Energy Modelling for South Africa, Latest Approaches & Results in a Rapidly Changing Energy Environment

Keynote Address at STERG Symposium 2017

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Research Groups overview:
Value-chain logic, driven by end-user demand and system view

Technology-focussed Research Groups

ED – Energy Demand
- Energy Efficiency Technologies
- Demand Shaping Technologies

ESu – Energy Supply
- Energy Meteorology
- Renewable Energy Technologies

ESt – Energy Storage
- Battery Technologies
- Hydrogen Technologies
- Heat Storage Technologies

System-focussed Research Group

ESy – Energy Systems
- Energy System Design
- Energy System Operation

End user-focussed Research Groups

EI – Energy Industry (DTI)

EM – E. Market Design (DoE/NERSA)

Technology performance and cost (today and future)

System view on technologies → user requirements

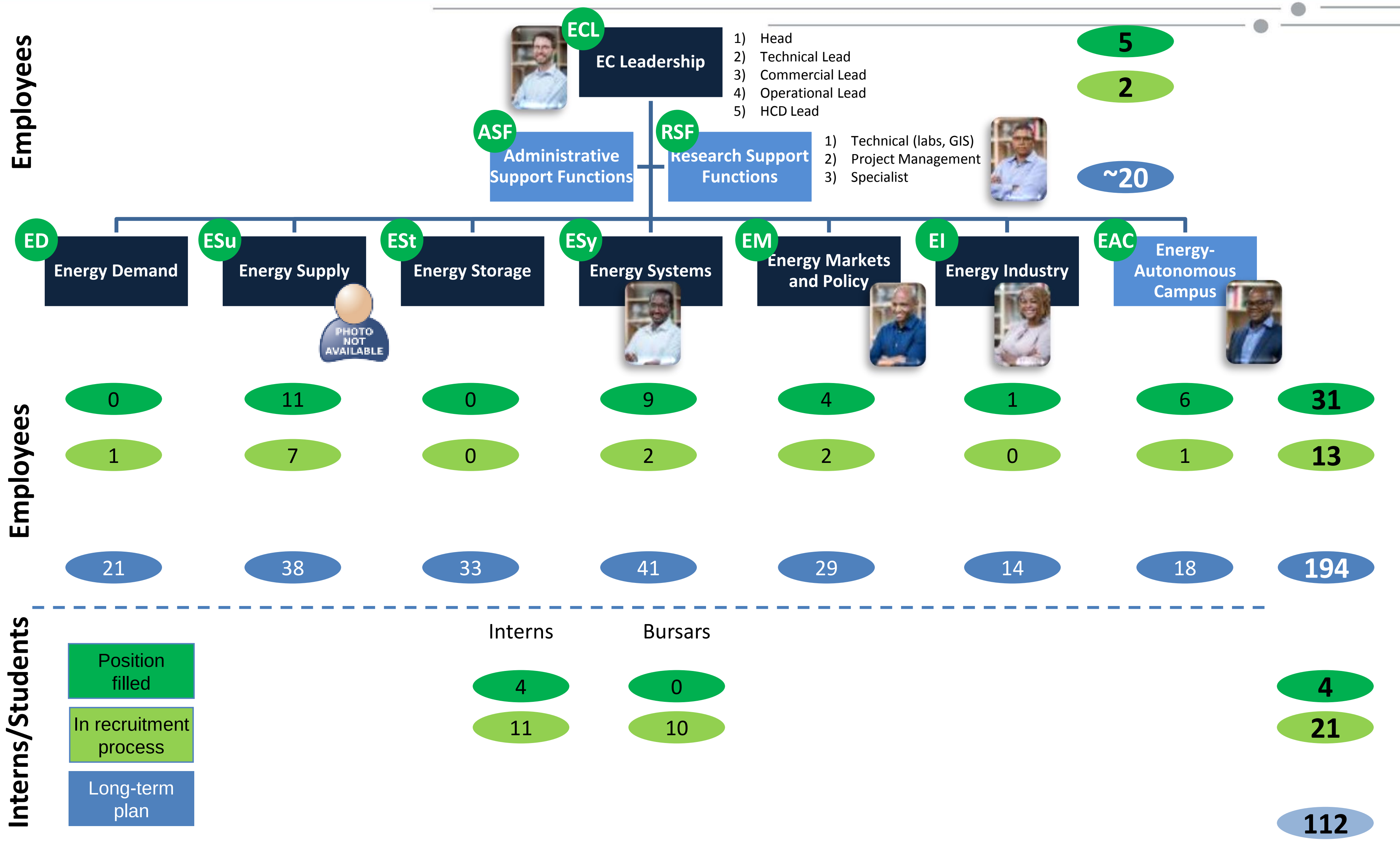
Industry demand / pull

Products (hardware), solutions (software)

Real-world implementation of research programme

EAC – Energy-Autonomous Campus

CSIR's Energy Centre currently has ~40 highly qualified staff members



HCD Highlights: Quick ramp up, very strong and diverse team

Very fast, yet very high-profile ramp-up achieved so far (from 0 in July 2014 to 40 in July 2017)

Entire leadership team (Research Group Leaders and Programme Managers) is South African and black

4 black female engineers (South African)

Examples of internationally recognised experts

- Former head of systems operations at Eskom, was in charge to operate entire national grid
- Energy Commissioner in the National Planning Commission led by Minister in the Presidency
- Former CEO/MD of Swaziland Electricity Company, well connected in the region
- Chief Engineer transmission grid planning for Eskom and the region

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Context

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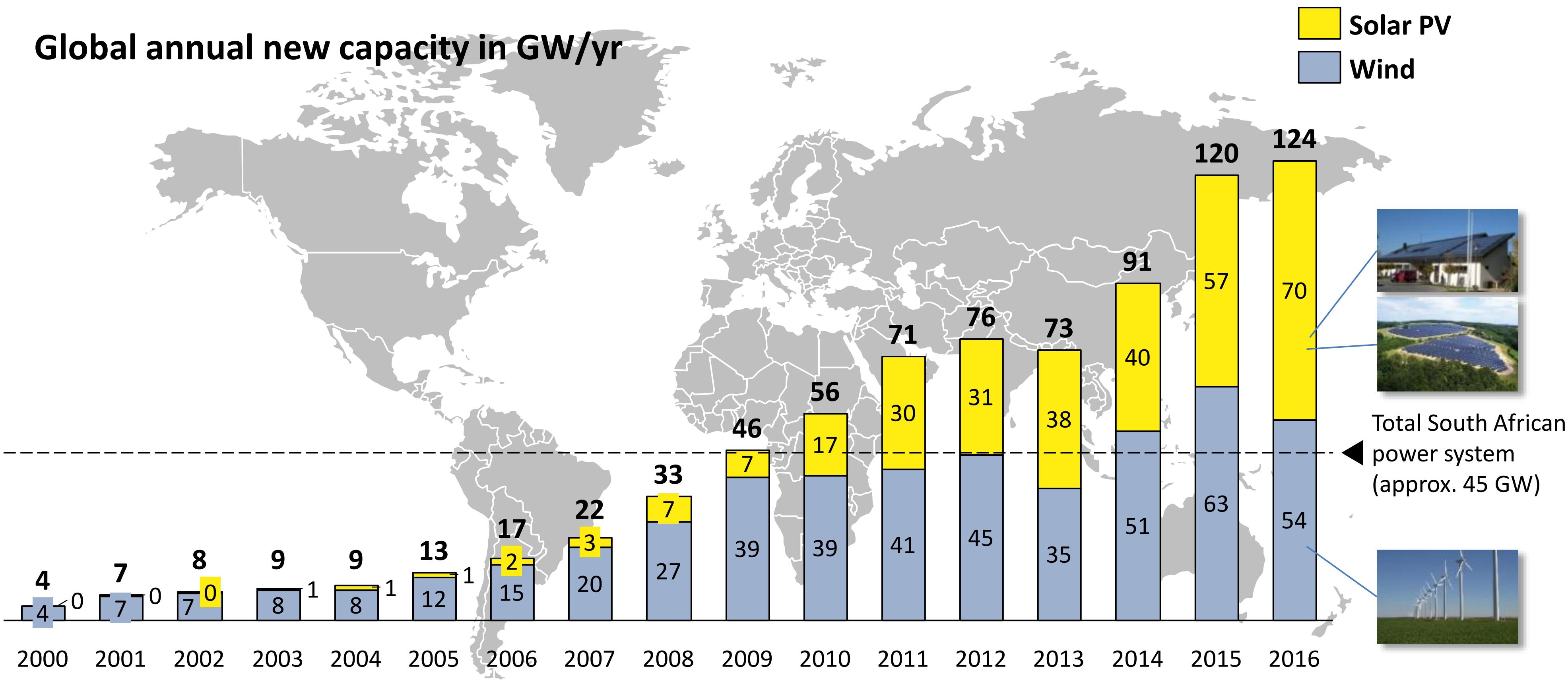
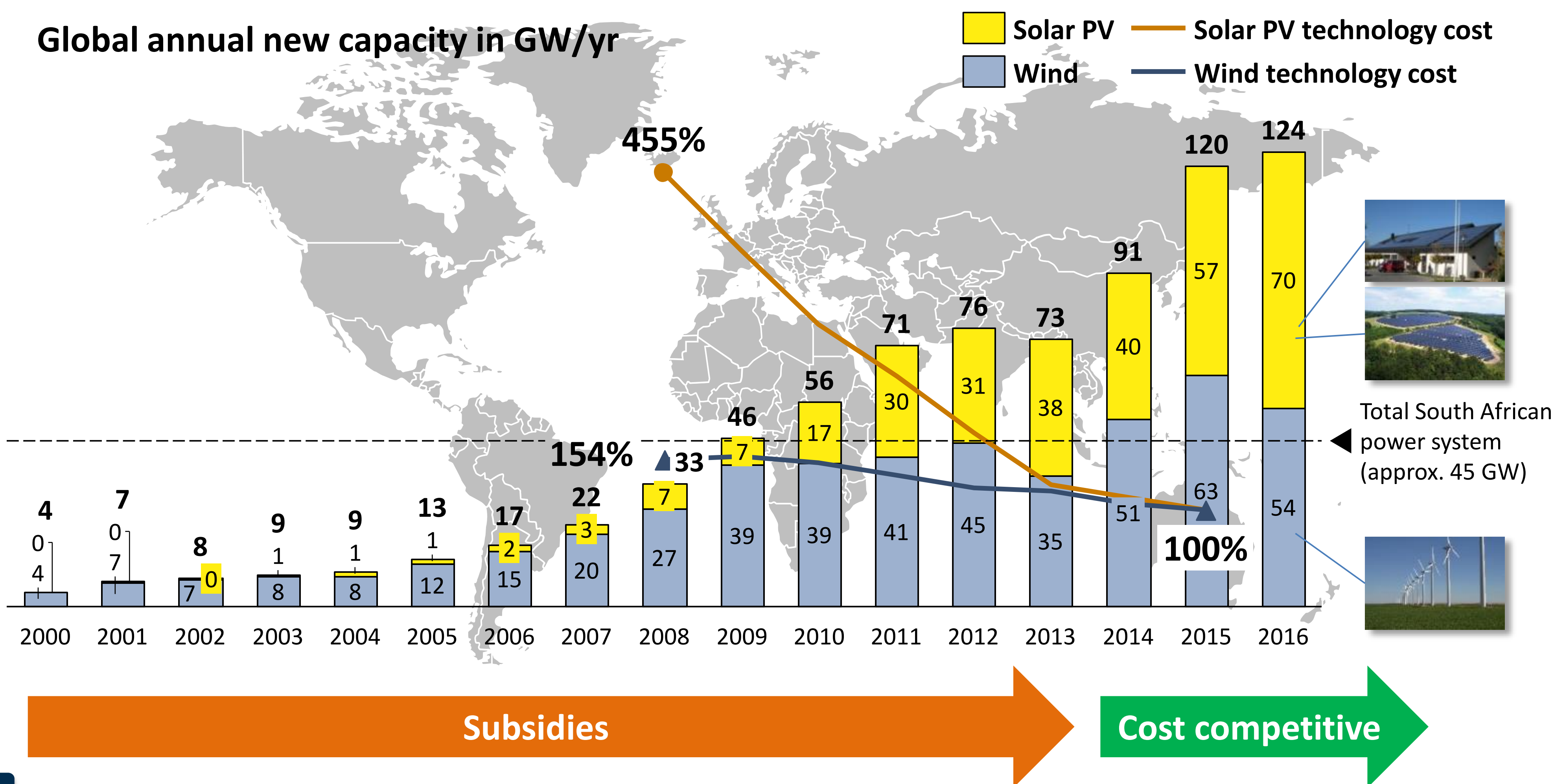
World:
In 2016, 124 GW of new wind and solar PV capacity installed globally



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

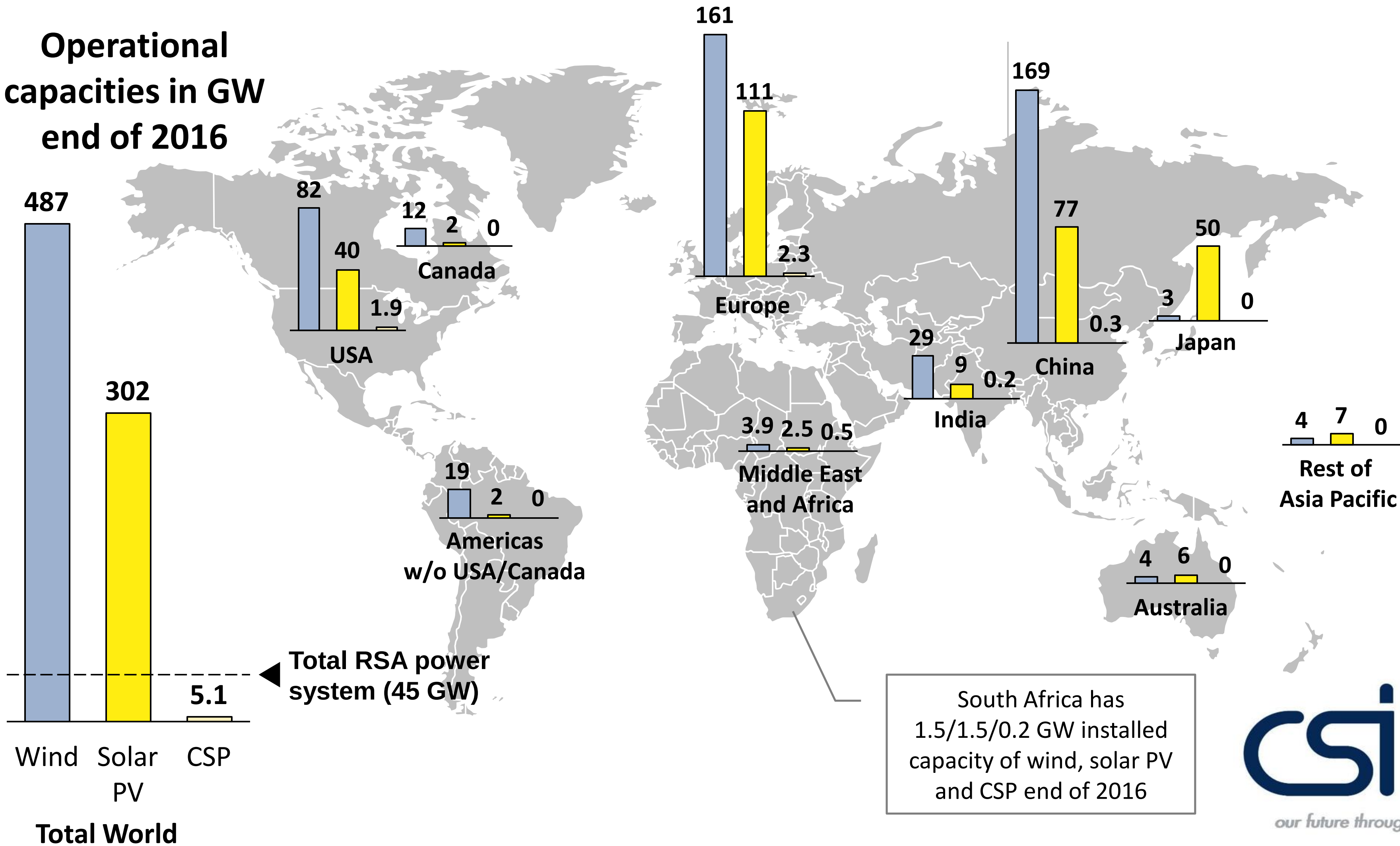
World:
Significant cost reductions materialised in the last 5-8 years



