What could South Africa's Energy future look like?

Presentation at workshop hosted by Project 90 by 2030

Dr Tobias Bischof-Niemz, Head of the CSIR Energy Centre

Cape Town, 27 February 2017

Dr Tobias Bischof-Niemz
+27 83 403 1108
tbischofniemz@csir.co.za

our future through science

Agenda

Background

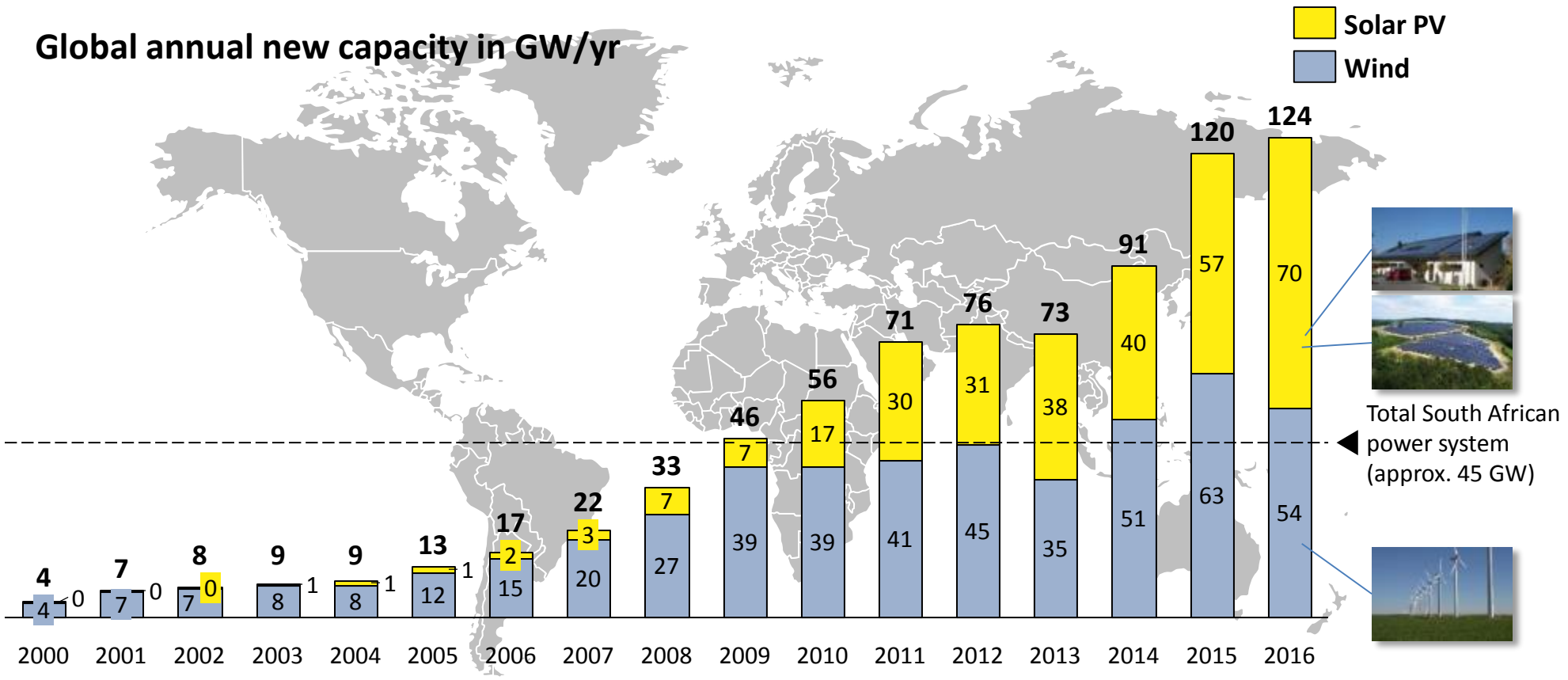
CSIR's Approach and Project Team

Comments on IRP Assumptions

IRP Results and Least-cost Scenario

Energy Sector Implications

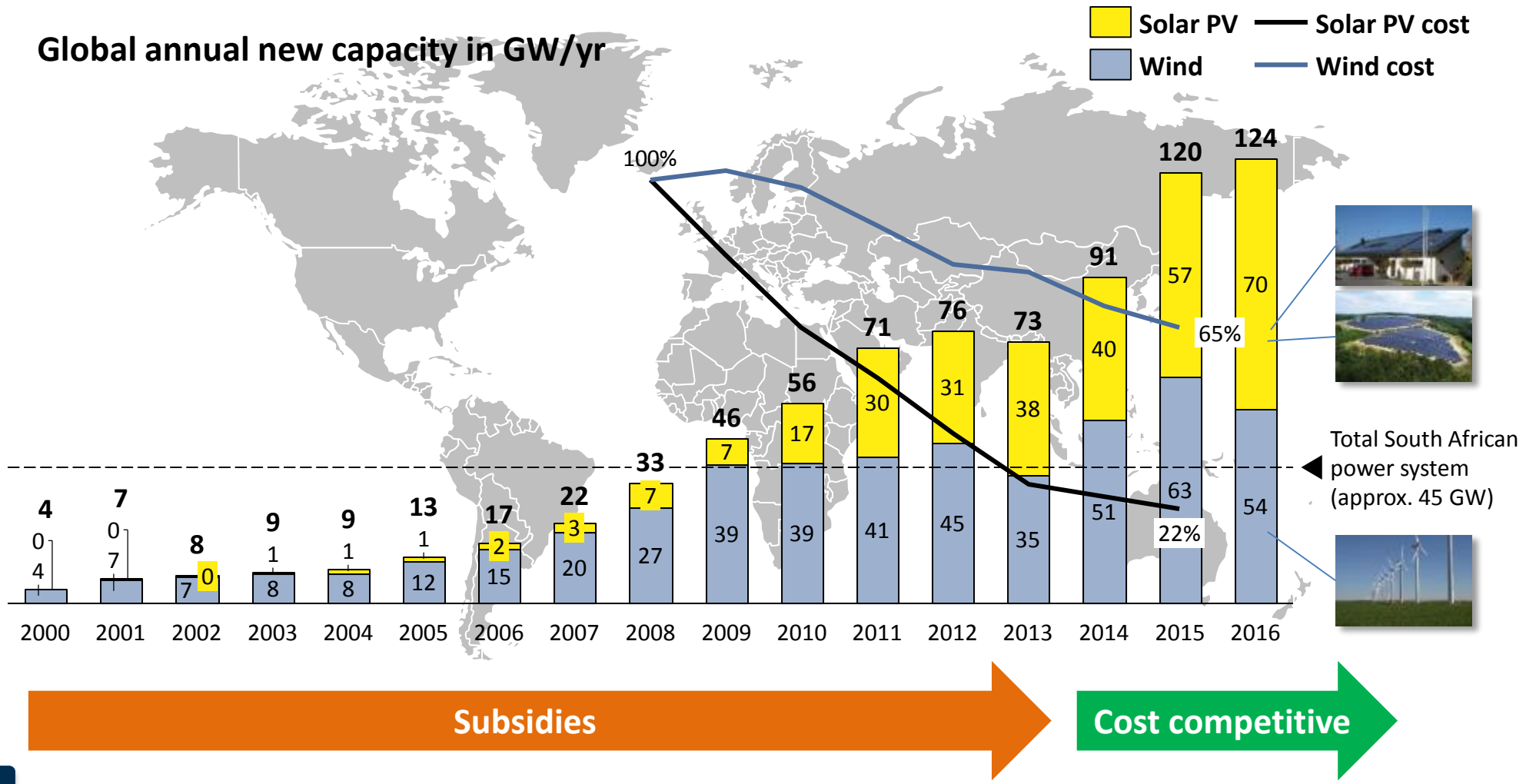
World:
In 2016, 124 GW of new wind and solar PV capacity installed globally



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

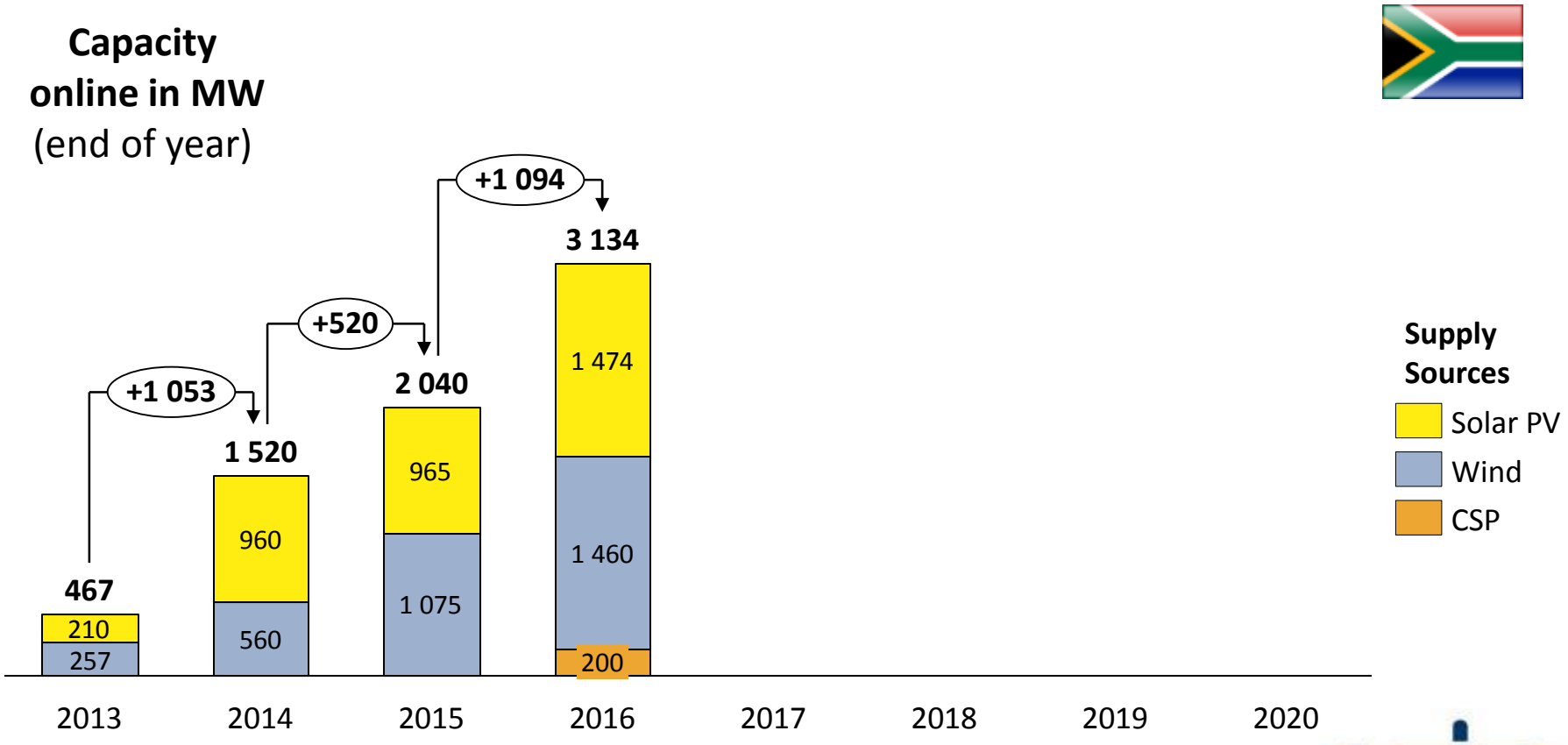
Sources: GWEC; EPIA; BNEF; CSIR analysis

