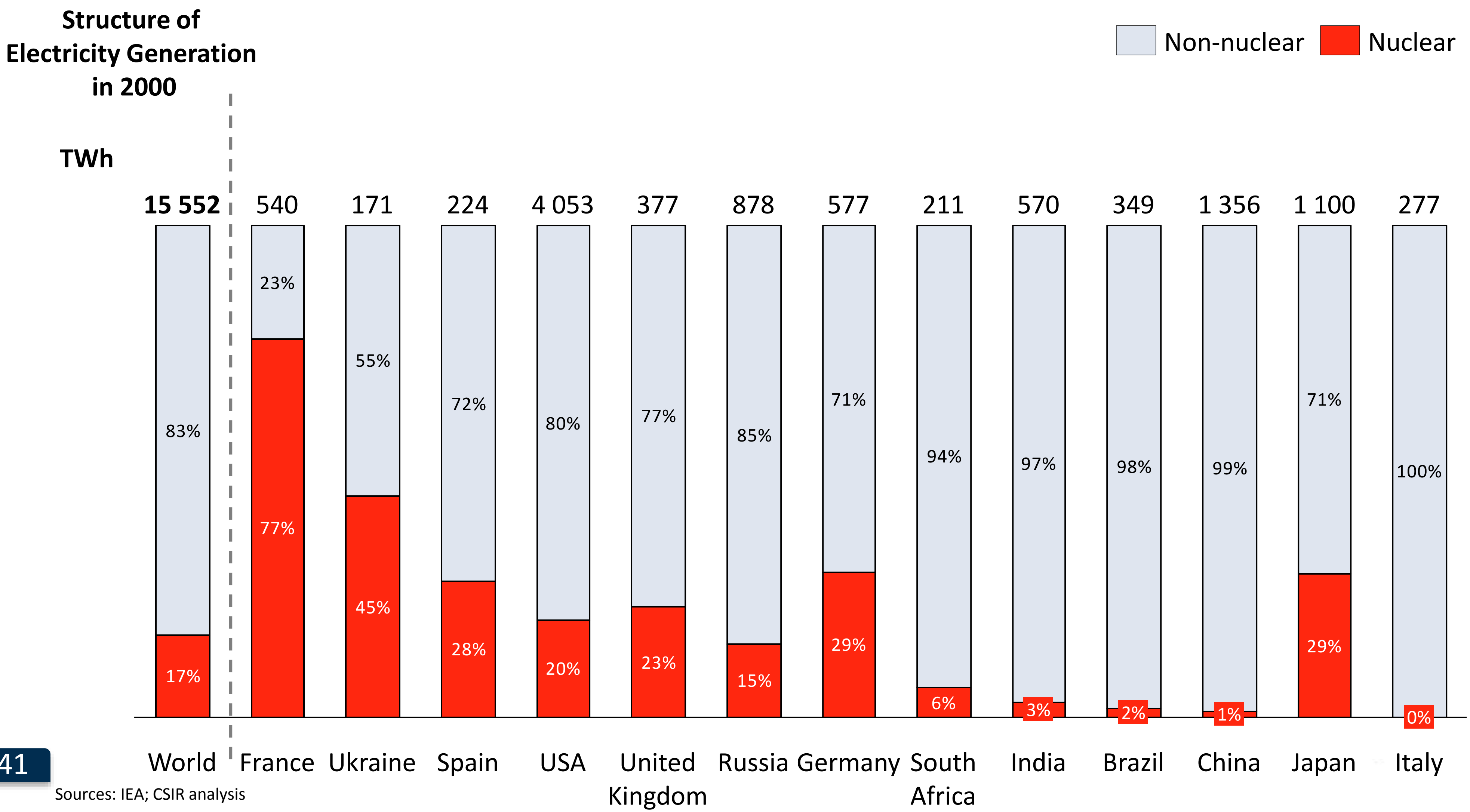
Natural gas

Solar PV, Wind, CSP, Biogas

CSIR
our future through science

2000: South Africa produced 6% of its electricity from nuclear

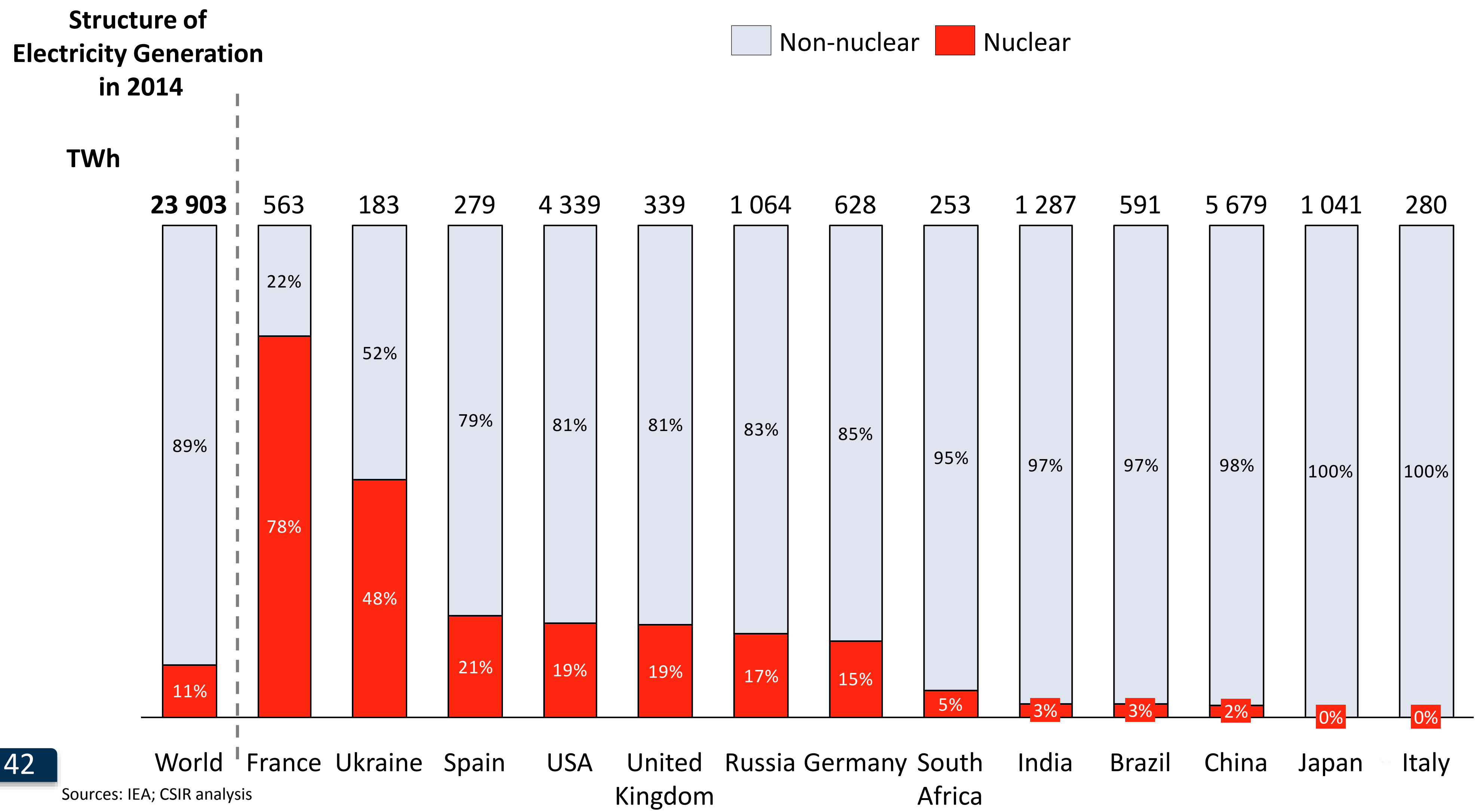
Structure of electricity generation for selected countries



Sources: IEA; CSIR analysis

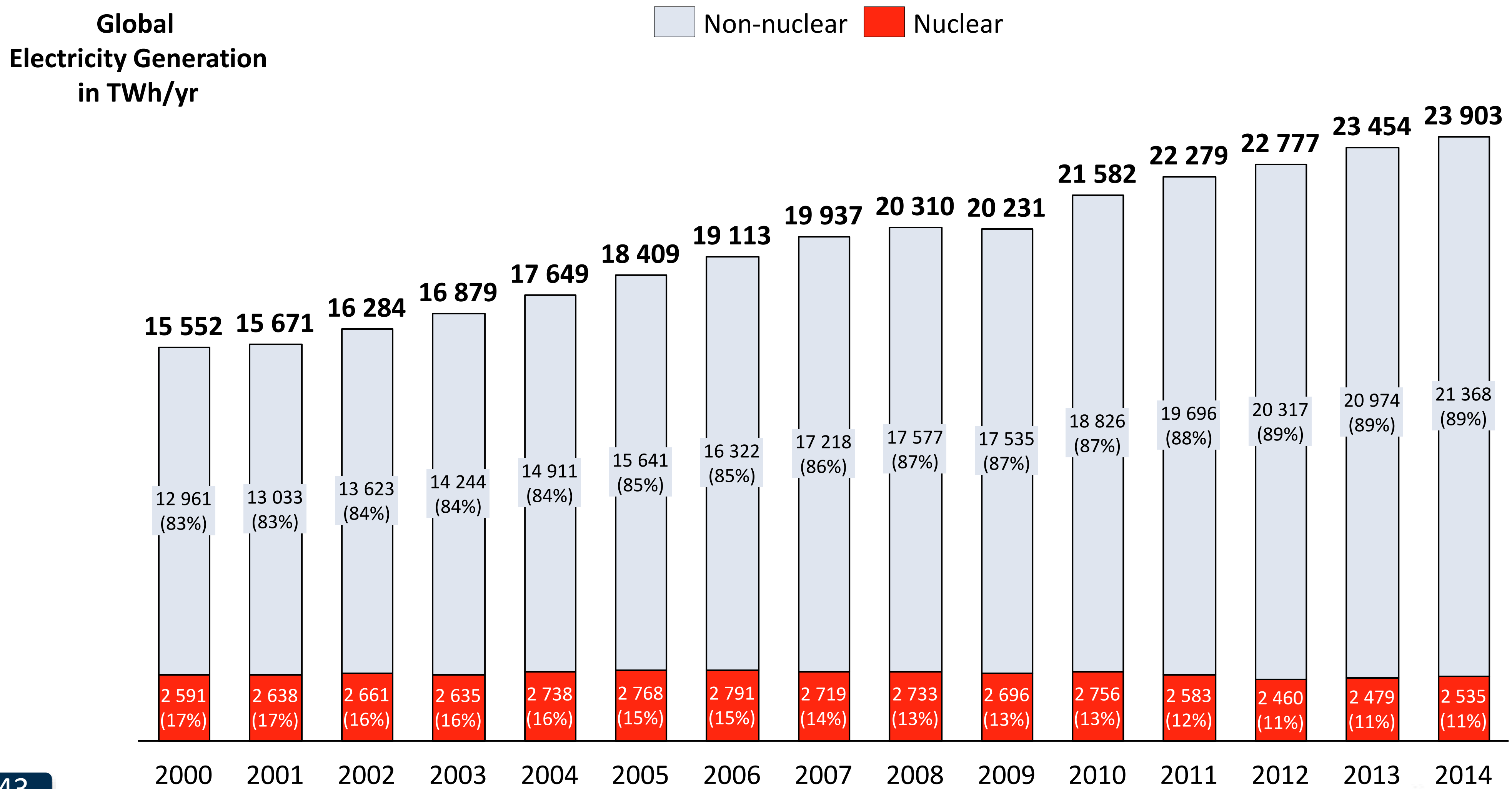
2014: South Africa produced 5% of its electricity from nuclear

Structure of electricity generation for selected countries



Sources: IEA; CSIR analysis

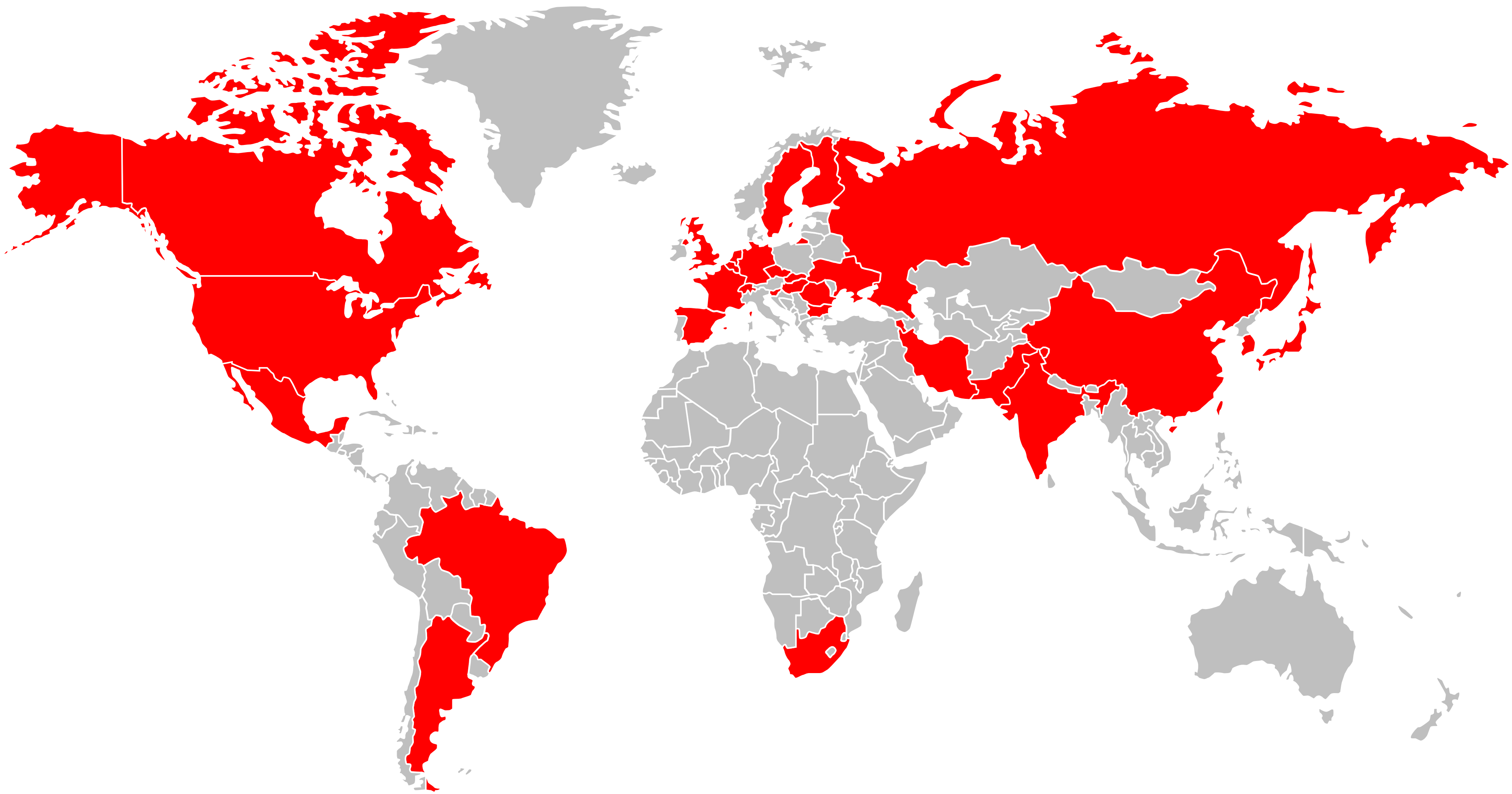
Total global nuclear electricity generation stayed constant since 2000, its share in global electricity generation decreased from 17% to 11%



Sources: IEA; CSIR analysis

31 countries worldwide have operational nuclear power plants

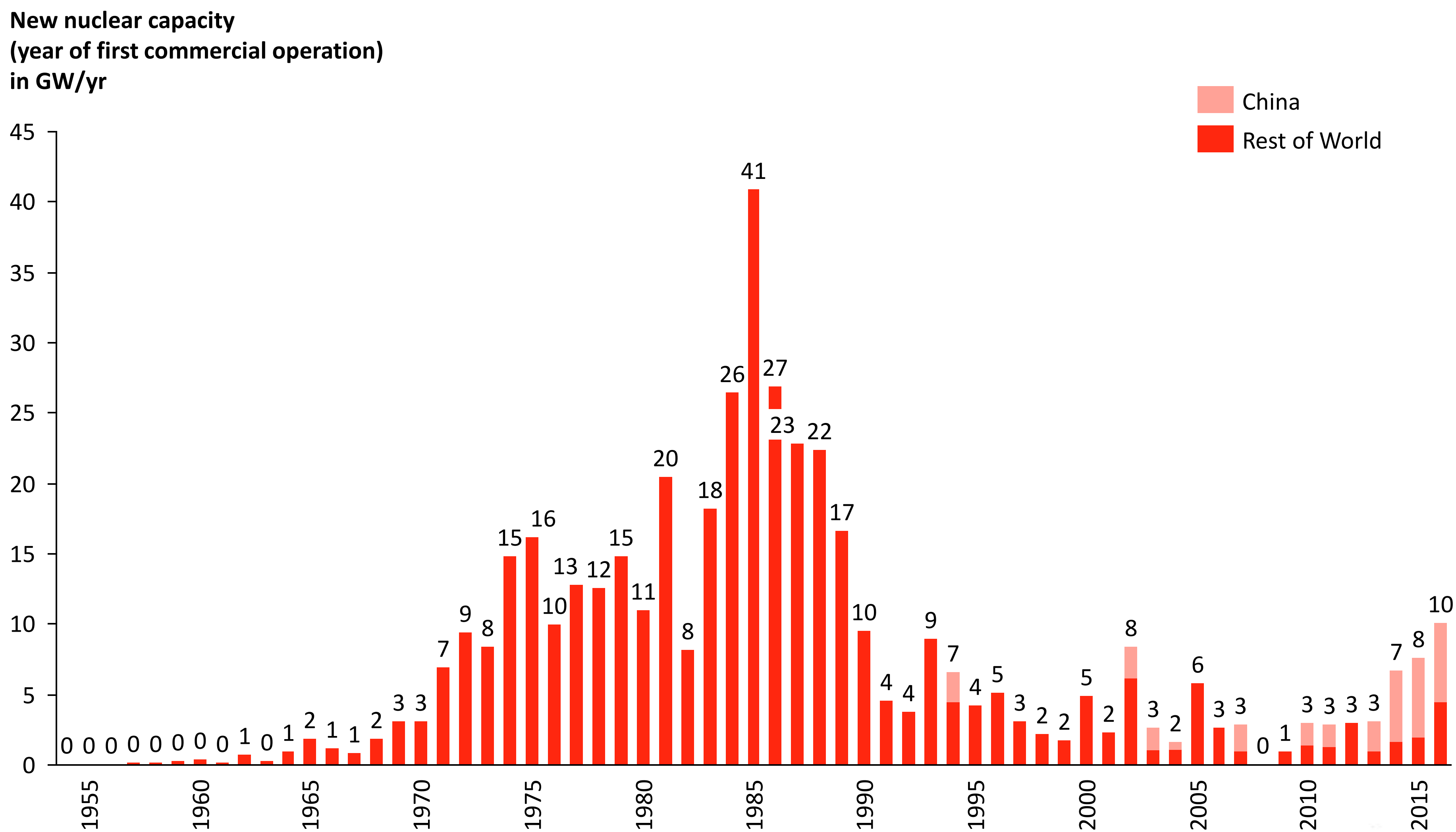
Map of countries with operational nuclear reactors for commercial electricity production



Sources: World Nuclear Association - Reactor data base, CSIR analysis

In the last decade, 60% of nuclear capacity additions came from China

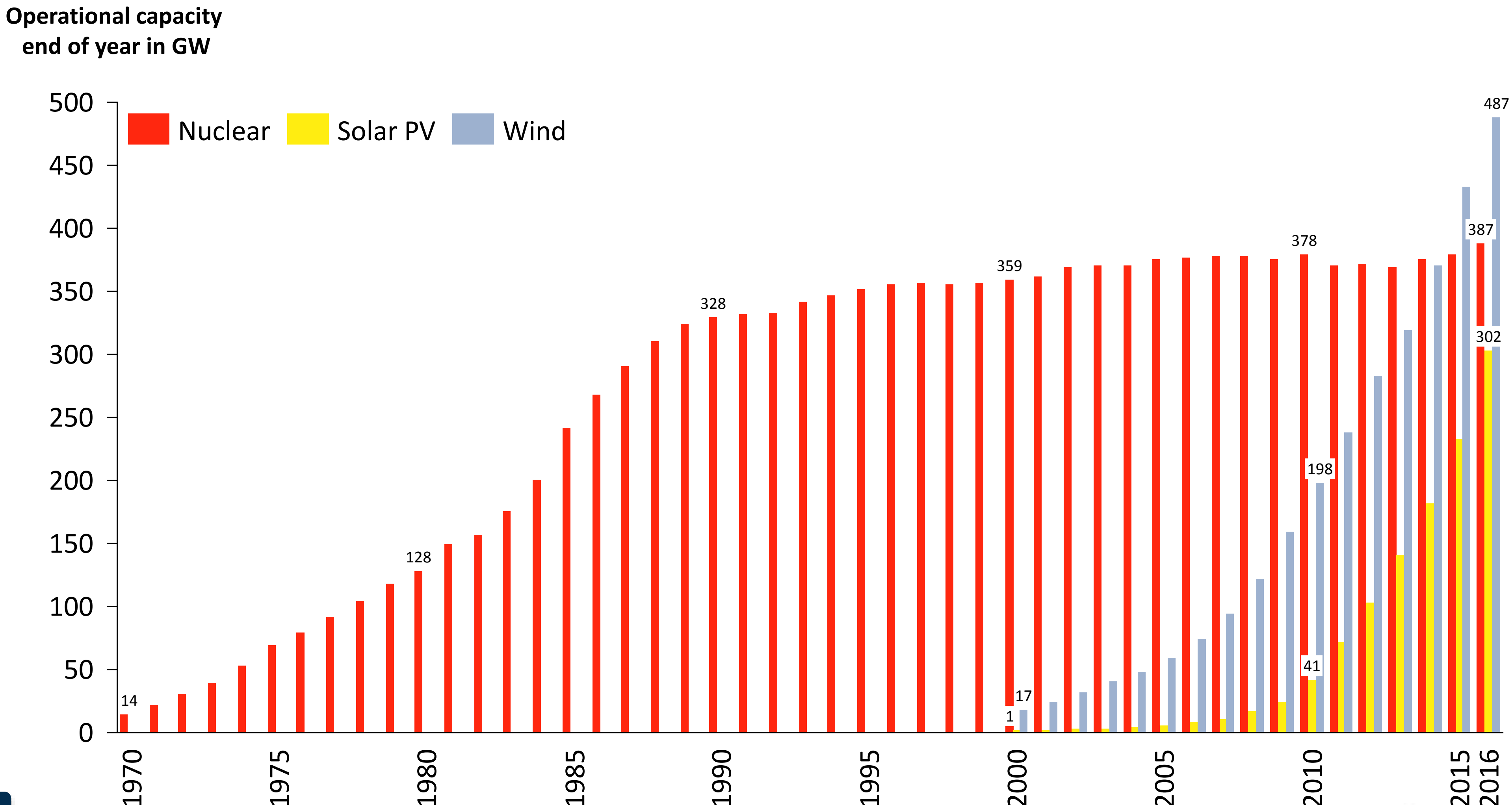
New nuclear capacity commissioned per year since 1950s



Sources: World Nuclear Association – Reactor database; CSIR analysis

After global ramp-up from 1970-1990, nuclear installed capacity stable

Global installed capacity end of year for nuclear, wind and solar PV (1970-2016) in GW (net)



Sources: World Nuclear Association – Reactor database; EPIA; GWEC; CSIR analysis

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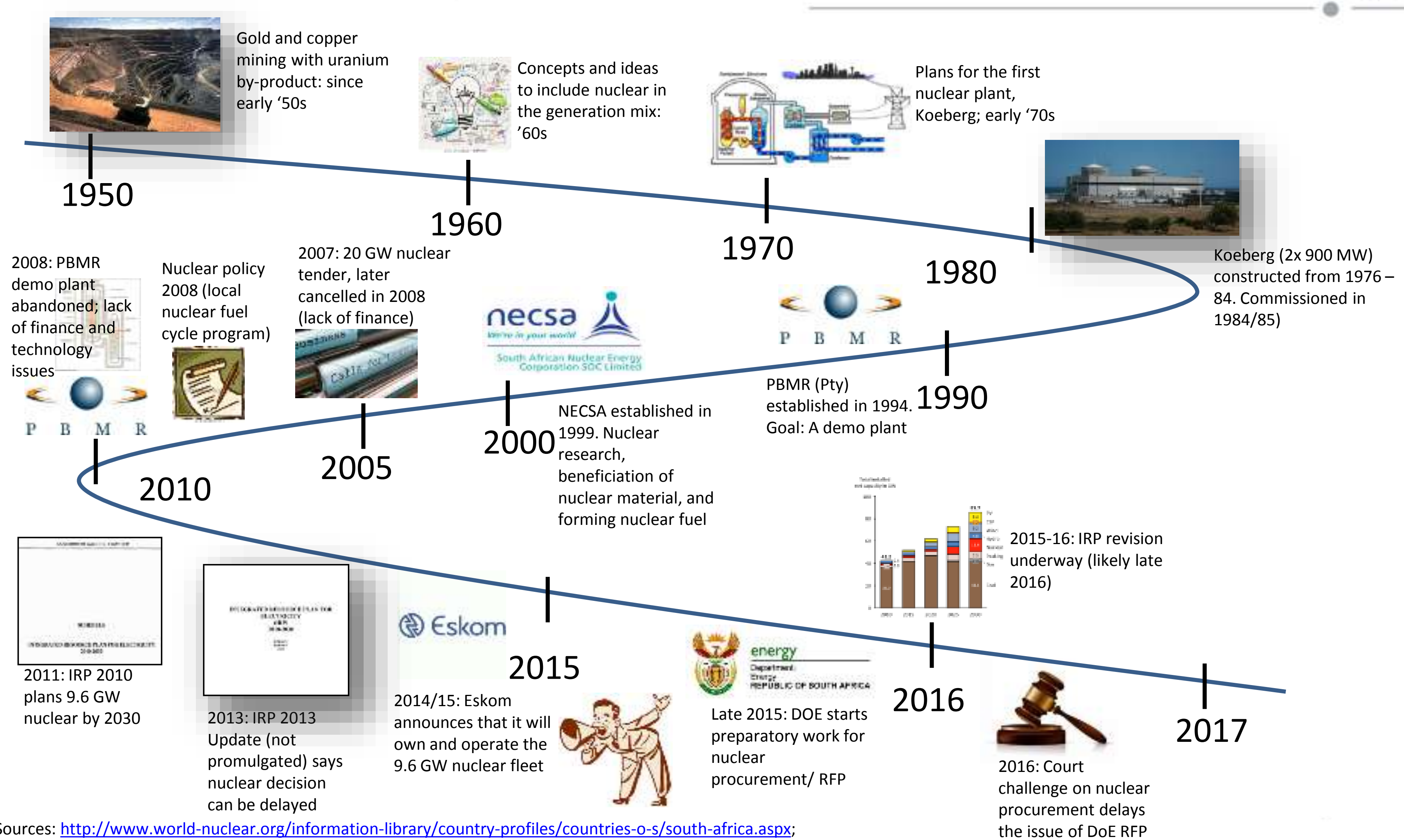
Nuclear power has been part of South Africa since 1970s

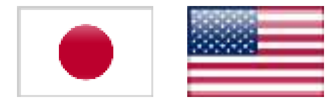
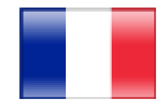
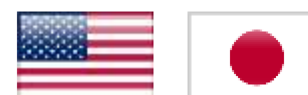
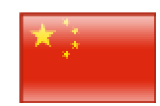
History of key decisions and milestones related to nuclear for power generation in South Africa



Sources: http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-africa.aspx; http://www.fin24.com/Economy/energy-dept-postpones-nuclear-bid-gazette-as-court-case-looms-20160406

Gen III+ nuclear reactors can be sourced from various vendors

Reactor name, size, vendor and representative country likely available for South Africa’s nuclear procurement

Name	Size $MW_{e\text{-}net}$ (MW_{th} /$MW_{e\text{-}gross}$)	Vendor	Vendor countries
AP1000 Pressurised Water Reactor (PWR)	1,100 (4,590/1,200)	Westinghouse[2]	
Evolutionary Power Reactor (EPR)	1,650 (3,400/1,770)	Areva/EDF	
Water-Water Energetic Reactor (VVER)[1]	1,082 (3,200/1,170)	Rosatom	
Advanced Boiling Water Reactor (ABWR)	1,350 (3,926/1,420)	GE-Hitachi (and Toshiba)	
Advanced Power Reactor (APR) 1400	1,400 (3,983/1,455)	Korea HNP (KHNP)	
Hualong One (HPR 1000)	1,100 (3,050/1,150)	CNNC/CGN	

[1] RU: Vodo-Vodyanoi Energetichesky Reaktor (VVER); [2] Owned by Toshiba

Sources: https://aris.iaea.org/sites/..%5CPDF%5CAP1000.pdf; https://aris.iaea.org/sites/..%5CPDF%5CEPR.pdf; https://www.iaea.org/NuclearPower/Downloadable/aris/2013/36.VVER-1200(V-491).pdf; https://aris.iaea.org/sites/..%5CPDF%5CABWR.pdf; https://aris.iaea.org/sites/..%5CPDF%5CAPR1400.pdf; https://www.iaea.org/NuclearPower/Downloadable/Meetings/2015/2015-09-01-09-03-NPTDS41894/DAY2/10_Chinas_Nuclear_Power_Development_and_Hualong_One_(HPR1000).pdf

Hinkley Point C will be the first nuclear power plant built on the back of a Power Purchase Agreement with an Independent Power Producer

The **3.2 GW Hinkley Point C** nuclear power station is to be built by **Electricite de France (EDF)** under a Power Purchase Agreement (PPA) and is planned to be **operational by 2025**

The power plant will be jointly owned by French Electricite de France (EDF) and Chinese China General Nuclear CGN (China)

This is the first time ever that a **nuclear power plant** is built on the basis of a **PPA** (all project risks with the plant owner)

The **resultant tariff** in the PPA is hence the most transparent cost of nuclear so far, as it **is reflective of the project risks**

Catastrophic risks are excluded (i.e. borne by the state)

Known Hinkley Point C PPA parameters

- **35 years** PPA lifetime
- **Tariff indexed to inflation** (CPI)
- Initial tariff: **92.5 GBP/MWh** (2012) i.e. **1.53 ZAR/kWh**[1]

[1] Annual average GBP/ZAR exchange rate for 2012 (13.0) and ZAR-CPI inflation from 2012 to 2016

Sources: https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/investors-analysts/events/special-announcements/agreement_reached_on_commercial_terms_for_the_planned_hinkley_point_c_nuclear_power_station.pdf; http://www.power-eng.com/articles/npi/print/volume-9/issue-2/departments/enrichment/questions-doubts-swirl-around-hinkley-point-c.html; https://www.resbank.co.za/Research/Rates/Pages/SelectedHistoricalExchangeAndInterestRates.aspx

Nuclear decommissioning costs generally not included in an IRP: the long asset lifetime makes the costs negligible in present value

The International Energy Agency (IEA) said that 200 of the 434 reactors in operation around the globe would be retired by 2040 with de-commissioning costs >$500 million per reactor[1]

The US Nuclear Regulatory Commission (NRC) estimates in the range of $350-500 per kW of net installed capacity ($300-400 million per reactor)

France's nuclear safety authority (ASN[2]) estimates costs at between $600-700 per kW of net installed capacity ($550-650 million per reactor)

Germany made provisions of $1,500 per kW of net installed capacity ($1.1 billion per reactor)

Japanese government estimates around $800 per kW of net installed capacity ($625 million per reactor)

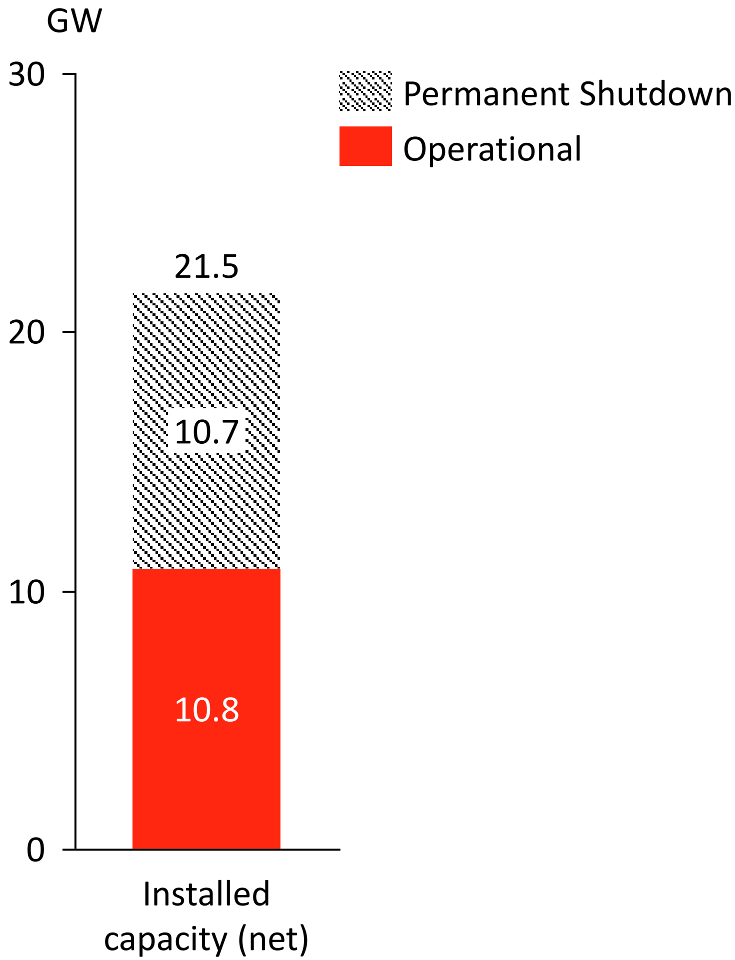
Russia's costs are estimated to range from $800-1,500 per kW of net installed capacity ($500 million to $1 billion per reactor)

Long asset lifetime makes present value of costs negligible – real cash provision needs to be made though

[1] These costs do not include waste disposal and long-term fuel storage   [2] ASN - Autorite de Surete Nucleaire
Sources: World Nuclear Association - Reactor database, SA Reserve Bank, Exchange rate (2015 average); http://www.reuters.com/article/nuclear-decommissioning-idUSL6N0UV2BI20150119

Submitted to DoE on 31 March 2017

In Germany, waste management and storage costs were recently transferred by private operators to the government for EUR24 billion



Nuclear plant operators in Germany have agreed to pay EUR 24 billion into a German government fund to transfer risk/liability of waste storage/handling

This is equivalent to additional "CAPEX" of EUR 1,100 per kW of net capacity, i.e. ≈ $1,200 per kW

Sources: World Nuclear Association - Reactor data base; http://www.handelsblatt.com/politik/international/atommuell-lagerung-kommission-will-rund-24-milliarden-euro-von-den-betreibern/13482042.html

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2000: South Africa produced 3% of its electricity from natural gas

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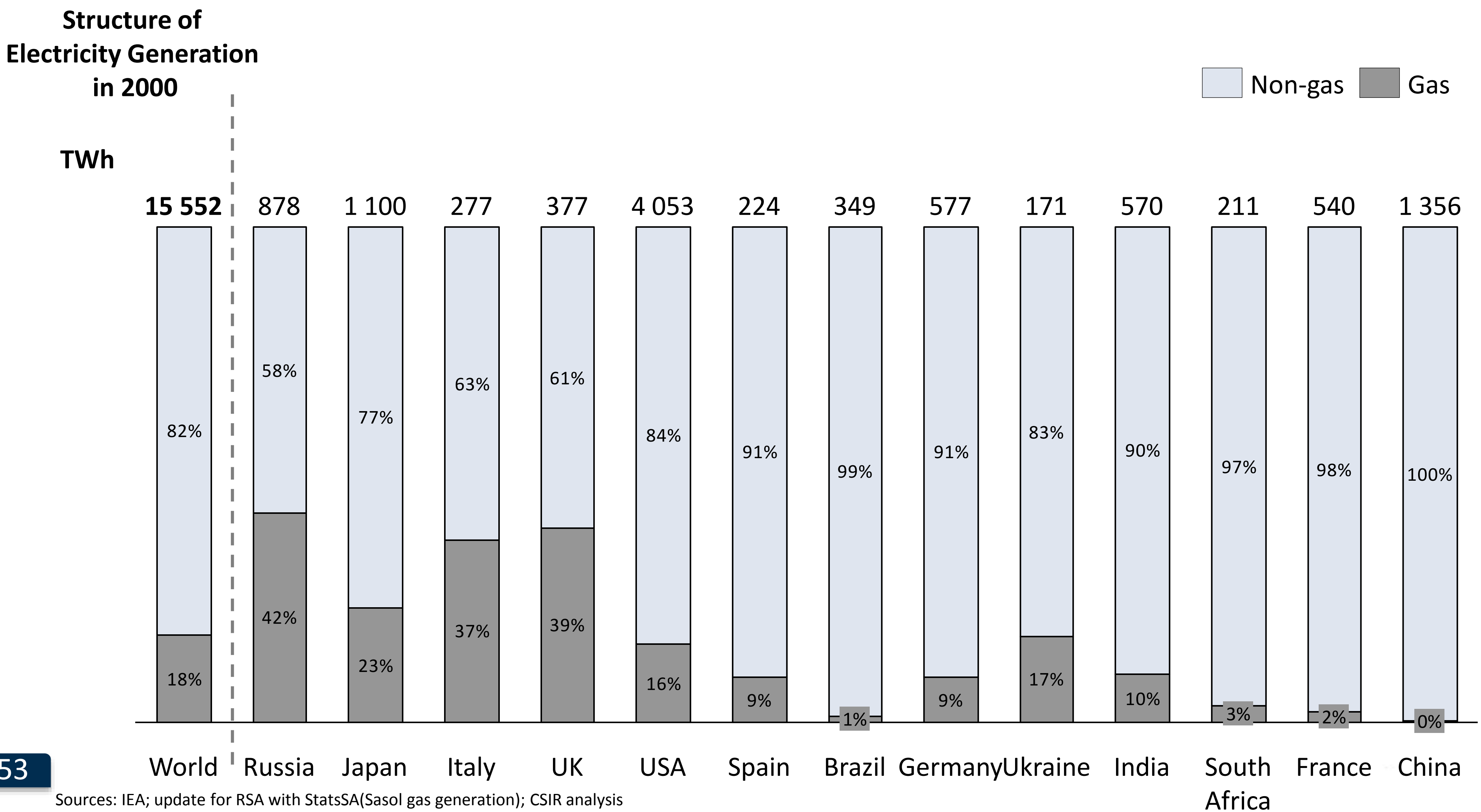

Sources: IEA; update for RSA with StatsSA(Sasol gas generation); CSIR analysis

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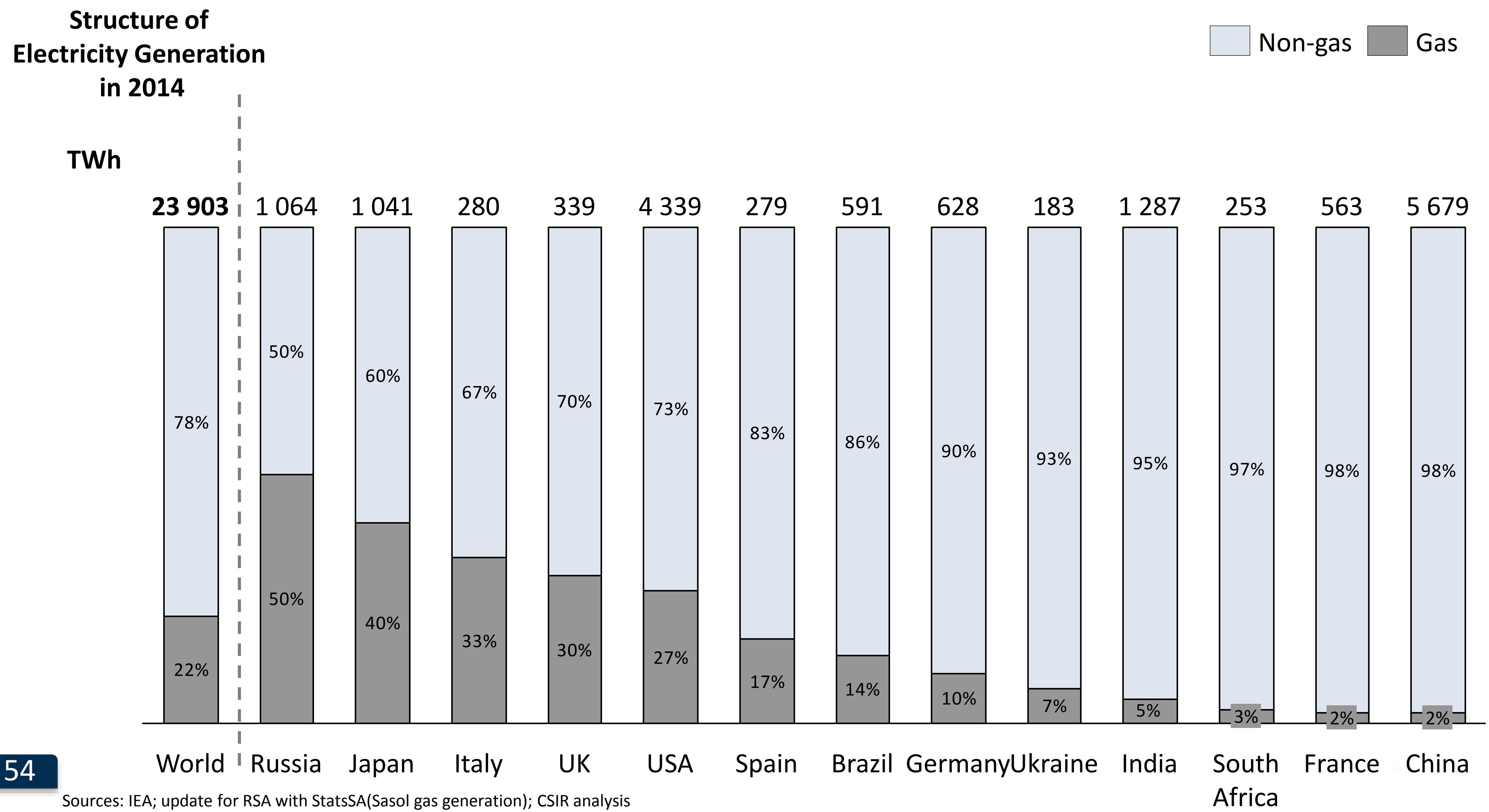
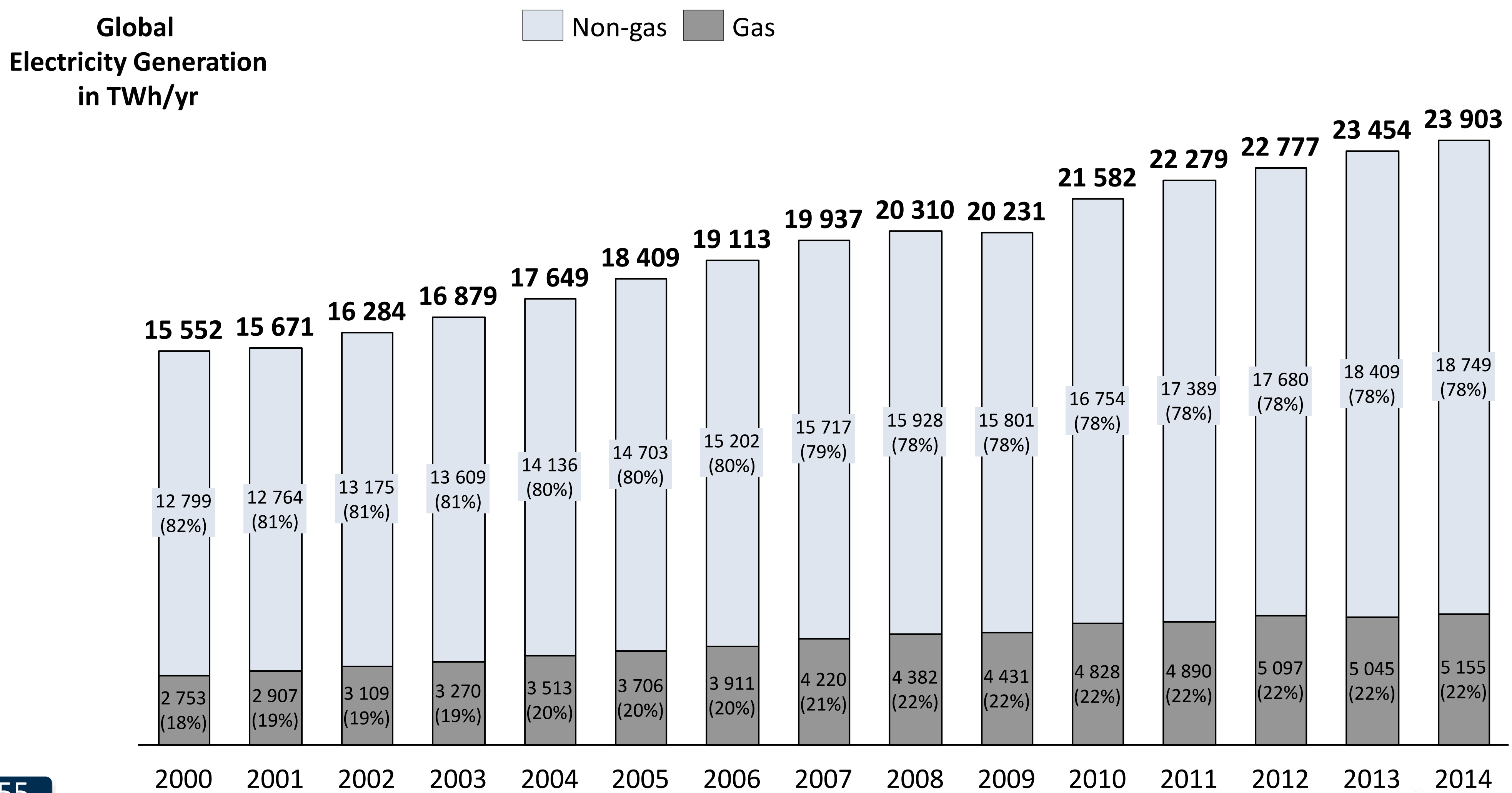


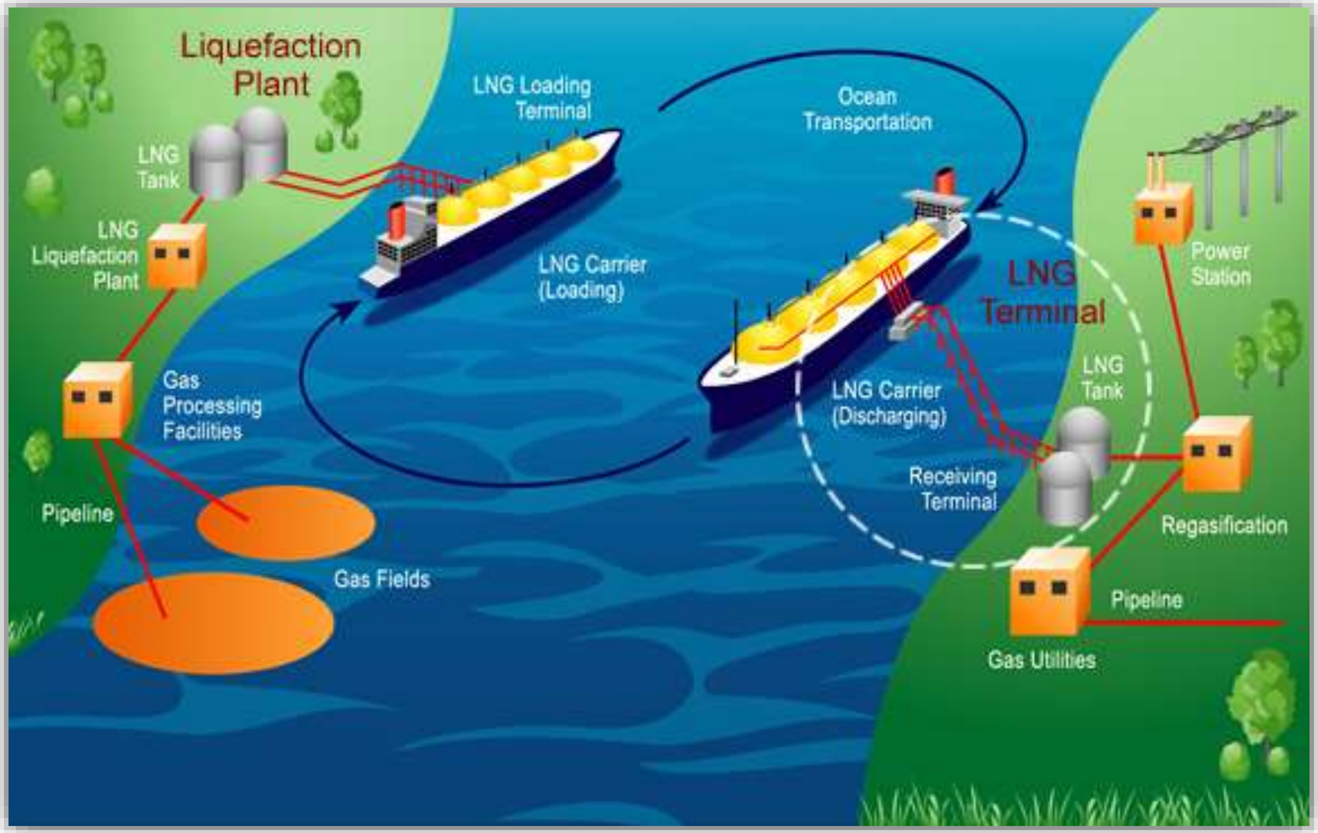
Sources: IEA; update for RSA with StatsSA(Sasol gas generation); CSIR analysis

Total global electricity generation from natural gas increased by 90% since 2000, its share in global electricity generation rose by 4%-points



Sources: IEA; CSIR analysis

LNG supply chain from natural gas field over liquefaction and ocean shipping to regasification at the destination, where the gas is used



Sources: Exxon Mobile

Liquefied Natural Gas (LNG) high-level overview

LNG is natural gas that has been super-cooled into a liquid that is one six hundredth of its original volume: storage and transport of imported LNG is made easier by this significant reduction in volume

Fair price of LNG today: 7-9 $/MMBtu; this is an ex-ship price

Re-gasification adds 0.5–1 $/MMBtu

Storage plus transport add another 0.2-0.8 $/MMBtu if the power plant is far away from the LNG landing terminal

FSRUs (Floating Storage and Re-gasification Unit) can be used for regasification without building a full-scale land-based LNG terminal

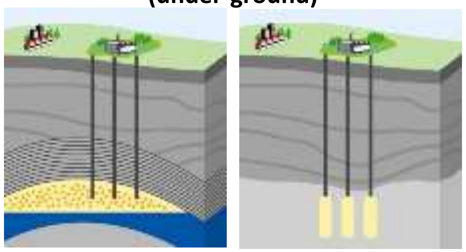
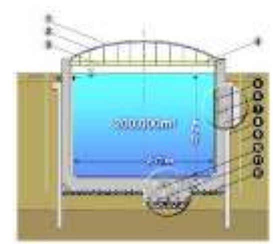
Minimum size for land-based LNG terminal is around 2–3 bcm p.a. sent out; most big ones are around 10 bcm p.a.

LNG carrier typically with a capacity of 100 to 140 tcm (LNG)

FSRU typically with a capacity of 100 to 170 tcm storage (LNG) and 7 mcm/d (gas) regasification

Dominion Cove Point LNG terminal with a capacity of 0.4 bcm storage (LNG); 18.6 bcm/a regasification

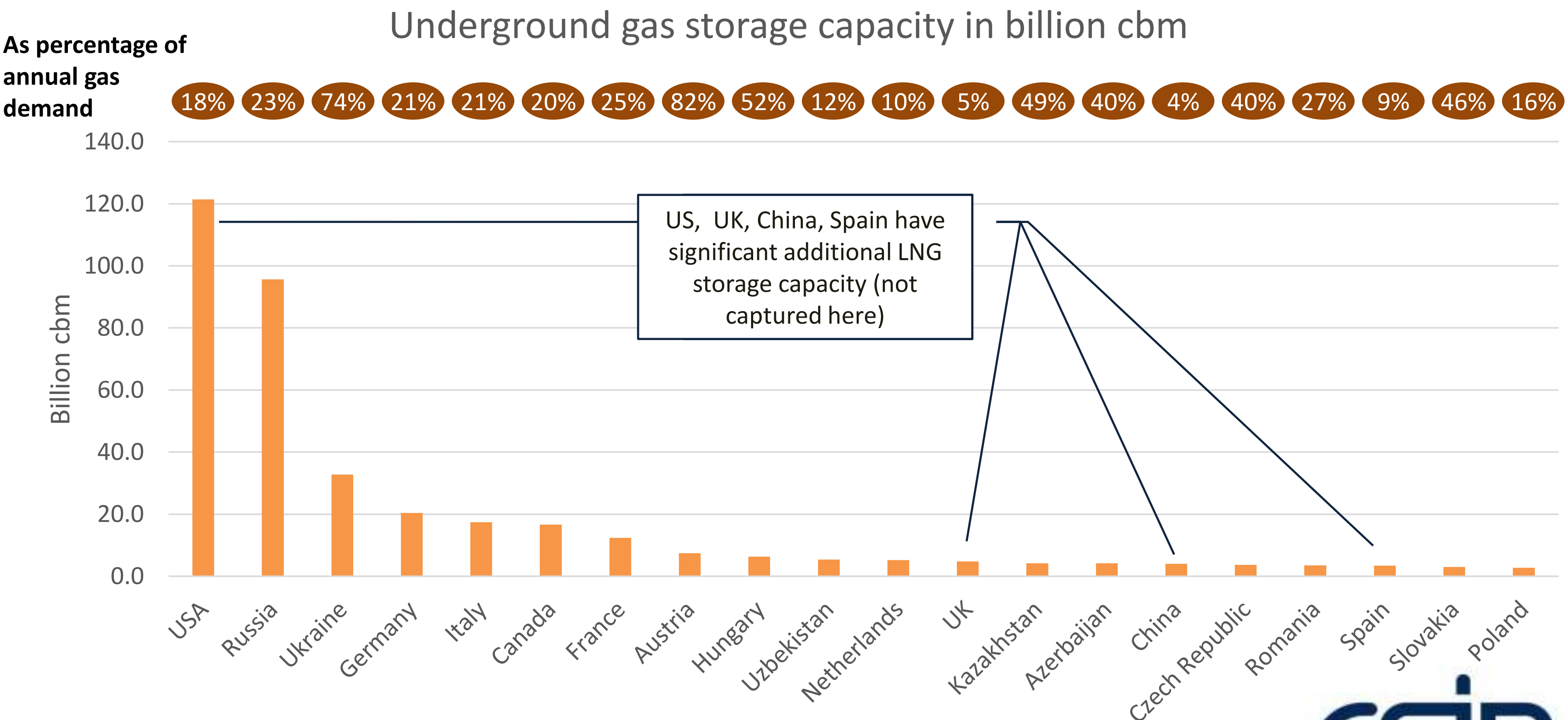
Properties of different types of gas storage

	Natural Gas Storage				Liquefied Natural Gas (LNG) Storage	
	Porous storage and caverns (under-ground)	Tube (in-ground)	Sphere (on-ground)	Gas holder (on-ground)	Large-scale tanks (in-ground)	Standard-sized tanks (on-ground)
						
Operating temperature	Ambient	Ambient	Ambient	Ambient	-162˚C	-162˚C
Operating pressure	High: 60-190 bar (above atmospheric)	High: 100 bar (above atmospheric)	Medium: 5 to 20 bar (above atmospheric)	Low: 15 to 150 mbar (above atmospheric)	Low: 100-250 mbar (above atmospheric)	Low to medium: 0.3-16 bar (above atmospheric)
Withdrawal rate	0.6-2.3 million m^3/h					
Working gas storage capacity	60-100 million m^3 (norm) = **600 to 1 000 GWh_{th}** (per cavern)	0.5-0.7 million m^3 (norm) = **5 to 7 GWh_{th}** (per 20 tubes, 200 m each)	30-170 thsd m^3 (norm) = **0.3 to 1.7 GWh_{th}**	30-170 thsd m^3 (norm) = **0.3 to 1.7 GWh_{th}**	130-250 thsd m^3 (LNG) = **800 to 1 500 GWh_{th}**	60-700 m^3 (LNG) = **0.4 to 4 GWh_{th}**
Invest	R 0.1 to 1 million / GWh_{th} (depends on geology)	R 20 to 30 million / GWh_{th}	R 20 to 30 million / GWh_{th}	R 20 to 30 million / GWh_{th}	R 1 to 1.5 million / GWh_{th}	R 2 to 6 million / GWh_{th}

Sources: websites of operators of gas storages, research institutes, CSIR analysis

Submitted to DoE on 31 March 2017

Underground natural gas storage typically only in countries with substantial heating demand and large seasonal variations



Note: Japan and Korea have very large LNG storage capacities (but no underground natural gas storage)

Sources: Magazine “Erdoel, Erdgas, Kohle”; LNG Report 2011; CSIR analysis

Gas conversions

LNG parameters

- Heat value of LNG: 45 MJ/kg = 12.5 kWh/kg (note: 1 MMBtu = 1.05587 GJ)
- Mass density of LNG: 450 kg/m^3
- Typical storage size of an FSRU: 170 000 m^3
- Energy stored in a typical FSRU: 3.44 PJ = 0.96 TWh_{th} (per 170 000 m^3)

Gas throughput for one FSRU

- Typical recharging cycle of the FSRU: Monthly → 12 re-charges per year, 150 000 m^3 each
- Typical amount of LNG per year: 1 800 000 m^3/a (for one FSRU with 12 re-charges per year) → 810 000 t/a = 0.8 mmtpa → 36.5 PJ/a = 10.1 TWh_{th}/a

Electricity generation from one FSRU

- Typical electricity production: 5.1 TWh_{el}/a from 1 FSRU that supplies a 50% efficient gas plant

Comparisons

- Sasol produces approx. 7 TWh_{el}/a from its gas-fired power plants in South Africa
- South Africa (Sasol and PetroSA) converts > 100 PJ/a into liquid fuels today
- South Africa imports approx. 200 PJ/a today from Mozambique through a pipeline

Annual electricity production and LNG offtake from a gas fleet

Annual electricity production in TWh/yr from a gas fleet of size A, operating at a capacity factor B

B: Average annual capacity factor of the gas fleet →

A: Size of the gas fleet in GW	10%	20%	30%	40%	50%	60%	70%	80%	90%
2.5	2.2	4.4	6.6	8.8	11.0	13.1	15.3	17.5	19.7
5.0	4.4	8.8	13.1	17.5	21.9	26.3	30.7	35.0	39.4
7.5	6.6	13.1	19.7	26.3	32.9	39.4	46.0	52.6	59.1
10.0	8.8	17.5	26.3	35.0	43.8	52.6	61.3	70.1	78.8
12.5	11.0	21.9	32.9	43.8	54.8	65.7	76.7	87.6	98.6
15.0	13.1	26.3	39.4	52.6	65.7	78.8	92.0	105.1	118.3

Annual LNG offtake in mmtpa from a gas fleet of size A, operating at a capacity factor B

B: Average annual capacity factor of the gas fleet →

A: Size of the gas fleet in GW	10%	20%	30%	40%	50%	60%	70%	80%	90%
2.5	0.4	0.7	1.1	1.4	1.8	2.1	2.5	2.8	3.2
5.0	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3
7.5	1.1	2.1	3.2	4.2	5.3	6.3	7.4	8.4	9.5
10.0	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6
12.5	1.8	3.5	5.3	7.0	8.8	10.5	12.3	14.0	15.8
15.0	2.1	4.2	6.3	8.4	10.5	12.6	14.7	16.8	18.9

Note: Assumption of an average 50% electrical efficiency of the gas fleet

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Global electricity sector generation mix

Coal

Nuclear

Natural gas

Solar PV, Wind, CSP, Biogas

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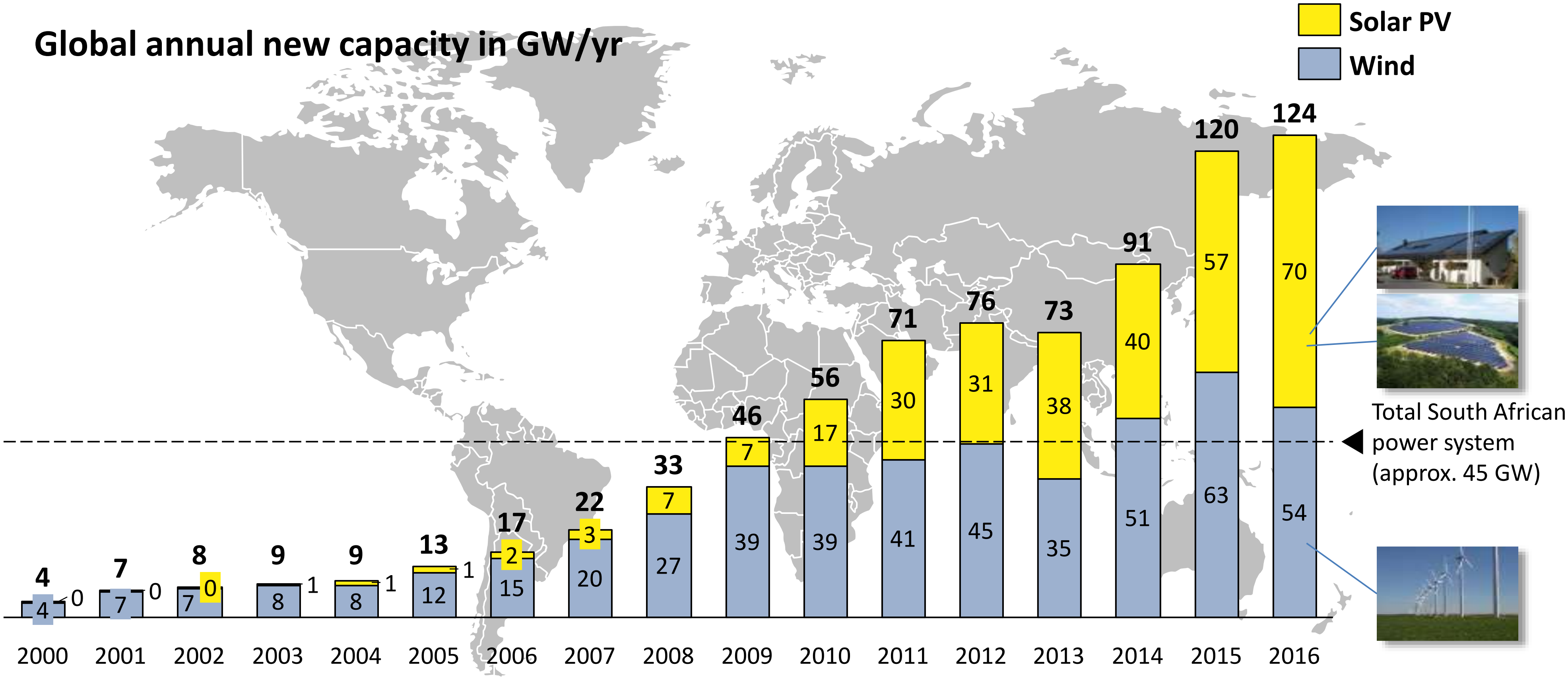
World:
In 2016, 124 GW of new wind and solar PV capacity installed globally

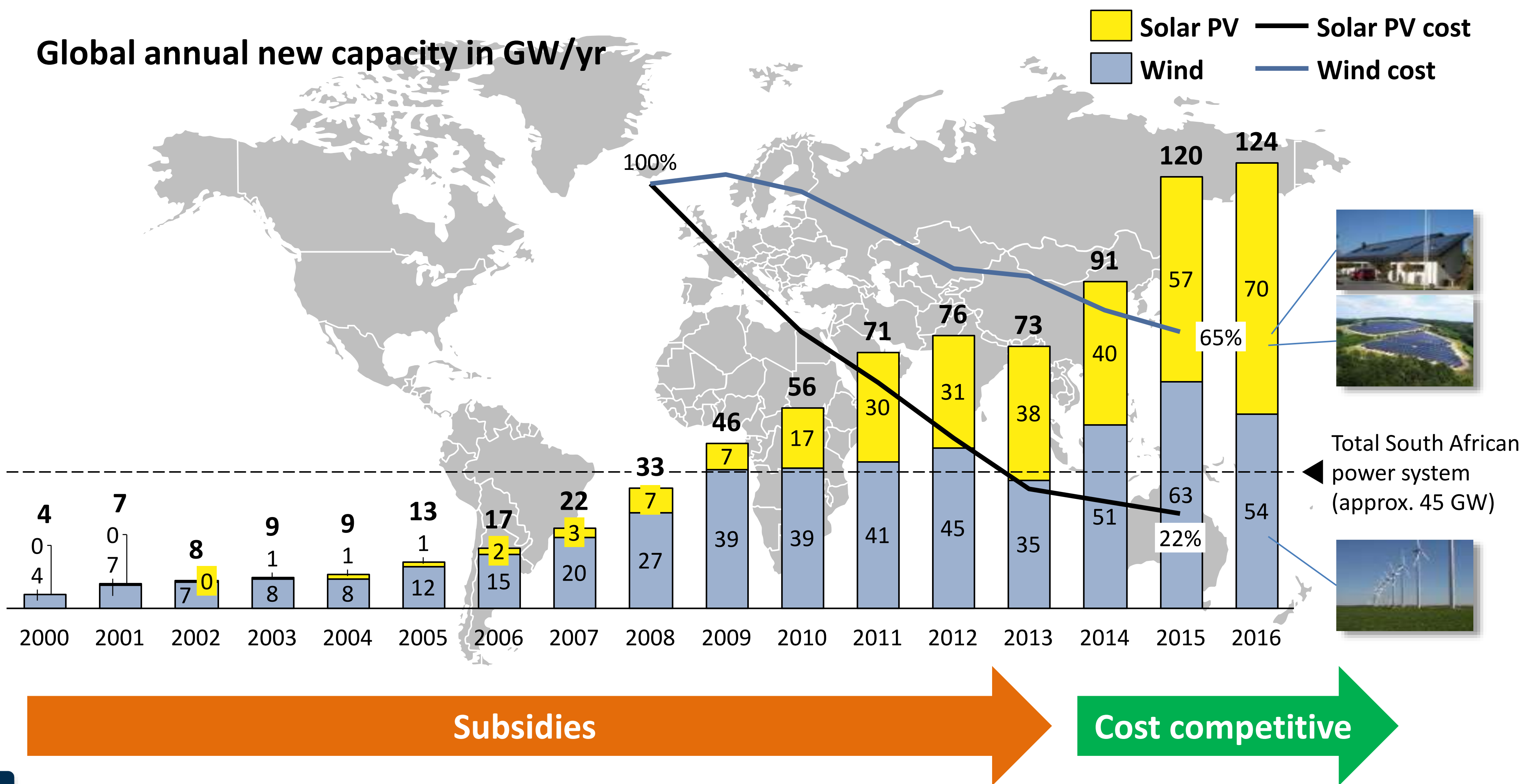


This is all very new: Roughly 80% of the globally existing solar PV capacity was installed during the last five years

Sources: GWEC; EPIA; BNEF; CSIR analysis

Submitted to DoE on 31 March 2017

World:
Significant cost reductions materialised in the last 5-8 years



Sources: IEA; GWEC; EPIA; BNEF; CSIR analysis

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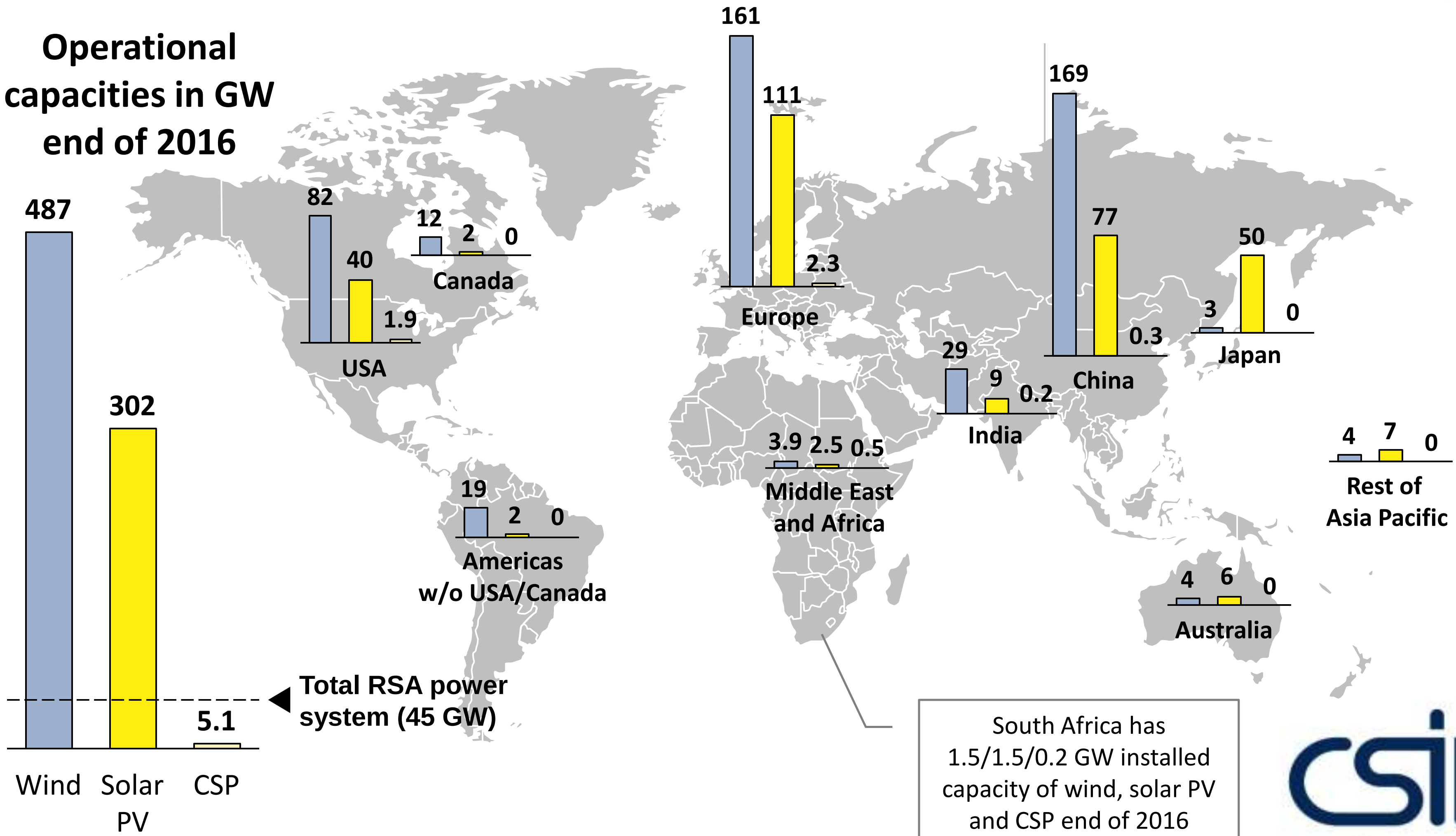
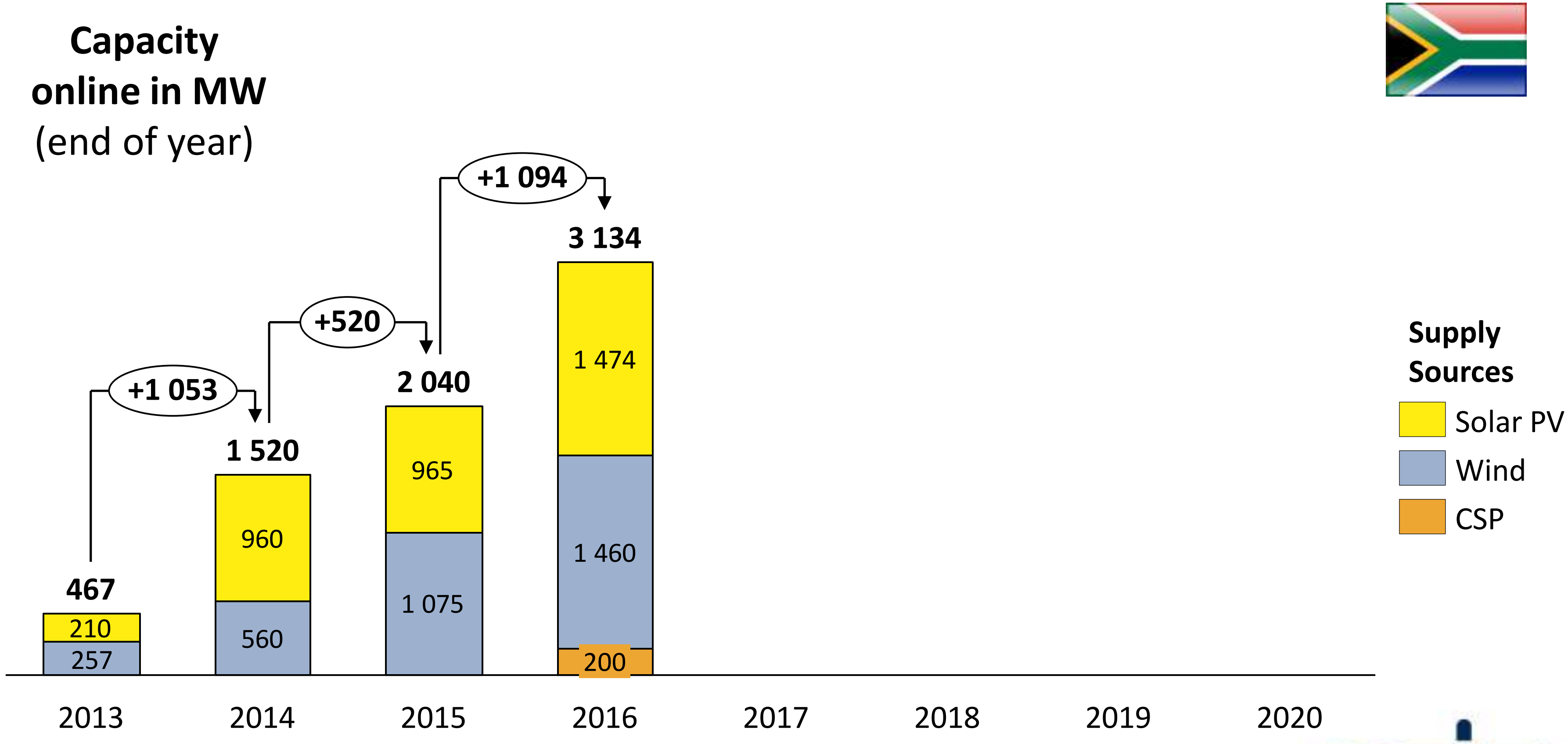
Renewables until today mainly driven by US, Europe, China and Japan

Globally installed capacities for three major renewables wind, solar PV and CSP end of 2015



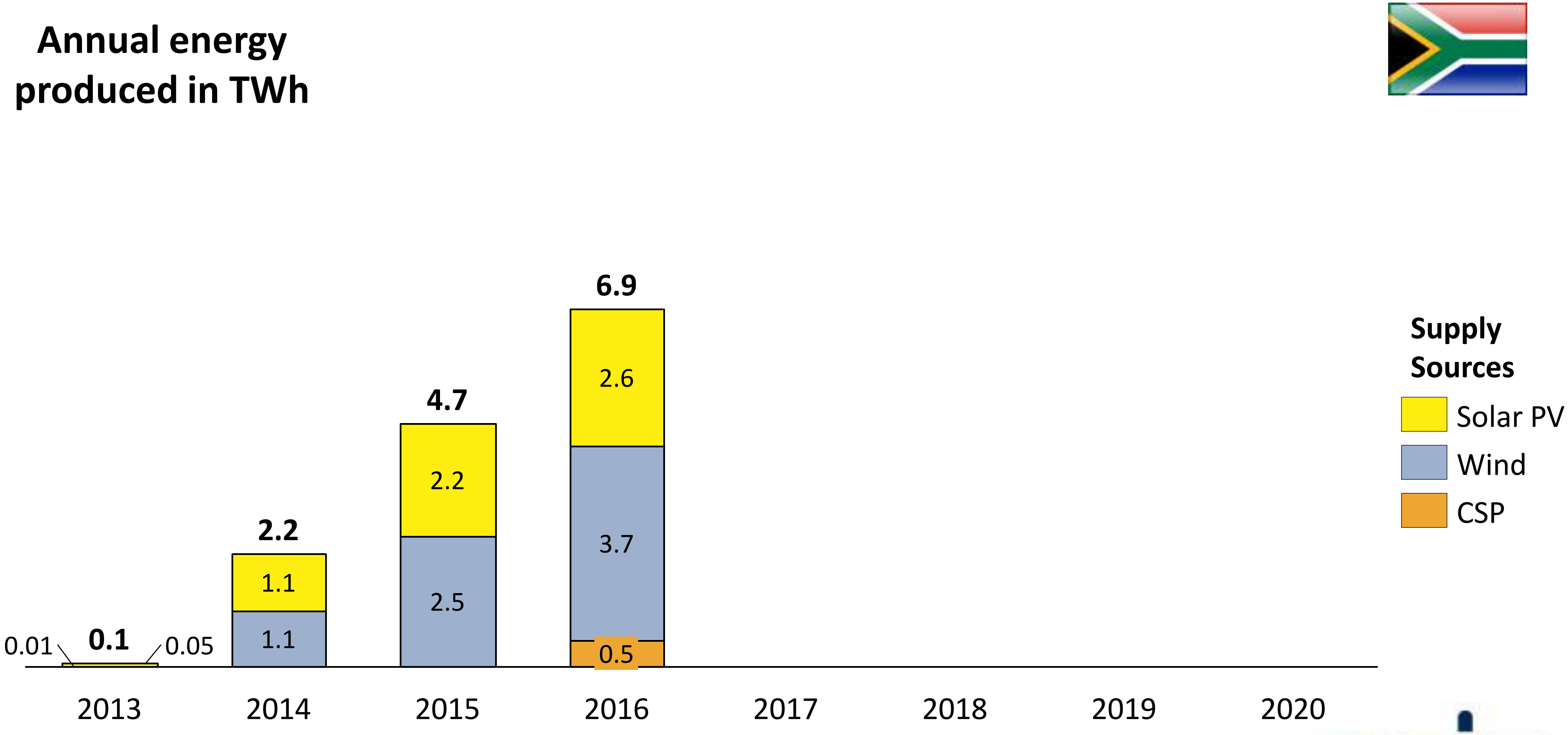
Sources: GWEC; EPIA; CSPToday; CSIR analysis

South Africa:
From 2013 to 2016, 3.1 GW of wind, solar PV and CSP commissioned



Notes: RSA = Republic of South Africa. Solar PV capacity = capacity at point of common coupling. Wind includes Eskom's Sere wind farm (100 MW)
Sources: Eskom; DoE IPP Office

South Africa:
In 2016, almost 7 TWh electricity produced from wind, solar PV & CSP



Notes: Wind includes Eskom's Sere wind farm (100 MW)
Sources: Eskom; DoE IPP Office

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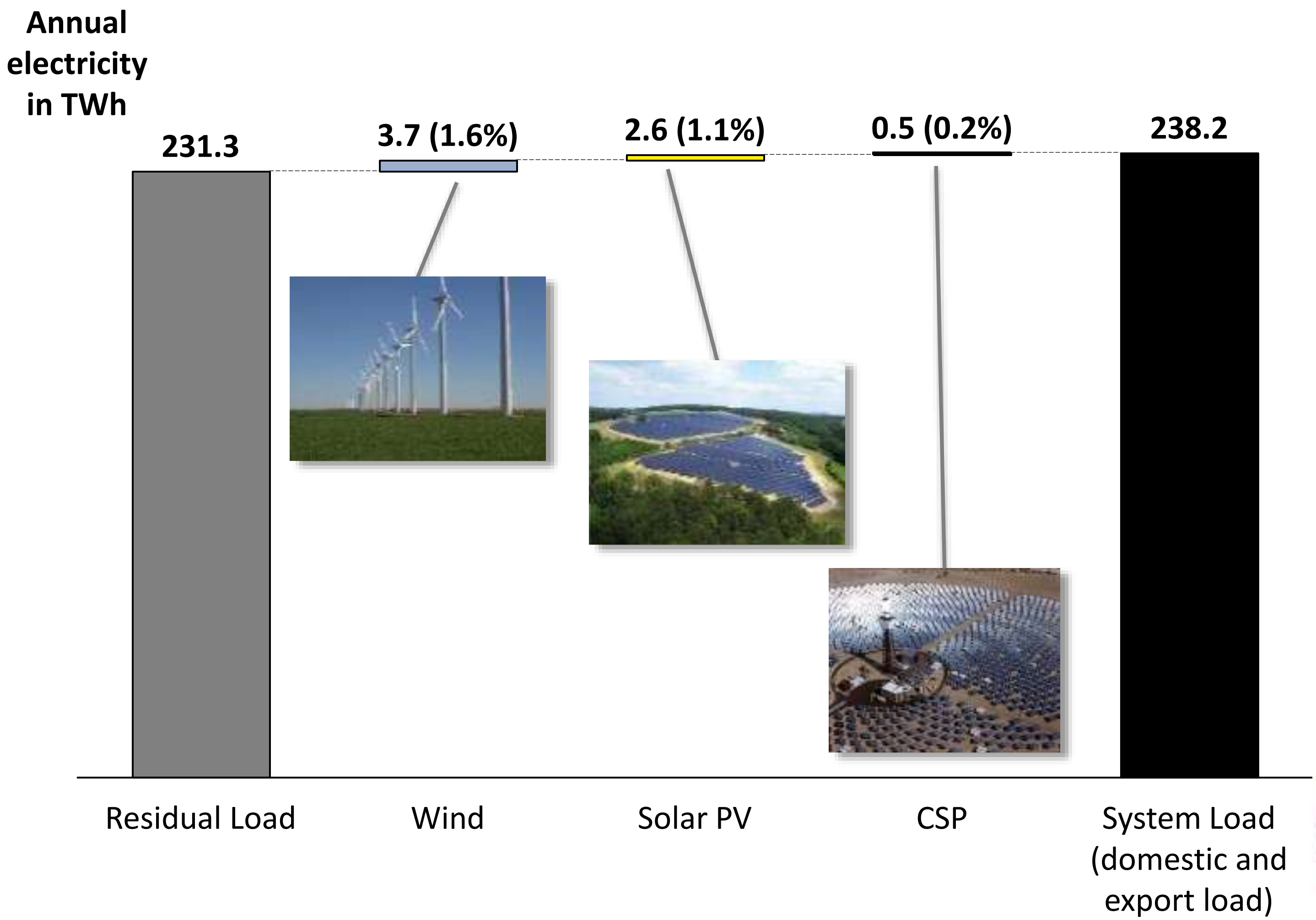
2016: Wind, solar PV and CSP supplied 3% of the total RSA system load

Actuals captured in wholesale market for Jan-Dec 2016 (i.e. without self-consumption of embedded plants)



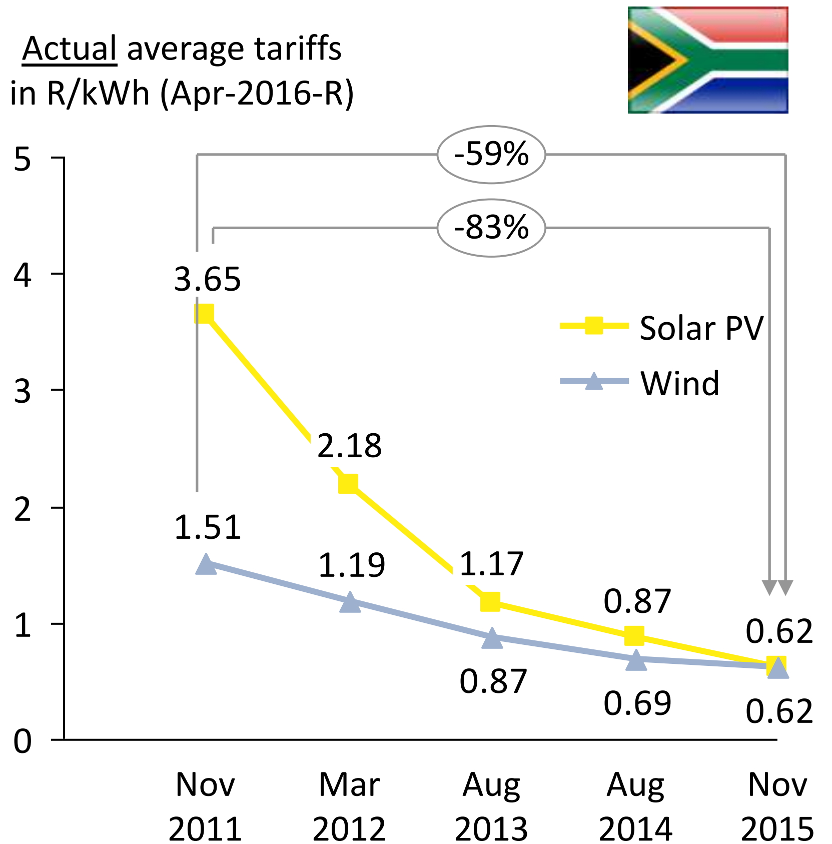
Notes: Wind includes Eskom’s Sere wind farm (100 MW)

Sources: Eskom; DoE IPP Office

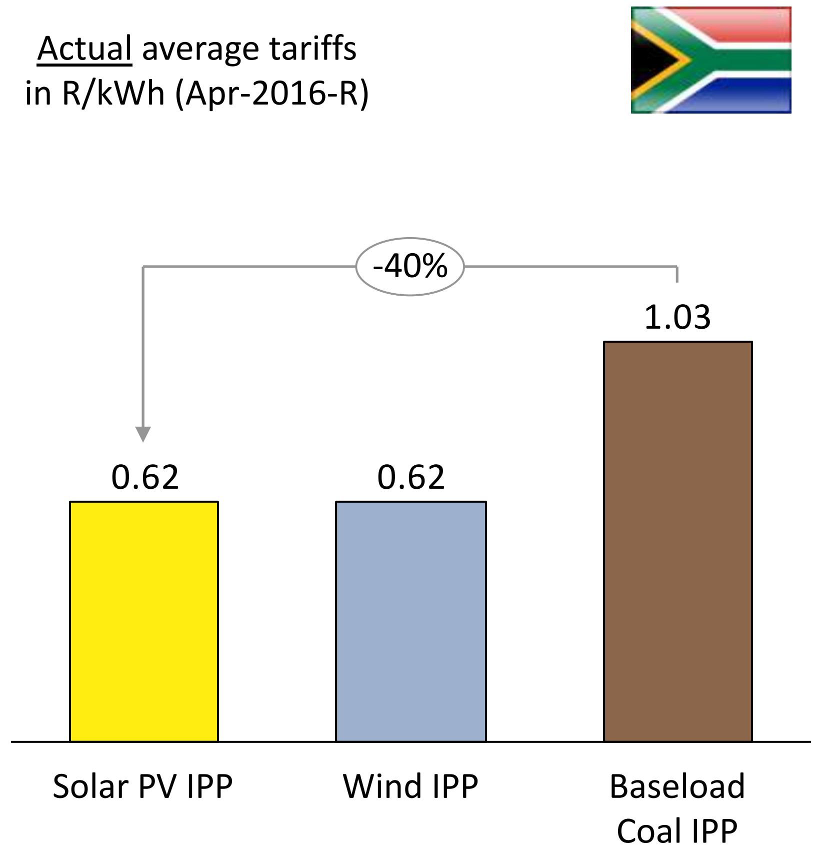
Actual tariffs: new wind/solar PV 40% cheaper than new coal in RSA

Results of Department of Energy's RE IPP Procurement Programme (REIPPPP) and Coal IPP Proc. Programme

Significant reductions in actual tariffs …



… have made new solar PV & wind power 40% cheaper than new coal in South Africa today



Notes: Exchange rate of 14 USD/ZAR assumed Sources: http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; http://www.saippa.org.za/Portals/24/Documents/2016/Coal%20IPP%20factsheet.pdf; http://www.ee.co.za/wp-content/uploads/2016/10/New_Power_Generators_RSA-CSIR-14Oct2016.pdf; StatsSA on CPI; CSIR analysis