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

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

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



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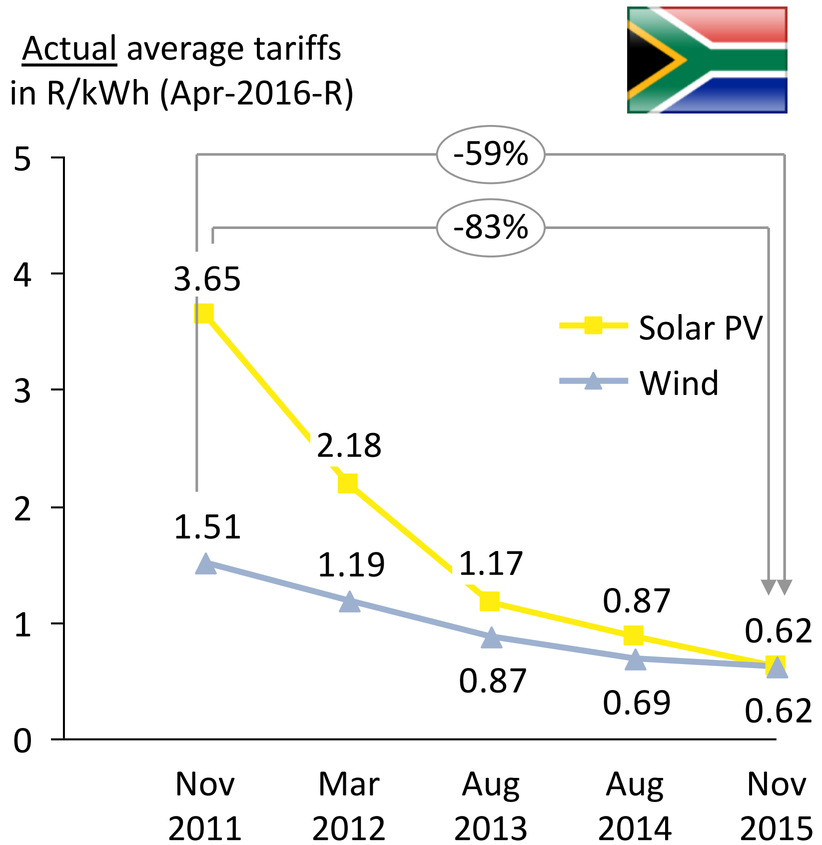
Sources: GWEC; EPIA; CSPToday; CSIR analysis

REIPPPP results: new wind/solar PV 60-80% cheaper than first projects

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

Significant reductions in actual tariffs …

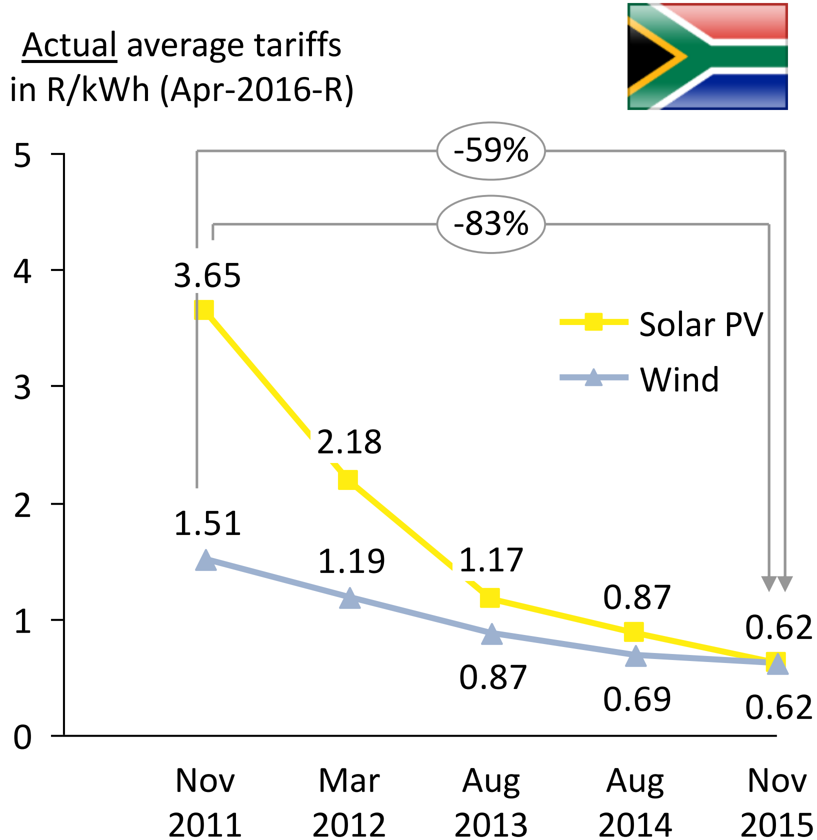


Notes: Exchange rate of 14 USD/ZAR assumed Sources: http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; http://www.saippa.org.za/Portals/24/Documents/2016/Coal%20IPP%20factsheet.pdf; http://www.ee.co.za/wp-content/uploads/2016/10/New_Power_Generators_RSA-CSIR-14Oct2016.pdf;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

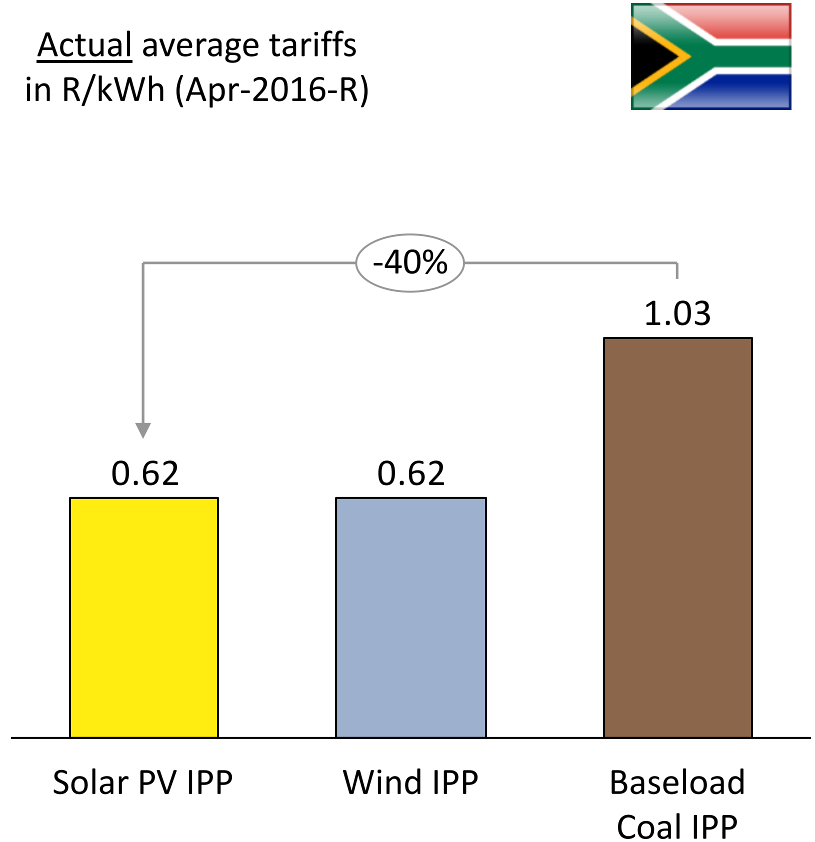
Actual tariffs: new wind/solar PV 40% cheaper than new coal in RSA

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

Approach to Power-System Planning

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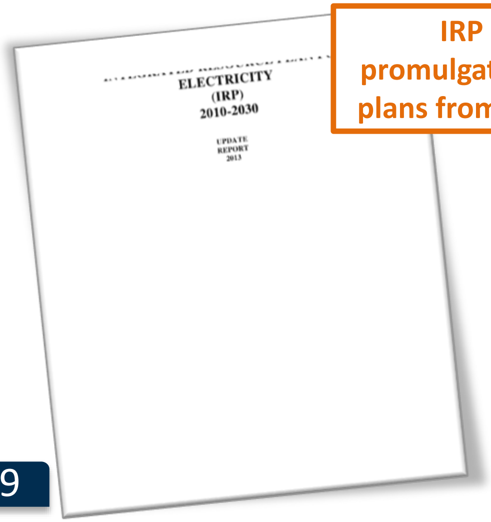
Last promulgated IRP is IRP 2010, update currently ongoing (IRP 2016)

The enforceable IRP in South Africa is still the IRP 2010 as promulgated in 2011, it planned until 2030

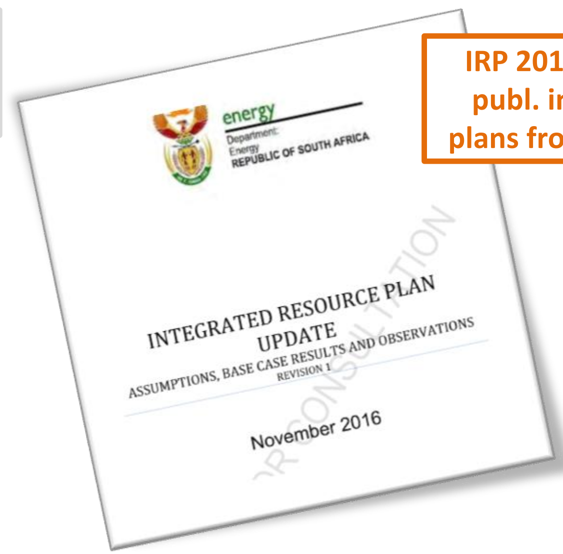
A number of changes since IRP 2010 (demand forecast and confirmation of wind/solar PV cost decrease)

The IRP 2016 plans until 2050 and is currently being developed



IRP 2010: promulgated in 2011, plans from 2010-2030

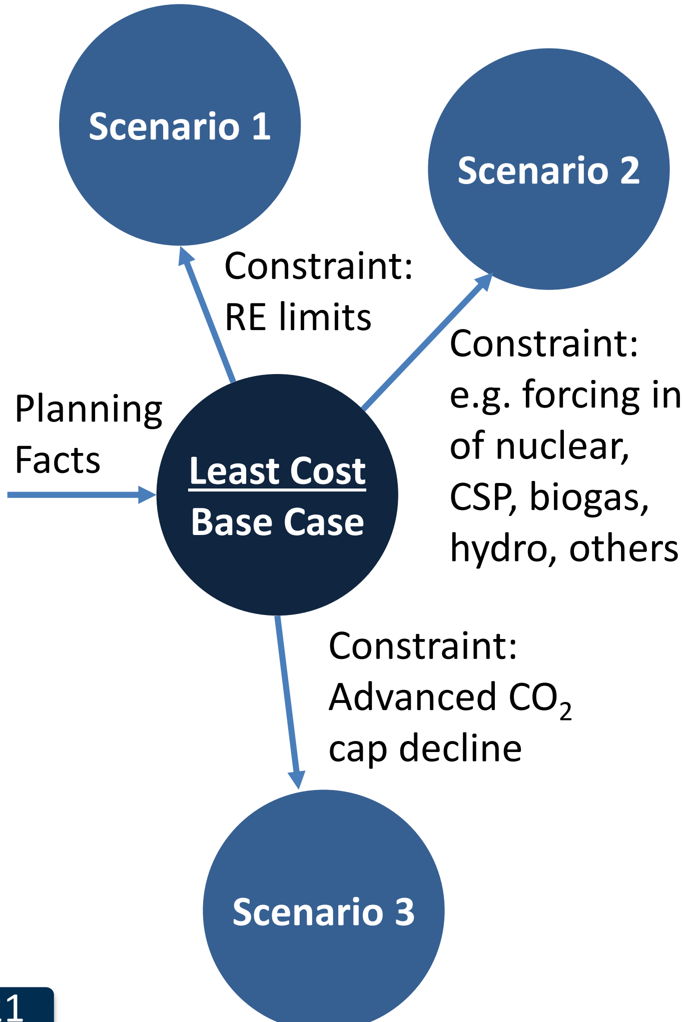
IRP Update 2013: Not promulgated



IRP 2016: first draft publ. in Nov 2016, plans from 2016-2050

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

Ideal approach



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

The CSIR conducted in-depth power-system analyses to determine the least-cost expansion path for the South African electricity system

The Integrated Resource Plan (IRP) is currently being updated by the Department of Energy / Eskom

Draft IRP 2016 Base Case entails a limitation: Amount of wind and solar PV capacity that the model is allowed to build per year is limited, which is neither technically nor economically justified/explained (no techno-economical reason provided)

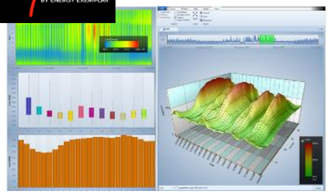
The CSIR is therefore conducting a study to determine the Least Cost electricity mix in RSA until 2050

- Majority of assumptions kept exactly as per the Draft IRP 2016 Base Case
- First and most important deviation from IRP 2016: no new-build limits on renewables (wind/solar PV)
- Second (smaller) deviation: costing for solar PV and wind until 2030 aligned with latest IPP tariff results
- Scope of the CSIR study: purely techno-economical optimisation of the costs directly incurred in the power system

Two scenarios from the Draft IRP 2016 are compared with the Least Cost case

- "Draft IRP 2016 Base Case" – new coal, new nuclear
- "Draft IRP 2016 Carbon Budget" – significant new nuclear
- "Least Cost" – least-cost without constraints

An hourly capacity expansion and dispatch model (incl. unit commitment) using PLEXOS is run for all scenarios to test for technical adequacy → same software platform as by Eskom/DoE for the IRP