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



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

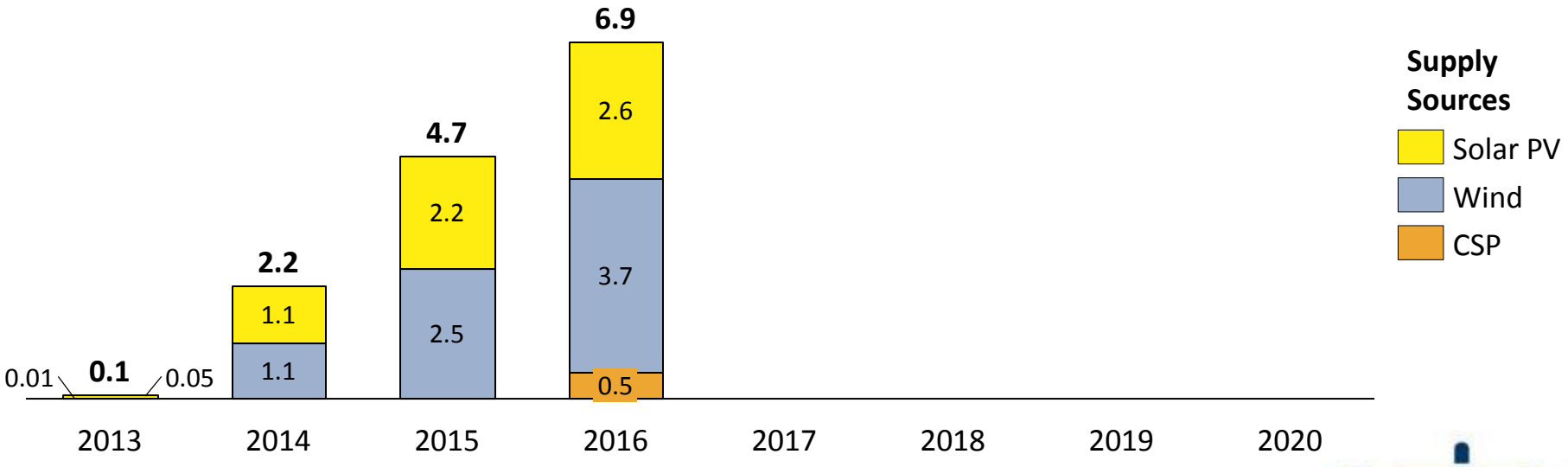
South Africa:
From 2013 to 2016, 3.1 GW of wind, solar PV and CSP commissioned



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

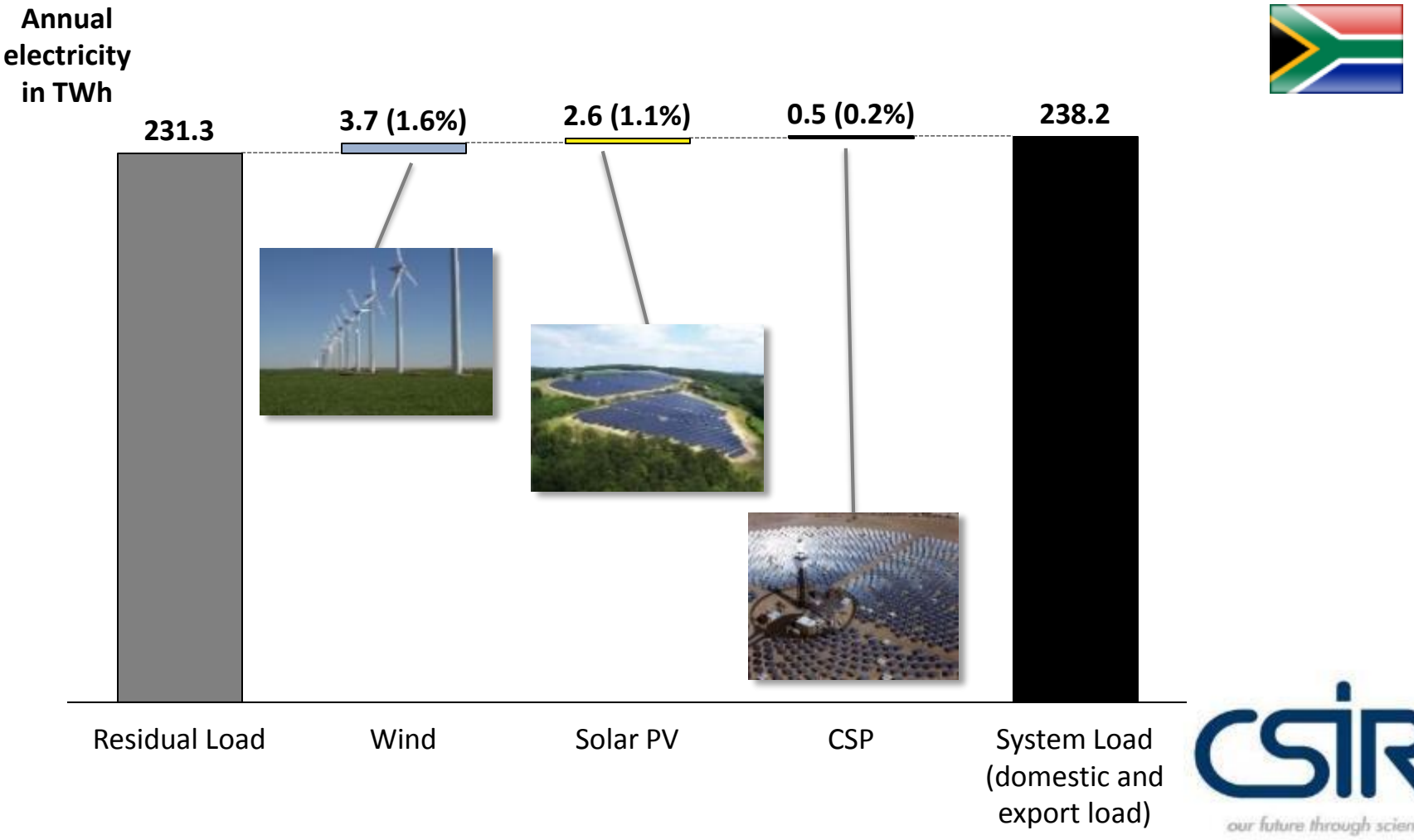
Annual energy produced in TWh



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

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)

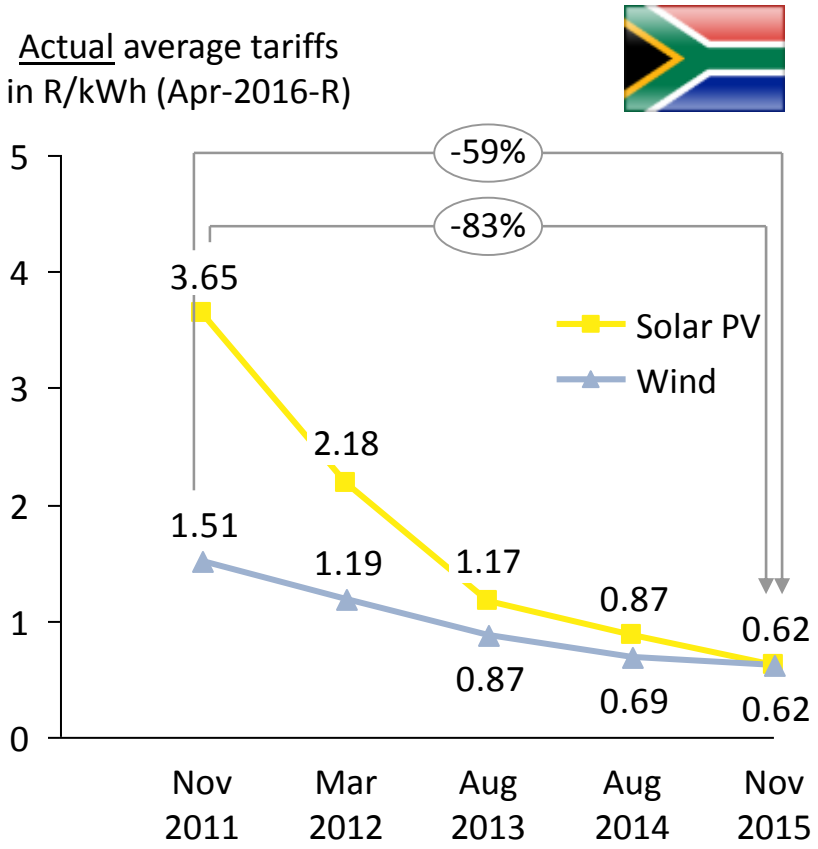


Notes: Wind includes Eskom's Sere wind farm (100 MW)
Sources: Eskom; DoE IPP Office