METHODOLOGY AND APPROACH

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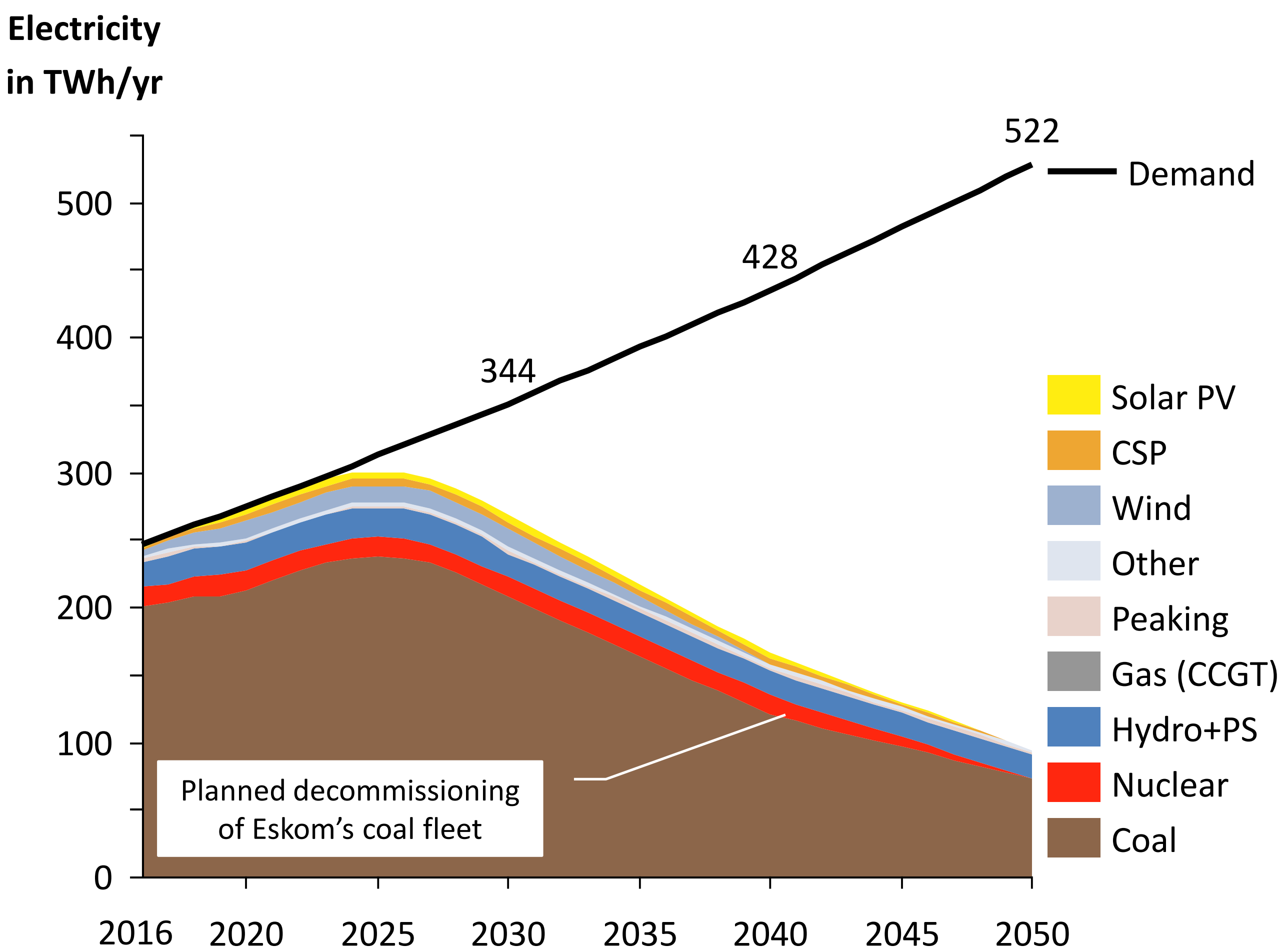
The existing fleet of power generators phases out until 2050

Decommissioning schedule for the South African electricity system from 2016 to 2050



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

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

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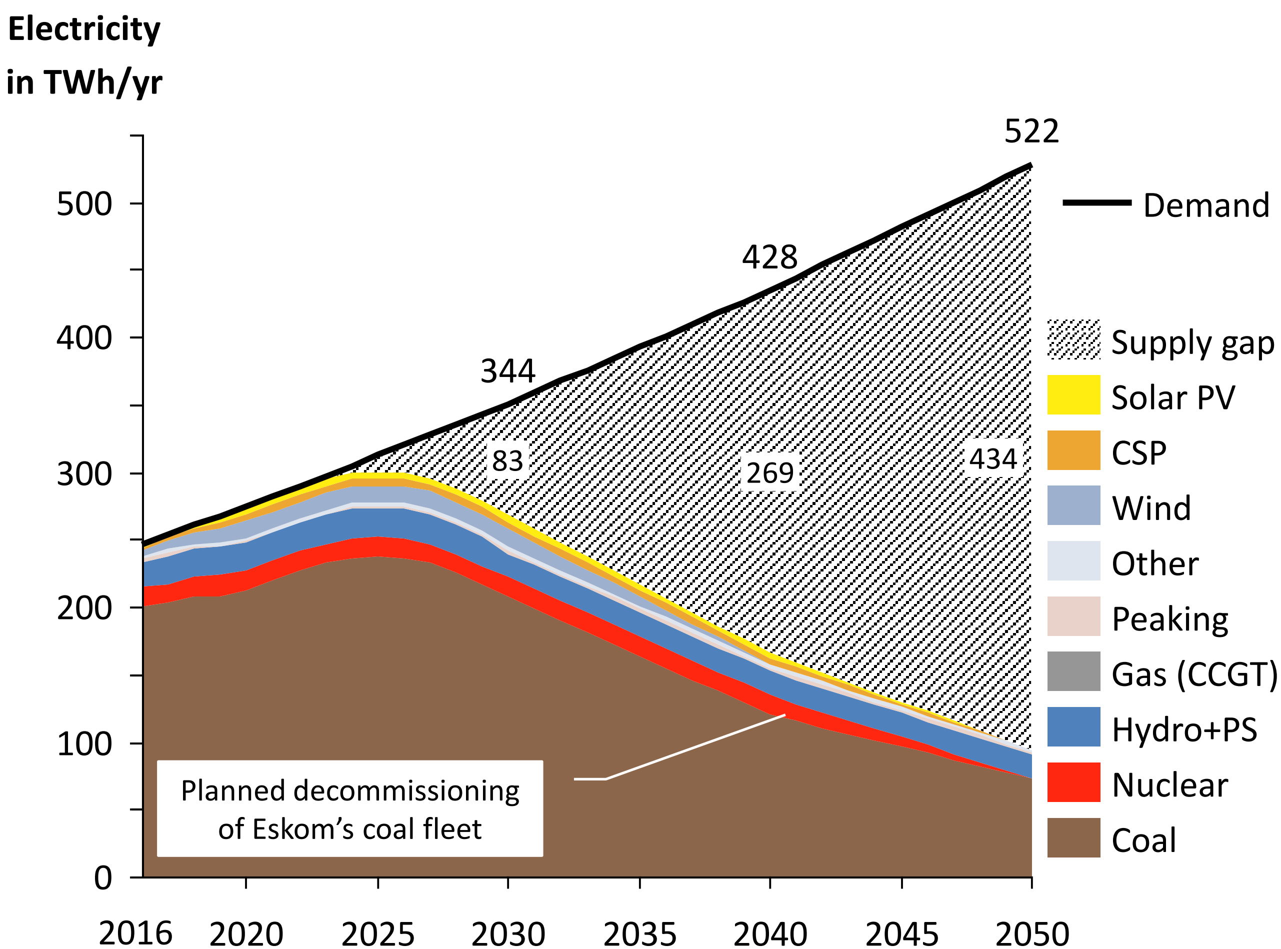
Sources: DoE (IRP 2016); Eskom MTSAO 2016-2021; StatsSA; World Bank; CSIR analysis

Demand grows, existing fleet phases out – gap needs to be filled

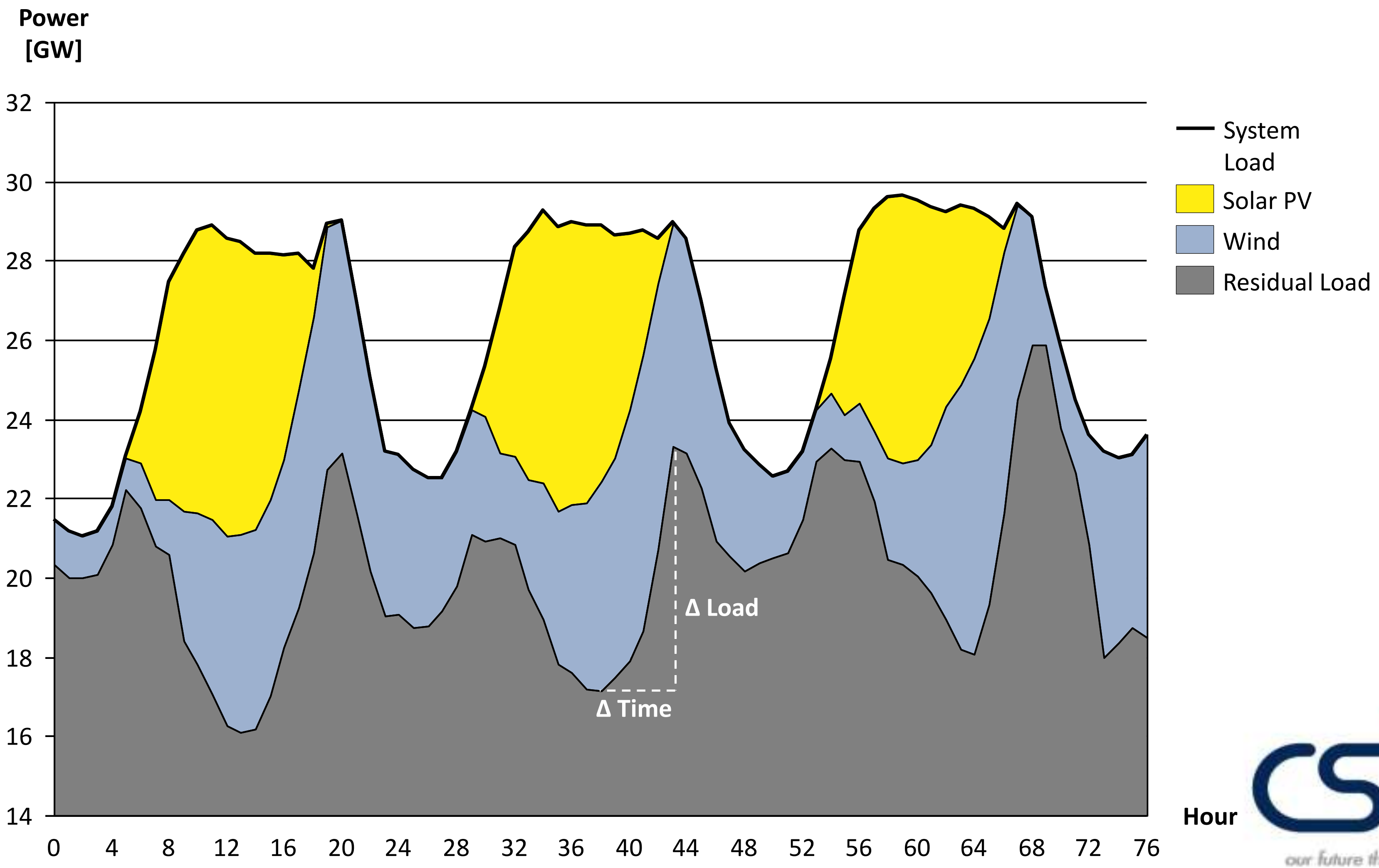
Forecasted supply and demand balance for the South African electricity system from 2016 to 2050



The IRP model fills the supply gap in the least-cost manner, subject to any constraints imposed on the model

Note: All power plants considered for "existing fleet" that are either Existing in 2016, Under construction, or Procured (preferred bidder)
Sources: DoE (IRP 2016); Eskom MTSAO 2016-2021; StatsSA; World Bank; CSIR analysis

Definition of residual load



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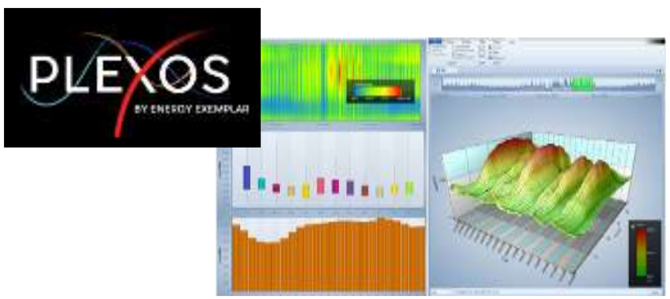
CSIR uses an industry standard software package for expansion planning of the power system – same package as used by DoE/Eskom

Commercial software used by DoE & CSIR …

Co-optimisation of long-term investment & operational decisions in hourly time resolution from today to 2050

- What mix to build?
- How to operate the mix once built?
- Objective function: Least Cost, subject to an adequate (i.e. reliable) power system



Key technical limitations of power generators covered

- Maximum ramp rates (% of installed capacity/h)
- Minimum operating levels (% of installed capacity)
- Minimum up & down times (h btw start/stop)
- Start-up and shut-down profiles

… covers all key cost drivers of a power system

Costs <u>covered</u> in the model include

- All capacity-related costs of all power generators
  - CAPEX of new power plants (R/kW)
  - Fixed Operation and Maintenance (FOM) cost (R/kW/yr)
- All energy-related costs of all power generators
  - Variable Operation and Maintenance (VOM) cost (R/kWh)
  - Fuel cost (R/GJ)
- Efficiency losses due to more flexible operation
- Reserves provision (included in capacity costs)
- Start-up and shut-down costs

Costs <u>not covered</u> in the model currently used are

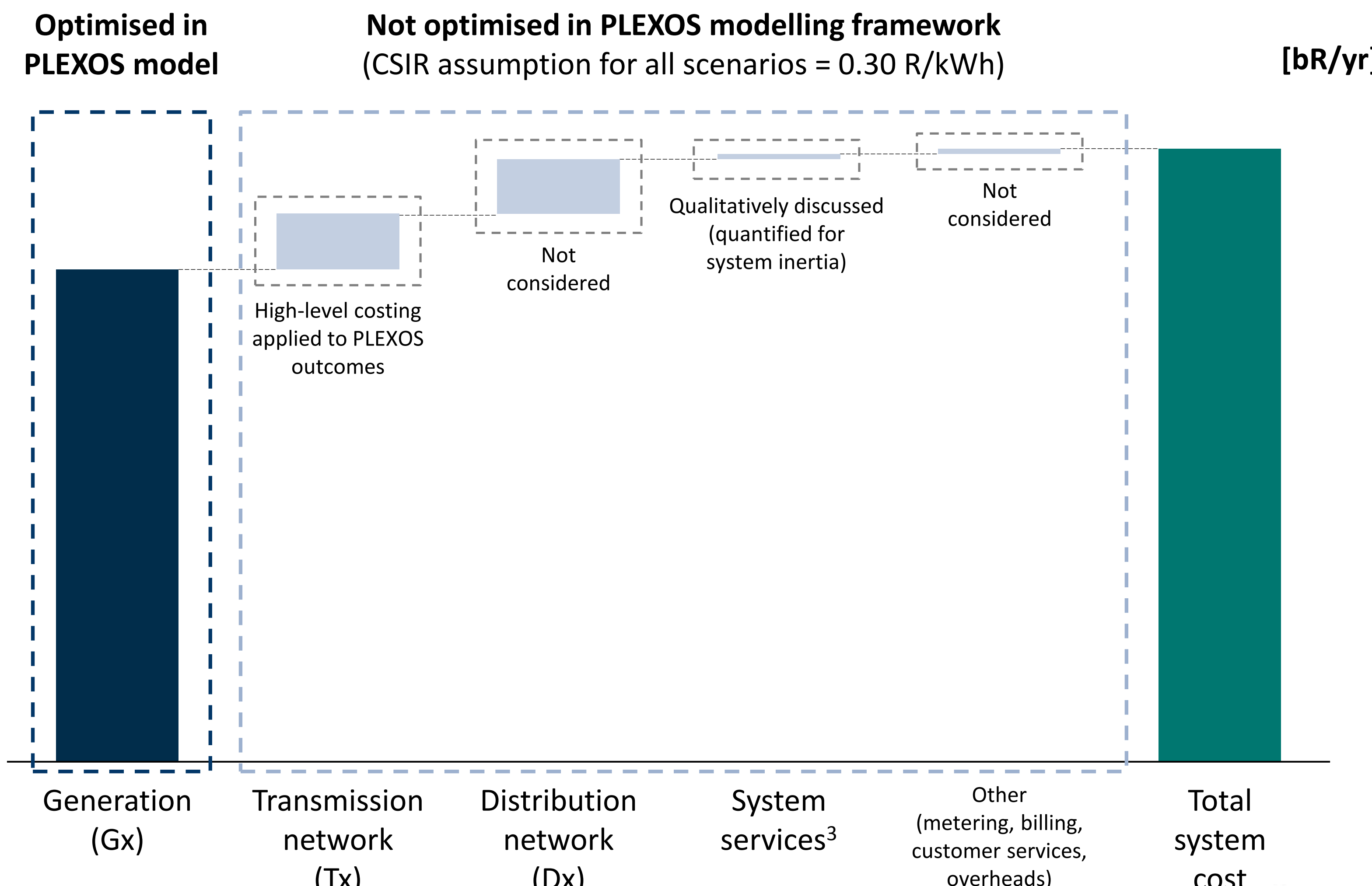
- Any grid-related costs (note: transmission-level grid costs typically ~10-15% of generation costs)
- Costs related to add. system services (e.g. inertia requirements, black-start and reactive power)

Sources: CSIR analysis

The IRP currently only optimises for the generation cost component of total system cost (this is the dominant component)

Costs included in Gx optimisation model:
- CAPEX (plant level)
- FOM[1]
- VOM[2]
- Fuel

Costs excluded in Gx optimisation model:
- Externalities e.g. CO_2 emissions costs
- Decommissioning costs
- Waste management and/or rehabilitation
- Major mid-life overhaul
- Shallow grid connection costs



[1] FOM = Fixed Operations and Maintenence costs; [2] VOM = Variable Operations and Maintenence costs; [3] Typically referred to as Ancillary Services includes services to ensure frequency stability, transient stability, provide reactive power/voltage control, ensure black start capability and system operator costs.

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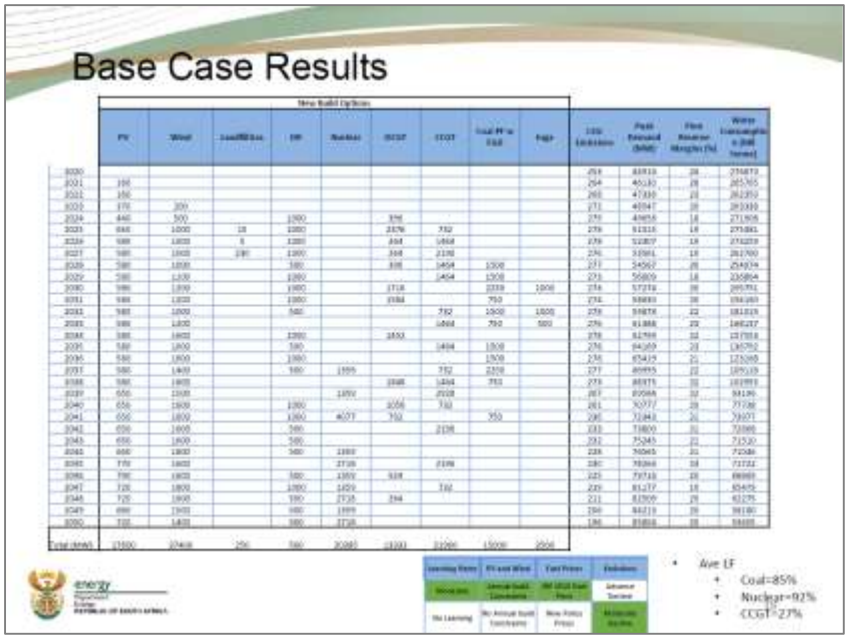
Common reporting layout applied to all scenarios by DoE and by CSIR

IRP scenarios as published by the DoE …



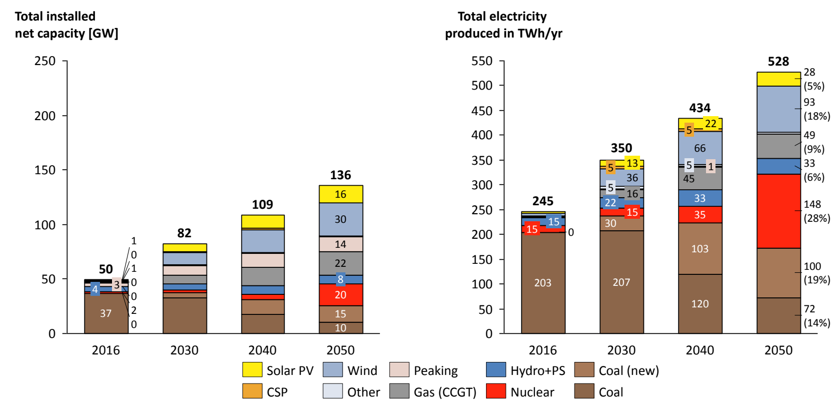
Scenarios of the Draft IRP 2016 show the annual new installed capacity per year per technology

… are analysed with respect to total installed capacity (GW) and energy balance (TWh/yr)

Determine total operational capacity per year

- Add existing fleet & its decommissioning schedule
- Decommission new plants at the end of their economic life e.g. wind = 20, solar PV = 25 years

Determine energy balances for different technologies and calibrate with IRP outputs



Sources: Draft IRP 2016, http://www.energy.gov.za/IRP/irp-presentaions/IRP-Update-Presentation-22-Nov-2016.pdf; CSIR analysis

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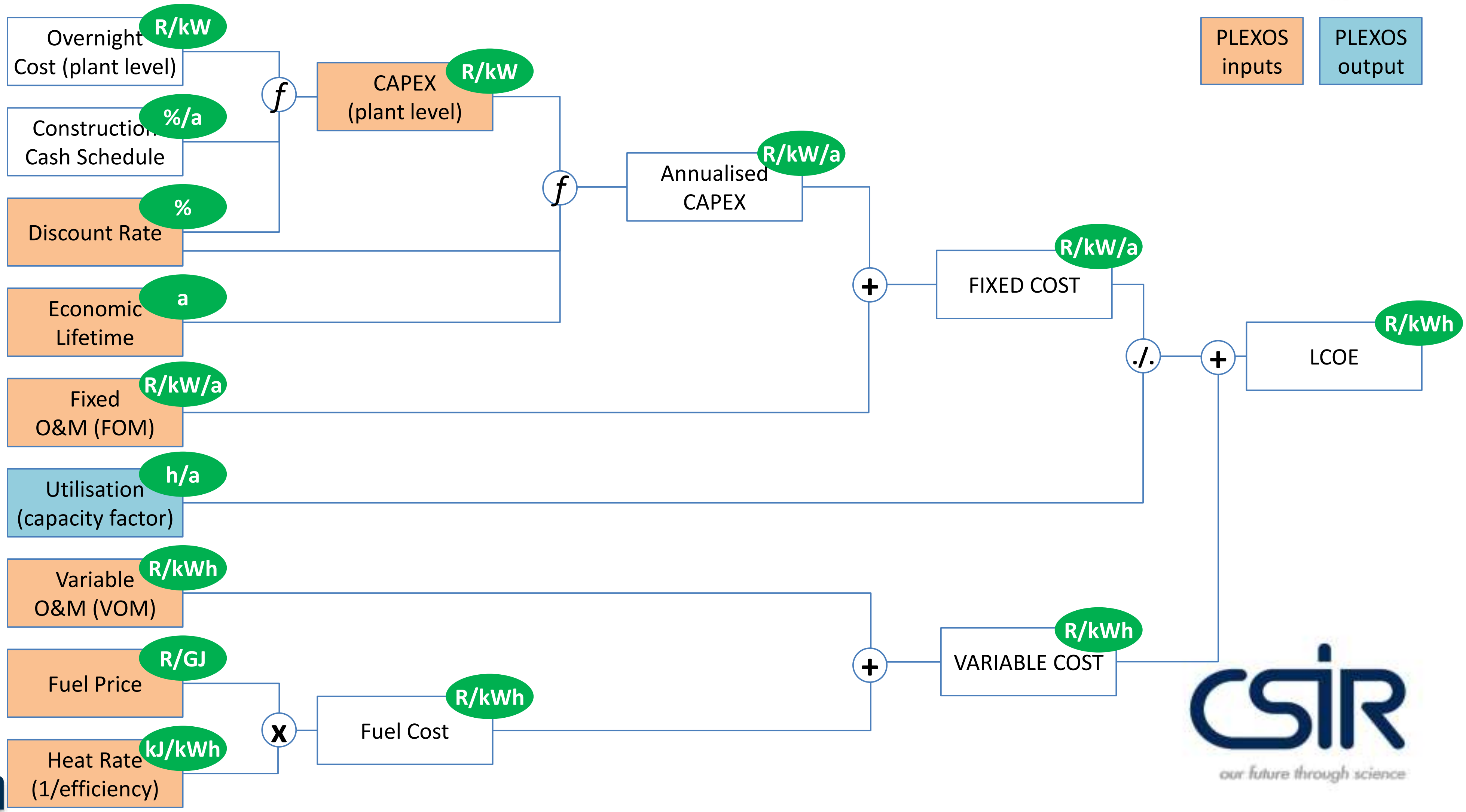
PLEXOS actual inputs are individual cost items that together with the utilisation of the plant (a model output) allow to calculate LCOE



Note: Start-up and shut-down costs are an additional cost item that PLEXOS models. Input is the cost in R/start.

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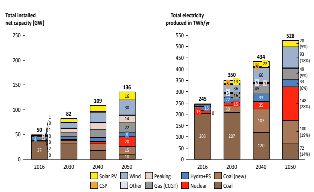
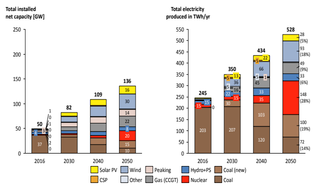
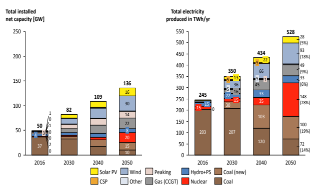
Overview of scenarios

Scenario	Source	Difference to Draft IRP 2016 Base Case
Draft IRP 2016 Base Case 	**Department of Energy** Draft IRP 2016 as of November 2016	**N/A**
Draft IRP 2016 Carbon Budget 	**Department of Energy** Draft IRP 2016 as of November 2016	**Tighter carbon reduction targets**
Draft IRP 2016 "Unconstrained Base Case" 	**Department of Energy** Scenario run by DoE/Eskom as per request of the Ministerial Advisory Council on Energy (MACE)	**No constraints on new build technologies**
Least Cost 	**CSIR**	**No constraints on new build technologies** **RE costing aligned with latest REIPPPP** **Demand shaping from residential EWHs**

Overview of scenarios

Scenario	Source	Difference to Draft IRP 2016 Base Case
Decarbonised 	**CSIR**	**No constraints on new build technologies** **95% CO_2 emissions reduction in the electricity sector compared to 2016** **Early coal fleet decommissioning** **Medupi and coal IPPs decommissioned from 2045** **Kusile is not commissioned**
Least-cost ("Expected") costs 	**CSIR**	**No constraints on new build technologies** **Expected realistic further cost reductions for solar PV, wind, CSP & batteries applied** **Electric vehicle uptake**

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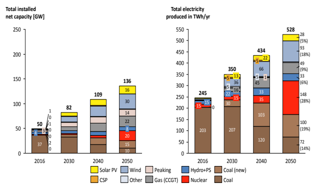
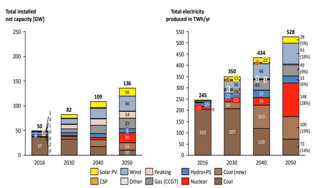
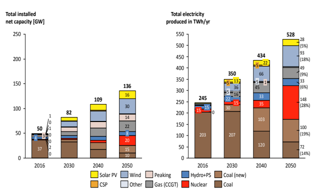
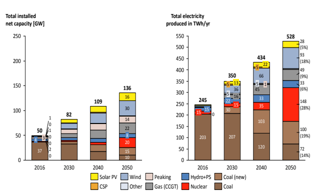
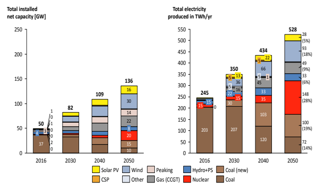
Overview of sensitivities

Sensitivity		Source	Difference to Draft IRP 2016 Base Case
Base Case (Low demand)		**CSIR**	**Low demand (EIUG)**
"Unconstrained Base Case" (Low demand)		**CSIR**	**Low demand (EIUG)** **No constraints on new build technologies**
Least Cost (Low demand)		**CSIR**	**Low demand (EIUG)** **No constraints on new build technologies** **RE costing aligned with latest REIPPPP** **Demand shaping from residential EWHs**
Supply technology tipping points		**CSIR**	**Least cost scenario input assumptions** **Lower costs for supply technologies not in least cost scenario e.g. nuclear, CSP etc**

Overview of sensitivities

Sensitivity		Source	Difference to Draft IRP 2016 Base Case
Low Supply		**CSIR**	**Least cost scenario input assumptions** **Delay Medupi and Kusile by 1 year per unit** **Follow Eskom's low plant performance path**

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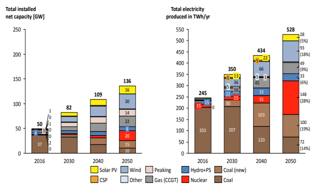
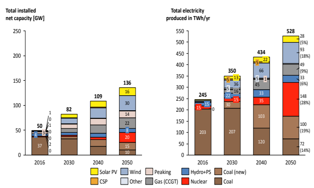
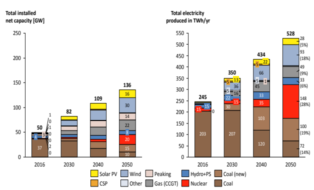
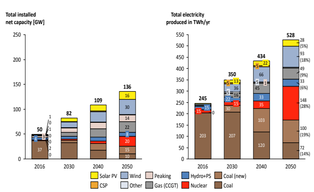
Overview of What-If analyses

What-If		Source	Difference to Draft IRP 2016 Base Case
Draft IRP 2016 Base Case (over-investment)		**CSIR**	**Least cost scenario input assumptions** **Low demand (EIUG)** **Hard-coded installed capacity from this scenario but with lower demand forecast**
Draft IRP 2016 Carbon Budget (over-investment)		**CSIR**	**Least cost scenario input assumptions** **Low demand (EIUG)** **Hard-coded installed capacity from this scenario but with lower demand forecast**
Draft IRP 2016 "Unconstrained Base Case" (over-investment)		**CSIR**	**Least cost scenario input assumptions** **Low demand (EIUG)** **Hard-coded installed capacity from this scenario but with lower demand forecast**
Least Cost (over-investment)		**CSIR**	**Least cost scenario input assumptions** **Low demand (EIUG)** **Hard-coded installed capacity from this scenario but with lower demand forecast**

INPUT ASSUMPTIONS

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Supply technologies (cost characteristics)

Supply technologies (technical characteristics)

Existing fleet

Reserve requirements

Electrical energy demand forecast

Demand shaping - domestic Electric Water Heaters (EWHs)

Electricity sector CO_2 emissions trajectories

Jobs per technology

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Supply technologies (cost characteristics)

Supply technologies (technical characteristics)

Existing fleet

Reserve requirements

Electrical energy demand forecast

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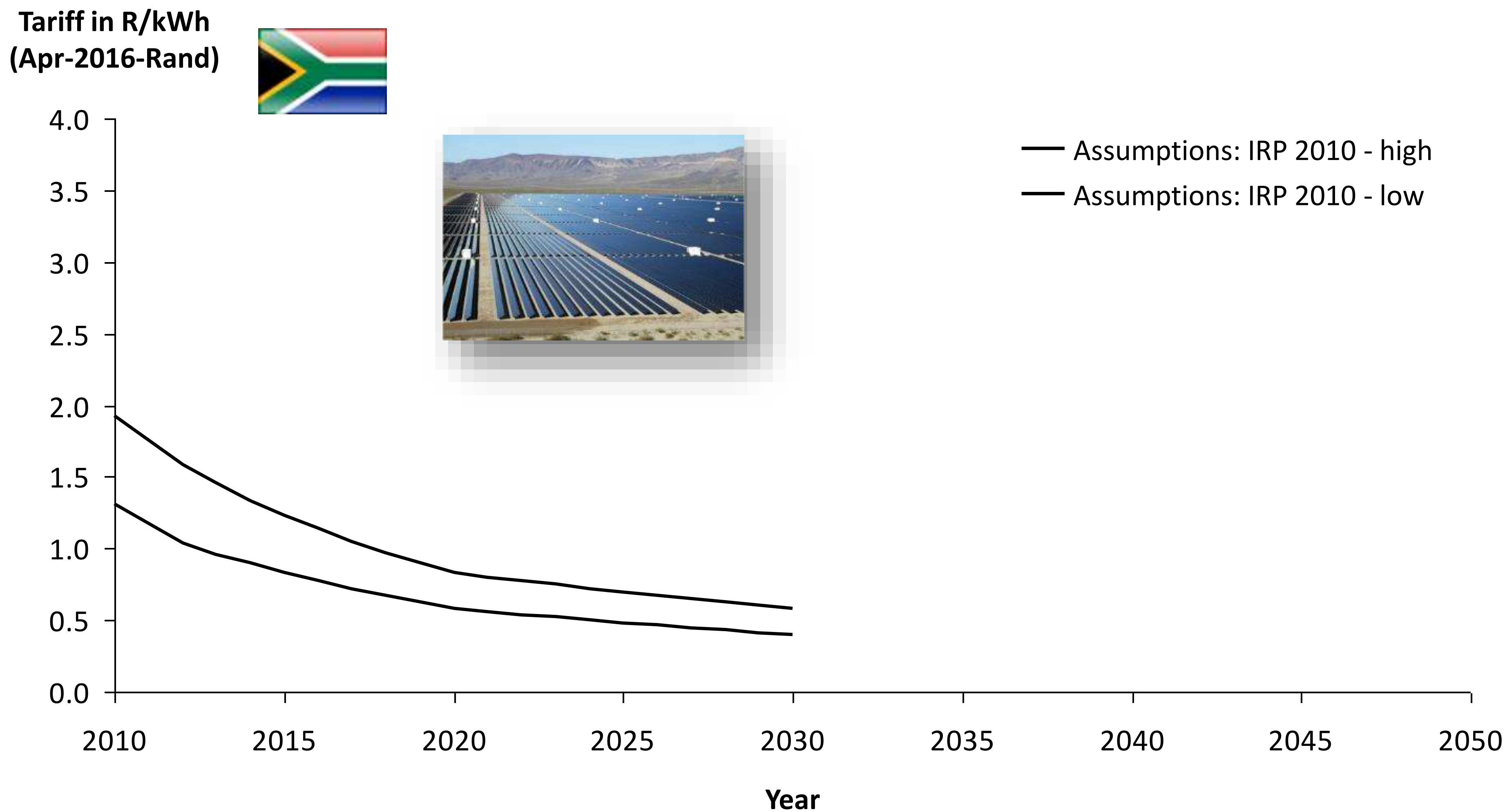
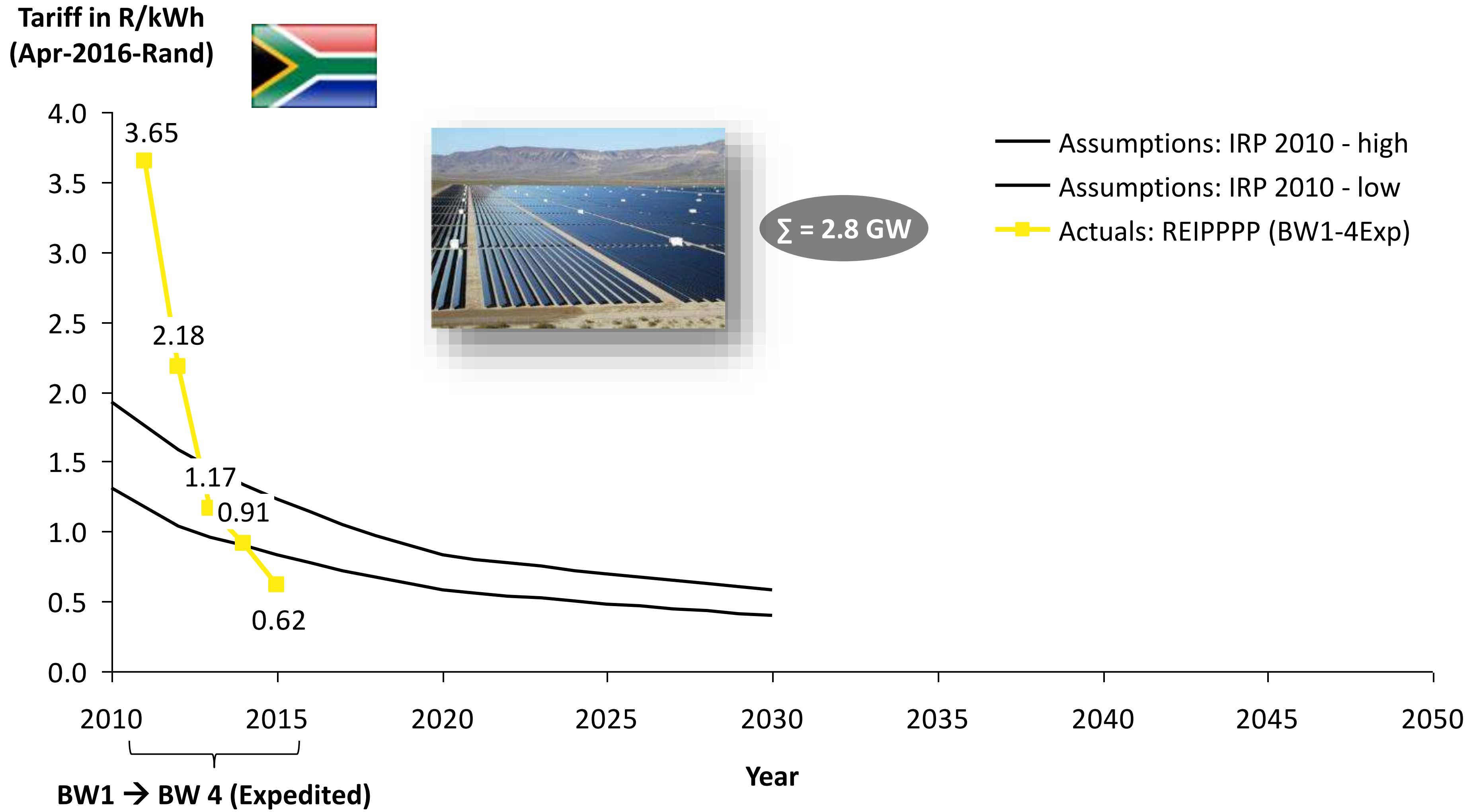
IRP 2010 forecasted steep cost decline for solar PV from 2010 to 2030



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 solar PV tariffs quickly moved below IRP 2010 cost assumptions



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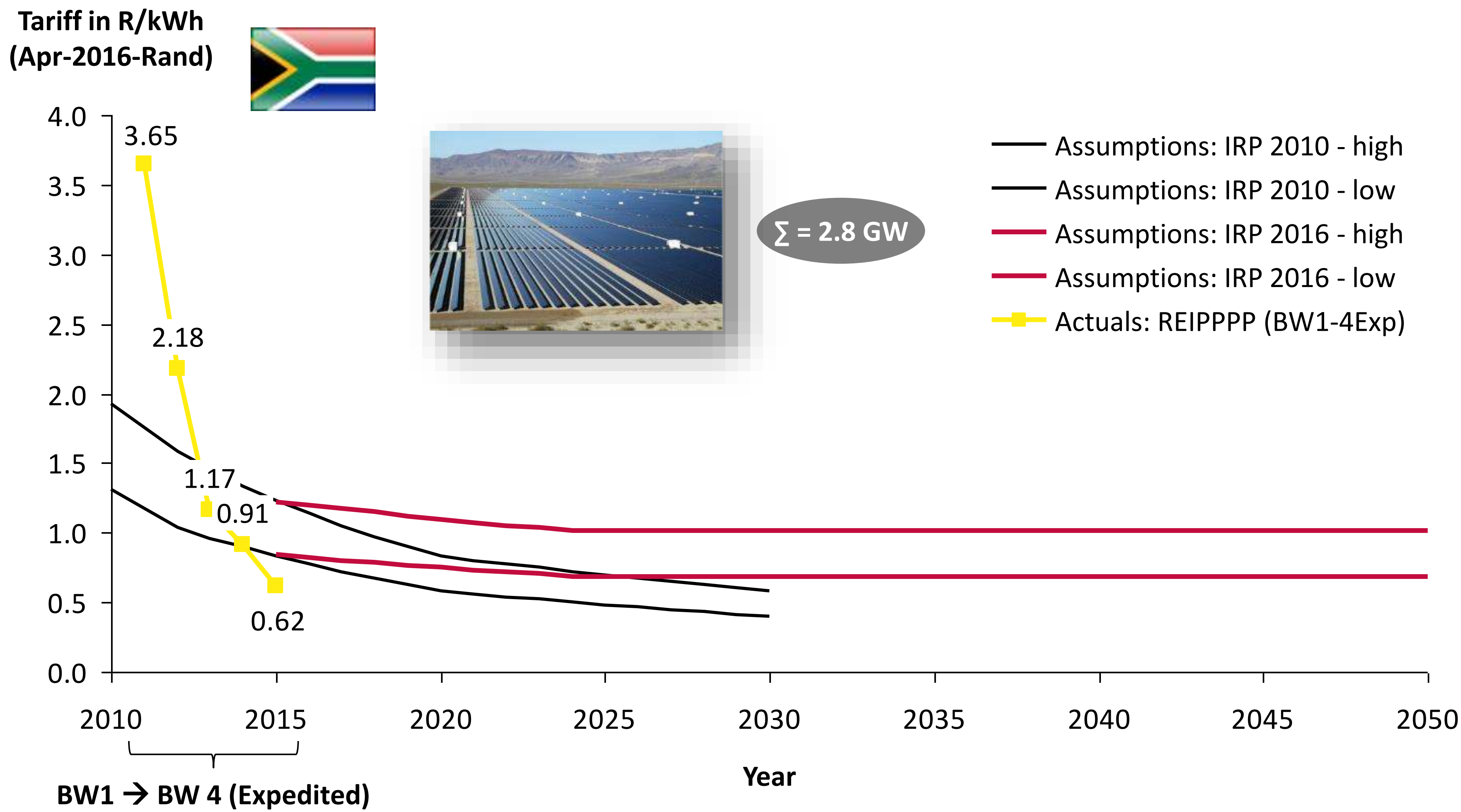
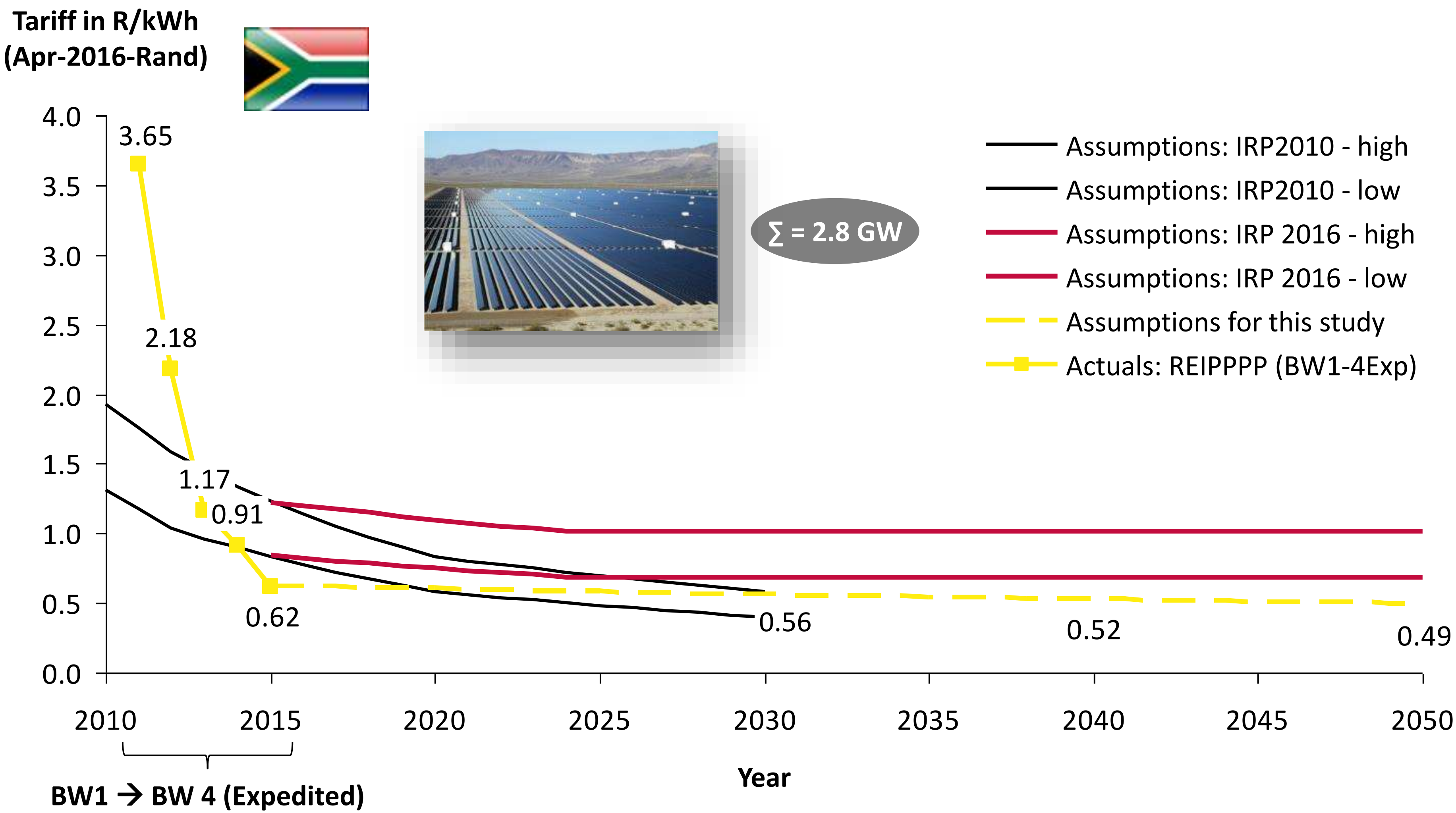
IRP 2016 increases cost assumptions for solar PV compared to IRP 2010



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

CSIR study cost input assumptions for solar PV: 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

Solar PV:
Cost input and supply profile assumptions

Technology-specific inputs

CAPEX	9 240 R/kW
FOM	200 R/kW/a
VOM	0 R/kWh
Fuel price	N/A
Heat rate	N/A
Lifetime	25 a

General input across all technologies

Discount rate	8.2%

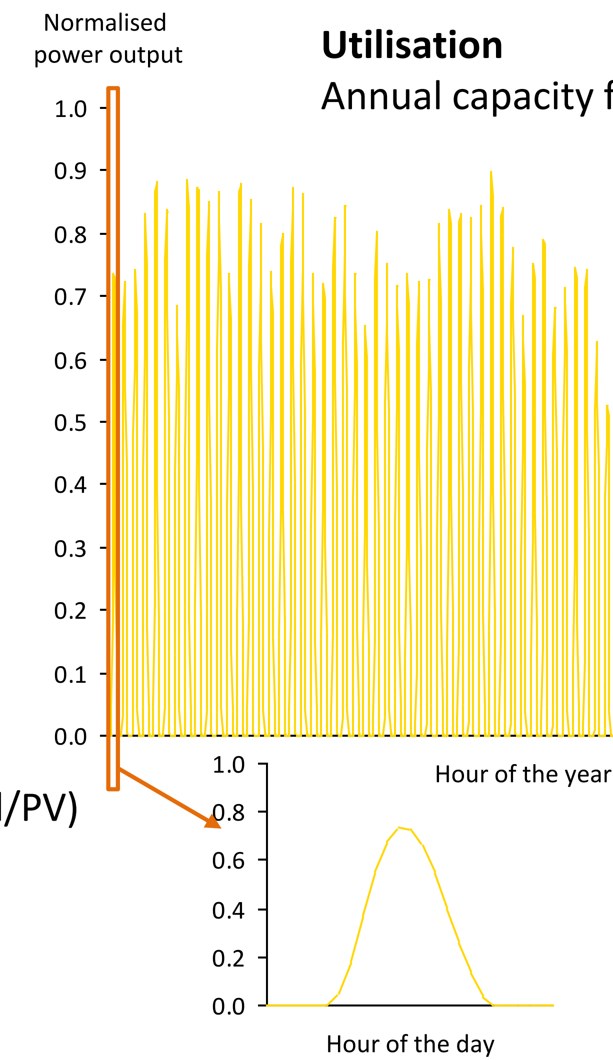
Utilisation

Capacity factor	25%

(a model output for all technologies other than wind/PV)

Resulting cost per energy unit

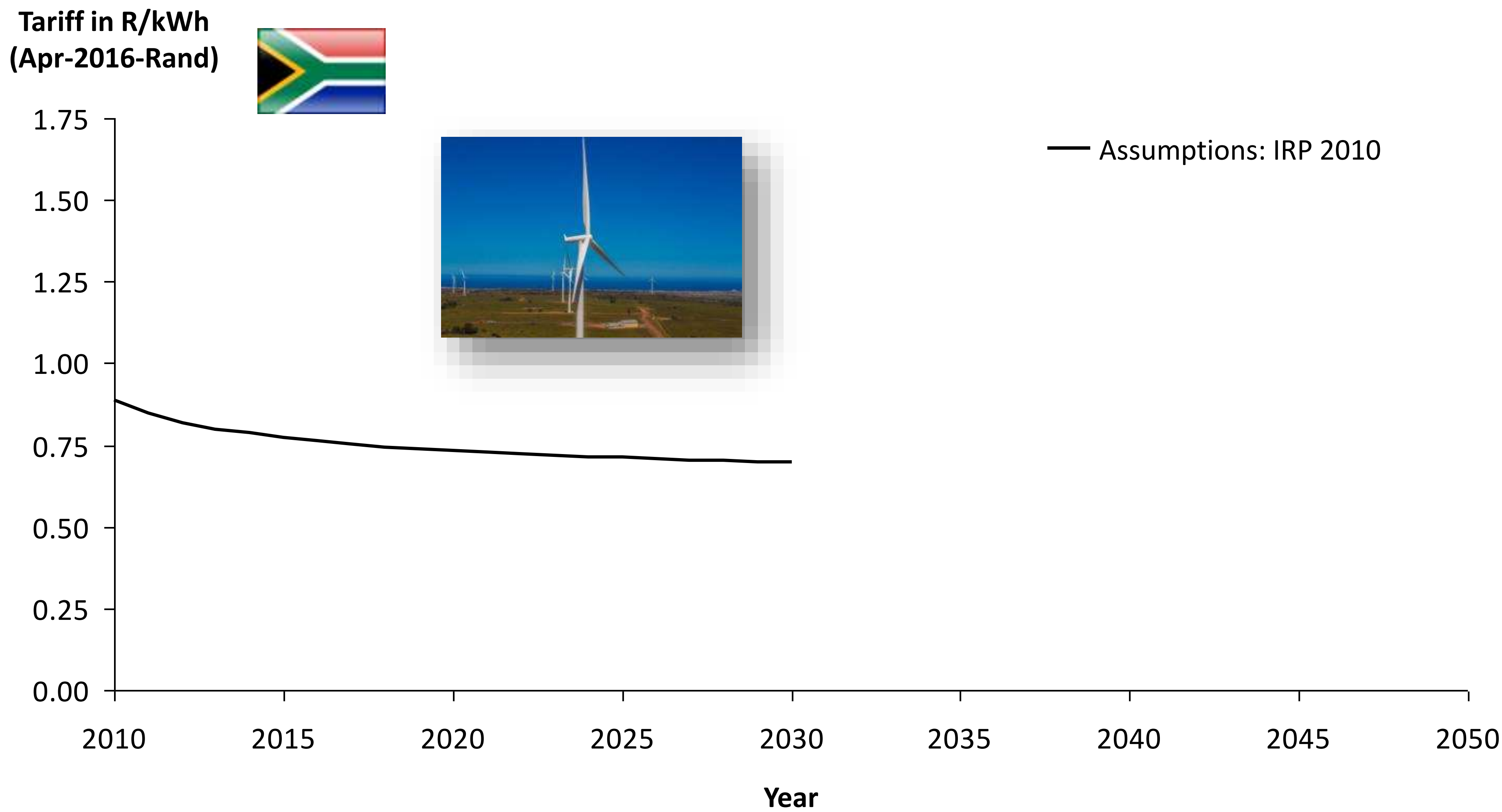
LCOE	0.62 R/kWh



Utilisation

Annual capacity factor = 20.4%

IRP 2010 forecasted small cost decline for wind from 2010 to 2030



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

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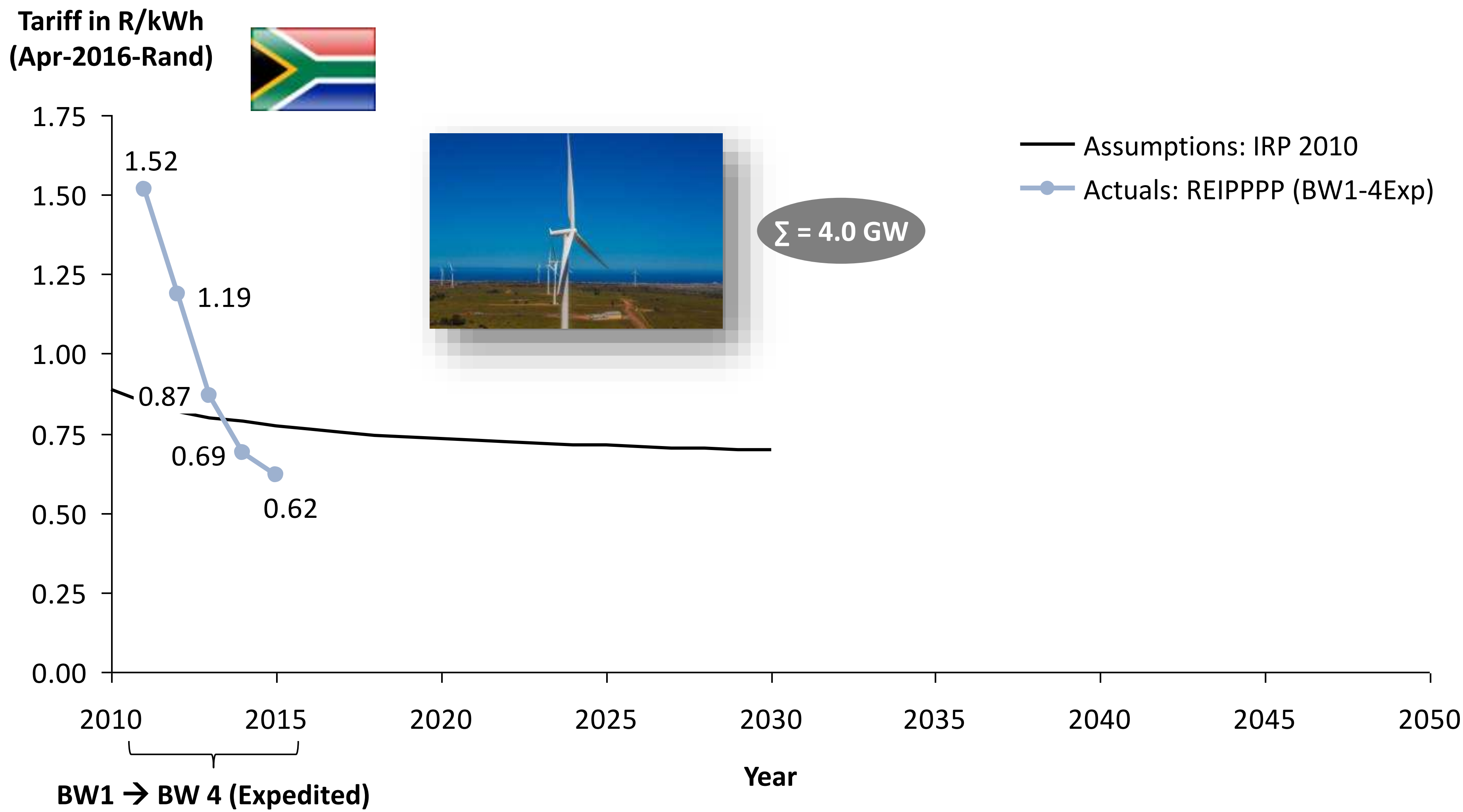
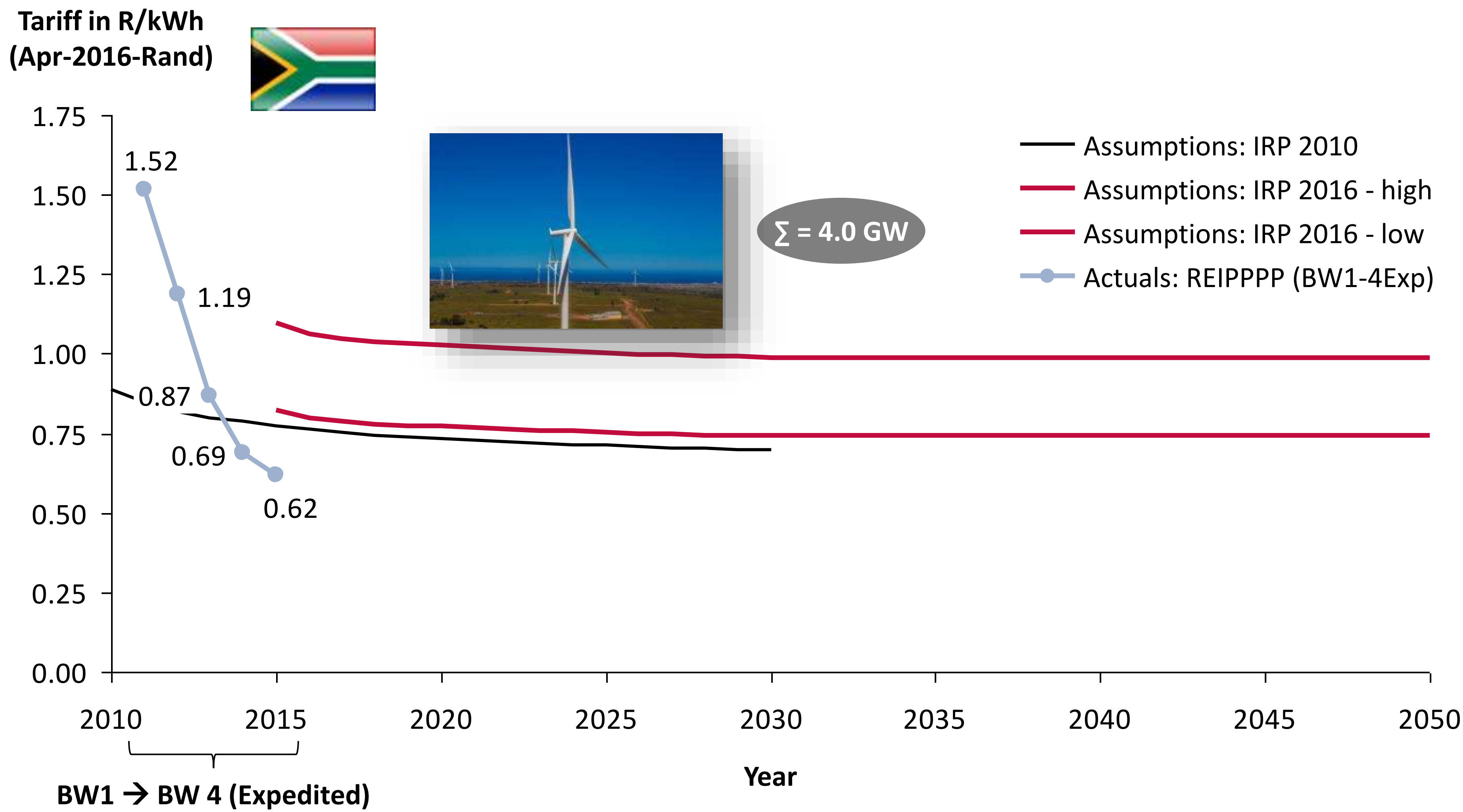
Actual wind tariffs quickly moved below IRP 2010 assumptions



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

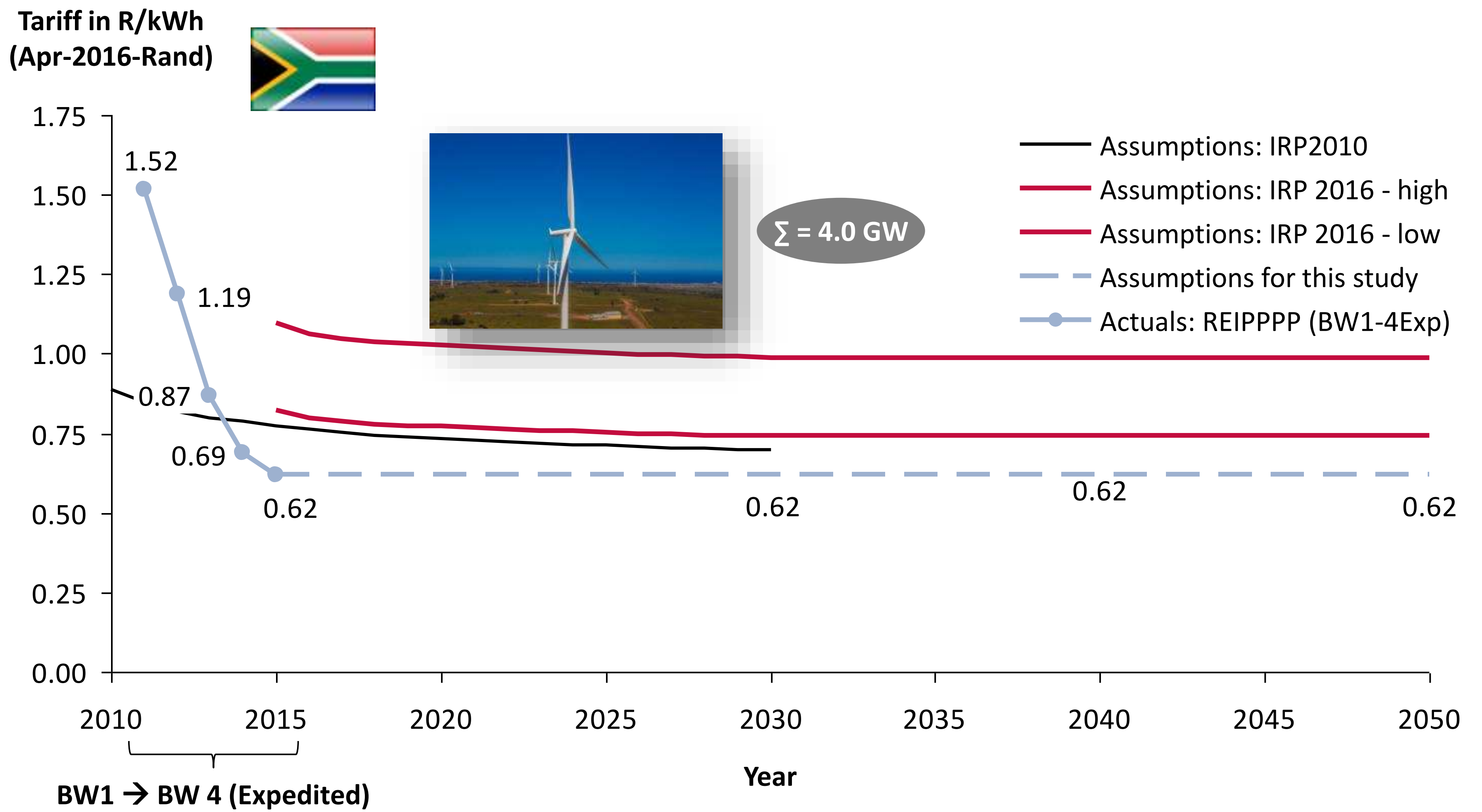
IRP 2016 increases cost assumptions for wind compared to IRP 2010



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

Submitted to DoE on 31 March 2017

CSIR study cost input assumptions for wind:
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

Wind:
Cost input and supply profile assumptions

Technology-specific inputs

CAPEX	13 250 R/kW
FOM	500 R/kW/a
VOM	0 R/kWh
Fuel price	N/A
Heat rate	N/A
Lifetime	20 a

General input across all technologies

Discount rate	8.2%

Utilisation

Capacity factor	36%

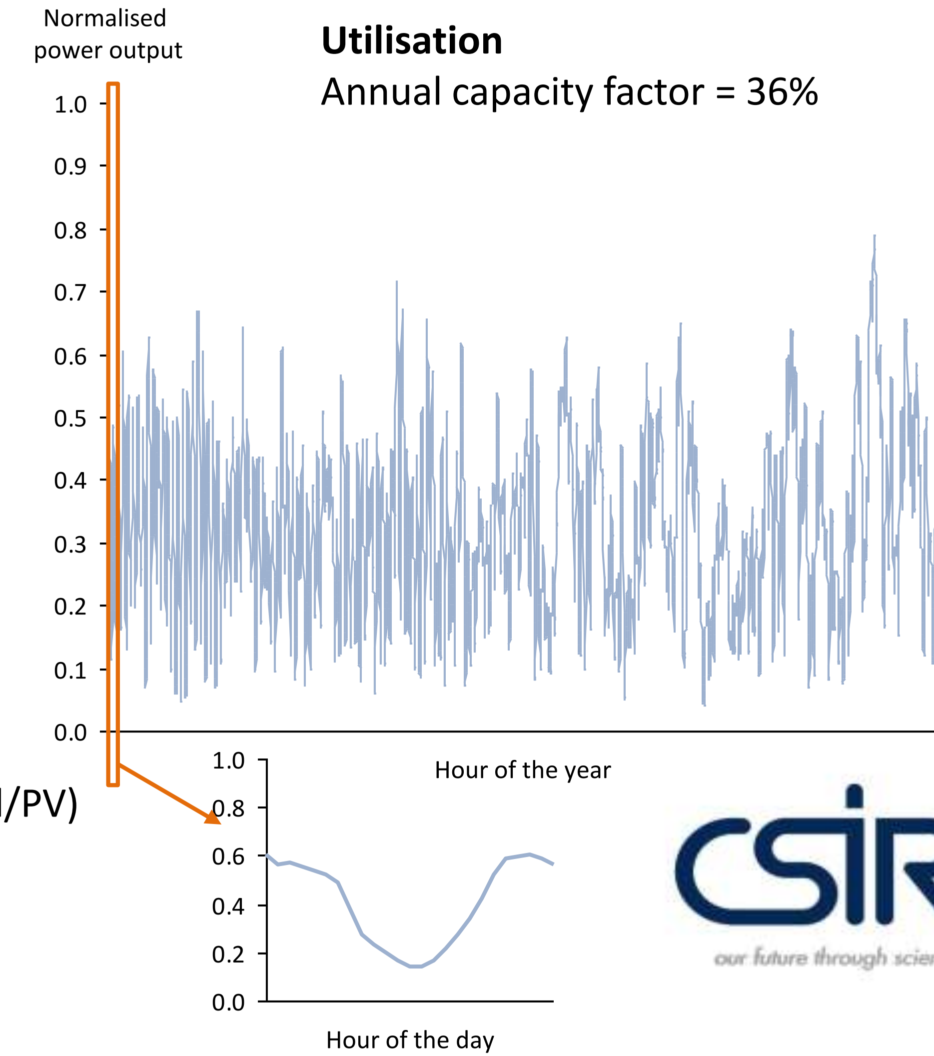
(a model <u>output</u> for all technologies other than wind/PV)

Resulting cost per energy unit

LCOE	0.62 R/kWh

Utilisation

Annual capacity factor = 36%



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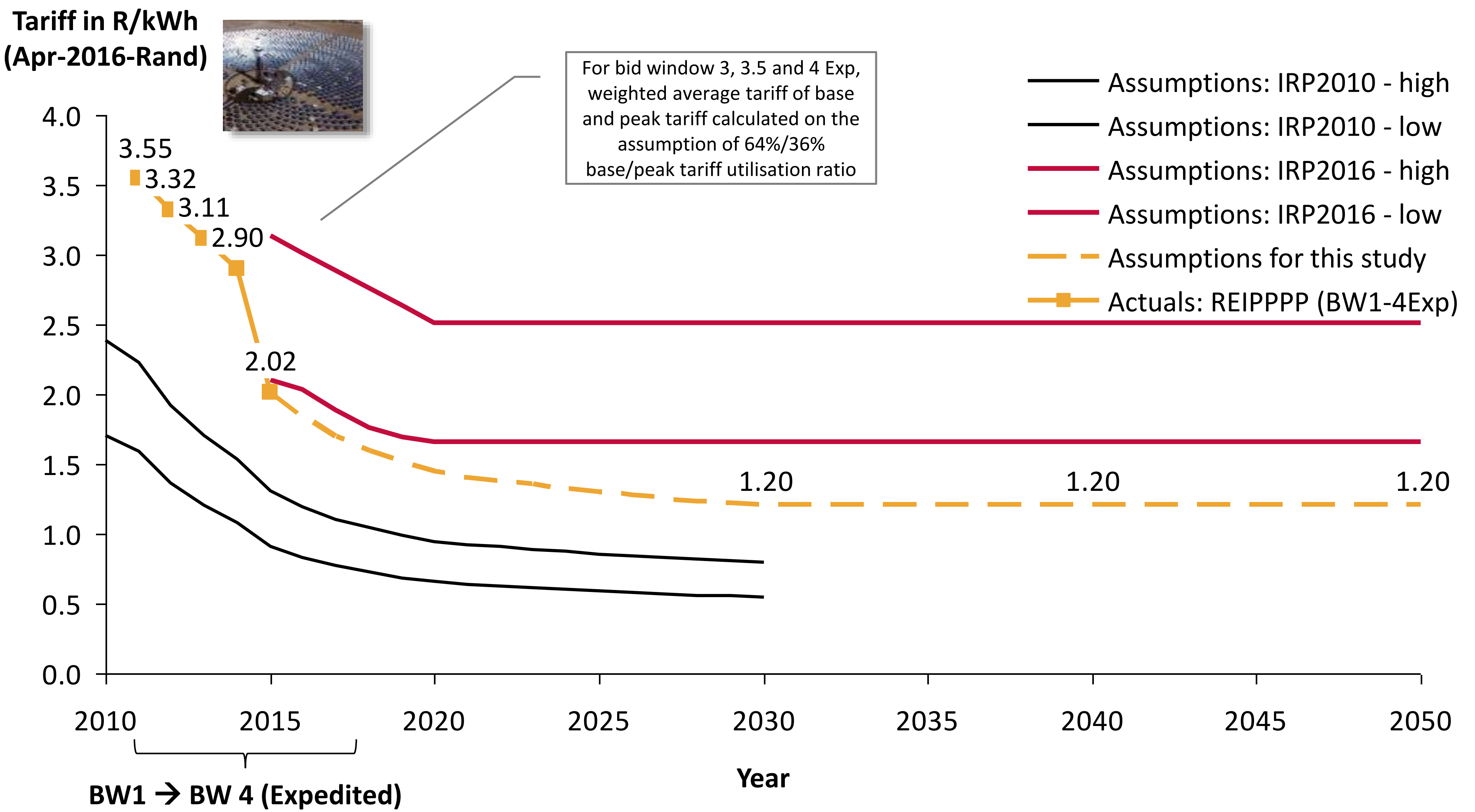
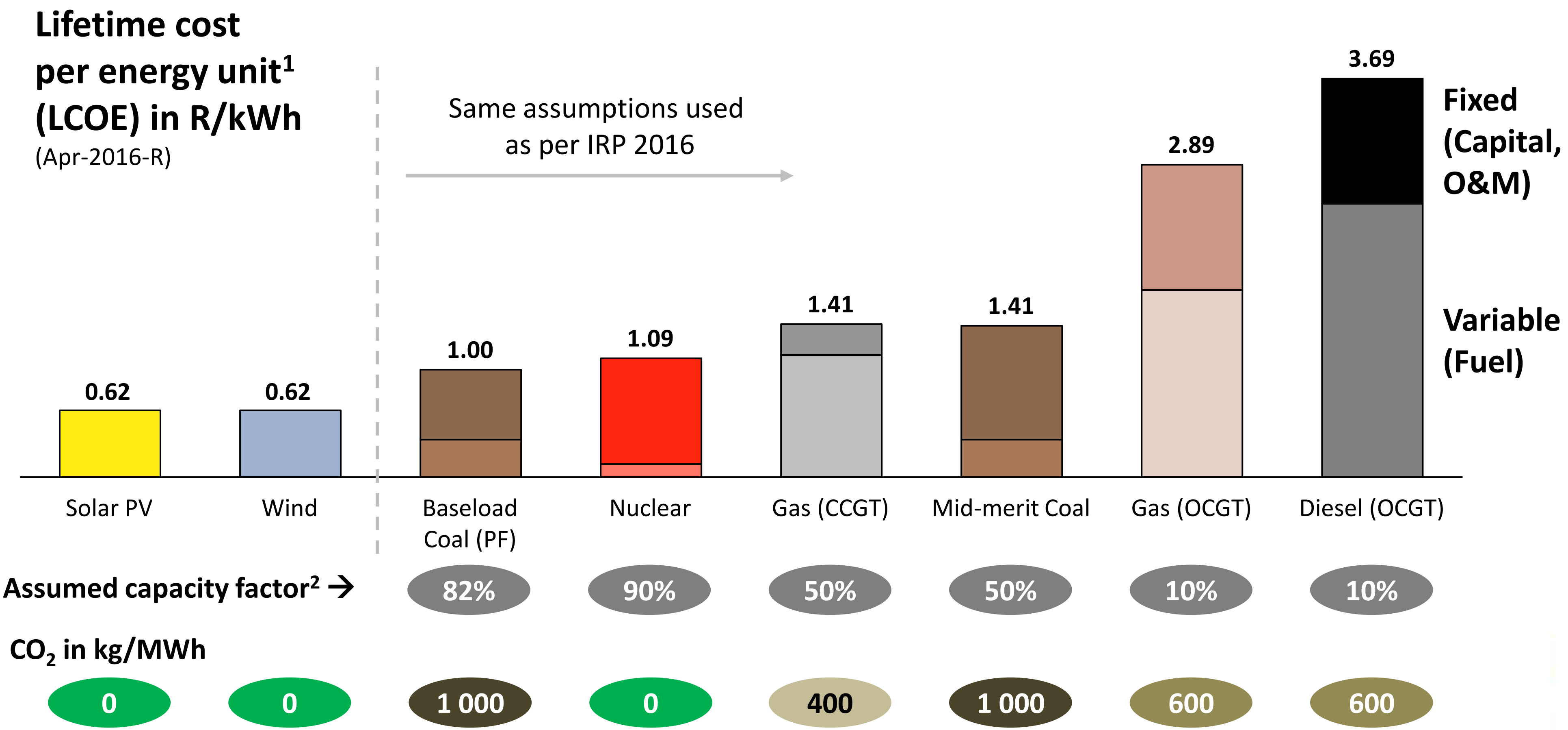
CSIR study cost input assumptions for CSP: Today's latest tariff as starting point, same cost decline as per IRP 2010



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

Inputs as per IRP 2016: Key resulting LCOE from 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 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

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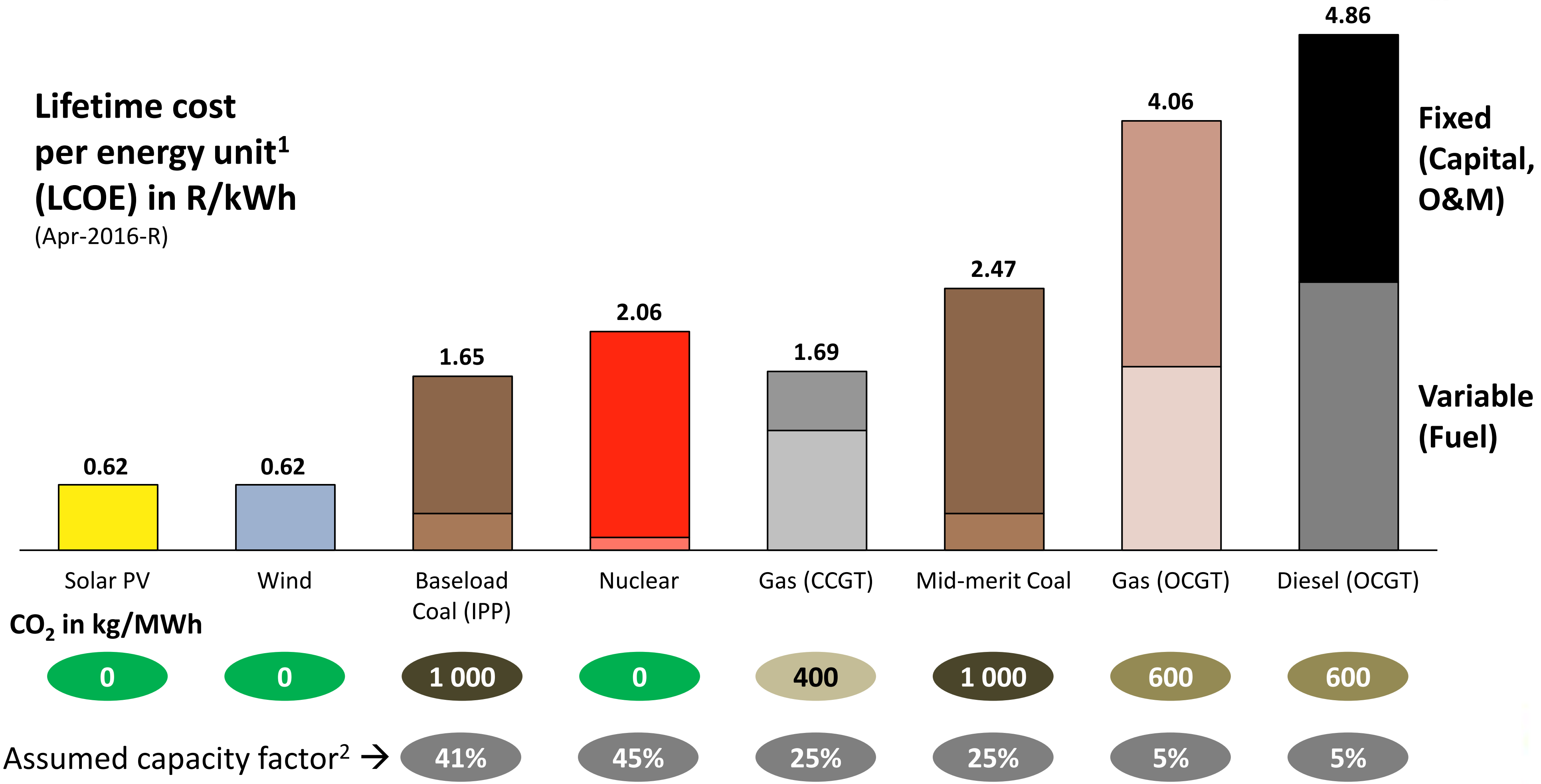
Sensitivity: 50% reduction of capacity factor hits capital-intensive power generators most



[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 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

**PLEASE REFER TO REPORT AND TO EXCEL SPREADSHEETS
FOR FULL SET OF COST INPUT ASSUMPTIONS FOR ALL TECHNOLOGIES**

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Electricity sector CO_2 emissions trajectories

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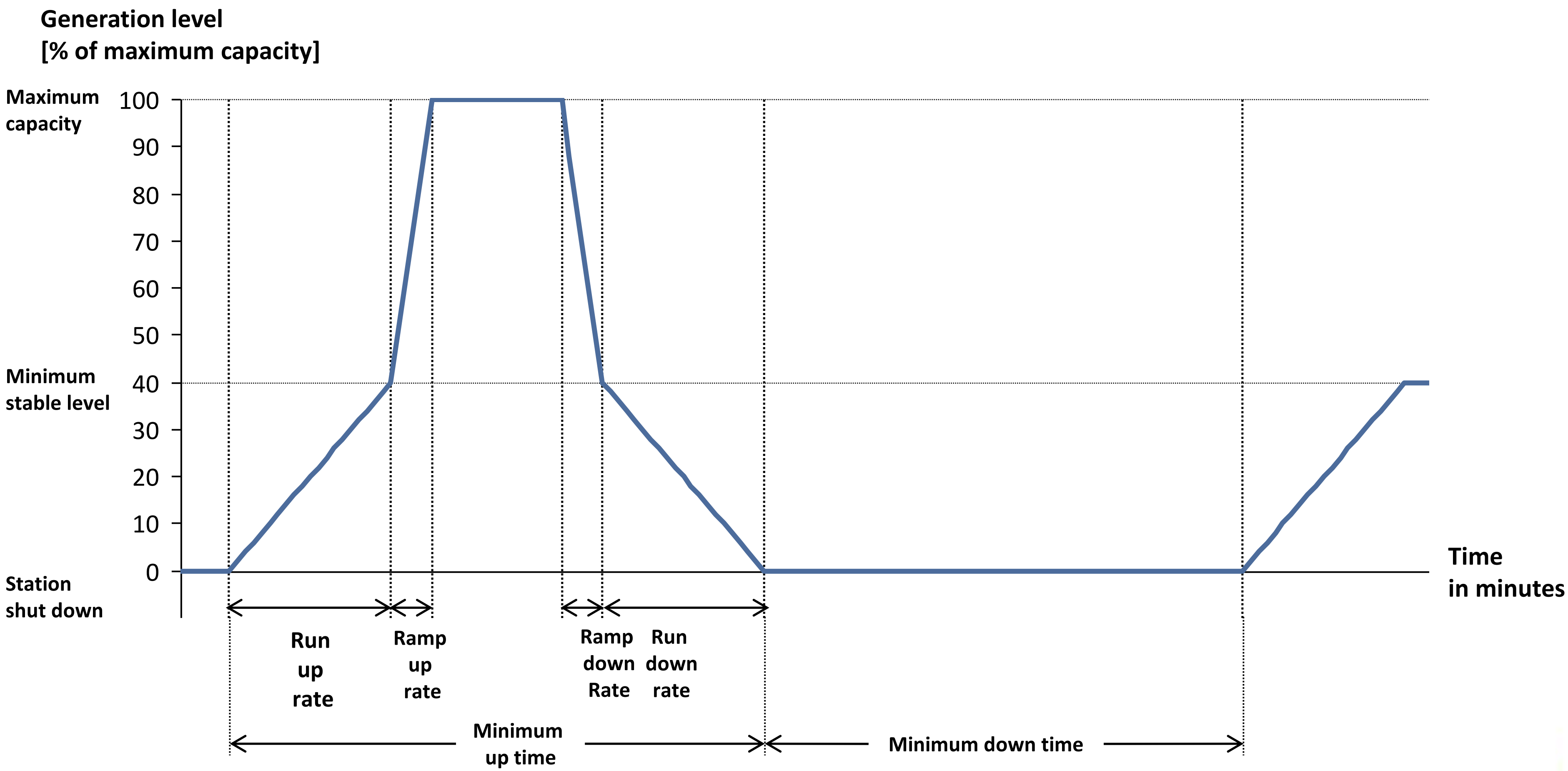
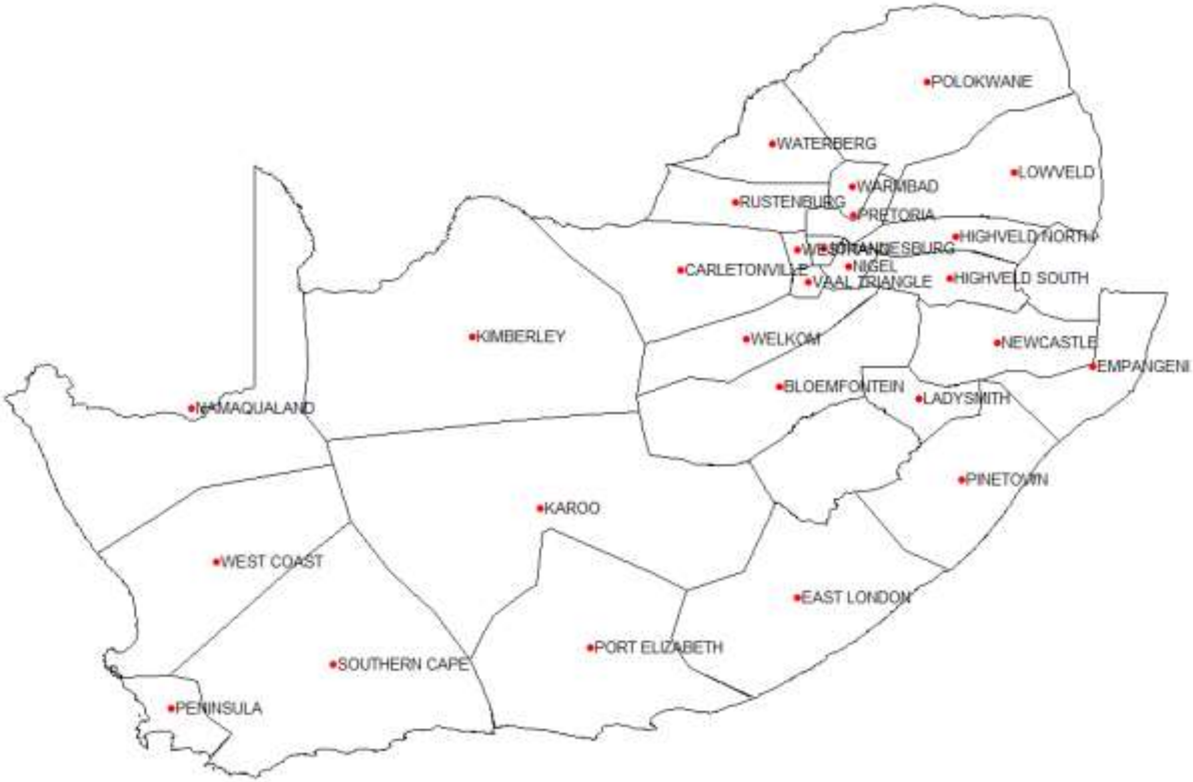
Supply technologies (technical characteristics)



All relevant generators were modelled with appropriate technical constraints as stylised above

Sources: CSIR Estimates; GE; Wartsila; EPRI

Supply technologies (technical characteristics)

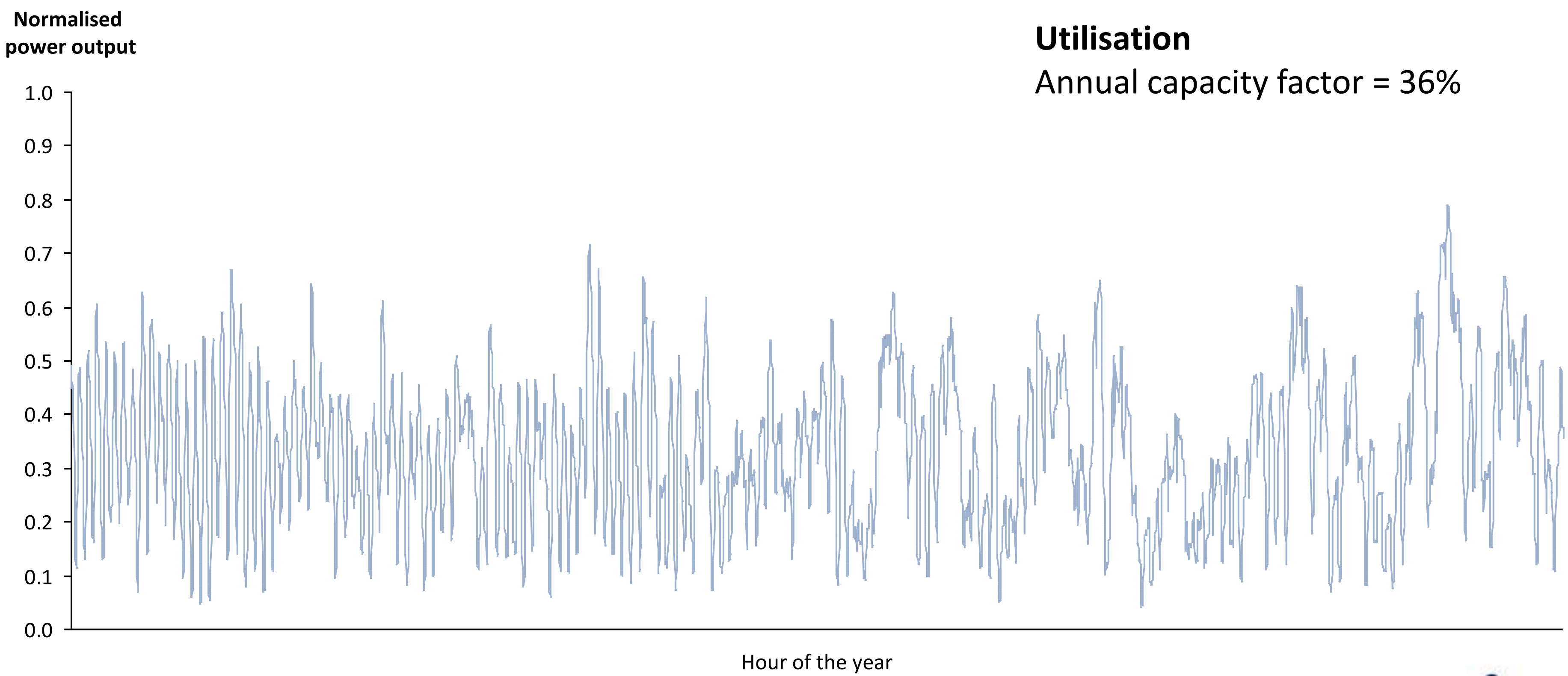


Similar to the IRP 2016 - wind and solar PV profiles for 27 supply areas (with exclusion masks) were used