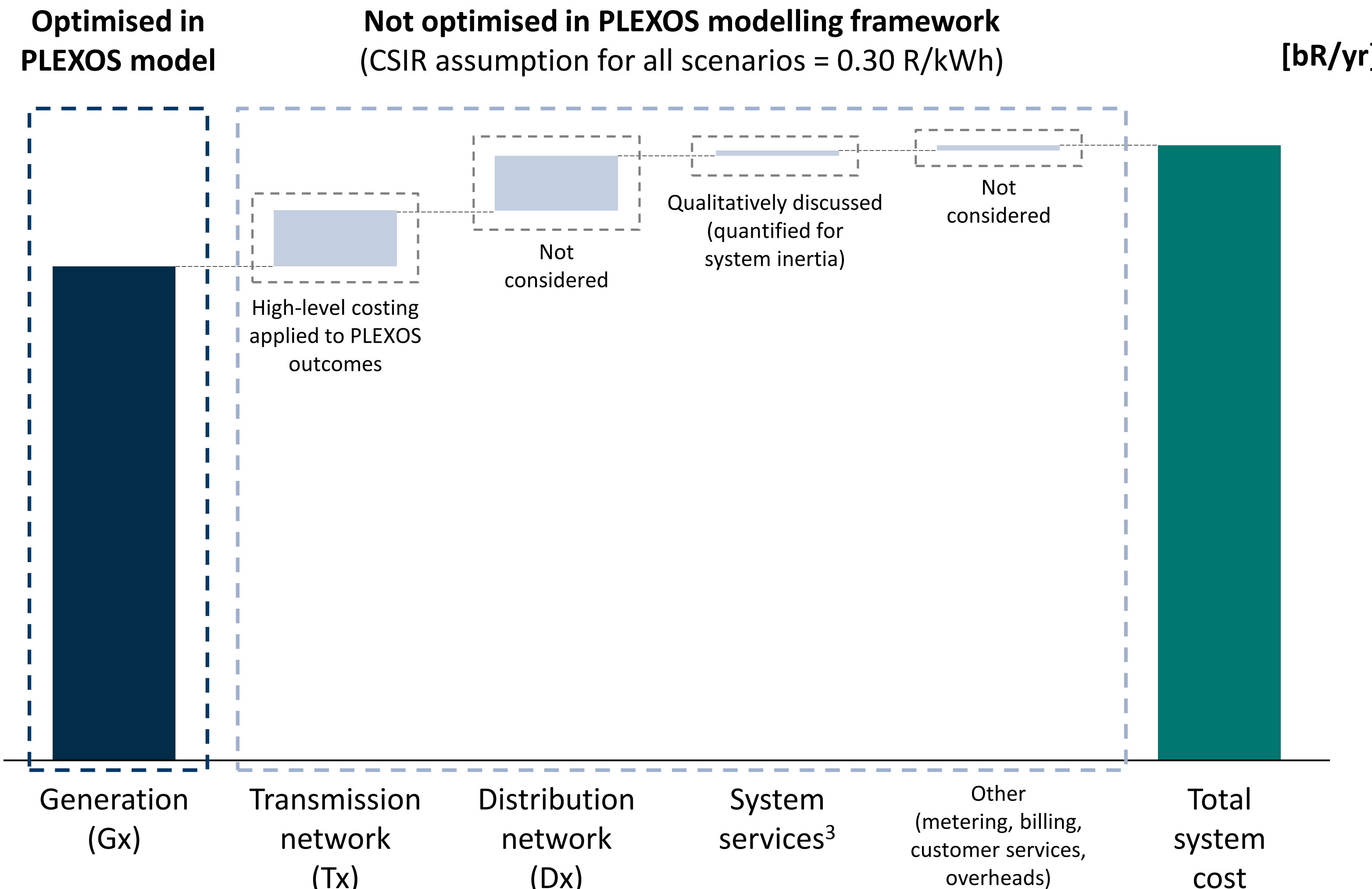


Sources: CSIR analysis

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.

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) under previous Minister
- 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
- Former engineer in Eskom that produced the 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

Key Input Assumptions

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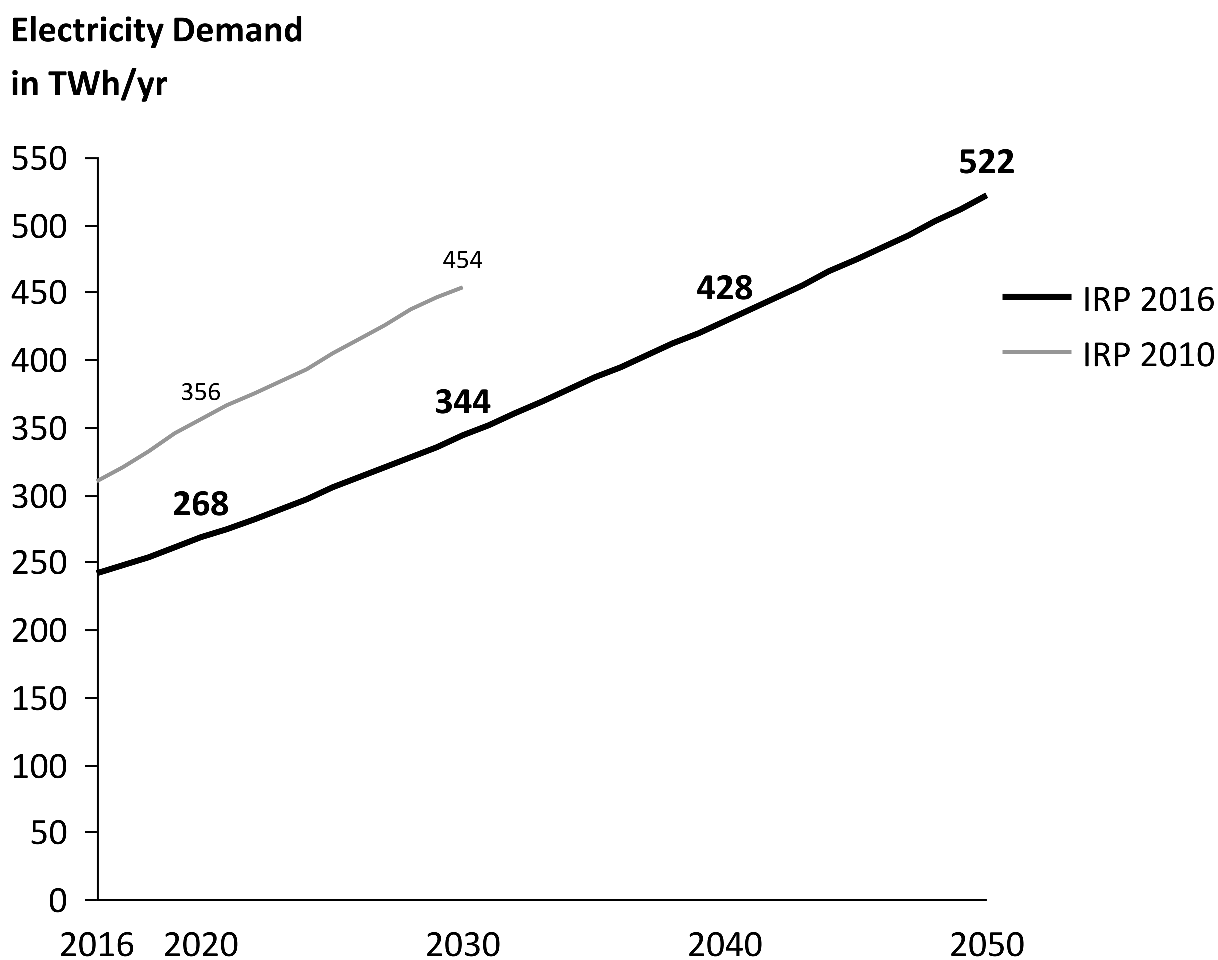
Input as per IRP 2016: Demand is forecasted to double by 2050

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

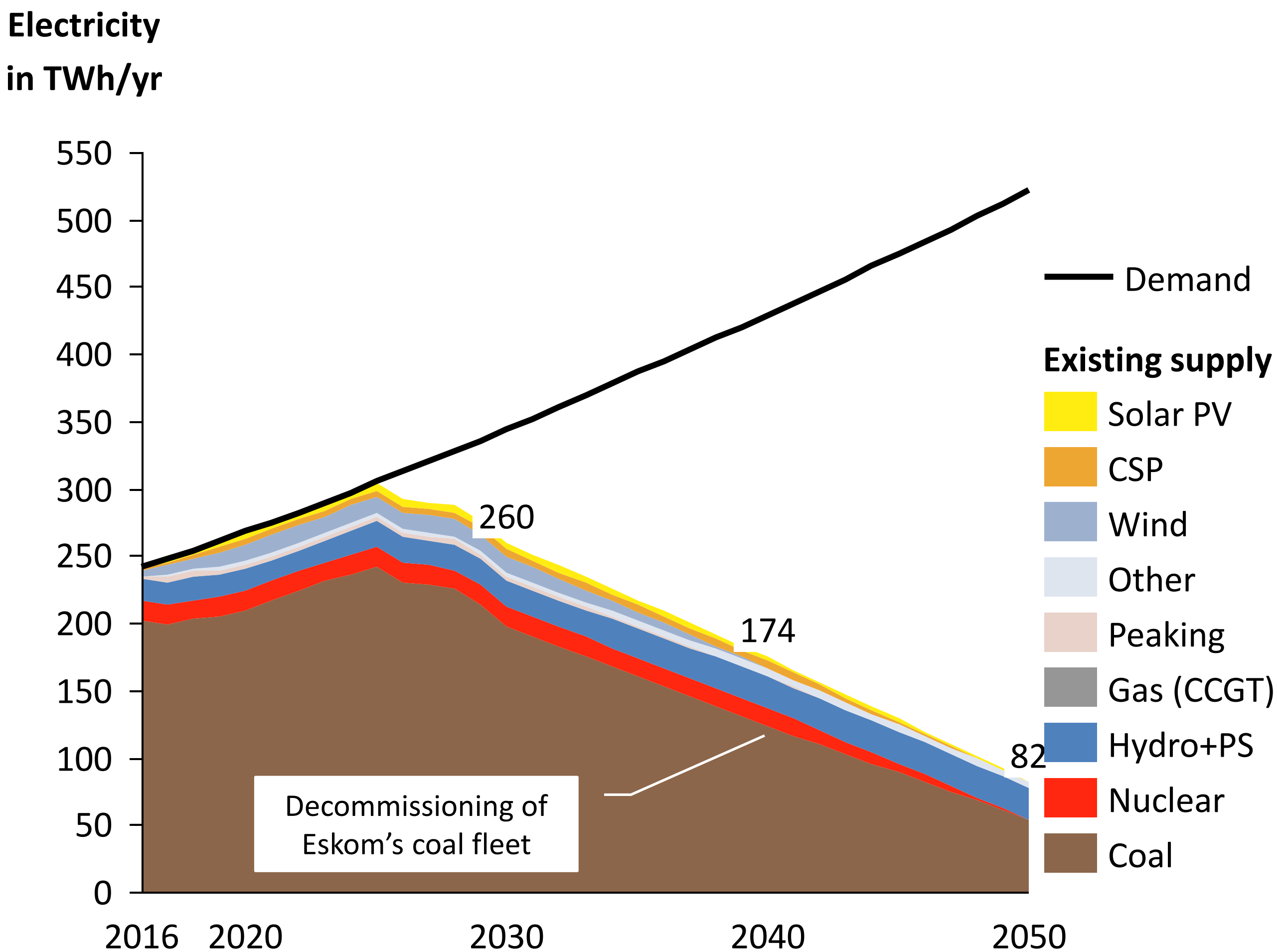


Note: by 2050 the electricity demand per capita would still be less than that of Australia today

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

Input as per IRP 2016: Decommissioning schedule for existing plants

Energy supplied to the South African electricity system from existing plants between 2016 and 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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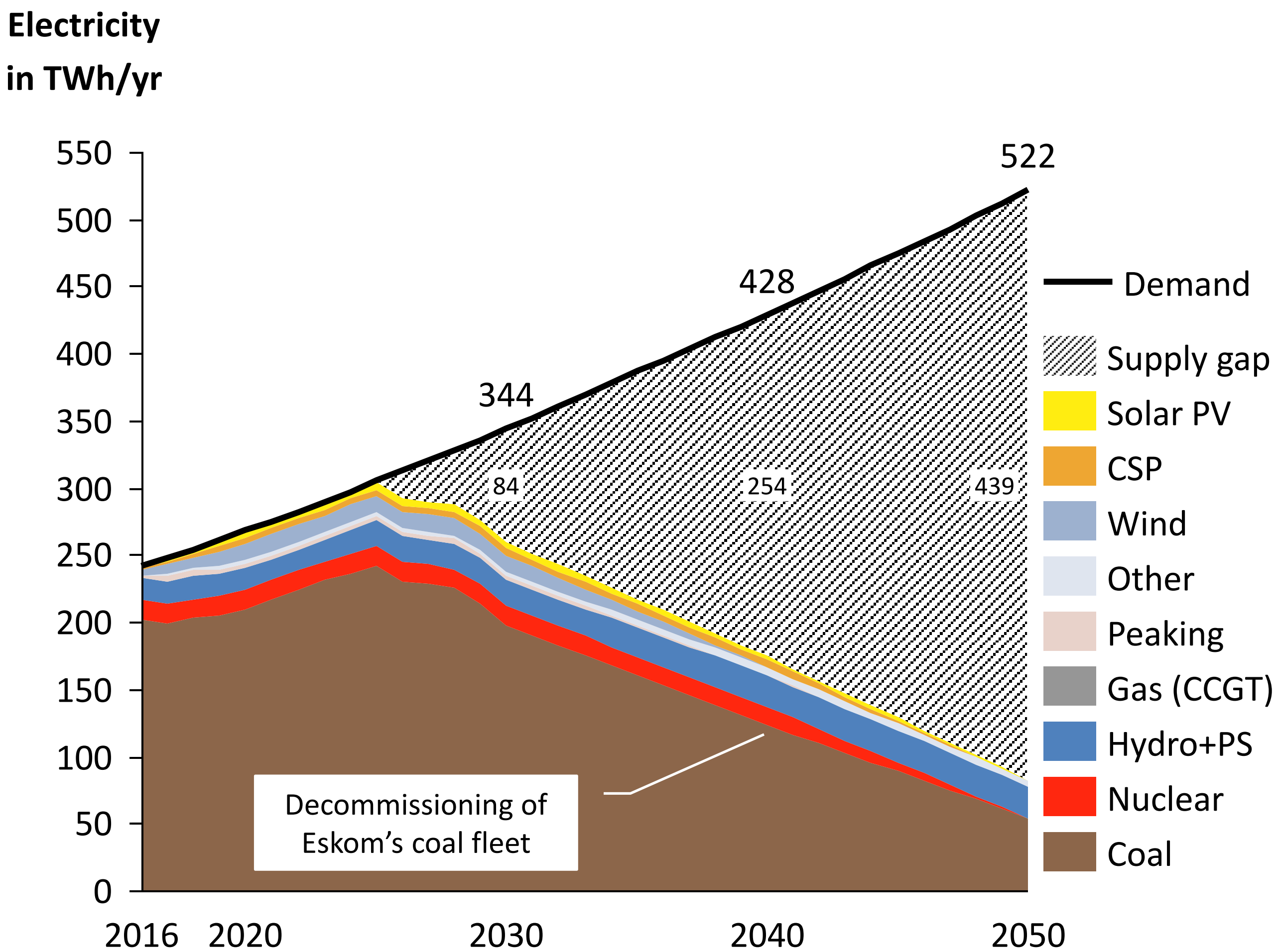
Sources: DoE (IRP 2016); Eskom MTSAO 2016-2021; StatsSA; World Bank; CSIR analysis