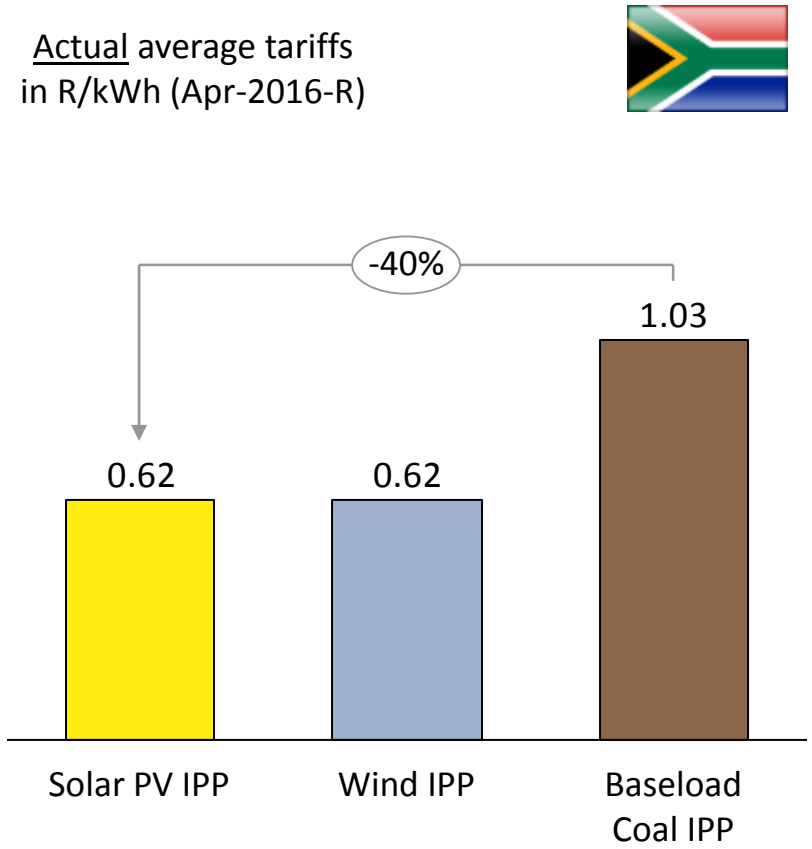
Actual tariffs: new wind/solar PV 40% cheaper than new coal in RSA

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

Agenda

Background

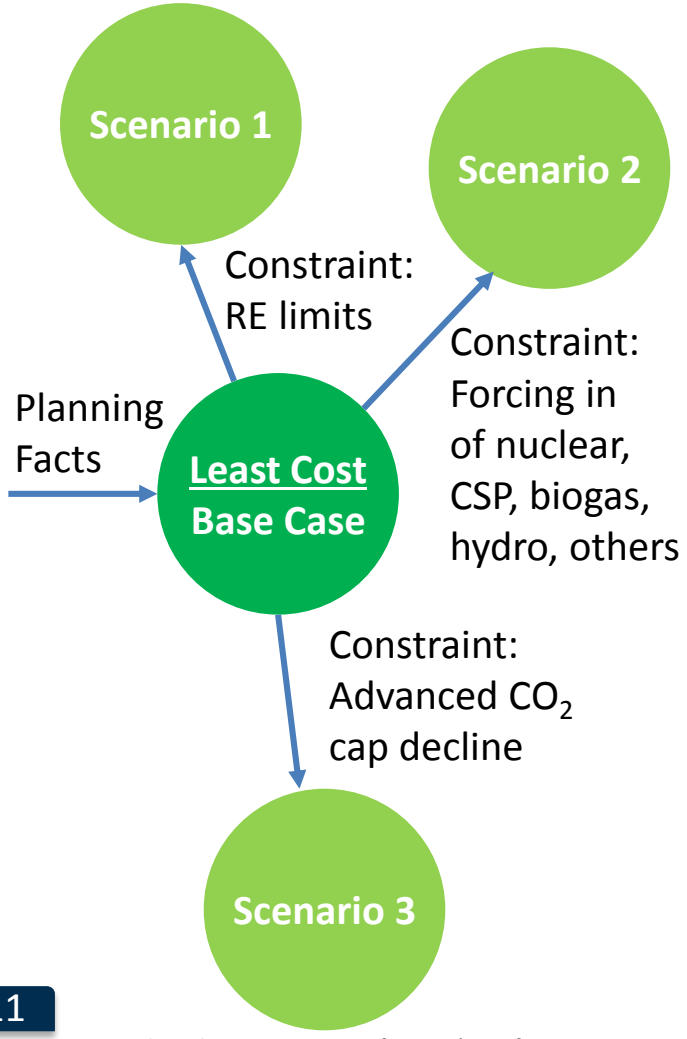
CSIR's Approach and Project Team

Comments on IRP Assumptions

IRP Results and Least-cost Scenario

Energy Sector Implications

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

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 has embarked on power-system analyses to determine the least-cost expansion path for the South African electricity system

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

- Starting point of the IRP Base Case: pure techno-economic analysis to determine least-cost way to supply electricity
- Later process steps: least-cost mix can be policy adjusted to cater for aspects not captured in techno-economic model

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

CSIR
our future through science

Sources: CSIR analysis

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

Agenda

Background

CSIR's Approach and Project Team

Comments on IRP Assumptions

IRP Results and Least-cost Scenario

Energy Sector Implications

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%	1 600	3.6%
2025	51 015	1 000	2.0%	1 600	3.1%
2030	57 274	1 000	1.7%	1 600	2.8%
2035	64 169	1 000	1.6%	1 600	2.5%
2040	70 777	1 000	1.4%	1 600	2.3%
2045	78 263	1 000	1.3%	1 600	2.0%
2050	85 804	1 000	1.2%	1 600	1.9%