NOTE: These profiles were then aggregated into one profile that defines expected new wind and solar PV profiles

Sources: CSIR Wind and solar Aggregation Study

Wind: supply profile assumptions

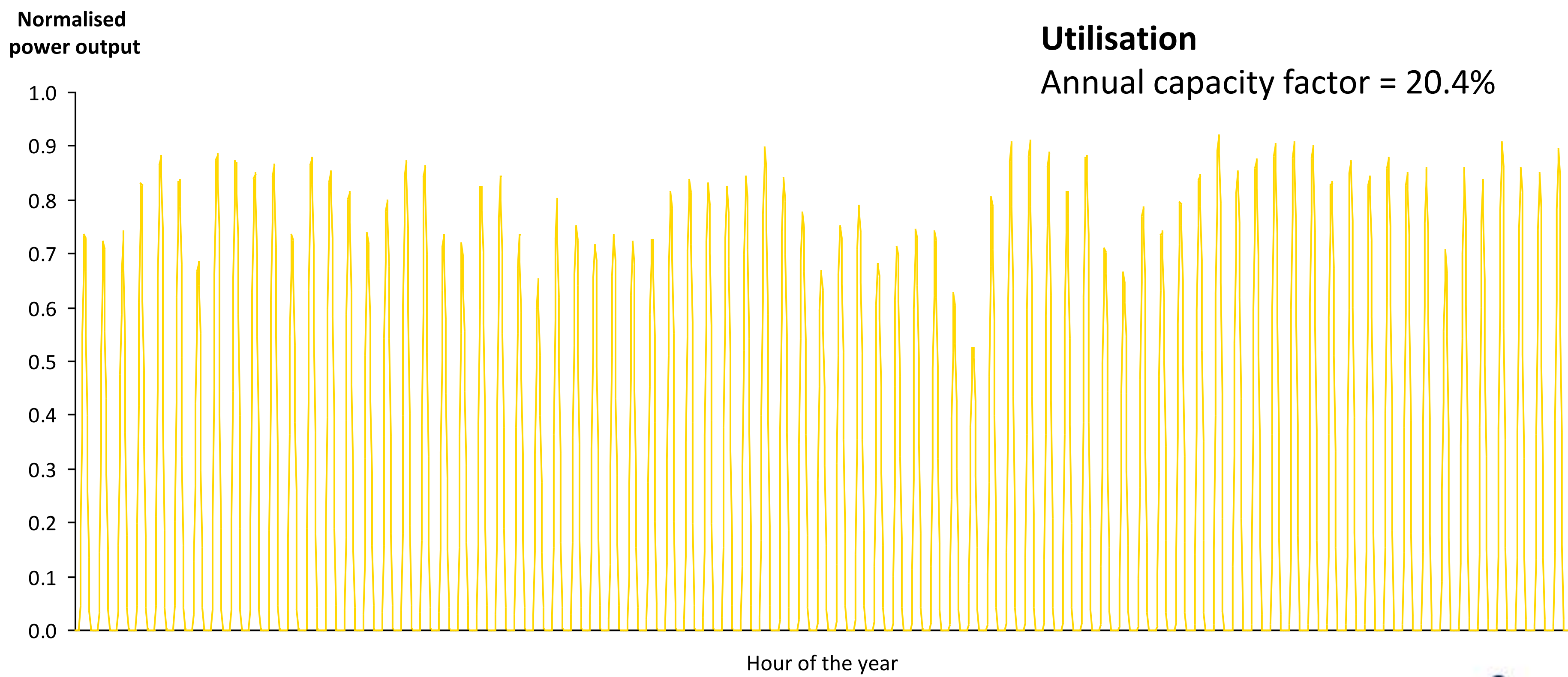


Utilisation

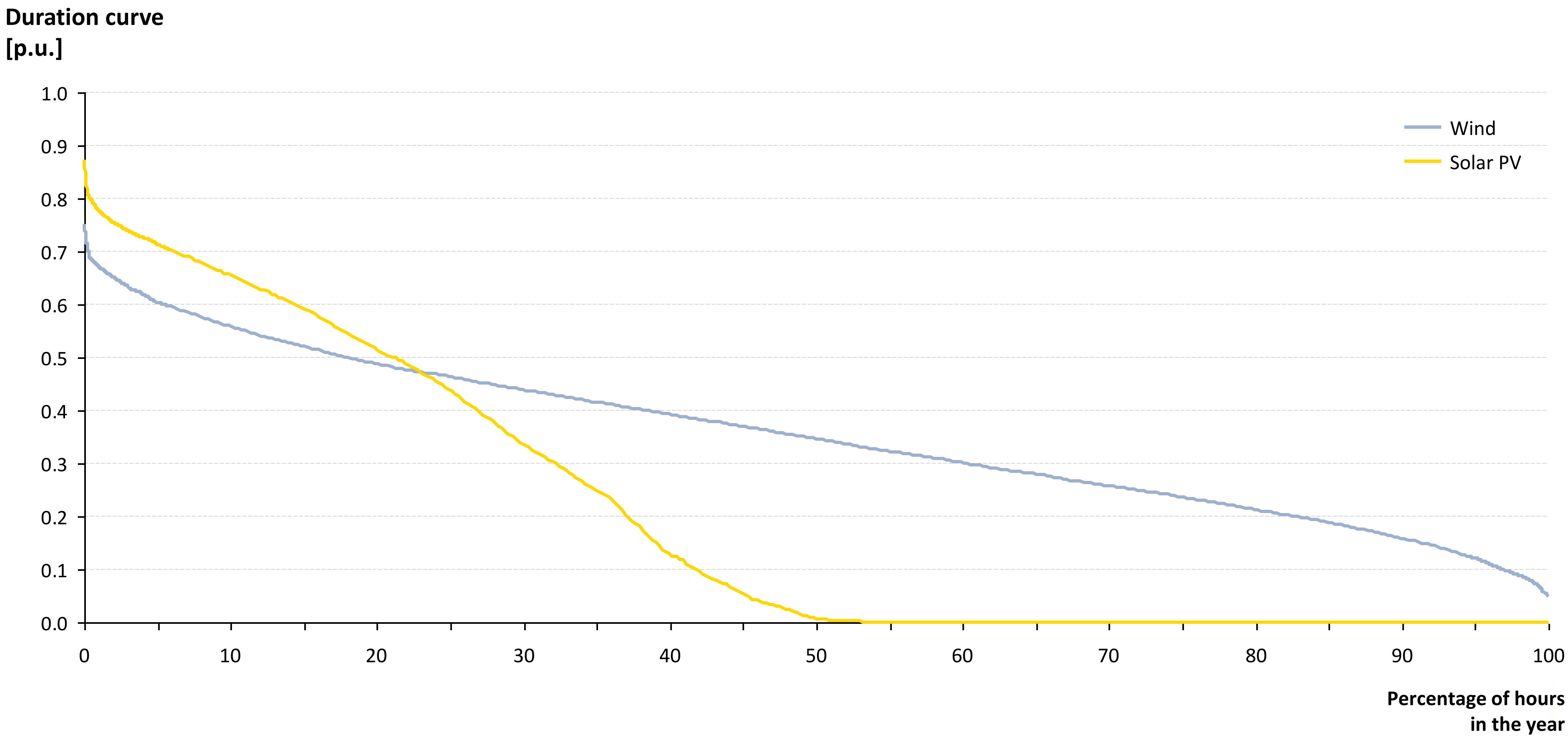
Annual capacity factor = 36%

Solar PV: supply profile assumptions

Utilisation
Annual capacity factor = 20.4%

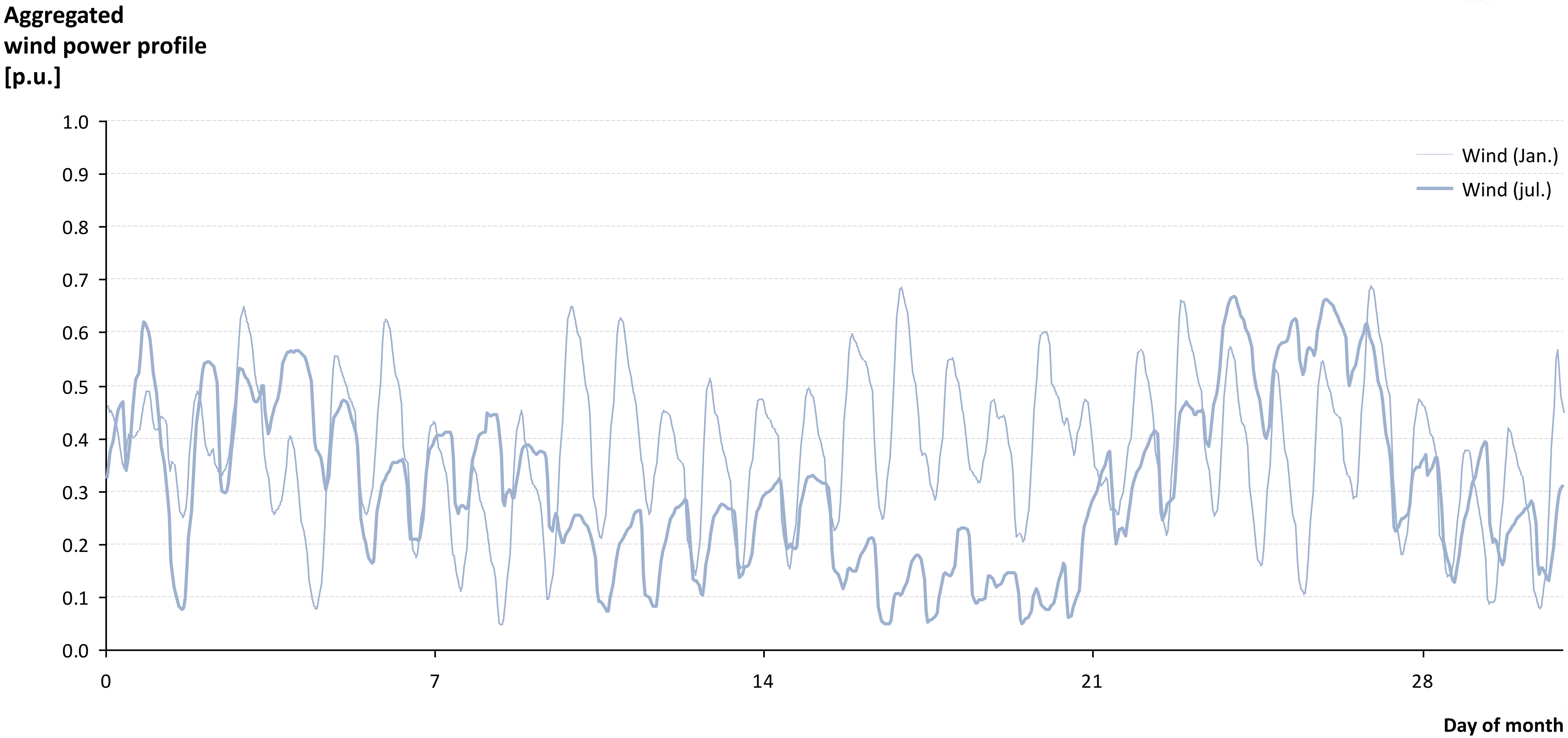


Supply technologies (technical characteristics)



Sources: CSIR Wind and solar Aggregation Study

Supply technologies (technical characteristics)



Sources: CSIR Wind and solar Aggregation Study

Supply technologies (technical characteristics)

Sources: CSIR Wind and solar Aggregation Study

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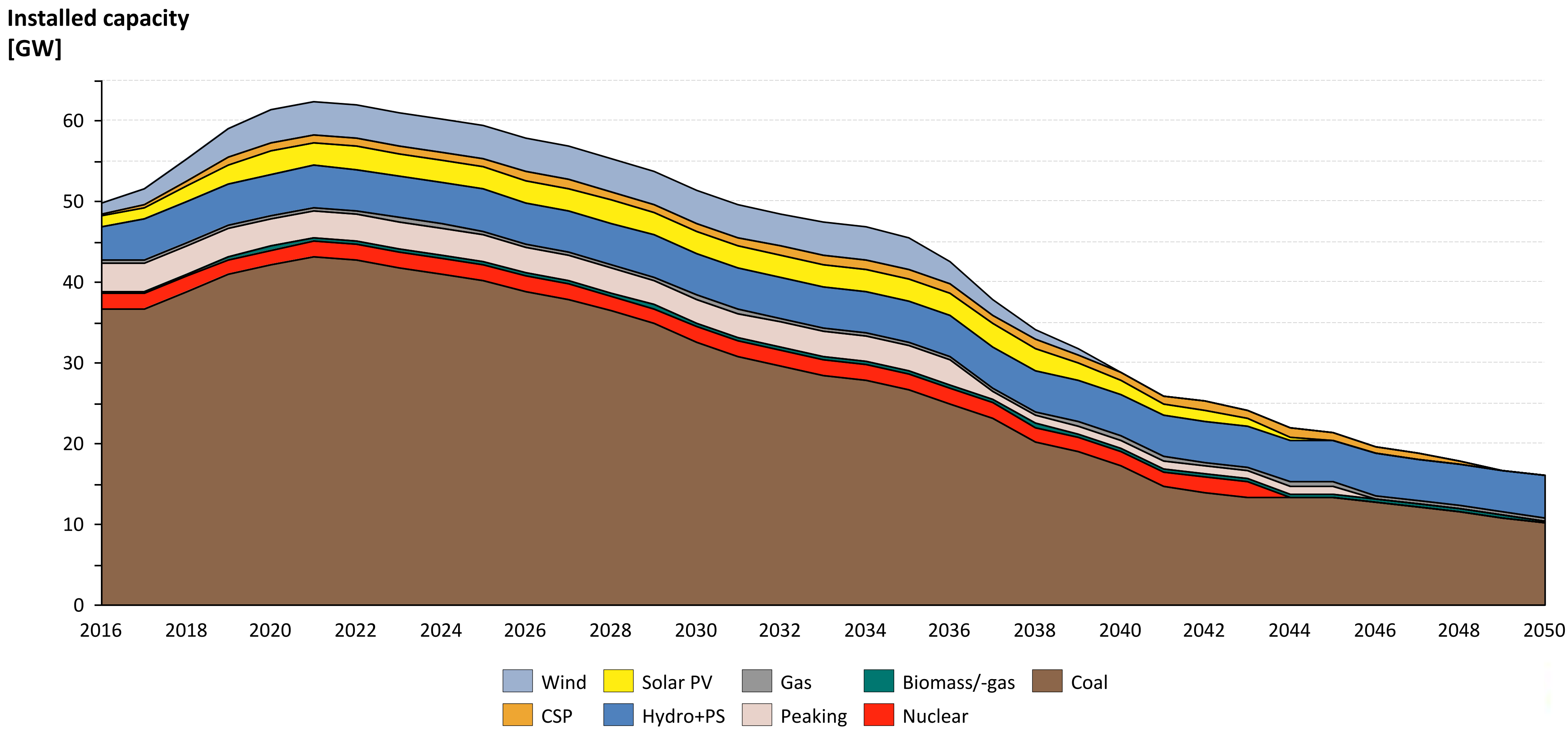
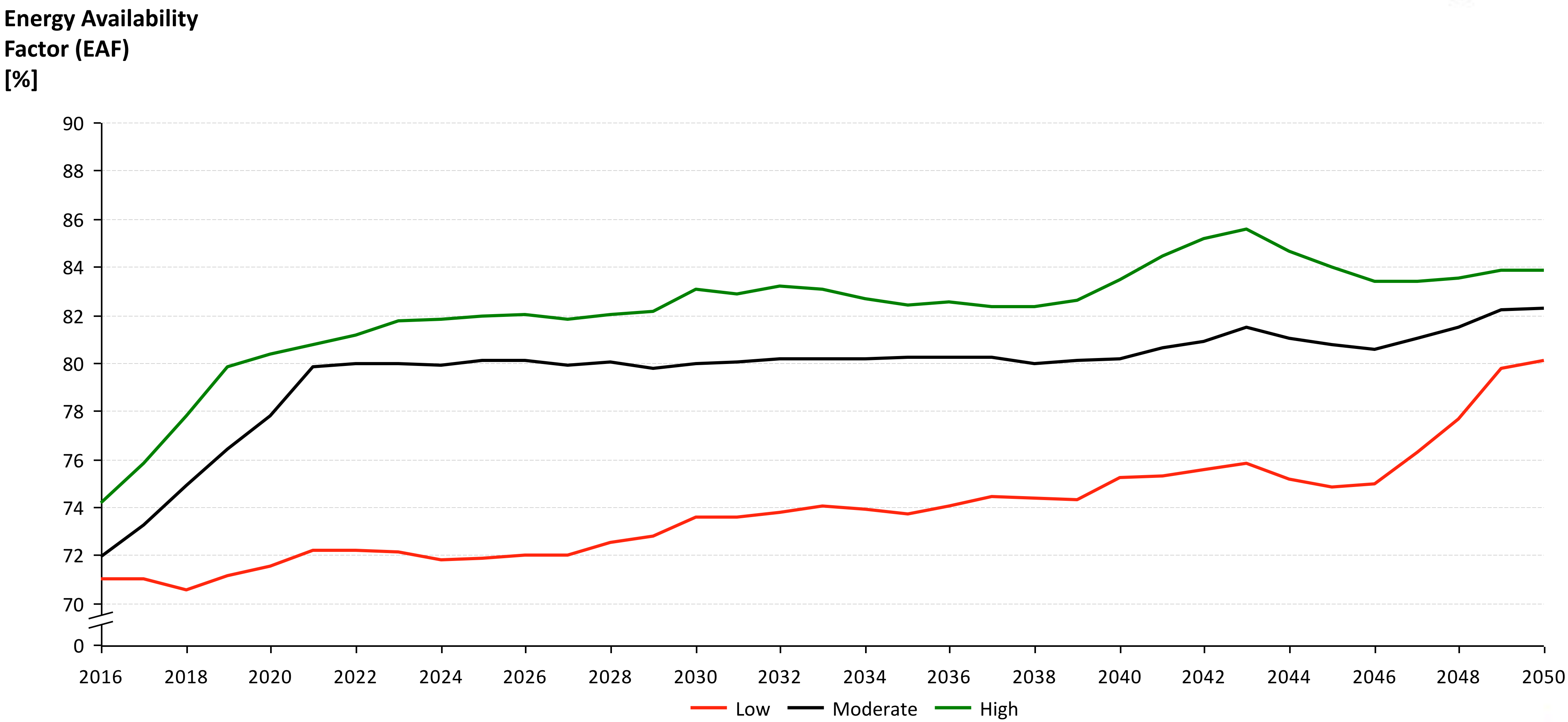
Decommissioning schedule (IRP 2016)



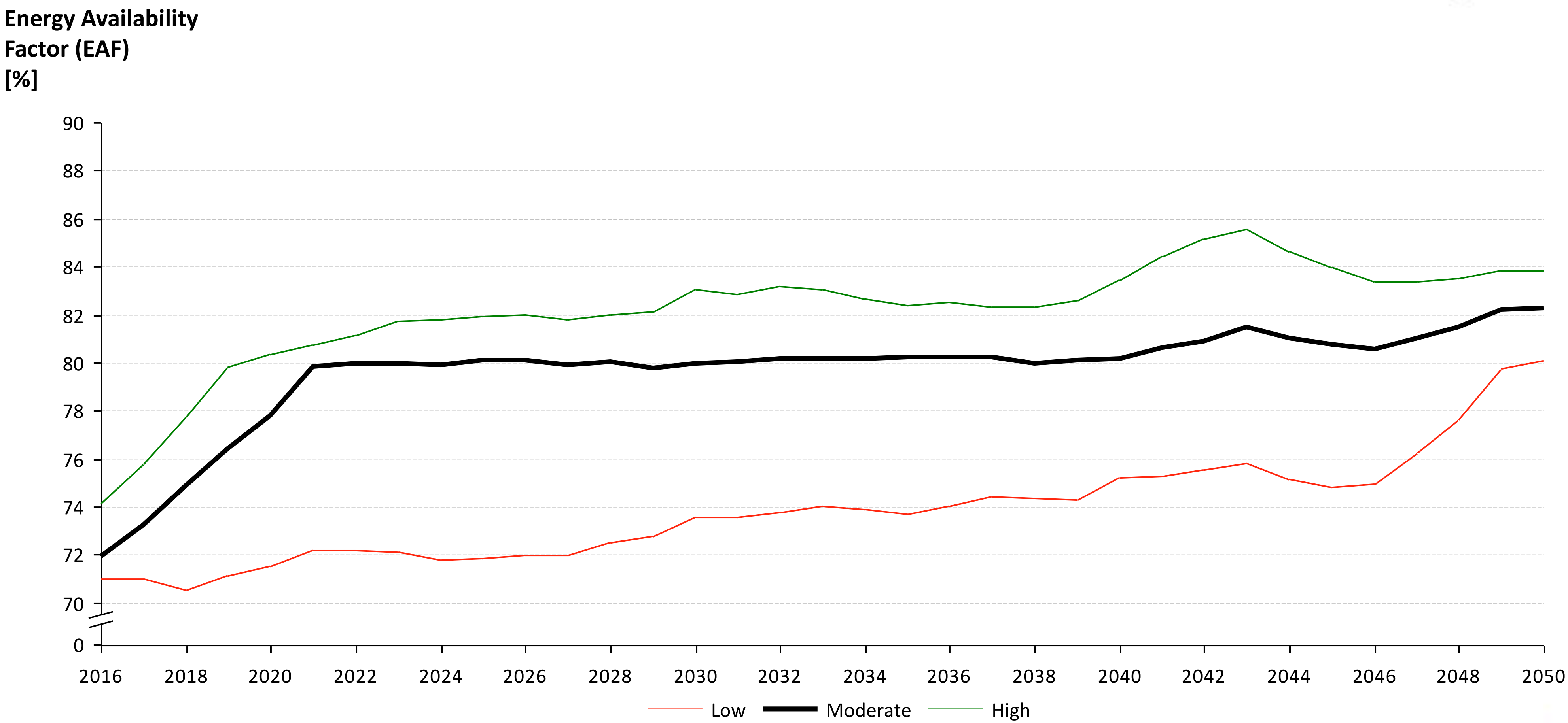
Sources: CSIR analysis

Three EAF scenarios defined in the IRP 2016



Sources: DoE Draft IRP 2016

In IRP 2016 and in Least Cost case the moderate EAF is used



Sources: DoE Draft IRP 2016

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Reserve requirements initially defined by Eskom Ancillary Services requirements and extrapolated forward after 2022

			2016-2019	2020-2022	2023-2024	2025-2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054
Instantaneous	**Summer**	**Peak**	500	500	500	500	500	500	500	500	500
		Off-peak	500	500	500	500	500	500	500	500	500
	Winter	**Peak**	500	500	500	500	500	500	500	500	500
		Off-peak	800	800	800	800	800	800	800	800	800
Regulating	**Summer**	**Peak**	550	550	570	640	720	800	890	990	1 010
		Off-peak	550	550	570	640	720	800	890	990	1 010
	Winter	**Peak**	600	600	630	720	820	920	1 020	1 120	1 140
		Off-peak	600	600	630	720	820	920	1 020	1 120	1 140
Ten-minute	**Summer**	**Peak**	1 150	1 150	1 130	2 260	2 180	2 100	2 010	1 910	1 890
		Off-peak	850	850	830	1 960	1 880	1 800	1 710	1 610	1 590
	Winter	**Peak**	1 100	1 100	1 070	2 180	2 080	1 980	1 880	1 780	1 760
		Off-peak	800	800	770	1 880	1 780	1 680	1 580	1 480	1 460
Operating	**Summer**	**Peak**	2 200	2 200	2 200	3 400	3 400	3 400	3 400	3 400	3 400
		Off-peak	2 200	2 200	2 200	3 400	3 400	3 400	3 400	3 400	3 400
	Winter	**Peak**	2 200	2 200	2 200	3 400	3 400	3 400	3 400	3 400	3 400
		Off-peak	2 200	2 200	2 200	3 400	3 400	3 400	3 400	3 400	3 400
Supplemental	**Summer/ Winter**	**Peak/ Off-peak**	1 300	1 300	1 300	1 300	1 300	1 300	1 300	1 300	1 300
Emergency			300	900	900	900	900	900	900	900	900
Total	**Summer/ Winter**	**Peak/ Off-peak**	3 800	4 400	4 400	5 600	5 600	5 600	5 600	5 600	5 600

MTST assumptions (Instantaneous, Regulating, Ten-minute and Operating rows)

LT assumptions (Total row)

Sources: Eskom; CSIR assumptions

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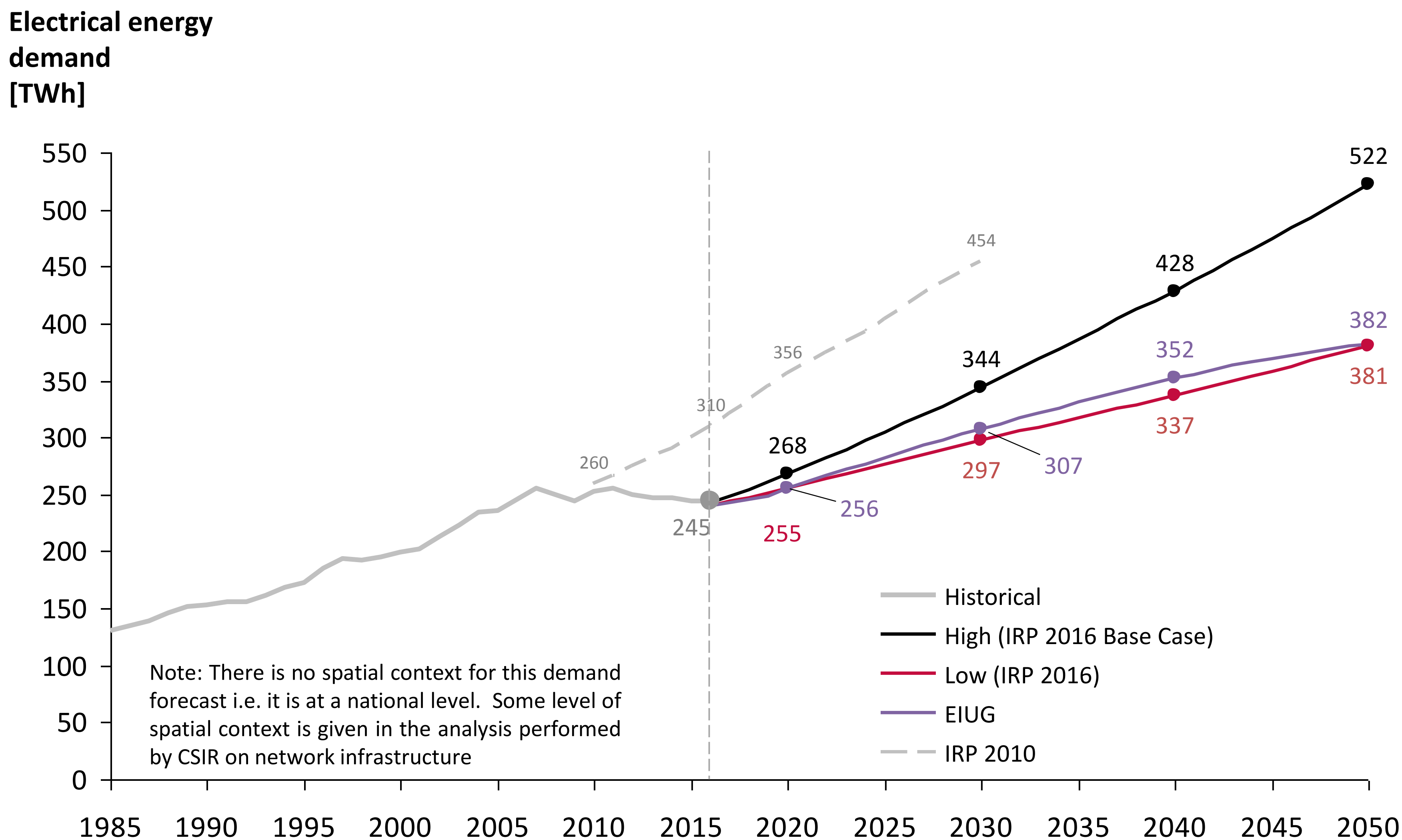
Demand forecasts



Sources: CSIR analysis

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Demand shaping as a demand side resource - domestic electric heaters (EWHs)

Many opportunities for demand shaping in a number of end-use sectors (domestic, commercial, industrial)

In the scenarios assessed by CSIR - the intention of including one particular demand shaping opportunity (domestic electric water heating) is to demonstrate the significant impact this can have on the power system.

Modelled as a resource with intra-day controllability (can be dispatched as needed on any given day) based on power system needs

Key input parameters to estimate potential demand shaping via EWH:

- South African population (to 2050)
- Number of households (current)
- Number of persons per household (future)
- EWHs (current)
- EWHs per household (future)
- Adoption rate of demand shaping via EWHs (future)
- Calibration for power (MW) and energy (TWh) used for electric water heating (existing)
- Movement to EWH technologies i.e. heat pumps vs electric geysers (future)

CSIR our future through science

Demand shaping can provide ~24 GW/3 GW (demand increase/decrease) with ~70 GWh/d of dispatchable energy by 2050

Property	Unit	2016-2019	2020	2030	2040	2050
Population	[mln]	55.7 - 57.5	58.0	61.7	64.9	68.2
Number of HHs	[mln]	16.9 - 18.1	18.5	22.4	26.0	27.3
Residents per HH	[ppl/HH]	3.29 - 3.17	3.13	2.75	2.50	2.50
HHs with EWH	[%]	28 - 33	34	50	75	100
HHs with EWH	[mln]	4.7 - 5.9	6.3	11.2	19.5	27.3
Demand shaping adoption	[%]	-	2	25	100	100
Demand shaping	[TWh/a]	-	0.4	5.4	28.3	26.4
Demand shaping	[GWh/d]	-	1.1	14.9	77.4	72.3
Demand shaping (demand increase)	[MW]	-	371	4 991	25 970	24 265
Demand shaping (demand decrease)	[MW]	-	46	620	3 226	3 015

Sources: CSIR estimates; StatsSA; AMPS survey; Stastista; Eskom; Draft IRP 2016

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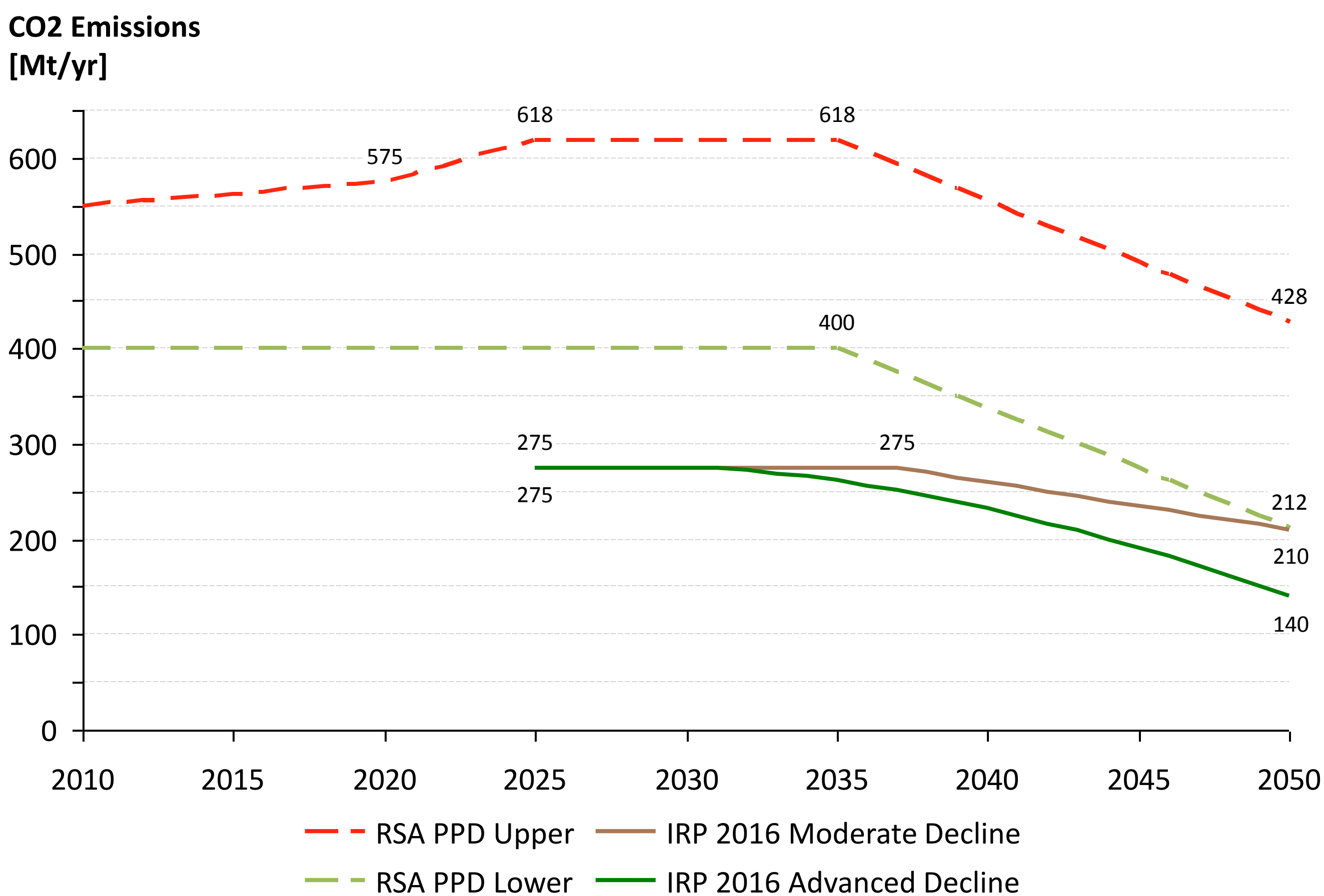
CO_2 emissions constrained by RSA's Peak-Plateau-Decline objective

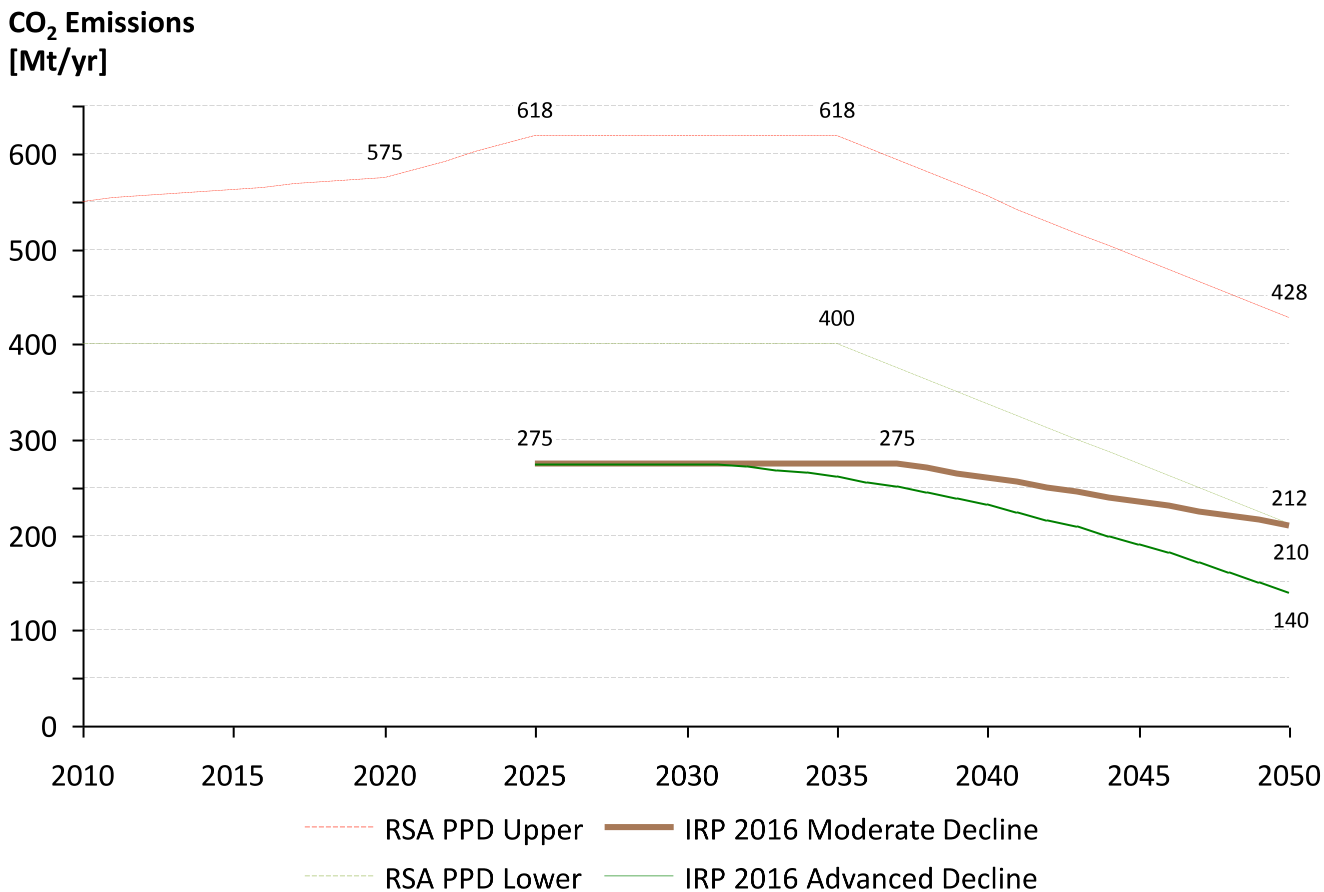
PPD that constrains CO_2 emission for the whole country and from the electricity sector



PPD = Peak Plateau Decline

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

Moderate Decline applied in IRP 2016 and in Least Cost



PPD = Peak Plateau Decline

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

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Localised job creation per technology is a function of capital (build-out) as well as operations (utilisation) for each technology

A study was commissioned by the DoE and undertaken by McKinsey & Company as part of the IEP:

- "Potential for Job Creation and Localisation of the electricity generating technologies"

– IEP 2016 Annexure B: macroeconomic parameters

As part of this work, job creation for each major technology was determined on the following basis:

- Direct jobs: For "capex" (job-years/GW) and "opex"(annual jobs/TWh)
- Supplier jobs: For "capex" (job-years/GW) and "opex"(annual jobs/TWh)
- Multipliers for indirect and induced jobs

These jobs were further classified into 5 categories (for localisation potential).

- The CSIR has assumed that all categories constitute localised jobs except the "Global demand required" category

The CSIR has also only included direct and supplier jobs. The analysis performed by CSIR calculates the number of jobs in each scenario as a result of the capacity build-out (MW) and energy utilisation (TWh)

Sources: DoE IEP 2016 Annexure B: Macroeconomic parameters

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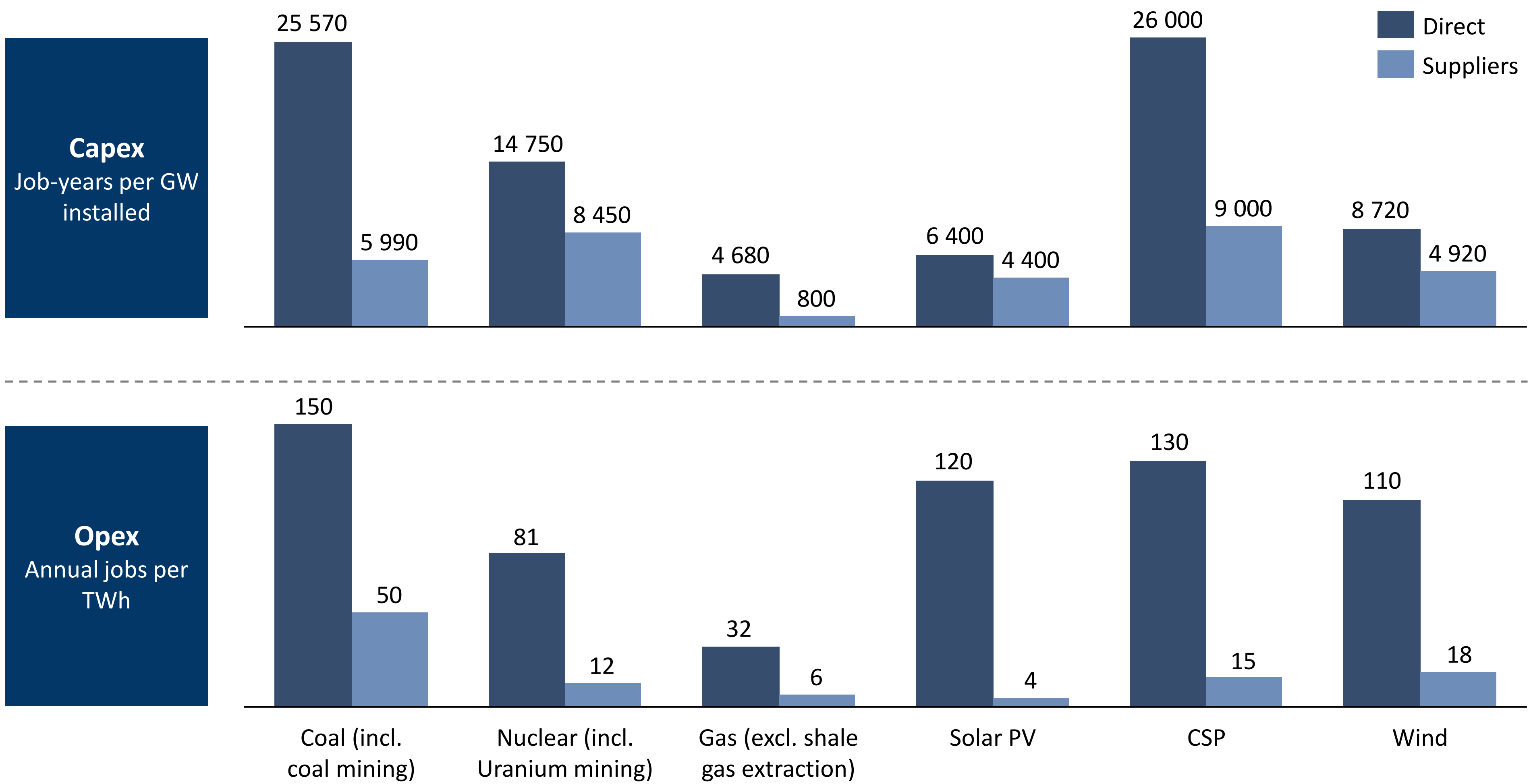
Localised job creation per technology is a function of capital (build-out) as well as operations (utilisation) for each technology



Note: It seems like the McKinsey study (appendix of IEP) under-estimates direct/supply job numbers in the coal industry. Thus, CSIR have assumed more jobs in the coal industry than in the Mickinsey study.

Sources: DoE IEP 2016 Annexure B: Macroeconomic parameters

LONG-TERM EXPANSION PLAN RESULTS (SCENARIOS)

our future through science

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Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost (“Expected” costs)

Scenario comparison and summary

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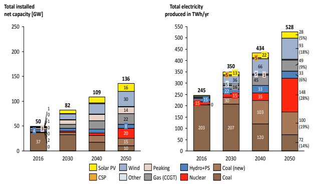
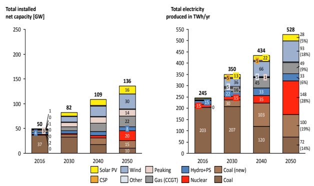
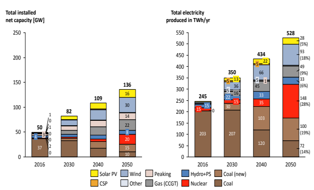
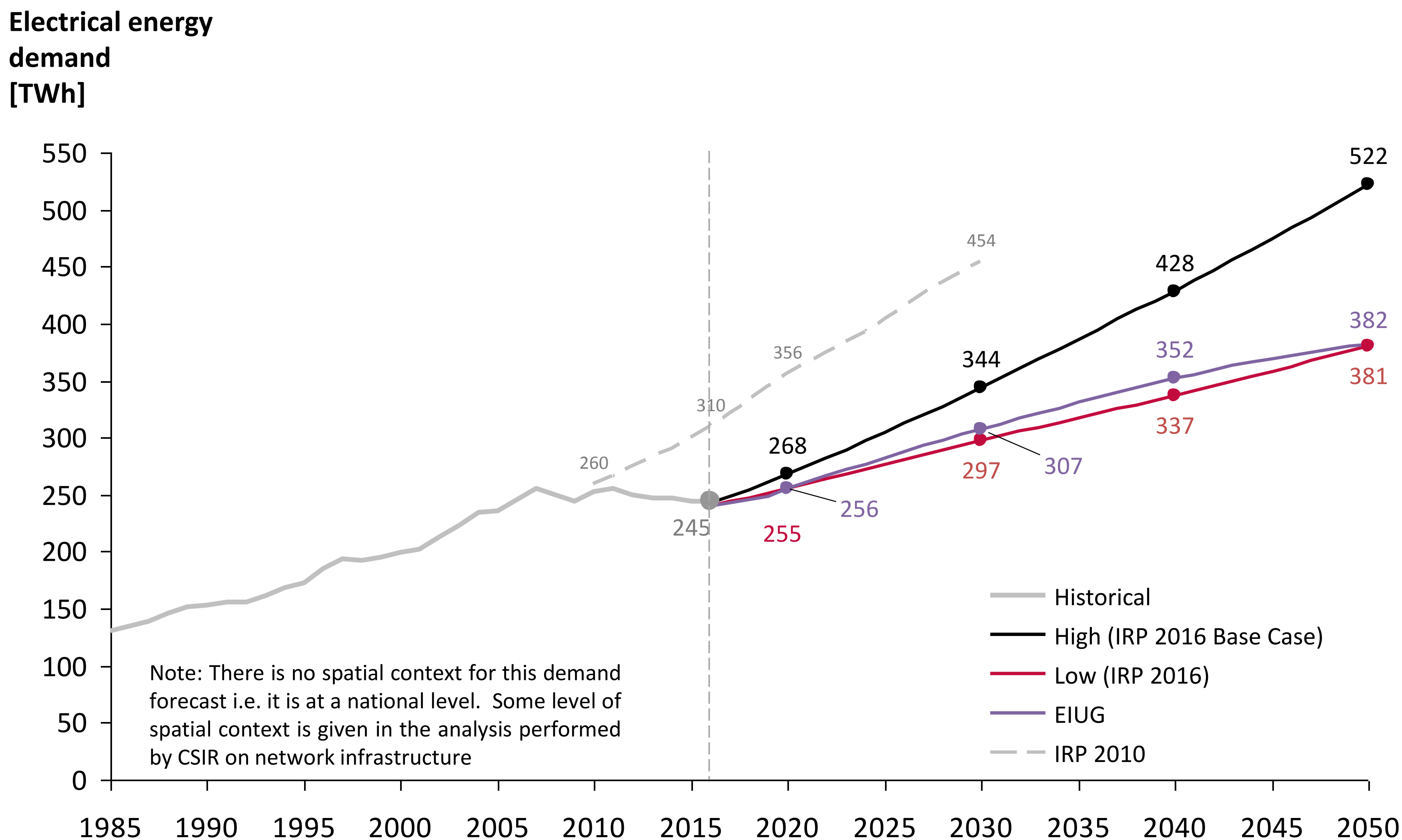
Overview of scenarios

Scenario		Source	Difference to Draft IRP 2016 Base Case
Draft IRP 2016 Base Case		**Department of Energy** Draft IRP 2016 as of November 2016	**N/A**
Draft IRP 2016 Carbon Budget		**Department of Energy** Draft IRP 2016 as of November 2016	**Tighter carbon reduction targets**
Draft IRP 2016 "Unconstrained Base Case"		**Department of Energy** Scenario run by DoE/Eskom as per request of the Ministerial Advisory Council on Energy (MACE)	**No constraints on new build technologies**
Least Cost		**CSIR**	**No constraints on new build technologies** **RE costing aligned with latest REIPPPP** **Demand shaping from residential EWHs**

Overview of scenarios

Scenario		Source	Difference to Draft IRP 2016 Base Case
Decarbonised		**CSIR**	**Cost assumptions of Least-cost scenario** **No constraints on new build technologies** **95% reduction of CO_2 by 2050)** **Early coal fleet decommissioning** **Medupi and coal IPPs decommission 2045** **No Kusile**
Least cost ("Expected" costs)		**CSIR**	**No constraints on any new build technologies** **More realistic learning rates for solar PV and wind i.e. more aggressive** **Learning rates for storage** **Electric vehicle uptake**

Demand forecasts



Sources: IRP 2016; EIUG; CSIR analysis

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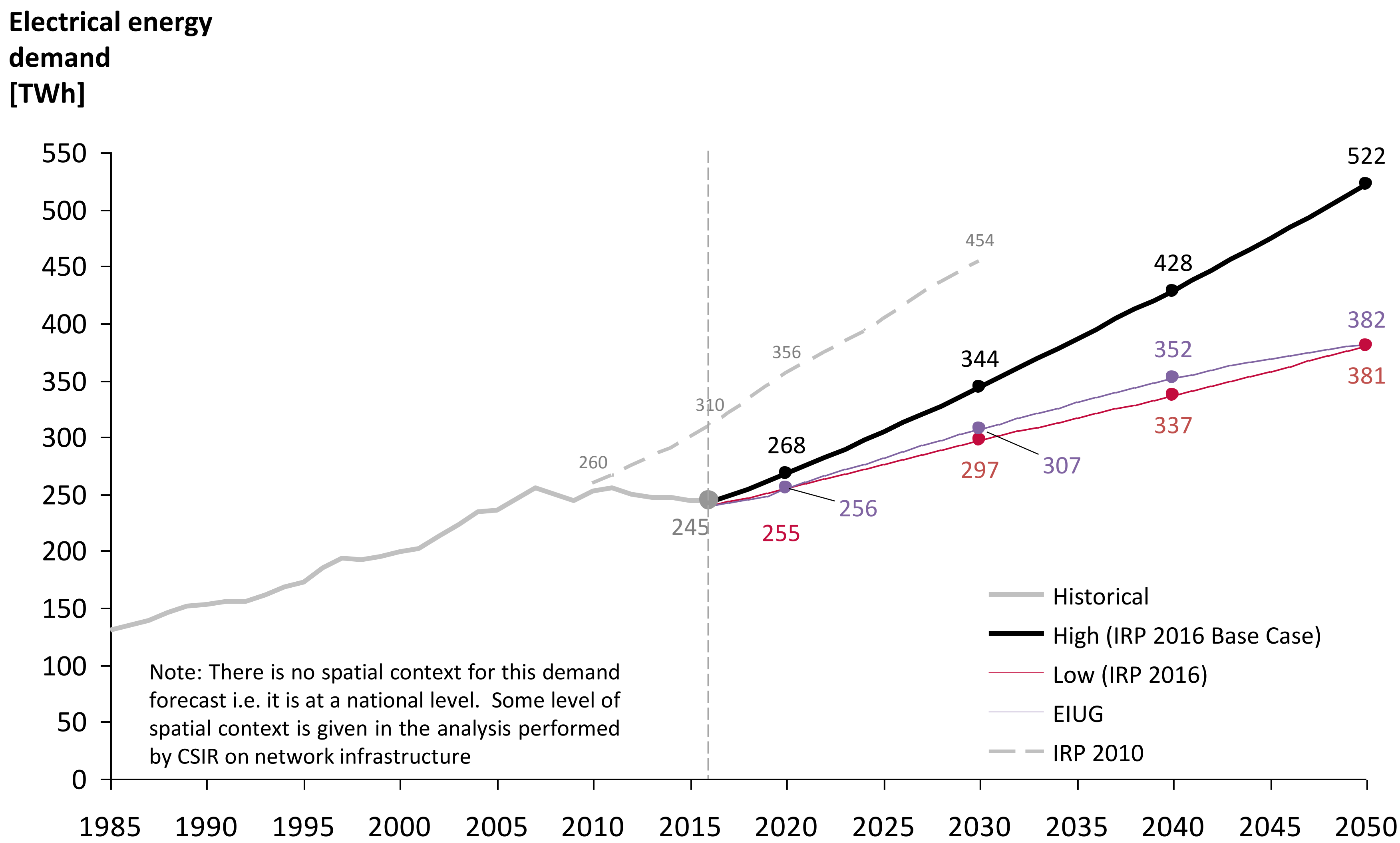
Same demand forecast as per IRP 2016 Base Case applied



Sources: CSIR analysis

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Draft IRP 2016: Carbon Budget

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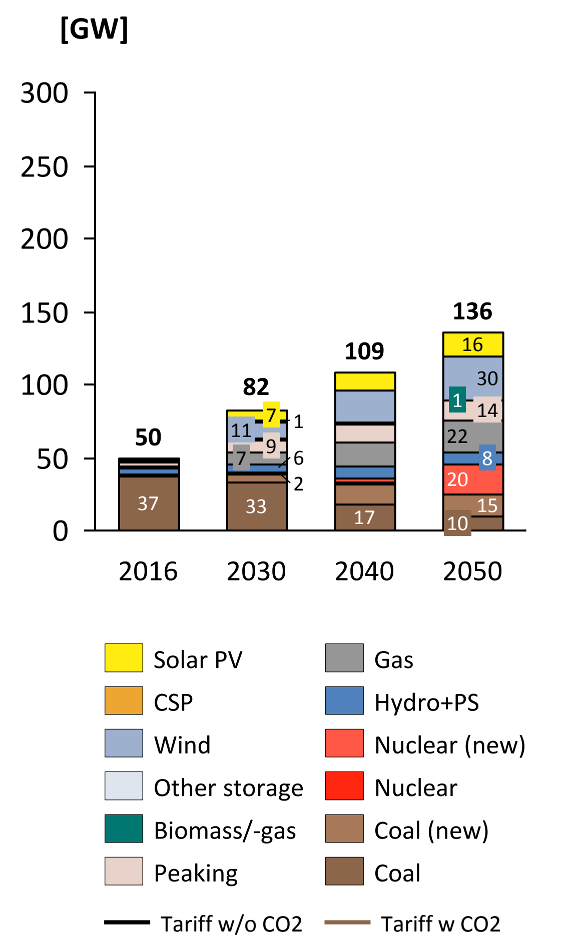
Scenario: Draft IRP 2016 Base Case

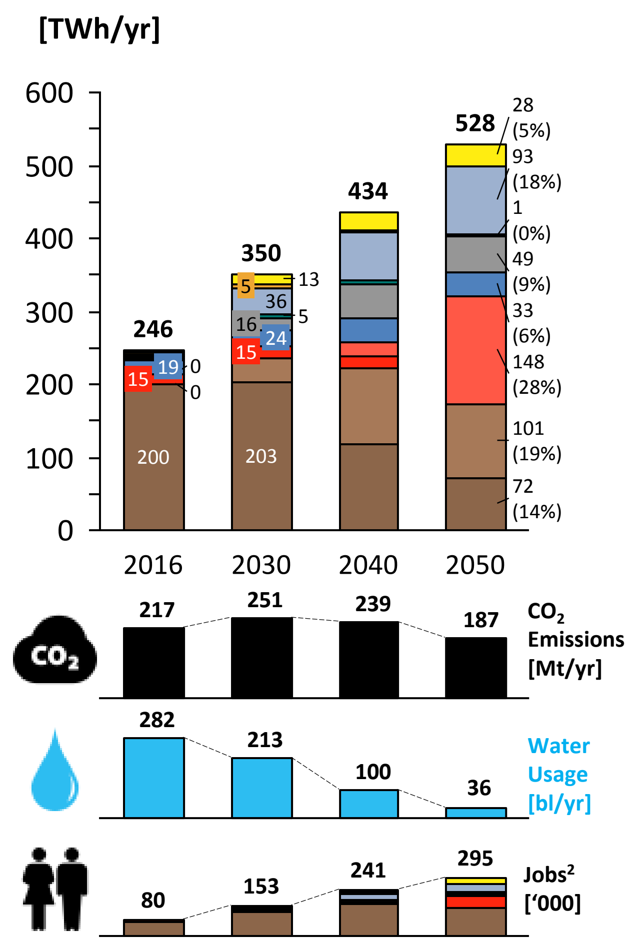
1/3 coal, 1/3 nuclear, 1/3 solar PV/wind/gas, ≈R690 bn/yr cost in 2050

As per Draft IRP 2016

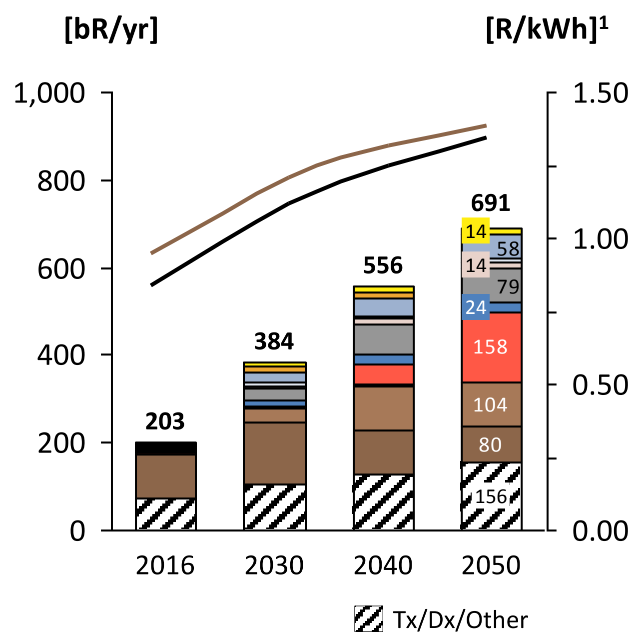
Installed Capacity



Energy Produced



System cost and average tariff

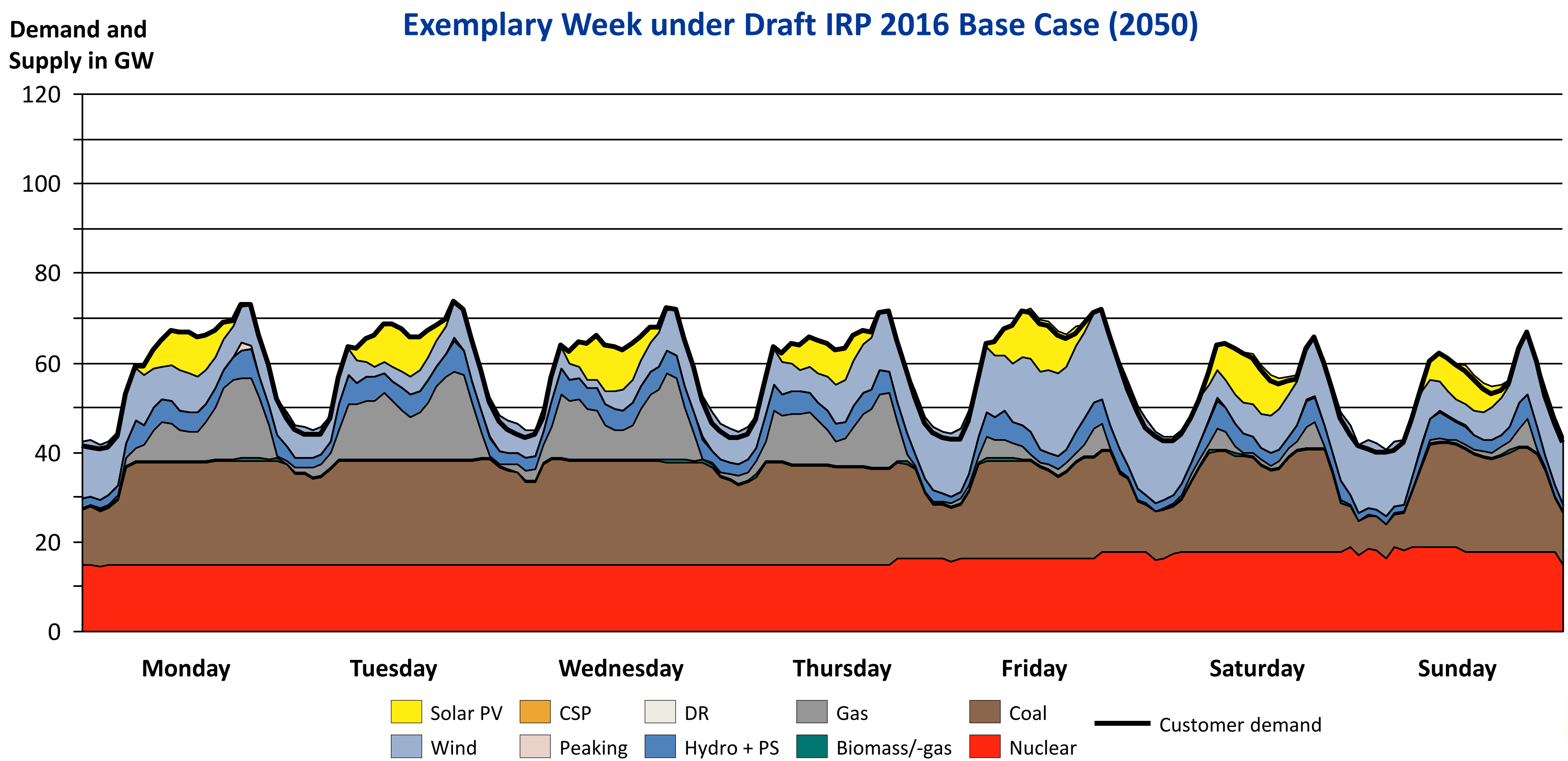


Difference to Draft IRP 2016 Base Case

- N/A

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; [2] Direct and supplier jobs only; Sources: CSIR; Eskom; DoE

Draft IRP 2016 Base Case: Nuclear and coal dominate the supply mix in 2050



Sources: CSIR analysis, based on DoE's Draft IRP 2016

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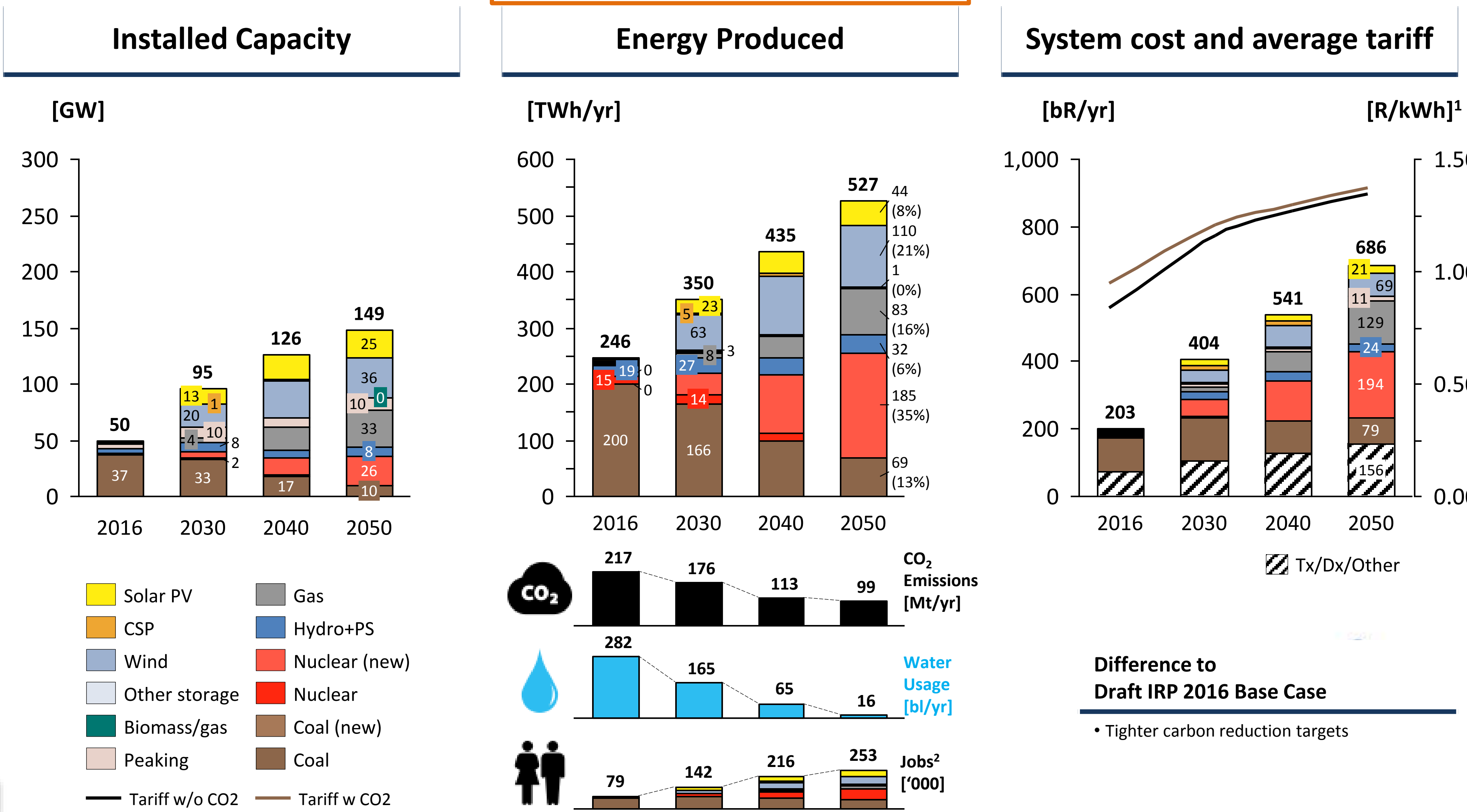
Scenario: Draft IRP 2016 Carbon Budget

Nuclear, renewables and gas replace coal, ≈R690-billion/yr cost in 2050

As per Draft IRP 2016



Difference to Draft IRP 2016 Base Case

- Tighter carbon reduction targets

¹ Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; ² Direct and supplier jobs only; Sources: CSIR; Eskom; DoE

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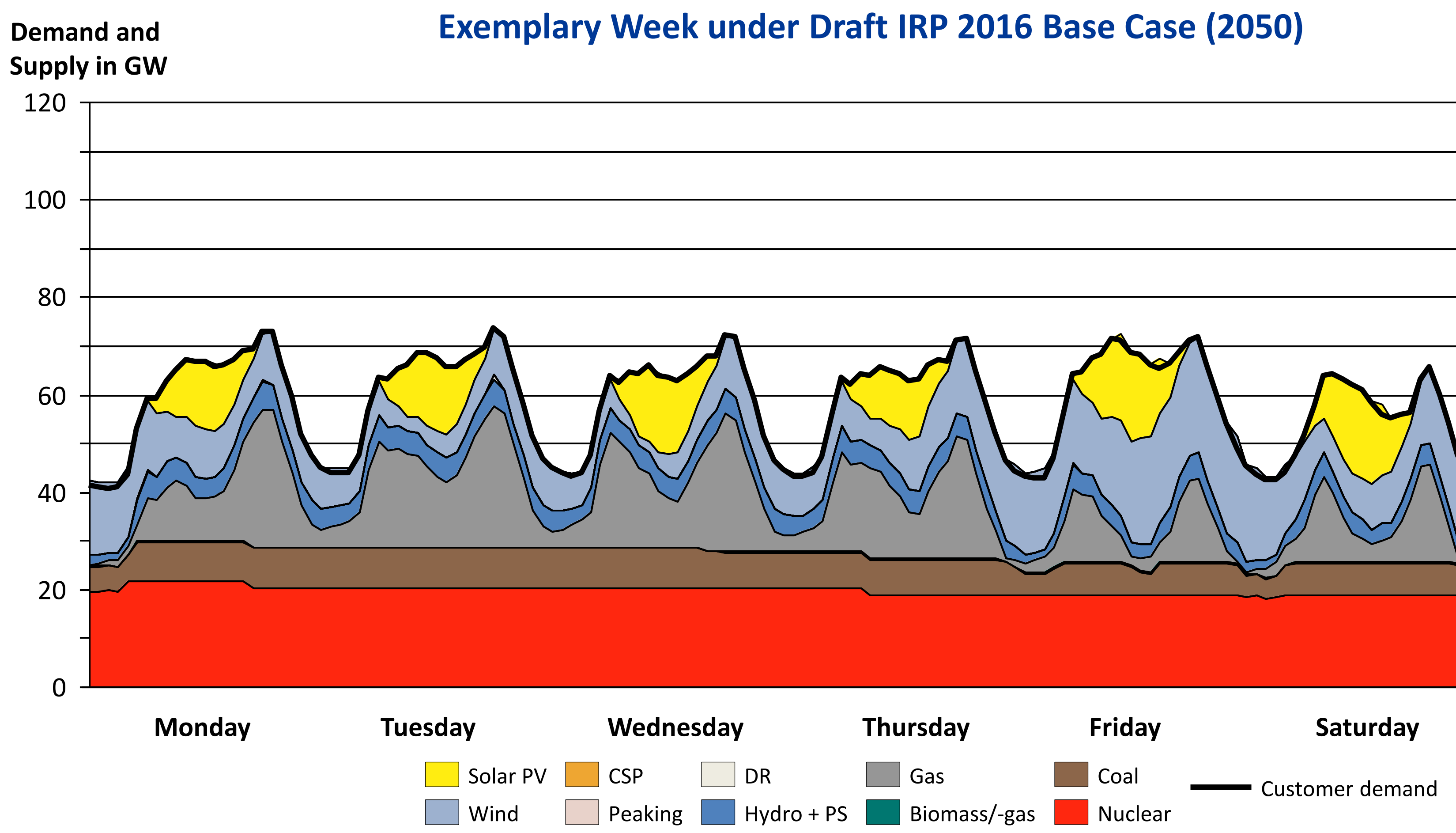
Draft IRP 2016 Carbon Budget: Nuclear dominates with additional RE means additional flexibility required from gas



Sources: CSIR analysis, based on DoE's Draft IRP 2016

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Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

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Least-cost ("Expected" costs)

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Draft IRP 2016 limits the annual build-out rates for solar PV and wind

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 techno-economical reason/justification is provided for these limits. No explanation given why the limits are constant until 2050 while the power system grows

Year	System Peak Load in MW (as per Draft IRP)	New-build limit Solar PV in MW/yr (as per Draft IRP)	Relative new-build limit Solar PV (derived from IRP)	New-build limit Wind in MW/yr (as per Draft IRP)	Relative new-build limit Wind (derived from IRP)
2020	44 916	1 000	2.2%	1 800	4.0%
2025	51 015	1 000	2.0%	1 800	3.5%
2030	57 274	1 000	1.7%	1 800	3.1%
2035	64 169	1 000	1.6%	1 800	2.8%
2040	70 777	1 000	1.4%	1 800	2.5%
2045	78 263	1 000	1.3%	1 800	2.3%
2050	85 804	1 000	1.2%	1 800	2.1%

Note: Relative new-build limit = New-build limit / system peak load

Sources: IRP 2016 Draft; CSIR analysis

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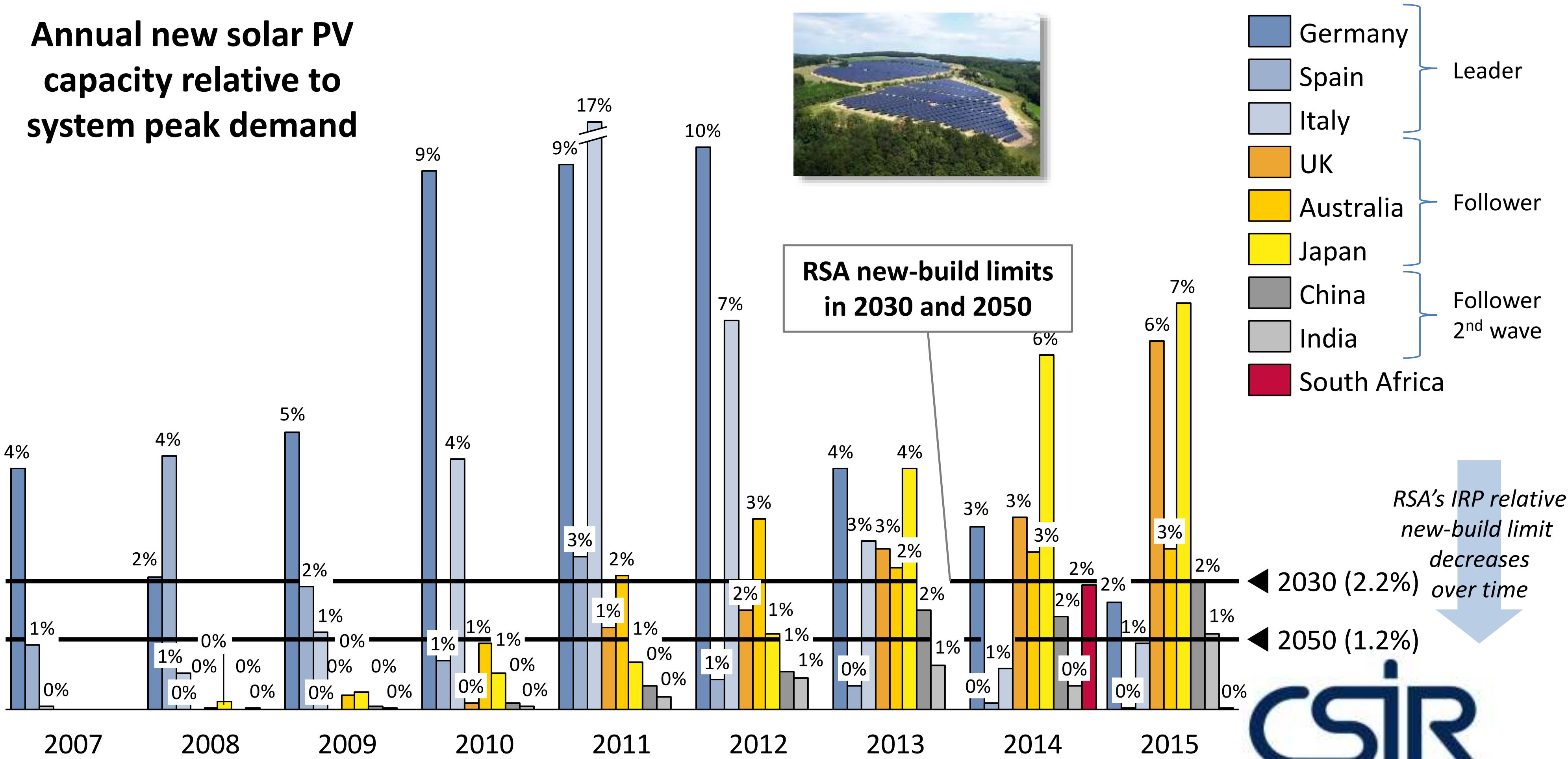
Today: Both leading and follower countries are installing more new solar PV capacity per year than South Africa's IRP limits for 2030/2050

Annual new solar PV capacity relative to system peak demand



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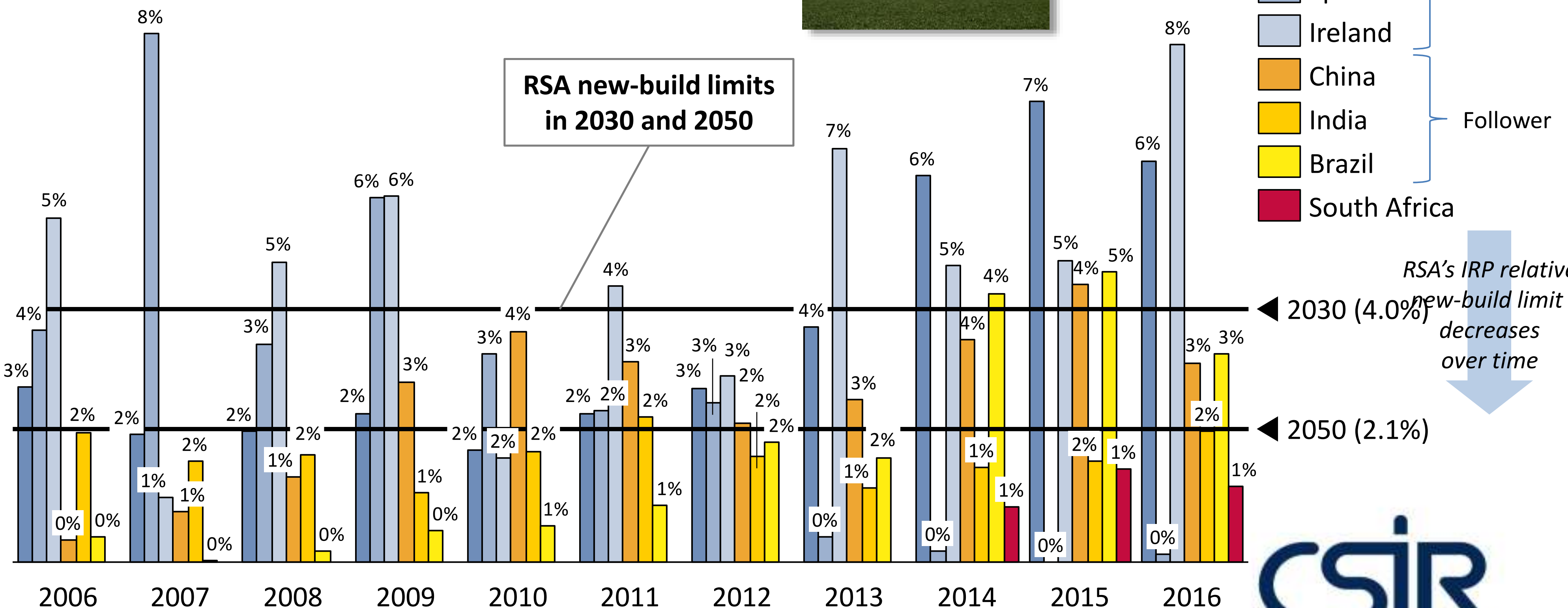
Sources: SolarPowerEurope; CIGRE; websites of System Operators; IRP 2016 Draft; CSIR analysis

Today: Both leading and follower countries are installing more new wind capacity per year than South Africa's IRP limits for 2030/2050

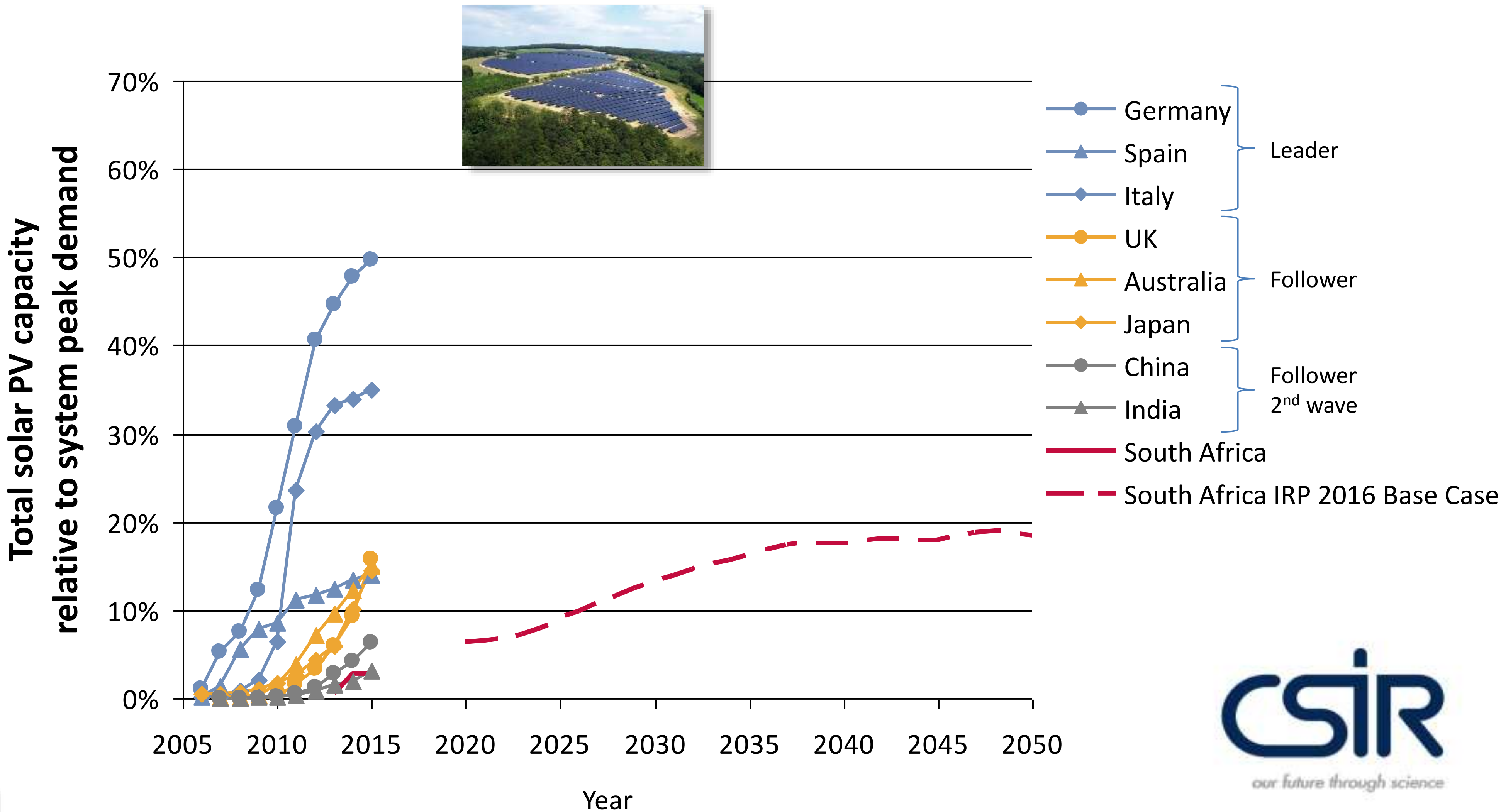
Annual new wind capacity relative to system peak demand



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

Submitted to DoE on 31 March 2017

Solar PV penetration in leading countries today is 2.5 times that of South Africa’s Draft IRP 2016 Base Case for the year 2050



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

Total wind capacity relative to system peak demand

Total wind capacity relative to system peak demand

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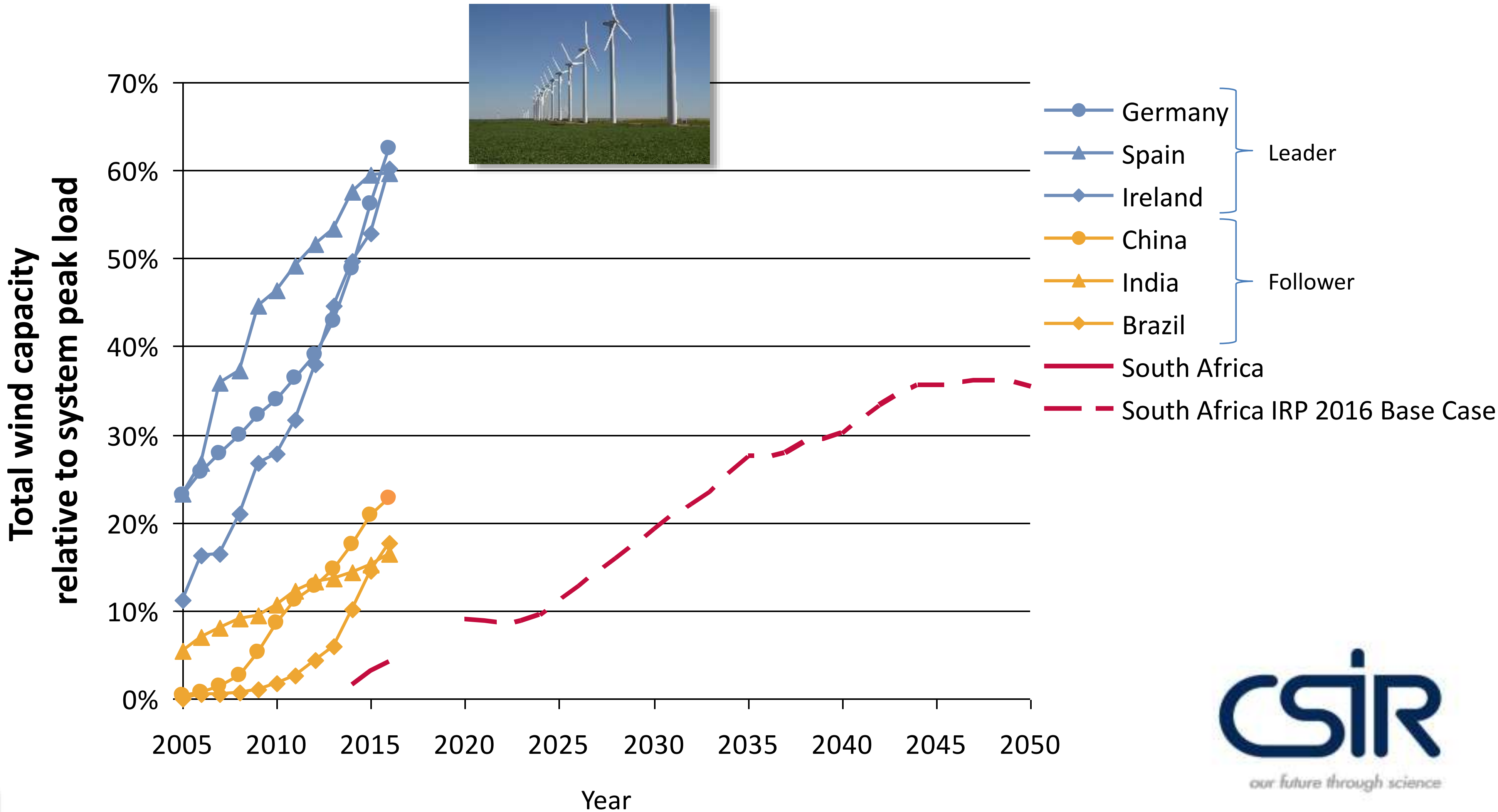
Wind penetration in leading countries today is 1.7-1.8 times that of South Africa's Draft IRP 2016 Base Case for the year 2050



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

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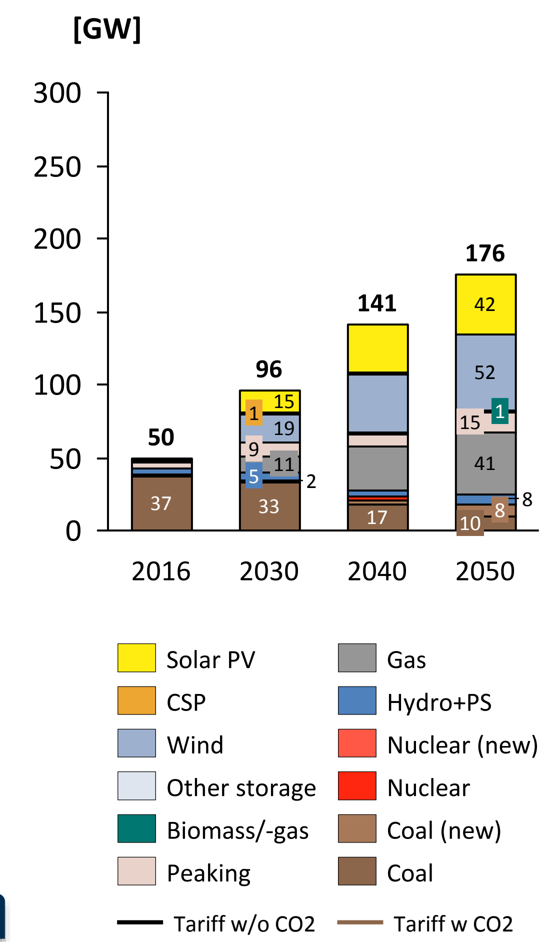
Scenario: Unconstrained Base Case

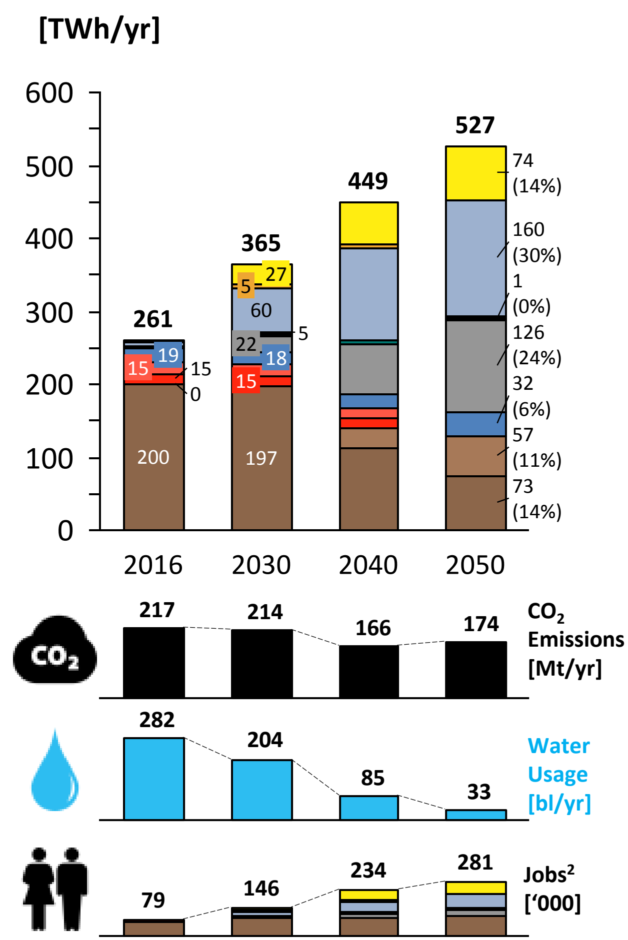
No new nuclear, some new coal, PV/wind/gas – R660 bn/yr by 2050