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

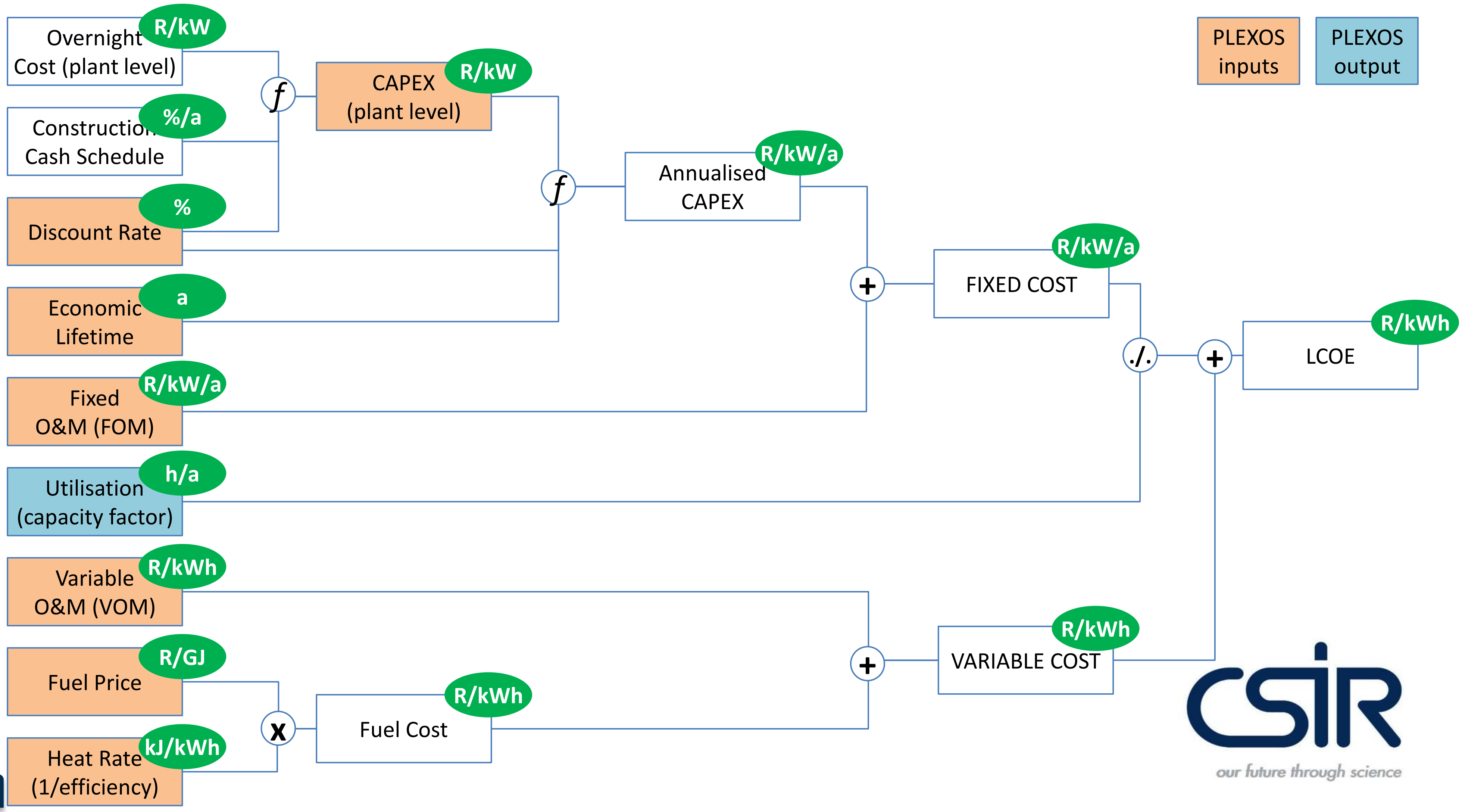


The IRP model fills the supply gap in the least-cost manner, subject to any constraints imposed on the model

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

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



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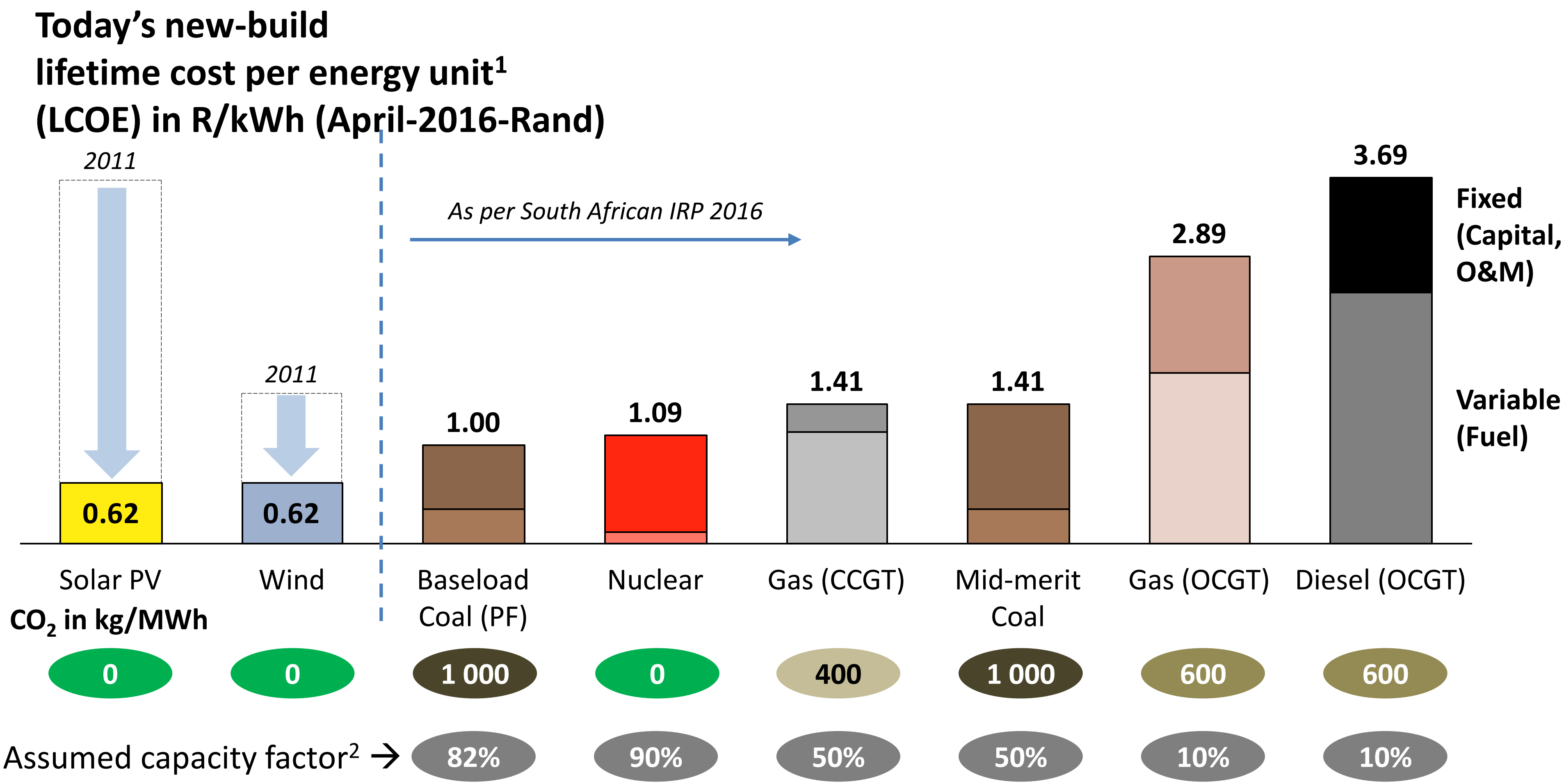
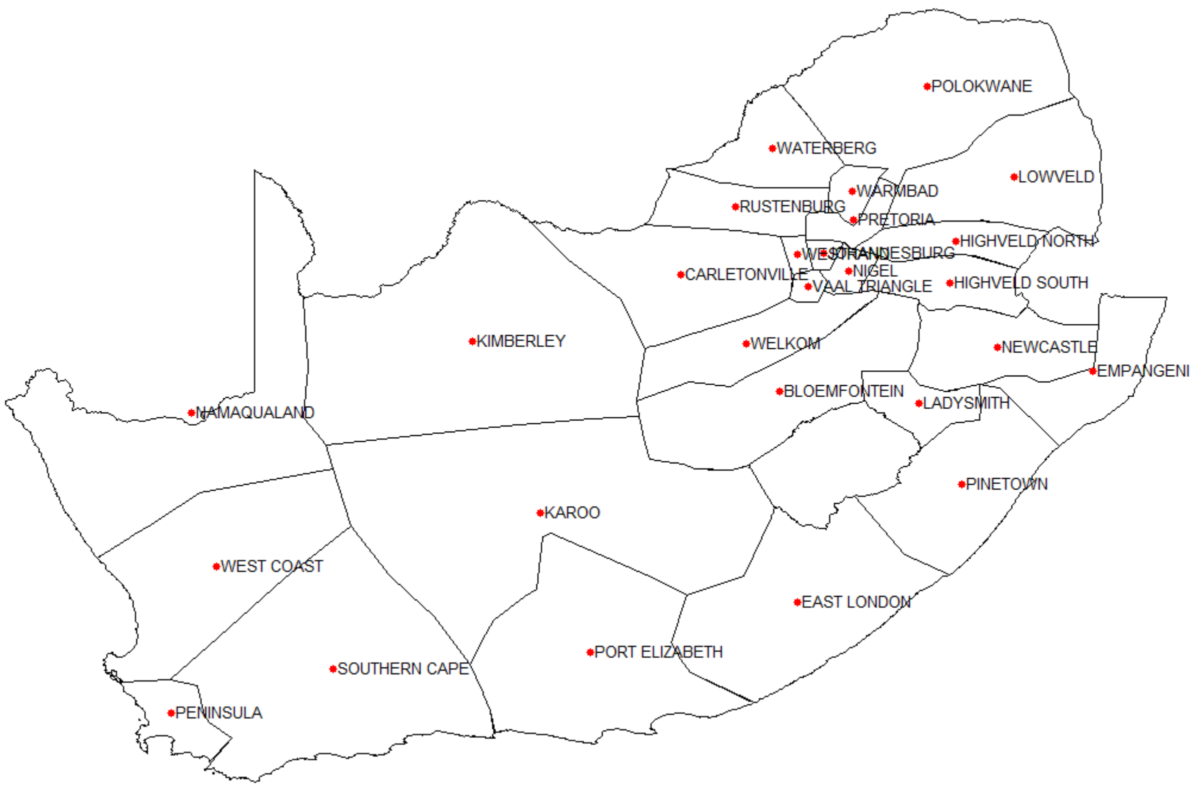
Inputs as per IRP 2016:
Key resulting LCOE from cost assumptions for new supply technologies



[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

Supply technologies (technical characteristics)

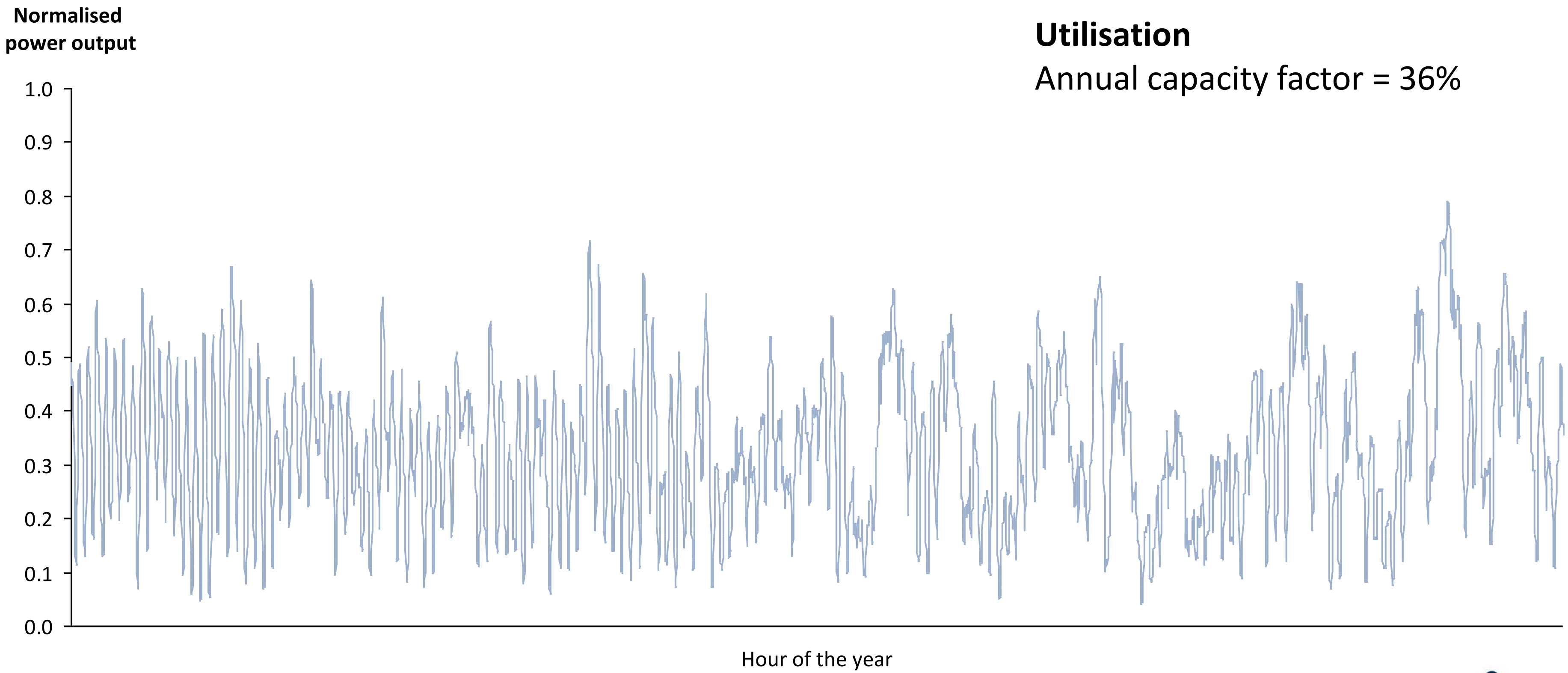


Similar to the IRP 2016 - wind and solar PV profiles for 27 supply areas (with exclusion masks) were used