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

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

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

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

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

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

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

Agenda

Background

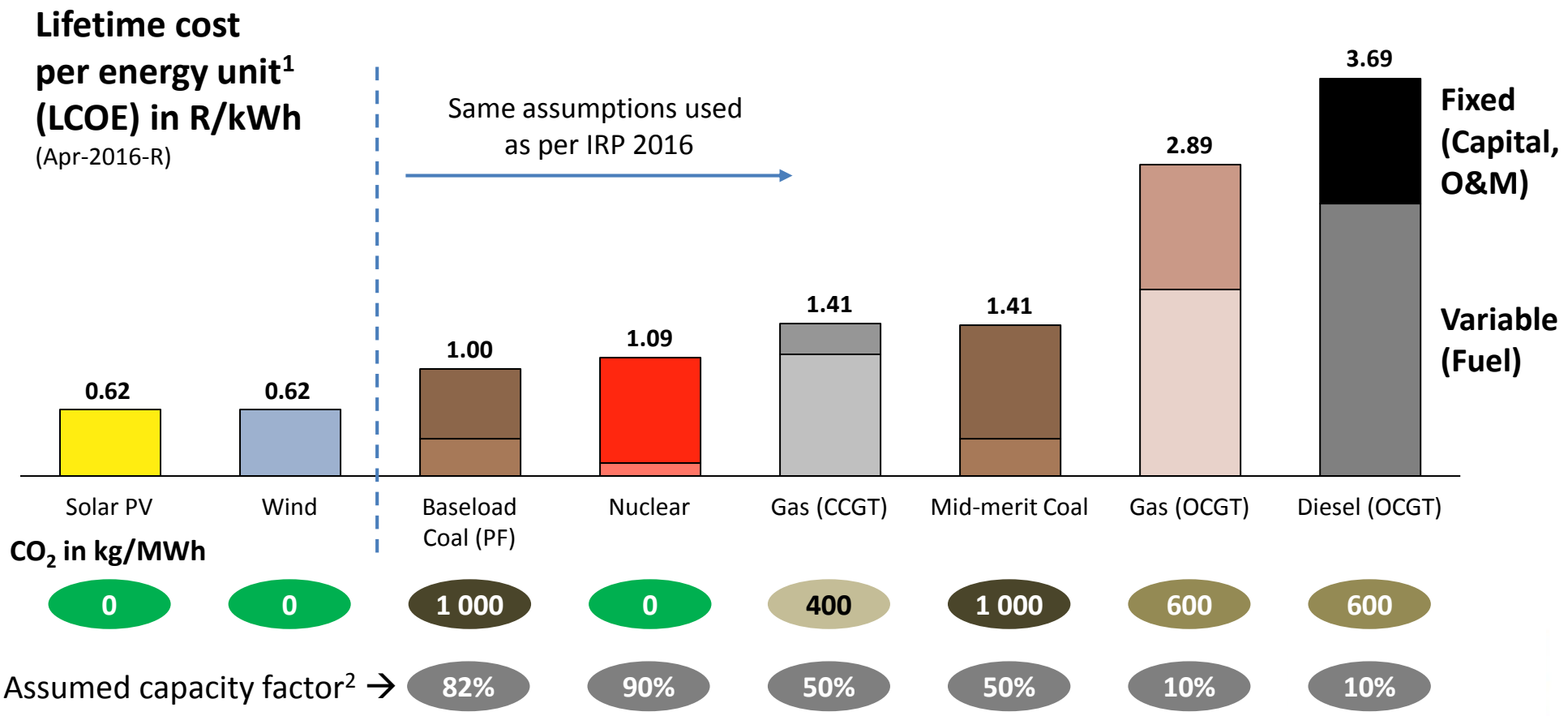
CSIR's Approach and Project Team

Comments on IRP Assumptions

IRP Results and Least-cost Scenario

Energy Sector Implications

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

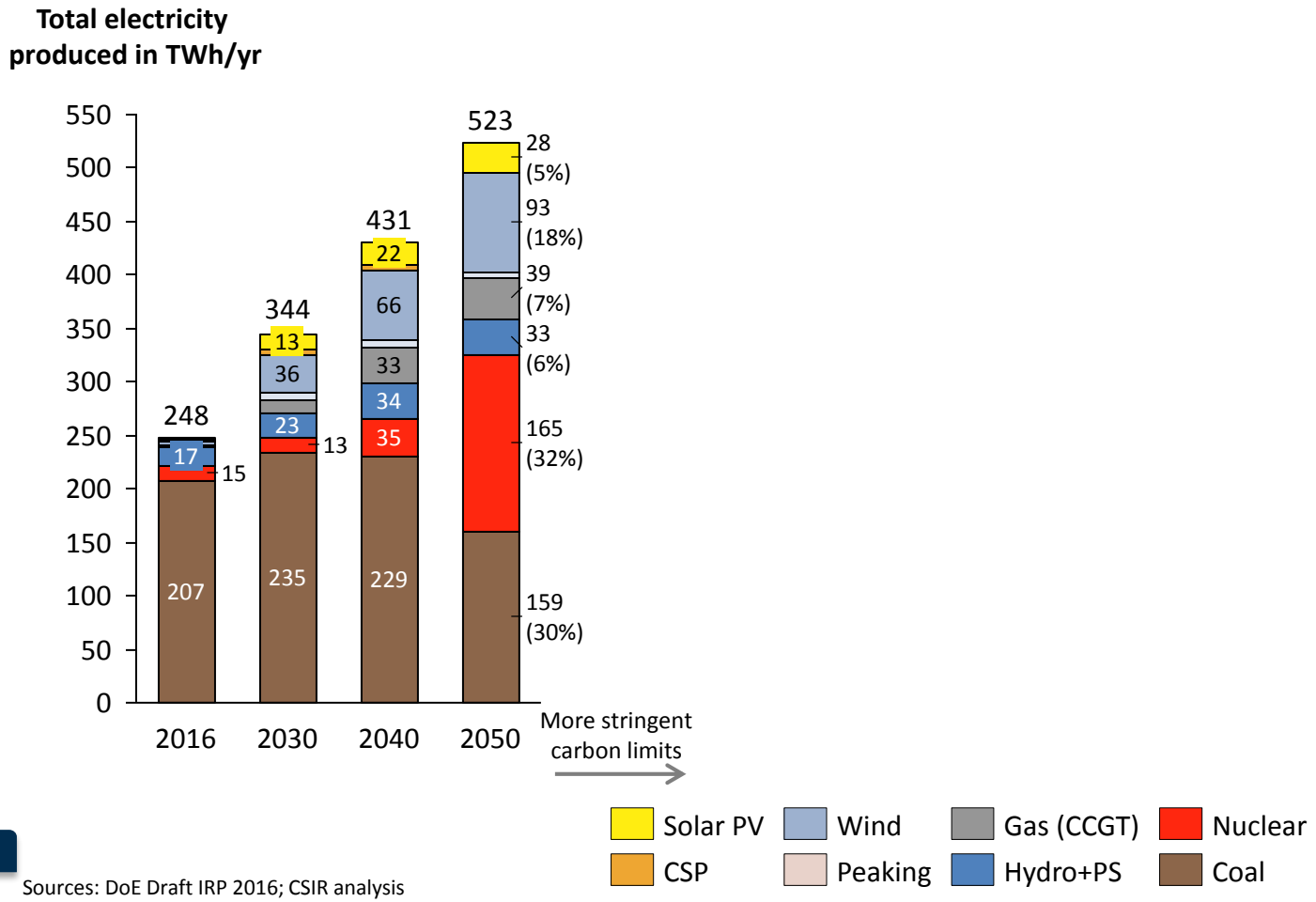


[1] Lifetime cost per energy unit is only presented for brevity. The model inherently includes the specific cost structures of each technology i.e. capex, Fixed O&M, variable O&M, fuel costs etc.
[2] Changing full-load hours for new-build options drastically changes the fixed cost components per kWh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

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



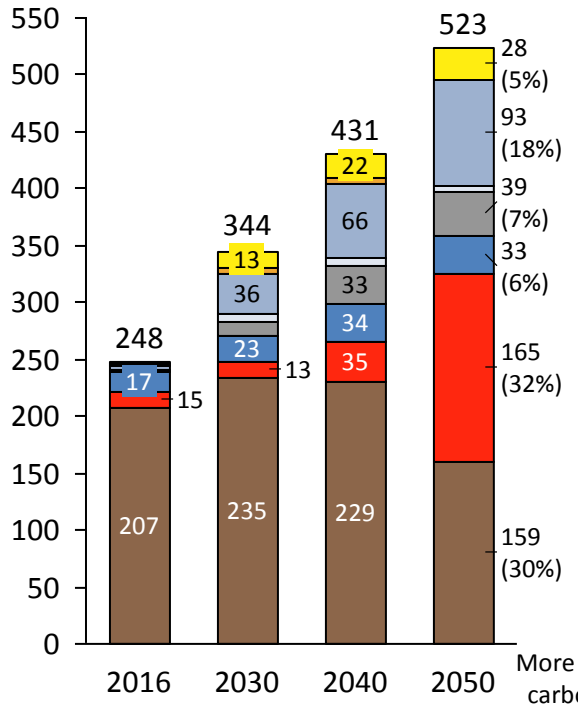
Sources: DoE Draft IRP 2016; CSIR analysis

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

As per Draft IRP 2016

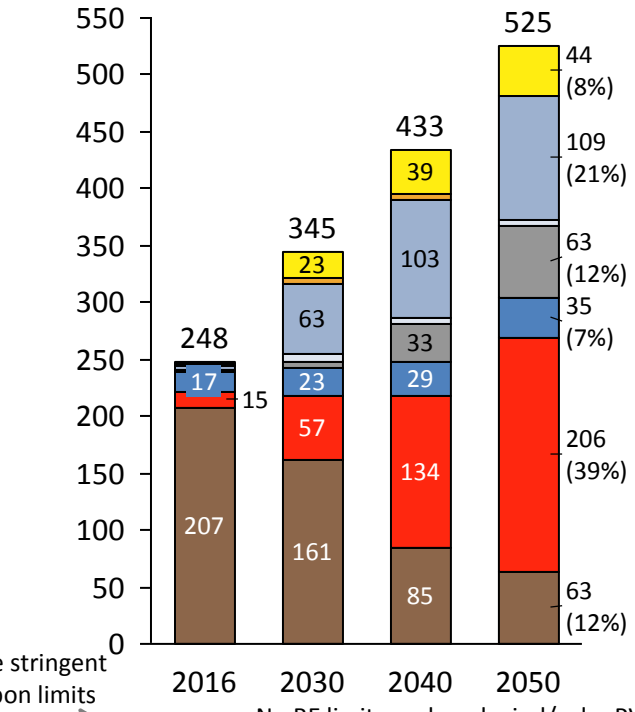
Draft IRP 2016 Base Case

Total electricity produced in TWh/yr



Draft IRP 2016 Carbon Budget

Total electricity produced in TWh/yr



More stringent carbon limits

No RE limits, reduced wind/solar PV costing, warm water demand flexibility

Solar PV | Wind | Gas (CCGT) | Nuclear
CSP | Peaking | Hydro+PS | Coal

Sources: DoE Draft IRP 2016; CSIR analysis

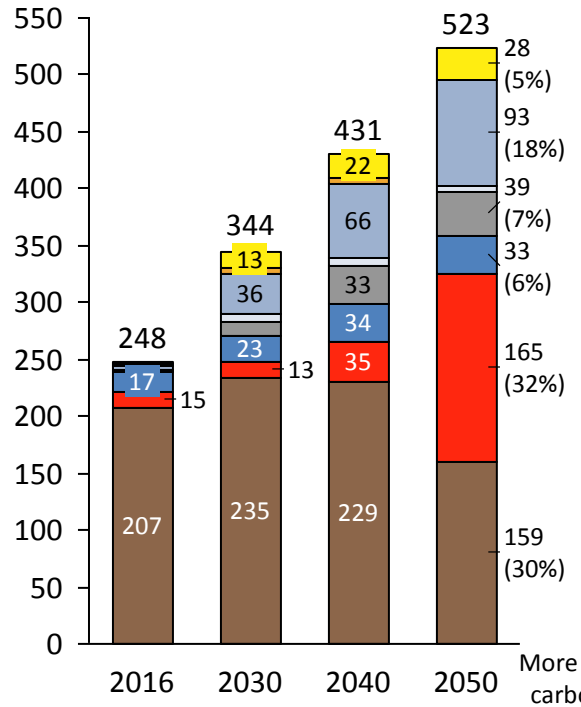
Least Cost case is largely based on wind and solar PV

Preliminary results

As per Draft IRP 2016

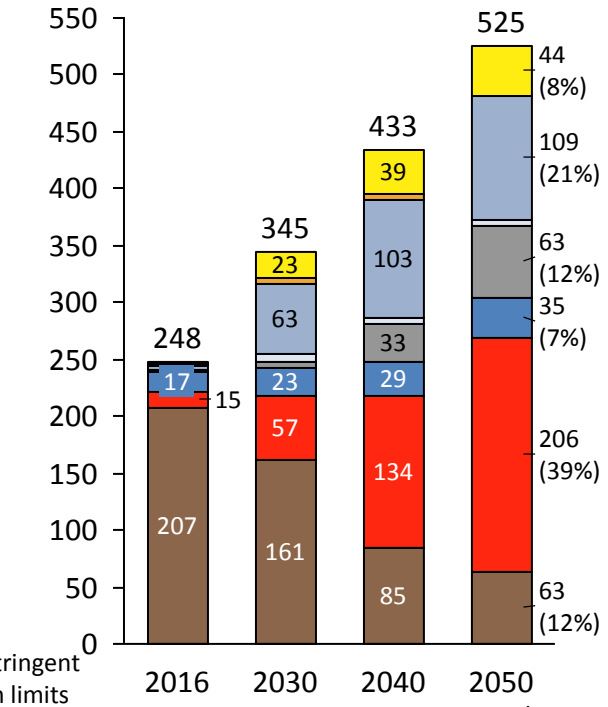
Draft IRP 2016 Base Case

Total electricity produced in TWh/yr



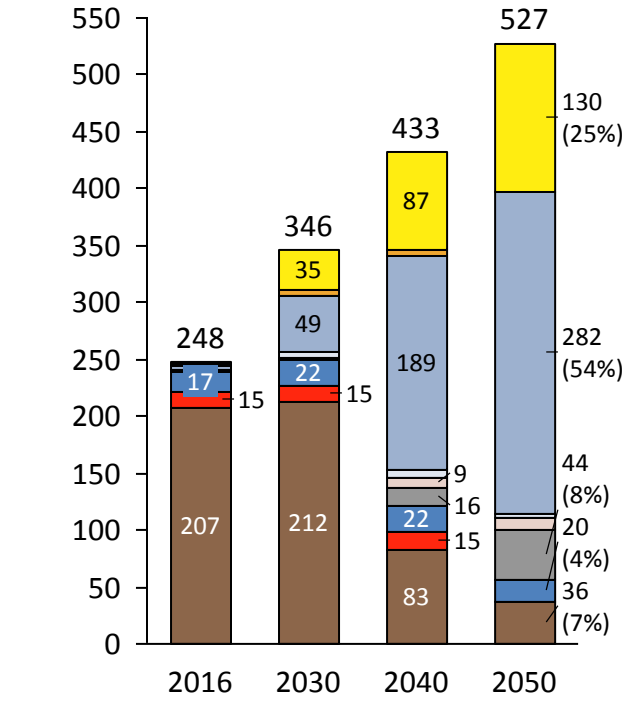
Draft IRP 2016 Carbon Budget

Total electricity produced in TWh/yr



Least Cost

Total electricity produced in TWh/yr



More stringent carbon limits

No RE limits, reduced wind/solar PV costing, warm water demand flexibility

Solar PV | Wind | Gas (CCGT) | Nuclear
CSP | Peaking | Hydro+PS | Coal

Sources: DoE Draft IRP 2016; CSIR analysis

Least Cost means no new coal and no new nuclear until 2050, instead 90 GW of wind and 70 GW of solar PV plus flexible capacities