As per DoE

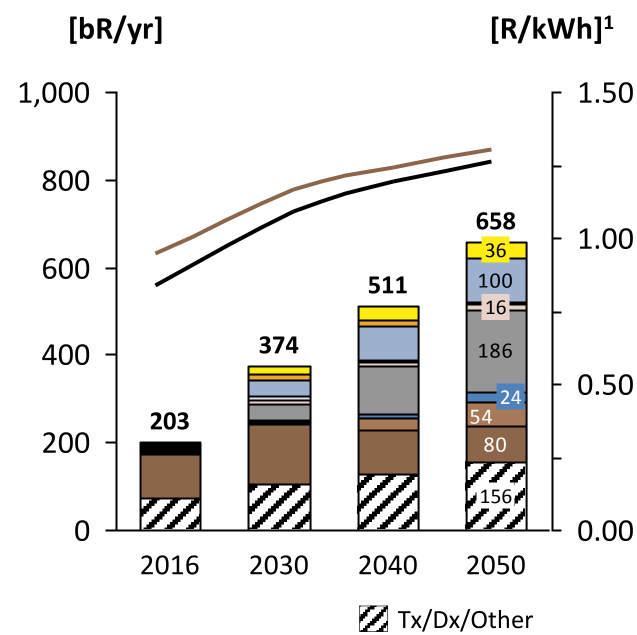
Installed Capacity



Energy Produced



System cost and average tariff

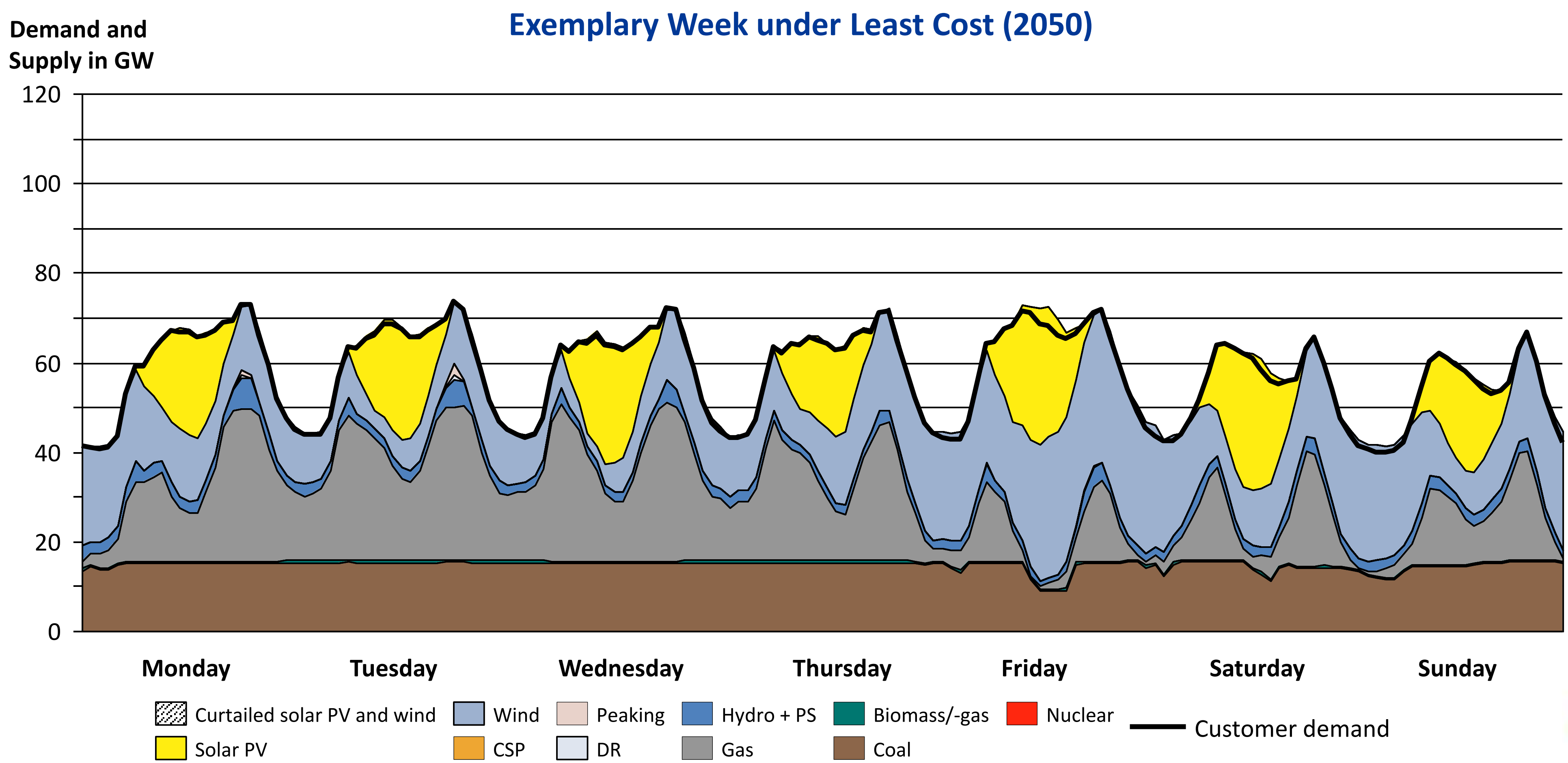


Difference to Draft IRP 2016 Base Case

- No build-out constraints on any technology

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; [2] Direct and supplier jobs only; Sources: CSIR; Eskom

Unconstrained Base Case: Solar PV, wind and gas with some new coal in the supply mix in 2050



Sources: CSIR analysis

Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost ("Expected" costs)

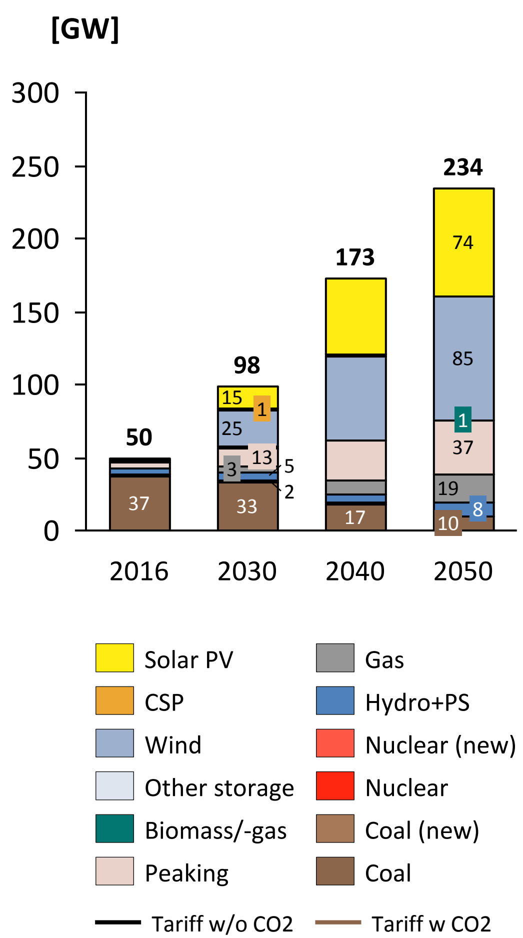
Scenario comparison and summary

Submitted to DoE on 31 March 2017

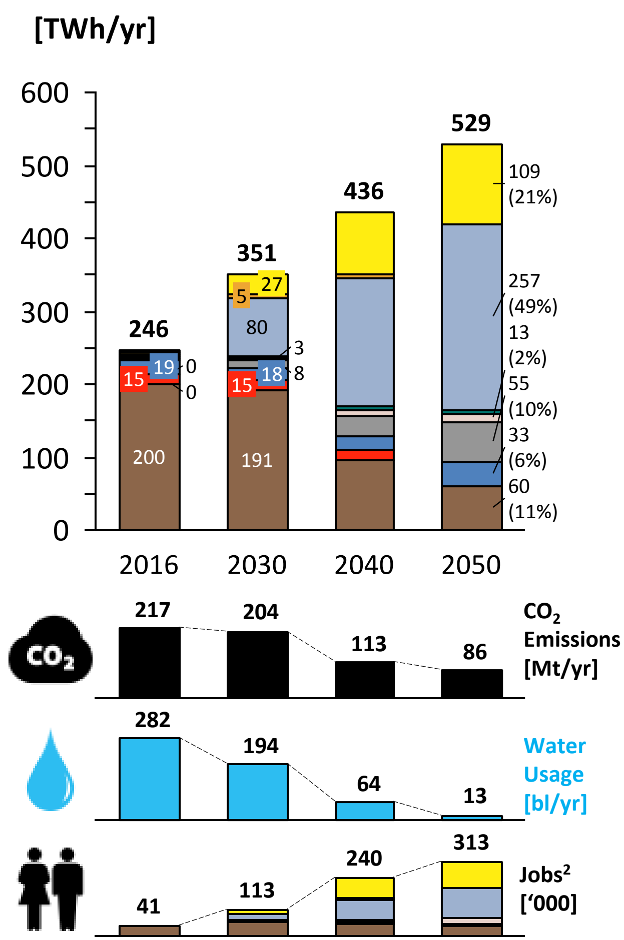
Scenario: Least Cost

No new nuclear, no new coal, 75% RE by 2050, R630 billion/yr in 2050

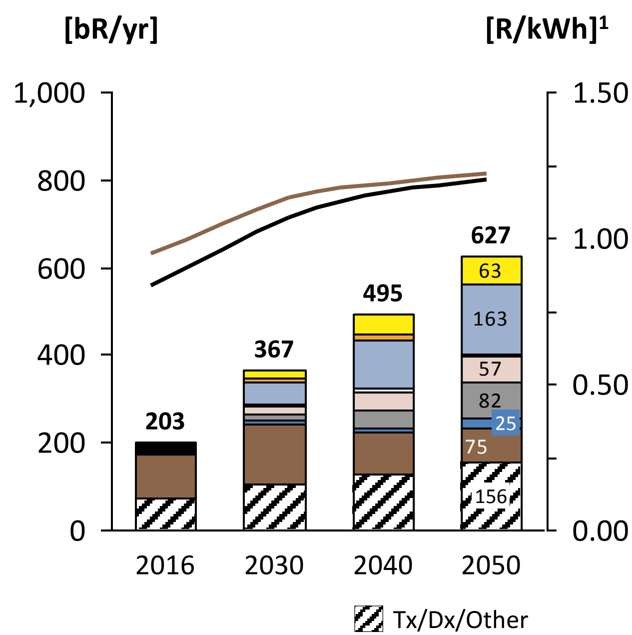
Installed Capacity



Energy Produced



System cost and average tariff



Difference to Draft IRP 2016 Base Case

- No build-out constraints on any technology
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHs

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; [2] Direct and supplier jobs only; Sources: CSIR; Eskom

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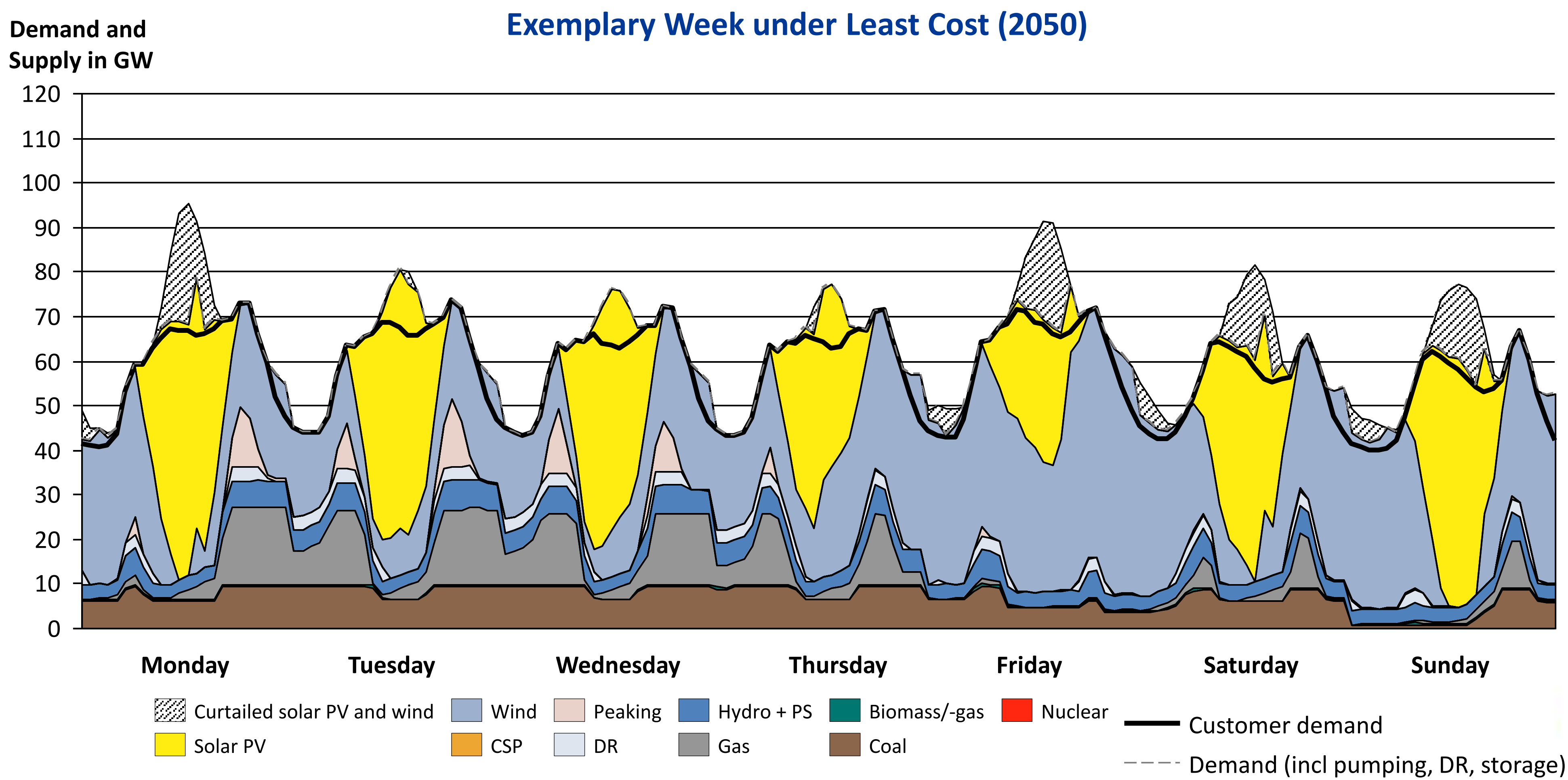
Scenario: Least Cost - Solar PV and wind dominate supply mix in 2050, with curtailment and variability managed by flexible gas



Sources: CSIR analysis

Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost ("Expected" costs)

Scenario comparison and summary

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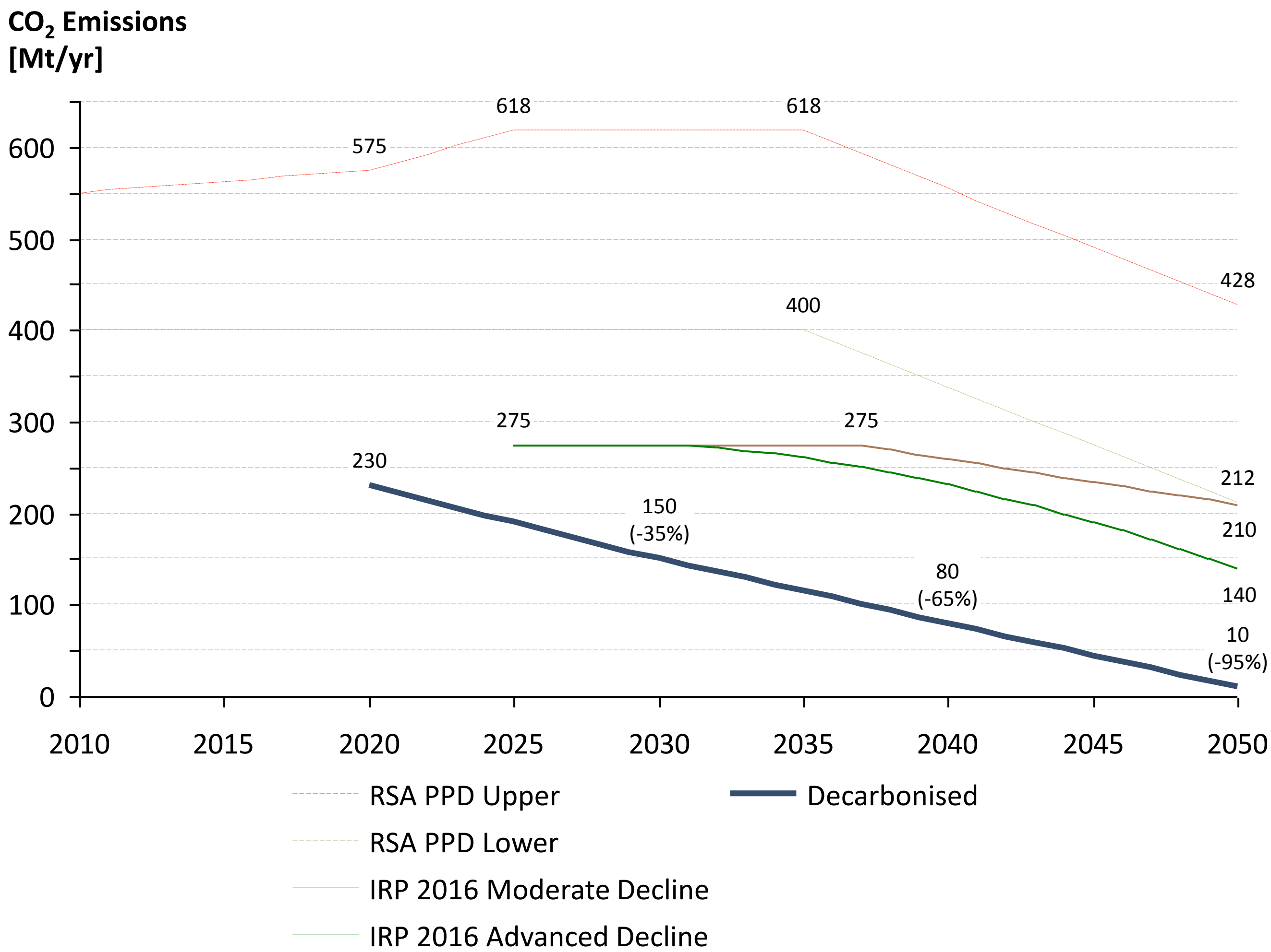
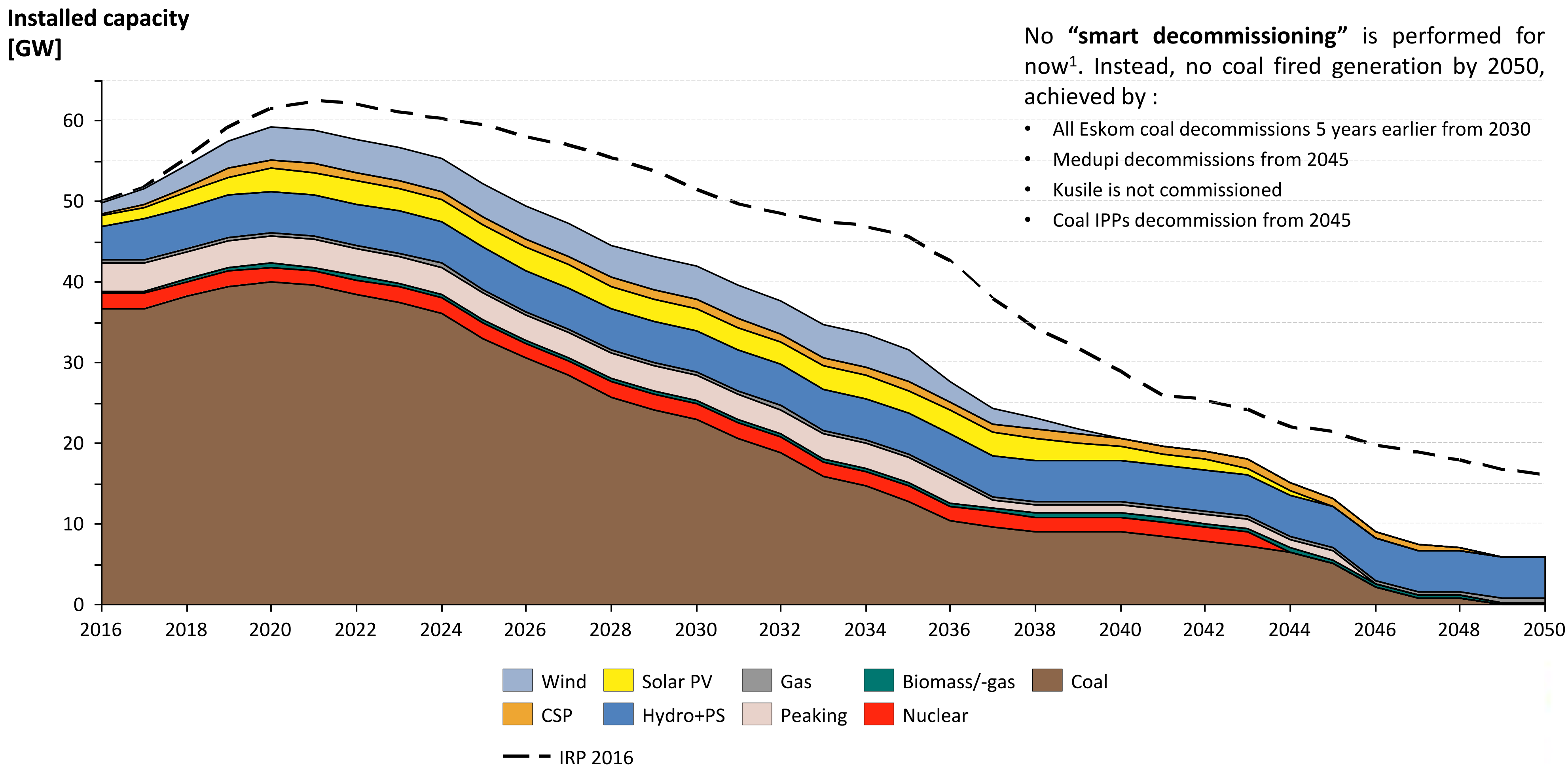
Assumption: 95% decarbonisation of the South African power sector by 2050 compared to 2016, which means down to 10 Mt/yr of CO2



PPD = Peak Plateau Decline
Sources: DoE (IRP 2010-2030 Update); StatsSA; CSIR analysis

Decommissioning schedule for Decarbonised scenario



No **"smart decommissioning"** is performed for now[1]. Instead, no coal fired generation by 2050, achieved by :

- All Eskom coal decommissions 5 years earlier from 2030
- Medupi decommissions from 2045
- Kusile is not commissioned
- Coal IPPs decommission from 2045

[1] Optimising if/when to decommission existing coal fleet is not performed (Eskom, coal IPPs, Sasol)
Sources: CSIR analysis

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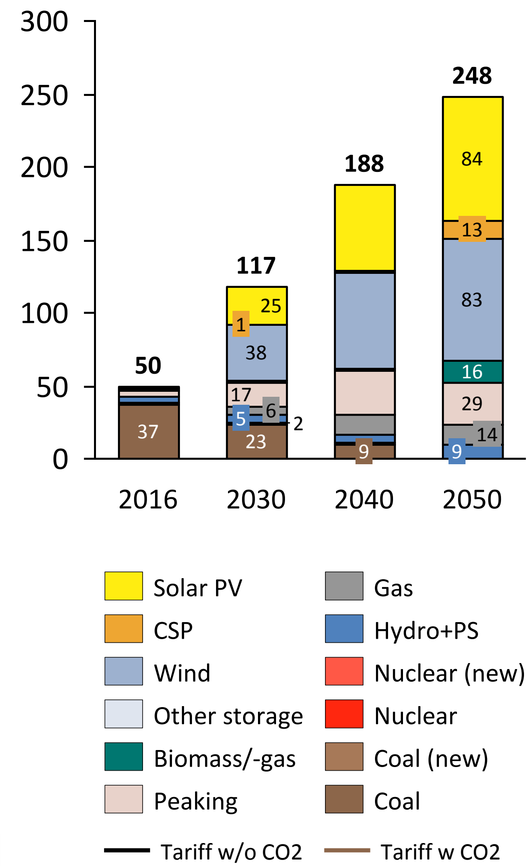
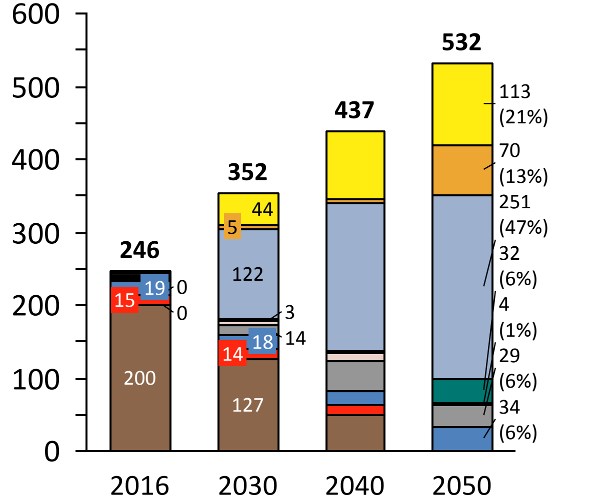
Scenario: Decarbonised

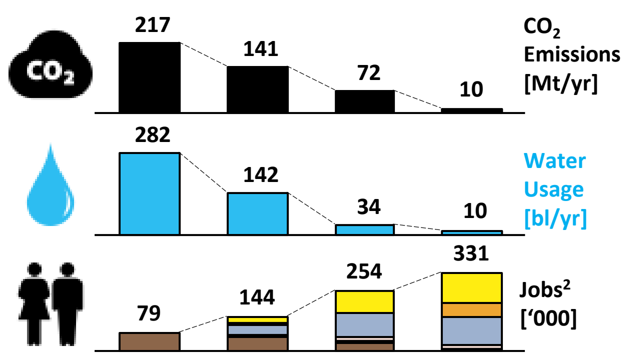
>90% RE by 2050 mostly PV & wind with biomass/-gas and CSP

Installed Capacity

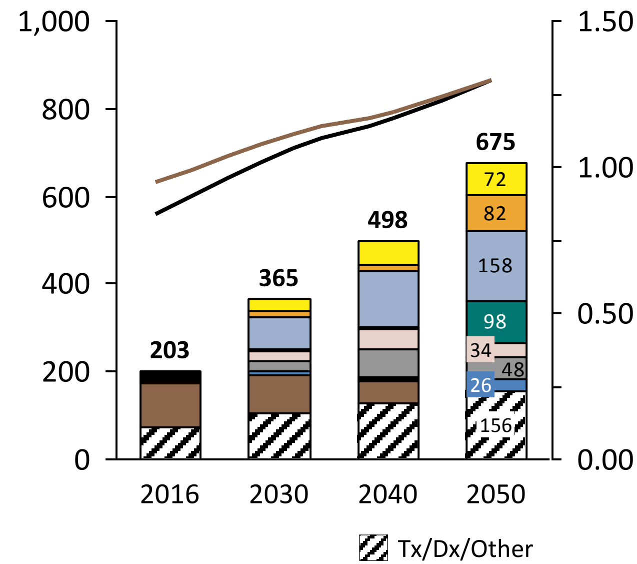


Energy Produced





System cost and average tariff



Difference to Draft IRP 2016 Base Case

- Cost assumptions of Least-cost scenario
- No constraints on new build technologies
- 95% reduction of CO_2 by 2050
- Early coal fleet decommissioning
- Medupi and coal IPPs decommission 2045
- No Kusile

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; [2] Direct and supplier jobs only; Sources: CSIR; Eskom

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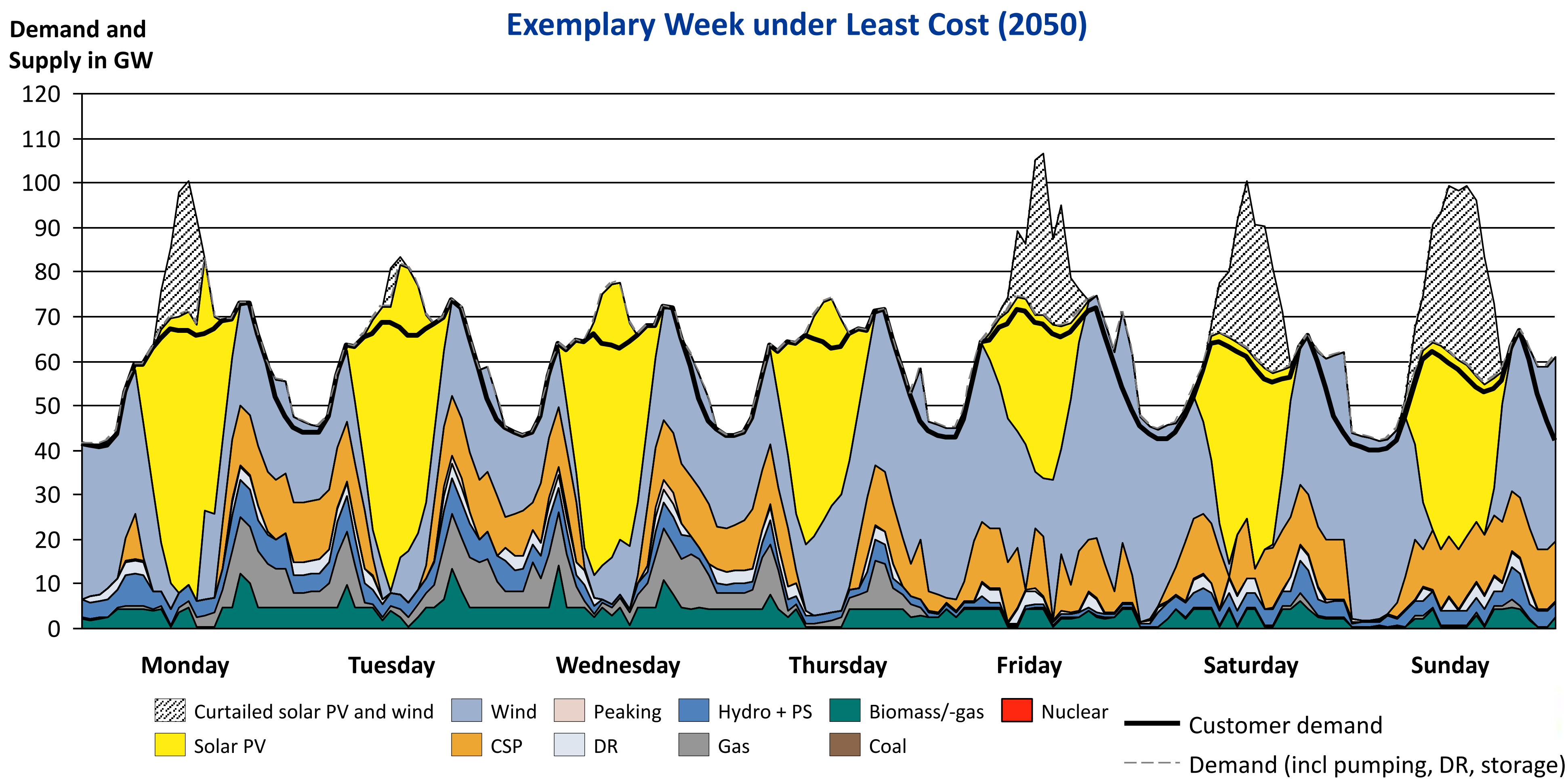
Scenario: Decarbonised- Solar PV and wind dominate supply mix in 2050, with curtailment and variability managed by flexible gas



Sources: CSIR analysis

Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

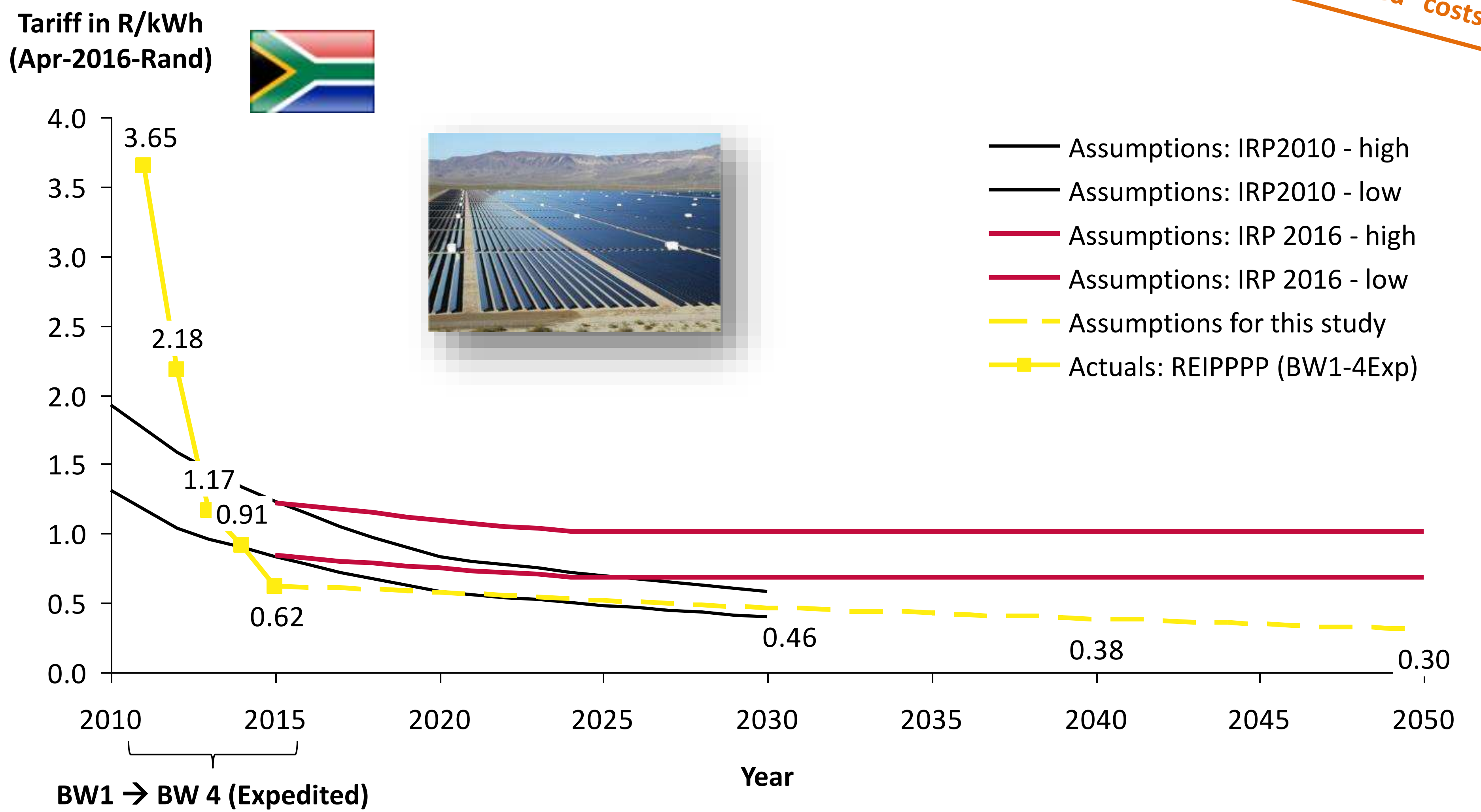
Least-cost ("Expected" costs)

Scenario comparison and summary

Submitted to DoE on 31 March 2017

CSIR study cost input assumptions for solar PV: Realistic future cost assumptions for solar PV

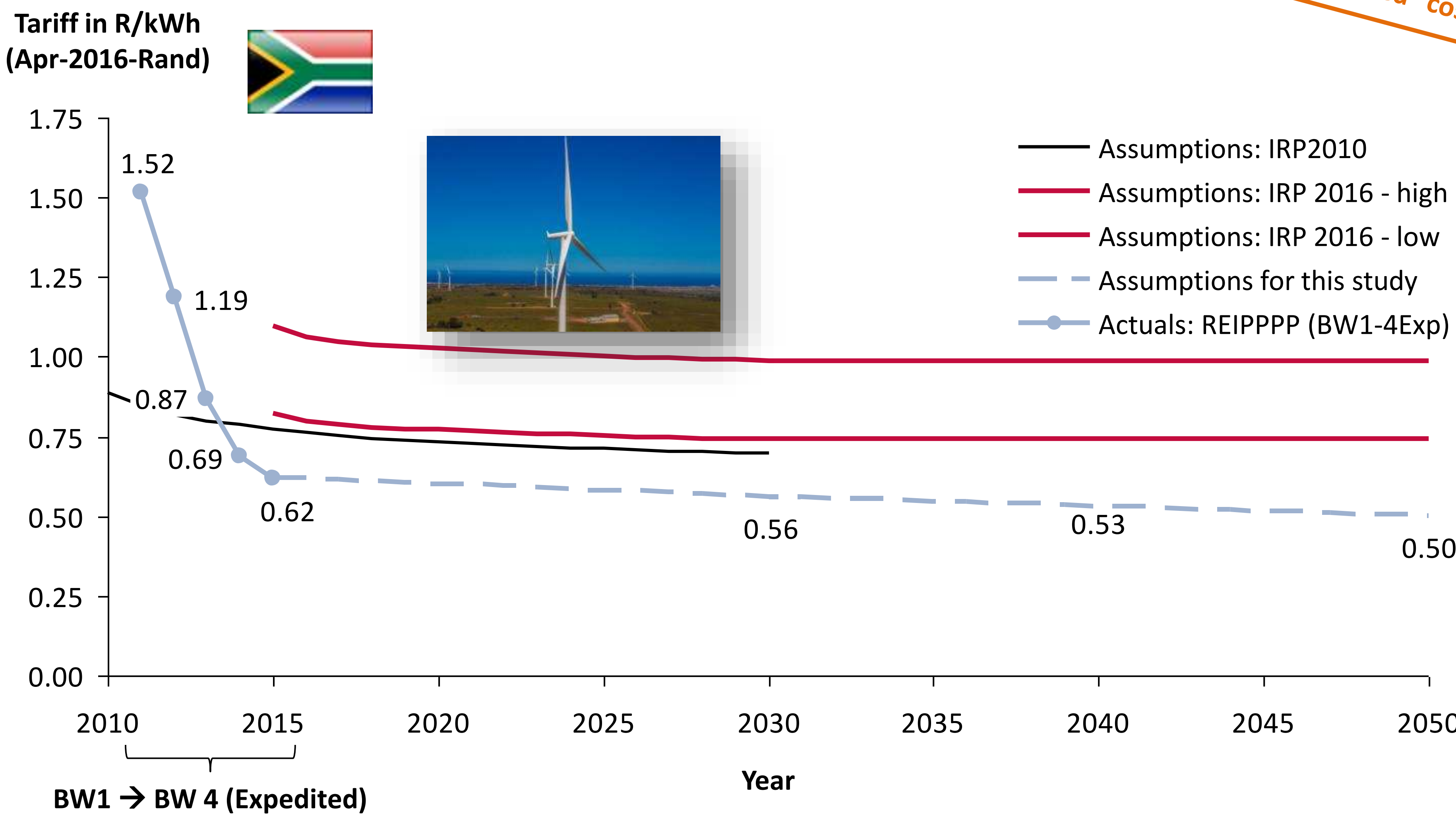
For Least Cost ("Expected" costs)



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

CSIR study cost input assumptions for wind: Realistic future cost assumptions for wind

For Least Cost ("Expected" costs)



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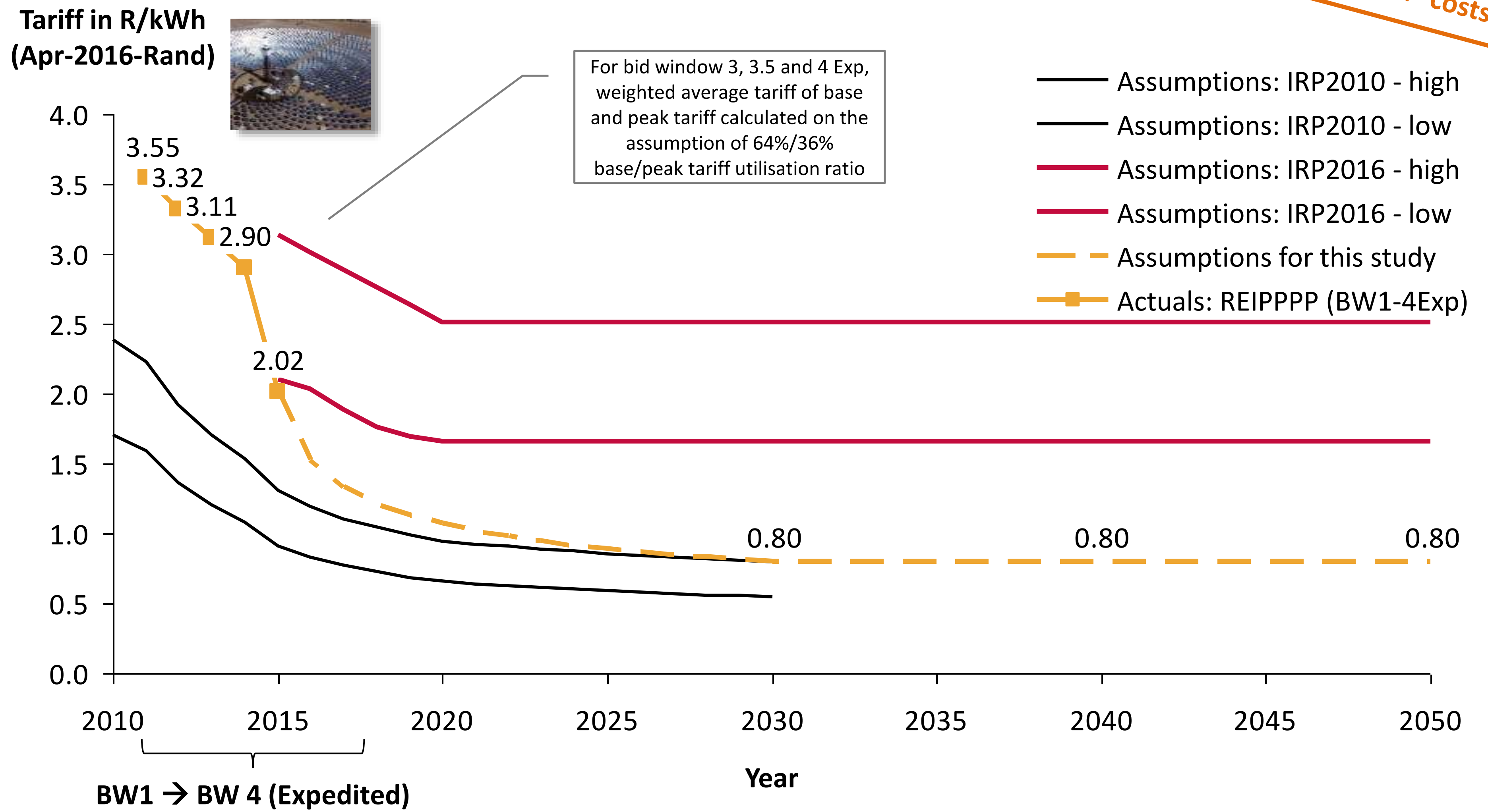
CSIR study cost input assumptions for CSP: Today's latest tariff as starting point, same cost decline as per IRP 2010

For Least Cost ("Expected" costs)



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

Storage technology (from IRP 2016) with assumed learning rates

For Least Cost ("Expected" costs)

High level assumptions (for now) on learning rates for storage:

Technology		2016		2030		2040		2050	
(Apr-2016 ZAR)	Capacity [MW]	Capex[1] [R/kWh]	FOM[2] [R/kW/yr]	Capex[1] [R/kWh]	FOM[2] [R/kW/yr]	Capex[1] [R/kWh]	FOM[2] [R/kW/yr]	Capex[1] [R/kWh]	FOM[2] [R/kW/yr]
Lithium-ion (1 hrs)	3	9 891	618	2 000	309	1 000	309	800	309
Lithium-ion (3 hrs)	3	9 891	618	2 000	309	1 000	309	800	309
CAES (8 hrs)	180	3 459	212	3 459	212	3 459	212	3 459	212

[1] Capex = Capital expenditure (including IDC); [2] FOM = Fixed Operations and Maintenance Costs

Electric vehicle usage for demand side flexibility

For Least Cost ("Expected" costs)

Inclusion of a demand side flexibility resource in the form of mobile storage (electric motor vehicles) demonstrates impact on the power system as adoption increases

Modelled similar to EWH demand shaping as a resource with intra-day controllability (can be dispatched as needed on any given day) based on power system needs

Key input parameters to estimate potential demand shaping via electric motor vehicles:

- Current population
- Expected population growth to 2050
- Current number of motor vehicles
- Expected motor vehicles per capita
- Adoption rate of electric vehicles to 2050
- Electric vehicle fleet capacity (MW)
- Electric vehicle energy requirement (GWh/d)
- Proportion of electric vehicle fleet connected simultaneously

Electric vehicle demand shaping can provide ~48 GW/1.7 GW (demand increase/decrease) with ~40 GWh/d of dispatchable energy by 2050

For Least Cost
("Expected" costs)

Property	Unit	2016-2019	2020	2030	2040	2050
Population	[mln]	0 - 0	58.0	61.7	64.9	68.2
Number of motor vehicles	[mln]	7 - 7.3	7.3	8.0	8.4	8.9
EVs adoption rate	[%]	0 - 0	0.9	10.0	25.0	55.5
Number of EVs	[mln]	0 - 0	0.1	0.8	2.1	5.0
EVs energy requirement	[TWh/a]	-	0.2	2.4	6.3	15.0
EVs energy requirement	[GWh/d]	-	0.5	6.6	17.3	41.1
EVs (demand increase)	[MW]	-	600	7 700	20 400	48 300
EVs (demand decrease)	[MW]	-	-	300	700	1 700

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Sources: CSIR estimates; StatsSA; eNaTis

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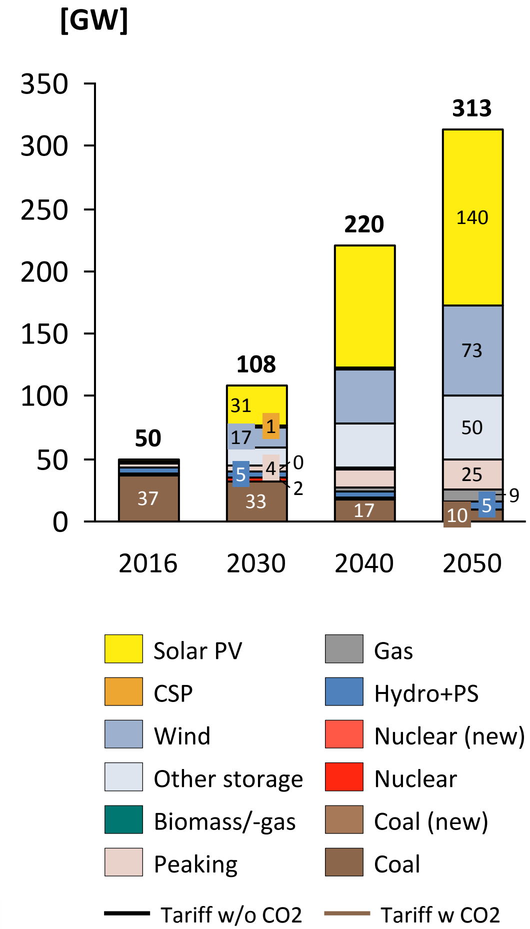
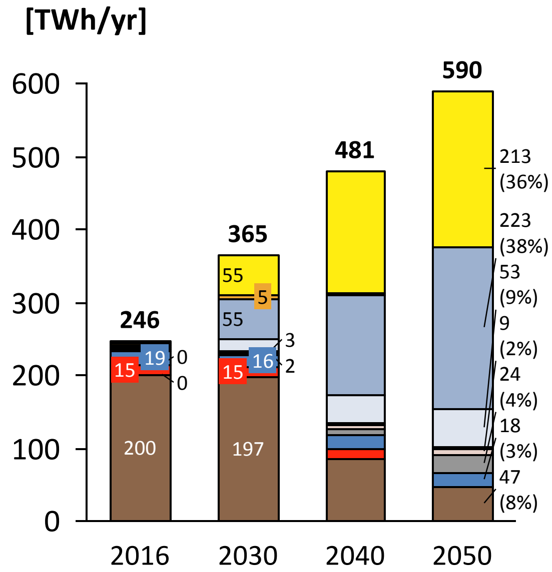
Scenario: Least cost (Expected costs)

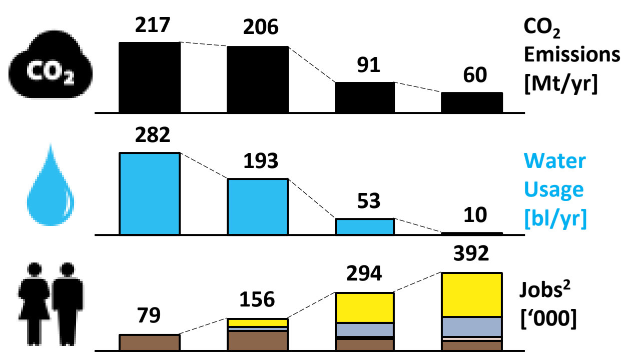
If solar PV, wind and battery cost drop as expected

Installed Capacity
("Expected" costs)

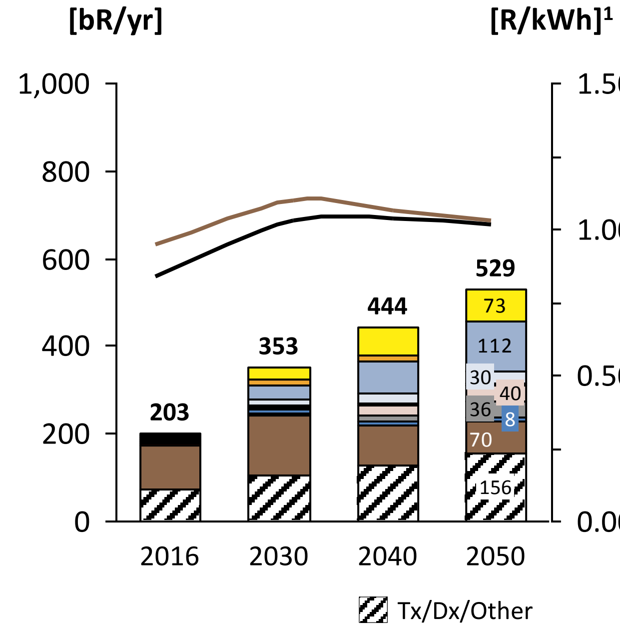


Energy Produced
("Expected" costs)





System cost and average tariff
("Expected" costs)



Difference to Draft IRP 2016 Base Case

- No constraints on new build technologies
- More realistic learning rates for PV and wind
- Learning rates for storage
- Demand shaping via EWHs
- Electric vehicle uptake

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; [2] Direct and supplier jobs only; Sources: CSIR; Eskom

Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

Least-cost ("Expected" costs)

Scenario comparison and summary

- Conservative RE/battery cost
- Expected RE/battery cost

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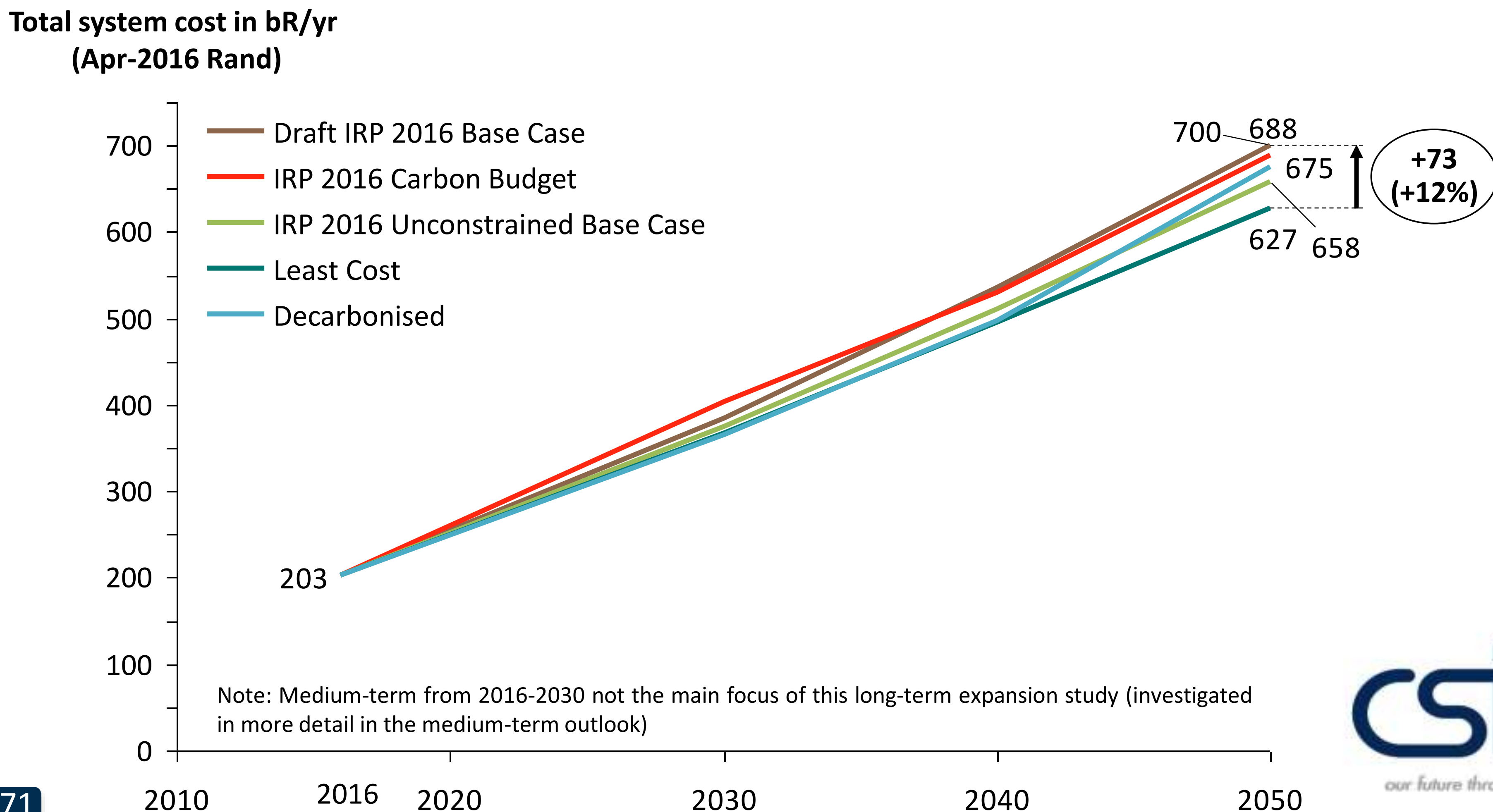
Total system cost : Draft IRP 2016 Base Case ≈R70 bn/year more expensive by 2050 than Least Cost (without cost of CO_2)



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items)

Sources: Eskom on Tx, Dx cost; CSIR analysis

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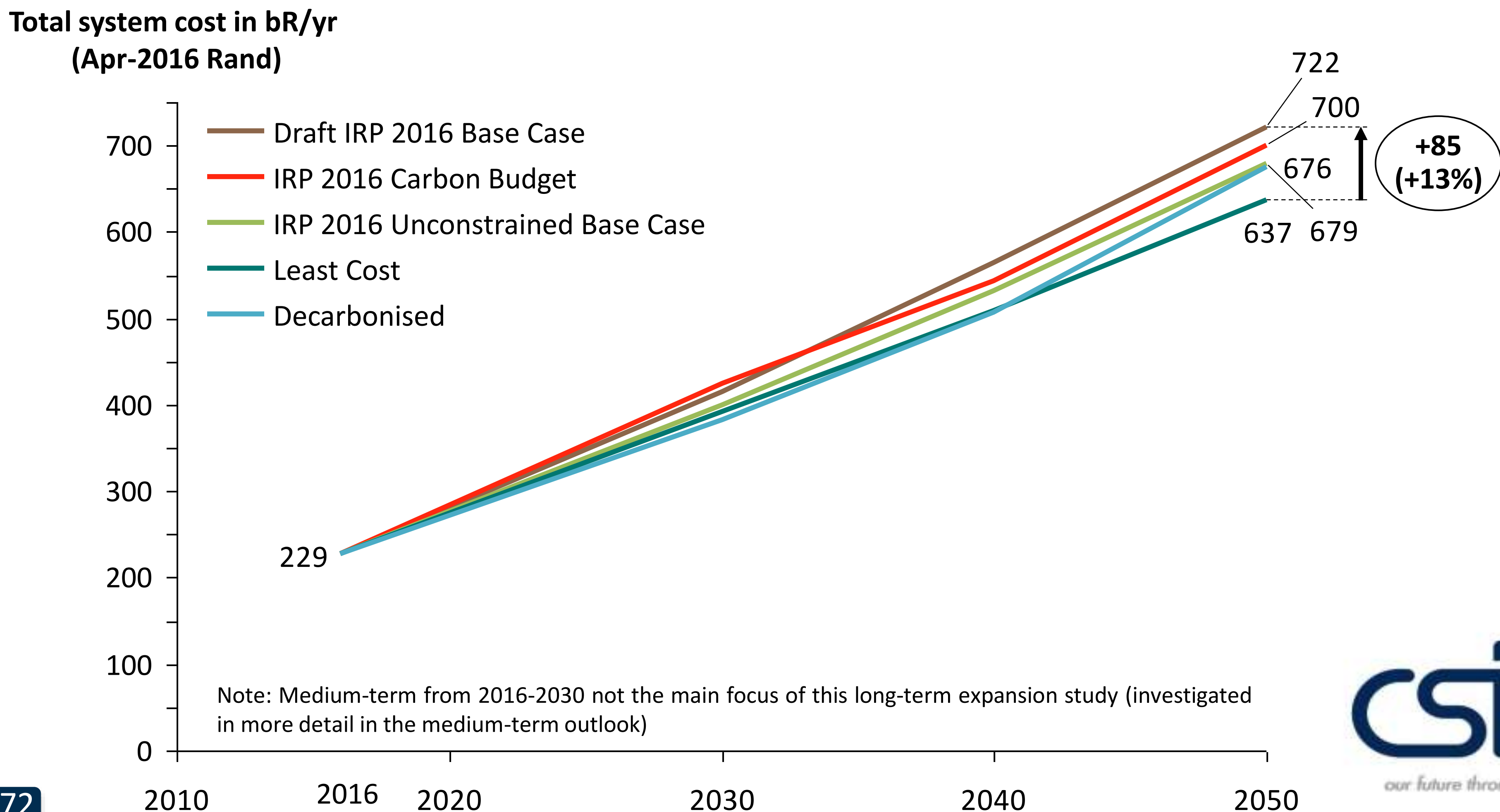
Total system cost: Draft IRP 2016 Base Case ≈R85 bn/year more expensive by 2050 than Least Cost (with cost of CO_2)



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Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

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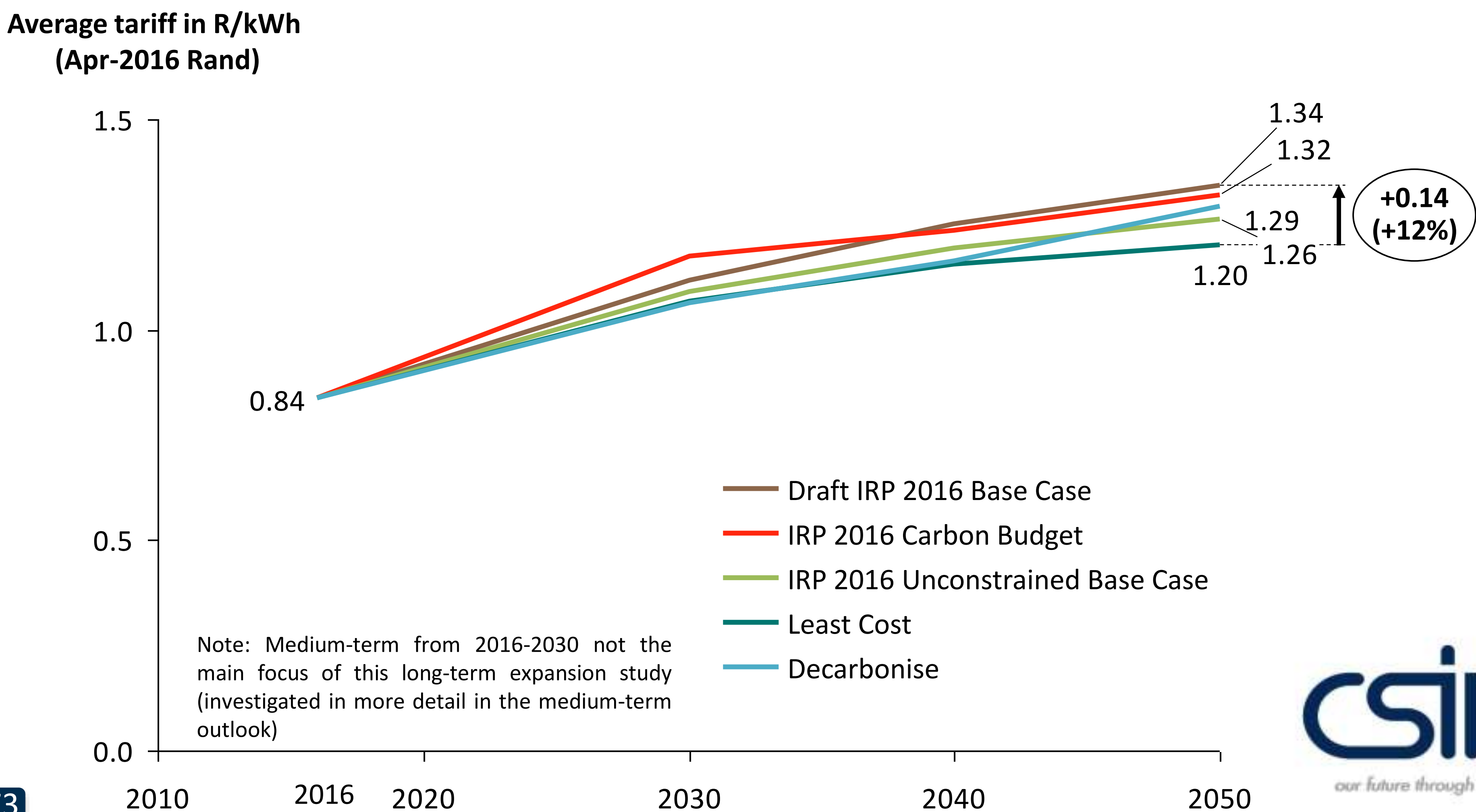
Average tariff (without cost of CO_2): Draft IRP Base Case tariff 12 cents/kWh higher than Least Cost by 2050



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Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

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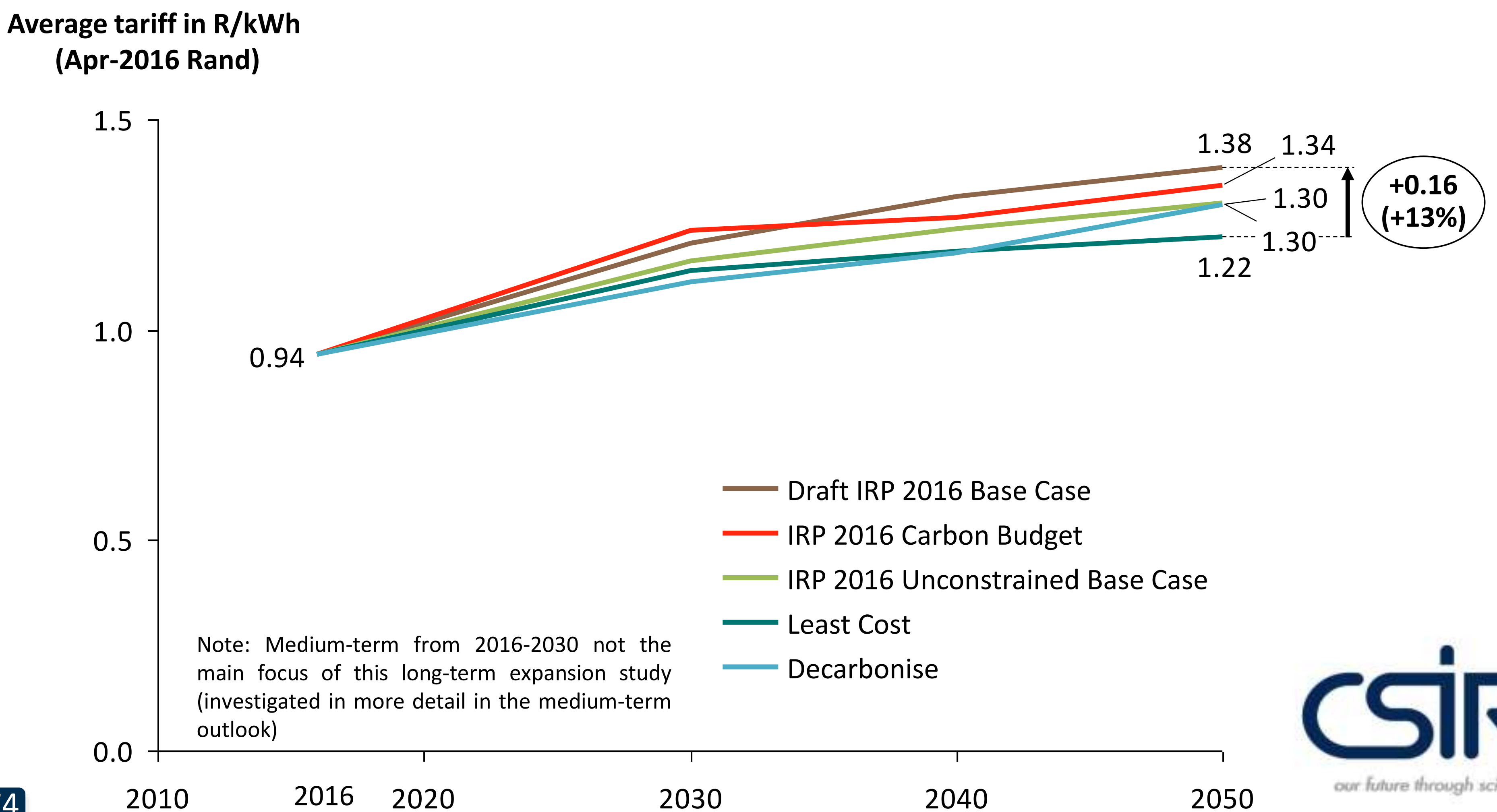
Average tariff (with cost of CO_2): Draft IRP Base Case tariff 16 cents/kWh higher than Least Cost by 2050



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Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

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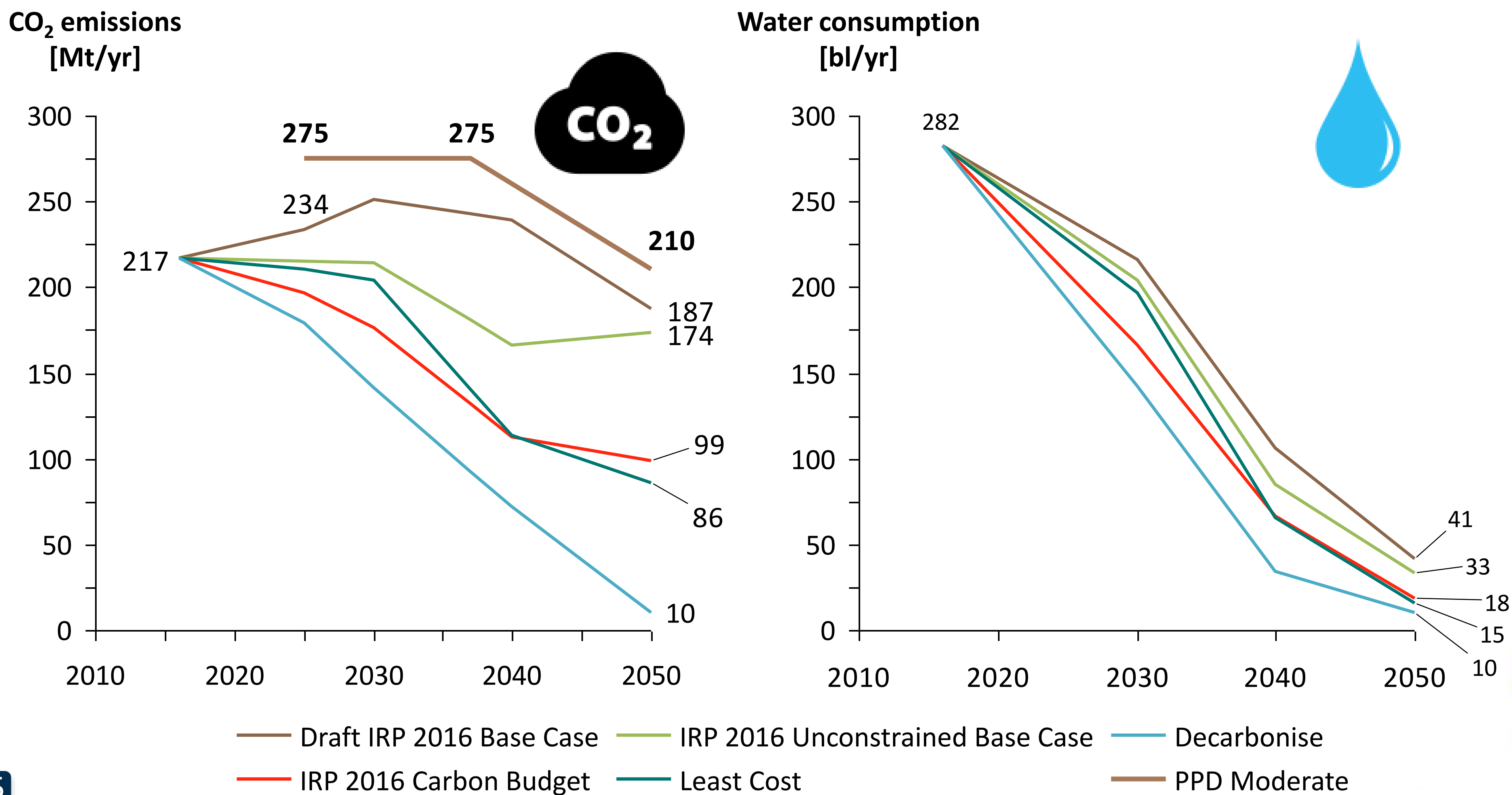
CO_2 emissions trajectories and water usage summary



Source: CSIR analyses

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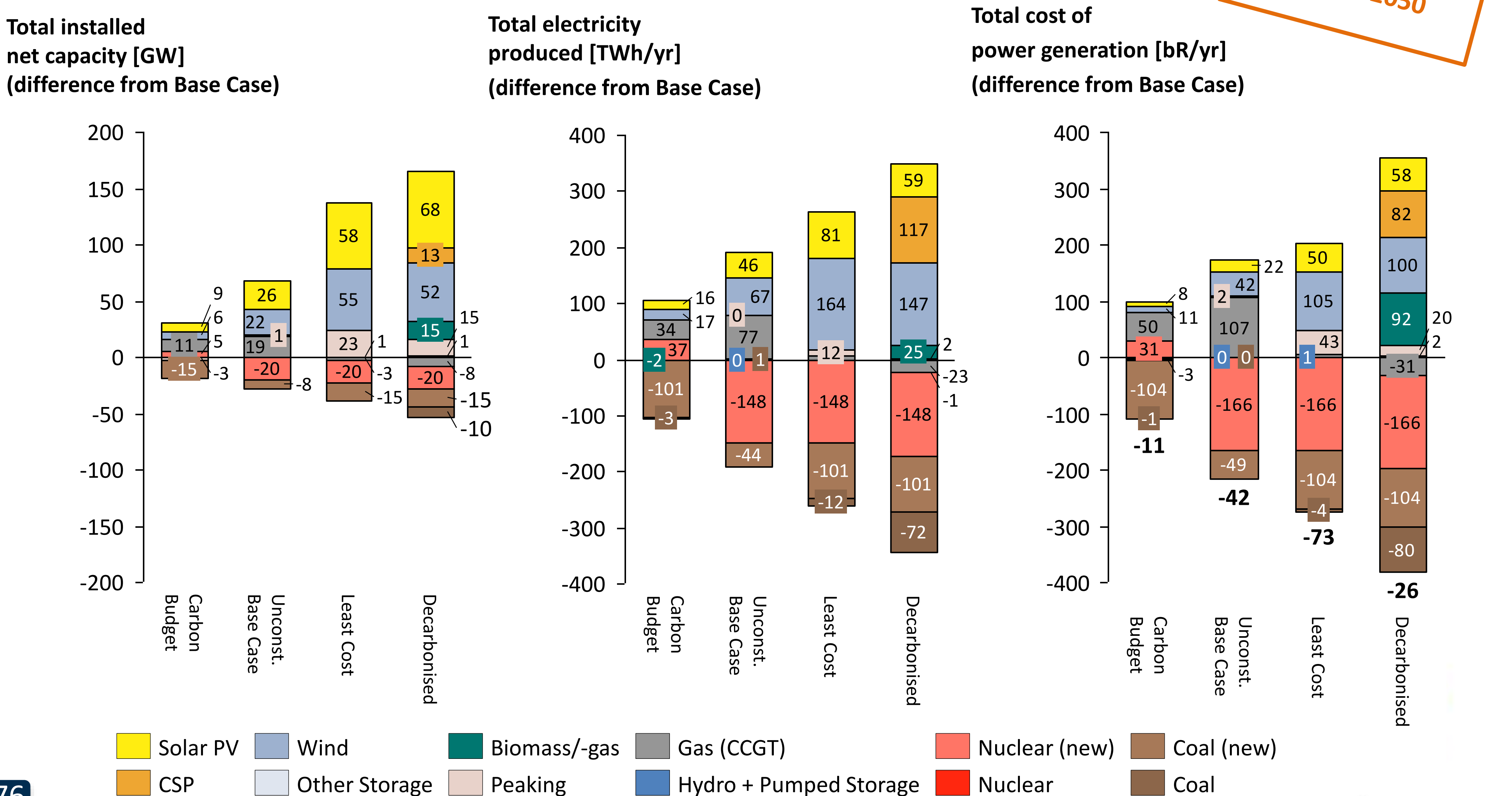
The Least-Cost and Decarbonised scenarios install significantly more wind and solar PV as well as more flexible peaking capacity

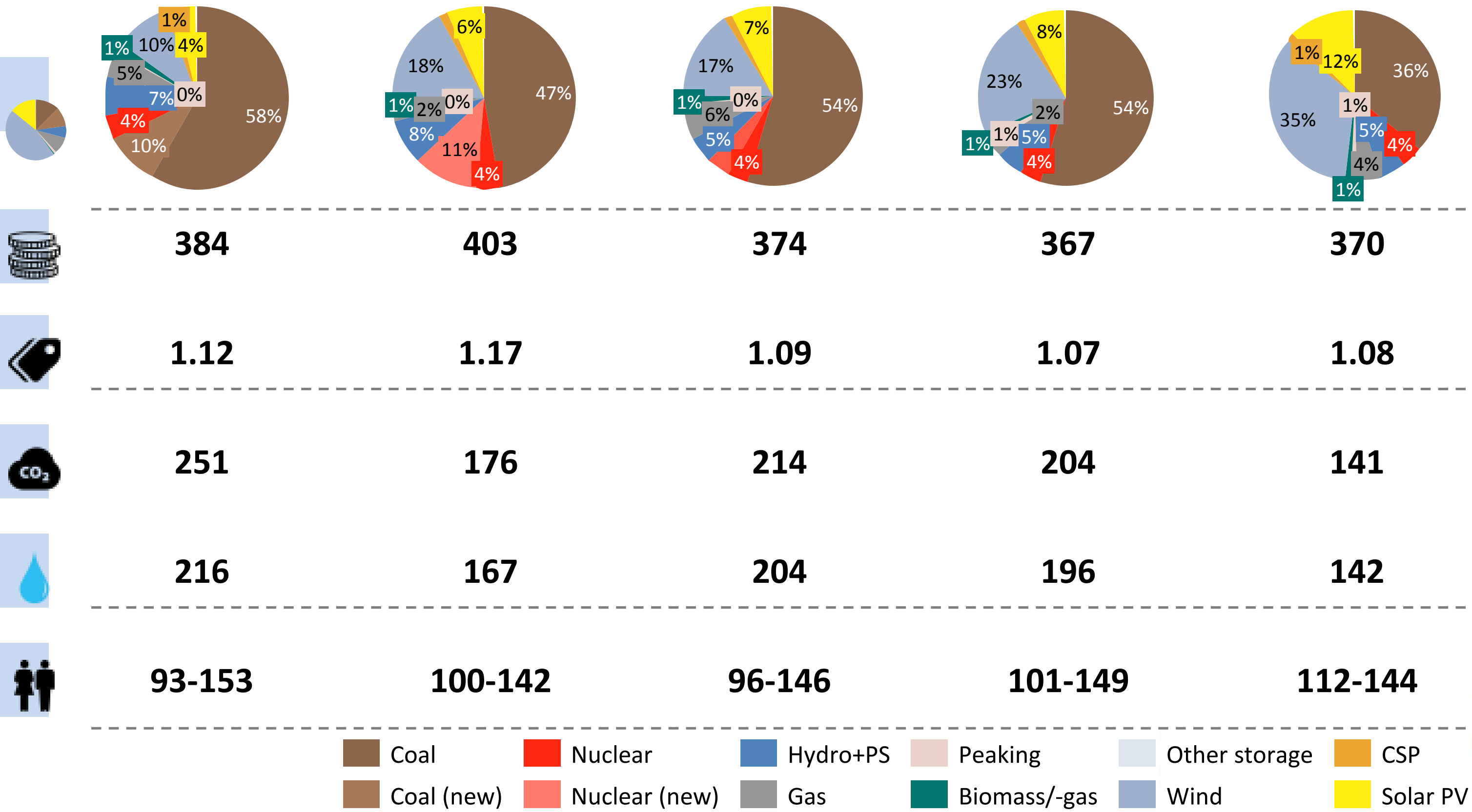
By year 2050



Least Cost is ≈R20-40 billion/yr cheaper by 2030 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

As per Draft IRP 2016 | As per DoE

2030		IRP 2016 Base Case	IRP 2016 Carbon Budget	Unconstrained Base Case	Least Cost	Decarbonised
Energy Mix in 2030	**Demand: 343 TWh**					
Cost in 2030	**Total system cost**[1] (R-billion/yr)	384	403	374	367	370
	Average tariff (R/kWh)	1.12	1.17	1.09	1.07	1.08
Environ-ment in 2030	**CO_2 emissions** (Mt/yr)	251	176	214	204	141
	Water usage (billion-litres/yr)	216	167	204	196	142
Jobs[2] in 2030	**Direct & supplier** ('000)	93-153	100-142	96-146	101-149	112-144

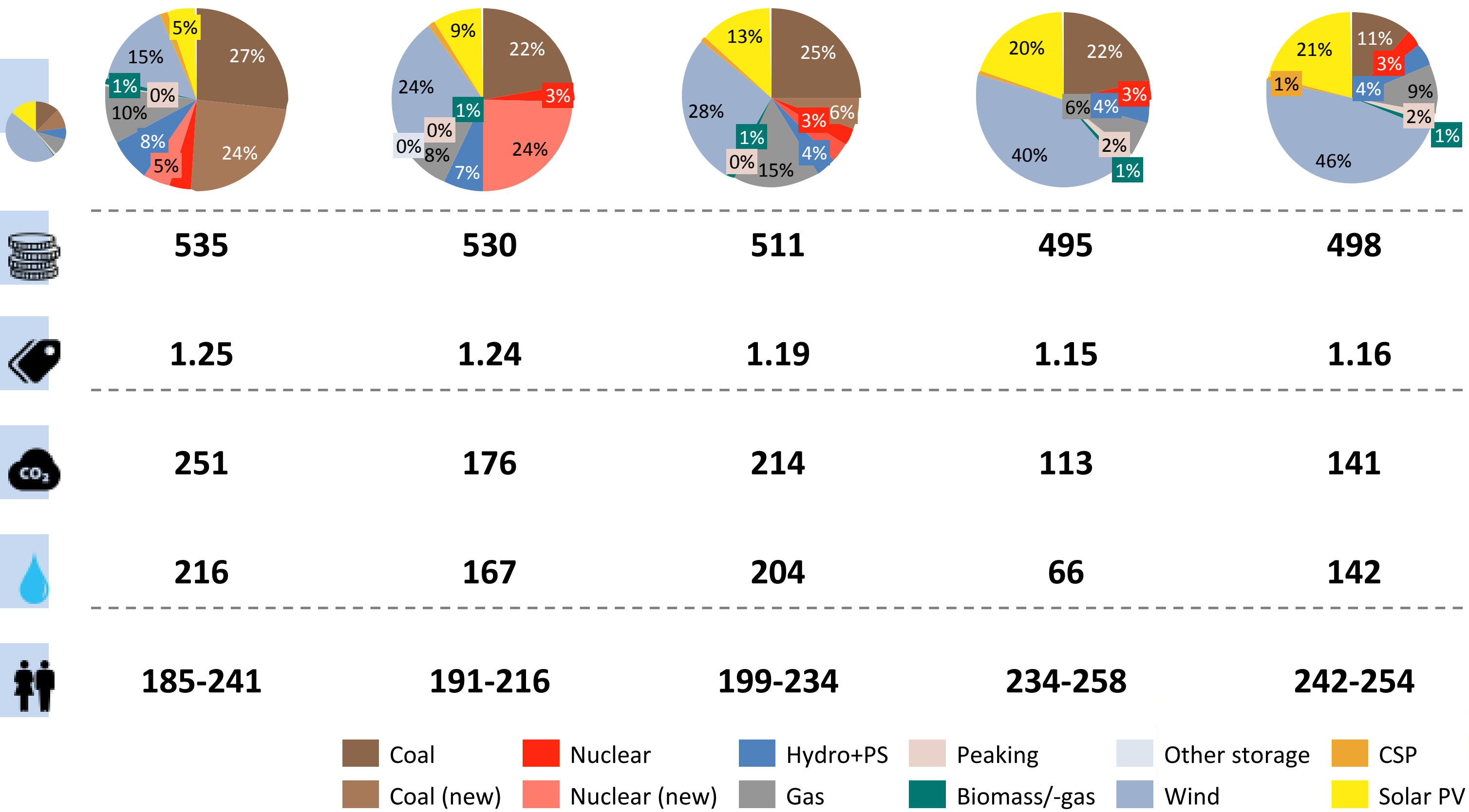


[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Submitted to DoE on 31 March 2017

Least Cost is ≈R45-60 billion/yr cheaper by 2040 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

2040		IRP 2016 Base Case (As per Draft IRP 2016)	IRP 2016 Carbon Budget (As per Draft IRP 2016)	Unconstrained Base Case (As per DoE)	Least Cost	Decarbonised
Energy Mix in 2040	**Demand: 428 TWh**	see pie charts below				
Cost in 2040	**Total system cost**[1] (R-billion/yr)	535	530	511	495	498
	Average tariff (R/kWh)	1.25	1.24	1.19	1.15	1.16
Environ-ment in 2040	**CO_2 emissions** (Mt/yr)	251	176	214	113	141
	Water usage (billion-litres/yr)	216	167	204	66	142
Jobs[2] in 2040	**Direct & supplier** ('000)	185-241	191-216	199-234	234-258	242-254



[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Submitted to DoE on 31 March 2017

Least Cost is ≈R60-65 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

As per Draft IRP 2016: IRP 2016 Base Case, IRP 2016 Carbon Budget

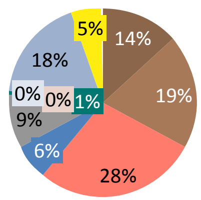
As per DoE: Unconstrained Base Case

2050

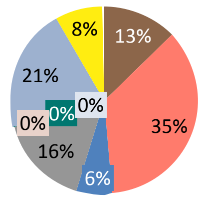
Energy Mix in 2050

Demand: 522 TWh

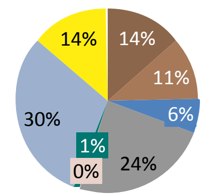
IRP 2016 Base Case



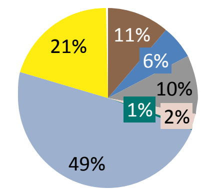
IRP 2016 Carbon Budget



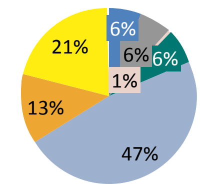
Unconstrained Base Case



Least Cost



Decarbonised



2050		IRP 2016 Base Case	IRP 2016 Carbon Budget	Unconstrained Base Case	Least Cost	Decarbonised
Cost in 2050	Total system cost[1] (R-billion/yr)	700	688	658	627	675
	Average tariff (R/kWh)	1.34	1.32	1.26	1.20	1.29
Environ-ment in 2050	CO_2 emissions (Mt/yr)	187	99	174	86	10
	Water usage (billion-litres/yr)	41	18	33	15	10
Jobs[2] in 2050	Direct & supplier ('000)	252-295	235-253	248-281	310-325	331

Legend: Coal; Coal (new); Nuclear; Nuclear (new); Hydro + PS; Gas; Peaking; Biomass/-gas; Other storage; Wind; CSP; Solar PV

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)

[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Agenda

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Unconstrained Base Case

Least Cost

Decarbonised

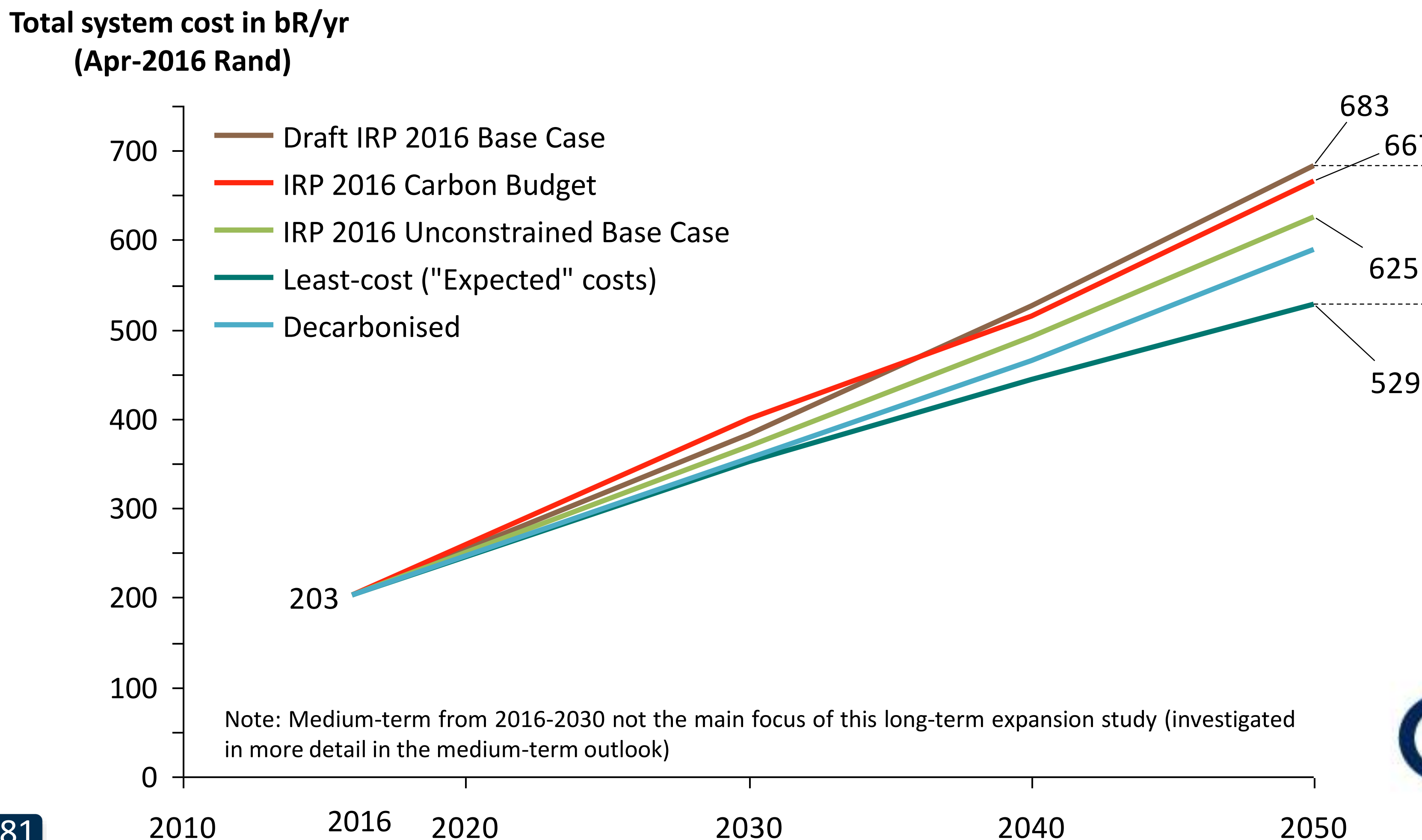
Least-cost ("Expected" costs)

Scenario comparison and summary

- Conservative RE/battery cost
- Expected RE/battery cost

Total system cost: Draft IRP 2016 Base Case ≈R155 bn/year more expensive by 2050 than Least Cost (without cost of CO_2)