<u>NOTE:</u> 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%

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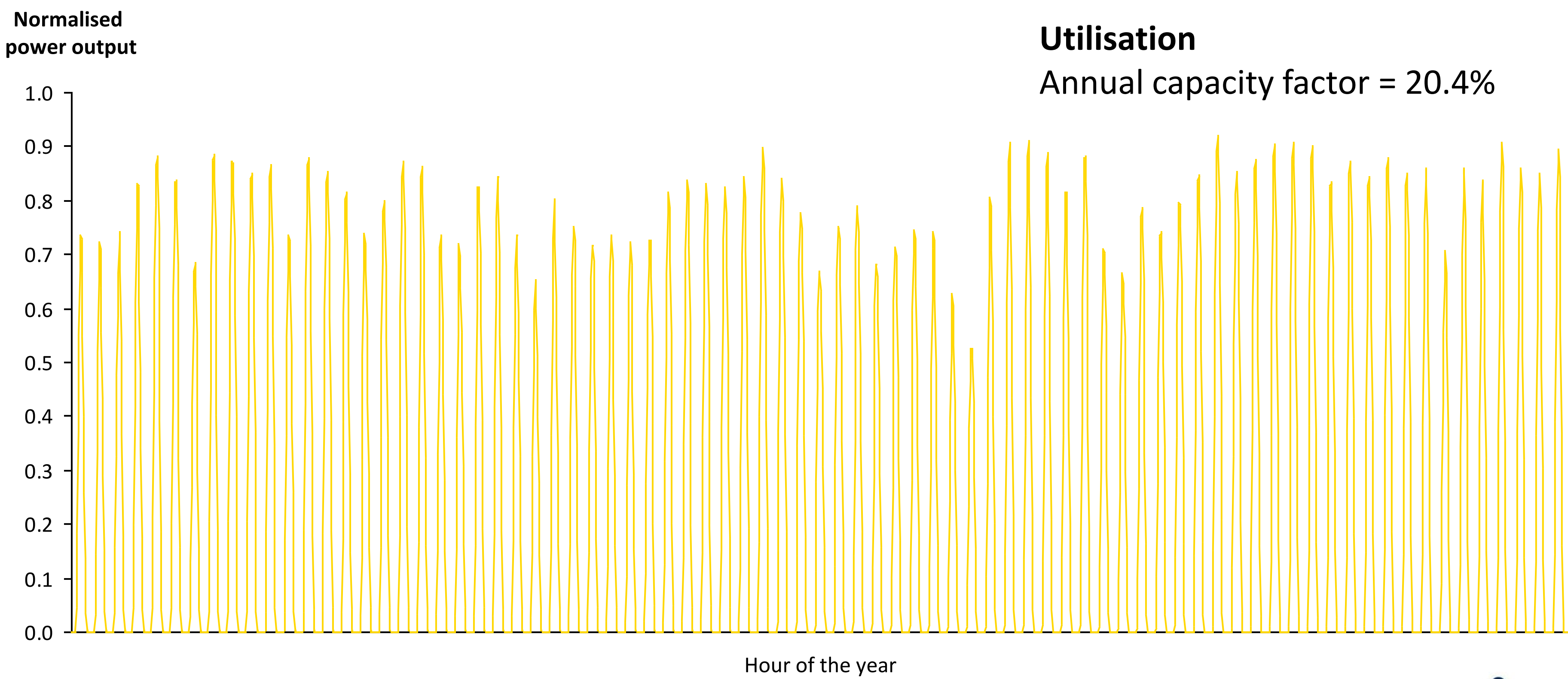
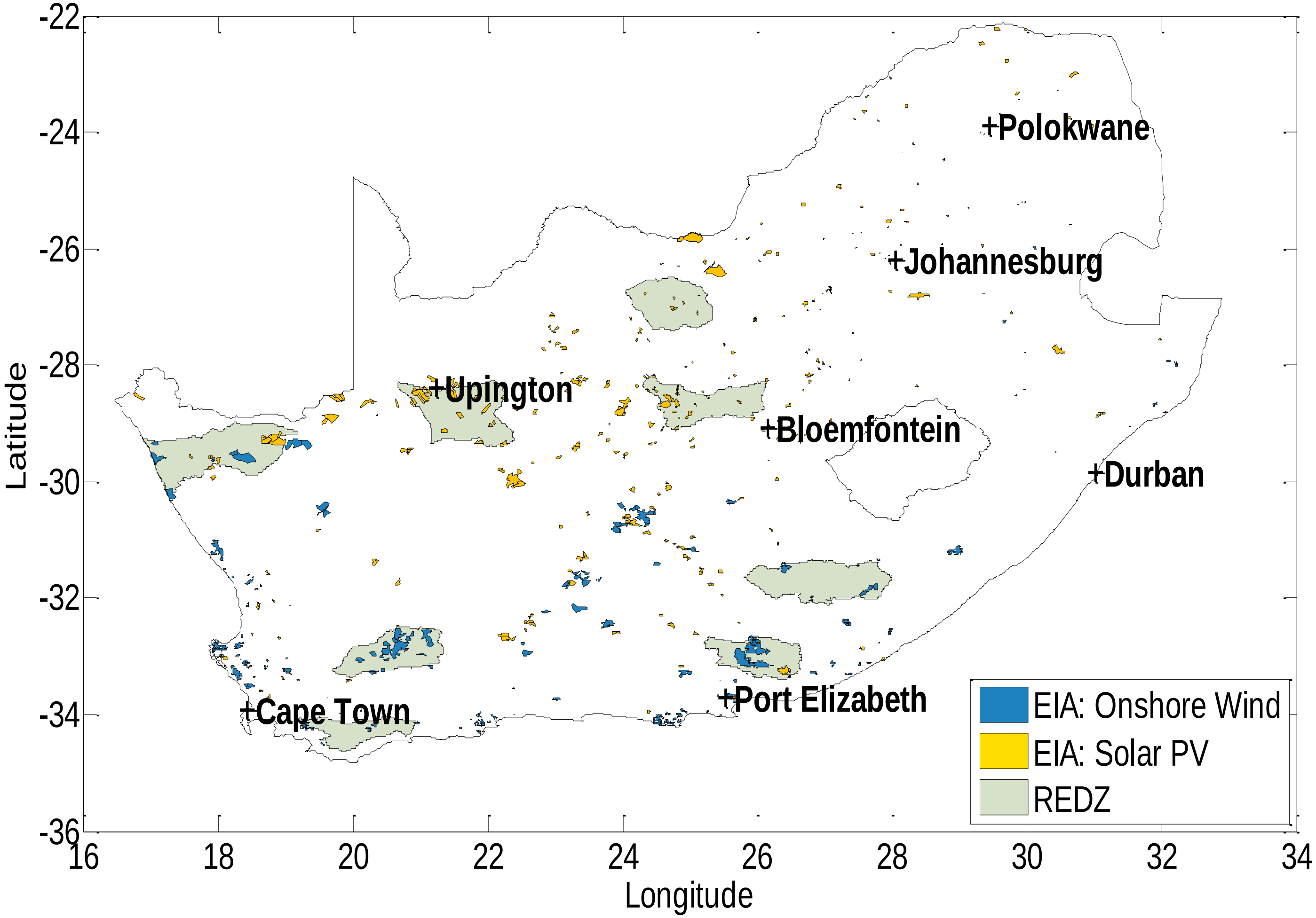
Solar PV: supply profile assumptions

Utilisation
Annual capacity factor = 20.4%



Areas already applied for Environmental Impact Assessments can cater for 90 / 330 wind / solar PV capacity



All EIAs
(status early 2016)

Wind: 90 GW
Solar PV: 330 GW

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Sources: https://www.csir.co.za/sites/default/files/Documents/Wind_and_PV_Aggregation_study_final_presentation_REV1.pdf; https://www.csir.co.za/sites/default/files/Documents/Wind%20and%20Solar%20PV%20Resource%20Aggregation%20Study%20for%20South%20Africa_Final%20report.pdf

Results

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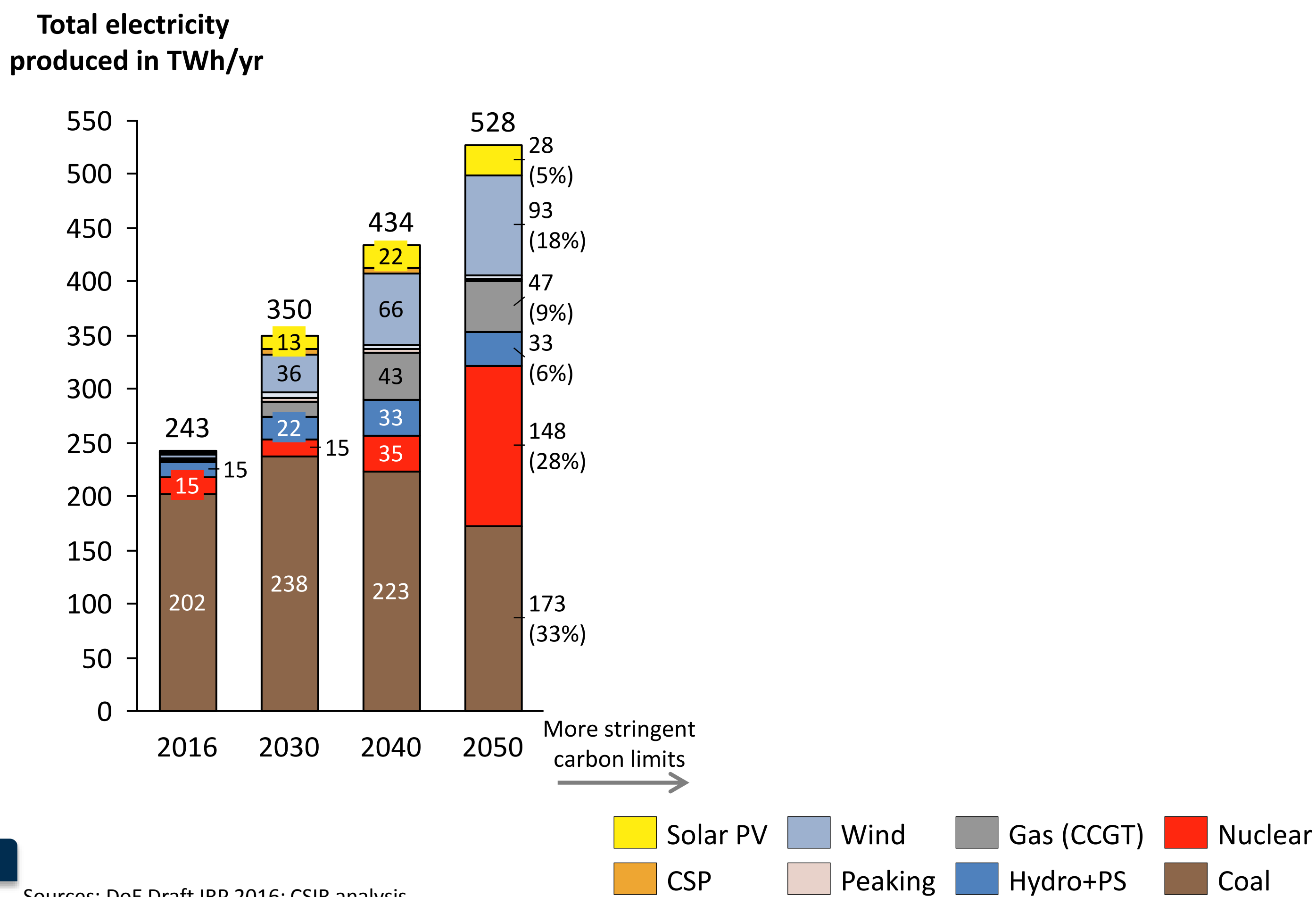
Draft IRP 2016 Base Case is a mix of roughly 1/3 coal, nuclear, RE each