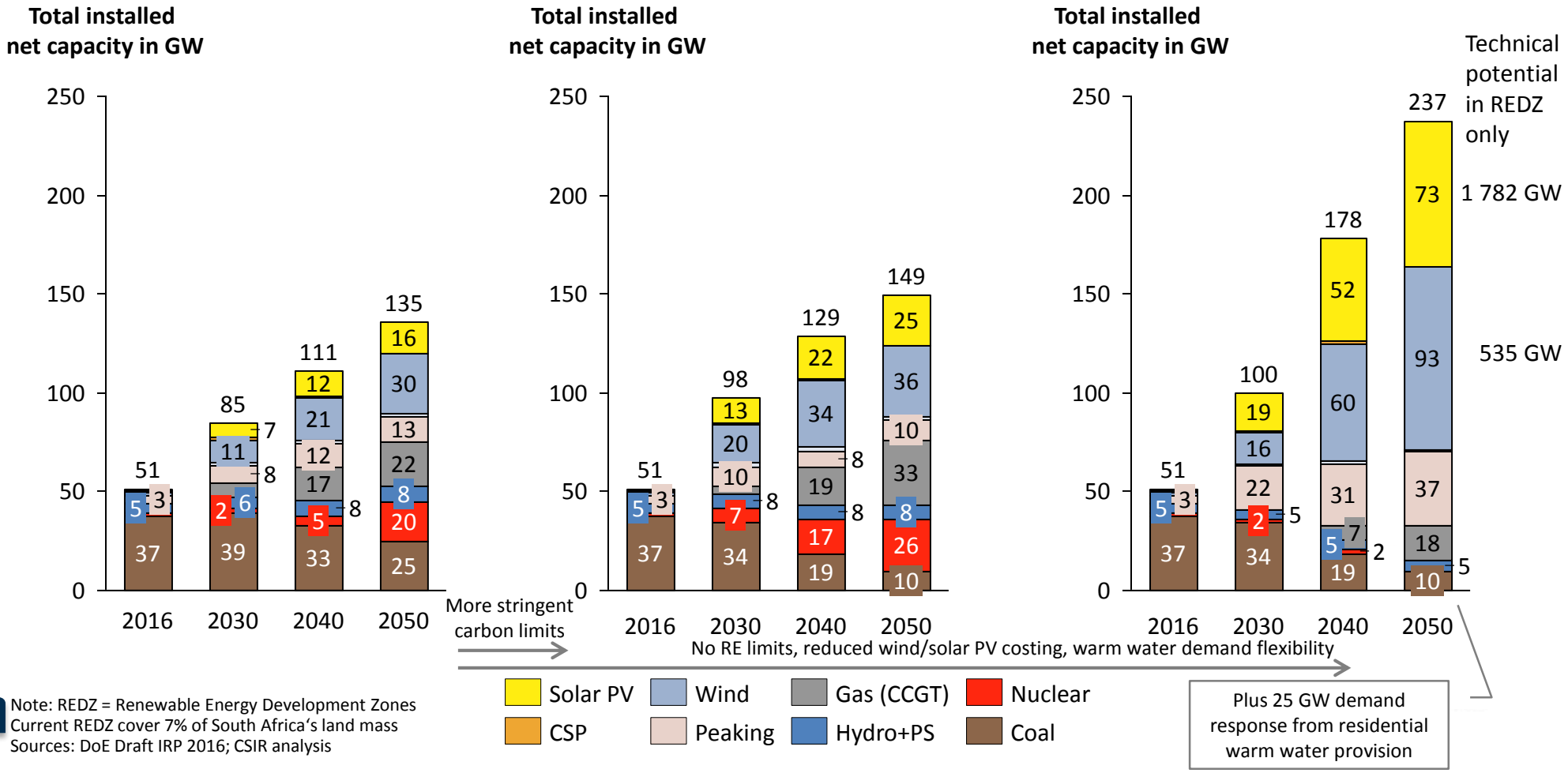
Preliminary results

As per Draft IRP 2016

Draft IRP 2016 Base Case

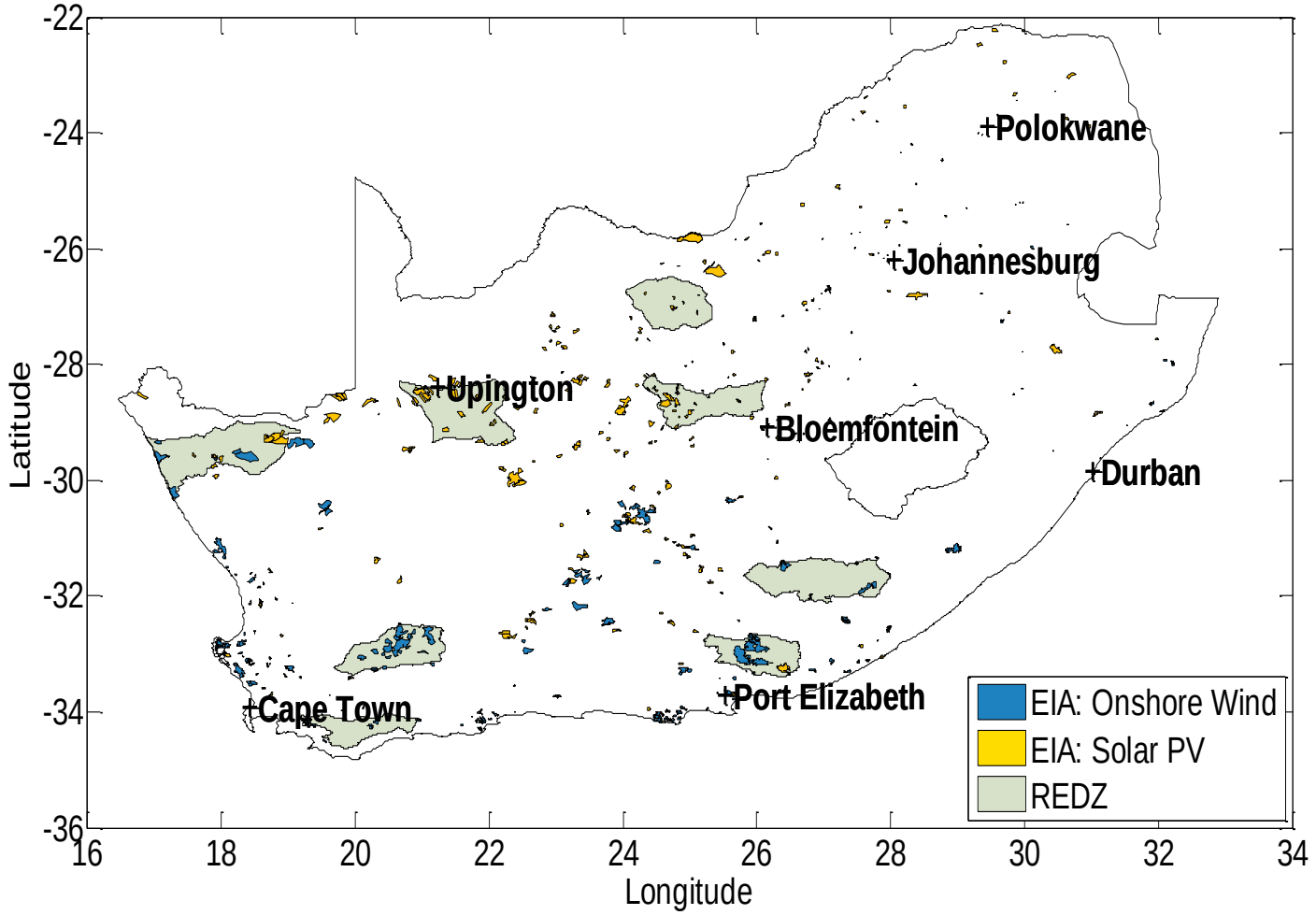
Draft IRP 2016 Carbon Budget

Least Cost



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

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

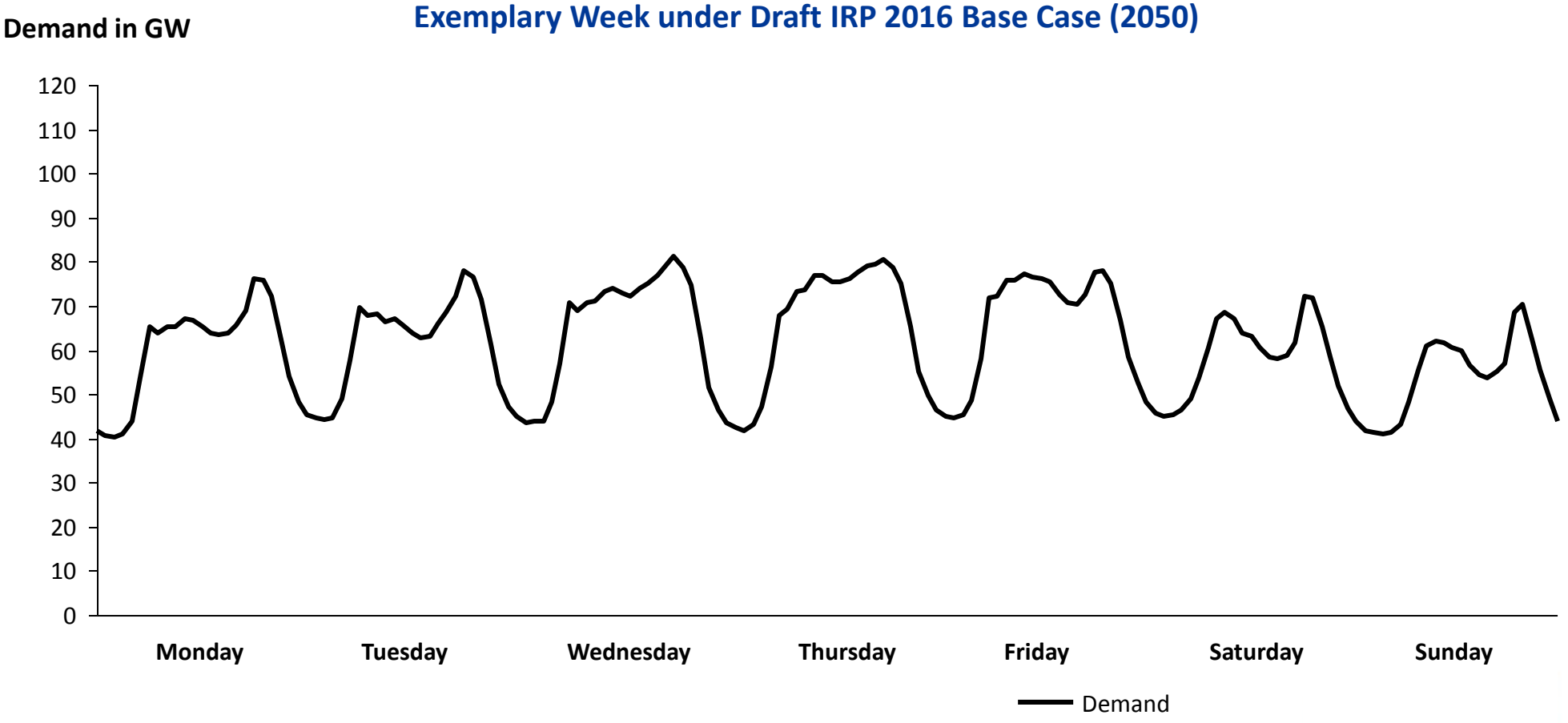
All REDZ
(phase 1)

Wind: 535 GW
Solar PV: 1 782 GW

CSIR
our future through science

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

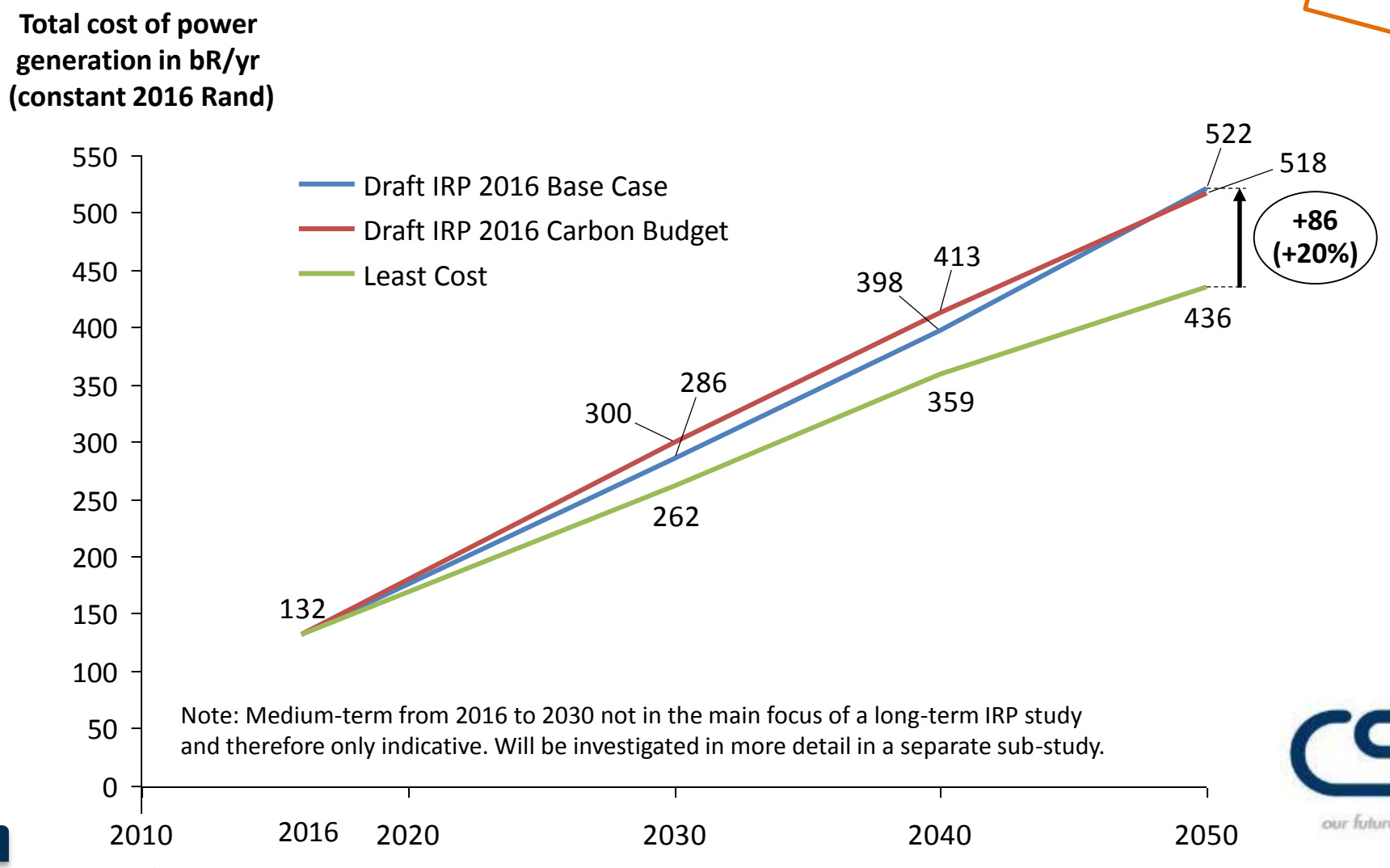
Draft IRP 2016 Base Case: Weekly electricity demand profile in 2050



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

Total cost of power generation: Draft IRP 2016 Base Case R86 bn/year more expensive by 2050 than Least Cost (without cost of CO_2)