Costs applied: "Expected" costs



Sources: CSIR analysis

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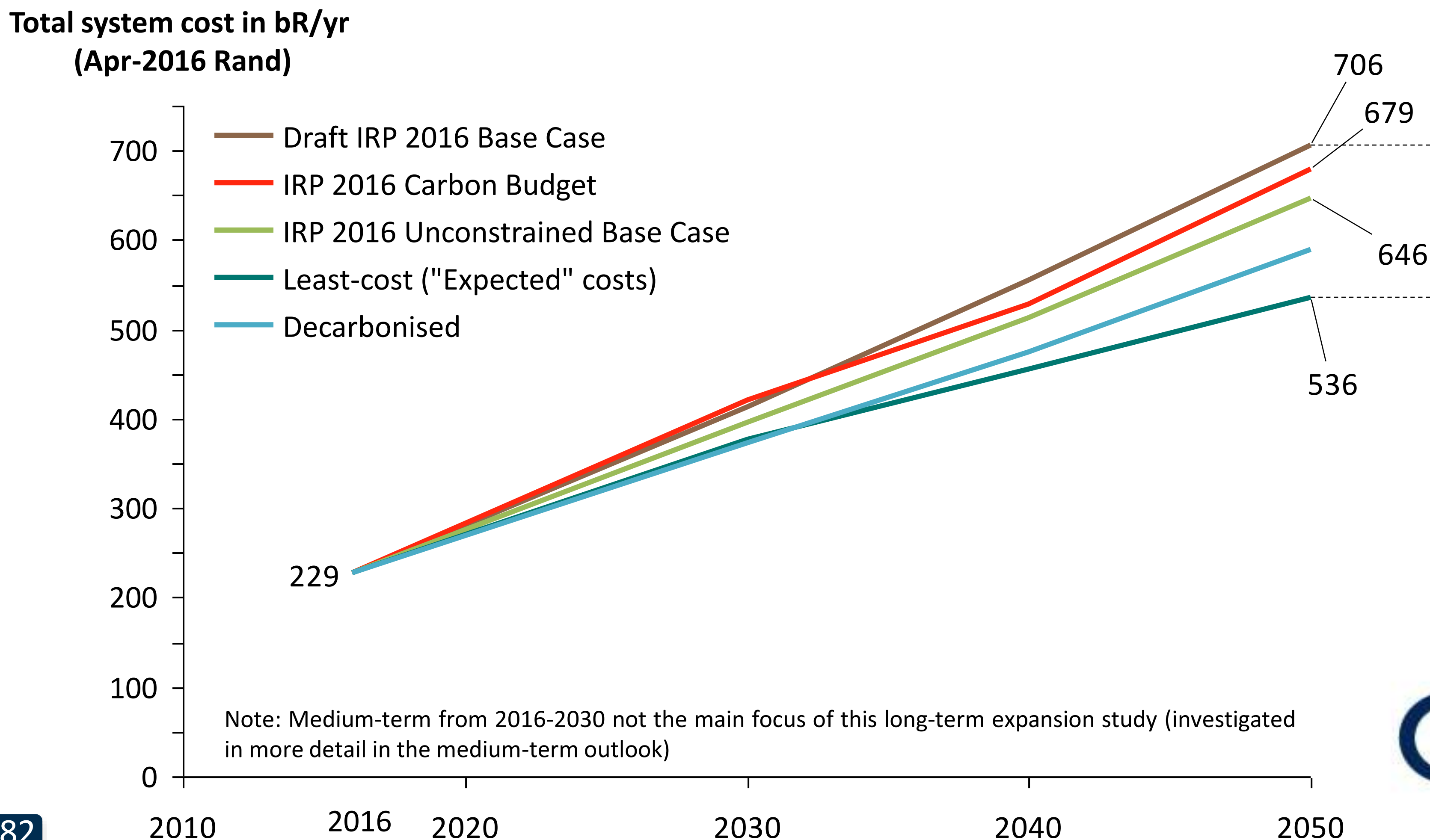
Total system cost: Draft IRP 2016 Base Case ≈R170 bn/year more expensive by 2050 than Least Cost (with cost of CO_2)

Costs applied: "Expected" costs

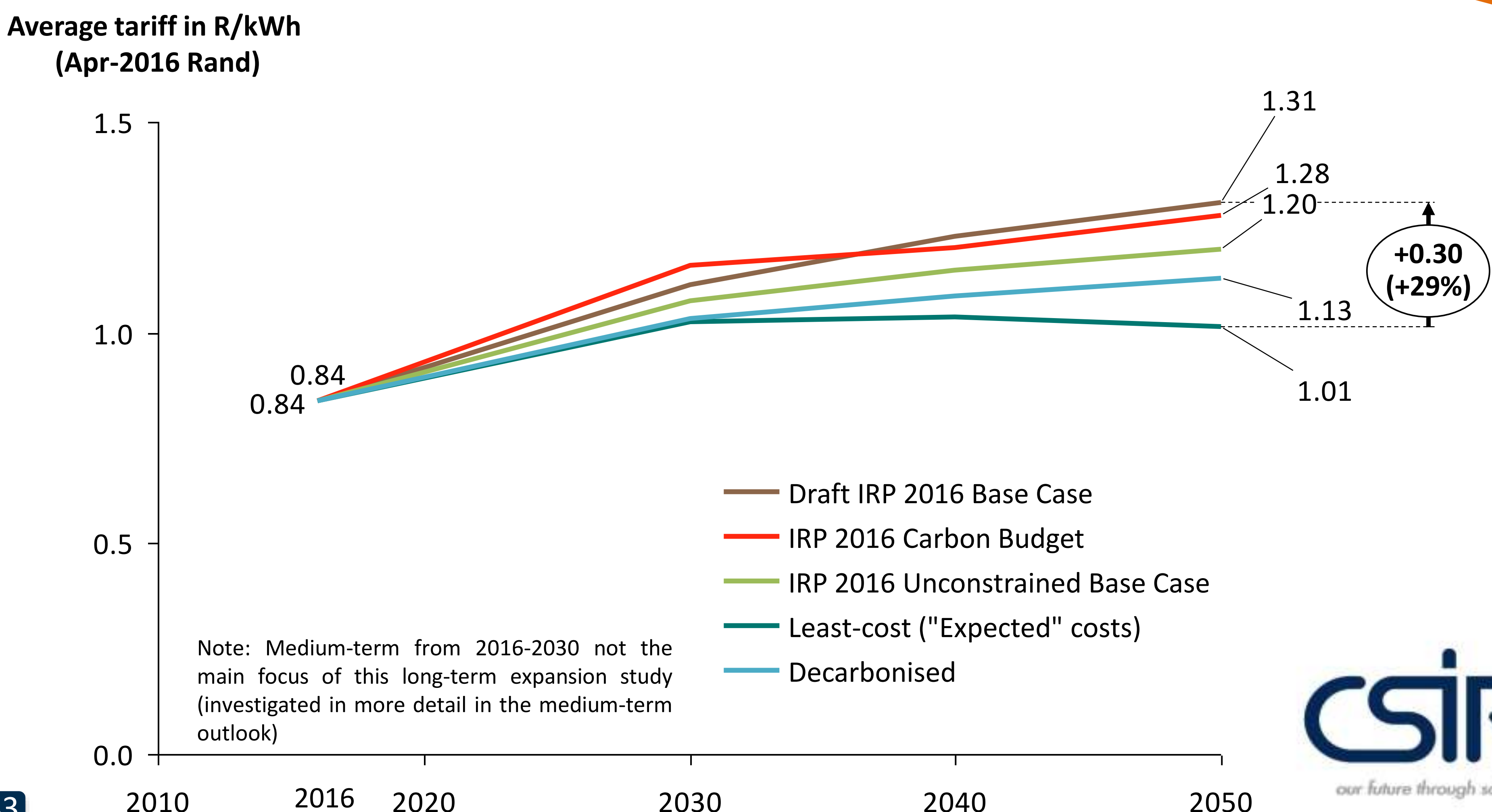


CSIR our future through science

Sources: CSIR analysis

Average tariff (without cost of CO_2): Draft IRP Base Case tariff 30 cents/kWh higher than Least Cost by 2050

Costs applied: "Expected" costs



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Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

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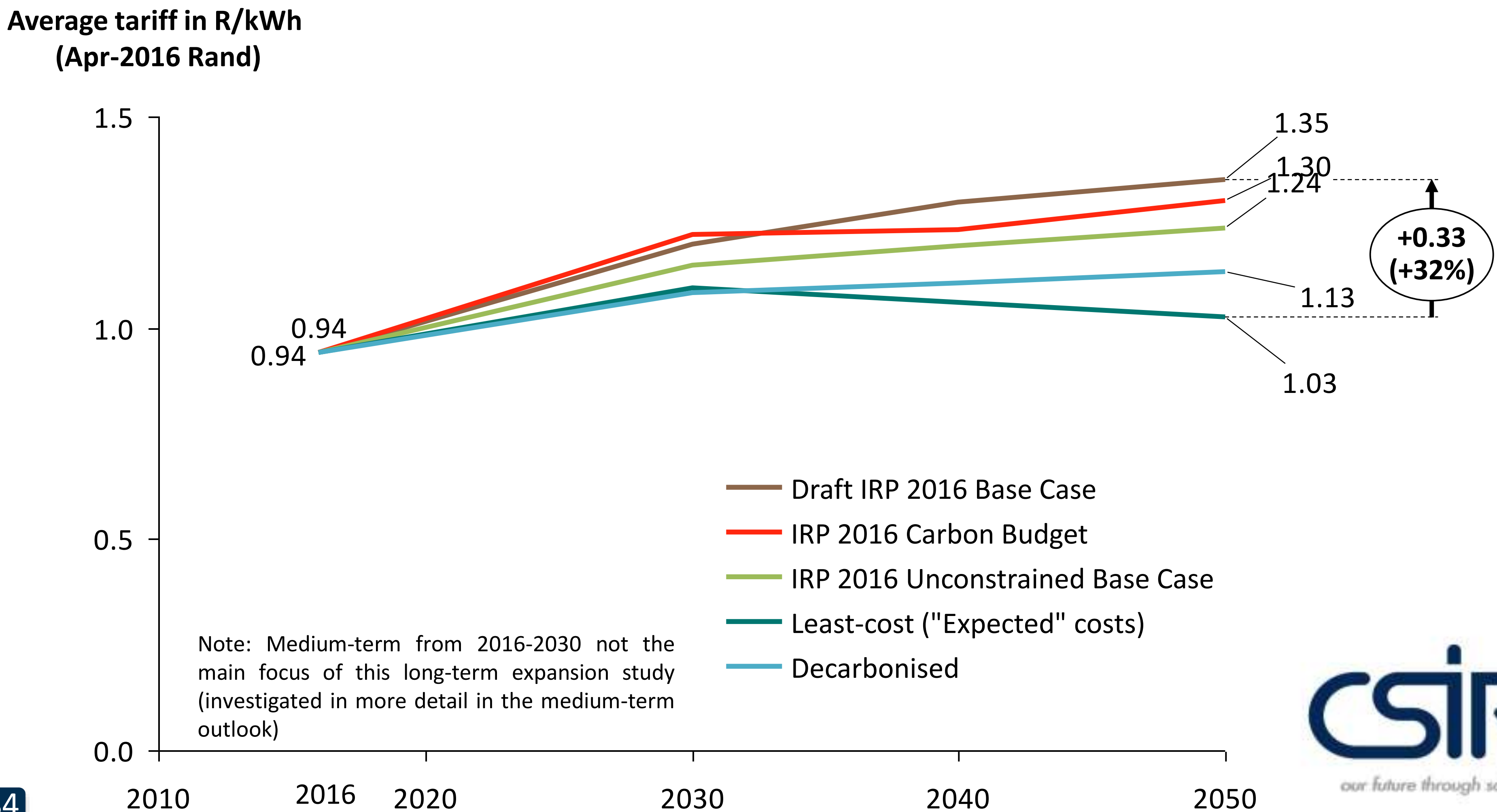
Average tariff (with cost of CO_2): Draft IRP Base Case tariff 33 cents/kWh higher than Least Cost by 2050

Costs applied: "Expected" costs



CSIR
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Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items)   Sources: Eskom on Tx, Dx cost; CSIR analysis

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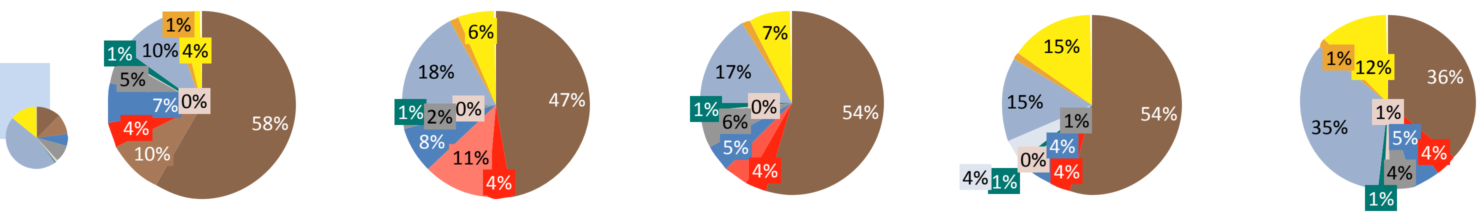
Least Cost is ≈R30-50 billion/yr cheaper by 2030 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

2030		As per Draft IRP 2016: IRP 2016 Base Case ("Expected" costs)	As per Draft IRP 2016: IRP 2016 Carbon Budget ("Expected" costs)	As per DoE: Unconstrained Base Case ("Expected" costs)	Least Cost ("Expected" costs)	Decarbonised ("Expected" costs)
Energy Mix in 2030	**Demand: 343 TWh**	see chart	see chart	see chart	see chart	see chart
Cost in 2030	**Total system cost**[1] (R-billion/yr)	382	399	369	353	355
	Average tariff (R/kWh)	1.11	1.16	1.08	1.03	1.03
Environ-ment in 2030	**CO_2 emissions** (Mt/yr)	251	176	214	206	141
	Water usage (billion-litres/yr)	216	167	204	193	142
Jobs[2] in 2030	**Direct & supplier** ('000)	93-153	100-142	96-146	106-156	112-144



Legend: Coal, Coal (new), Nuclear, Nuclear (new), Hydro+PS, Gas, Peaking, Biomass/-gas, Other storage, Wind, CSP, Solar PV

Because of lack of data, <u>zero</u> jobs for biomass/-gas assumed (affects Decarbonised)

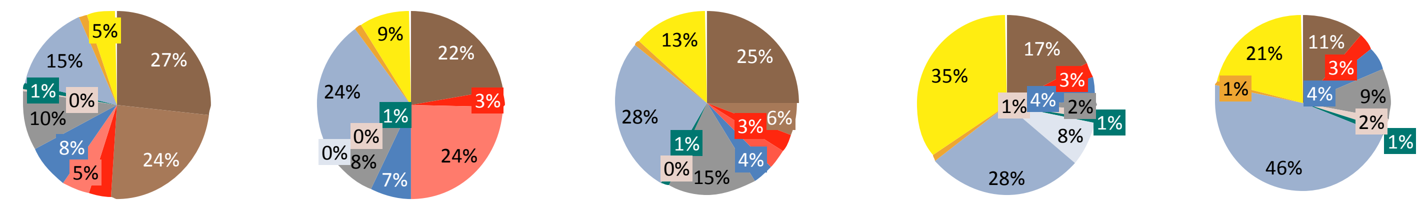
[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)

[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Submitted to DoE on 31 March 2017

Least Cost is ≈R80-105 billion/yr cheaper by 2040 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

2040		IRP 2016 Base Case ("Expected" costs)	IRP 2016 Carbon Budget ("Expected" costs)	Unconstrained Base Case ("Expected" costs)	Least Cost ("Expected" costs)	Decarbonised ("Expected" costs)
		As per Draft IRP 2016	As per Draft IRP 2016	As per DoE		
Energy Mix in 2040	**Demand: 428 TWh** 					
Cost in 2040	**Total system cost[1]** (R-billion/yr)	548	526	489	444	465
	Average tariff (R/kWh)	1.28	1.23	1.14	1.04	1.09
Environ-ment in 2040	**CO_2 emissions** (Mt/yr)	251	176	214	91	141
	Water usage (billion-litres/yr)	216	167	204	53	142
Jobs[2] in 2040	**Direct & supplier** ('000)	185-241	191-216	199-234	273-294	242-254



Coal | Coal (new) | Nuclear | Nuclear (new) | Hydro+PS | Gas | Peaking | Biomass/-gas | Other storage | Wind | CSP | Solar PV

Because of lack of data, zero jobs for biomass/-gas assumed (affects Decarbonised)

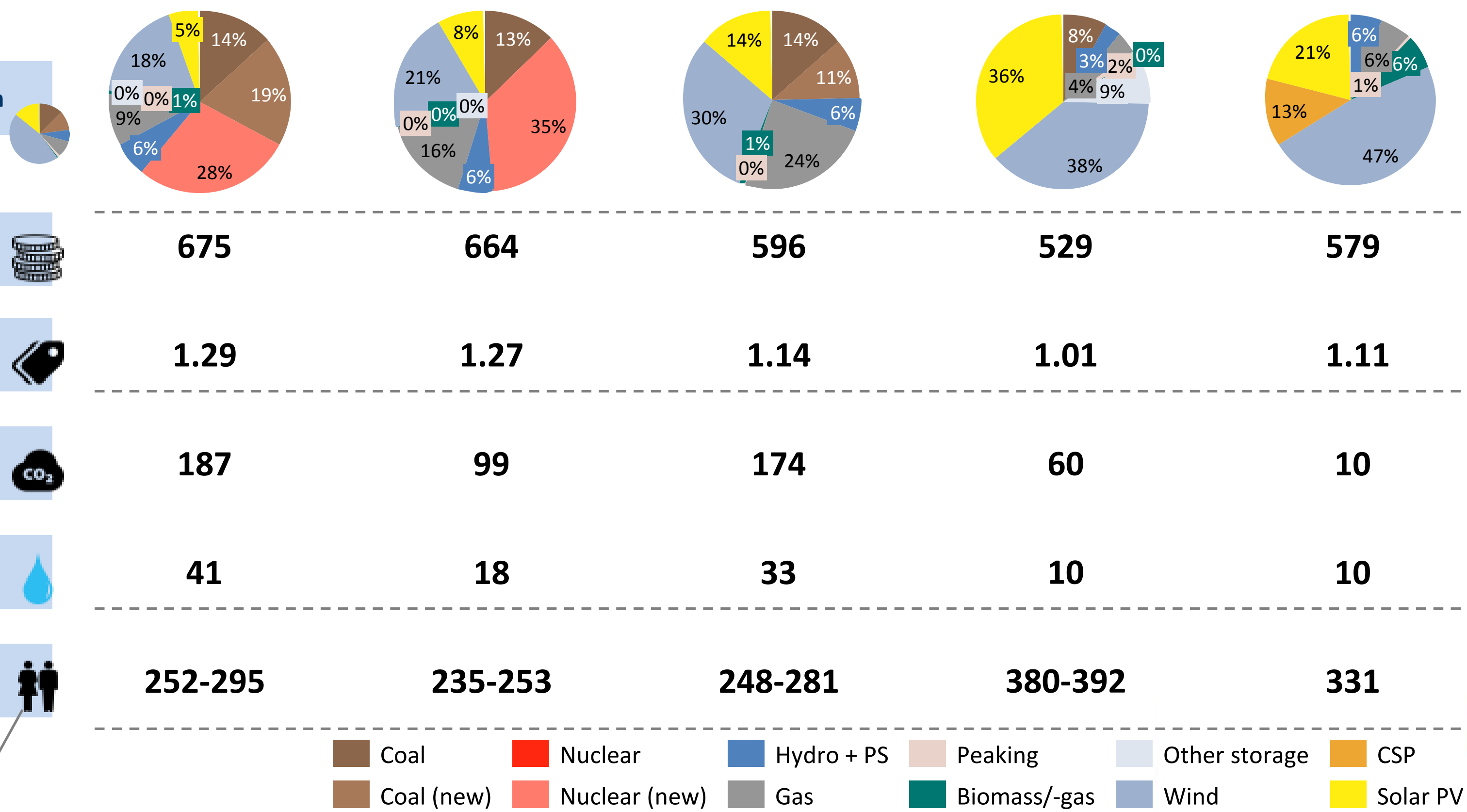
[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)

[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Submitted to DoE on 31 March 2017

Least Cost is ≈R135-145 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

2050		As per Draft IRP 2016: **IRP 2016 Base Case** ("Expected" costs)	As per Draft IRP 2016: **IRP 2016 Carbon Budget** ("Expected" costs)	As per DoE: **Unconstrained Base Case** ("Expected" costs)	**Least Cost** ("Expected" costs)	**Decarbonised** ("Expected" costs)
Energy Mix in 2050	**Demand: 522 TWh**					
Cost in 2050	**Total system cost**[1] (R-billion/yr)	675	664	596	529	579
	Average tariff (R/kWh)	1.29	1.27	1.14	1.01	1.11
Environ-ment in 2050	**CO_2 emissions** (Mt/yr)	187	99	174	60	10
	Water usage (billion-litres/yr)	41	18	33	10	10
Jobs[2] in 2050	**Direct & supplier** ('000)	252-295	235-253	248-281	380-392	331



Because of lack of data, zero jobs for biomass/-gas assumed (affects Decarbonised)

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)

[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Summary:
A mix of solar PV, wind and flexible power generators is least cost

It is cost-optimal to aim for >70% renewable energy share by 2050

- Solar PV, wind and flexible power generators (e.g. gas, CSP, hydro, biogas, demand response) are the cheapest new-build mix for the South African power system
- There is no technical limitation to solar PV and wind penetration over the planning horizon until 2050

“Clean” and “least-cost” is not a trade-off anymore: South Africa can de-carbonise its electricity sector at <u>negative</u> carbon-avoidance cost

- The “Least Cost” mix is ><u>70 billion per year</u> cheaper by 2050 than the current Draft IRP 2016 Base Case
- Additionally, Least Cost mix reduces CO_2 emissions by 55% (≈-100 Mt/yr) over Draft IRP 2016 Base Case

The IRP and this analysis factor in all first-order cost drivers <u>within</u> the boundaries of the electricity system, but not external costs and benefits of certain electricity mixes that occur <u>outside</u> of the electricity system

Deviations from the Least Cost electricity mix can be quantified to inform policy adjustments
(e.g. forcing in of certain technologies not selected by the least-cost mix like coal, nuclear, pumped storage, CSP, biogas, biomass, etc.)

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Note: Wind and solar PV would have to be 50% more expensive than assumed before the IRP Base Case and the Least Cost case break even
Sources: CSIR analysis

LONG-TERM EXPANSION PLAN RESULTS (SENSITIVITIES)

Agenda

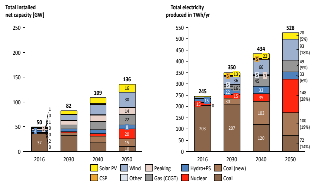
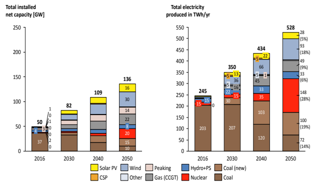
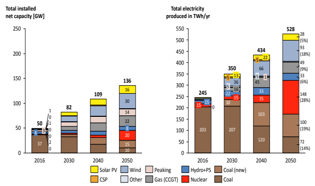
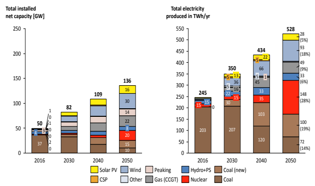
Low demand forecast

- **Base Case**
- **Unconstrained Base Case**
- **Least Cost**

Supply technology tipping points

our future through science

Overview of sensitivities

Sensitivity		Source	Difference to Draft IRP 2016 Base Case
Base Case (Low demand)		**CSIR**	**Low demand (EIUG)**
"Unconstrained Base Case" (Low demand)		**CSIR**	**Low demand (EIUG)** **No constraints on new build technologies**
Least Cost (Low demand)		**CSIR**	**Low demand (EIUG)** **No constraints on new build technologies** **RE costing aligned with latest REIPPPP** **Demand shaping from residential EWHs**
Supply technology tipping points		**CSIR**	**Least cost scenario input assumptions** **Lower costs for supply technologies not in least cost scenario e.g. nuclear, CSP etc**

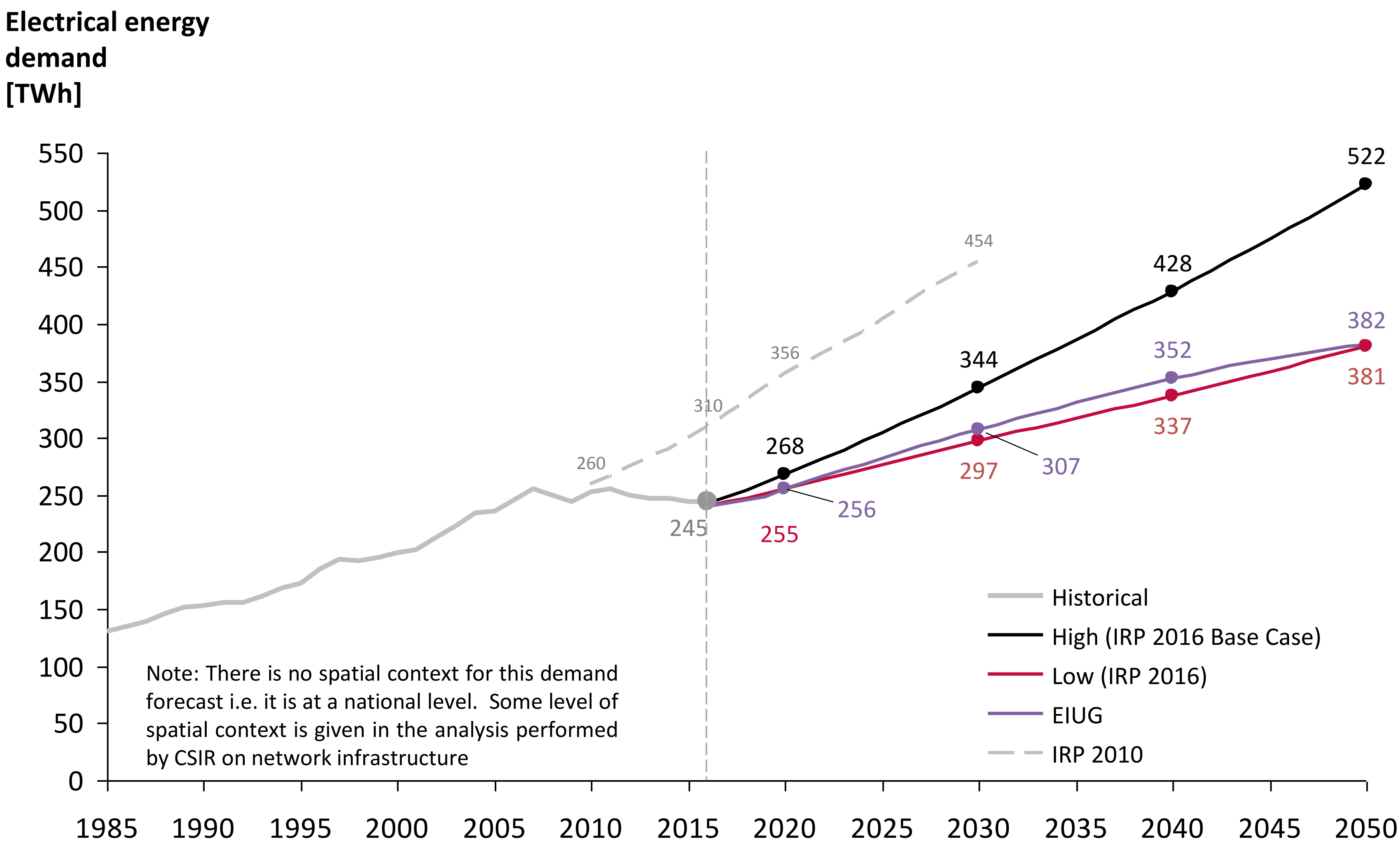
Agenda

Low demand forecast

- Base Case
- Unconstrained Base Case
- Least Cost

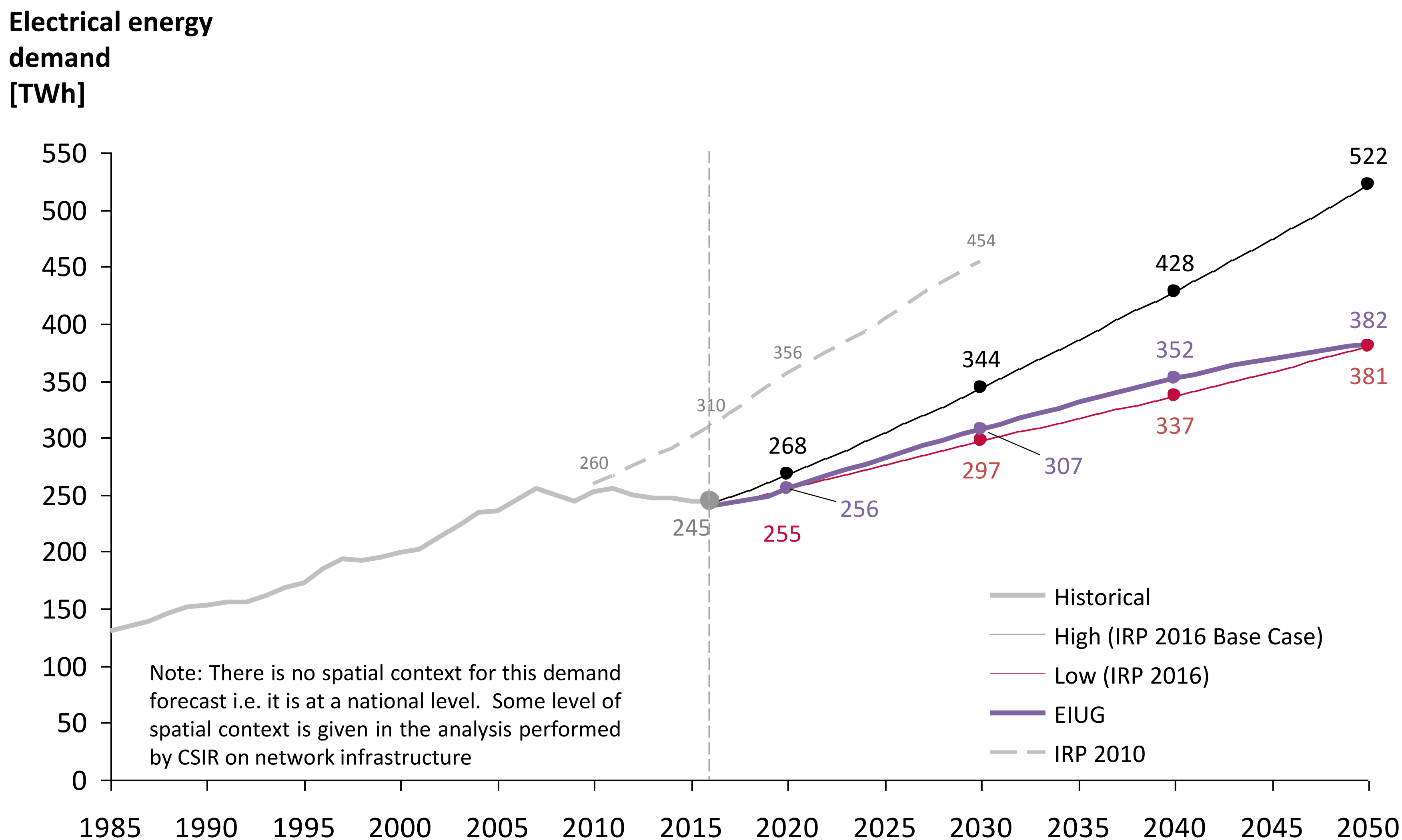
Supply technology tipping points

Demand forecasts



Sources: CSIR analysis

Lower demand forecast as per EIUG applied



Sources: CSIR analysis

Agenda

Low demand forecast

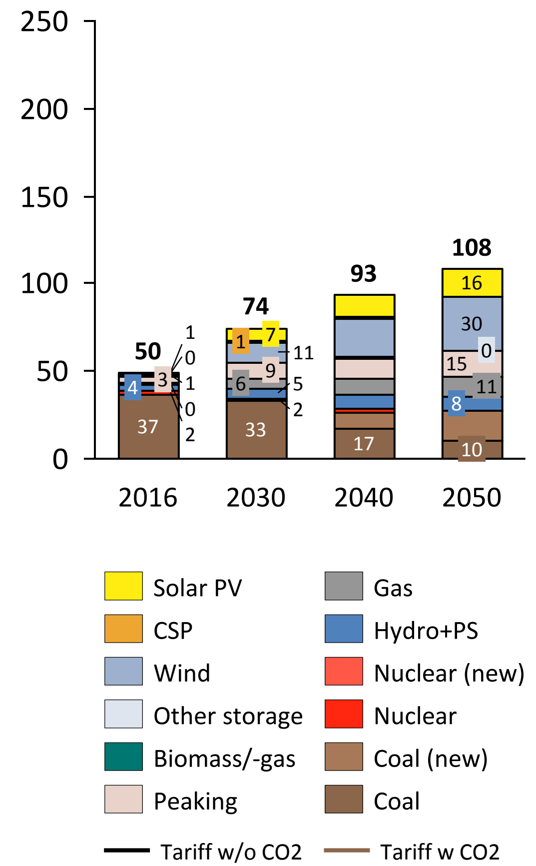
- **Base Case**
- Unconstrained Base Case
- Least Cost

Supply technology tipping points

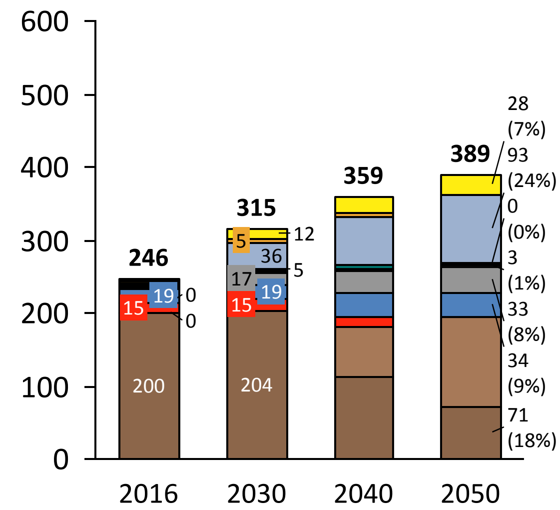
Scenario: Base Case (Low Demand)

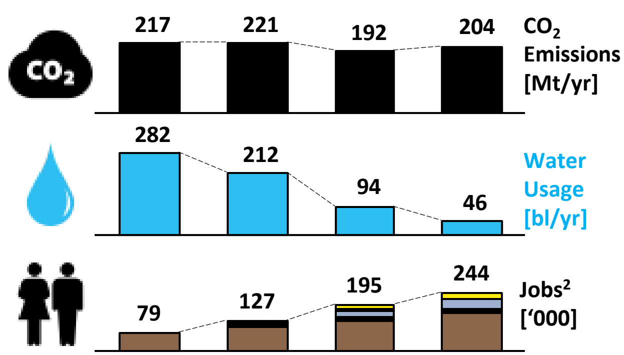
Significant new coal , some wind/PV - ≈R480-bln/yr cost in 2050

Installed Capacity

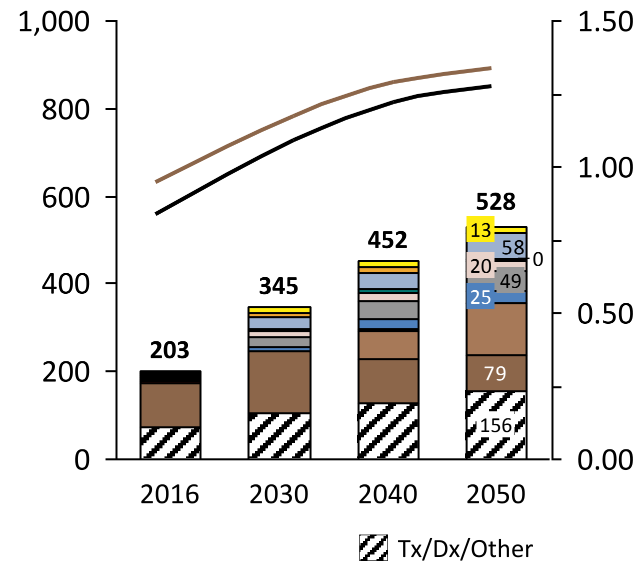


Energy Produced





System cost and average tariff



Difference to Draft IRP 2016 Base Case

- Low demand (EIUG)

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; [2] Direct and supplier jobs only; Sources: CSIR; Eskom

Agenda

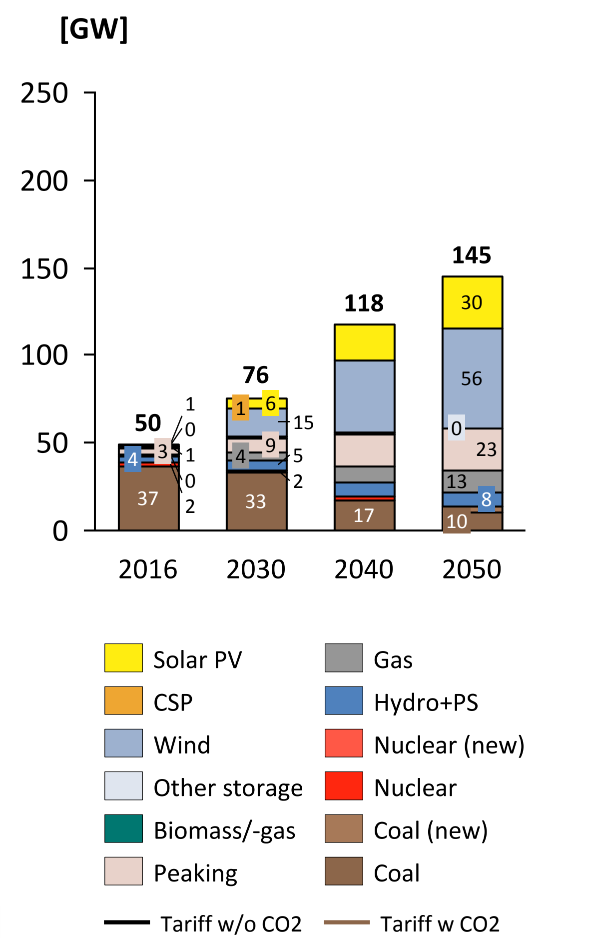
Low demand forecast

- Base Case
- **Unconstrained Base Case**
- Least Cost

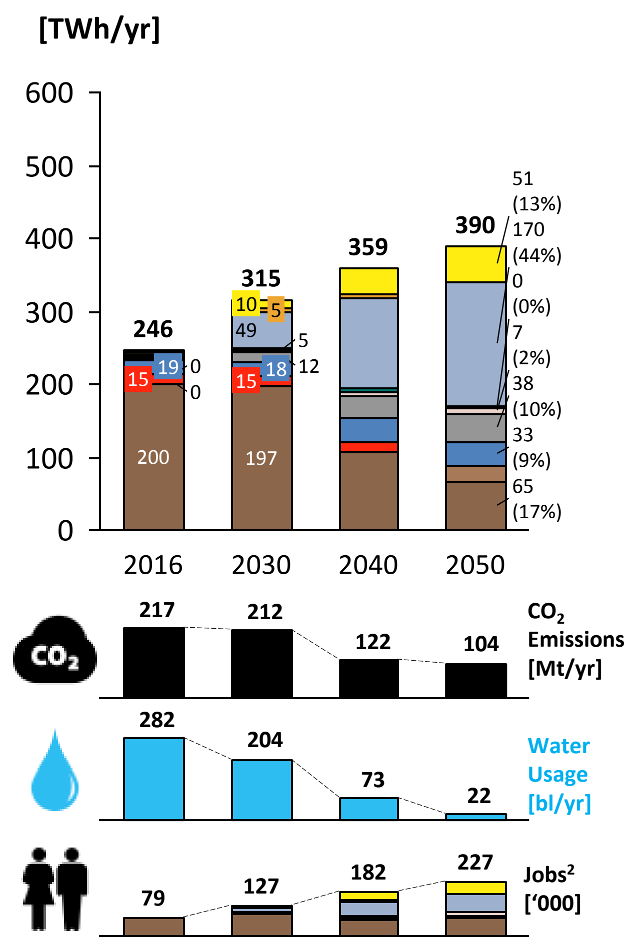
Supply technology tipping points

Scenario: Unconstrained Base Case (Low Demand)

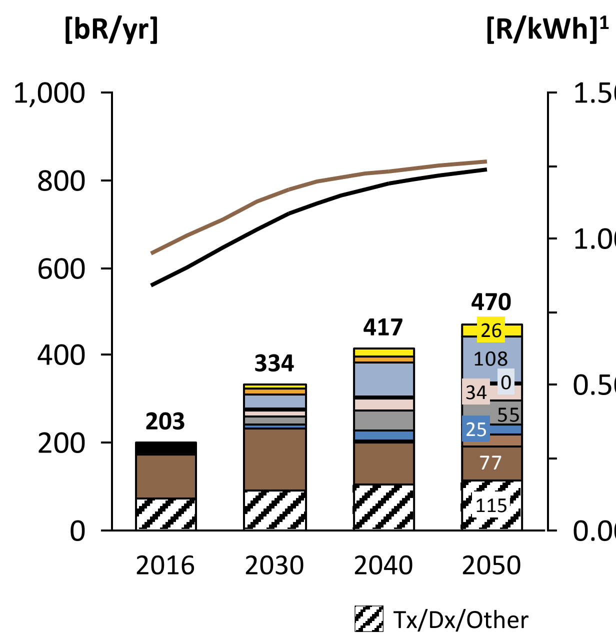
Installed Capacity



Energy Produced



System cost and average tariff



Difference to Draft IRP 2016 Base Case

- Low demand (EIUG)
- No constraints on new build technologies

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; [2] Direct and supplier jobs only; Sources: CSIR; Eskom

Agenda

Low demand forecast

- Base Case
- Unconstrained Base Case
- **Least Cost**

Supply technology tipping points

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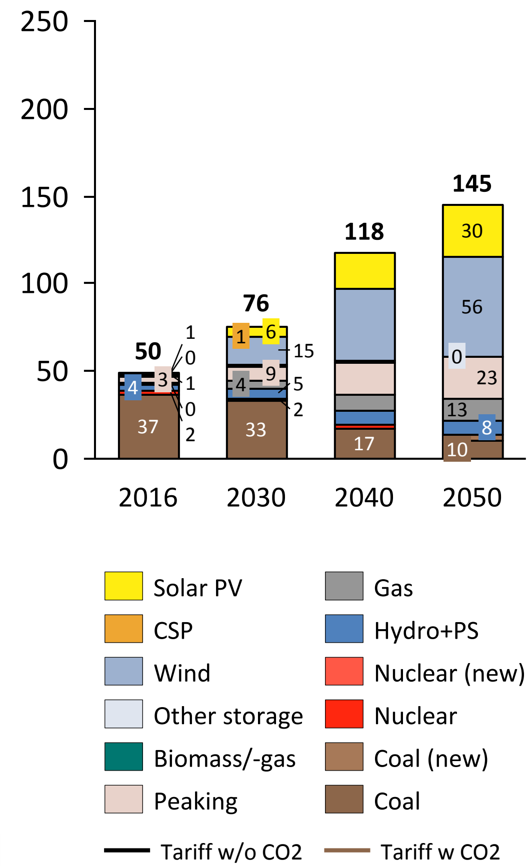
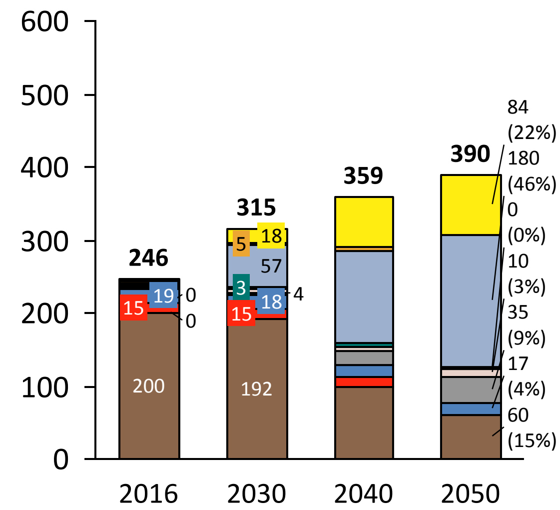
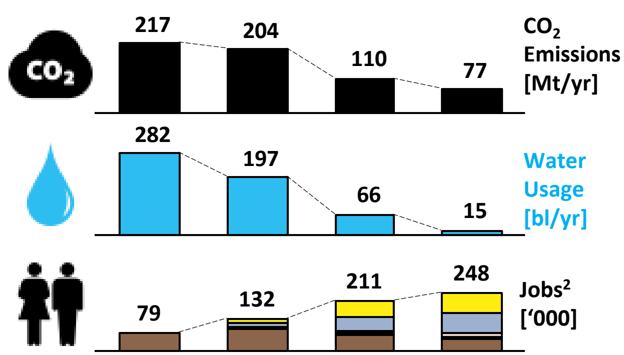
Scenario: Least Cost (Low Demand)

Installed Capacity

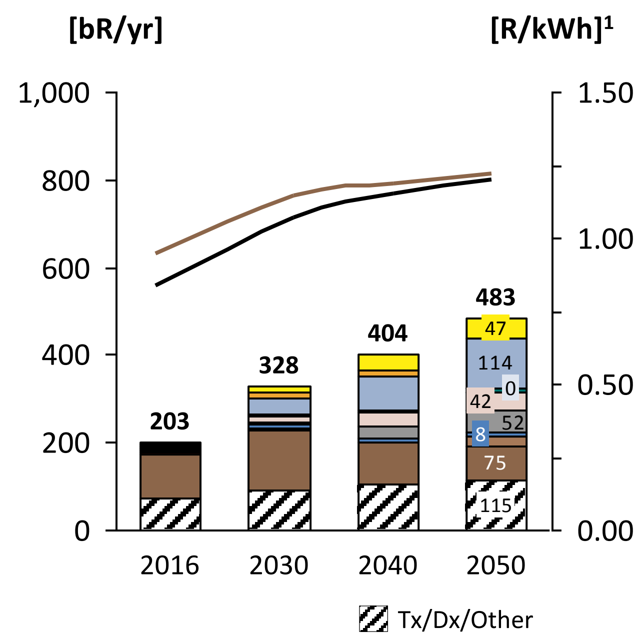


Energy Produced





System cost and average tariff



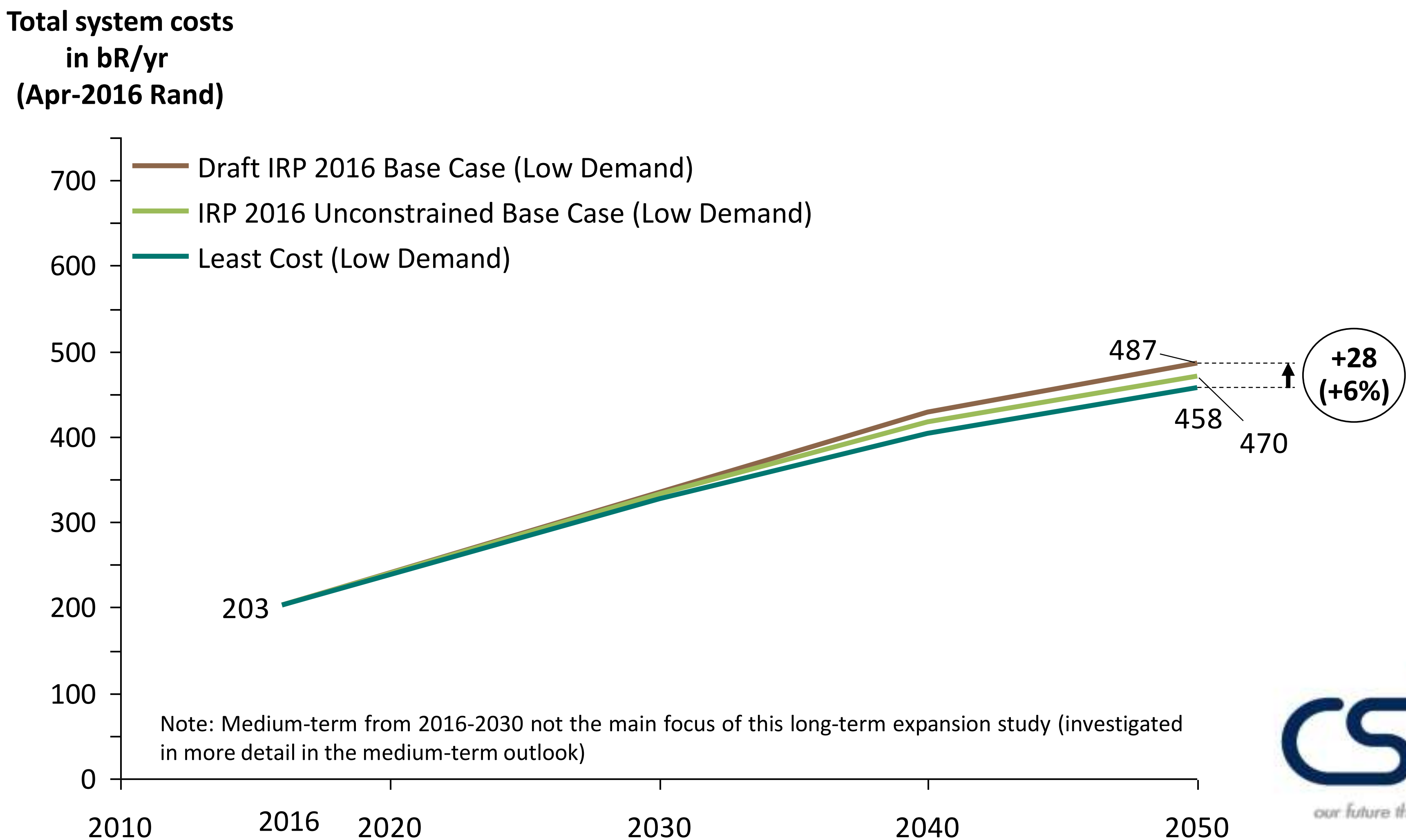
Difference to Draft IRP 2016 Base Case

- Low demand (EIUG)
- No constraints on new build technologies
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHs

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; [2] Direct and supplier jobs only; Sources: CSIR; Eskom

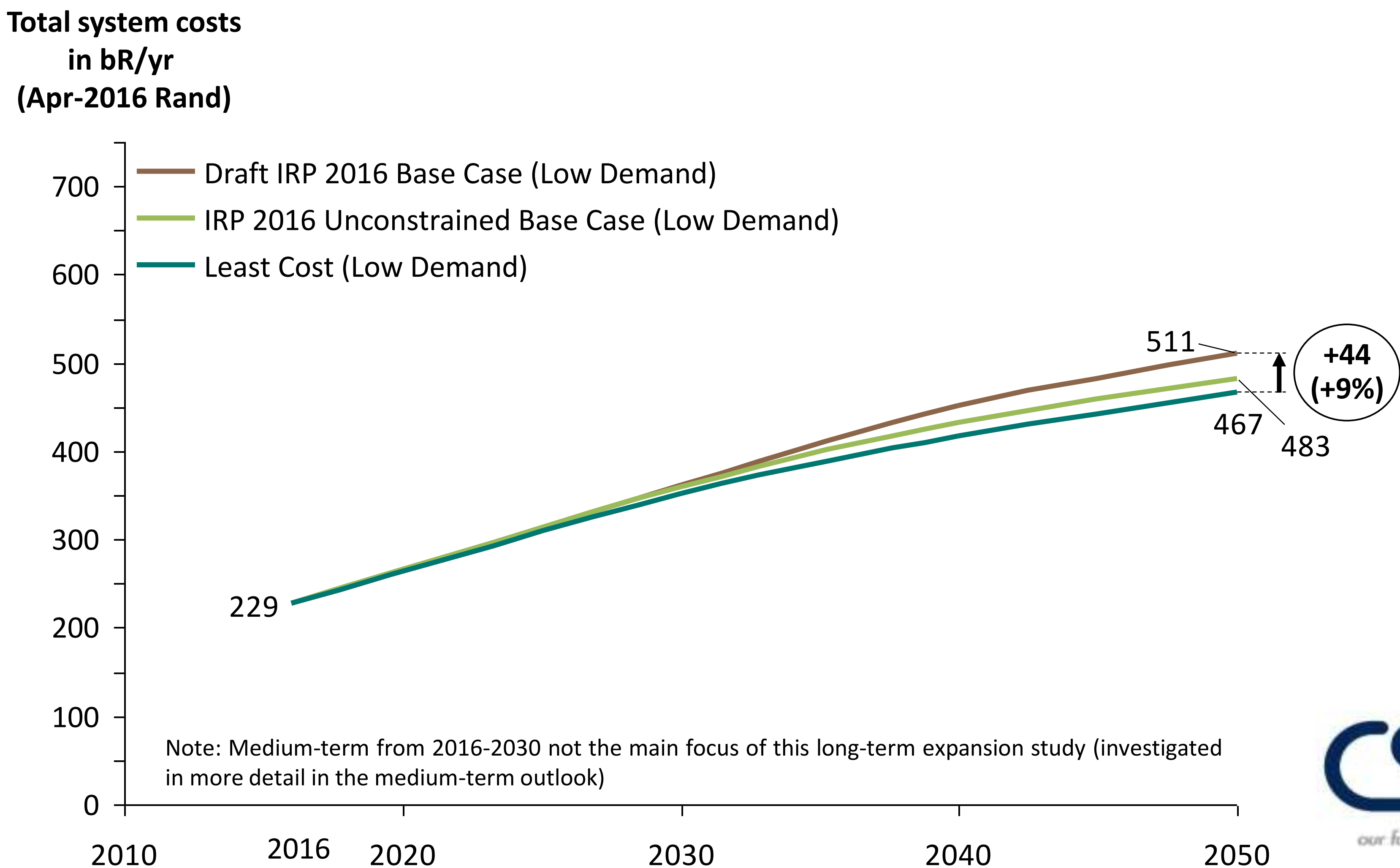
Submitted to DoE on 31 March 2017

Total system cost: IRP 2016 Base Case (Low Demand) ≈R30 bn/year more expensive by 2050 than Least Cost (without cost of CO_2)



Sources: CSIR analysis

Total system cost: Draft IRP 2016 Base Case ≈R45 bn/year more expensive by 2050 than Least Cost (with cost of CO_2)



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Sources: CSIR analysis

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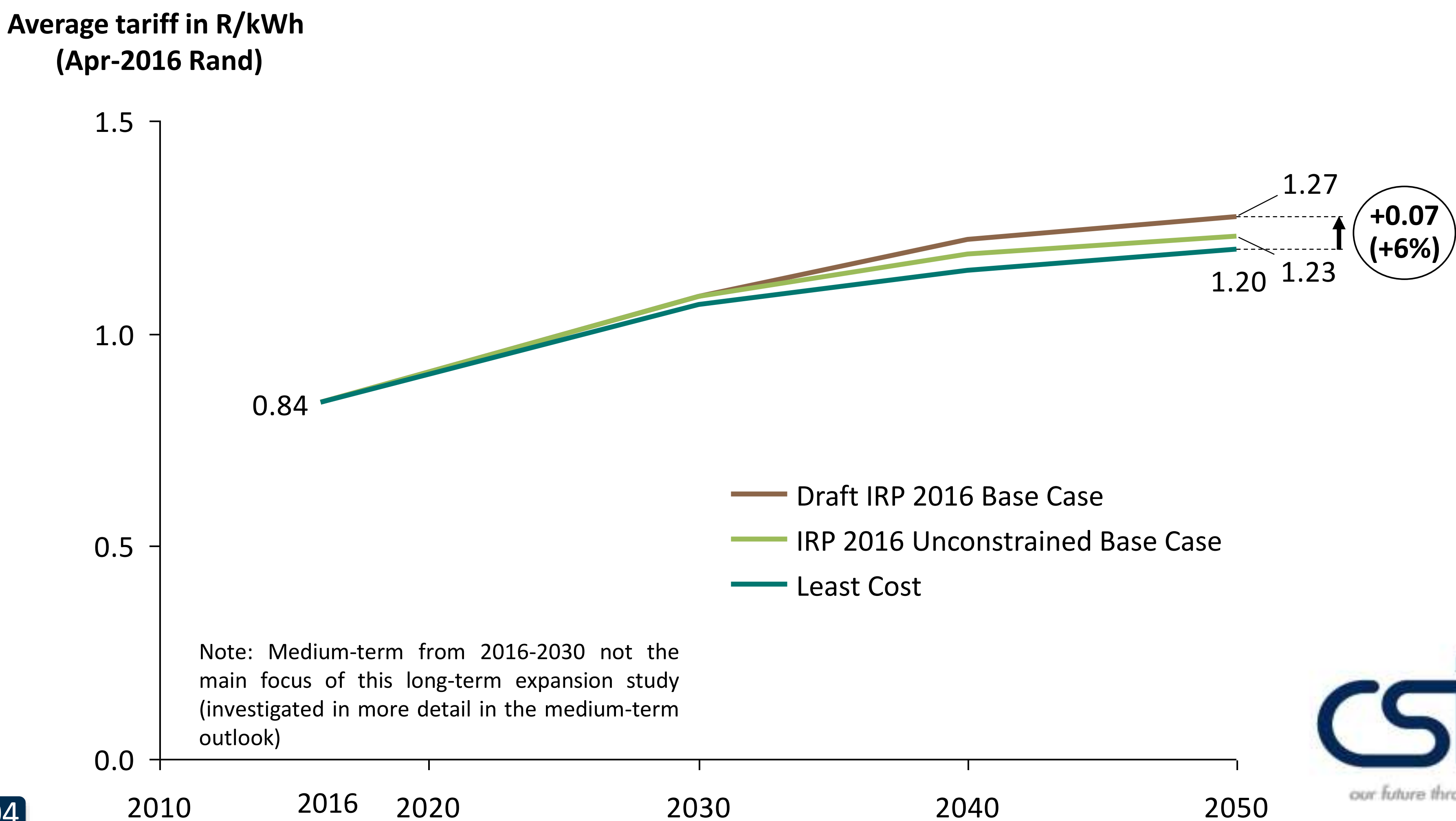
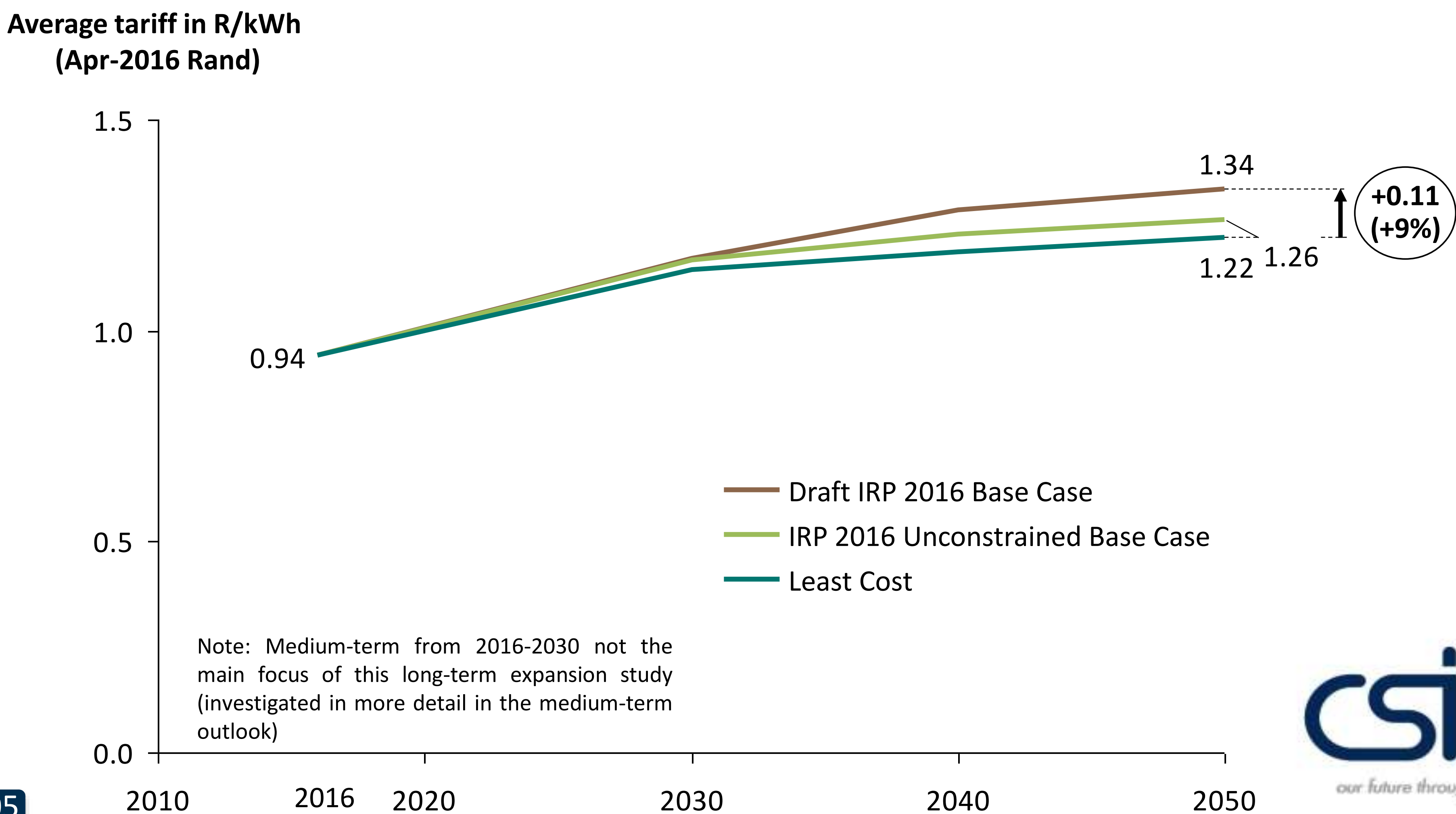
Average tariff (without cost of CO_2): Draft IRP Base Case tariff 7 cents/kWh higher than Least Cost by 2050



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

Average tariff (with cost of CO_2): Draft IRP Base Case tariff 11 cents/kWh higher than Least Cost by 2050



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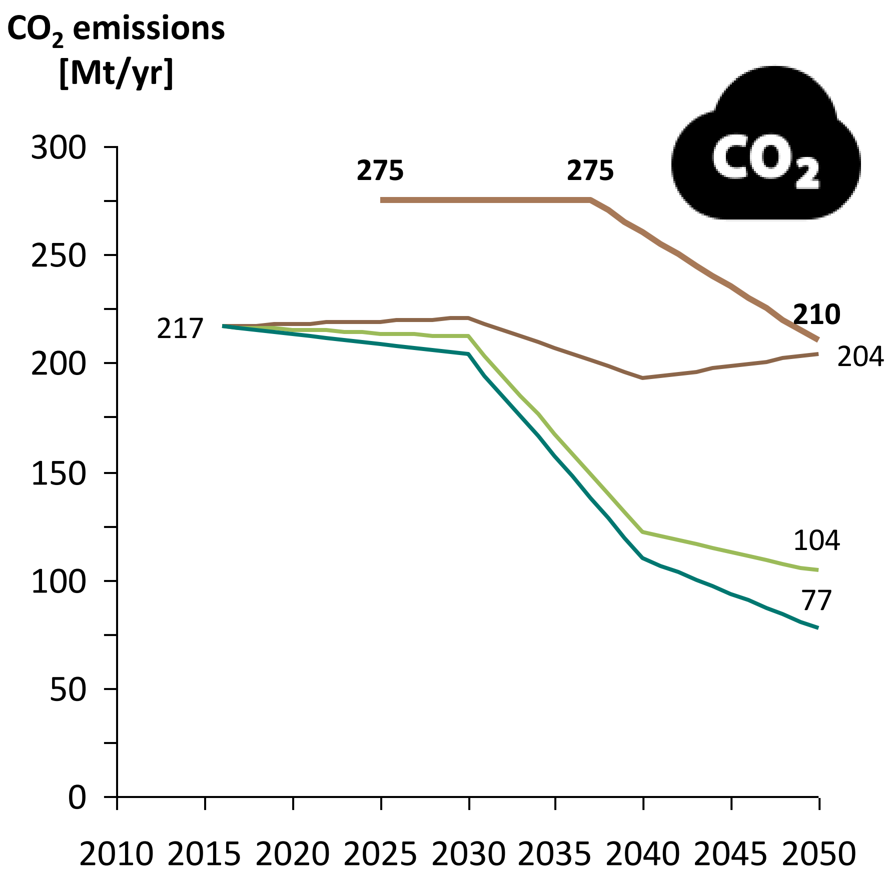
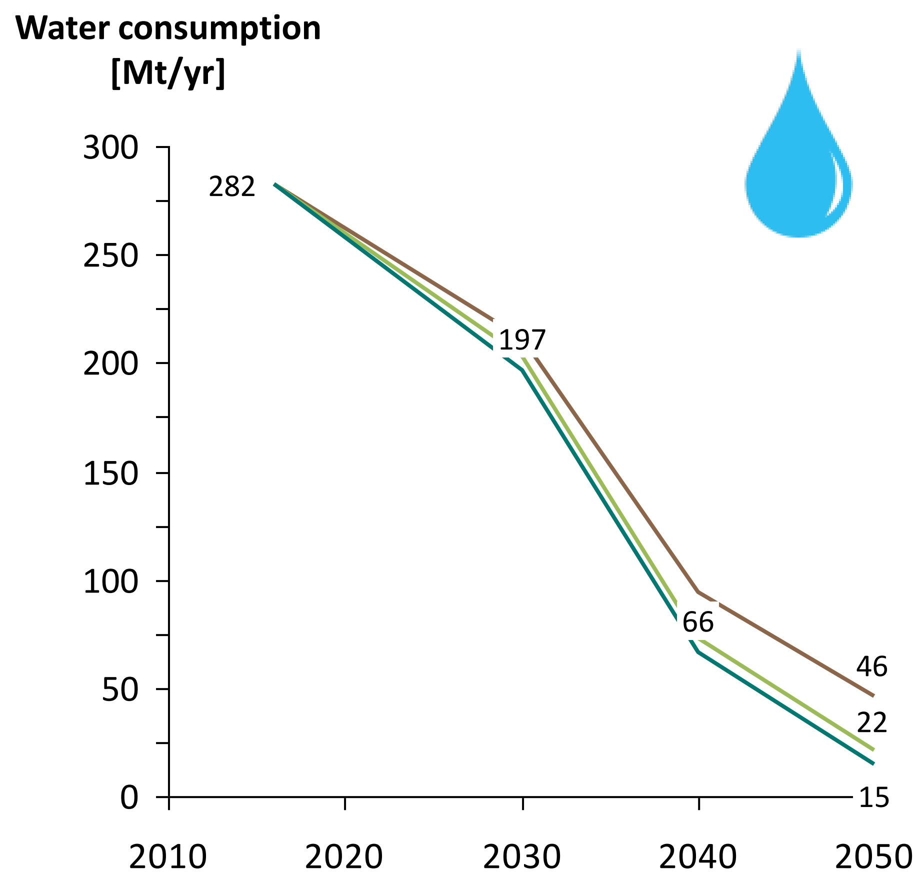
Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

CO_2 emissions trajectories and water usage summary



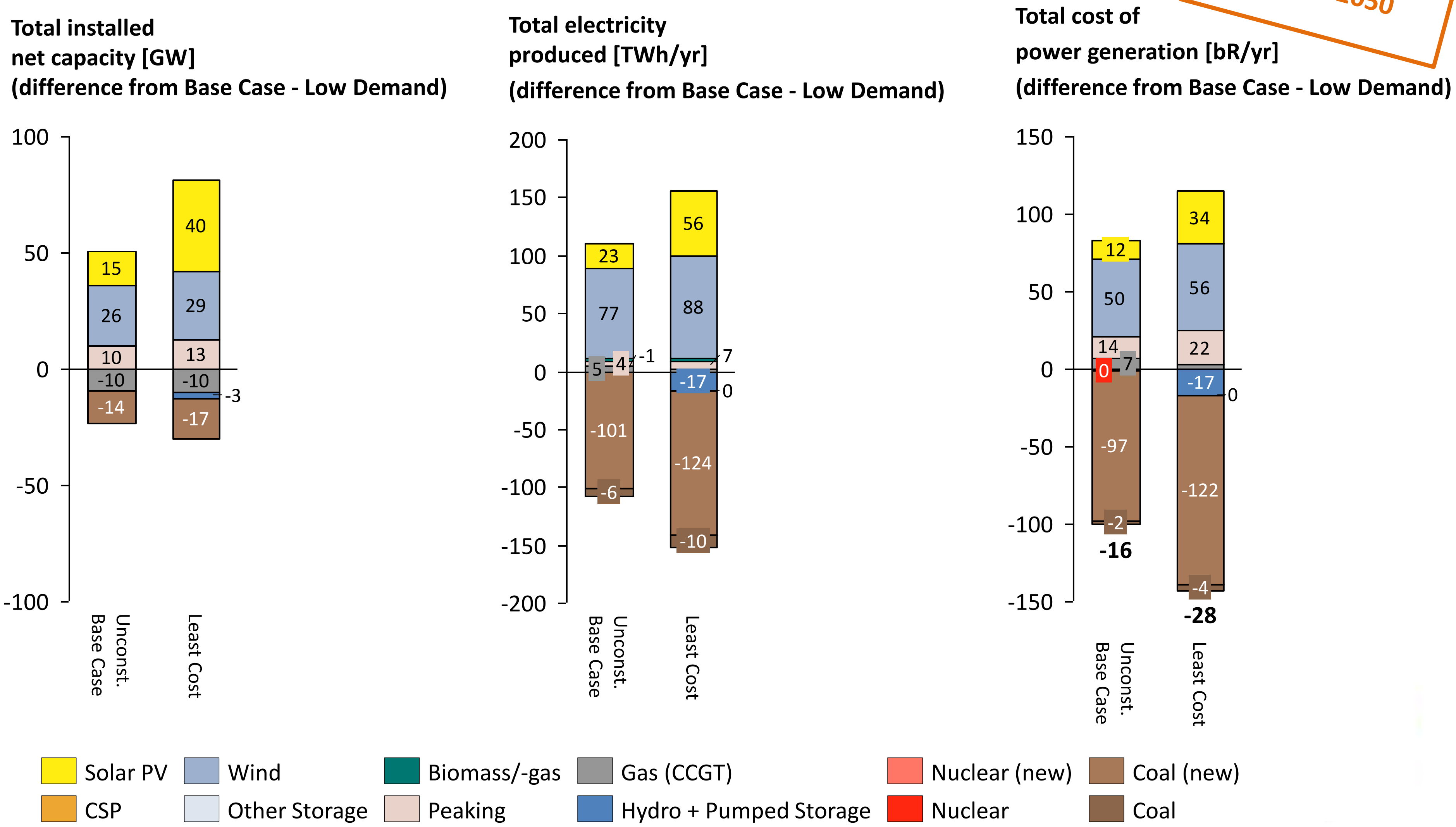


Draft IRP 2016 Base Case
IRP 2016 Unconstrained Base Case
Least Cost
PPD Moderate

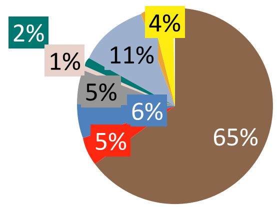
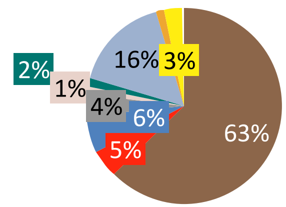
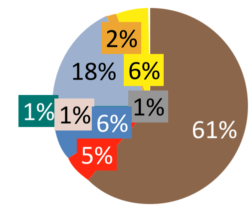
Source: CSIR analyses

The Least-Cost and Decarbonised scenarios install significantly more wind and solar PV as well as more flexible peaking capacity

By year 2050



Low Demand: Least Cost is ~R5 billion/yr cheaper by 2030 than Base Case

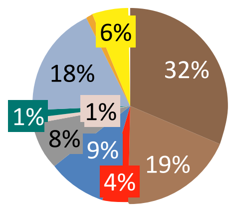
2030		Base Case (Low Demand)	Unconstrained Base Case (Low Demand)	Least Cost (Low Demand)
Energy Mix in 2030	**Demand: 307 TWh**			
Cost in 2030	**Total system cost**[1] (R-billion/yr)	334	334	328
	Average tariff (R/kWh)	1.09	1.09	1.07
Environ-ment in 2030	**CO_2 emissions** (Mt/yr)	221	212	204
	Water usage (billion-litres/yr)	212	204	197
Jobs[2] in 2030	**Direct & supplier** ('000)	76-127	78-127	84-132

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

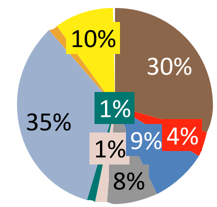
Low Demand: Least Cost is ~R25 billion/yr cheaper by 2040 than Base Case

Energy Mix in 2040 — Demand: 352 TWh

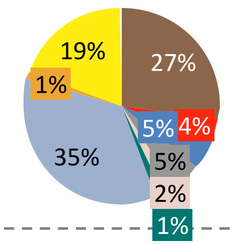
Base Case (Low Demand)



Unconstrained Base Case (Low Demand)



Least Cost (Low Demand)



2040		Base Case (Low Demand)	Unconstrained Base Case (Low Demand)	Least Cost (Low Demand)
Cost in 2040	**Total system cost**[1] (R-billion/yr)	**429**	**417**	**404**
	Average tariff (R/kWh)	**1.22**	**1.19**	**1.15**
Environ-ment in 2040	**CO_2 emissions** (Mt/yr)	**192**	**122**	**110**
	Water usage (billion-litres/yr)	**94**	**73**	**66**
Jobs[2] in 2040	**Direct & supplier** ('000)	**149-195**	**156-182**	**186-210**

Coal | Nuclear | Hydro+PS | Peaking | Other storage | CSP
Coal (new) | Nuclear (new) | Gas | Biomass/-gas | Wind | Solar PV

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

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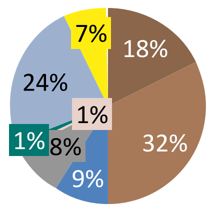
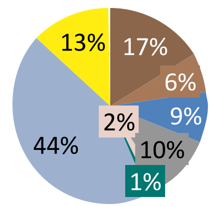
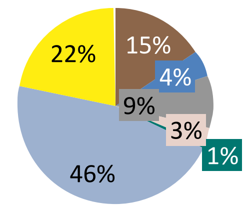
Low Demand: Least Cost is ~R30 billion/yr cheaper by 2050 than Base Case

2050		Base Case (Low Demand)	Unconstrained Base Case (Low Demand)	Least Cost (Low Demand)
Energy Mix in 2050	**Demand: 382 TWh**			
Cost in 2050	**Total system cost[1]** (R-billion/yr)	487	470	458
	Average tariff (R/kWh)	1.27	1.23	1.20
Environ-ment in 2050	**CO_2 emissions** (Mt/yr)	204	104	77
	Water usage (billion-litres/yr)	46	22	15
Jobs[2] in 2050	**Direct & supplier** ('000)	195-244	205-227	233-248

Coal | Coal (new) | Nuclear | Nuclear (new) | Hydro+PS | Gas | Peaking | Biomass/-gas | Other storage | Wind | CSP | Solar PV

[1] Only power generation (Gx) is optimised while cost of transmission (Tx), distribution (Dx) and customer services is assumed as ≈0.30 R/kWh (today's average cost for these items)
[2] Lower value based on McKinsey study (appendix of IEP), higher value based on CSIR assumption with more jobs in the coal industry; Sources: Eskom on Tx, Dx cost; CSIR analysis; flaticon.com

Agenda

Low demand forecast

- Base Case
- Unconstrained Base Case
- Least Cost

Supply technology tipping points

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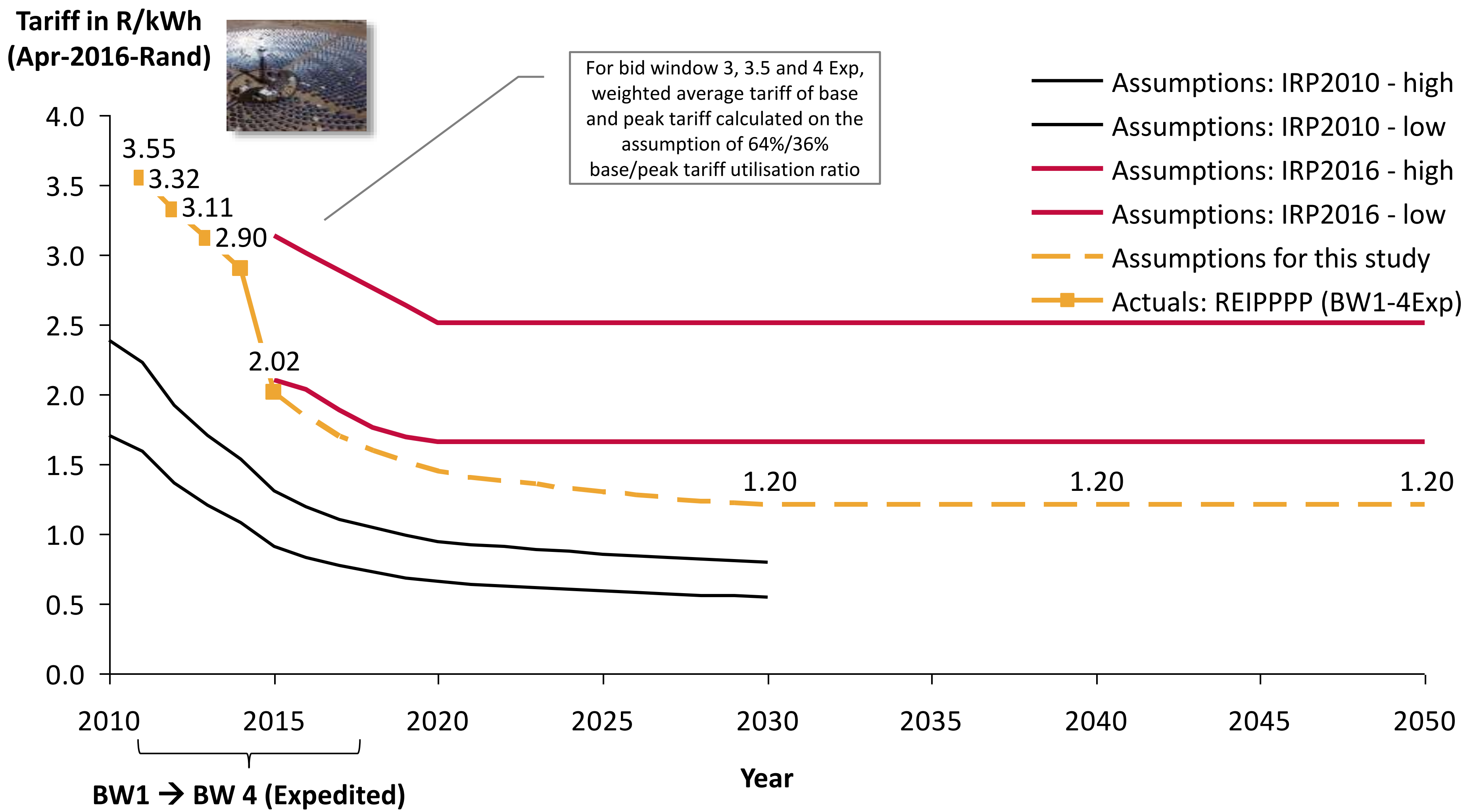
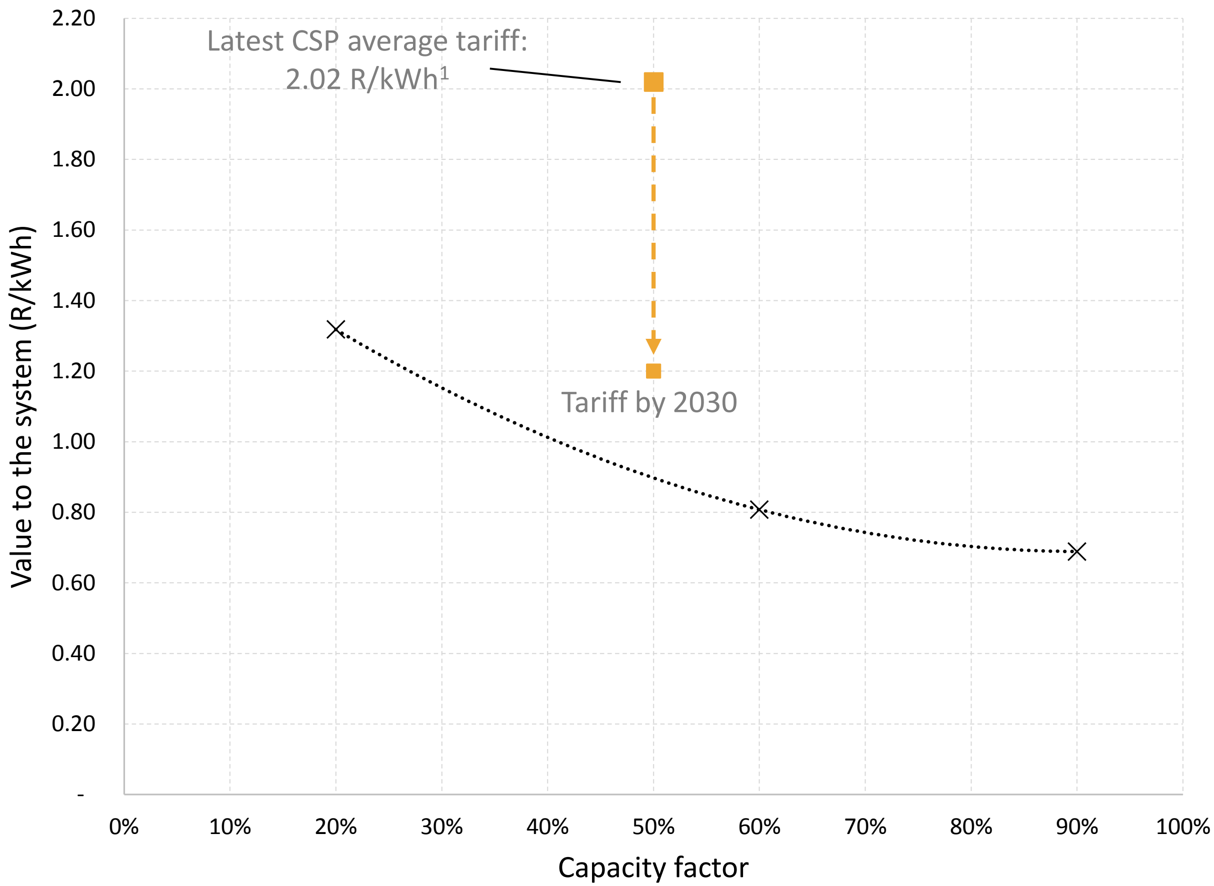
CSIR study cost input assumptions for CSP: Today's latest tariff as starting point, same cost decline as per IRP 2010



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

CSP example sensitivity – CSP would need to be below the curve to be chosen



[1] Weighted average tariff for bid window 3.5 calculated on the assumption of ~50% annual load factor and full utilisation of the 5 peak-tariff hours per day

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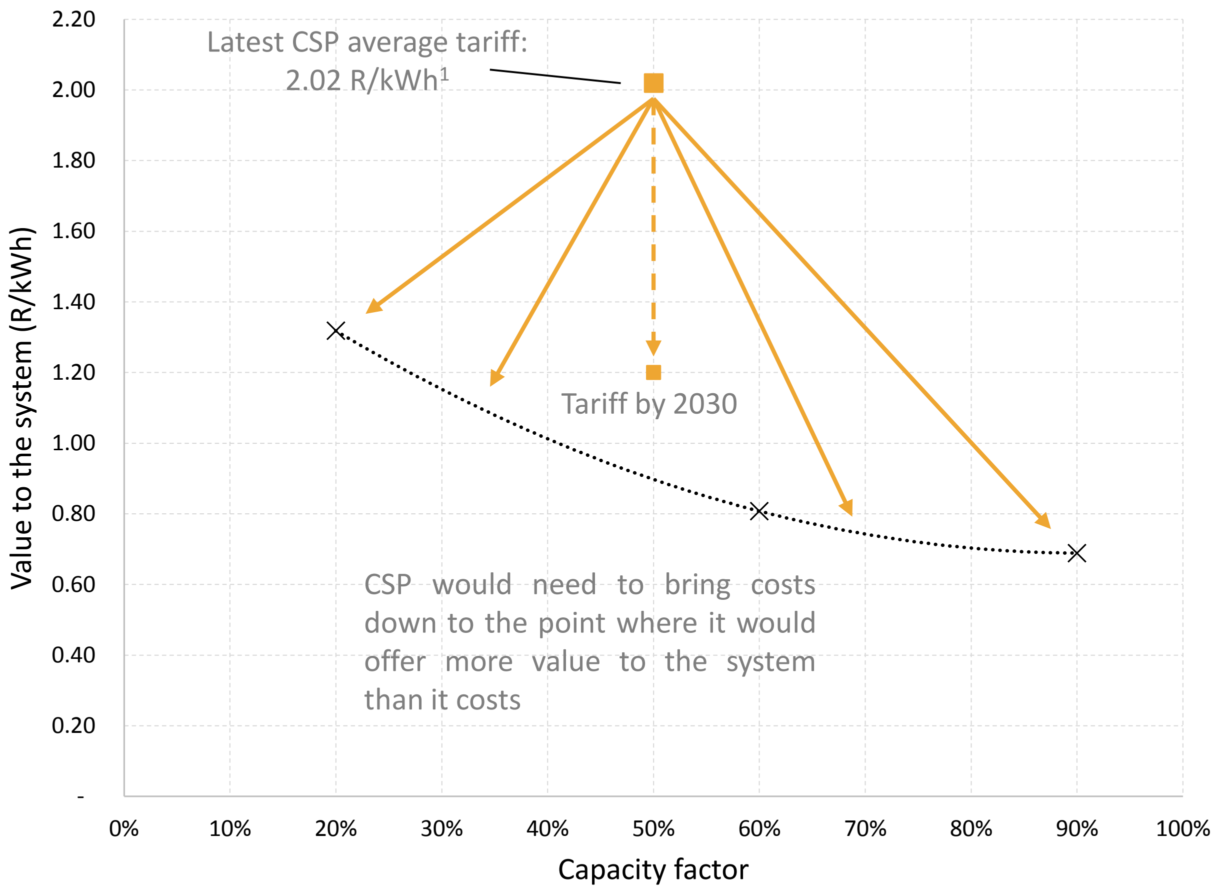
CSP example sensitivity – CSP would need to be below the curve to be chosen



Similar approach should be applied to other technologies not included in the Least Cost capacity expansion plan

[1] Weighted average tariff for bid window 3.5 calculated on the assumption of ~50% annual load factor and full utilisation of the 5 peak-tariff hours per day

MEDIUM TERM OUTLOOK

our future through science

Agenda

Scenarios

- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
- Least cost
- Linear build-out to 2030
- Scenario comparison and summary

Sensitivities

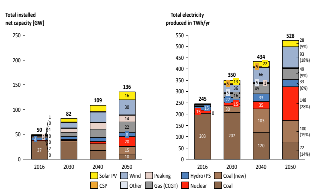
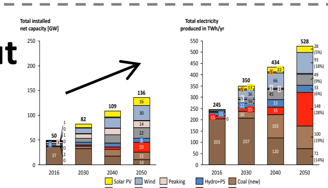
- Least cost (low demand forecast)
- Linear build-out to 2030 (low demand forecast)
- Low supply (low plant performance and delayed new builds)
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment

our future through science

Overview of scenarios

Scenario	Source	Difference to Draft IRP 2016 Base Case
Draft IRP 2016 Base Case 	**Department of Energy** Draft IRP 2016 as of November 2016	**N/A**
Draft IRP 2016 Carbon Budget 	**Department of Energy** Draft IRP 2016 as of November 2016	**Tighter carbon reduction targets**
Least Cost 	**CSIR**	**No constraints on any new build technologies** **RE costing aligned with latest REIPPPP** **Demand shaping from residential EWHs**
Linear build-out 	**CSIR**	**Spread wind and solar PV new build from 2030 Least Cost result linearly from 2021** **Re-optimise other supply options around linear build**

Scenarios

Draft IRP 2016: Base Case

Draft IRP 2016: Carbon Budget

Least cost

Linear build-out to 2030

Scenario comparison and summary

Sensitivities

Least cost (low demand forecast)

Linear build-out to 2030 (low demand forecast)

Low supply (low plant performance and delayed new builds)

Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

Over-investment

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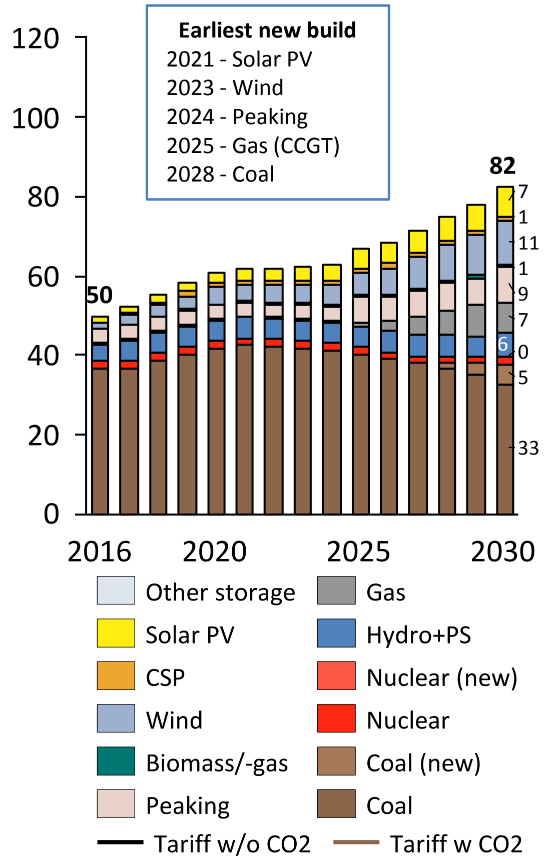
Scenario: Draft IRP 2016 Base Case