As per Draft IRP 2016

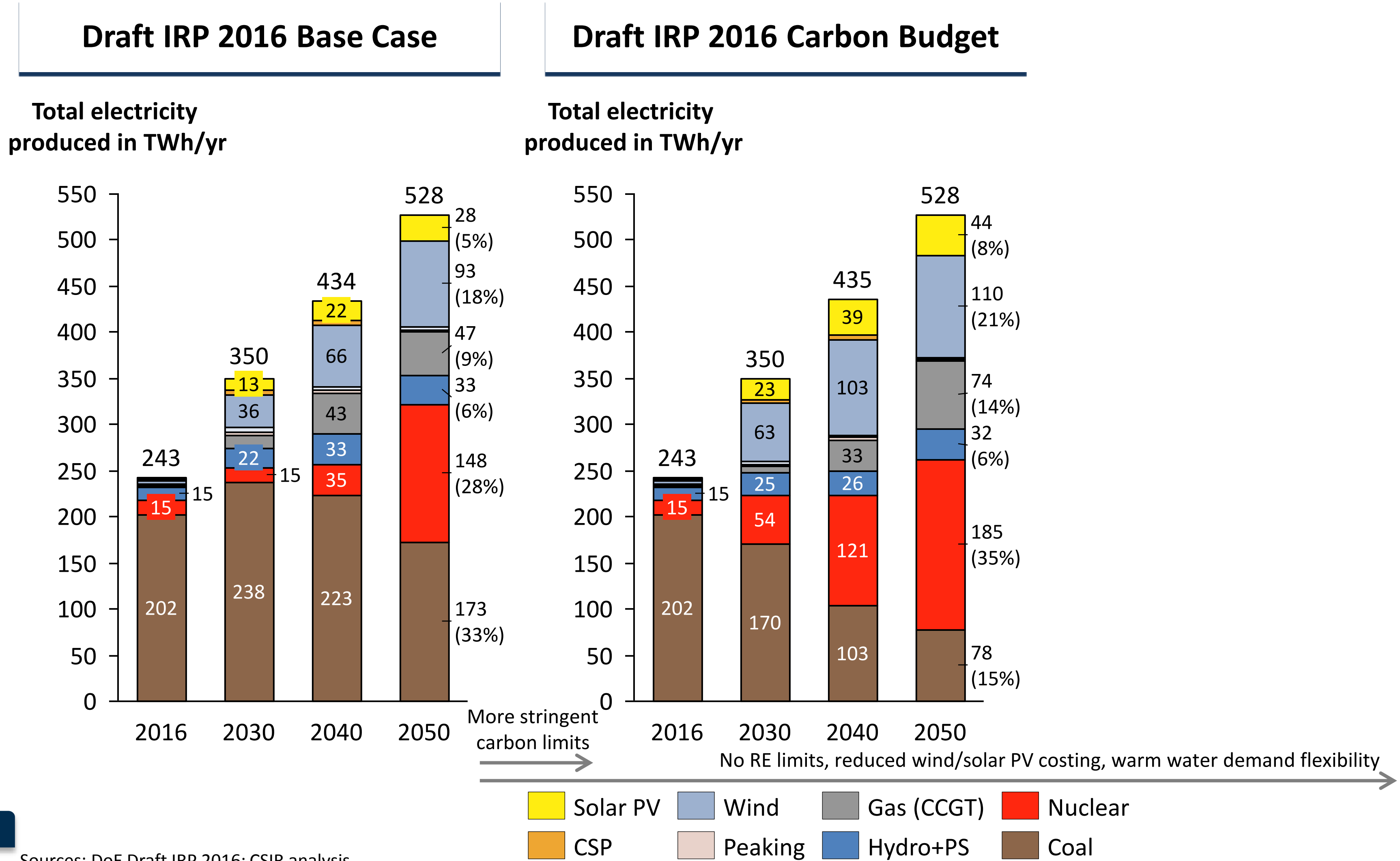
Draft IRP 2016 Base Case



Sources: DoE Draft IRP 2016; CSIR analysis

Draft IRP 2016 Carbon Budget case: 40% nuclear energy share by 2050

As per Draft IRP 2016

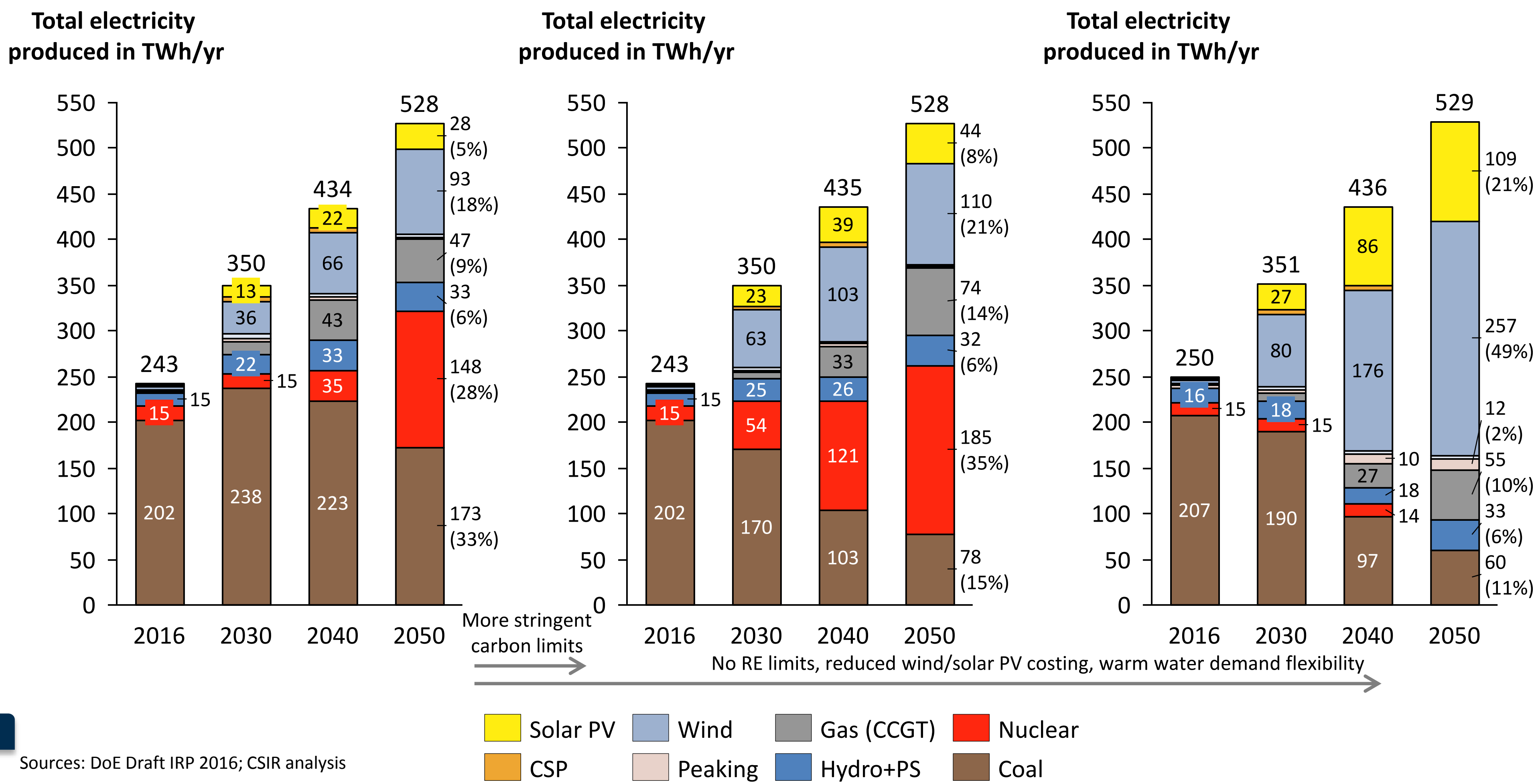


Sources: DoE Draft IRP 2016; CSIR analysis

Least Cost case is largely based on wind and solar PV

As per Draft IRP 2016

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



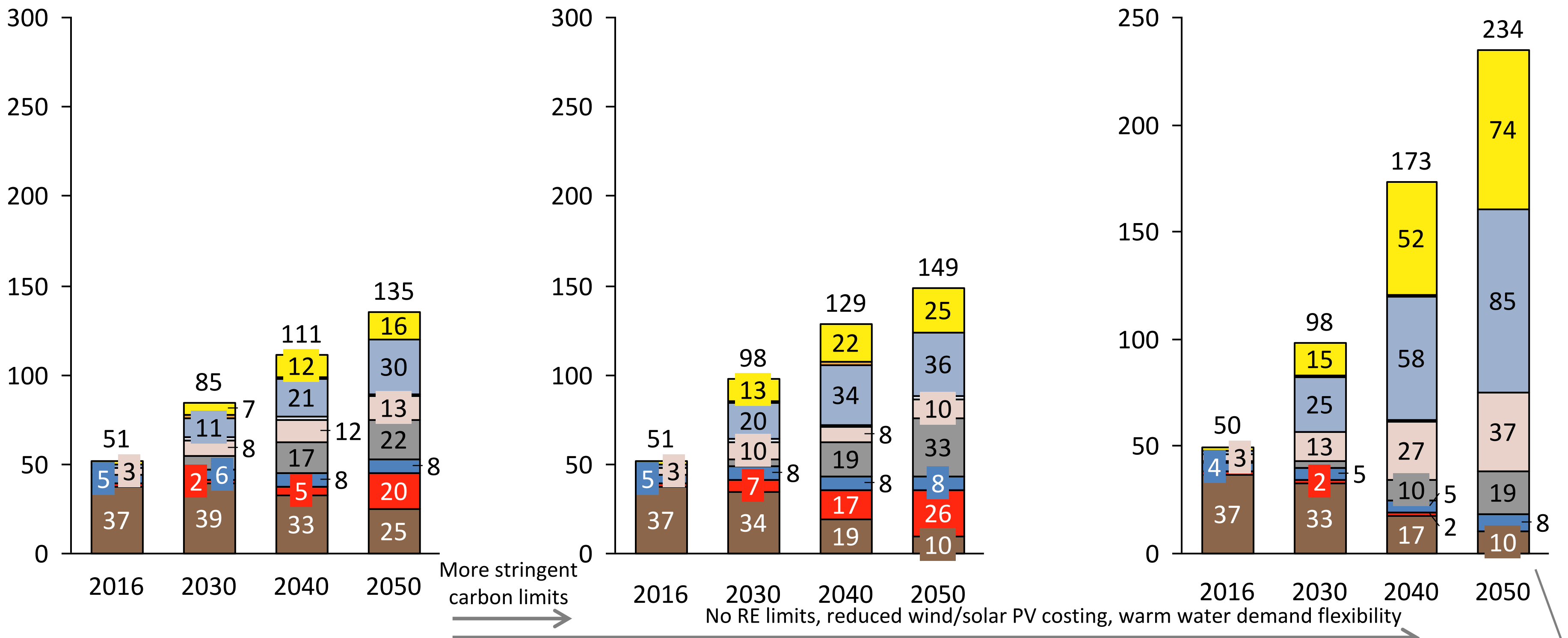
Sources: DoE Draft IRP 2016; CSIR analysis

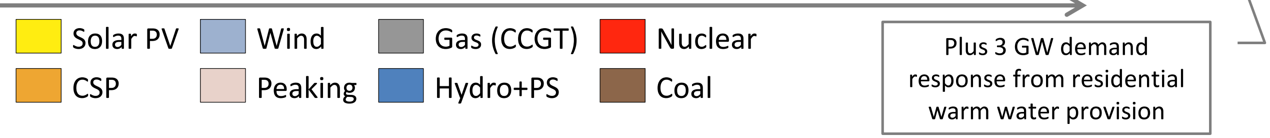
Least Cost means no new coal and no new nuclear until 2050, instead 85 GW of wind and 74 GW of solar PV plus flexible capacities

As per Draft IRP 2016

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

Total installed net capacity in GW





Note: REDZ = Renewable Energy Development Zones
Current REDZ cover 7% of South Africa's land mass
Sources: DoE Draft IRP 2016; CSIR analysis

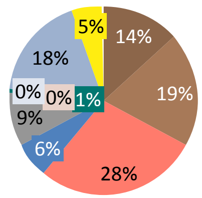
Conservative renewables and battery costing: Least Cost is R60-75 billion/yr cheaper than Draft IRP 2016 by 2050

As per Draft IRP 2016

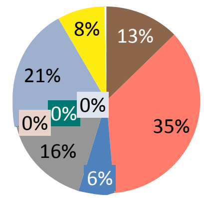
2050

Energy Mix in 2050 — Demand: 522 TWh

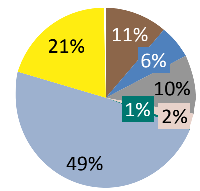
IRP 2016 Base Case



IRP 2016 Carbon Budget



Least Cost



2050		IRP 2016 Base Case	IRP 2016 Carbon Budget	Least Cost	
Cost in 2050	**Total system cost**[1] (R-billion/yr)	700	688	627	10% cheaper
	Average tariff (R/kWh)	1.34	1.32	1.20	
Environ-ment in 2050	**CO_2 emissions** (Mt/yr)	187	99	86	Cleaner
	Water usage (billion-litres/yr)	41	18	15	
Jobs[2] in 2050	**Direct & supplier** ('000)	252-295	235-253	310-325	10-20% more jobs

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

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

Operational Aspects

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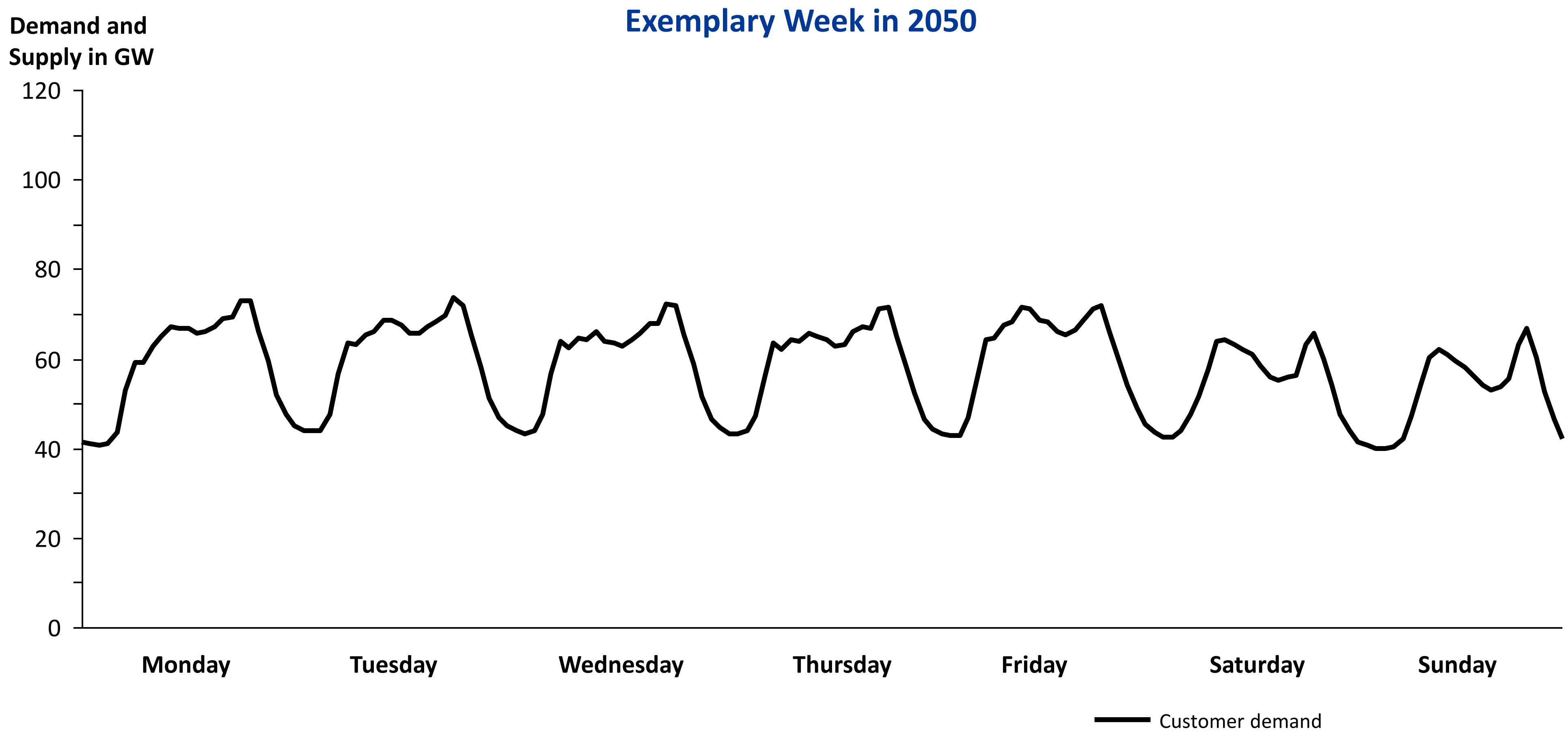
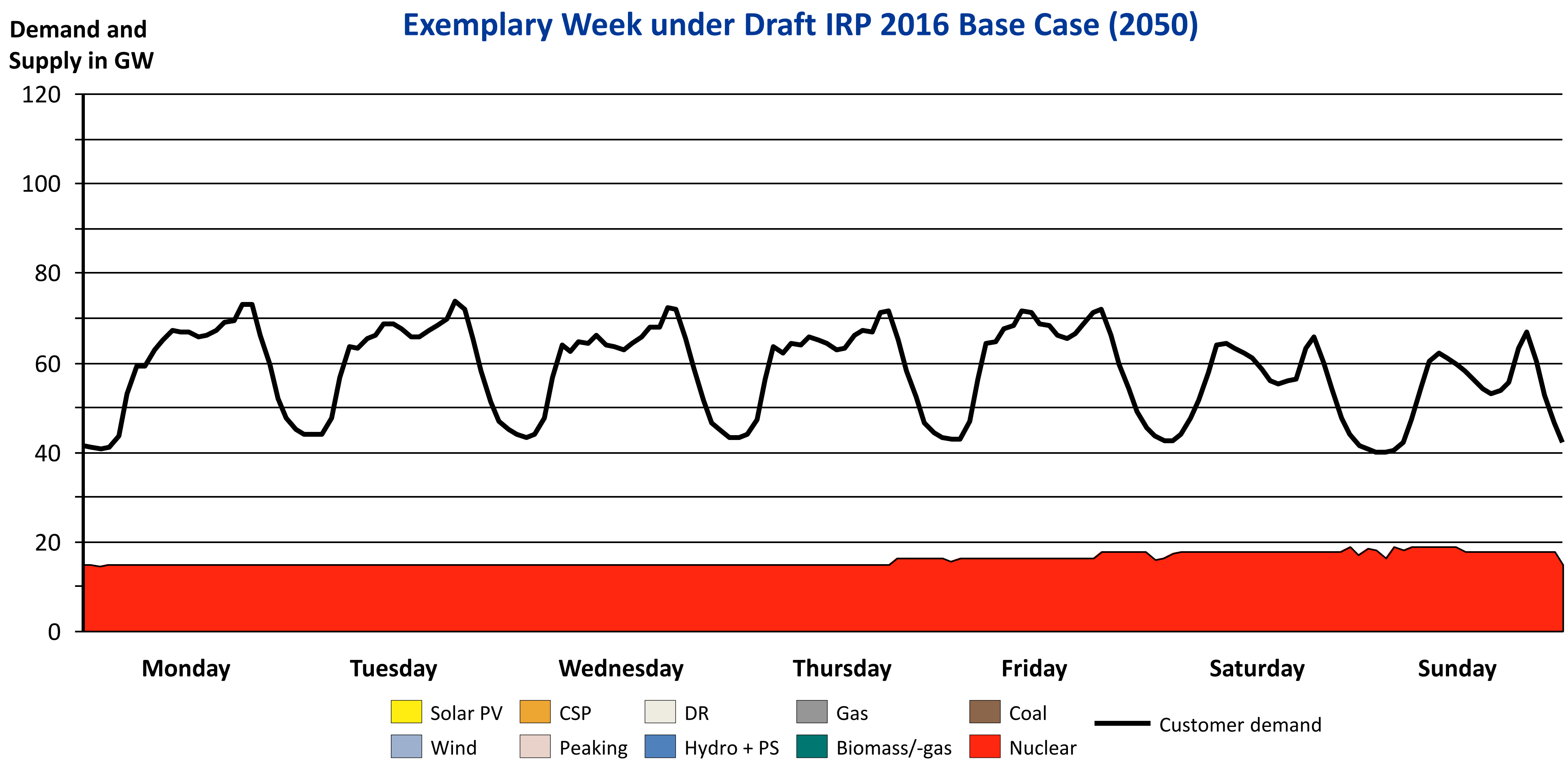
Weekly electricity demand profile in 2050