Preliminary results



Sources: CSIR analysis

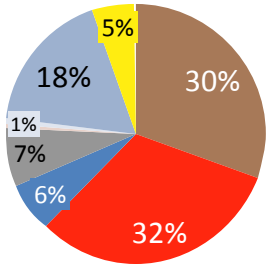
Least Cost without renewables limits is R82-86 billion/yr cheaper by 2050 than IRP 2016 Base Case and IRP 2016 Carbon Budget case

Preliminary results for the year 2050

As per Draft IRP 2016

Draft IRP 2016 Base Case

~525 TWh/yr



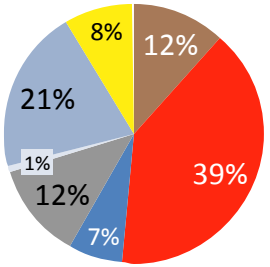
R522 billion/yr
Ø tariff = 1.29 R/kWh

200 Mt/yr

38 bn l/yr

Draft IRP 2016 Carbon Budget

~525 TWh/yr



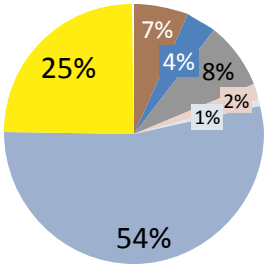
R518 billion/yr
Ø tariff = 1.29 R/kWh

100 Mt/yr

16 bn l/yr

Least Cost

~525 TWh/yr



R436 billion/yr
Ø tariff = 1.13 R/kWh

70 Mt/yr

9 bn l/yr

Coal | Nuclear | Hydro + Pumped Storage | Gas (CCGT) | Peaking | Other | Wind | CSP | Solar PV