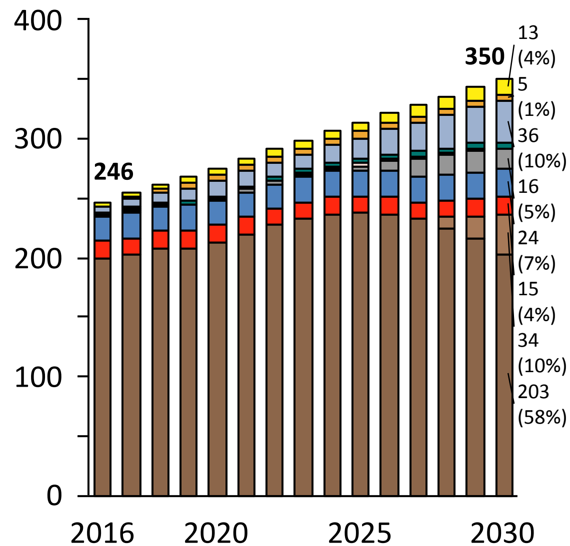
14% solar PV/wind energy share by 2030, R384 billion cost in 2030

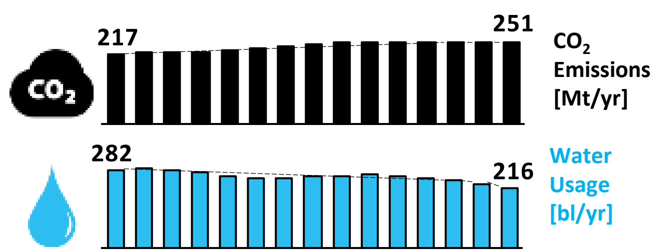
As per Draft IRP 2016

Capacity Installed

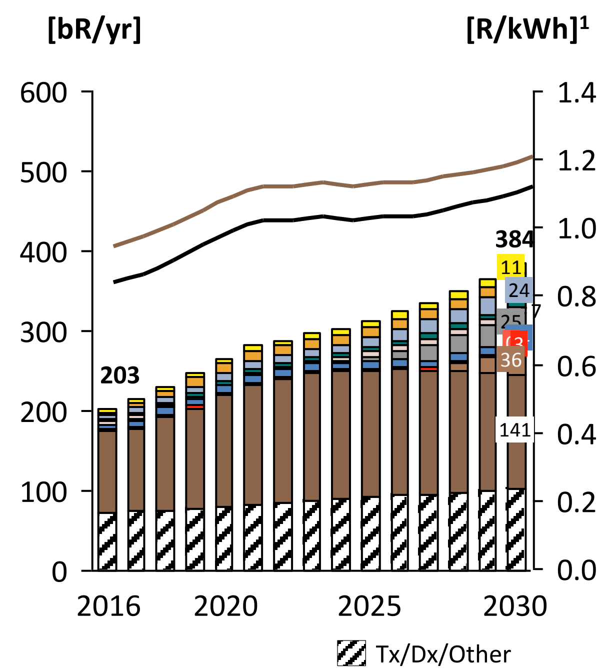


Energy Produced





Cost and Tariff



Difference to Draft IRP 2016 Base Case

- N/A

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

Agenda

Scenarios

- Draft IRP 2016: Base Case
- **Draft IRP 2016: Carbon Budget**
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Sensitivities

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- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment

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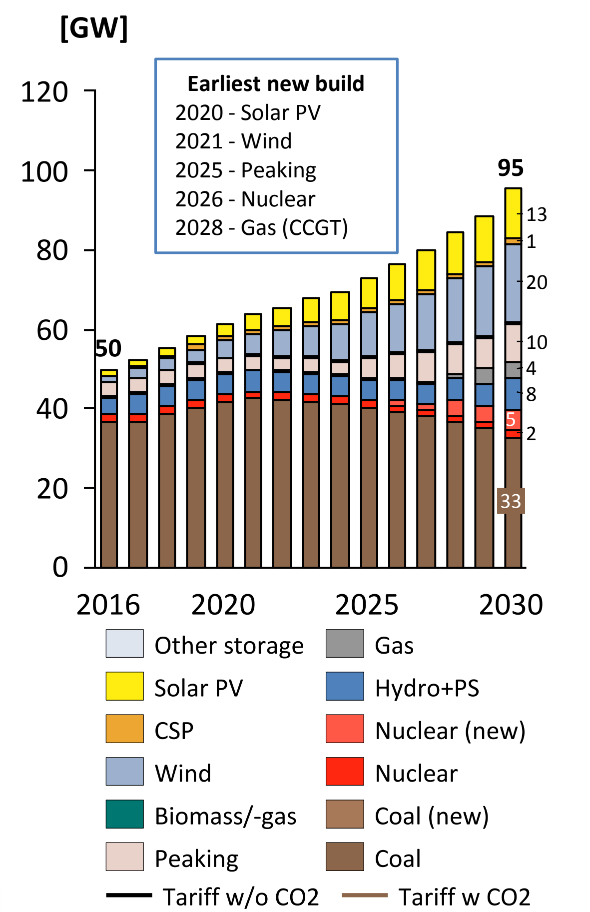
Scenario: Draft IRP 2016 Carbon Budget

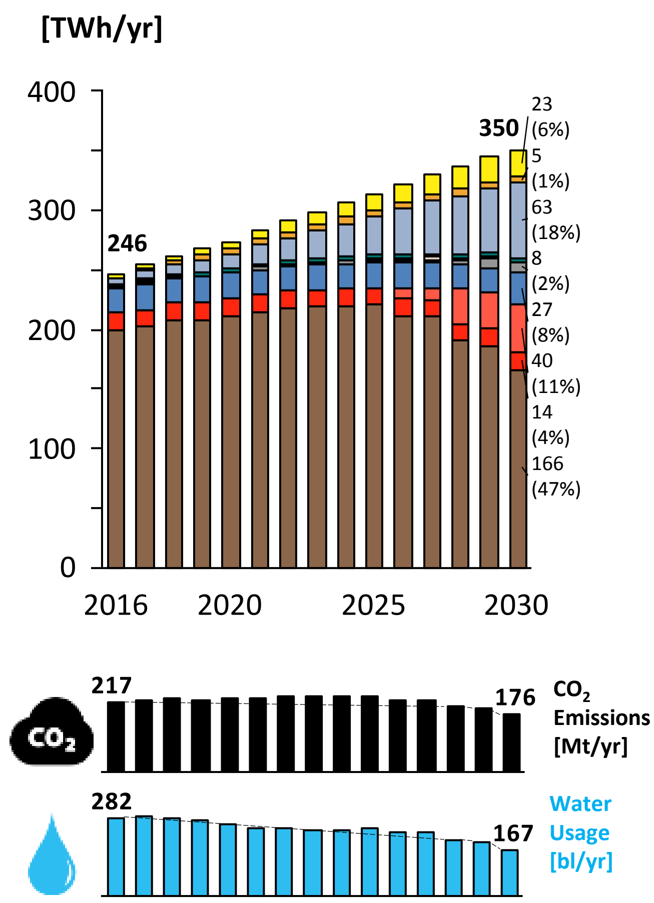
24% solar PV/wind energy share by 2030, R404 billion cost in 2030

As per Draft IRP 2016

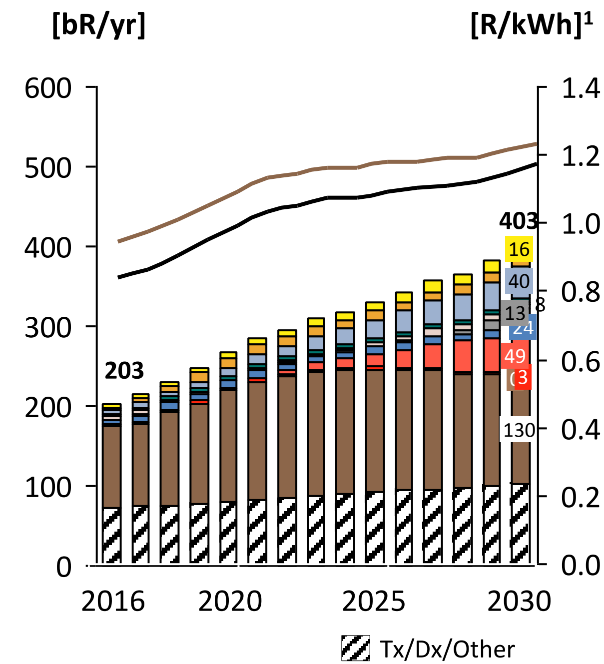
Capacity Installed



Energy Produced



Cost and Tariff



Difference to Draft IRP 2016 Base Case

- Tighter carbon reduction targets

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

Agenda

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- Least cost (low demand forecast)
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What-If analysis

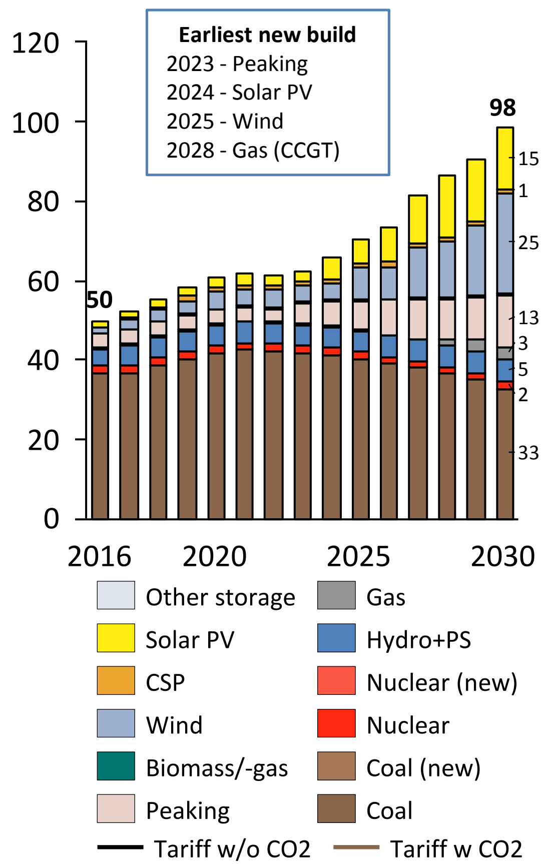
- Over-investment

CSIR our future through science

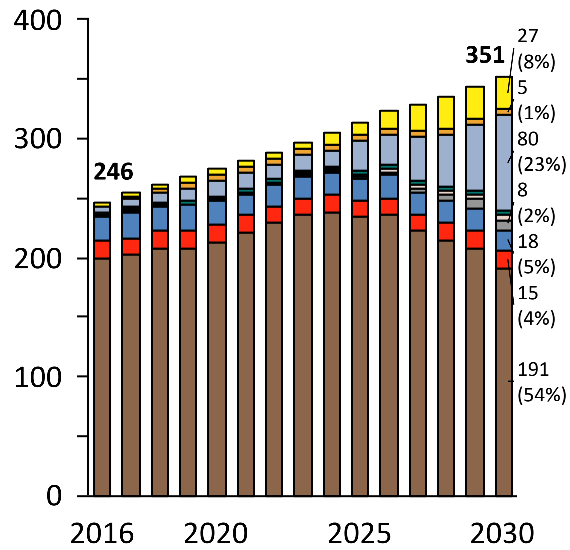
Scenario: Least Cost

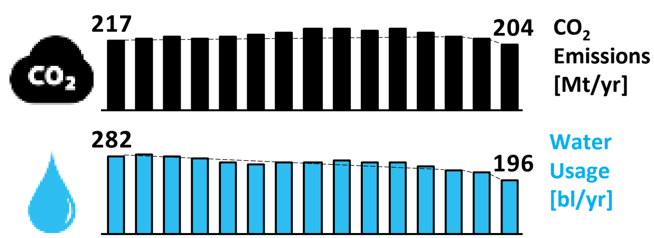
31% solar PV/wind energy share by 2030, R367 billion cost in 2030

Capacity Installed

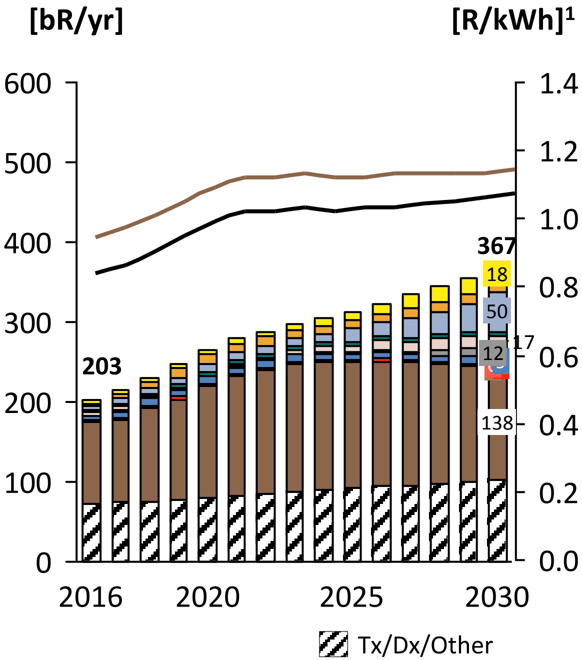


Energy Produced





Cost and Tariff



Difference to Draft IRP 2016 Base Case

- No build-out constraints on any technology
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHs

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

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- Least cost (low demand forecast)
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What-If analysis

- Over-investment

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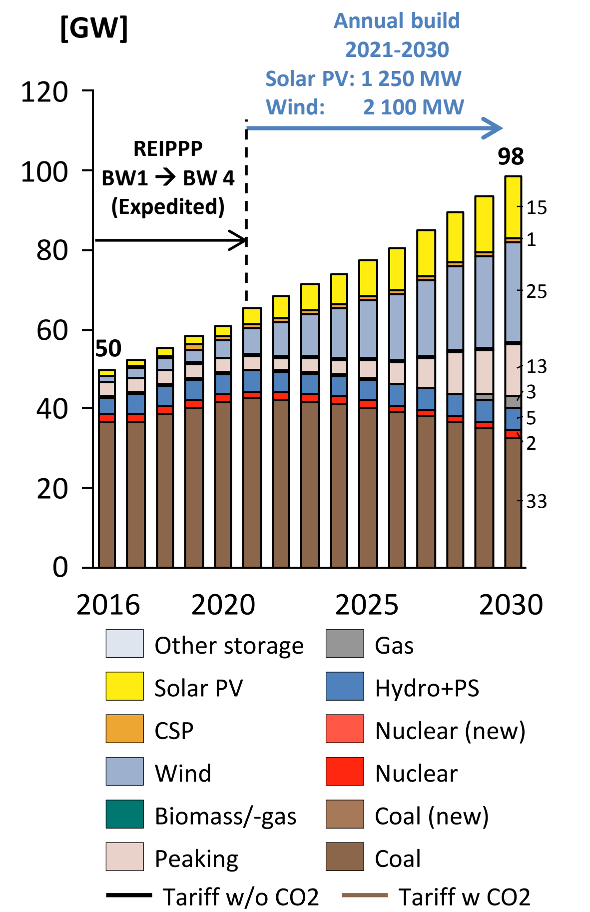
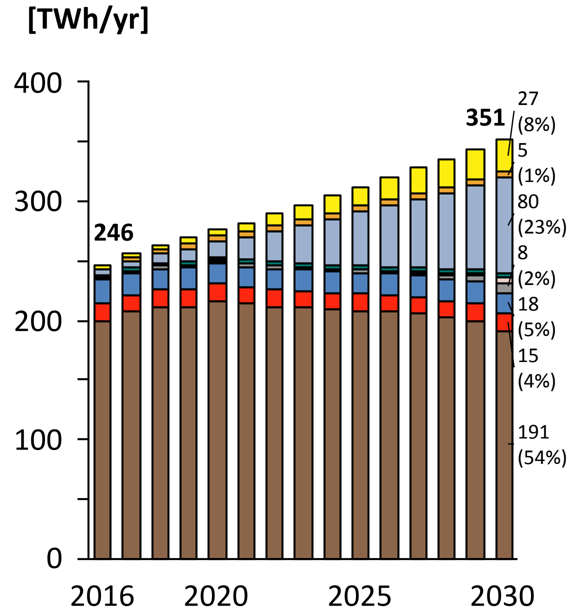
Scenario: Linear build-out of wind and Solar PV to 2030

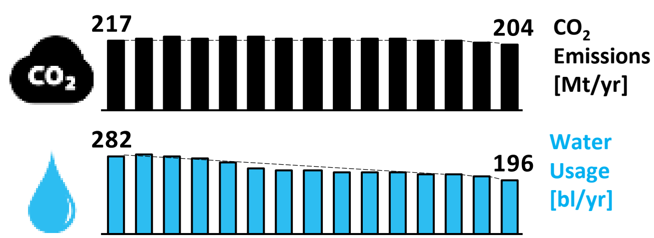
31% solar PV/wind energy share by 2030, R367 billion cost in 2030

Capacity Installed

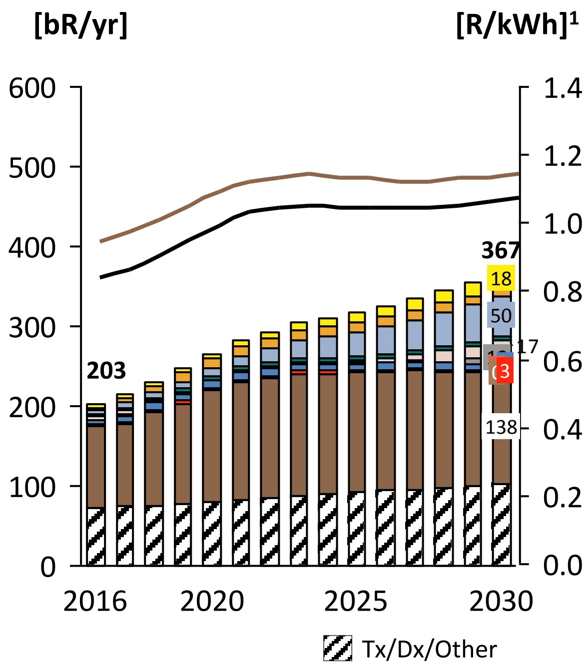


Energy Produced





Cost and Tariff

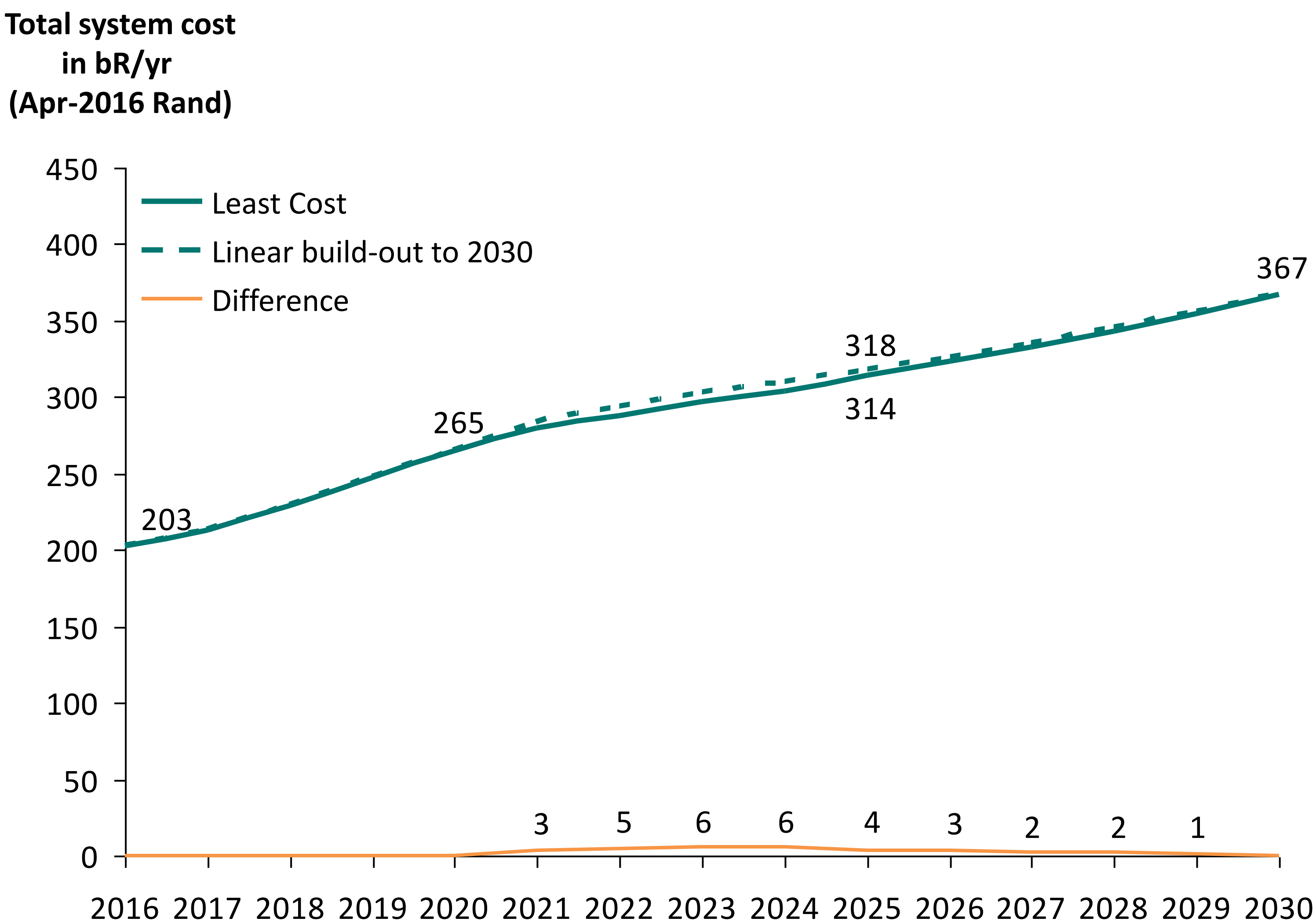


Difference to Draft IRP 2016 Base Case

- Same assumptions as Least Cost
- 2030 Wind and solar PV build from Least Cost scenario linearly built from 2021 to 2030

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

Shifting wind and solar PV earlier increases system costs (without cost of CO_2) ≈ 1 - 6 R billion/yr between 2021 and 2030



Sources: CSIR analysis

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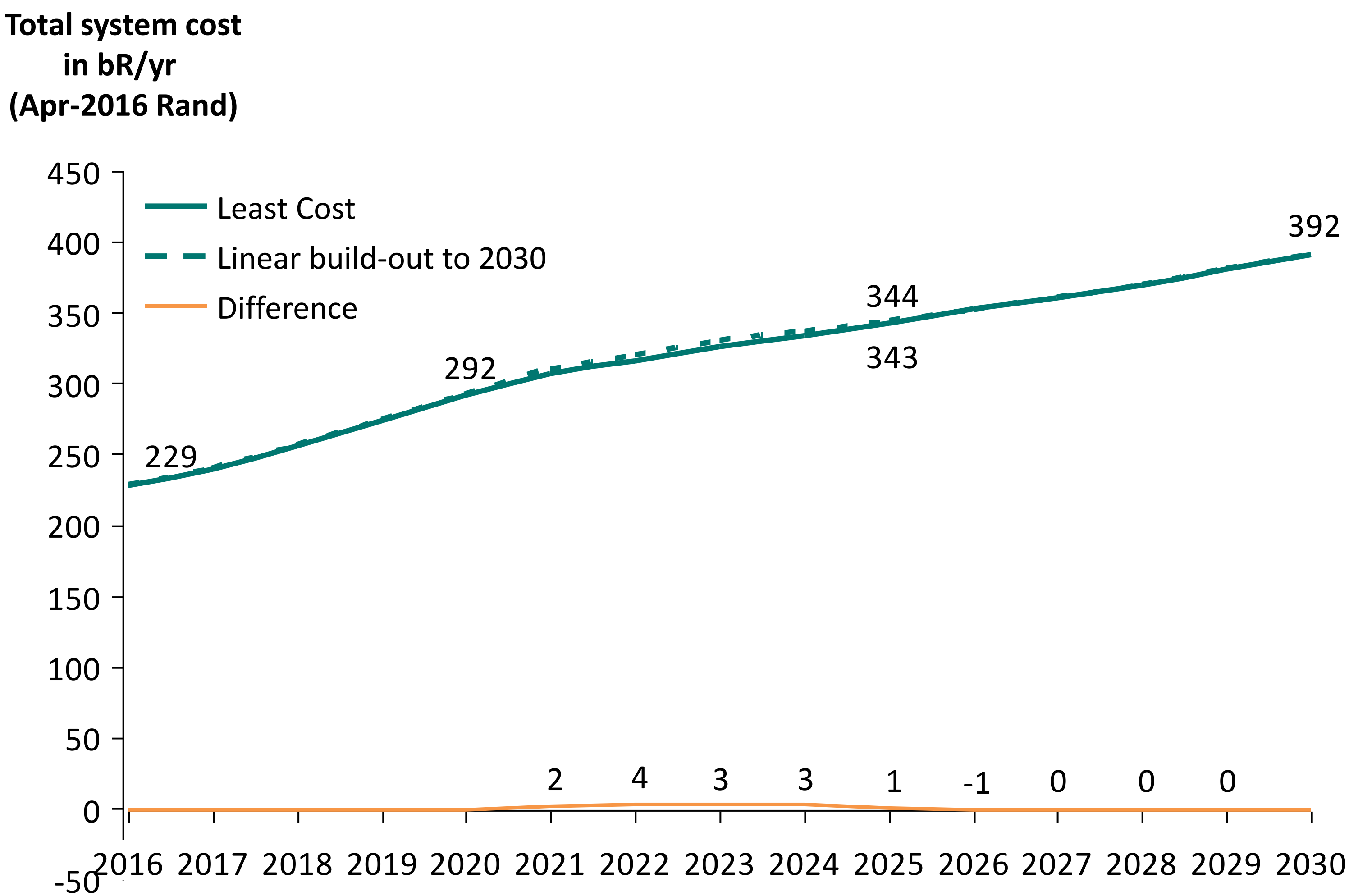
Shifting wind and solar PV earlier increases system costs (with cost of CO_2) ≈ 1 - 4 R billion/yr between 2021 and 2030



Sources: CSIR analysis

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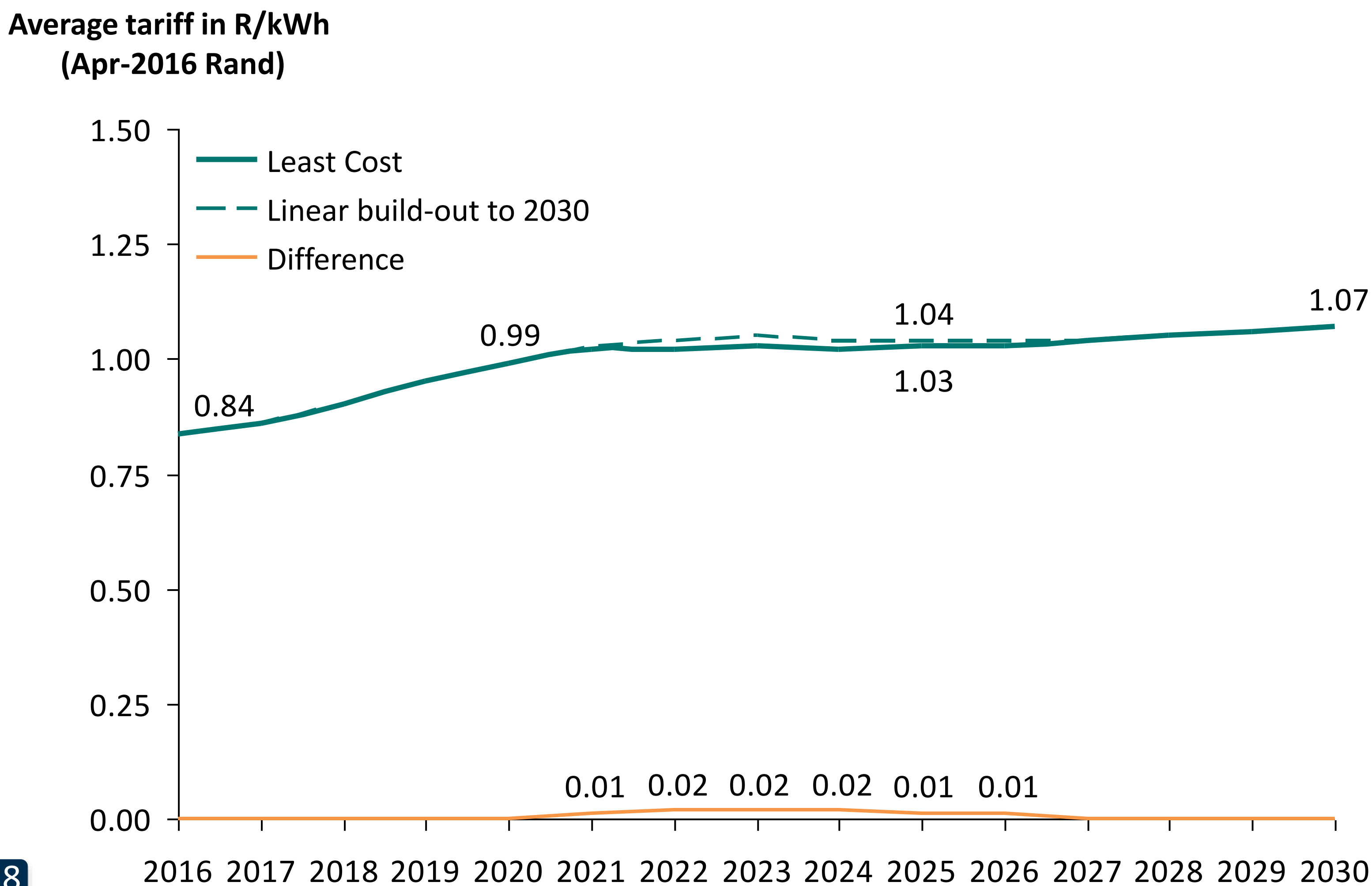
Average tariff (without cost of CO_2): Linear build ≈ 1-2 cents/kWh higher than Least Cost from 2021 - 2027



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Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

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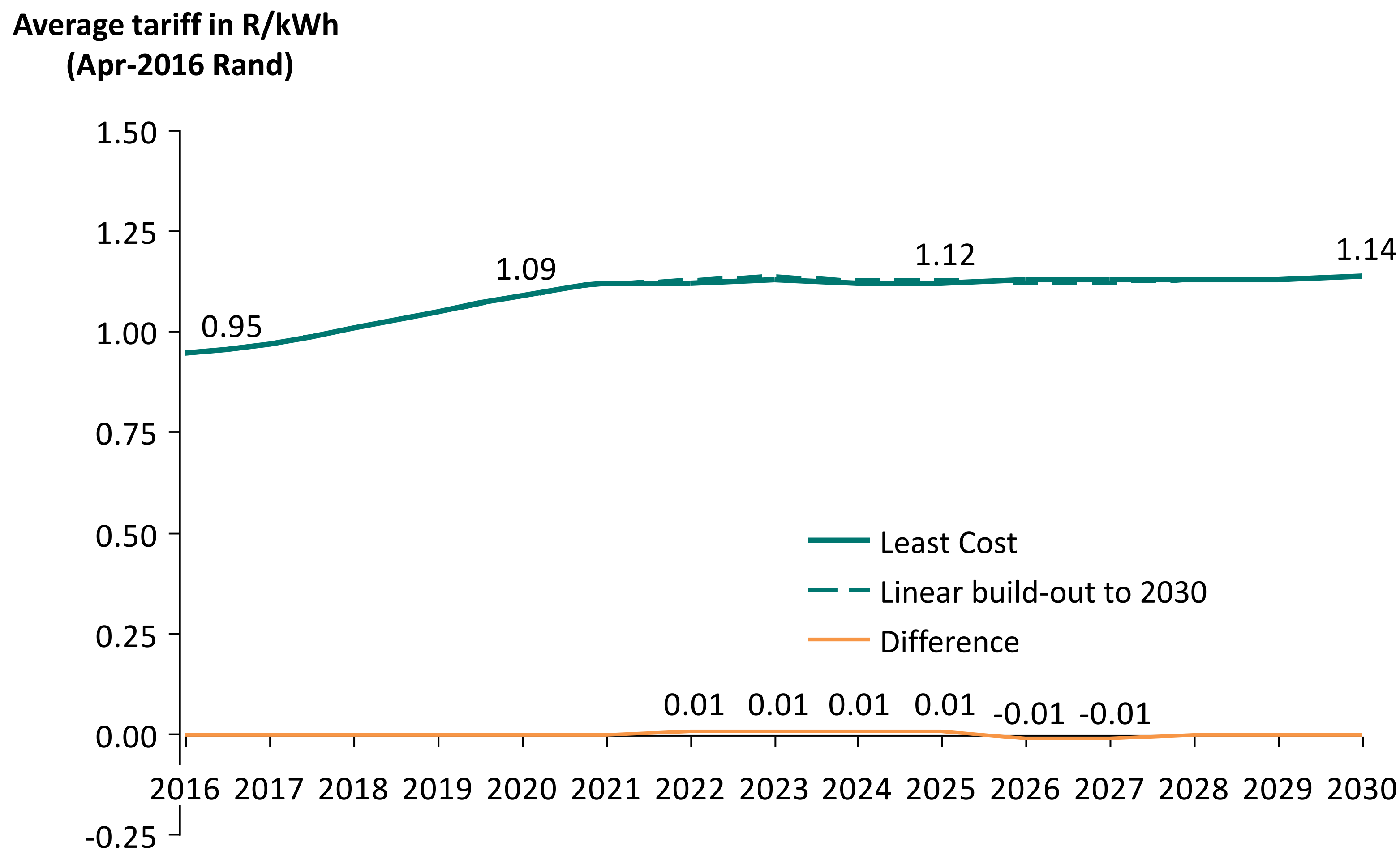
Average tariff (<u>with</u> cost of CO_2): Linear build ≈ 1 cents/kWh higher than Least Cost from 2022 - 2025



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

Agenda

Scenarios

- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
- Least cost
- Linear build-out to 2030
- **Scenario comparison and summary**

Sensitivities

- Least cost (low demand forecast)
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- Low supply (low plant performance and delayed new builds)
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment

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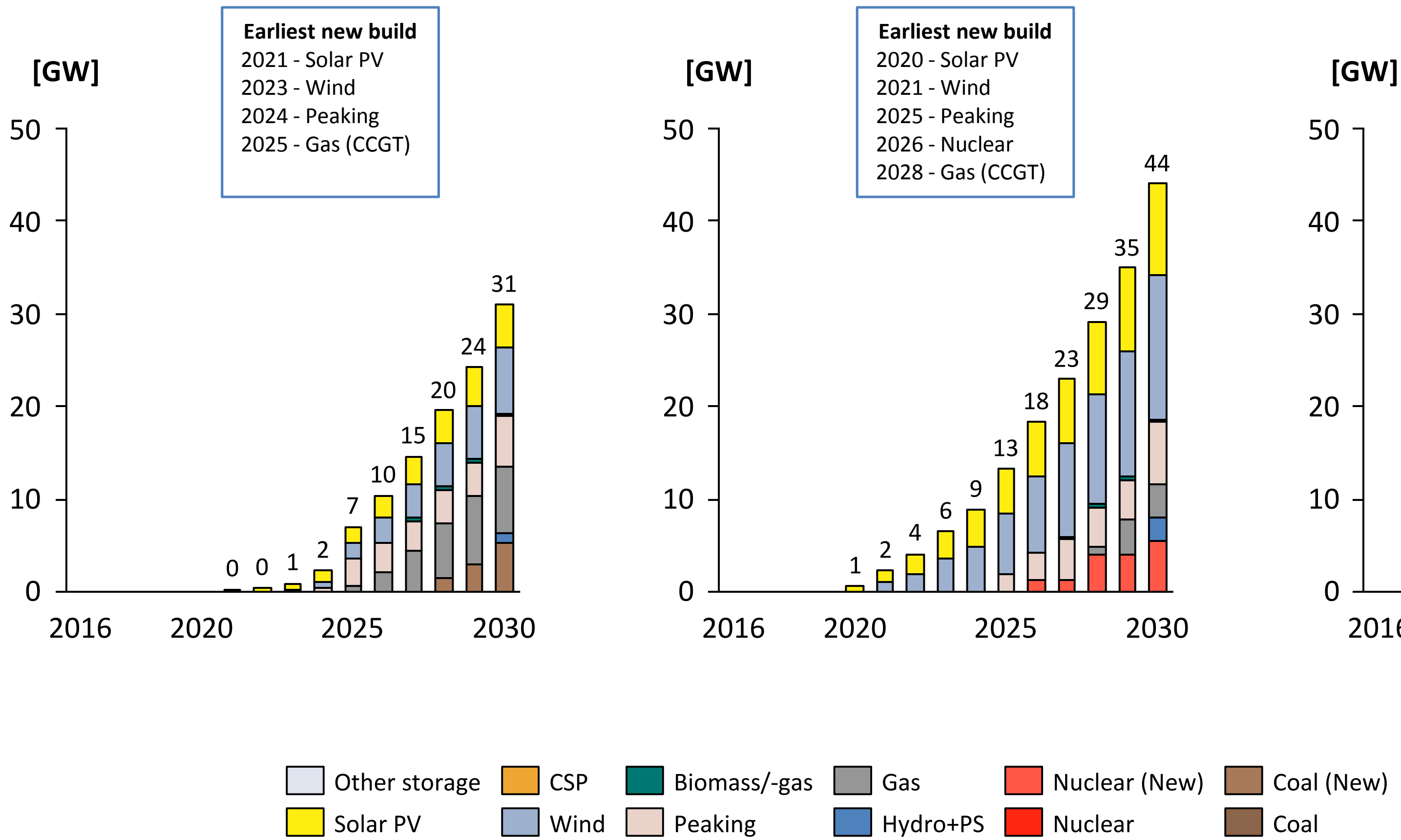
Scenario comparison: Total new installed capacity

Draft IRP 2016 Base Case

Draft IRP 2016 Carbon Budget

Least Cost



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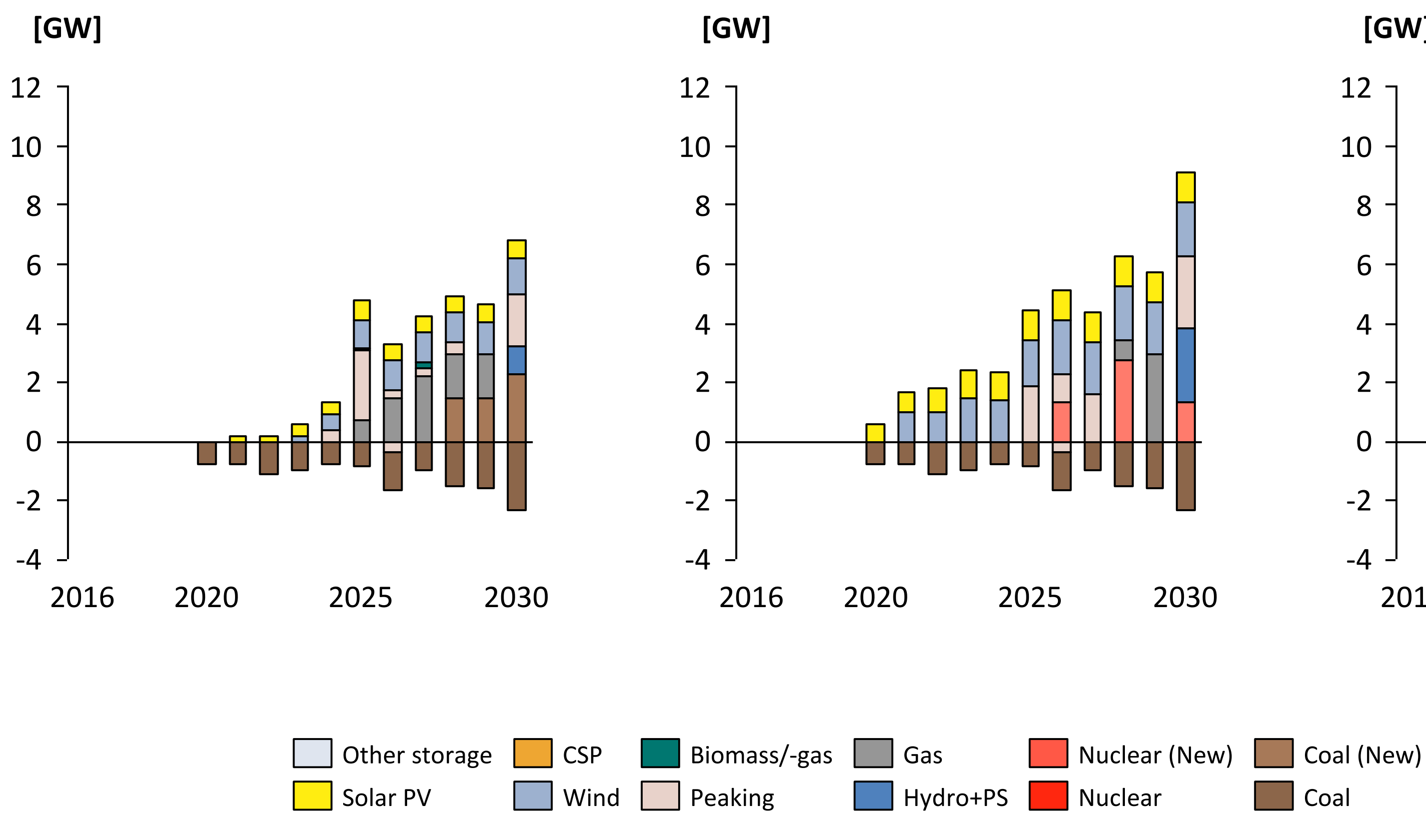
Scenario comparison: Annual new and decommissioned capacity

Draft IRP 2016 Base Case | **Draft IRP 2016 Carbon Budget** | **Least Cost**



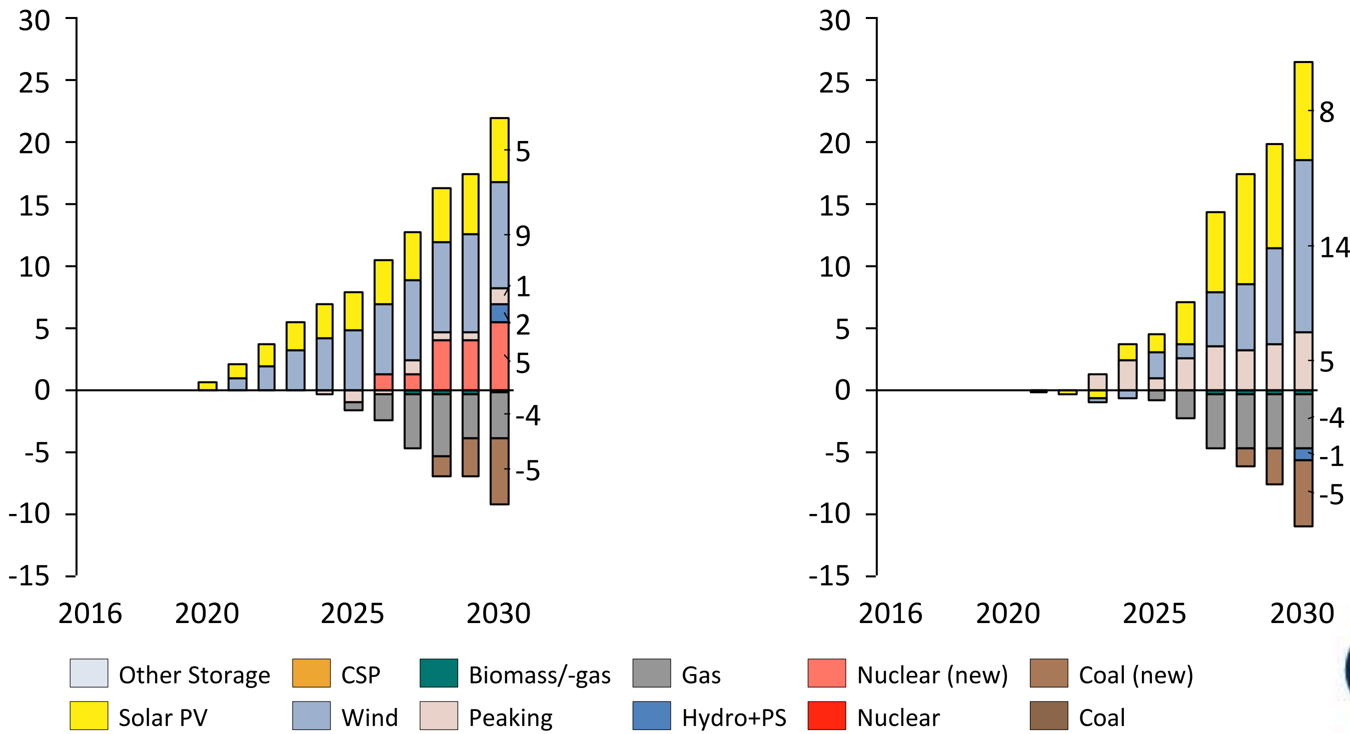
The Least-Cost scenario installs significantly more wind and solar PV as well as more flexible peaking capacity

Draft IRP 2016 Carbon Budget

Total installed net capacity [GW] (difference from Base Case)

Least Cost

Total installed net capacity [GW] (difference from Base Case)



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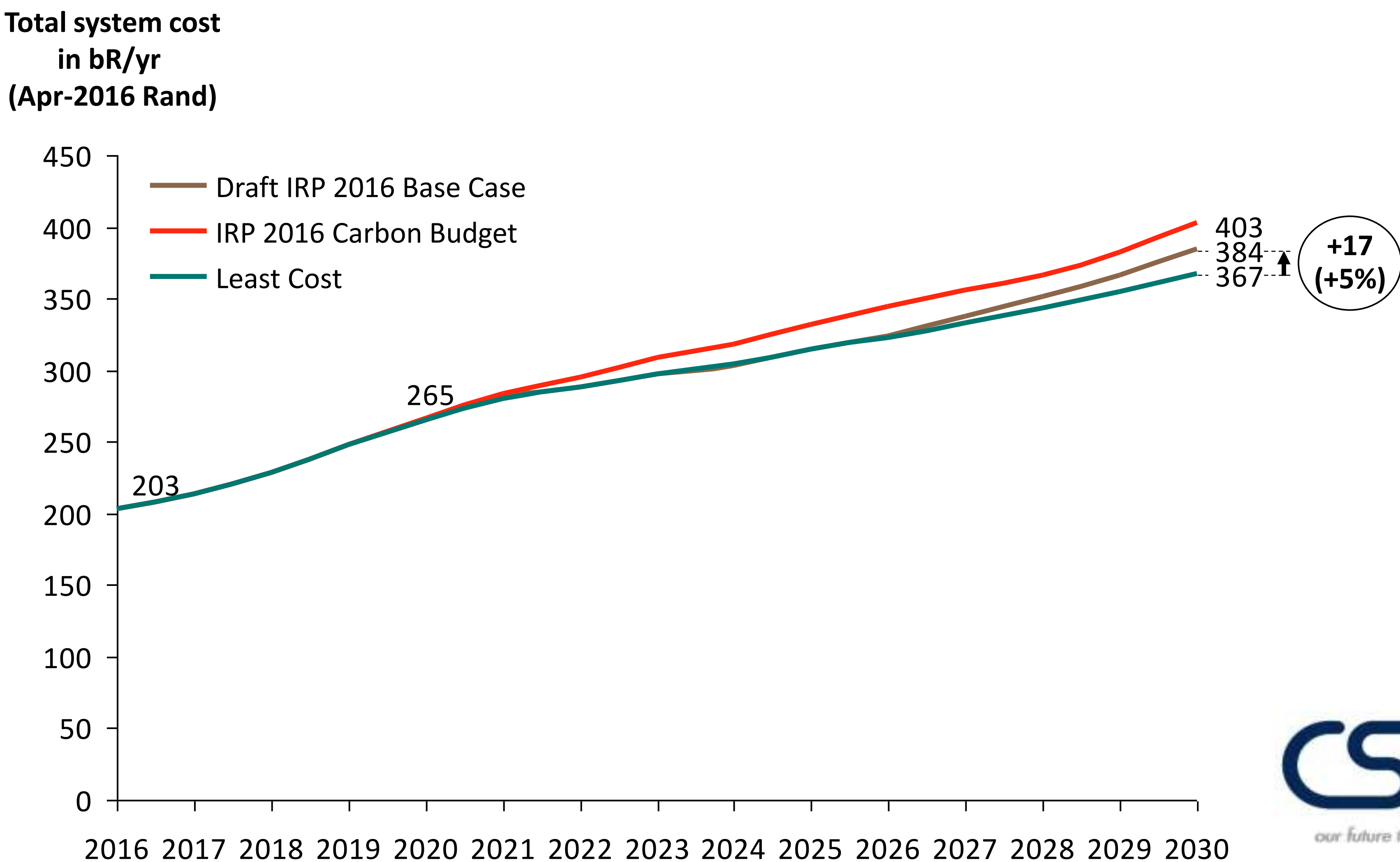
Total system cost: Draft IRP 2016 Base Case ≈R17 bn/year more expensive by 2030 than Least Cost (without cost of CO_2)



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items)   Sources: Eskom on Tx, Dx cost; CSIR analysis

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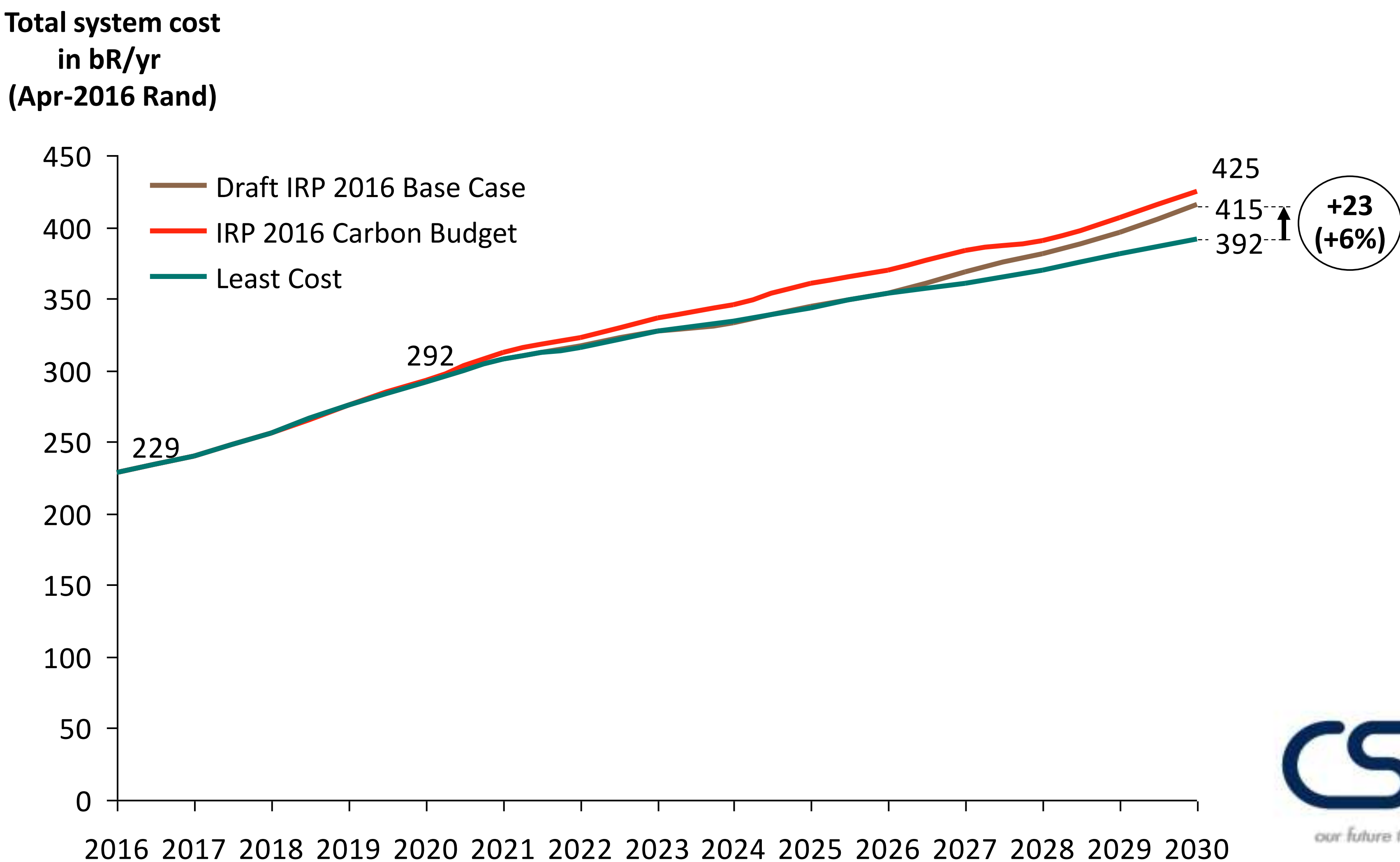
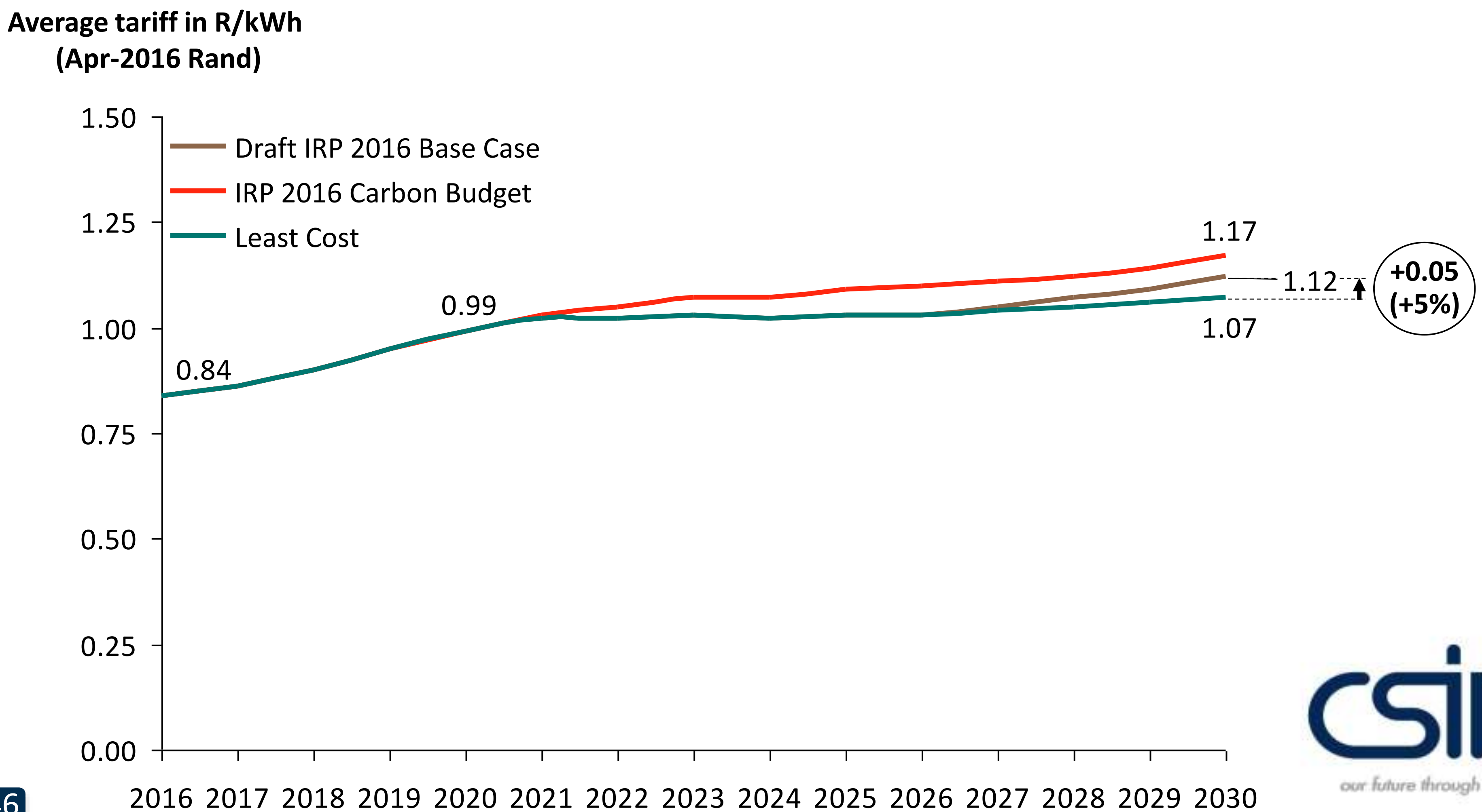
Total system cost: Draft IRP 2016 Base Case ≈R23 bn/year more expensive by 2030 than Least Cost (with cost of CO_2)



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

Average tariff (without cost of CO_2): Draft IRP Base Case tariff ≈5 cents/kWh higher than Least Cost by 2030



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

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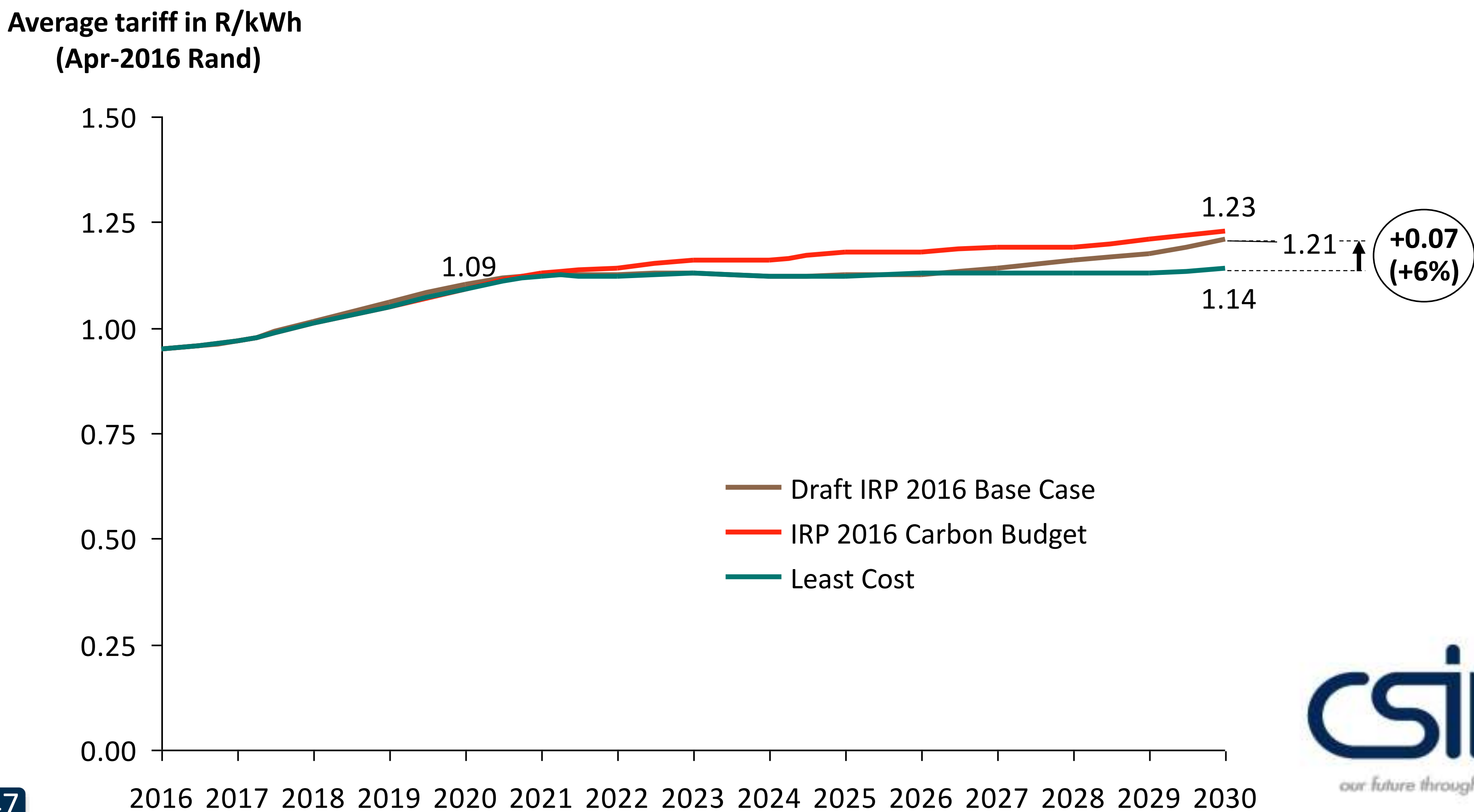
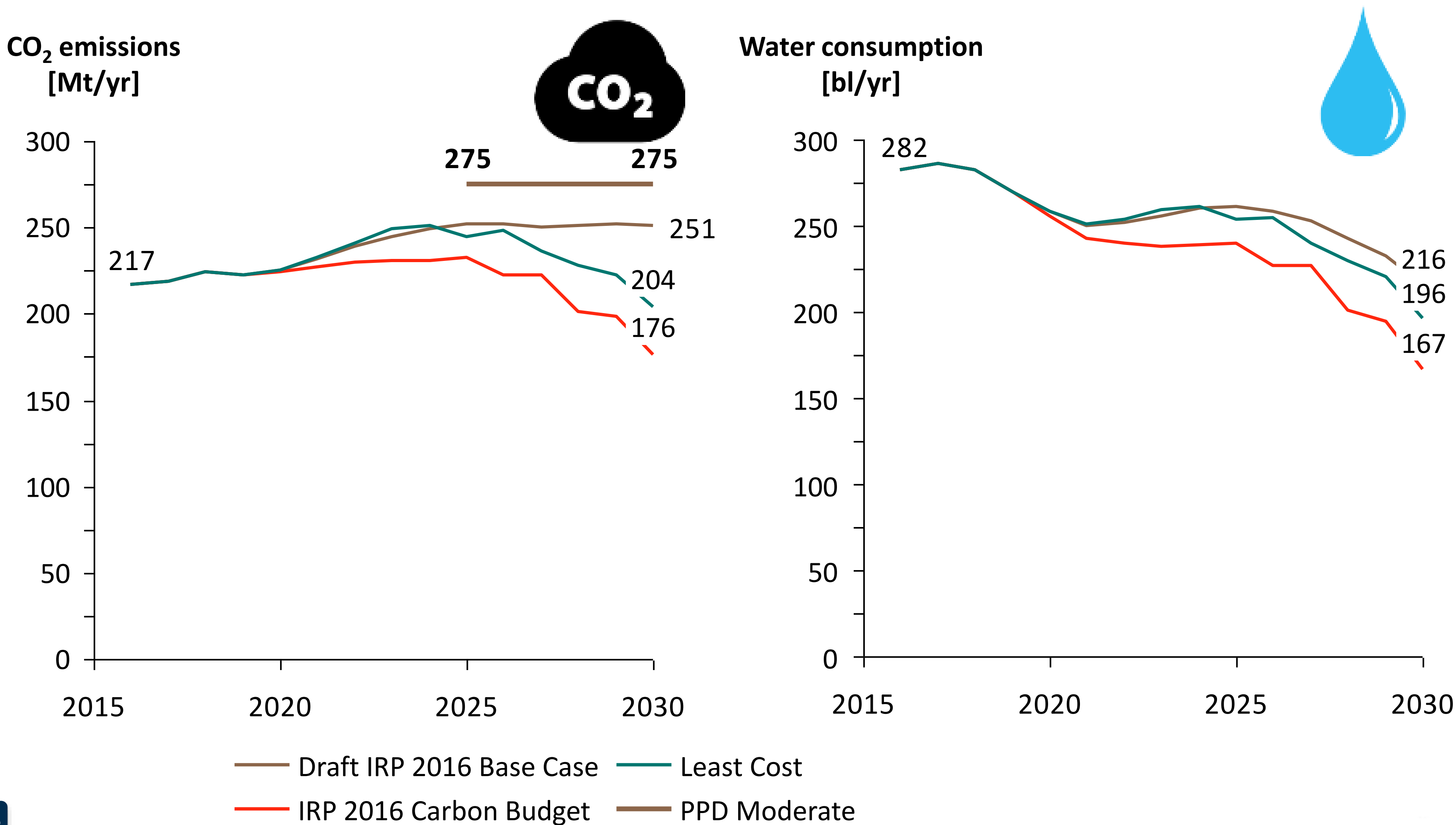
Average tariff (with cost of CO_2): Draft IRP Base Case tariff ≈7 cents/kWh higher than Least Cost by 2030



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

CO_2 emissions trajectories and water usage summary



Source: CSIR analyses

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- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment

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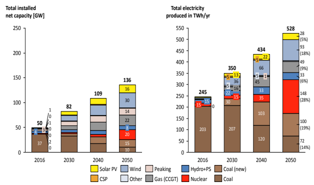
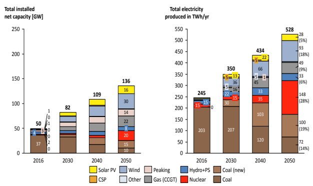
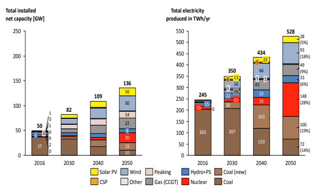
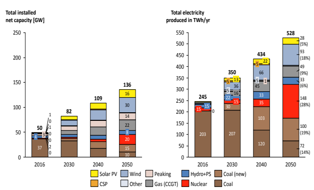
Overview of sensitivities

Sensitivity		Source	Difference to Draft IRP 2016 Base Case
Least Cost (Low demand)		**CSIR**	**Low demand (EIUG)** **No constraints on any new build technologies** **RE costing aligned with latest REIPPPP** **Demand shaping from residential EWHs**
Linear build-out (Low demand)		**CSIR**	**Spread wind and solar PV new build from 2030 Least Cost result linearly from 2021** **Re-optimise other supply options around linear build**
Low Supply		**CSIR**	**Least cost scenario input assumptions** **Delay Medupi and Kusile by 1 year/unit** **Follow Eskom's low plant performance path**
Low Supply (Low demand)		**CSIR**	**Low demand (EIUG)** **Least cost scenario input assumptions** **Delay Medupi and Kusile by 1 year/unit** **Follow Eskom's low plant performance path**

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- Linear build-out to 2030 (low demand forecast)
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- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment

CSIR
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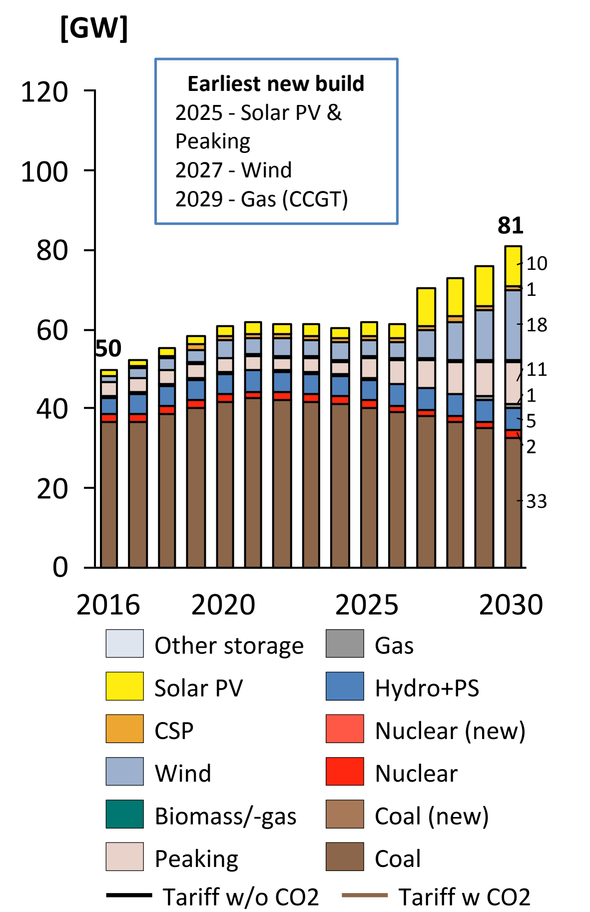
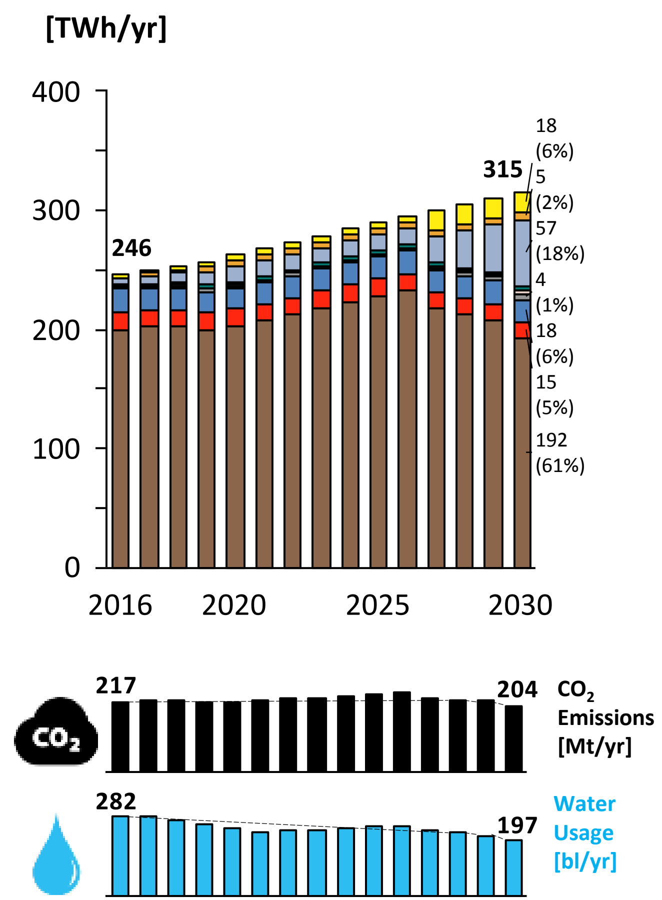
Scenario: Least Cost (low demand)

24% solar PV/wind energy share by 2030, R327 billion cost in 2030

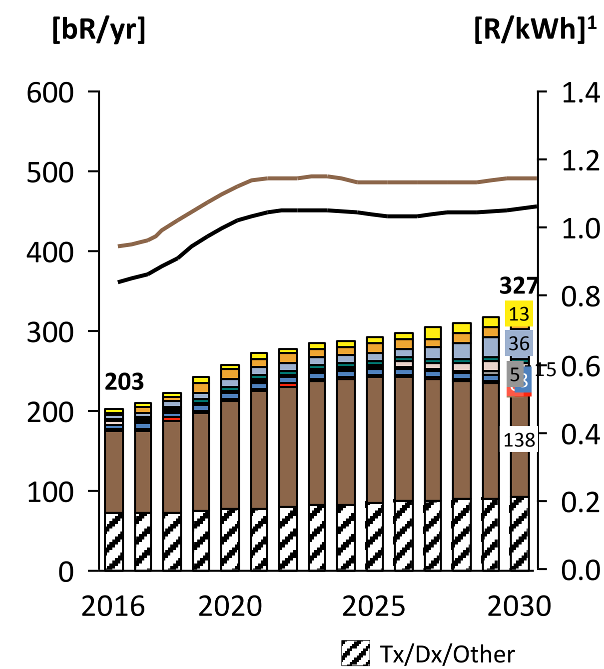
Capacity Installed



Energy Produced



Cost and Tariff



Difference to Draft IRP 2016 Base Case

- Low demand (EIUG)
- No build-out constraints on any technology
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHs

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

Agenda

Scenarios

- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
- Least cost
- Linear build-out to 2030
- Scenario comparison and summary

Sensitivities

- Least cost (low demand forecast)
- **Linear build-out to 2030 (low demand forecast)**
- Low supply (low plant performance and delayed new builds)
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment

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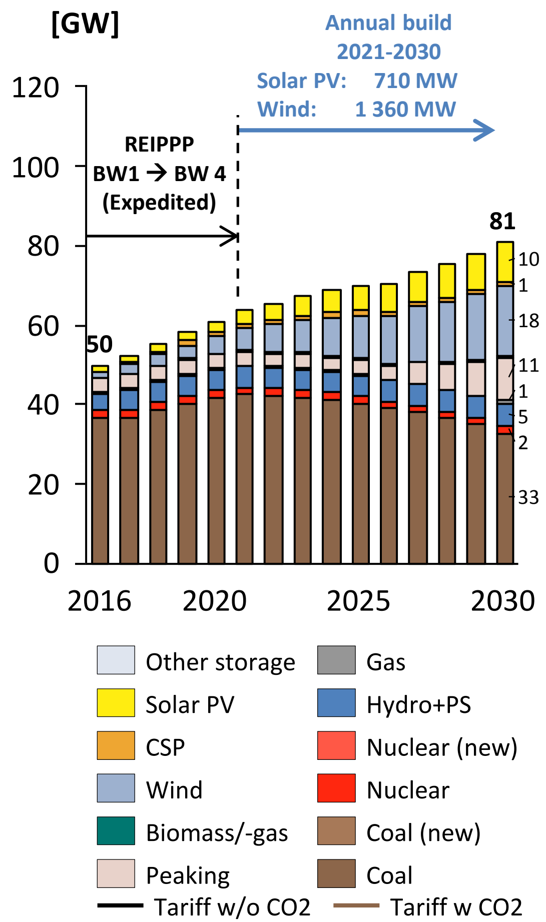
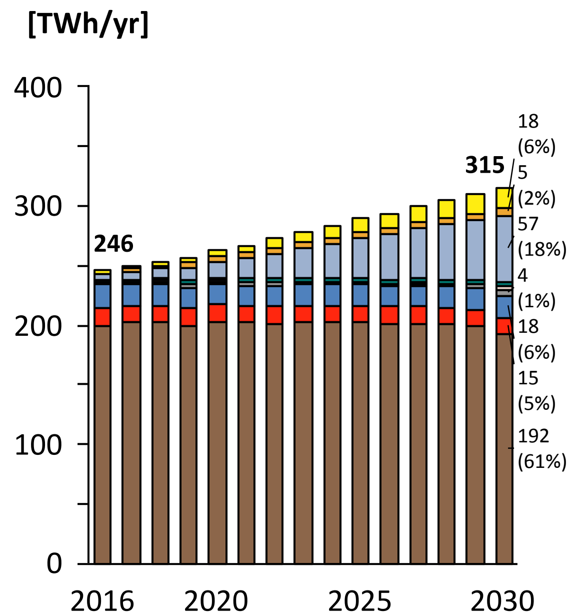
Scenario: Linear build-out of wind and Solar PV (low demand)

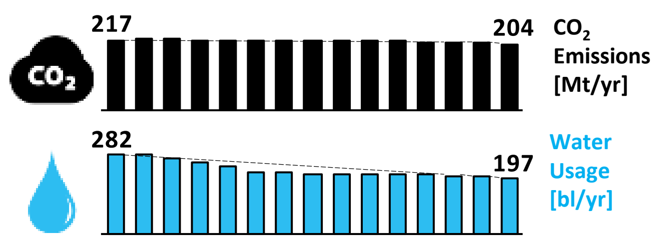
24% solar PV/wind energy share by 2030, R327 billion cost in 2030

Capacity Installed

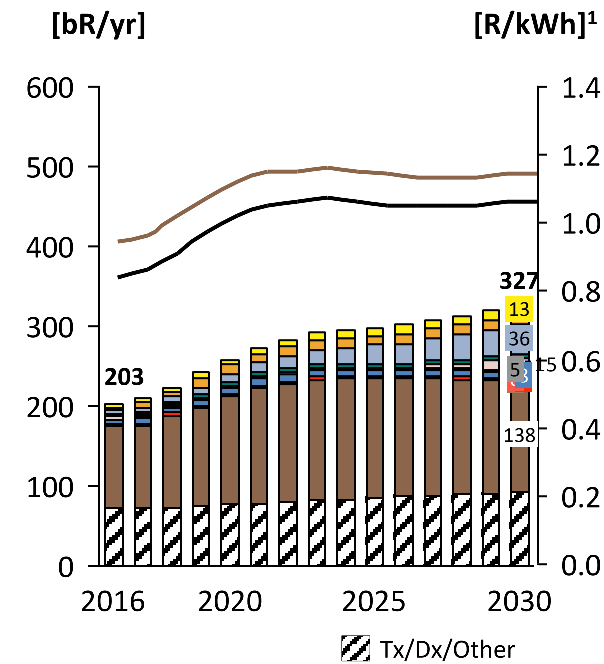


Energy Produced





Cost and Tariff



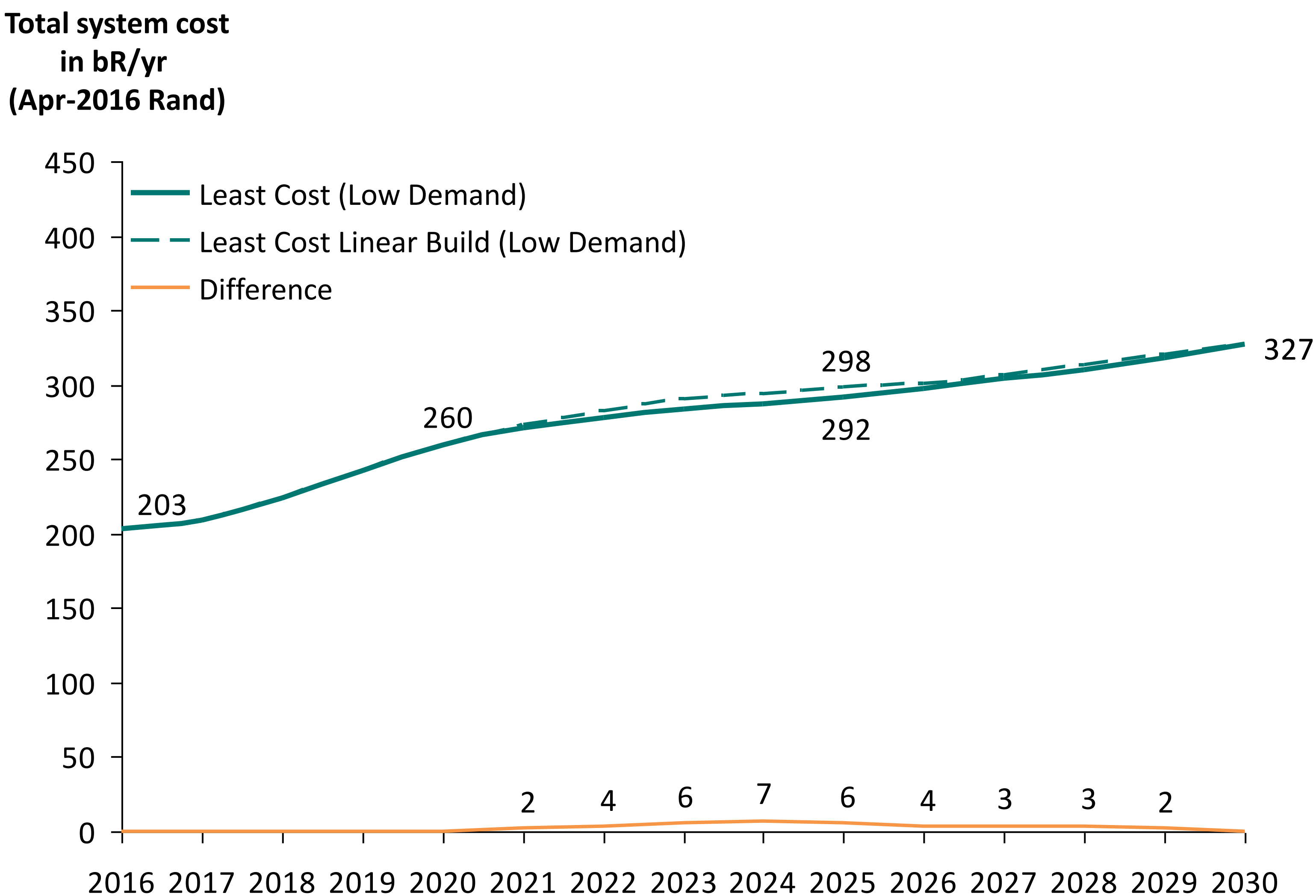
Difference to Draft IRP 2016 Base Case

- Same assumptions as Least Cost
- Low demand (EIUG)
- 2030 Wind and solar PV build from Least Cost scenario linearly built from 2021 to 2030

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

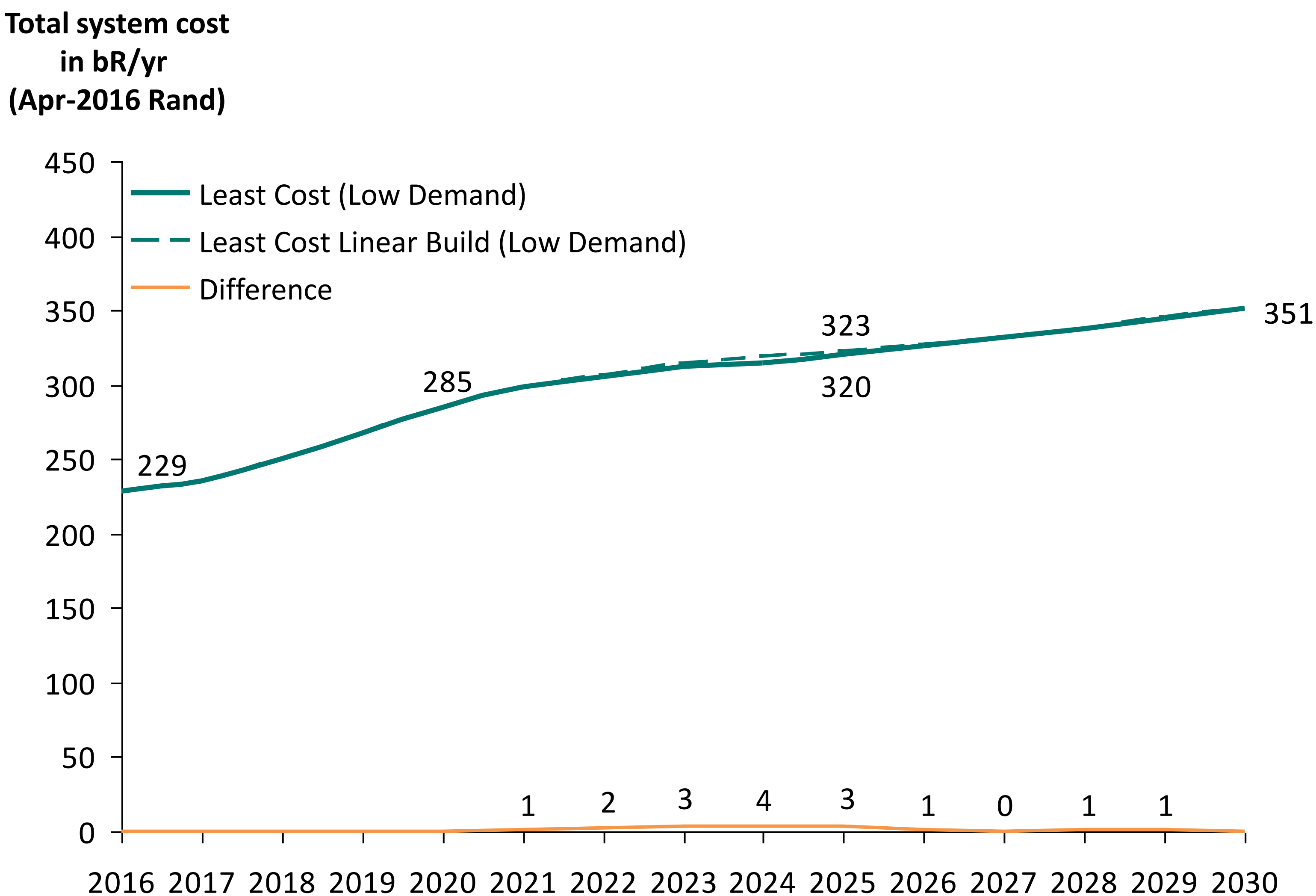
Submitted to DoE on 31 March 2017

Shifting wind and solar PV earlier increases system costs (without cost of CO_2) ≈ 1 - 7 R billion/yr between 2021 and 2029 with low demand



Sources: CSIR analysis

Shifting wind and solar PV earlier increases system costs (with cost of CO_2) ≈ 1 - 4 R billion/yr between 2021 and 2029 with low demand



Sources: CSIR analysis

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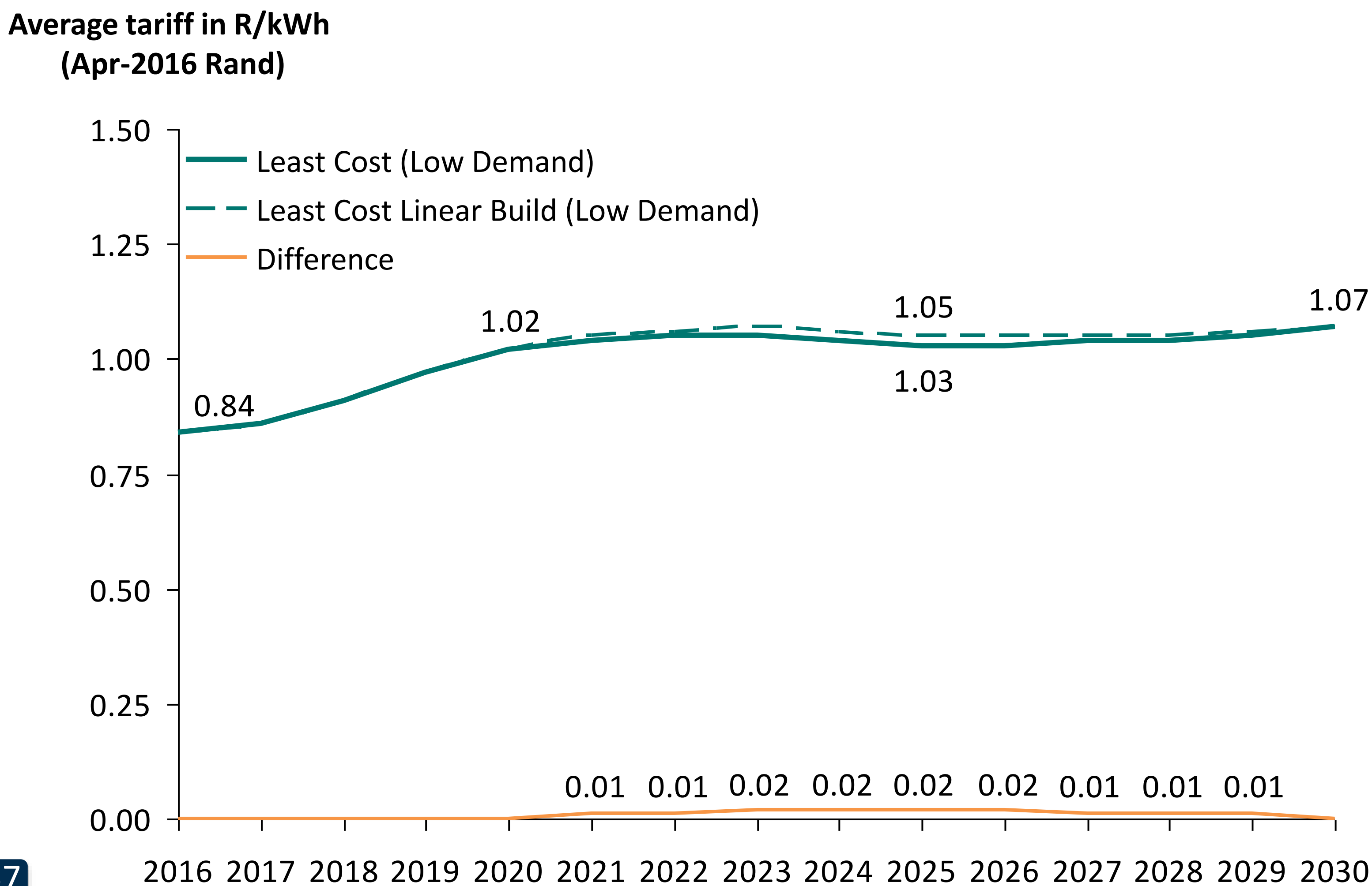
Average tariff (without cost of CO_2): Linear build ≈ 1-2 cents/kWh higher than Least Cost from 2021 - 2029 with low demand