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

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



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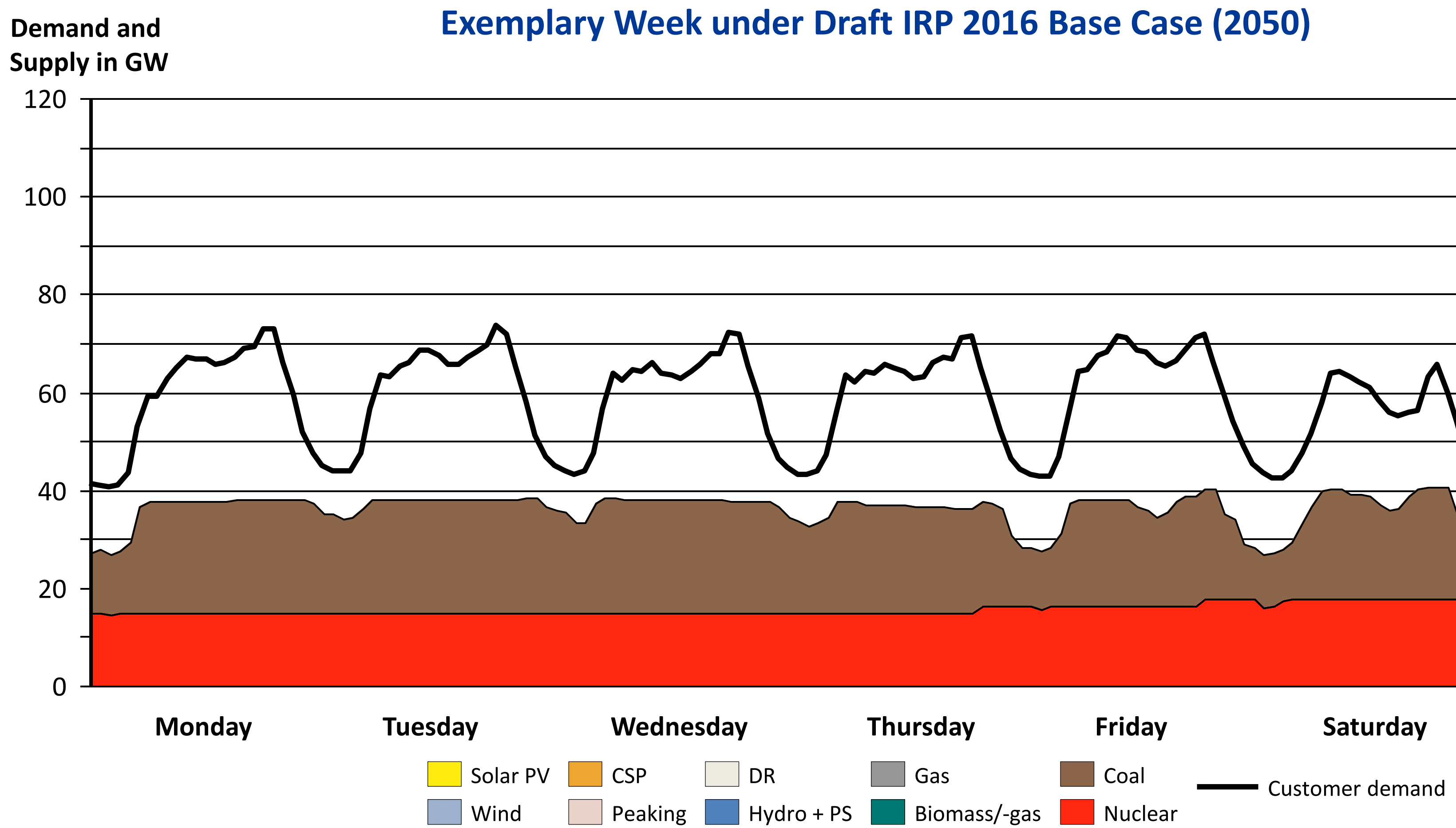

Sources: CSIR analysis, based on DoE's Draft IRP 2016

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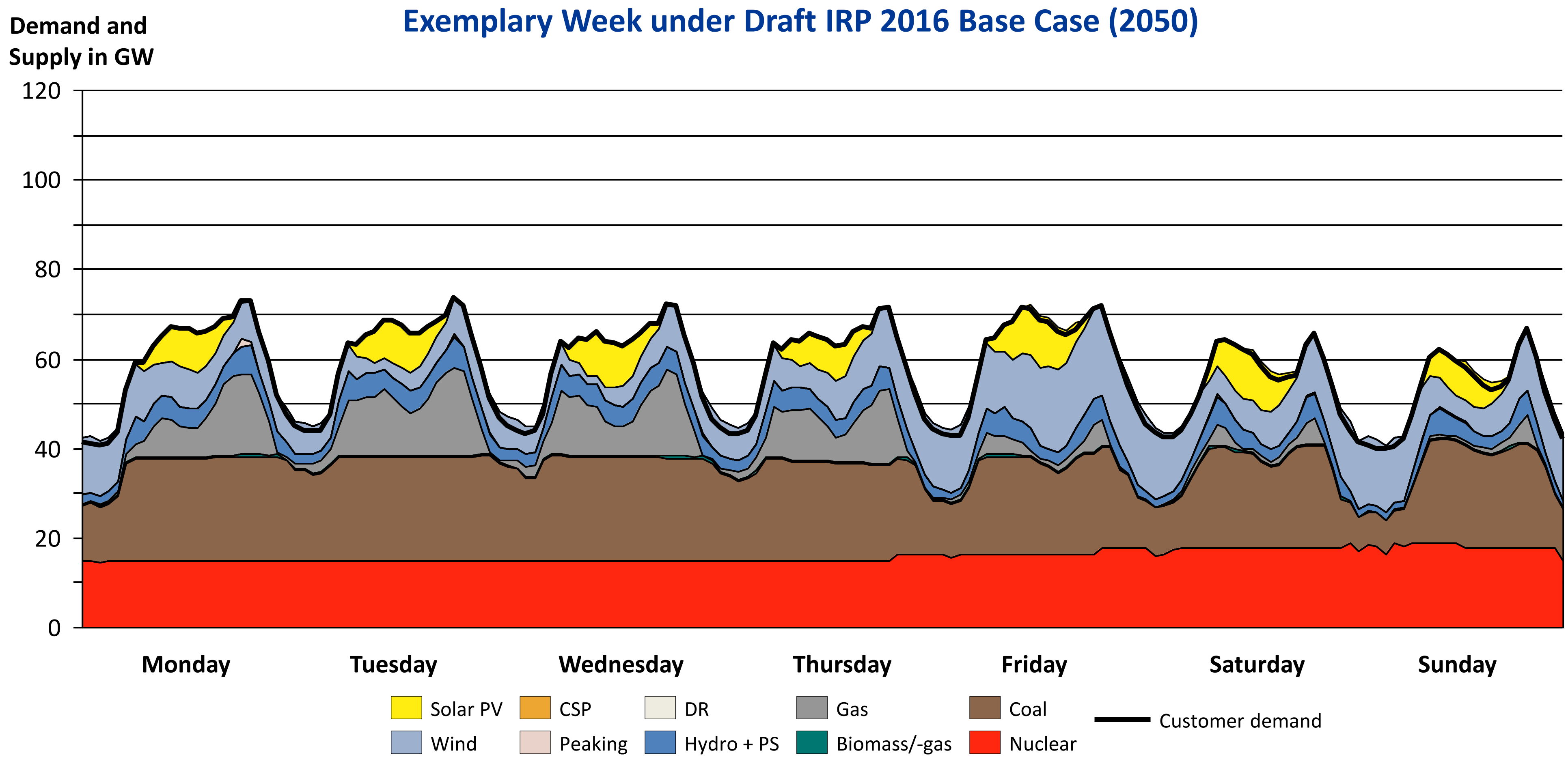
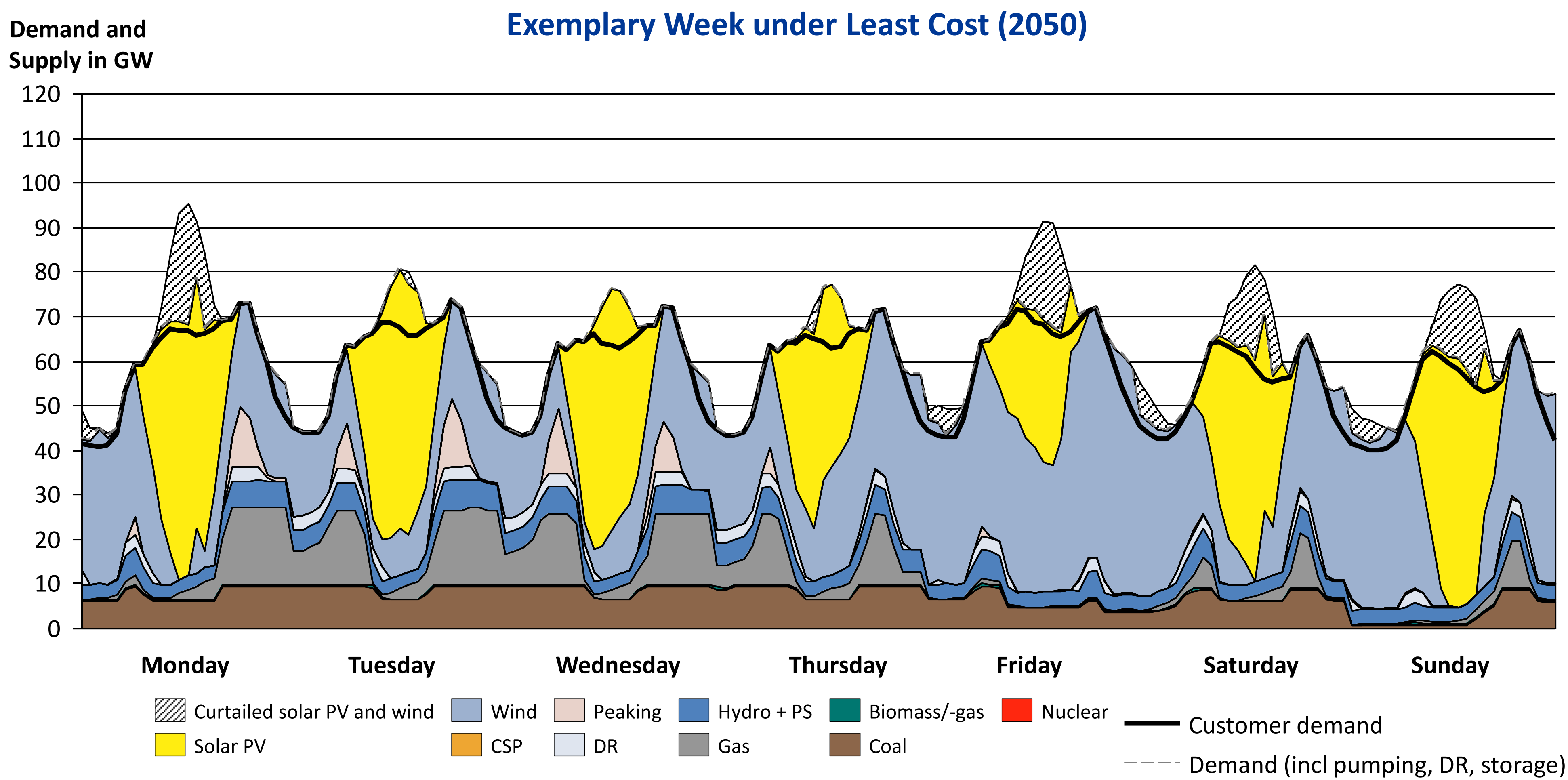


Sources: CSIR analysis, based on DoE's Draft IRP 2016

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

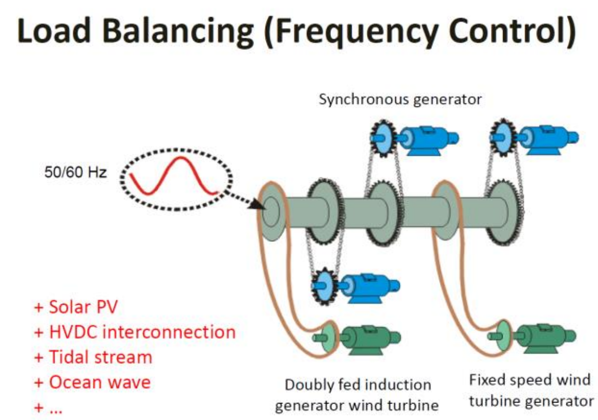


Sources: CSIR analysis

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

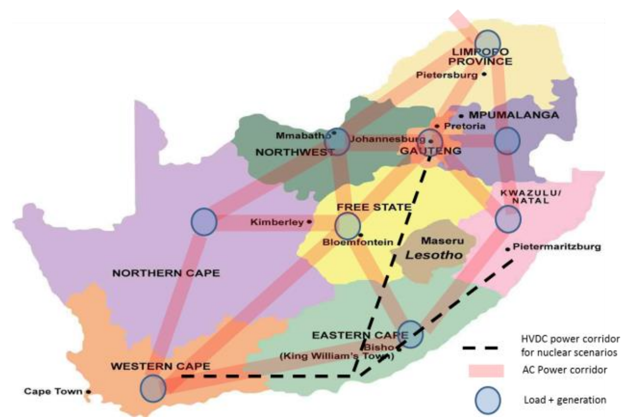
System Stability (inertia): <u>worst case</u> below 1% of Gx cost

- 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
- Technical solutions to operate low-inertia system exist
- In this study the “worst case” was costed
  - State-of-the-art technology (very high costs assumed, no further tech/cost advancements)
  - Assumption: No further increase in engineering of how to deal with low-inertia systems by 2050
- 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



Next Steps and Summary

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What has not been considered yet that makes Least Cost even cheaper?