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

Background

CSIR's Approach and Project Team

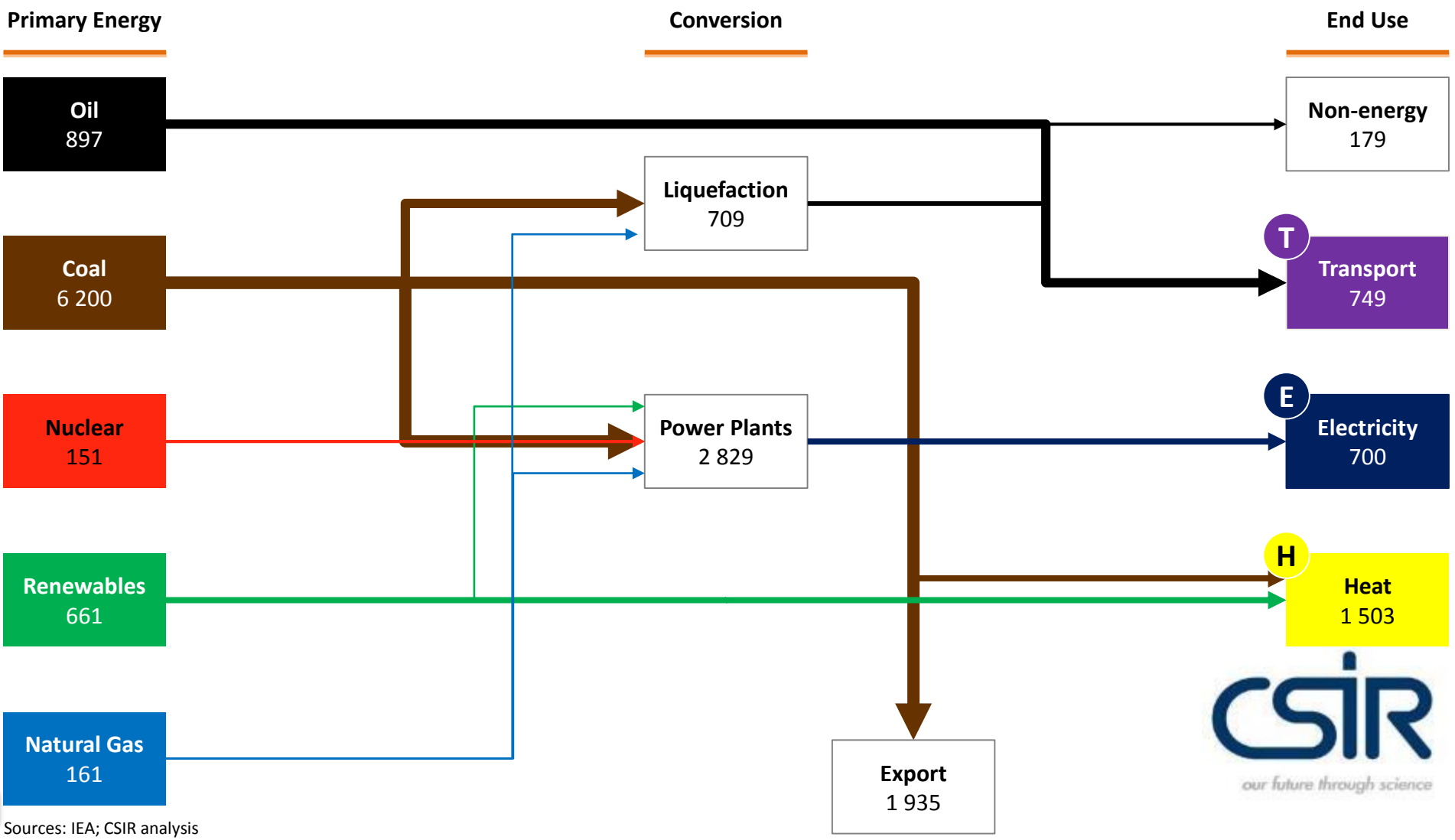
Comments on IRP Assumptions

IRP Results and Least-cost Scenario

Energy Sector Implications

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

Today, very little sector coupling – electricity relatively easy to de-carbonise, but transport and heat sector more challenging

	Primarily supplied by	Decarbonisation potential
E Electricity	Coal	Very high RE potential RE fully cost competitive
T Transport	Oil	Liquid biofuels limited potential Needs coupling to electricity
H Heat	Coal/biomass Electricity	Biomass limited potential Needs coupling to electricity

CSIR
our future through science

Workhorses of the future energy system: solar PV and wind

Solar PV and wind are the cheapest bulk energy providers

Their technical potential can be considered unlimited, especially in a large country like South Africa

our future through science

Additional renewable electricity sources in South Africa

Biogas from

- Municipal solid waste
- Waste water
- Agricultural waste
- Animal waste
- Energy crops

→ additionally: source of CO2

Other forms of biomass

Hydro

CSP (Concentrated Solar Power)

Power-to-Power storage

- Pumped hydro
- Battery storage

CSIR
our future through science

Transport sector consists of a number of sub-sectors

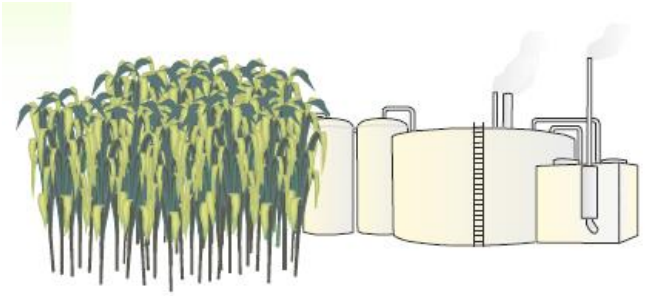
Ground transportation of people

Ground transportation of goods

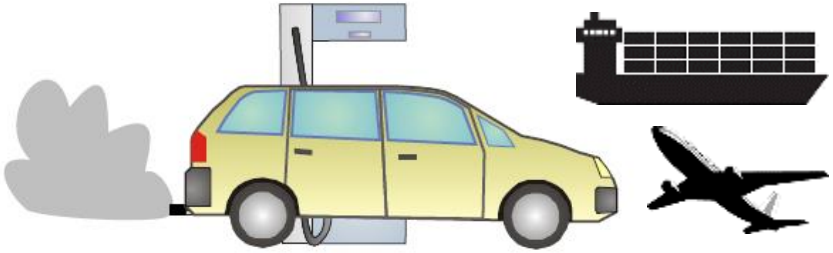
Aviation

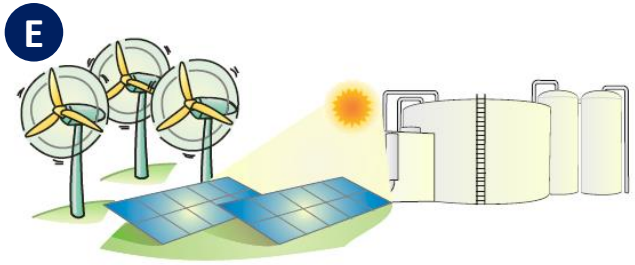
Shipping

In-principle options to decarbonise transportation

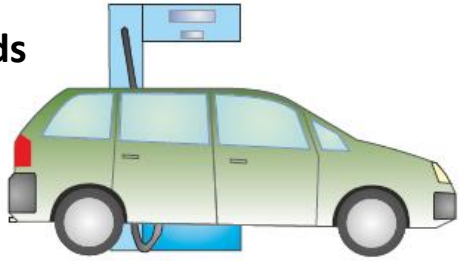


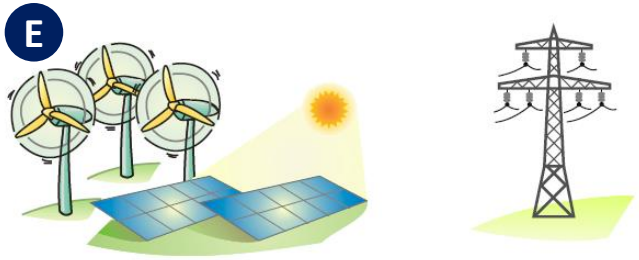
Liquid biofuels
- Biodiesel
- Bioethanol
- Biogas



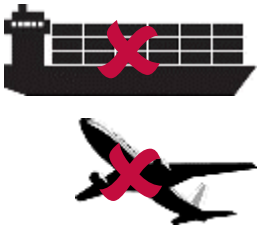


Power-to-Gas/-Liquids
- H2
- Methane
- Methanol
- Other liquid fuels





Power-to-eMobility
- Electricity

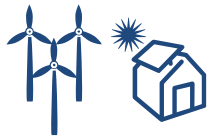


Sources: https://sh-gruene-partei.de/sites/sh-gruene-partei.de/files/2016-05-20_gruenstrom-enge-sande_quaschning.pdf

Hydrogen or hydro-carbons can be produced from RE electricity

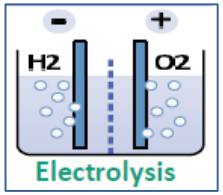
Inputs	Electrolysis	Fuel Production	Outputs

Renewable electricity



H2O

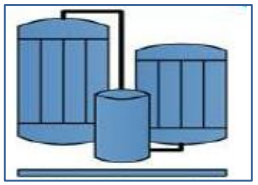
CO2



H2

H2

CO2



H2

Methane
Methanol
Other liquid fuels

CSIR
our future through science

Sources: CSIR Energy Centre analysis

Power-to-eMobility: battery driven for urban areas and highway overhead lines for long-distance transport of goods

Electrification of passenger transport

"Around the corner" (2020s will see large global uptake)

Electrification of transport of goods

Pilot projects

Space heating/cooling and warm water largely electrified already in RSA, industrial process heat to be converted from coal to electricity