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

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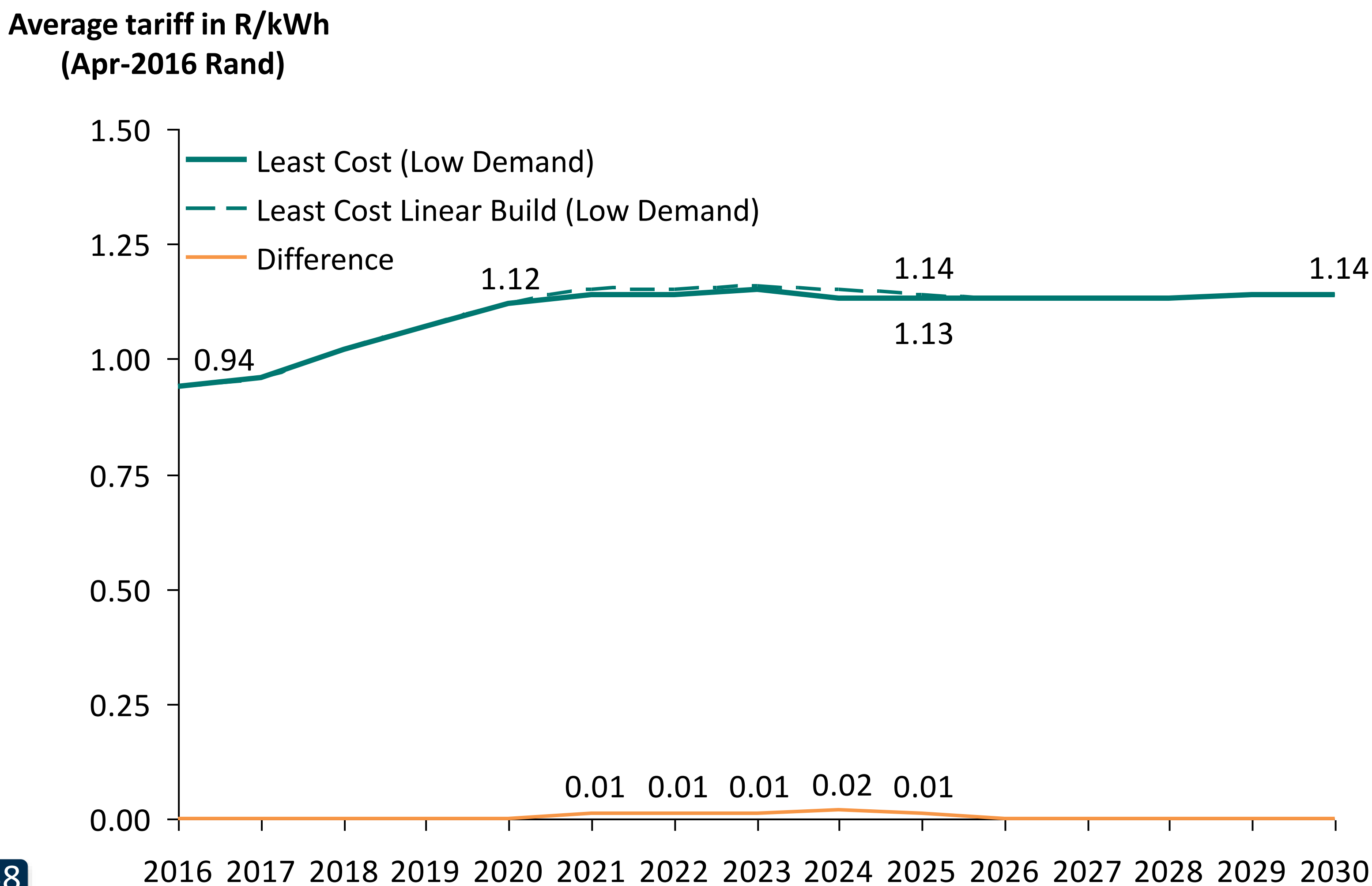
Average tariff (with cost of CO_2): Linear build ≈ 1-2 cents/kWh higher than Least Cost from 2021 - 2026 with low demand



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items)

Sources: Eskom on Tx, Dx cost; CSIR analysis

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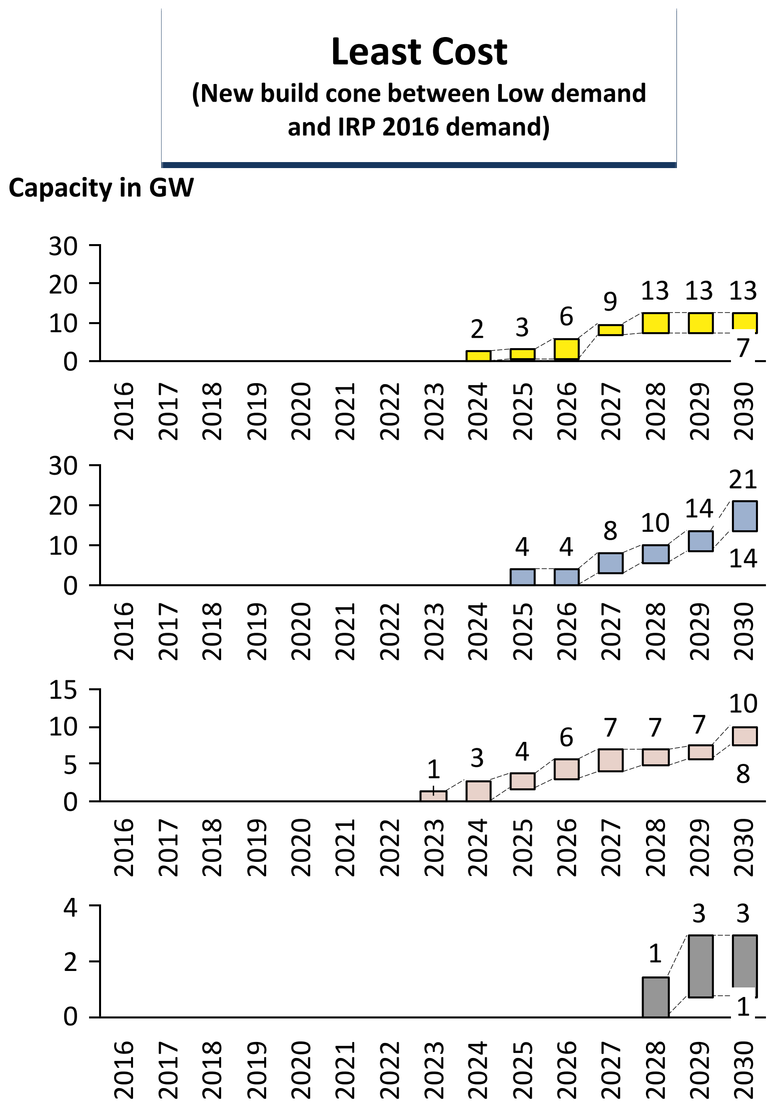
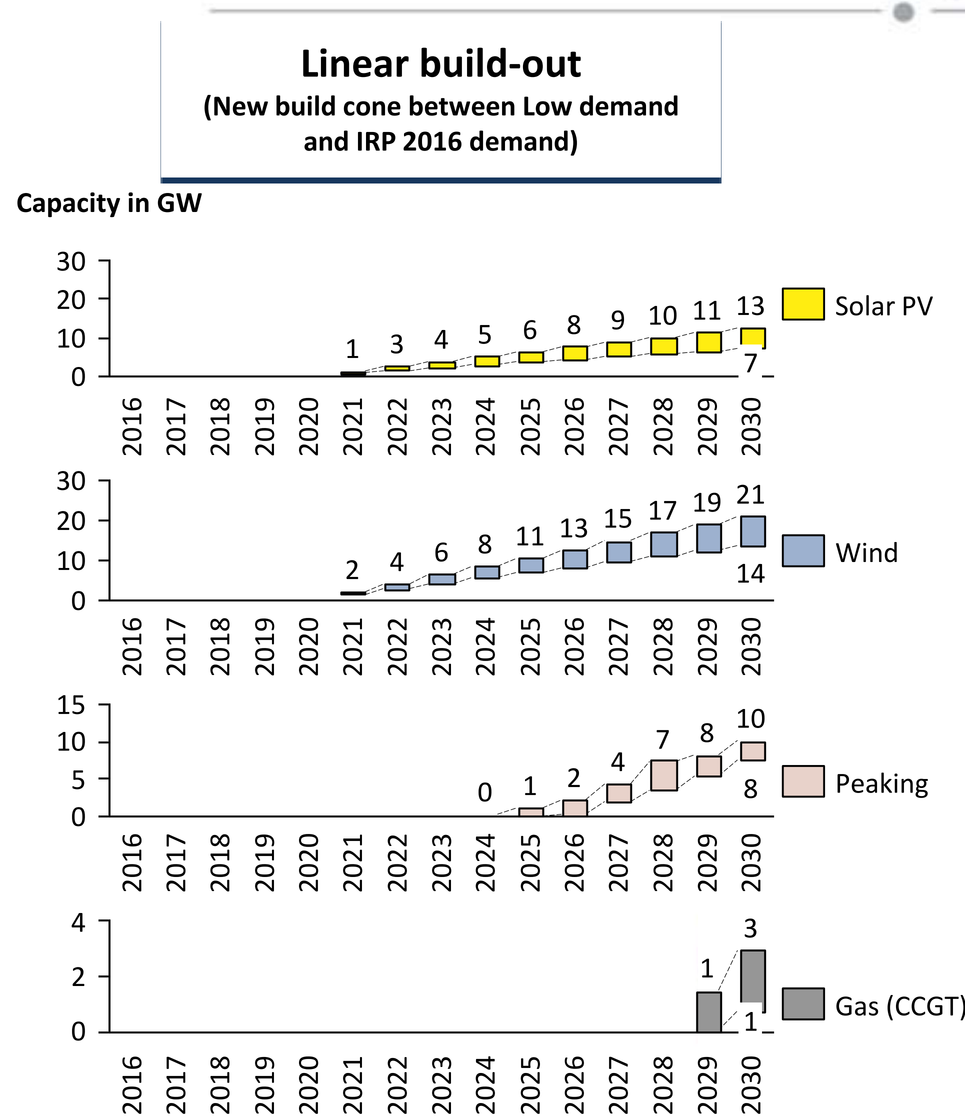
Building wind and solar PV earlier shifts the peaking and gas requirements later





Agenda

Scenarios

- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
- Least cost
- Linear build-out to 2030
- Scenario comparison and summary

Sensitivities

- Least cost (low demand forecast)
- Linear build-out to 2030 (low demand forecast)
- **Low supply (low plant performance and delayed new builds)**
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment

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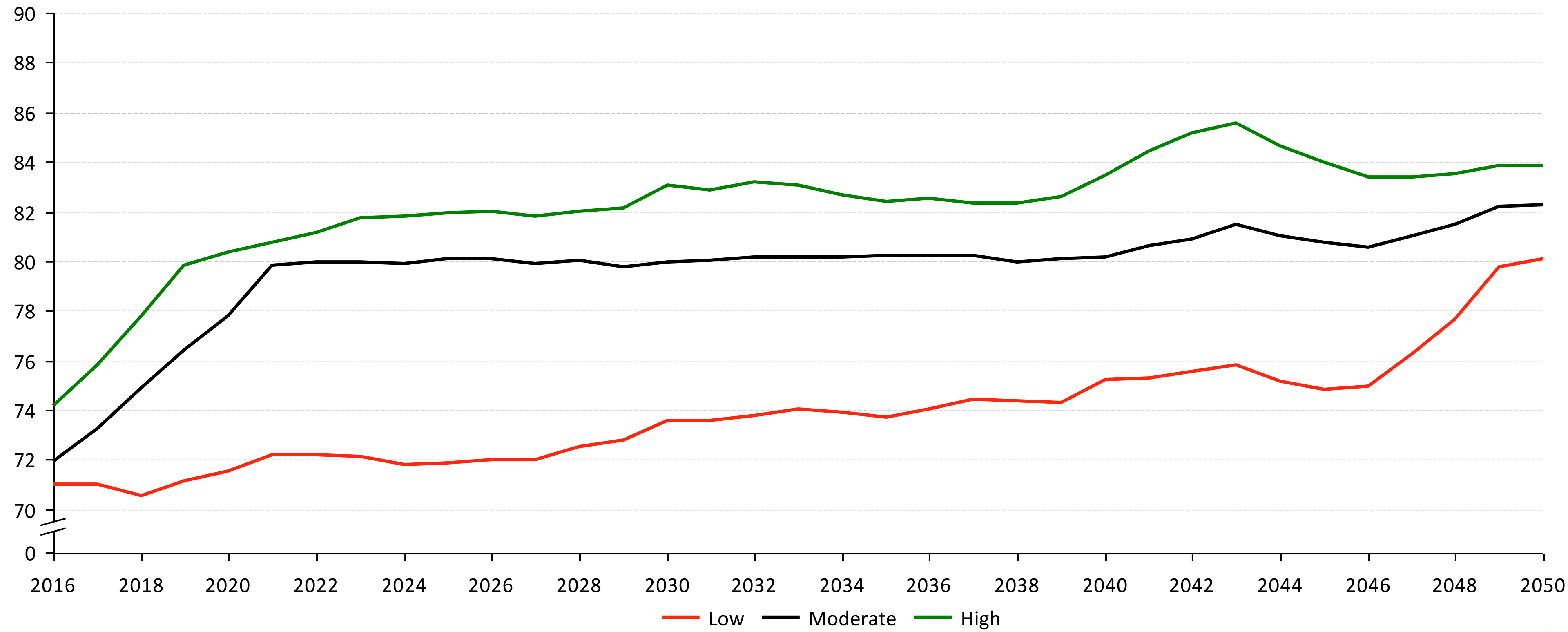
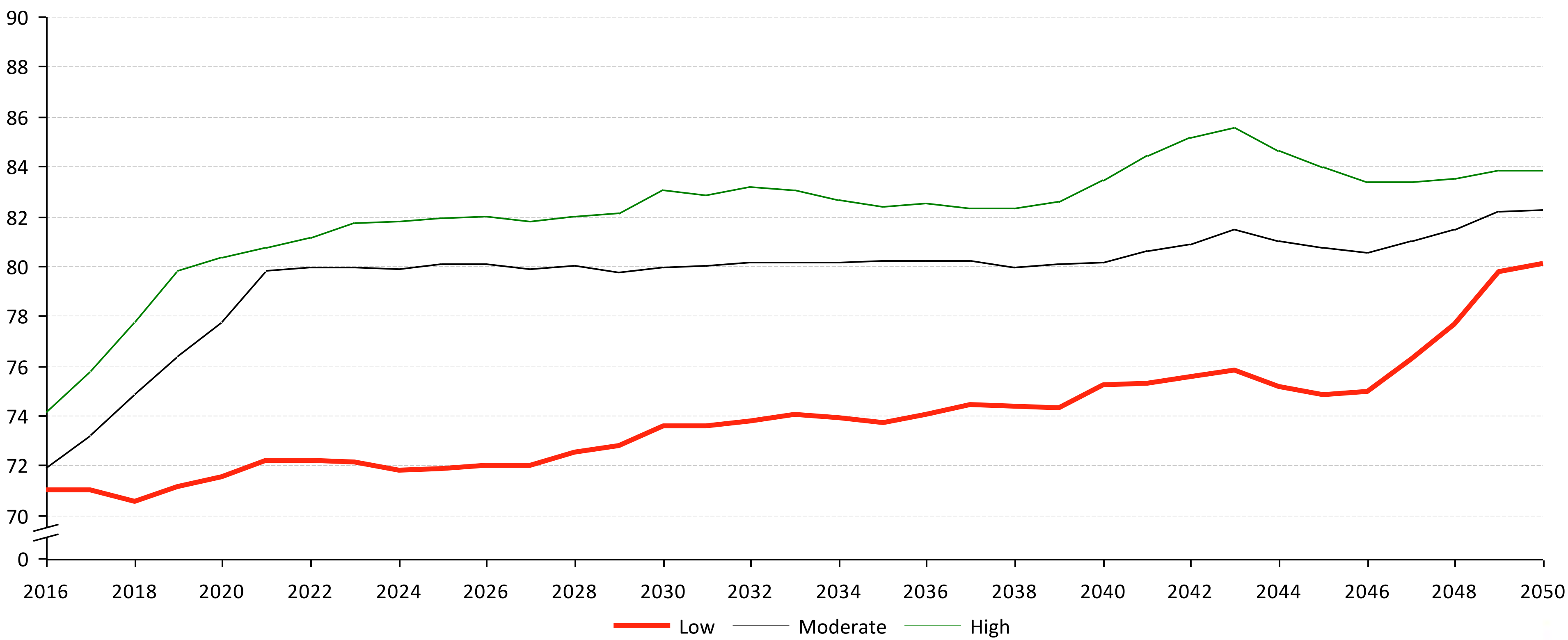
Energy Availability Factor (EAF) [%]



Sources: DoE Draft IRP 2016

Energy Availability Factor (EAF) [%]



Sources: DoE Draft IRP 2016

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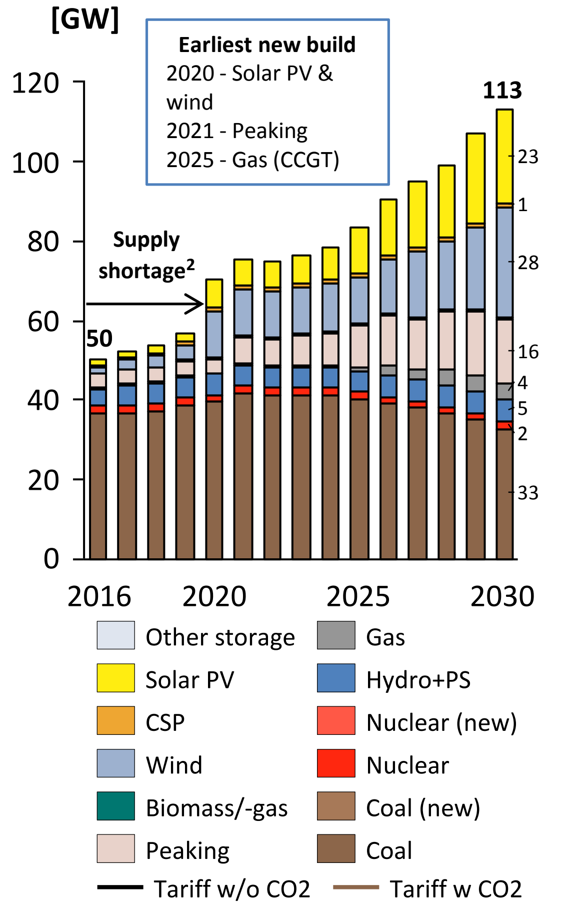
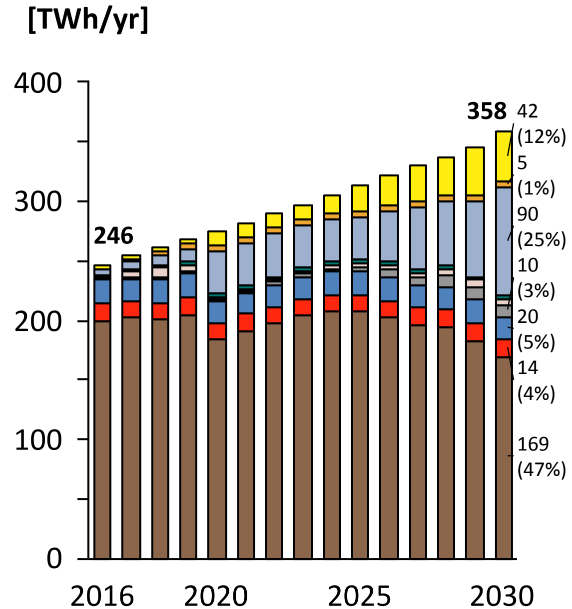
Scenario: Low Supply

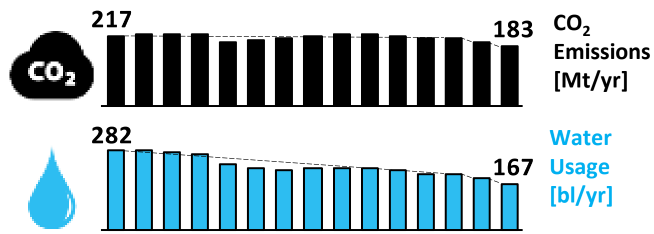
37% solar PV/wind energy share by 2030, R383 billion cost in 2030

Capacity Installed

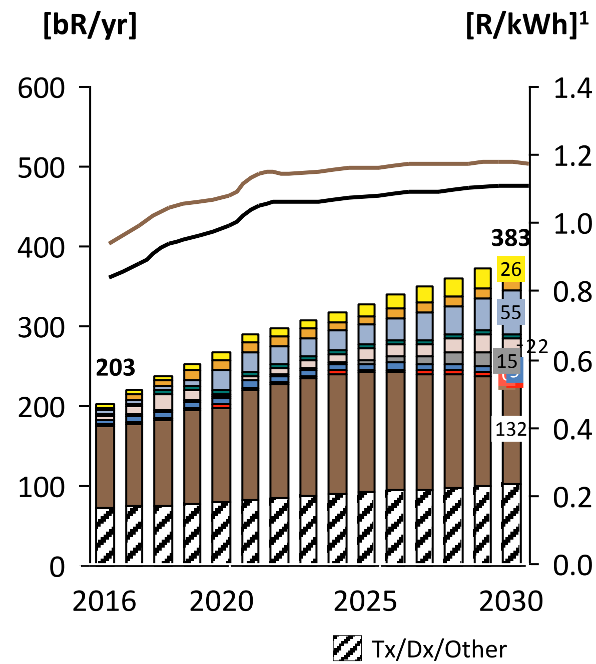


Energy Produced





Cost and Tariff



Difference to Draft IRP 2016 Base Case

- Same assumptions as Least Cost
- Delay Medupi and Kusile by 1 year per unit
- Follow Eskom's low plant performance path

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

[2] No new build allowed due to short term lead time constraints. First solar PV & wind allowed from 2020, peaking & gas from 2021, coal from 2022 & nuclear from 2025

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Agenda

Scenarios

- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
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- Linear build-out to 2030
- Scenario comparison and summary

Sensitivities

- Least cost (low demand forecast)
- Linear build-out to 2030 (low demand forecast)
- Low supply (low plant performance and delayed new builds)
- **Low supply (low plant performance and delayed new builds with low demand)**

What-If analysis

- Over-investment

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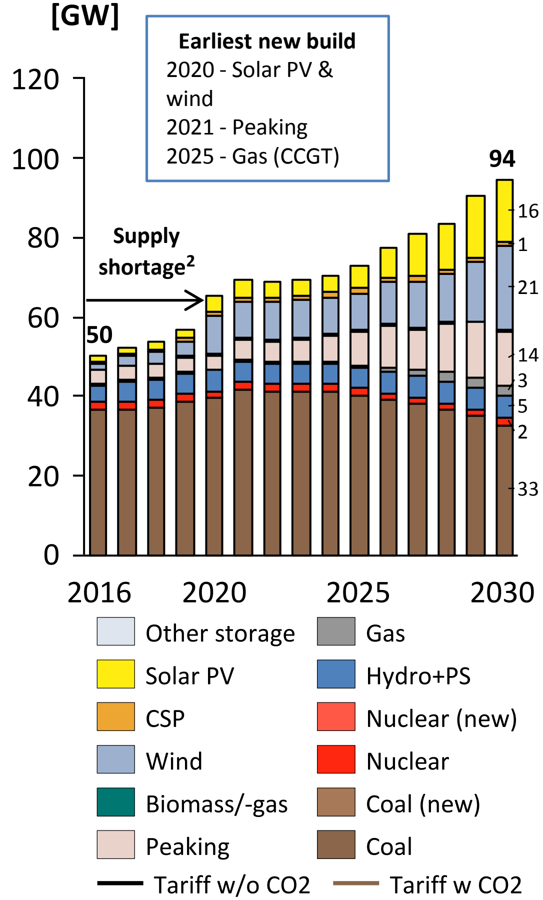
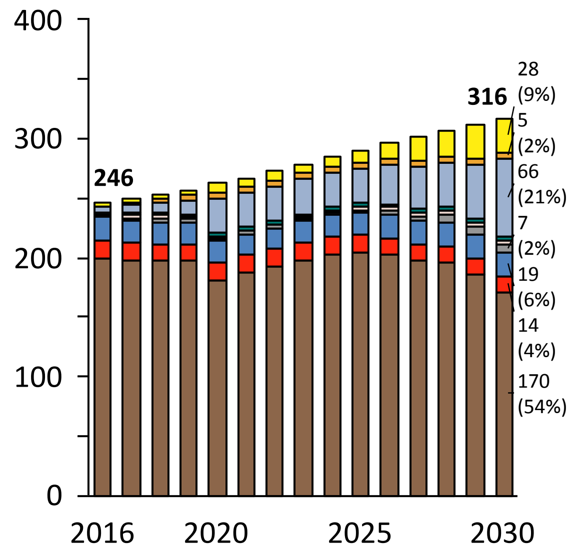
Scenario: Low Supply (low demand)

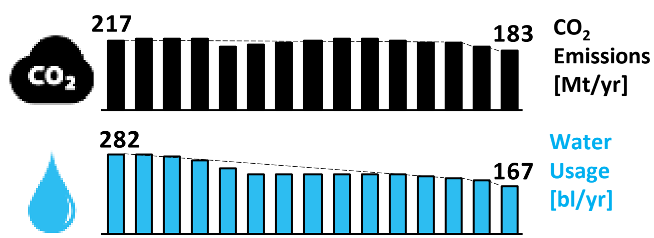
30% solar PV/wind energy share by 2030, R341 billion cost in 2030

Capacity Installed

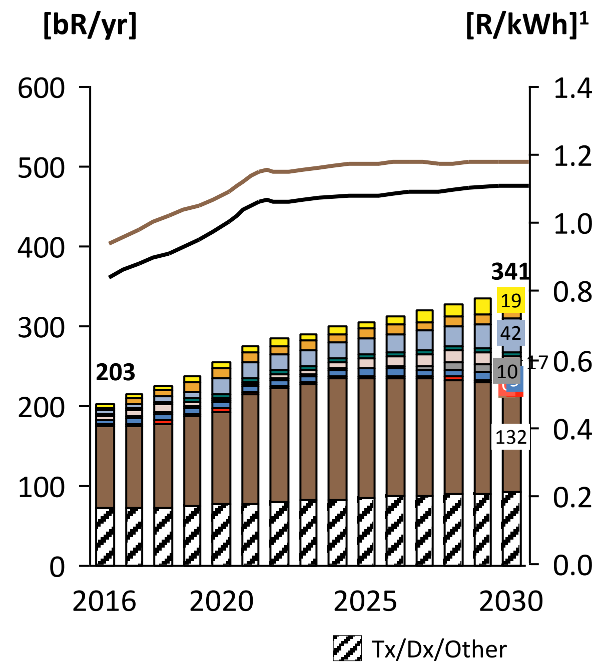


Energy Produced





Cost and Tariff



Difference to Draft IRP 2016 Base Case

- EIUG Low demand forecast
- Same assumptions as Least Cost
- Delay Medupi and Kusile by 1 year per unit
- Follow Eskom's low plant performance path

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

[2] No new build allowed due to short term lead time constraints. First solar PV & wind allowed from 2020, peaking & gas from 2021, coal from 2022 & nuclear from 2025

Agenda

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- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
- Least cost
- Linear build-out to 2030
- Scenario comparison and summary

Sensitivities

- Least cost (low demand forecast)
- Linear build-out to 2030 (low demand forecast)
- Low supply (low plant performance and delayed new builds)
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- Over-investment

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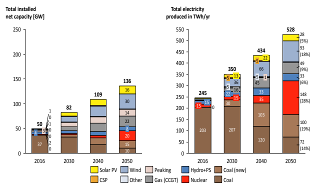
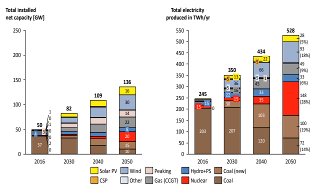
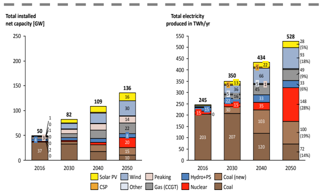
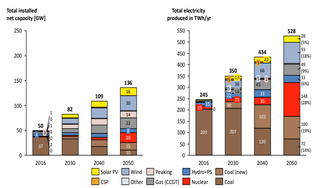
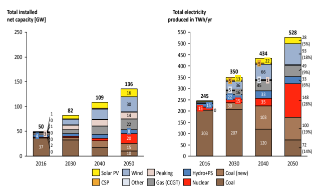
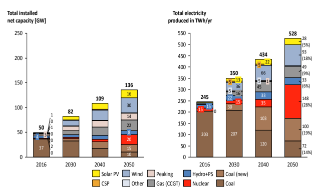
Overview of What-If analyses

Sensitivity		Source	Difference to Draft IRP 2016 Base Case
Draft IRP 2016 Base Case (over-investment)		**CSIR**	**Least cost scenario input assumptions** **Low demand (EIUG)** **Hard-coded installed capacity from this scenario but with lower demand forecast**
Draft IRP 2016 Carbon Budget (over-investment)		**CSIR**	**Least cost scenario input assumptions** **Low demand (EIUG)** **Hard-coded installed capacity from this scenario but with lower demand forecast**
Least Cost (over-investment)		**CSIR**	**Least cost scenario input assumptions** **Low demand (EIUG)** **Hard-coded installed capacity from this scenario but with lower demand forecast**

Overview of What-If analyses

Sensitivity	Source	Difference to Draft IRP 2016 Base Case
Fuel costs (Cheaper gas) 	**CSIR**	**Least cost scenario input assumptions** **Cheap natural gas**
Fuel costs (More expensive coal) 	**CSIR**	**Least cost scenario input assumptions** **Higher coal fuel price**
Resource availability (wind not available) 	**CSIR**	**Least cost scenario input assumptions** **Wind not available for extended periods**

Agenda

Scenarios

- Draft IRP 2016: Base Case
- Draft IRP 2016: Carbon Budget
- Least cost
- Linear build-out to 2030
- Decarbonise the electricity sector
- Scenario comparison and summary

Sensitivities

- Least cost (low demand forecast)
- Linear build-out to 2030 (low demand forecast)
- Low supply (low plant performance and delayed new builds)
- Low supply (low plant performance and delayed new builds with low demand)

What-If analysis

- **Over-investment**

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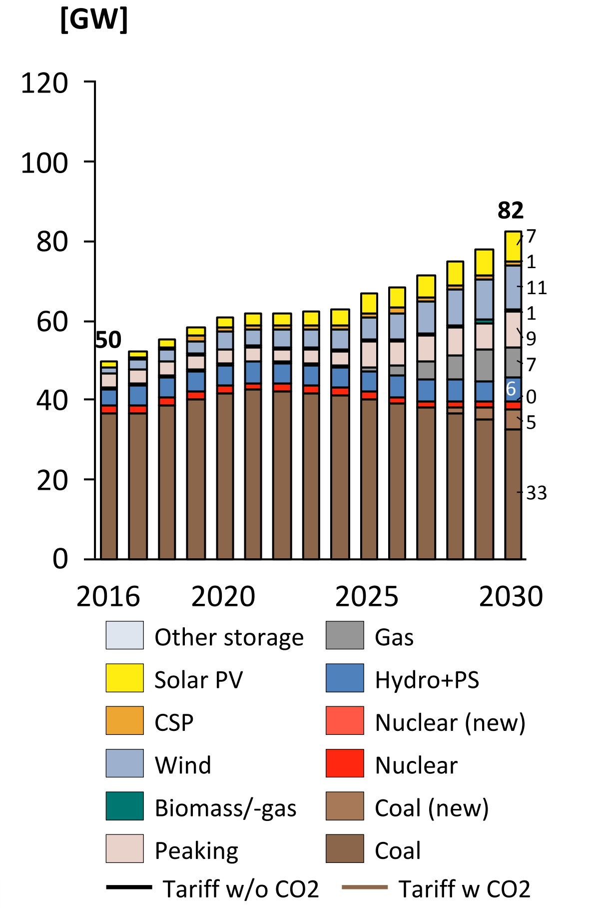
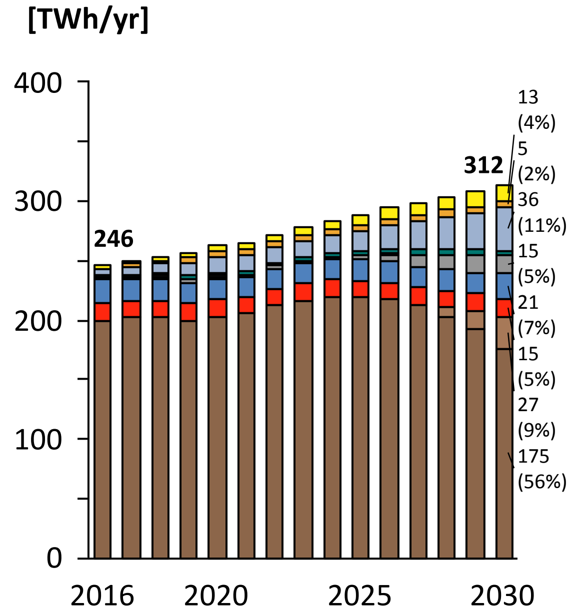
What-if: IRP 2016 Base Case (over-investment)

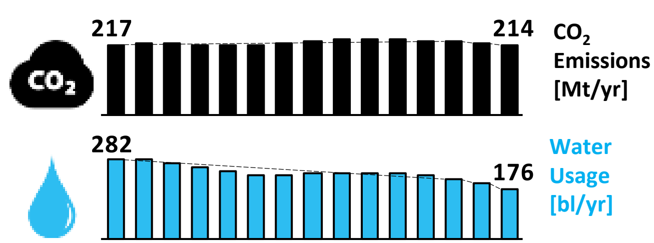
15% solar PV/wind energy share by 2030, R362 billion cost in 2030

Capacity Installed

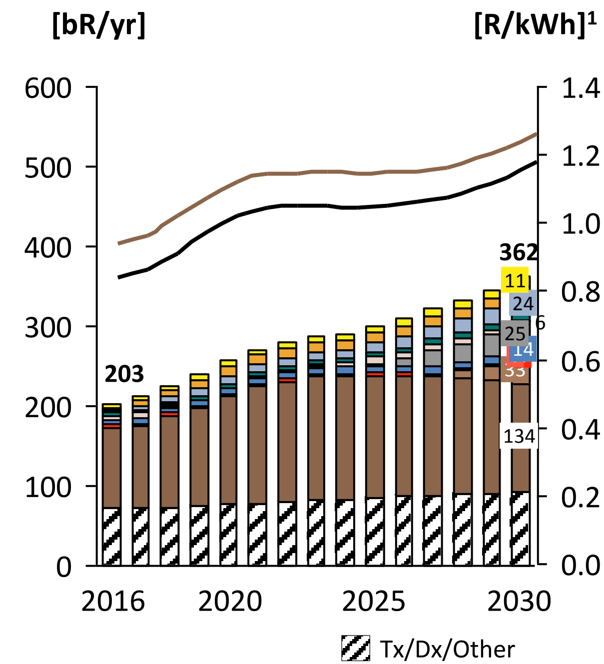


Energy Produced





Cost and Tariff



Difference to Draft IRP 2016 Base Case

- Low Demand (EIUG)
- Hard-coded installed capacity from this scenario but with lower demand forecast

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

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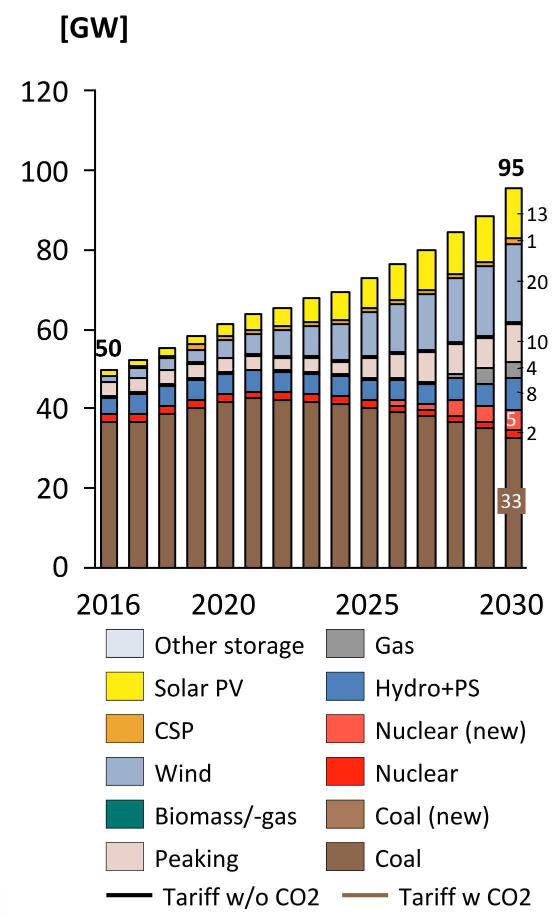
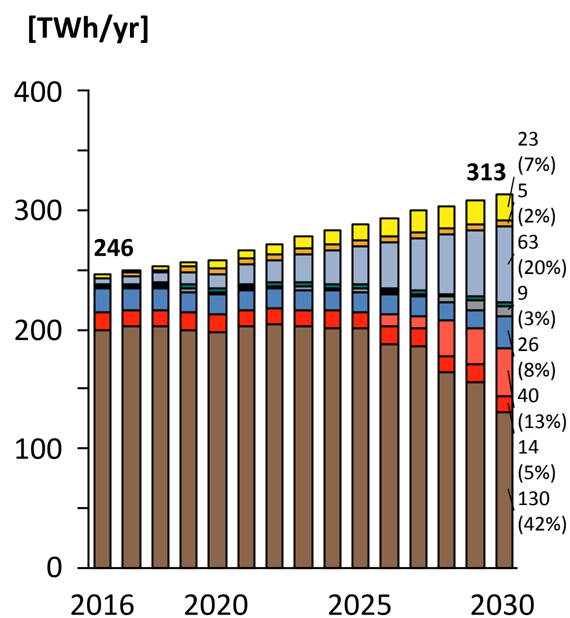
What-if: IRP 2016 Carbon Budget (over-investment)

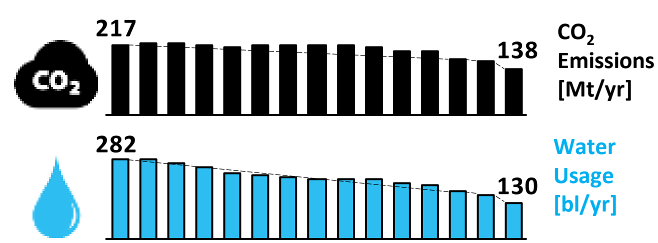
27% solar PV/wind energy share by 2030, R382 billion cost in 2030

Capacity Installed

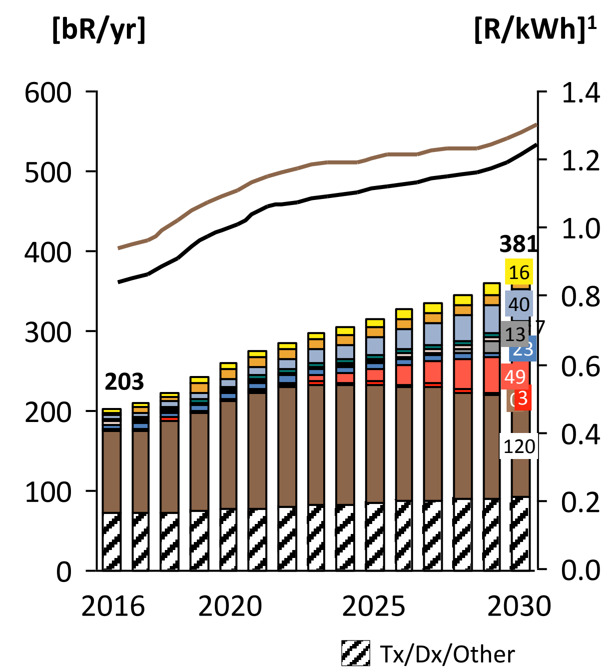


Energy Produced





Cost and Tariff



Difference to Draft IRP 2016 Base Case

- Low Demand (EIUG)
- Tighter carbon reduction targets
- Hard-coded installed capacity from this scenario but with lower demand forecast

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

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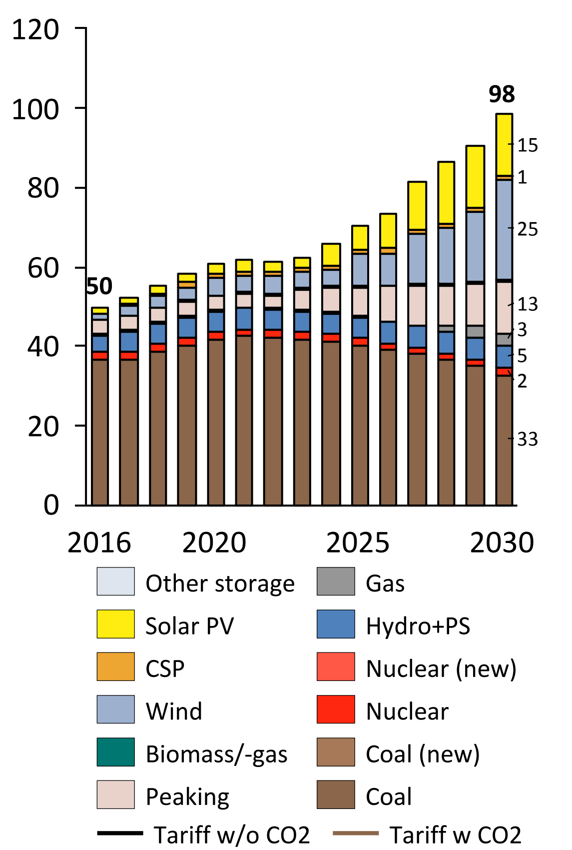
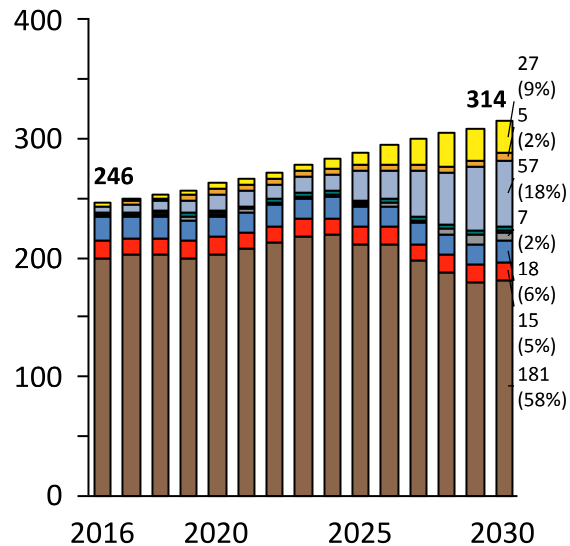
What-if: Least Cost (over-investment)

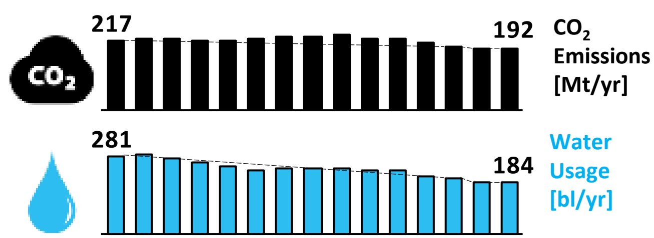
27% solar PV/wind energy share by 2030, R347 billion cost in 2030

Capacity Installed

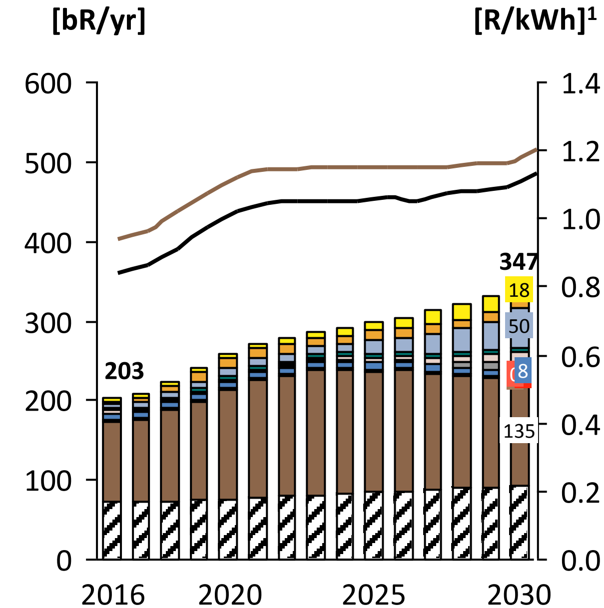


Energy Produced





Cost and Tariff

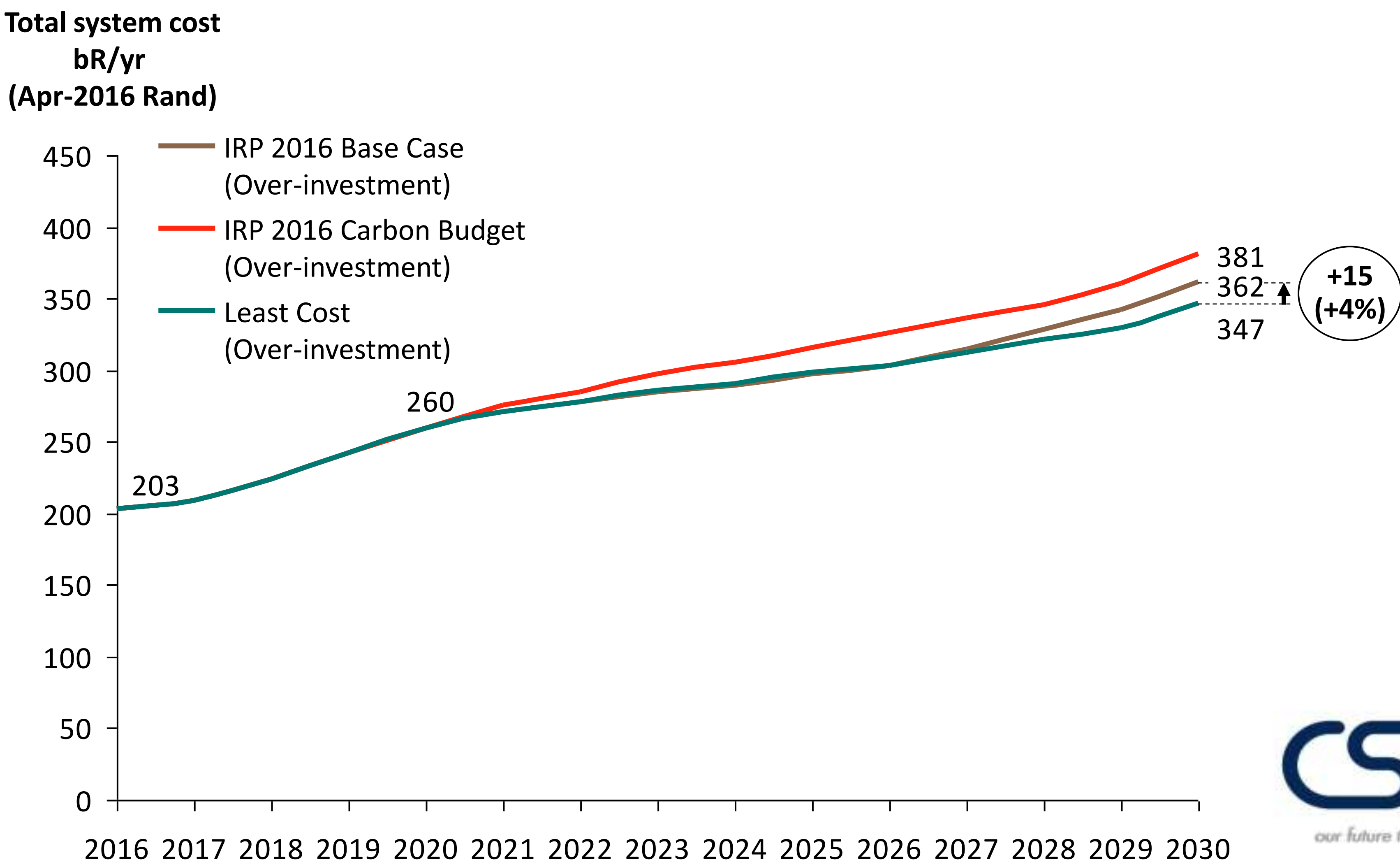


Difference to Draft IRP 2016 Base Case

- Low Demand (EIUG)
- No build-out constraints on any technology
- RE costing aligned with latest REIPPPP
- Demand shaping from residential EWHs

[1] Includes an assumed 0.30 R/kWh for transmission, distribution and customer services; Sources: CSIR analysis, based on DoE's Draft IRP 2016

Total system cost: IRP 2016 Base Case ≈R14 bn/year more expensive by 2030 than Least Cost (without cost of CO_2) if low demand materializes



Sources: CSIR analysis

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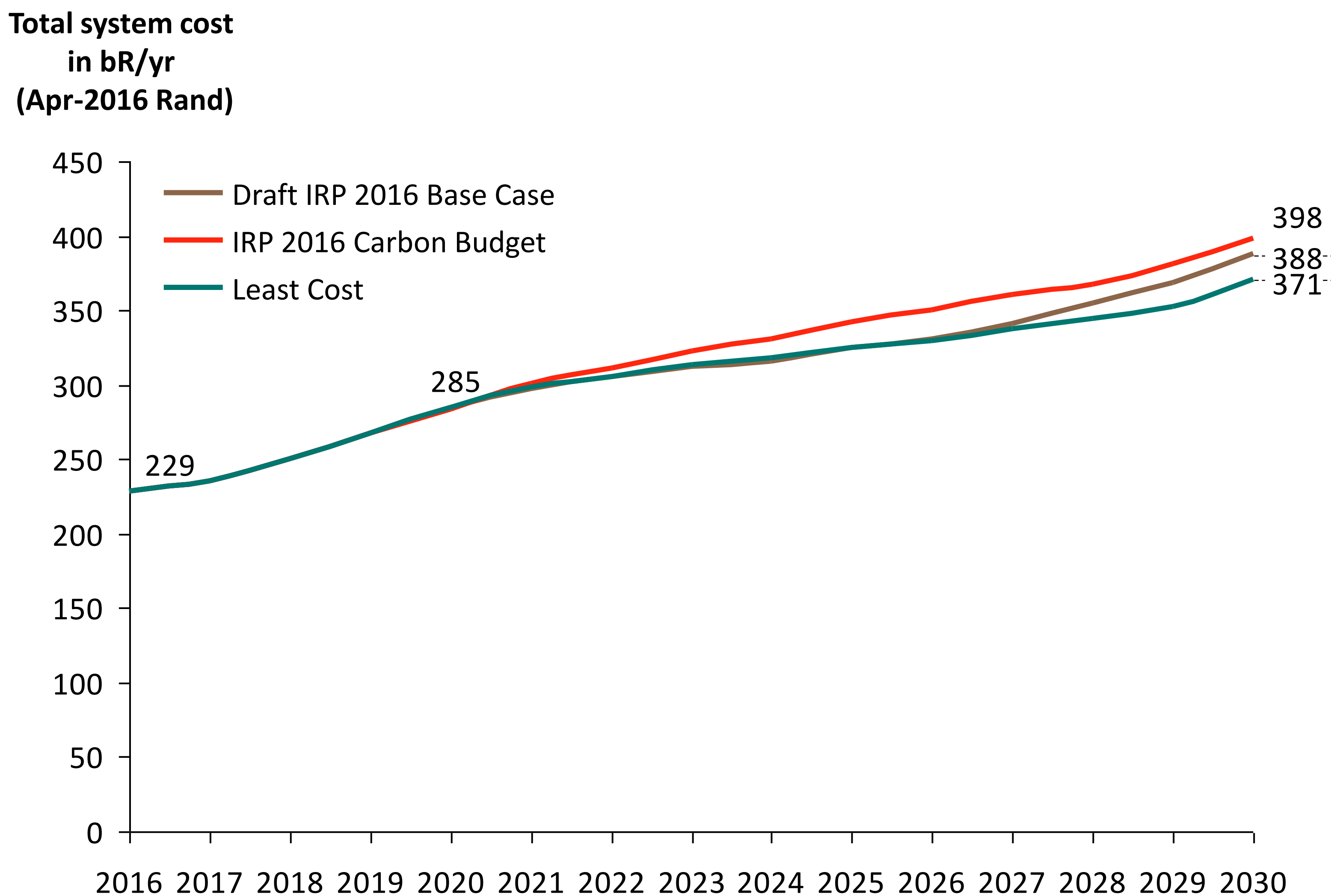
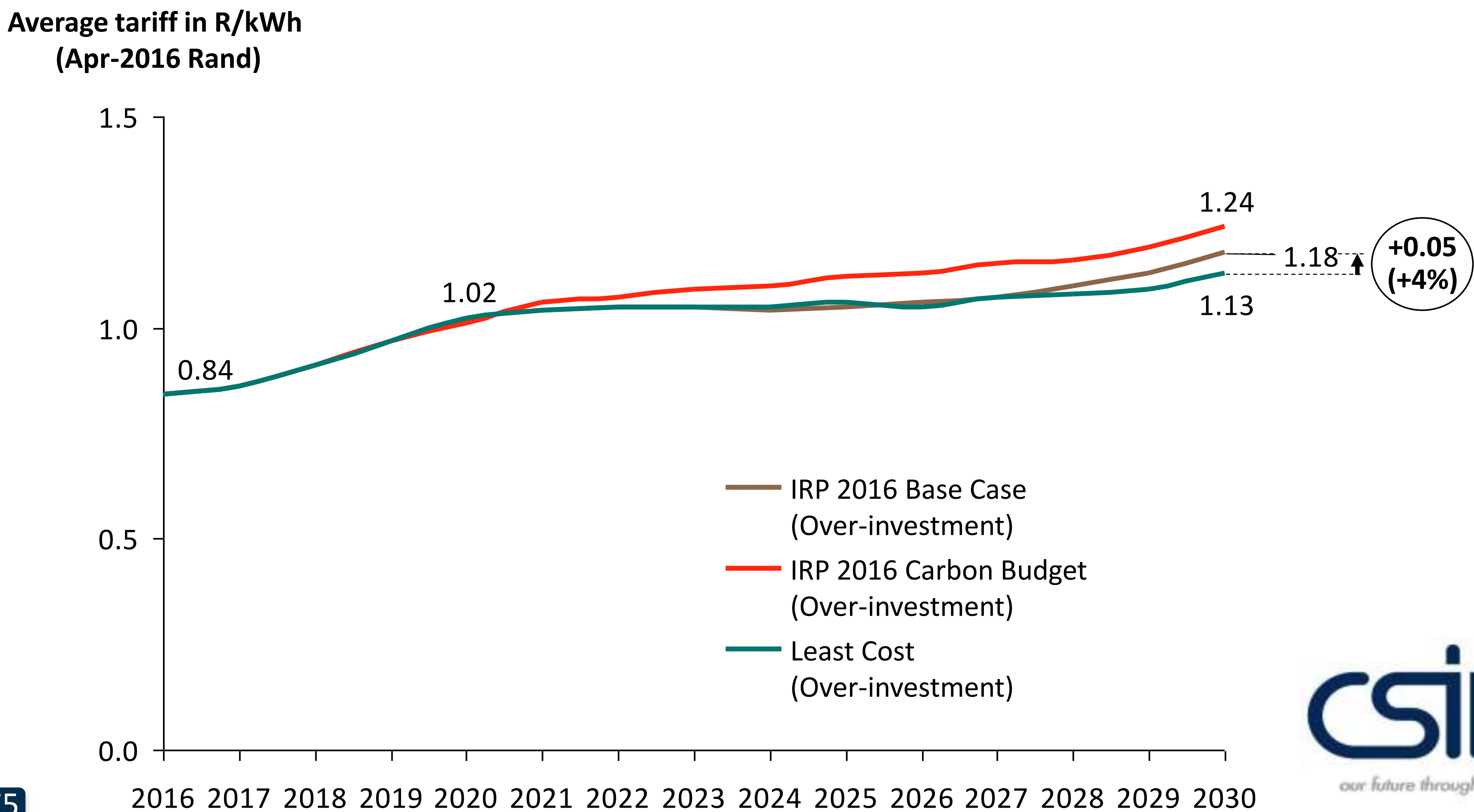
Total system cost: IRP 2016 Base Case ≈R17 bn/year more expensive by 2030 than Least Cost (with cost of CO_2) if low demand materializes



Sources: CSIR analysis

Average tariff (without cost of CO_2): Draft IRP Base Case tariff ≈ 5 cents/kWh higher than Least Cost by 2030 if low demand materializes



Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items)   Sources: Eskom on Tx, Dx cost; CSIR analysis

Average tariff (with cost of CO_2): Draft IRP Base Case tariff ≈ 6 cents/kWh higher than Least Cost by 2030 if the low demand materializes

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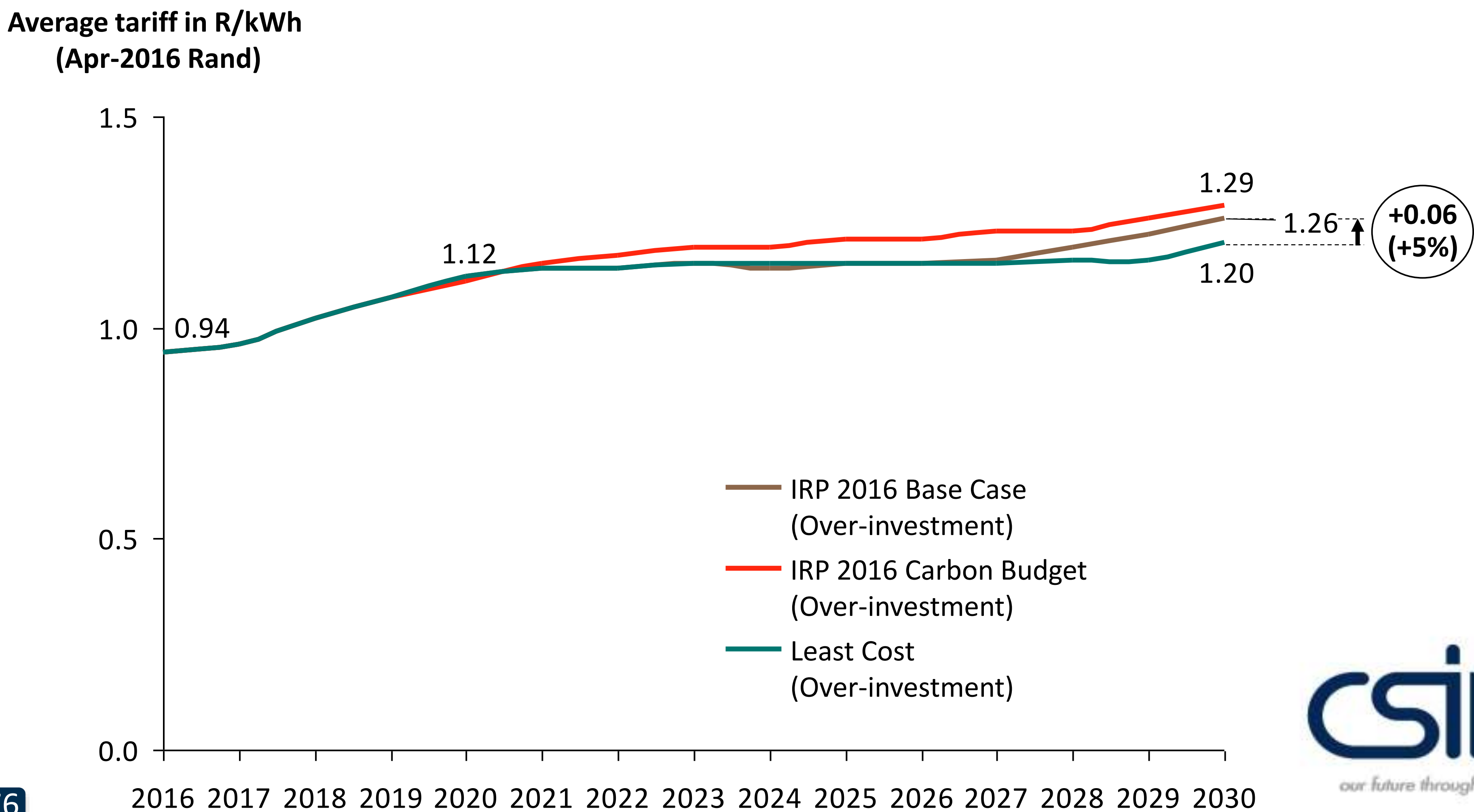

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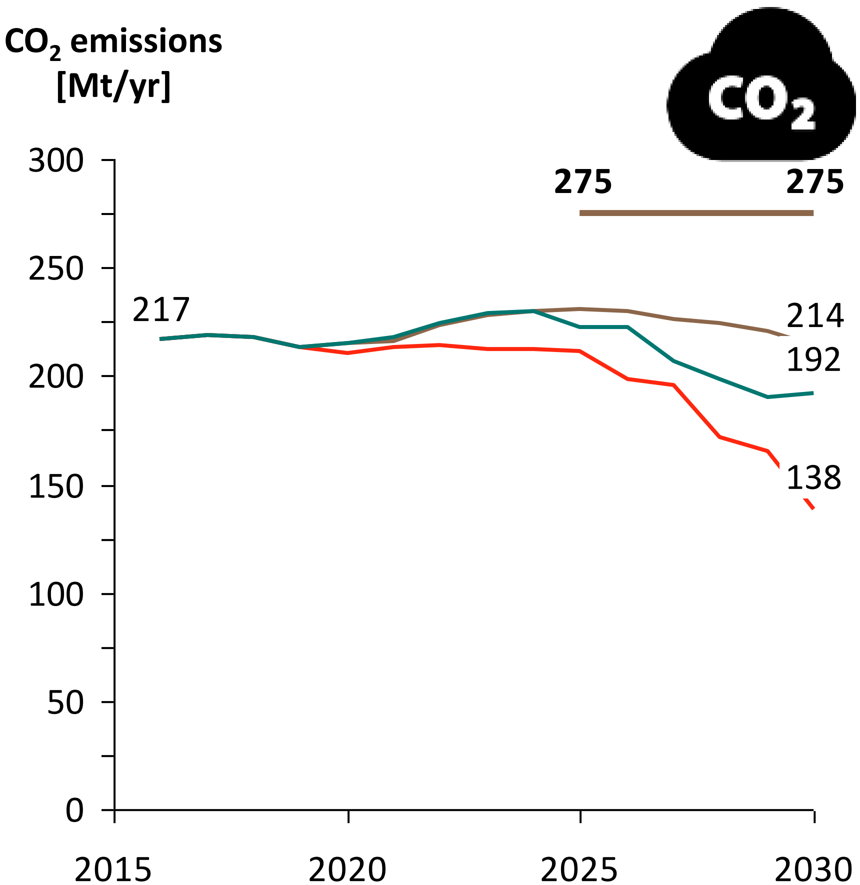
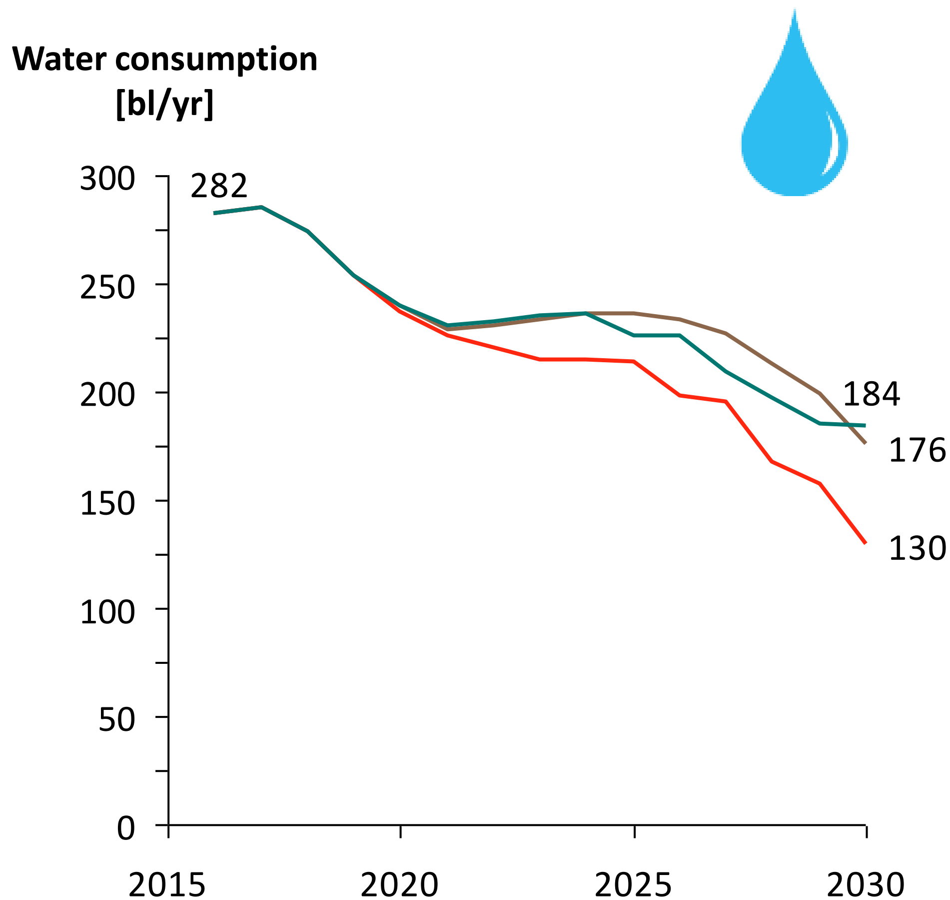
Note: Average tariff projections include 0.30 R/kWh for transmission, distribution and customer service (today's average cost for these items) Sources: Eskom on Tx, Dx cost; CSIR analysis

CO_2 emissions trajectories and water usage summary





IRP 2016 Base Case (Over-investment) | IRP 2016 Carbon Budget (Over-investment) | Least Cost (Over-investment) | PPD Moderate

Source: CSIR analyses

MODELLING APPROACH EXCLUSIONS

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Agenda

Network infrastructure

System services

- **Reactive power and voltage control**
- **Power system stability (transient)**
- **Power system stability (frequency)**

Agenda

Network infrastructure

System services

- Reactive power and voltage control
- Power system stability (transient)
- Power system stability (frequency)

Agenda

SA Grid Overview

Grid development plans

Provincial load location (2040 – spatial by Eskom) and 2050 (assumed)

Wind and solar PV resource location

Grid integration topology and costs – for direct connection

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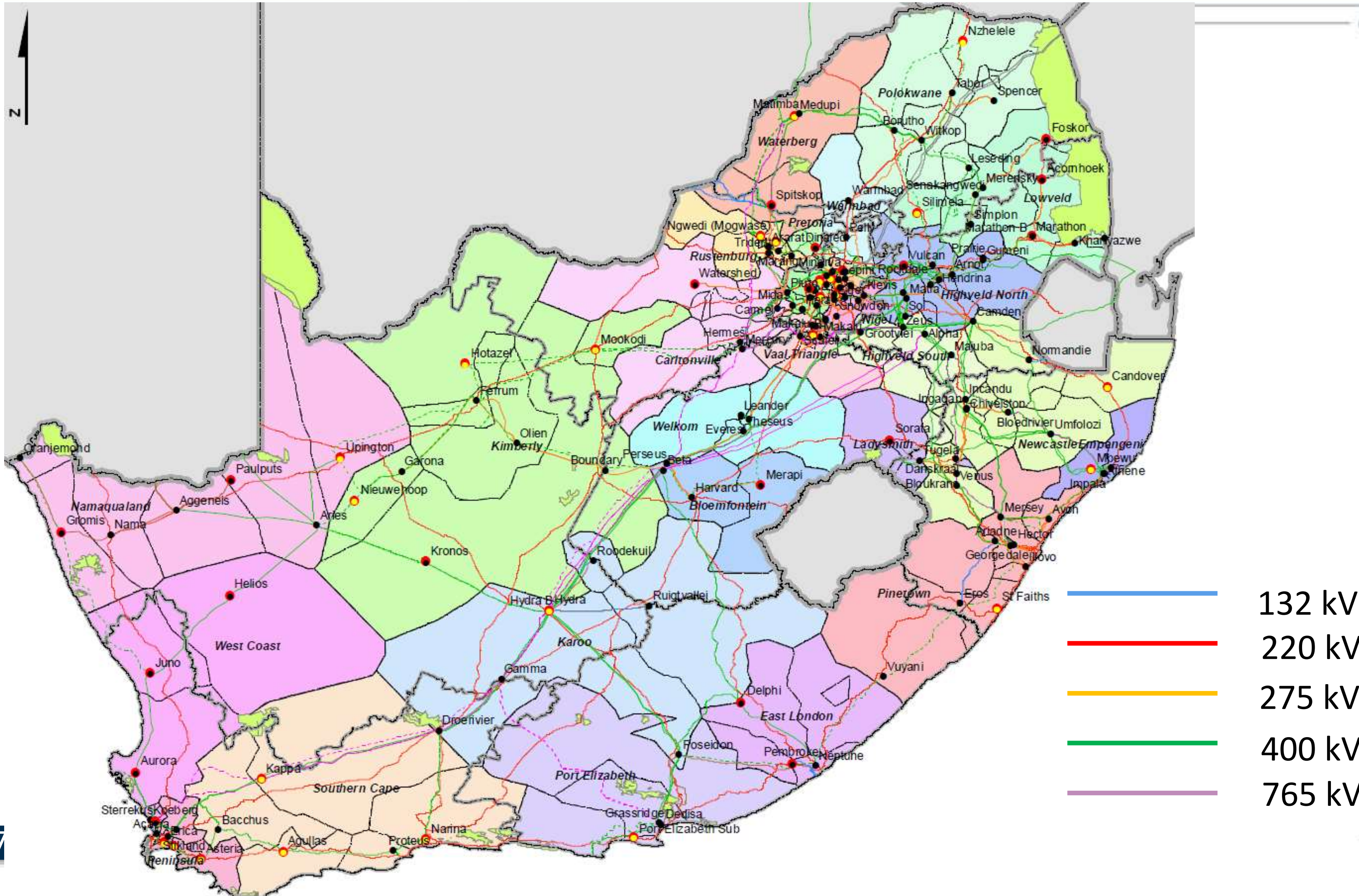
SA Grid overview by 2022



Agenda

SA Grid Overview

Grid development plans

Provincial load location (2040 – spatial by Eskom) and 2050 (assumed)

Wind and solar PV resource location

Grid integration topology and costs – for direct connection

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Plans for the development of a power system

Integrated Resource Plan (IRP)

- The Department of Energy (Energy Planner) is accountable for the Country Electricity Plan, which is called the Integrated Resource Plan For Electricity (IRP 2010-2030).
- The Integrated Resource Plan (IRP) is intended to drive all new generation capacity development.
- Nersa licences new generators according to this determination.

Strategic Grid Plan (SGP)

- The Strategic Grid Plan formulates long term strategic transmission corridor requirements
- The Plan is based on a range of generation scenarios and associated strategic network analysis
- Horizon date is 20 years
- Updated every 2 - 3 years

Transmission Development Plan (TDP)

- The Transmission Development Plan (TDP) represents the transmission network infrastructure investment requirements
- The TDP covers a 10 year window
- Updated annually
- Indicates financial commitments required in the short to medium term

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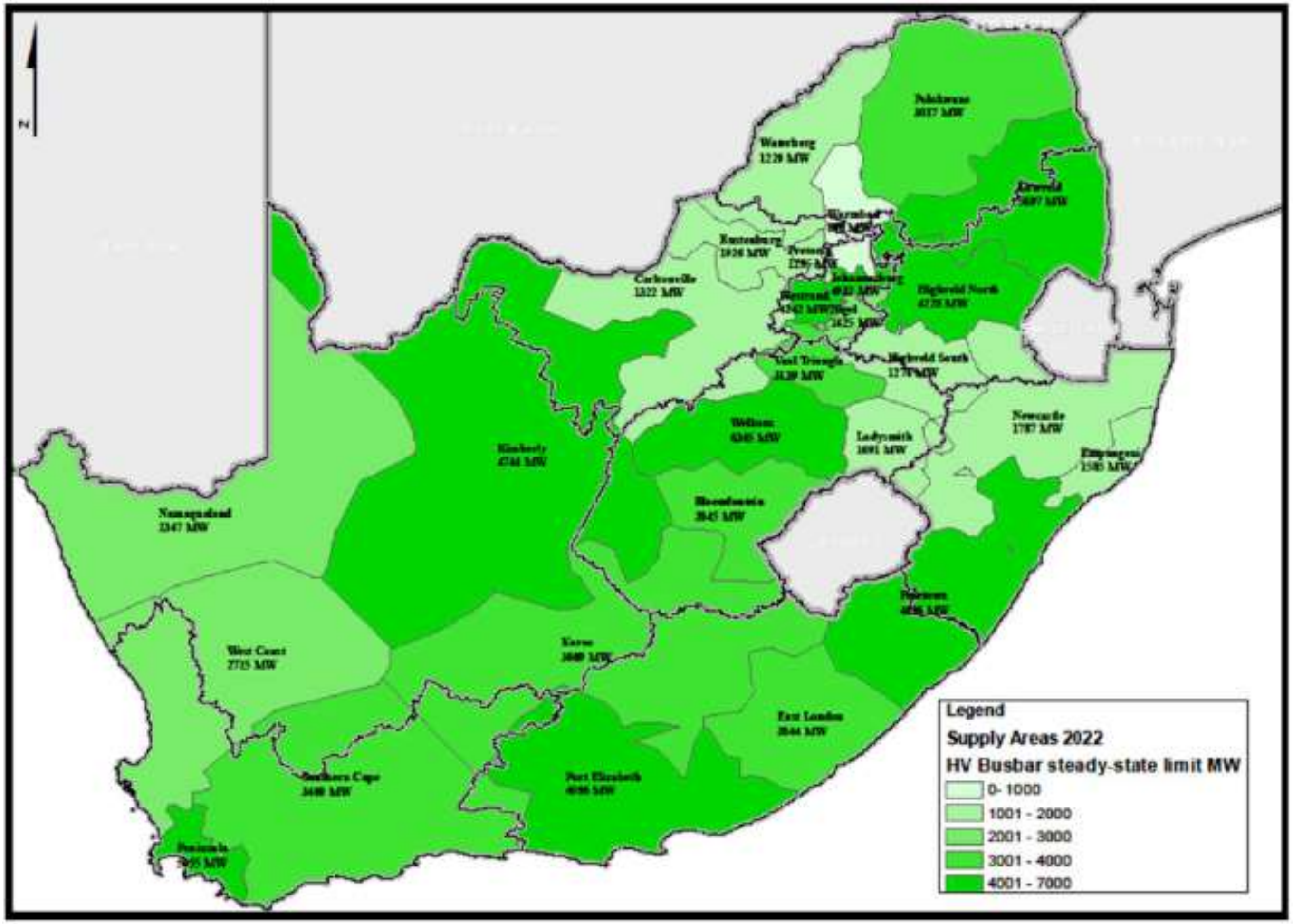
Sources: Eskom TDP 2016-2025: www.eskom.co.za/Whatweredoing/TransmissionDevelopmentPlan/

Transmission supply area generation connection capacity for simultaneous generation sources in an area



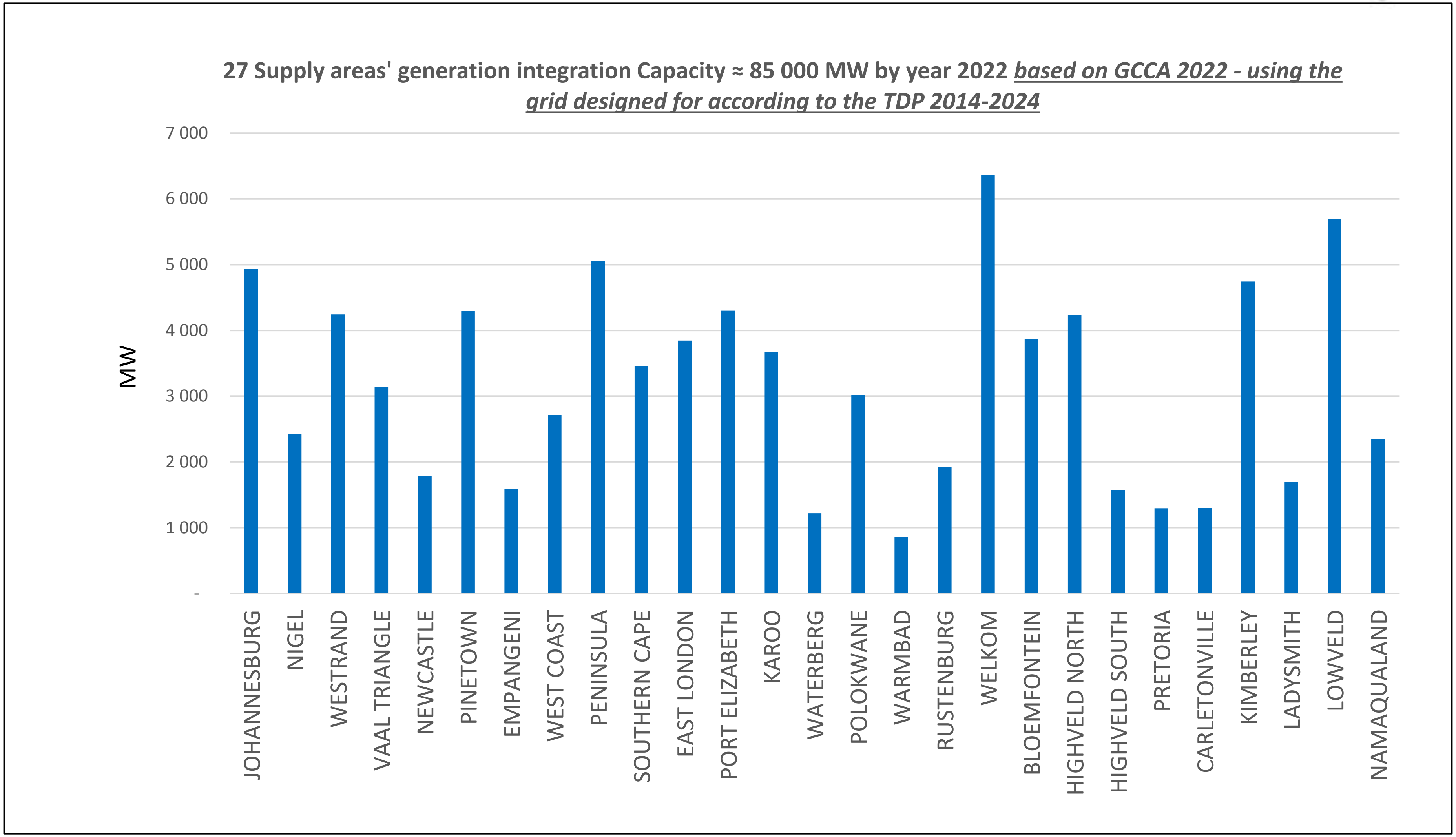
Grid capacity is available all over the country, therefore wind and PV projects should be incentivised to go where there is grid capacity in order to expedite time to connect to the grid.

Focusing only on the Northern Cape for Wind and PV will result in unnecessary delay to connect new plants since wind and PV resource is good all over the country

Source: GCCA 2022: http://www.eskom.co.za/Whatweredoing/GCCAReport/Pages/Default.aspx

Submitted to DoE on 31 March 2017

Transmission capacity for generation connection in the short term up year 2030 is not a limitation



Submitted to DoE on 31 March 2017

Strategic plans are in place to unlock over 36 GW of generation connection interest, but timelines are too long for large integration

Preparation Status

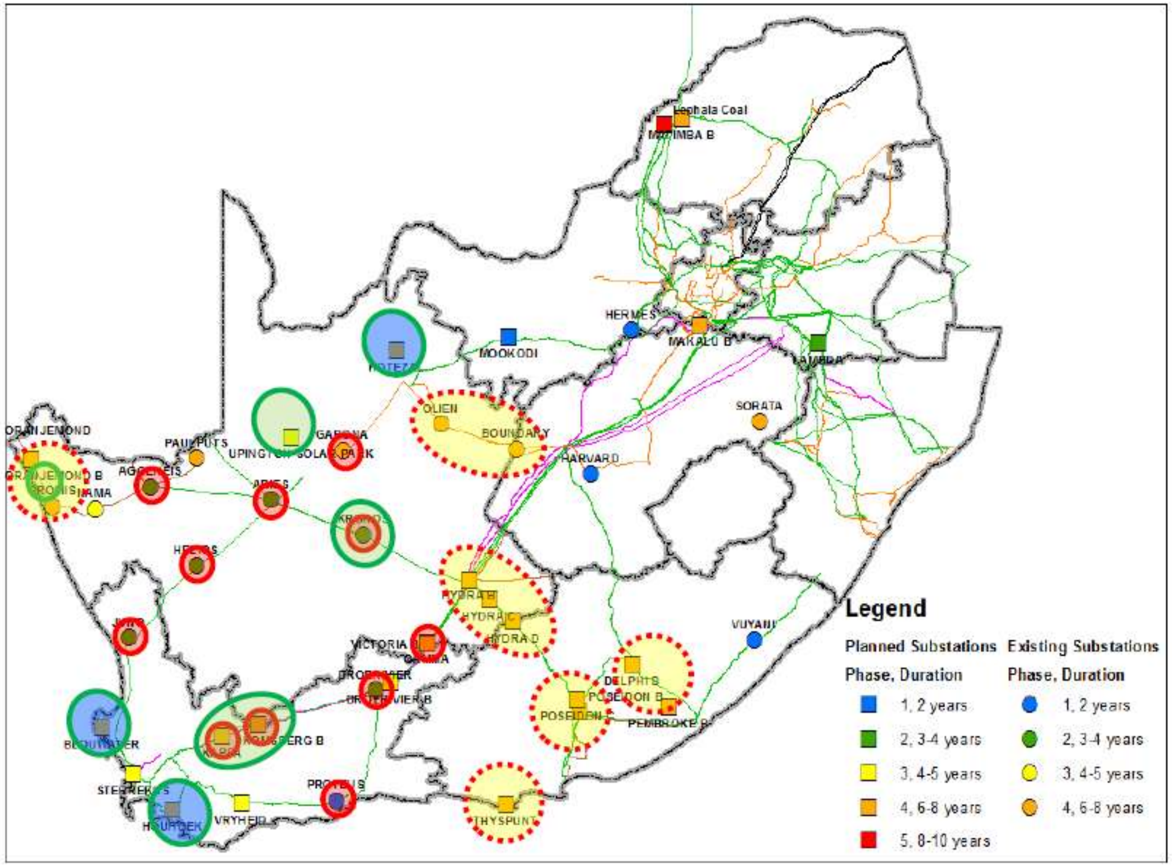
Already in TDP and projects to be accelerated

Projects triggered by successful RE Bids

Projects defined and ready to be developed

Complex projects still to be fully defined for development

Costing for all above projects being prepared



Sources: Eskom Transmission development plan 2016 -2025.

Agenda

SA Grid Overview

Grid development plans

Provincial load location (2040 – spatial by Eskom) and 2050 (assumed)

Wind and solar PV resource location

Grid integration topology and costs – for direct connection

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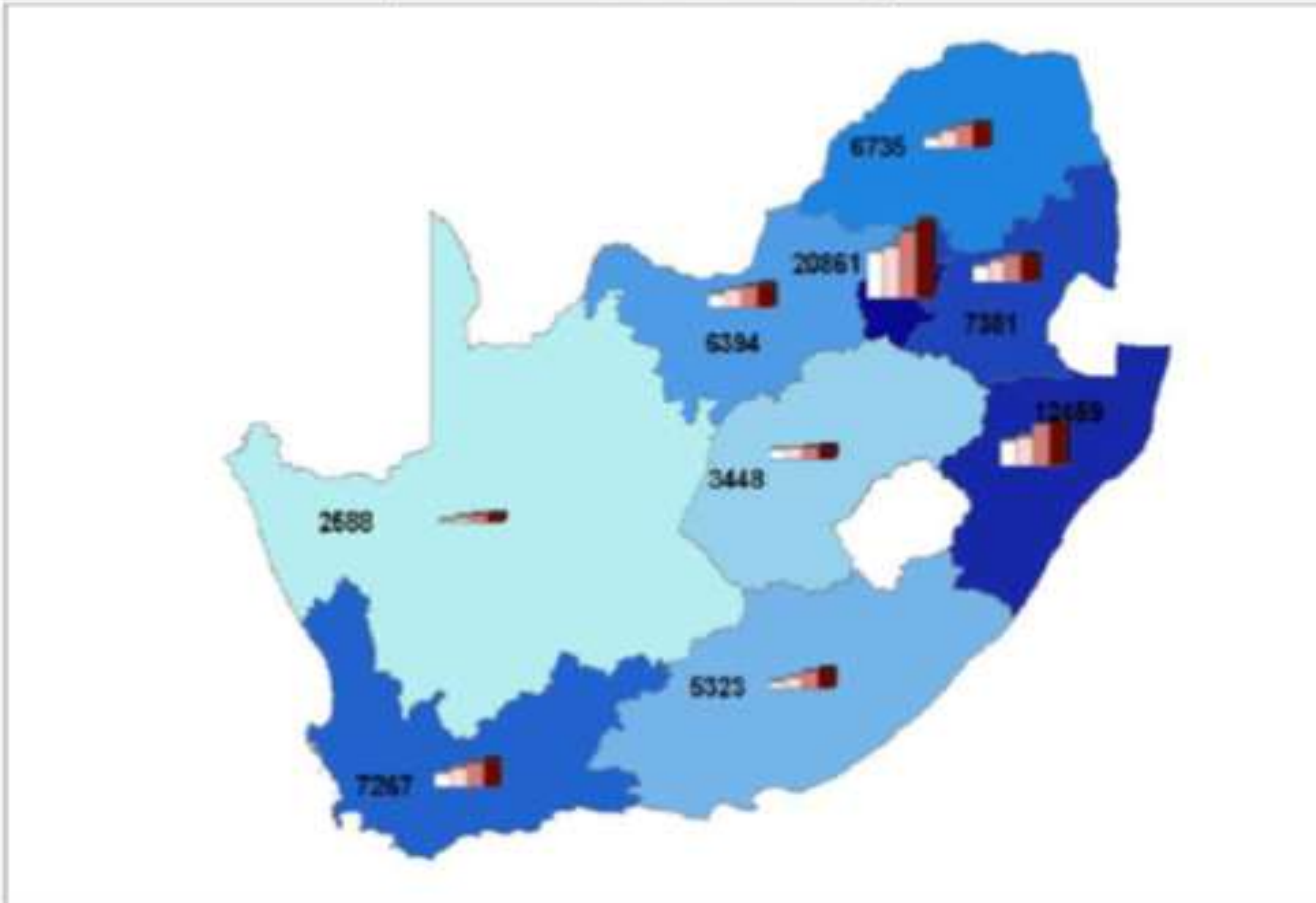
Demand generation by 2040; generation for Base IRP 2010 scenario

LOAD GROWTH BY 2040 PER PROVINCE
(Maximum Demand in MW)



Source: Eskom strategic grid plan

Load spatial location assumptions as per strategic grid plan

No	Province	SGP Demand 2040 (GW)	IRP 2016 Year 2050 (GW)	% Total Demand
1	Eastern Cape	5.3	6.3	7%
2	Free State	3.4	4.1	5%
3	Gauteng	20.9	24.8	29%
4	Kwazulu-Natal	12.5	14.8	17%
5	Limpopo	6.7	8.0	9%
6	Mpumalanga	7.4	8.8	10%
7	North West	6.4	7.6	9%
8	Northern Cape	2.6	3.1	4%
9	Western Cape	7.3	8.6	10%
TOTAL		72.5	86	100%

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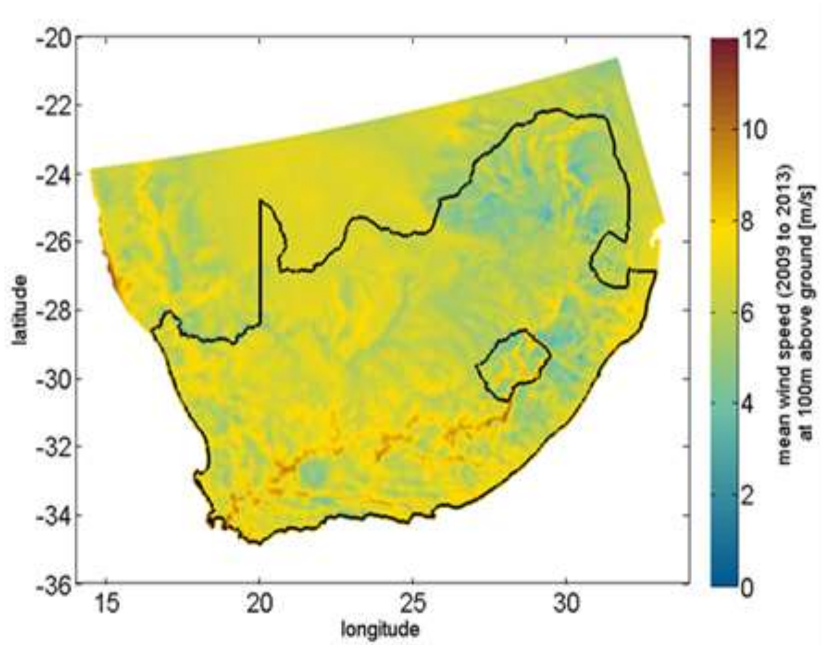
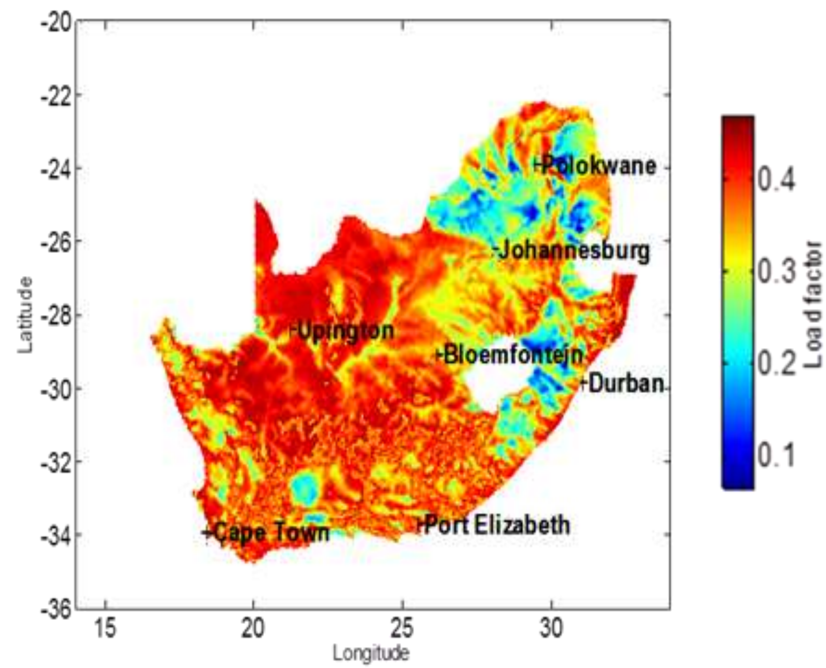
The wind resource is good virtually all over the country, location of collector substation existing grid capacity should be prioritised



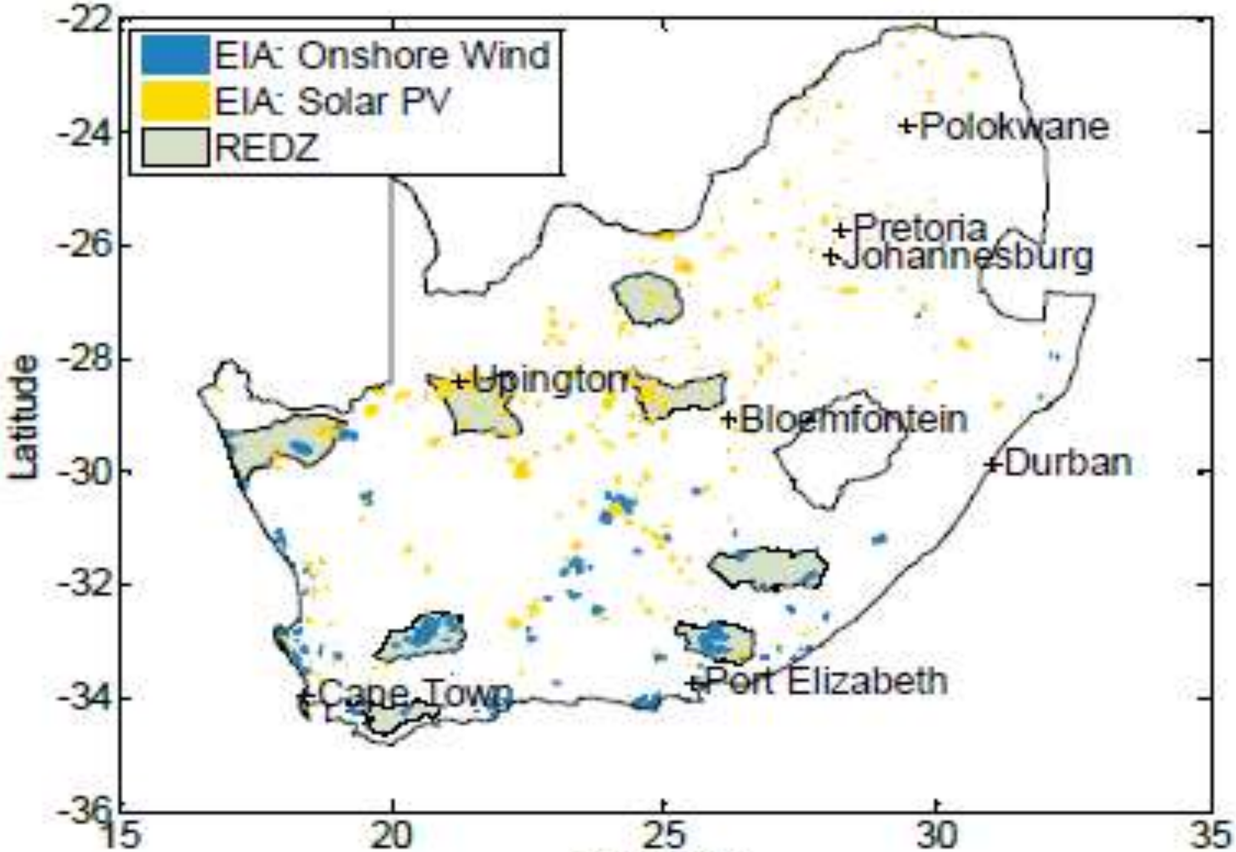


Collector substation and clustering allocation should prioritise:

- **Areas with existing grid capacity (GCCA 2022 provides guidance)**
- **Areas with minimal environmental constraints (Data sets from the REDZs study provide guidance)**

Sources:
Wind and solar resource aggregation study: http://www.csir.co.za/Energy_Centre/wind_solarpv.html

High potential for wind and solar PV, and space is no limitation



EIA applications: estimated Wind (89), PV(329); land use is roughly 1.21% of SA land
REDZ: estimated Wind (535 GW), PV (1782 GW); land use is roughly 4.4% of SA land

RE Rollout and Provincial Impact; the Cape area has been the focus, however, wind and solar resources are excellent in other provinces too.