Further cost reductions in solar PV, wind and battery technologies

- Solar PV cost were assumed to only decrease 20% by 2050
- Wind and battery cost were assumed to stay constant until 2050
- CSP cost were assumed to decrease to only 1.2 R/kWh until 2030 (for mid-merit operations)

→ With realistic cost reductions assumed, Least Cost is 25-30% cheaper than the IRP Base Case

Increasing penetration of Electric Vehicles (EV)

- No EV uptake assumed at all

→ With 5 million EVs by 2050, a large source of flexible demand is introduced into the system

Demand side flexibilisation only marginally considered

- Only source of flexibility considered: domestic electric warm water provision

→ With all heat/cool & pumping load made flexible, large source of flexible demand can be introduced

Transmission grid expansion for distributed power generators less costly

- Transmission grid costs assumed to be equal for all scenarios

→ Preliminary costing: transmission for Least Cost additionally R20-30 billion per year cheaper

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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>R70 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

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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

Outlook for Energy Planning beyond Electricity

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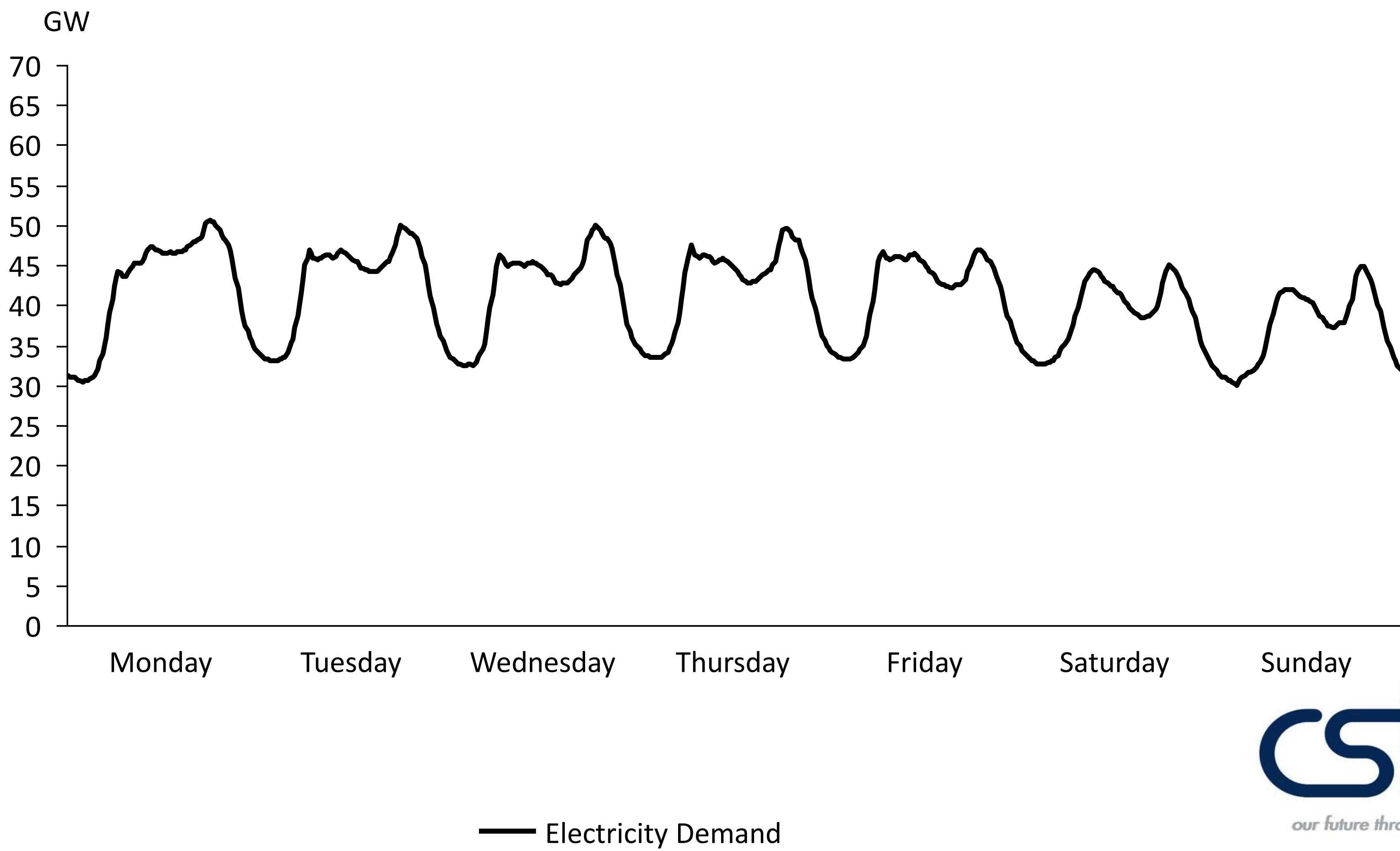
Electricity demand is fluctuating intraday, intra-week, and seasonally

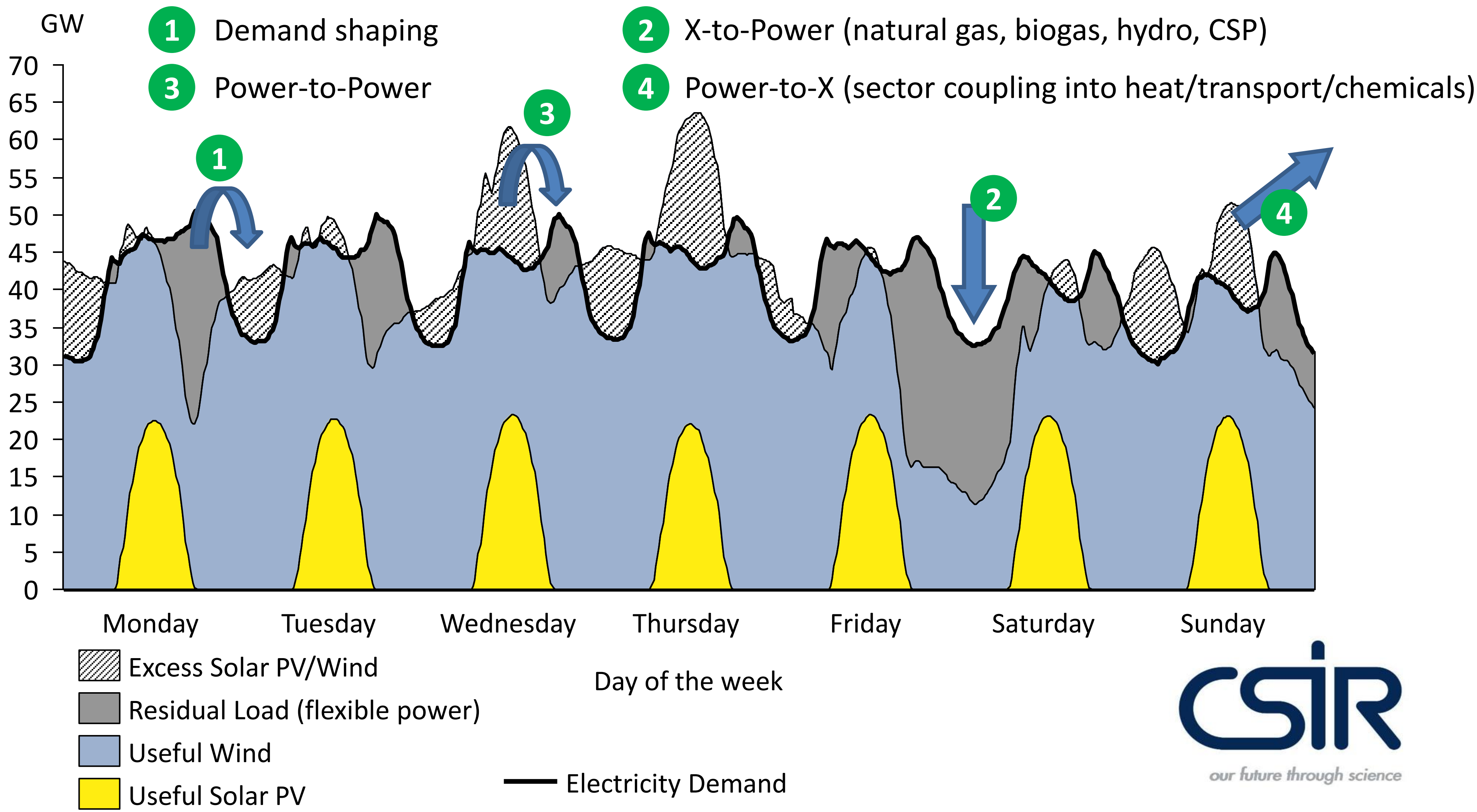
Actual RSA demand for week from 15-21 Aug ’11 in 15-minute resolution, scale to ~ 2025 demand level



Sources: CSIR analysis

Future energy system will be built around variability of solar PV & wind

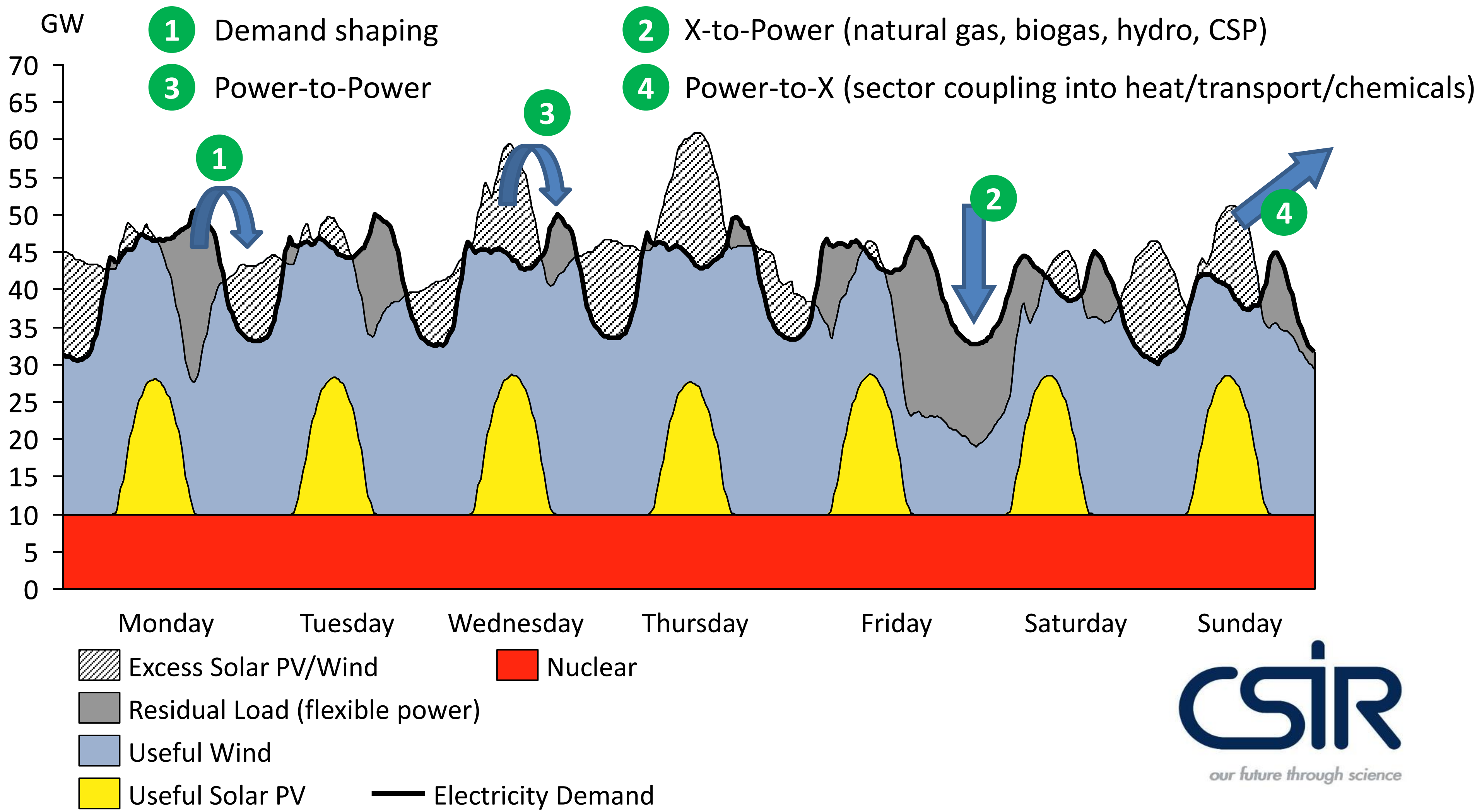
Actual scaled RSA demand & simulated 15-minute solar PV/wind power supply for week from 15-21 Aug '11



Sources: CSIR analysis

Nuclear can add carbon-free electricity: cost, not a technical question

Actual scaled RSA demand & simulated 15-minute solar PV/wind power supply for week from 15-21 Aug '11



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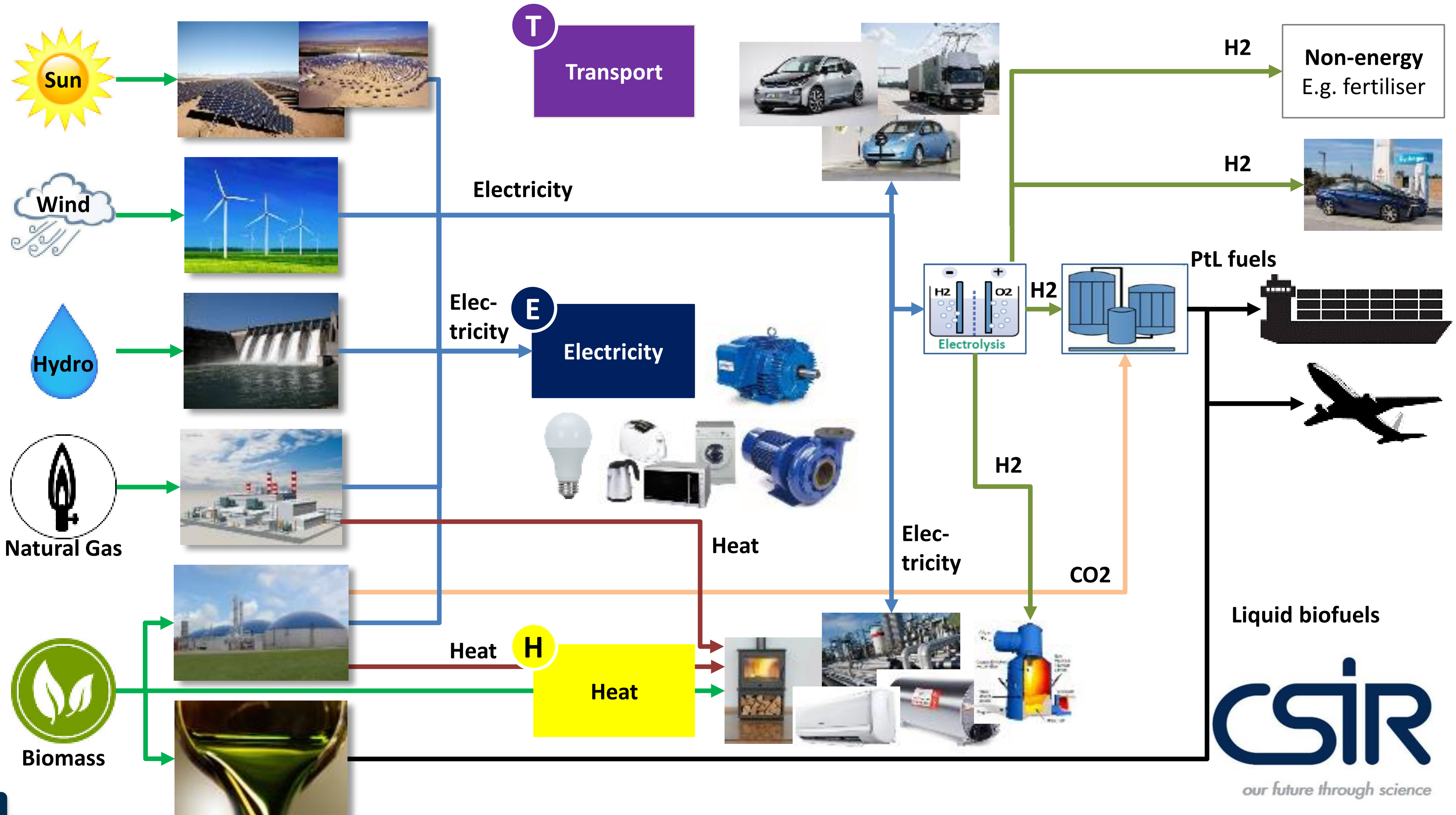
Sources: CSIR analysis

Scenario: Electricity the new primary energy, complemented by bio

Hypothetical energy-flow diagram (Sankey diagram) for South Africa in the year 20??



Re a leboha

Ha Khensa

Enkosi

Siyathokoza

Thank you

Re a leboga

Ro livhuha

Dankie

Siyabonga

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