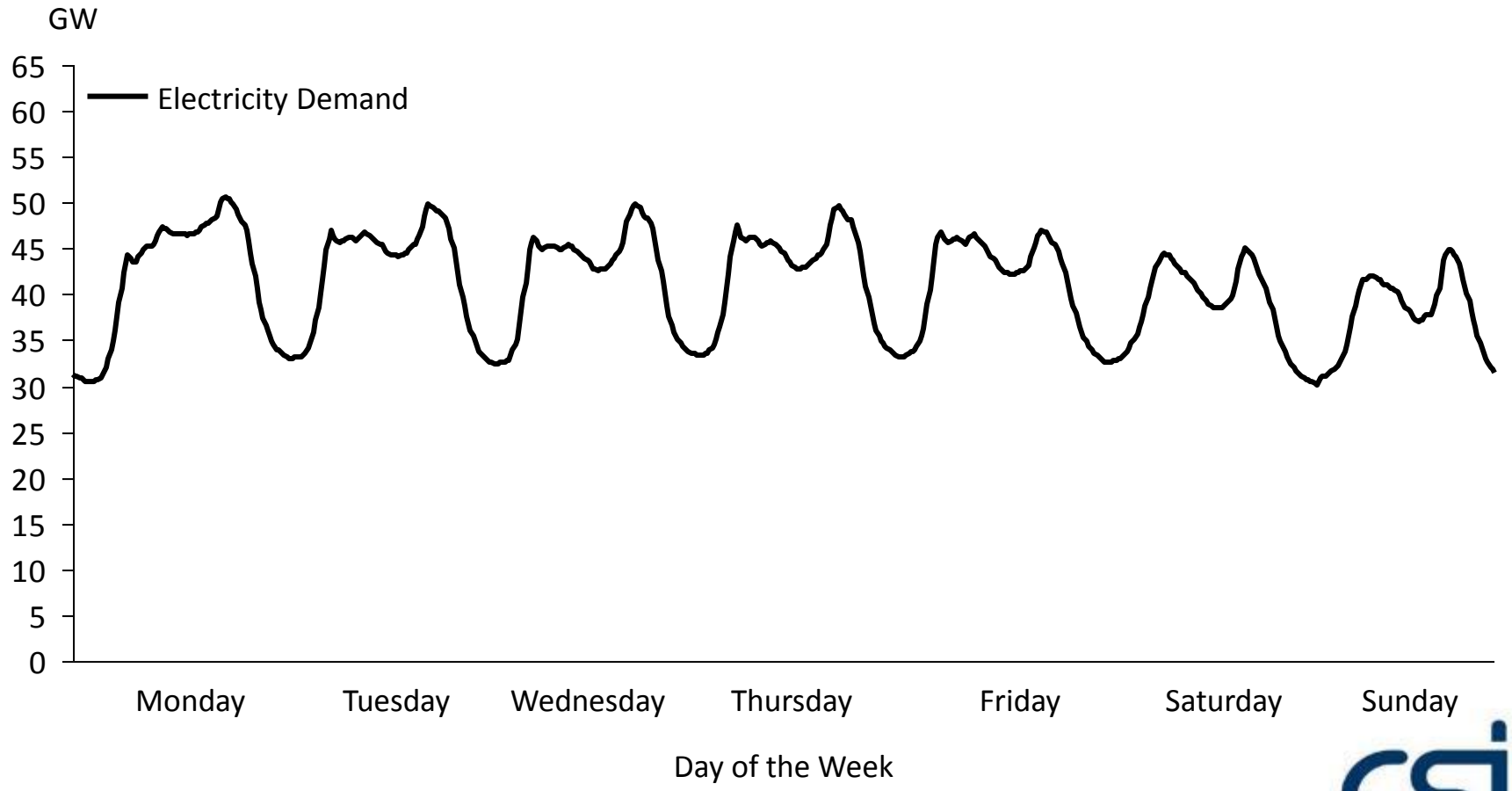
H

Space heating/cooling

Industrial process heat

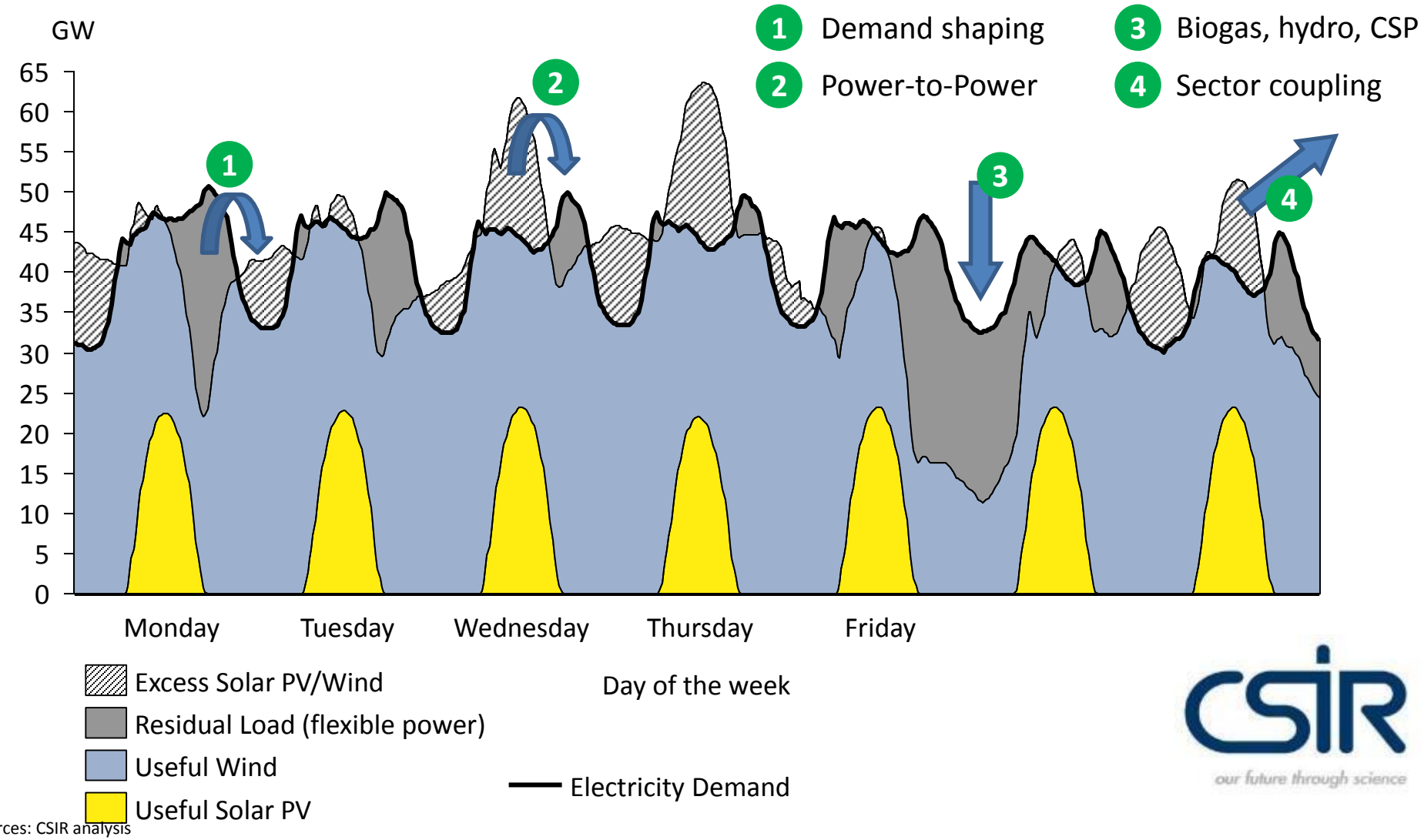
Warm water

E Electricity demand during a typical week



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

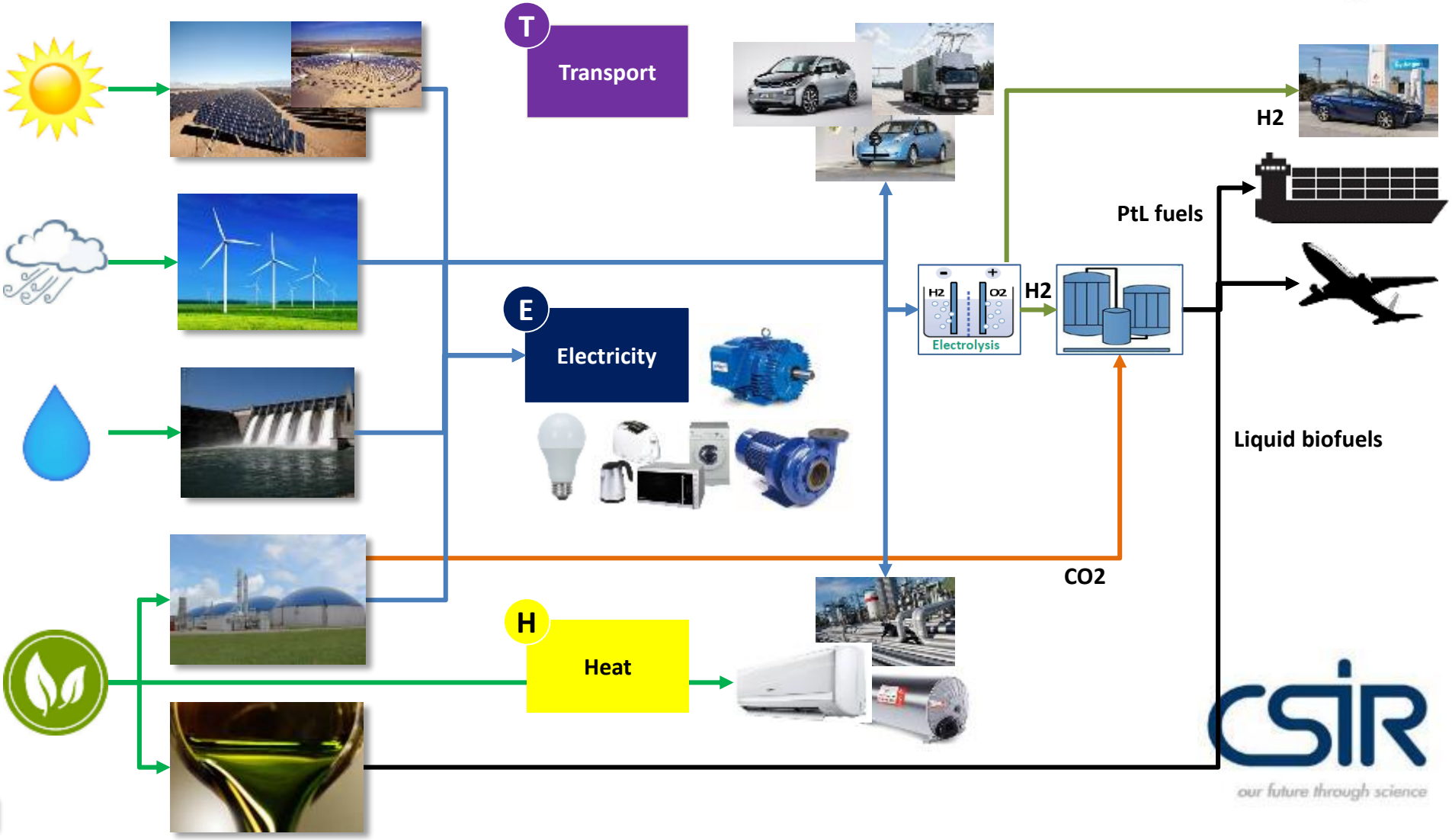
Actual scaled RSA demand & simulated 15-minute solar PV/wind power supply for week from 15-21 Aug '11



Sources: CSIR analysis

High Renewables: energy in RSA mostly from domestic renewables

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



100% of South Africa's energy needs could be supplied by renewables

Sector coupling (electricity, transport, heat) is an essential factor for cost-efficient High Renewables

Electricity will be the new primary energy source, with the bulk of the kWh coming from solar PV and wind

- Biomass will supply up to its economical potential 1) heat, 2) liquid biofuels and 3) biogas (CHP)
- Other flexible sources of electricity can complement variability from solar PV and wind (e.g. CSP, hydro)

All residual demand will be electrified

- All heat demand not met by burning biomass or CHP from biogas will be electrified (flexible demand)
- Whatever transport demand that can be electrified will be electrified
- Residual transport demand (aviation, trucks, sea shipping) will be supplied by biofuels/Power-to-Liquid
- In addition to heat (CHP), biogas will be a source of highly flexible electricity and of CO2 (for P-t-L)

With abundant, very cheap clean electricity, new demand in South Africa might be created

- Seawater desalination (new flexible pumping load) to address water shortage in RSA
- Export of CO2-neutral liquid fuels to less solar- and wind-endowed countries (e.g. EU)

CSIR
our future through science

Abundant wind/solar can make South Africa global leader in cost-competitive renewables energy systems

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