Province	Bid windows	Wind (MW)	PV (MW)	CSP (MW)	Total	% RE of Bid 1-4	Area (km^2)	% of SA Land
Eastern Cape	1,2,3,4	1440	70	0	1509	24%	168 966	14%
Free State	1,2,3,4	0	199	0	199	3%	129 825	11%
Gauteng		0	0	0	0	0%	16 548	1%
Kwazulu-Natal		0	0	0	0	0%	94 361	8%
Lompopo	1,3	0	118	0	118	2%	125 755	10%
Mpumalanga		0	0	0	0	0%	76 495	6%
North West	1,4	0	275	0	275	4%	106 512	9%
Northern Cape	1,2,3,3.5,4	1459	1497	600	3556	57%	372 889	31%
Western Cape	1,2,3,4	458	134	0	592	9%	129 462	11%
TOTAL		3357	2292	600	6249	100%	1 220 813	

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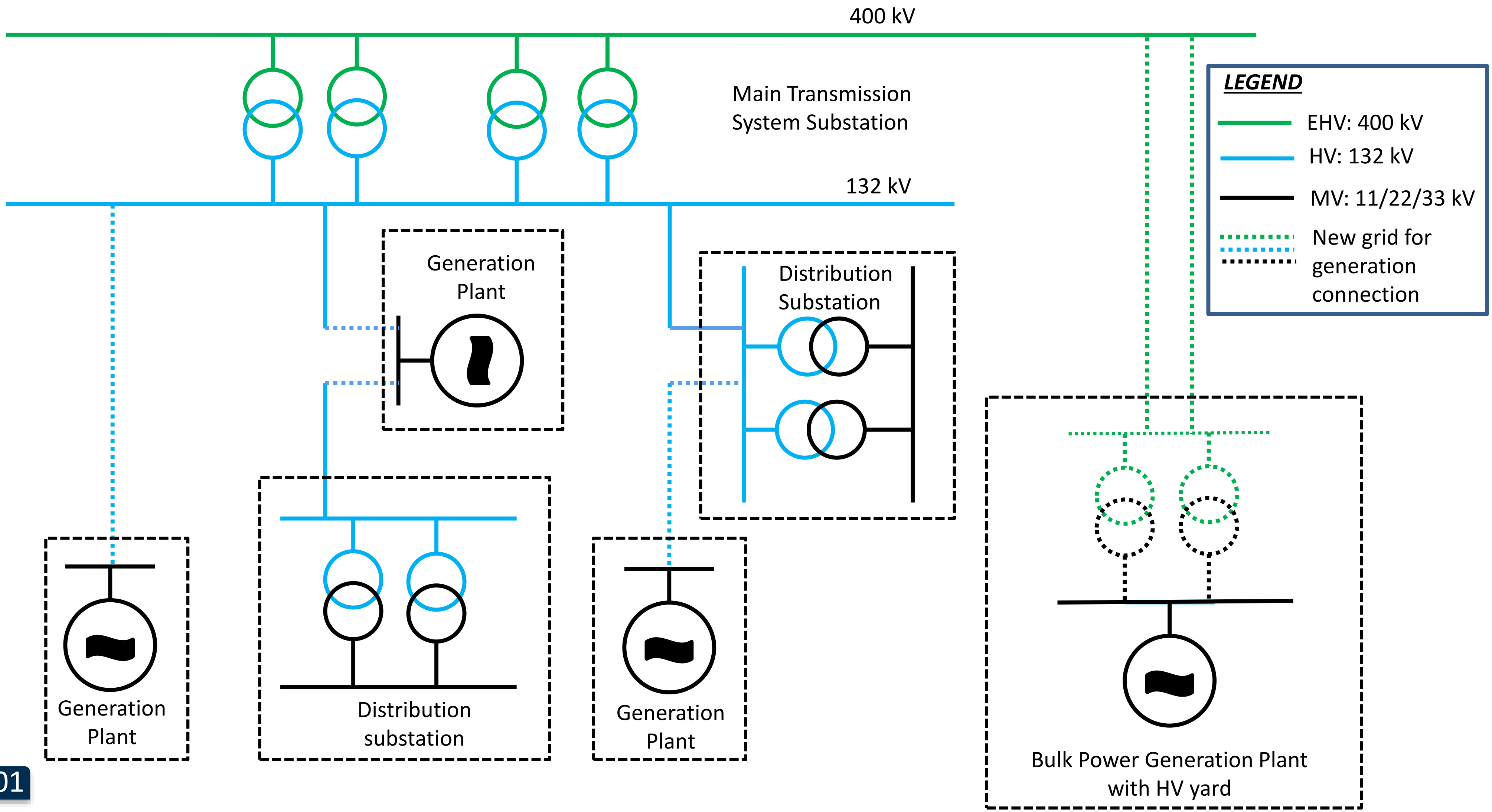
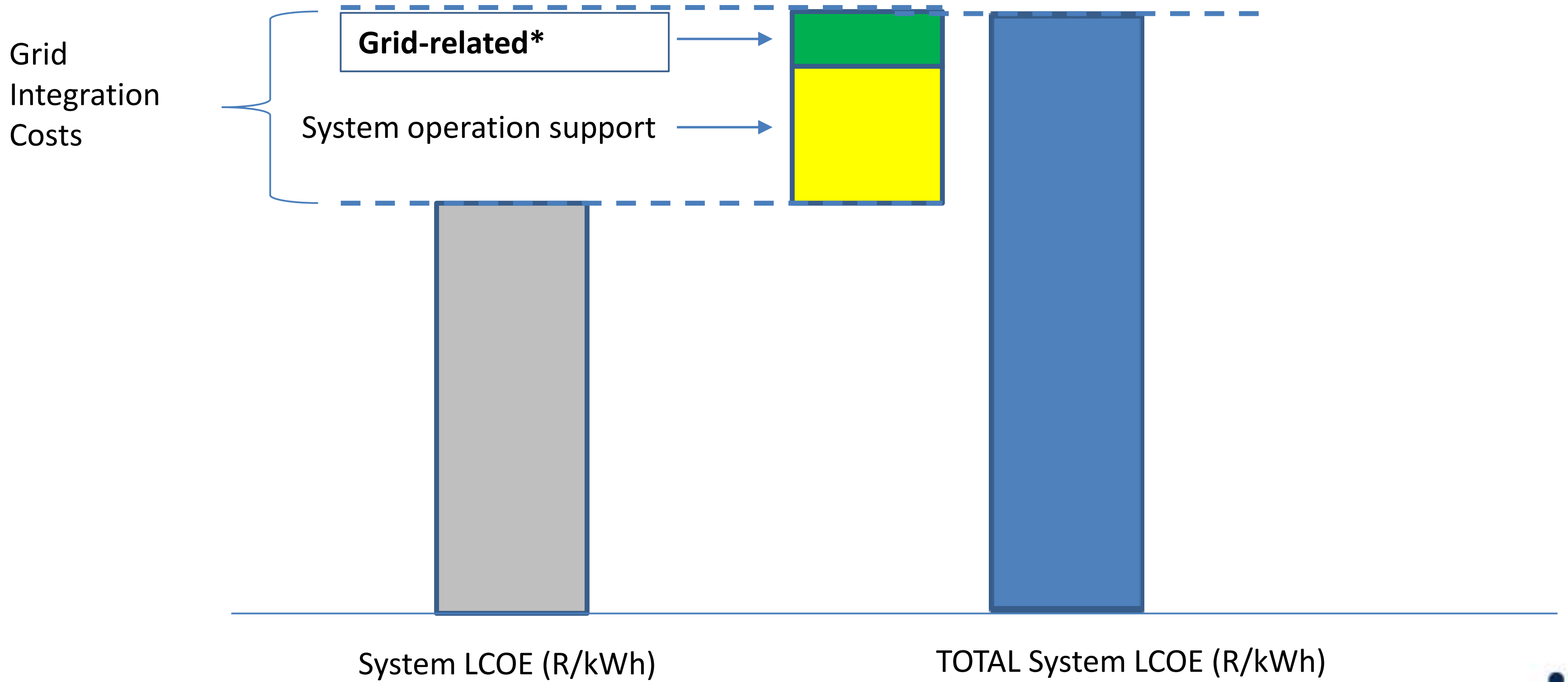
Grid integration topology and costs – for direct connection

Generation integration for topologies for distributed generation and bulk power or centralised generation



Grid connection costs are a small part of grid related costs asscociated with any generation integration



*Grid-related cost include; **grid connection capital cost**, losses, location based costs (e.g. nodal/zonal pricing)

Grid connection assumptions

Estimated direct connection costs

Technology	Plant Capital R/kW	Estimated % Capital cost	Estimated grid connection R/kW
Wind	13 097	5%	655
PV	4 639	5%	232
Coal	45 103	10%	4510
Nuclear	84 420	12%	10130
Hydro + PS	63 299	10%	6330
CCGT	10 772	10%	1077
Bio			

Estimated backbone connection costs

	R/kW	Comments
HVAC (excludes substations)	1600	Substations are cheaper that very long transmission lines
HVDC (excludes converter stations)	2900	Converter stations are the most expensive part of the HVDC system

Key assumptions

- Only direct grid connections considered, no backbone network considered; previous studies have shown that backbone grid is scenario neutral because it is largely load driven (but this can be revisited)
- ***Connection costs based on nameplate capacity – a worst case connection***
- Wind and PV distributed in all the provinces
- All PV assumed to be grid connected – worst case scenario in term of connection costs; in reality 20-30% of PV will be embedded
- HVDC costs for higher nuclear scenario not fully costed, assumption on costs is based on direction connection

Source: https://www.irena.org/DocumentDownloads/Publications/SAPP.pdf

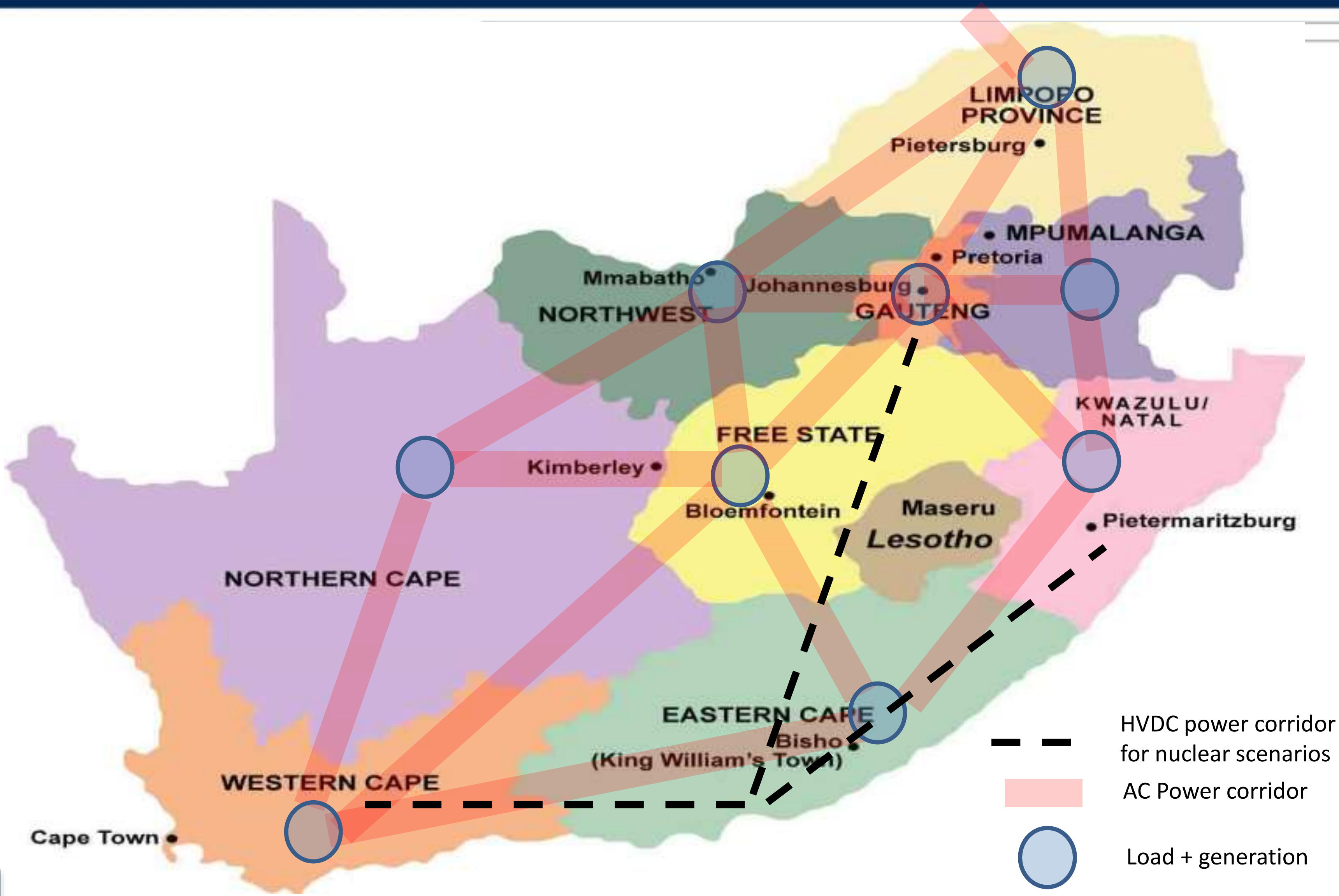
Grid connection costs - supply scenarios for 2050

	Estimated Direct connection costs		Estimated Backbone Costs		
	Capex (bR)	EAC (bR/yr)	Capex (bR)	EAC (bR/yr)	Total (bR/year)
IRP Base Case	436	39.5	274	24.8	64.2
IRP Carbon Budget	433	39.2	365	33.1	72.3
Unconstrained Base Case	254	23.0	224	20.3	43.3
Least Cost	233	21.1	263	23.8	44.9

Notes

- Equivalent annual cost: Economic lifetime = 30 years, discount rate = 8.2%
- Backbone grid for all scenarios will be estimated, but will likely be similar for all scenarios since it is load driven, and the least cost scenario benefits from spatial aggregation, base case and carbon budget have less spatial benefits
- Backbone costs exclude HVDC converter station for the Base and Carbon budget scenarios; olny HVDC lines assumed for the two scenarios.

Provincial grid node model – linear (dc) load flow



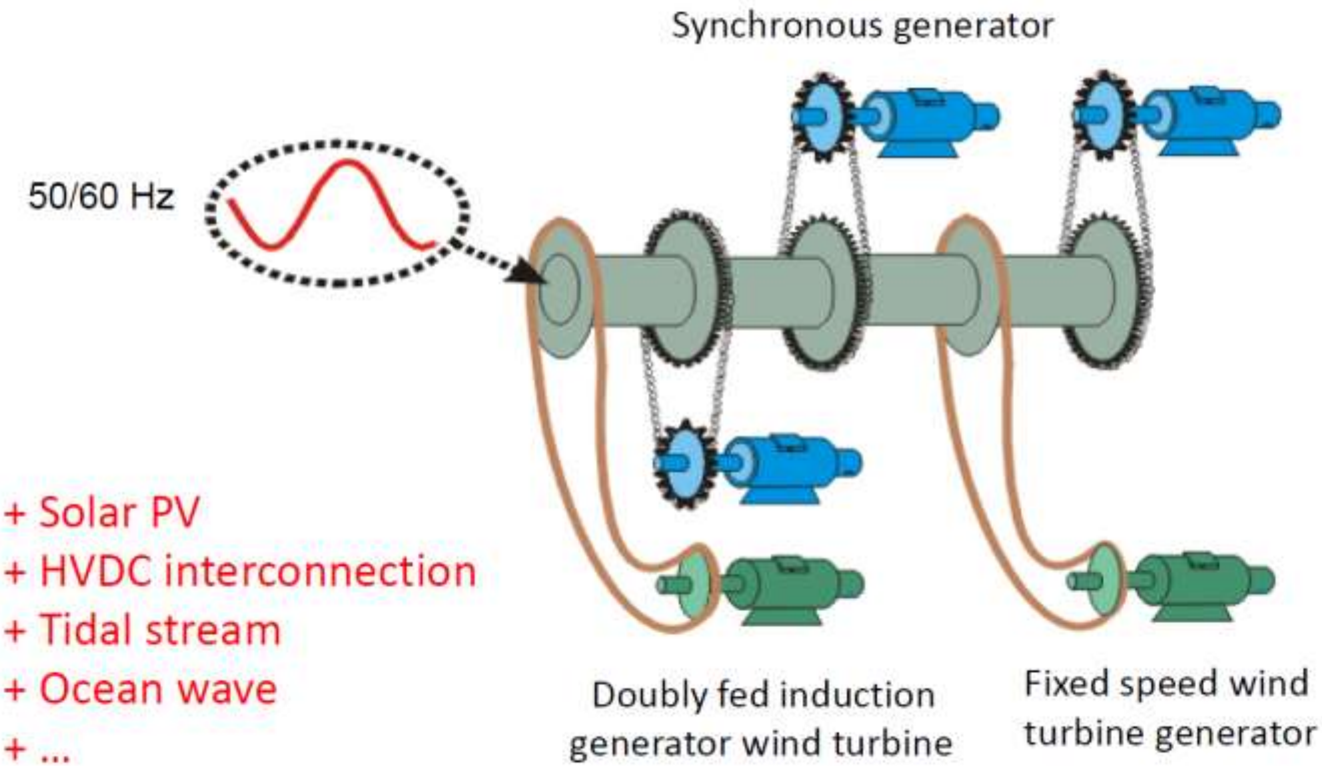
Network infrastructure

System services

- Reactive power and voltage control
- Power system stability (transient)
- **Power system stability (frequency)**

Synchronous generators inherently provide system stability through the direct, synchronous coupling of their physical inertia to the grid

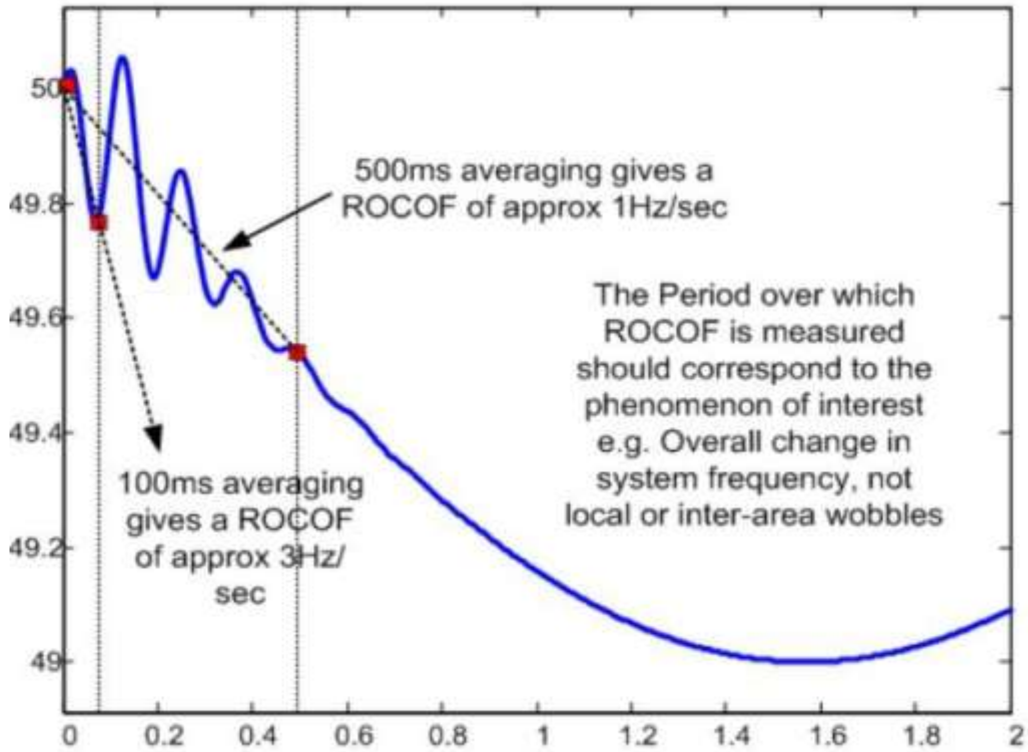
Load Balancing (Frequency Control)



+ Solar PV
+ HVDC interconnection
+ Tidal stream
+ Ocean wave
+ ...

Sources: Damian Flynn, UC Dublin

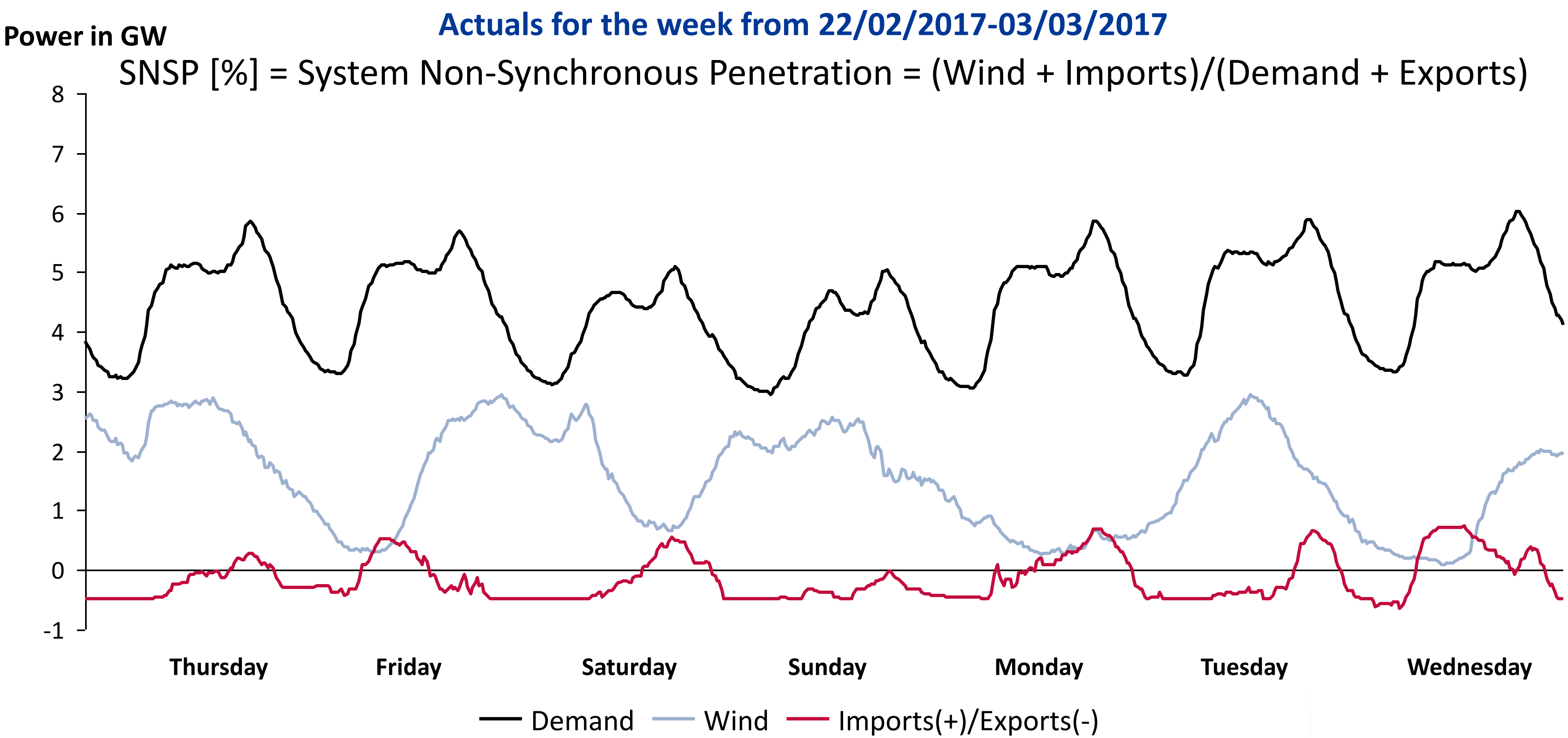
Averaging window is important – for frequency stability typically a 500 ms averaging window for RoCoF is considered



The RocoF should not exceed a particular threshold within the pre-defined averaging window e.g. 500 ms

Sources: EirGrid, SONI

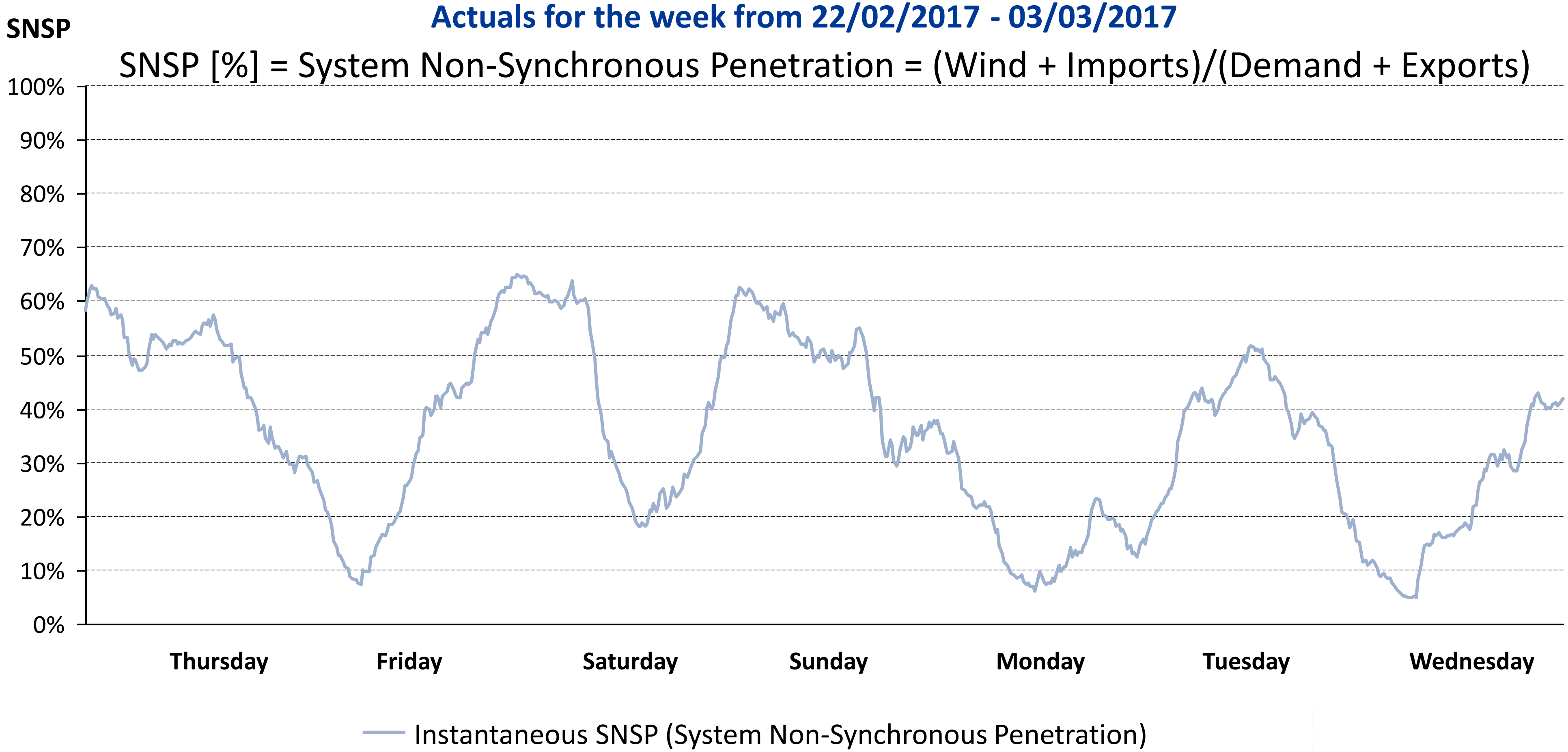
System operators are already managing high non-synchronous penetration levels… today e.g. Ireland



Sources: EirGrid

System operators are already managing high non-synchronous penetration levels… today e.g. Ireland

Actuals for the week from 22/02/2017 - 03/03/2017



Sources: EirGrid; CSIR analysis

The demand for system inertia is driven by two assumptions: the maximum allowable RoCoF & the largest assumed system contingency

Key assumptions:

Maximum allowed $RoCoF$:	1 Hz/s
Largest contingency (P_{cont}):	2 400 MW
Kinetic energy lost in contingency event $E_{kin(cont.)}$:	5 000 MWs

$$E_{kin.(min)} = P_{cont.} \frac{f_n}{2(RoCoF)} + E_{kin(cont.)}$$

Term "inertia" is used a bit loosely to describe the amount of kinetic energy that is stored in the rotating masses of all synchronously connected power generators
(and loads to be precise)

f_n = System frequency = 50 Hz

Demand for inertia

65 000 MWs of system inertia are required at any given point in time in order for RoCoF to stay below 1 Hz/s in the first 500 ms after the largest system contingency occurred

Sources: P. Kundur, Power System Stability and Control, 1994

As a starting point – we have assessed system inertia on an hourly basis via UCED in PLEXOS and some high level assumptions

Technology	Inertia constant [MWs/MVA]
Coal (old)	4.0
Coal (new)	2.0
OCGT	6.0
CCGT	9.0
Biomass	2.0
Hydro/PS	3.0
Imports	0.0
Nuclear	5.0[1]
Wind	0.0
PV	0.0
CSP	2.5
DR	0.0
ICE	2.0

Supply of inertia

Depending on what mix of power stations is operational at any given point in time, the total actual system inertia will be different

For example, if 20 GW of old coal, 10 GW of new coal and 2 GW of nuclear are online, system inertia is:

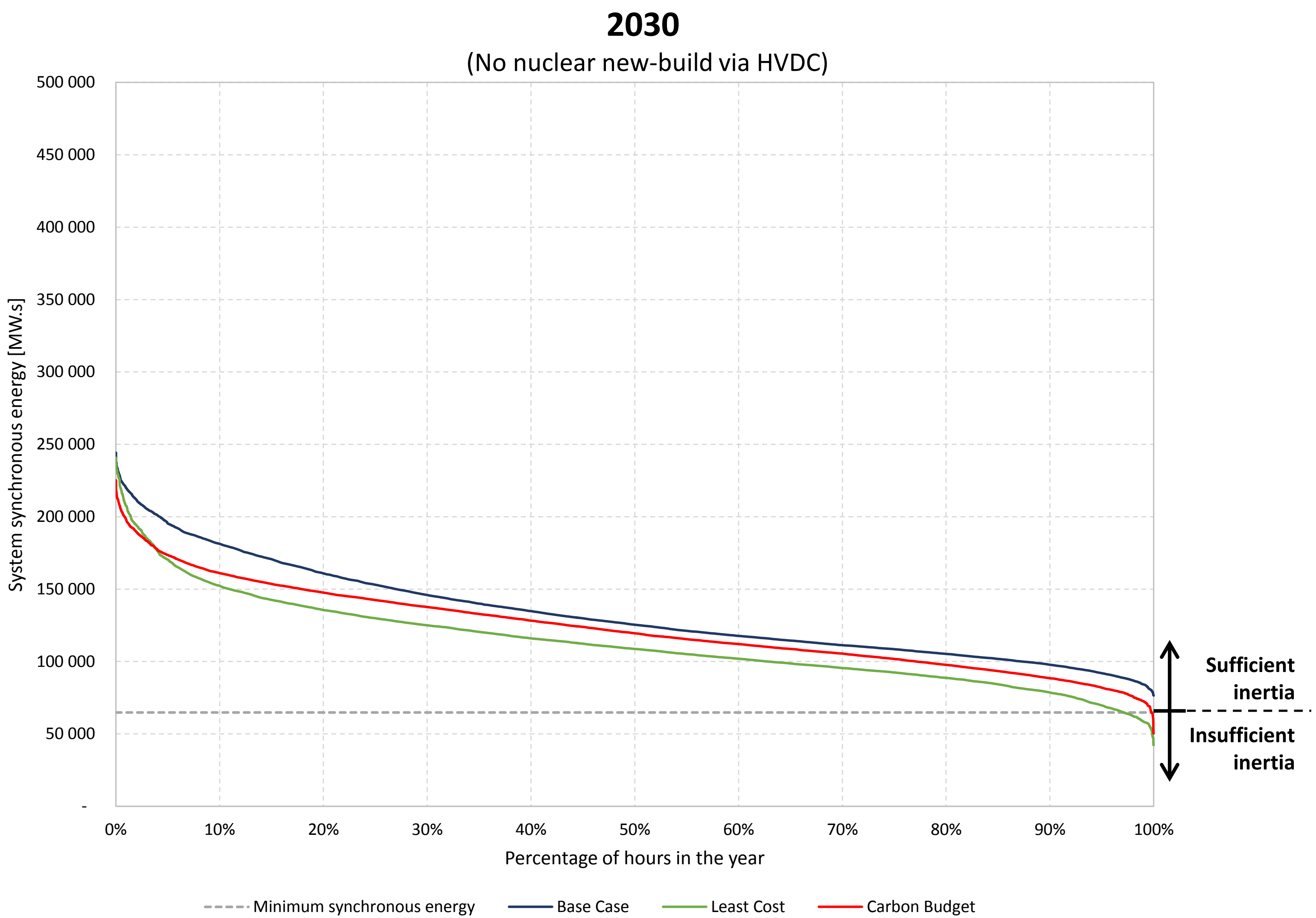
≈20 GW * 4 MWs/MVA + 10 GW * 2 MWs/MVA + 2 GW * 5 MWs/MVA

= 110 000 MWs

If wind, PV and 5 GW of CCGTs are online, system inertia is only 47 000 MWs

[1] Assumed in two cases:
1) At least half of the nuclear fleet is integrated via HVDC i.e. H = 2.5 MWs/MVA;
2) All of the nuclear fleet is integrated via HVDC i.e. H = 0 MW.s/MVA
Sources: P. Kundur, Power System Stability and Control, 1994

The system would likely require additional system inertia by 2030 in the Carbon Budget and Least-cost scenarios



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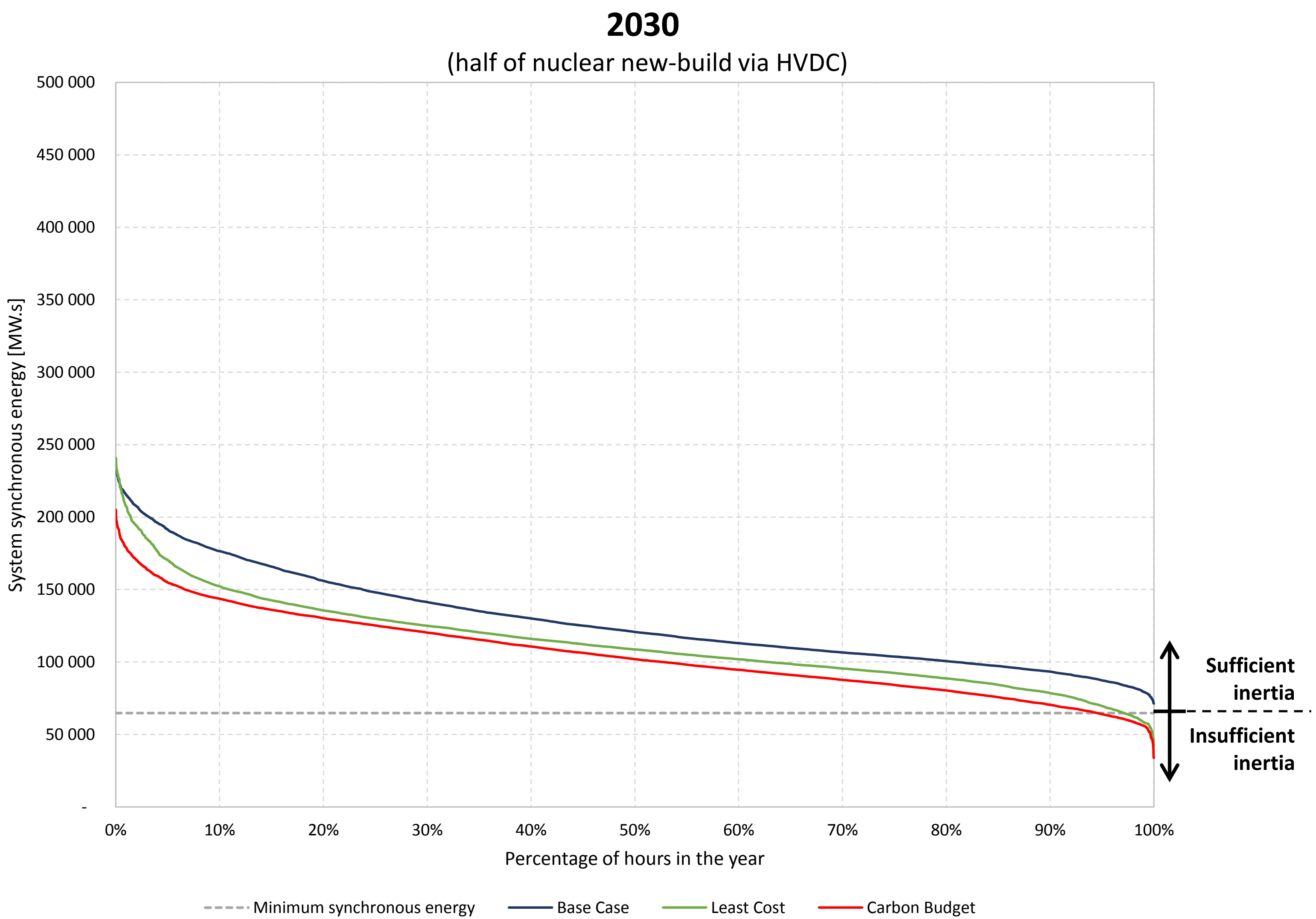
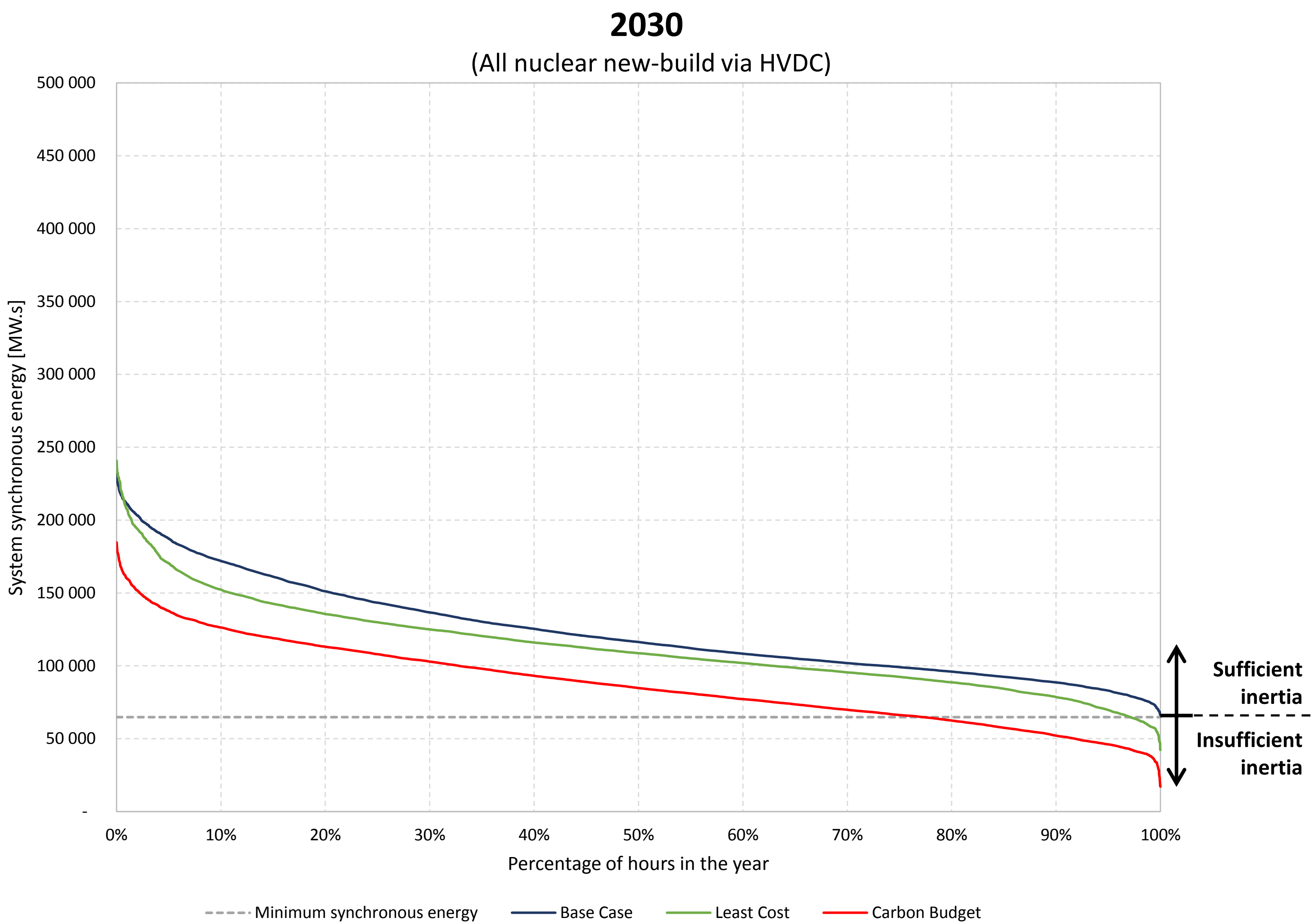


Additional system inertia by 2030 would be required if the nuclear fleet is assumed to be integrated via HVDC



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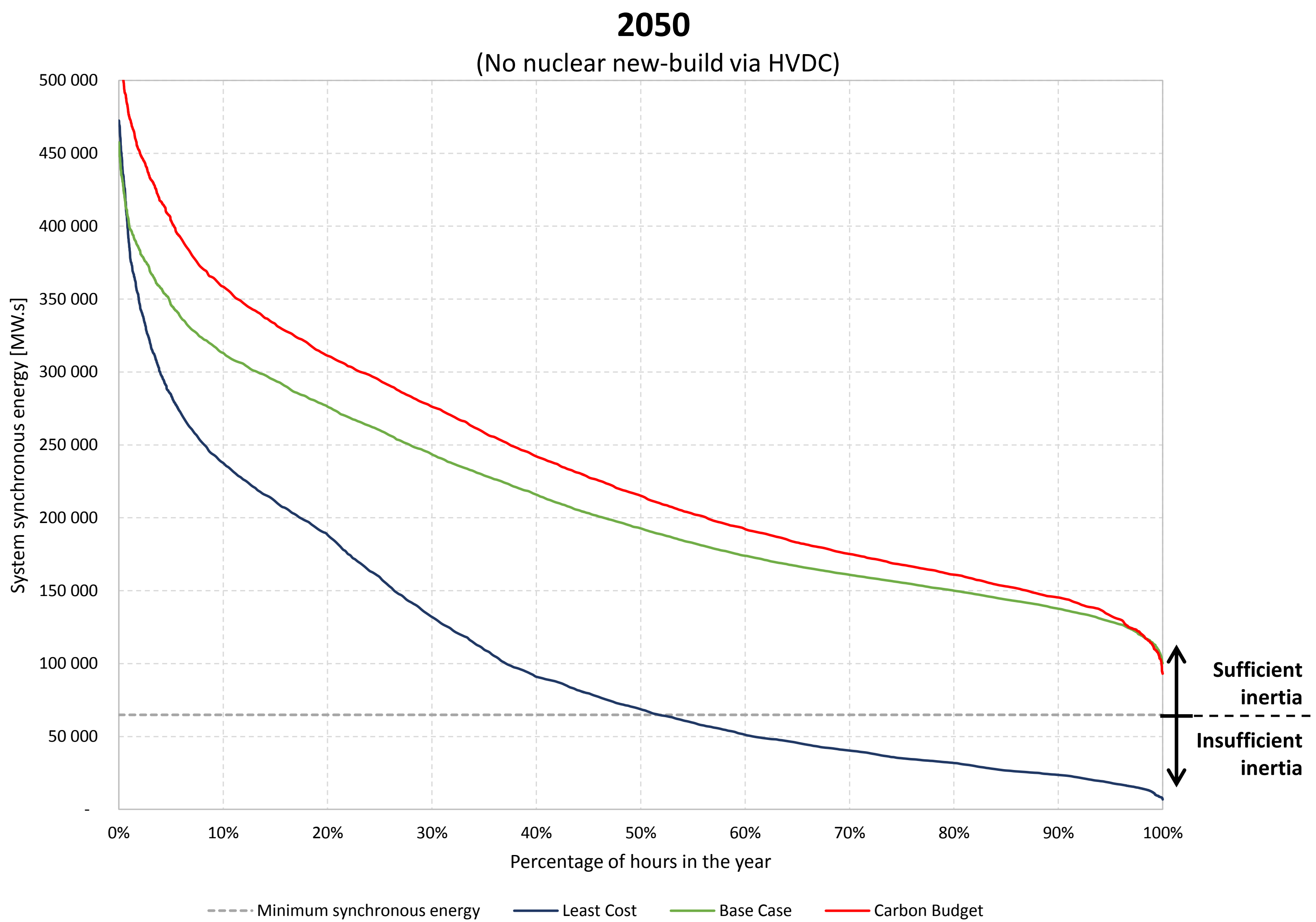
Additional inertia will be required by 2050 for all scenarios with the most being from the Least-cost scenario



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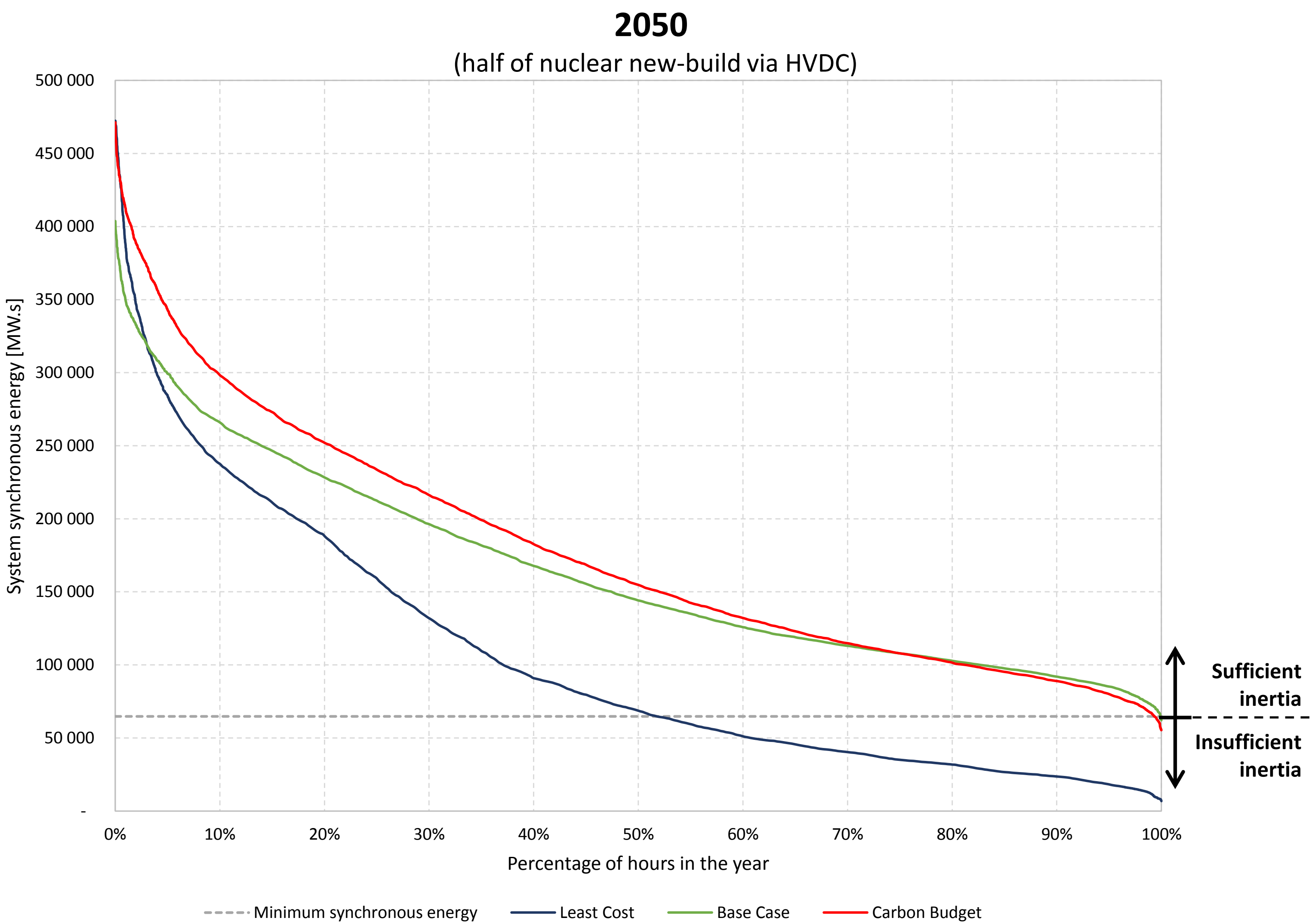
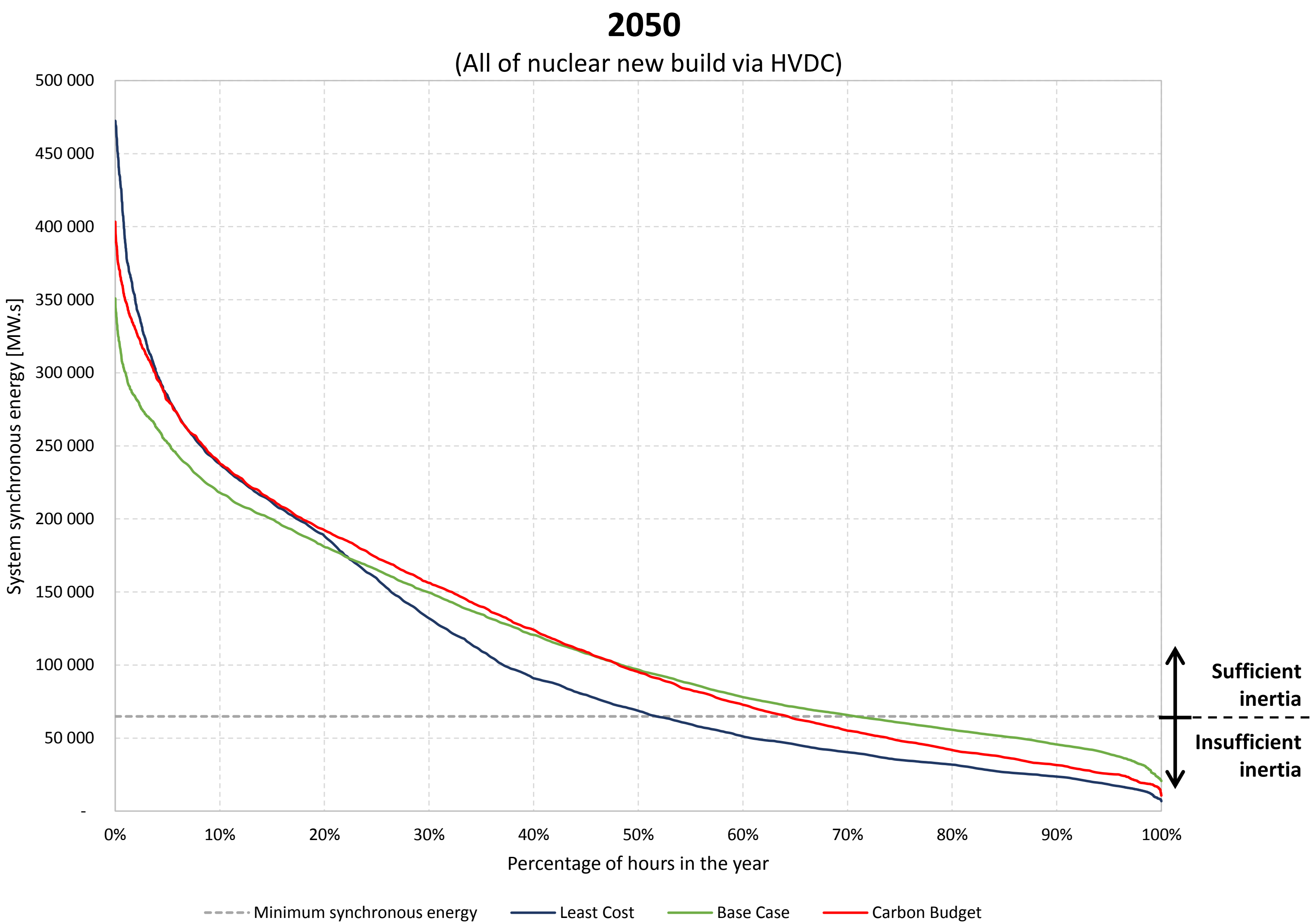


Similar additional inertia requirements in the Carbon Budget and Least-cost scenario by 2050 if nuclear is integrated fully via HVDC



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Integrating a nuclear fleet via HVDC reduces intrinsic system inertia in a similar manner to that of solar PV and wind

No nuclear fleet via HVDC

		2030			2050		
		Base Case	Carbon Budget	Least cost	Base Case	Carbon Budget	Least cost
Minimum inertia needed	[MW.s]	64 800	64 800	64 800	64 800	64 800	64 800
Minimum inertia (actual)	[MW.s]	76 500	50 300	42 300	100 200	93 100	6 800
Additional inertia needed	[MW.s]	-	14 500	22 500	-	-	58 000
Number of hours	[hrs]	-	210	440	-	-	4 320

Half nuclear fleet via HVDC

		2030			2050		
		Base Case	Carbon Budget	Least cost	Base Case	Carbon Budget	Least cost
Minimum inertia needed	[MW.s]	64 800	64 800	64 800	64 800	64 800	64 800
Minimum inertia (actual)	[MW.s]	71 300	33 900	42 300	62 100	55 400	6 800
Additional inertia needed	[MW.s]	-	30 900	22 500	2 700	9 400	58 000
Number of hours	[hrs]	-	660	440	200	250	4 320

Full nuclear fleet via HVDC

		2030			2050		
		Base Case	Carbon Budget	Least cost	Base Case	Carbon Budget	Least cost
Minimum inertia needed	[MW.s]	64 800	64 800	64 800	64 800	64 800	64 800
Minimum inertia (actual)	[MW.s]	66 200	17 100	42 300	20 600	10 700	6 800
Additional inertia needed	[MW.s]	-	47 700	22 500	44 200	54 100	58 000
Number of hours	[hrs]	-	2 140	440	2 680	3 240	4 320

There are a number of options to increase system inertia

In principle, there are two ways to deal with lower system inertia

1) **Conservative: Introduce additional intrinsic inertia (synchronous machines) to reduce RoCoF**
2) **Progressive: Introduce reactive measures and control algorithms to deal with an increased RoCoF**

Here we will only outline the technical solutions in the conservative approach to increase intrinsic system inertia / reduce RoCoF (Option 1 above). These technical solutions are:

- Synchronous compensators (new purpose built devices and retro-fitting of decommissioned generators, with/without flywheels)
- Rotating stabiliser devices (typically a multi-pole device incorporating a flywheel, which can be based on a Doubly-Fed Induction Generator or an synchronous machine)
- Wind turbines with doubly-fed induction generator
- Pumped hydro (assuming synchronous machines are deployed)
- "Parking" of conventional generators i.e. operating generation plant at low MW output levels but with reduced/no capability to provide system services (e.g. operating reserve) at the lower output levels
- Reduction in the minimum MW generation thresholds of conventional generation while still leaving the plant with the capability to fully provide system services
- New flexible thermal power plant with high inertia constant

Sources: DNV GL, http://www.eirgridgroup.com/site-files/library/EirGrid/RoCoF-Alternative-Solutions-Technology-Assessment-Phase-1-DNV-GL-Report_.pdf

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- New flexible thermal power plant with high inertia constant

Sources: DNV GL, http://www.eirgridgroup.com/site-files/library/EirGrid/RoCoF-Alternative-Solutions-Technology-Assessment-Phase-1-DNV-GL-Report_.pdf

Additional costs for rotating stabilisers to ensure sufficient system inertia by 2050 – <1% in all scenarios

No nuclear fleet via HVDC

		2030			2050		
		Base Case	**Carbon Budget**	**Least cost**	**Base Case**	**Carbon Budget**	**Least cost**
Additional inertia needed	[MW.s]	-	14 500	22 500	-	-	58 000
Number of hours	[hrs]	-	210	440	-	-	4 320
Rotating stabilisers needed	[MW]	-	360	560	-	-	1 450
Annual cost for rotating stabilisers	[bR/yr]	-	1.1	1.7	-	-	4.5
(% of system costs)	[%]	0.0%	0.3%	0.5%	0.0%	0.0%	0.7%

Half nuclear fleet via HVDC

		2030			2050		
		Base Case	**Carbon Budget**	**Least cost**	**Base Case**	**Carbon Budget**	**Least cost**
Additional inertia needed	[MW.s]	-	30 900	22 500	2 700	9 400	58 000
Number of hours	[hrs]	-	660	440	200	250	4 320
Rotating stabilisers needed	[MW]	-	770	560	70	240	1 450
Annual cost for rotating stabilisers	[bR/yr]	-	2.4	1.7	0.2	0.7	4.5
(% of system costs)	[%]	0.0%	0.6%	0.5%	0.0%	0.1%	0.7%

Full nuclear fleet via HVDC

		2030			2050		
		Base Case	**Carbon Budget**	**Least cost**	**Base Case**	**Carbon Budget**	**Least cost**
Additional inertia needed	[MW.s]	-	47 700	22 500	44 200	54 100	58 000
Number of hours	[hrs]	-	2 140	440	2 680	3 240	4 320
Rotating stabilisers needed	[MW]	-	1 190	560	1 110	1 350	1 450
Annual cost for rotating stabilisers	[bR/yr]	-	3.7	1.7	3.4	4.1	4.5
(% of system costs)	[%]	0.0%	0.9%	0.5%	0.5%	0.6%	0.7%

Rotating stabiliser properties: CAPEX = 20 000 R/kW; FOM = 3% of CAPEX; all year operation; cost of electricity = 1 R/kWh; H = 40 MW.s/MVA

Re a leboha

Ha Khensa

Enkosi

Siyathokoza

Thank you

Re a leboga

Ro livhuha

Dankie

Siyabonga

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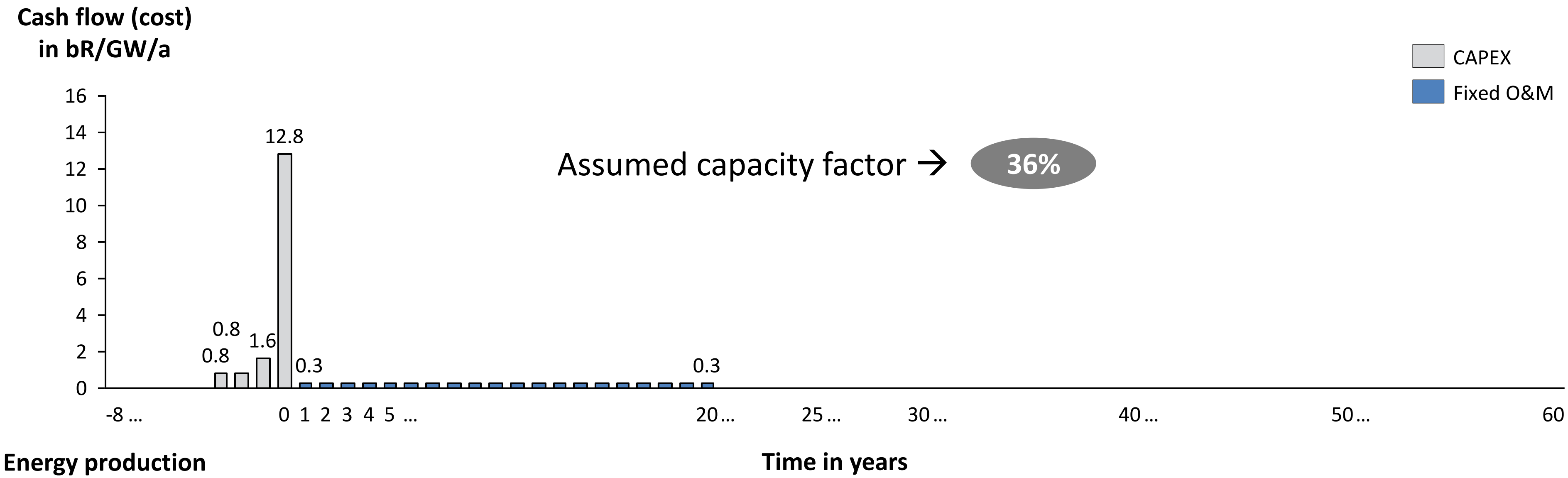
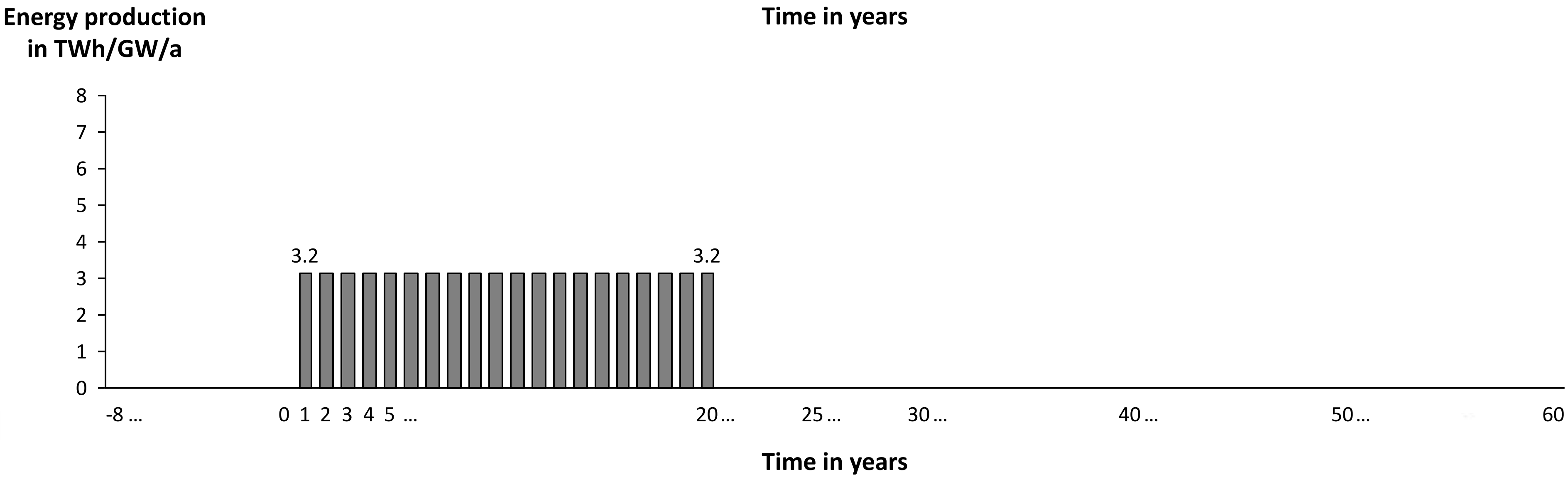
Note: "Thank you" in all official languages of the Republic of South Africa

BACKUP

Wind: Lifetime annual cash flow and annual energy production





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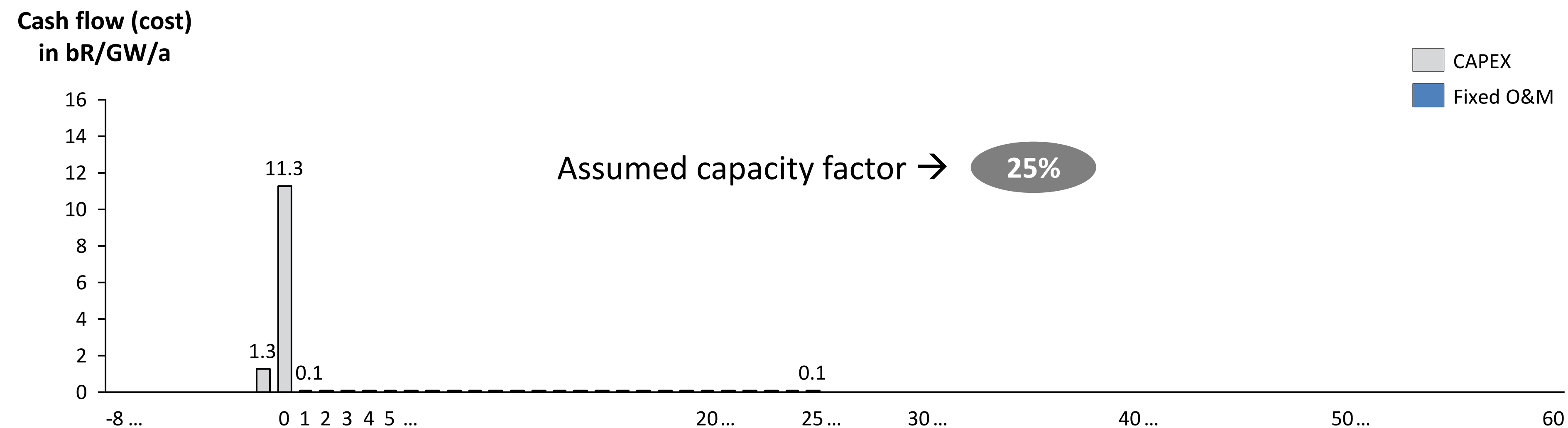
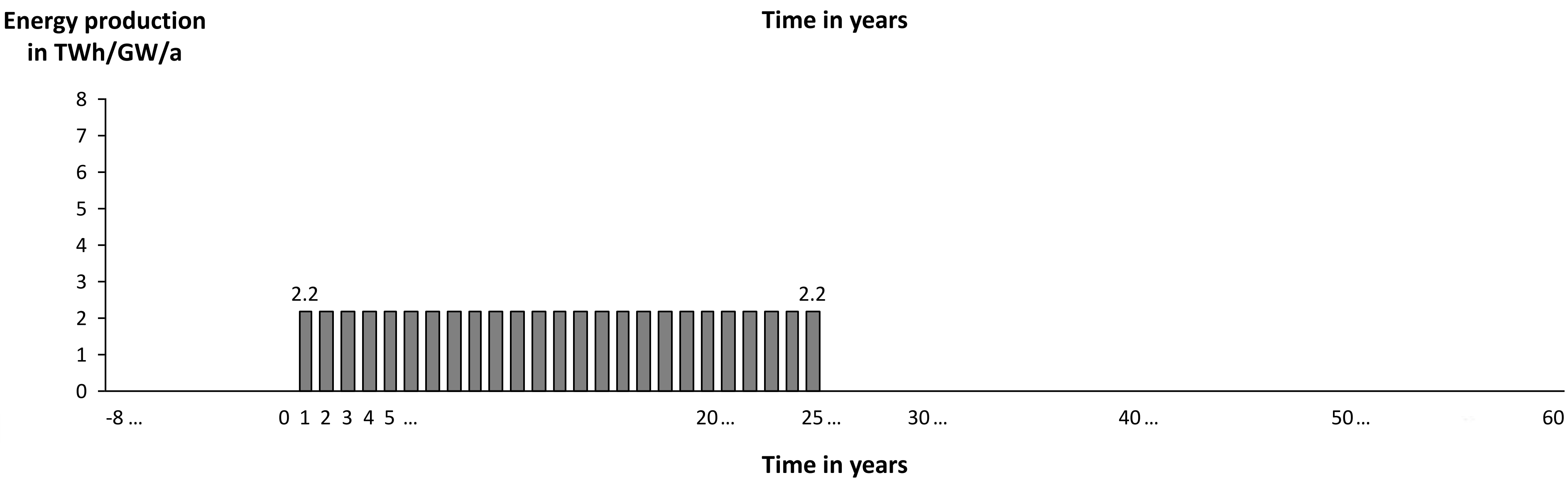
Solar PV:
Lifetime annual cash flow and annual energy production





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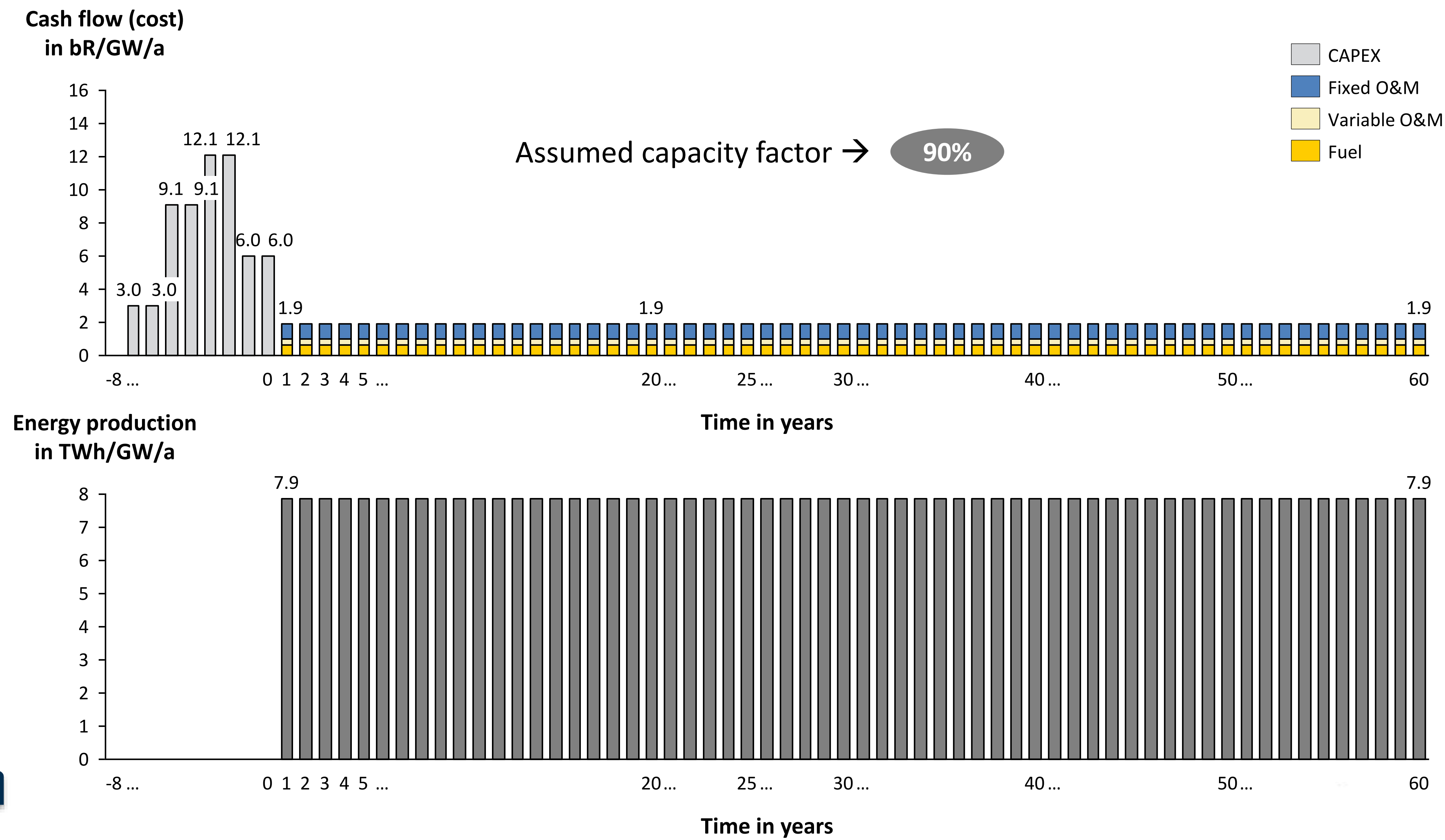
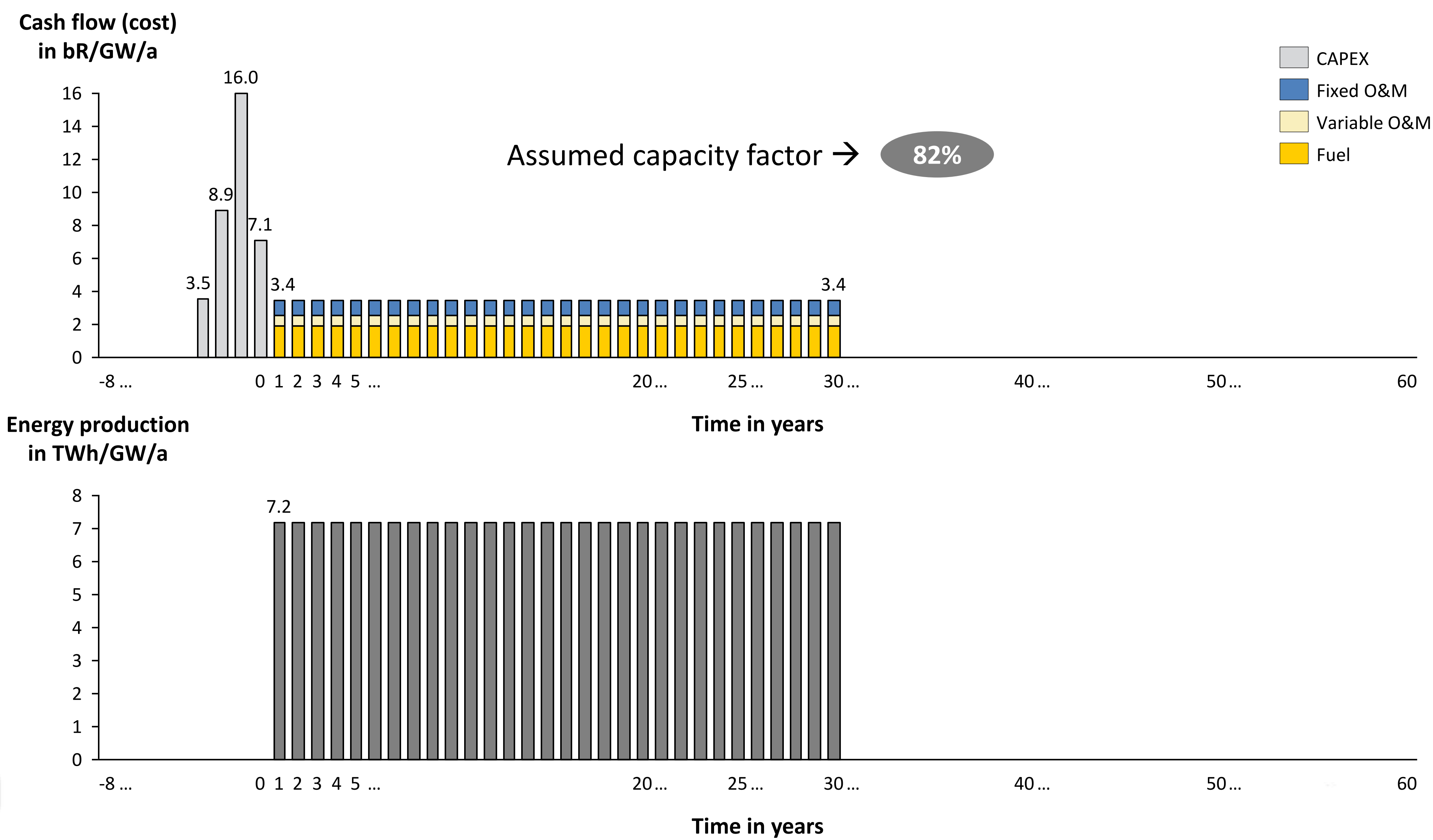
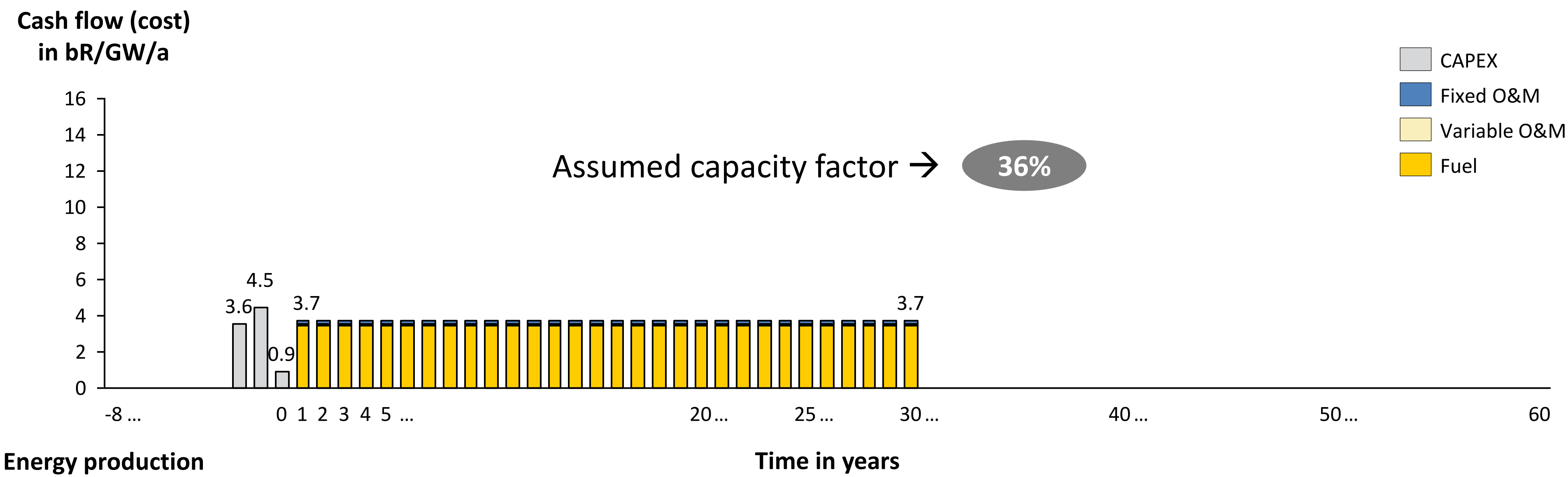
Nuclear:
Lifetime annual cash flow and annual energy production

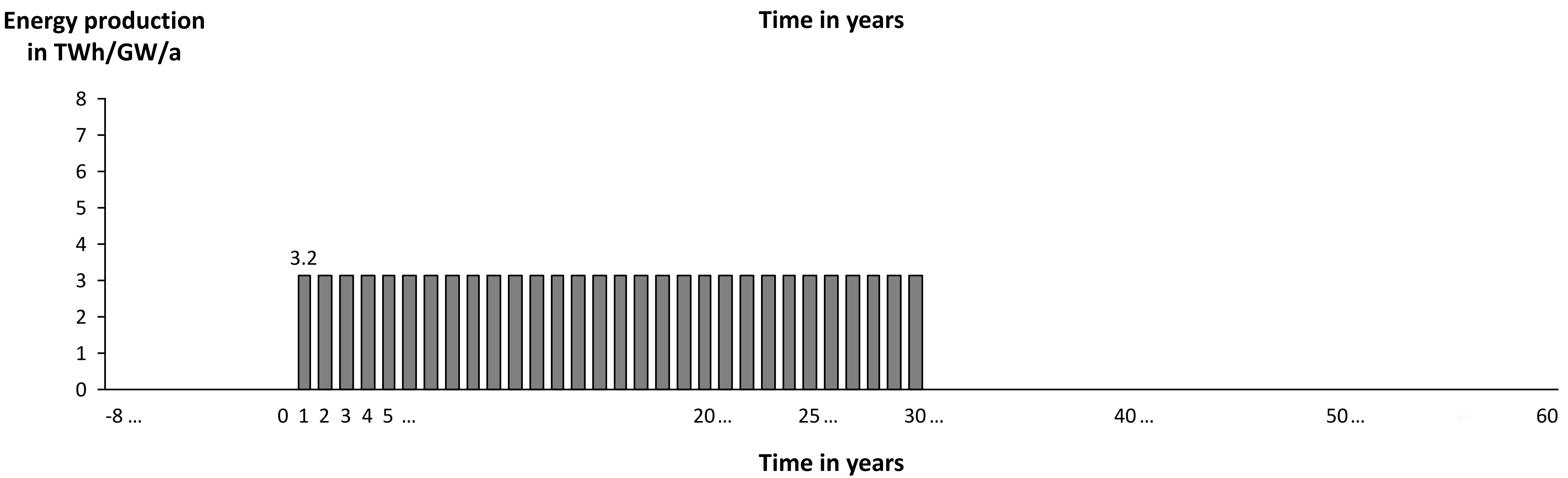


Coal: Lifetime annual cash flow and annual energy production



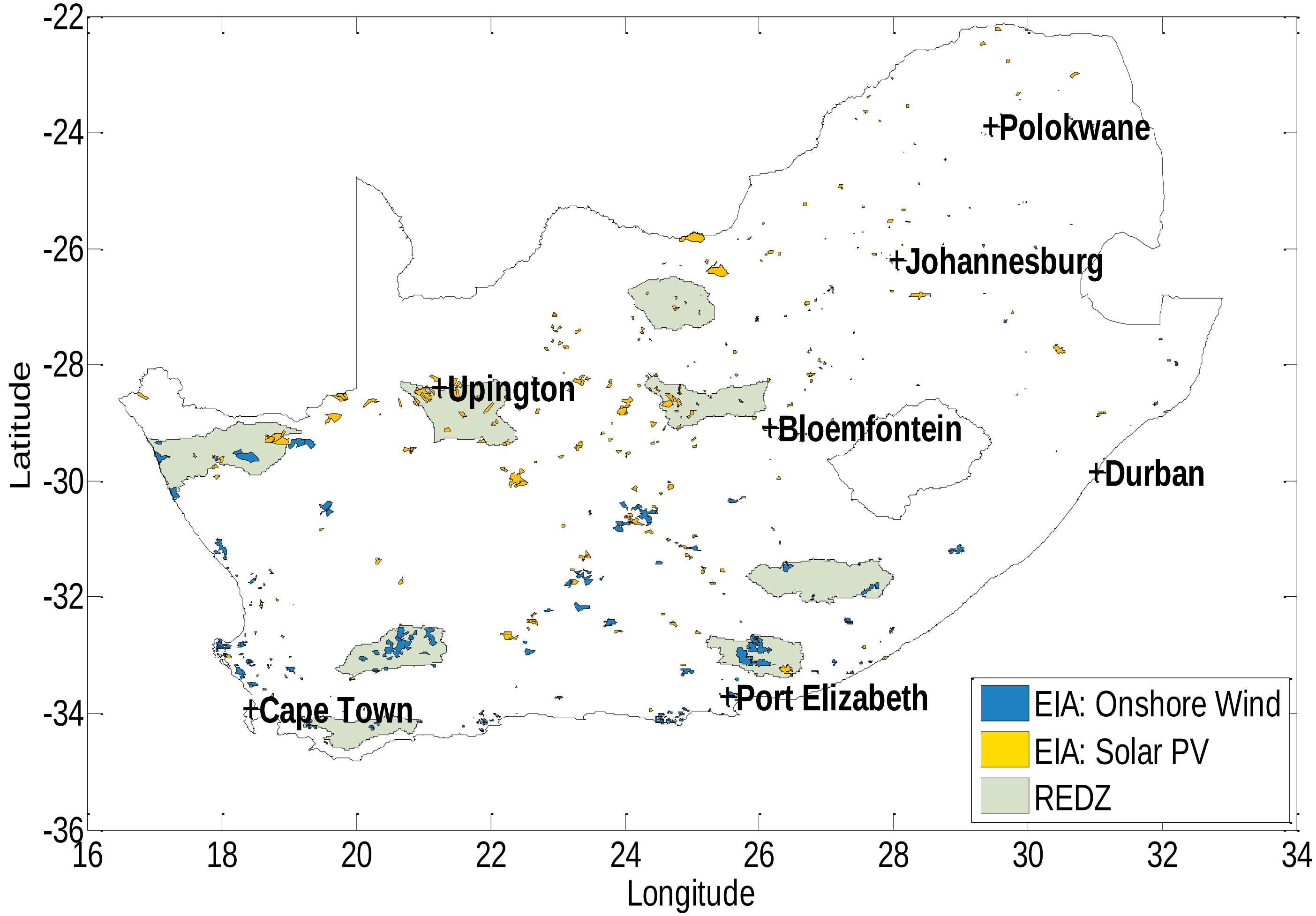
Gas (CCGT):
Lifetime annual cash flow and annual energy production





Submitted to DoE on 31 March 2017

Areas already applied for Environmental Impact Assessments have more capacity than what the current Least Cost case requires by 2050



All EIAs
(status early 2016)

Wind: 90 GW
Solar PV: 330 GW