The Importance of High Fidelity Data for a New Paradigm of Power Sector Planning

Presentation at “Planning for 21st Century Power Systems”

Dr Tobias Bischof-Niemz, CSIR Energy Centre Manager

Midrand, 21 April 2016

Cell: +27 83 403 1108
Email: TBischofNiemz@csir.co.za

our future through science

Dr Tobias Bischof-Niemz
Head of CSIR's Energy Centre

Professional Experience

- Member of the Ministerial Advisory Council on Energy (MACE)
- Extraordinary Associate Professor at Stellenbosch University
- Jul 2014 – today: Centre Manager at the CSIR, responsible to lead the establishment of an integrated energy research centre
- 2012 – 2014: PV/Renewables Specialist at Eskom in the team that developed the IRP; afterwards 2 months contract work in the DoE's IPP Unit on gas, coal IPP and rooftop PV
- 2007 – 2012: Senior consultant (energy system and renewables expert) at The Boston Consulting Group, Berlin and Frankfurt, Germany

Education

- Master of Public Administration (MPA) on energy and renewables policies in 2009 from Columbia University in New York City, USA
- PhD ("Dr.-Ing.") in 2006 in Automotive Engineering from TU Darmstadt, Germany
- Mechanical Engineering at Technical University of Darmstadt, Germany (Master – "Dipl.-Ing." in 2003) and at UC Berkeley, USA

Agenda

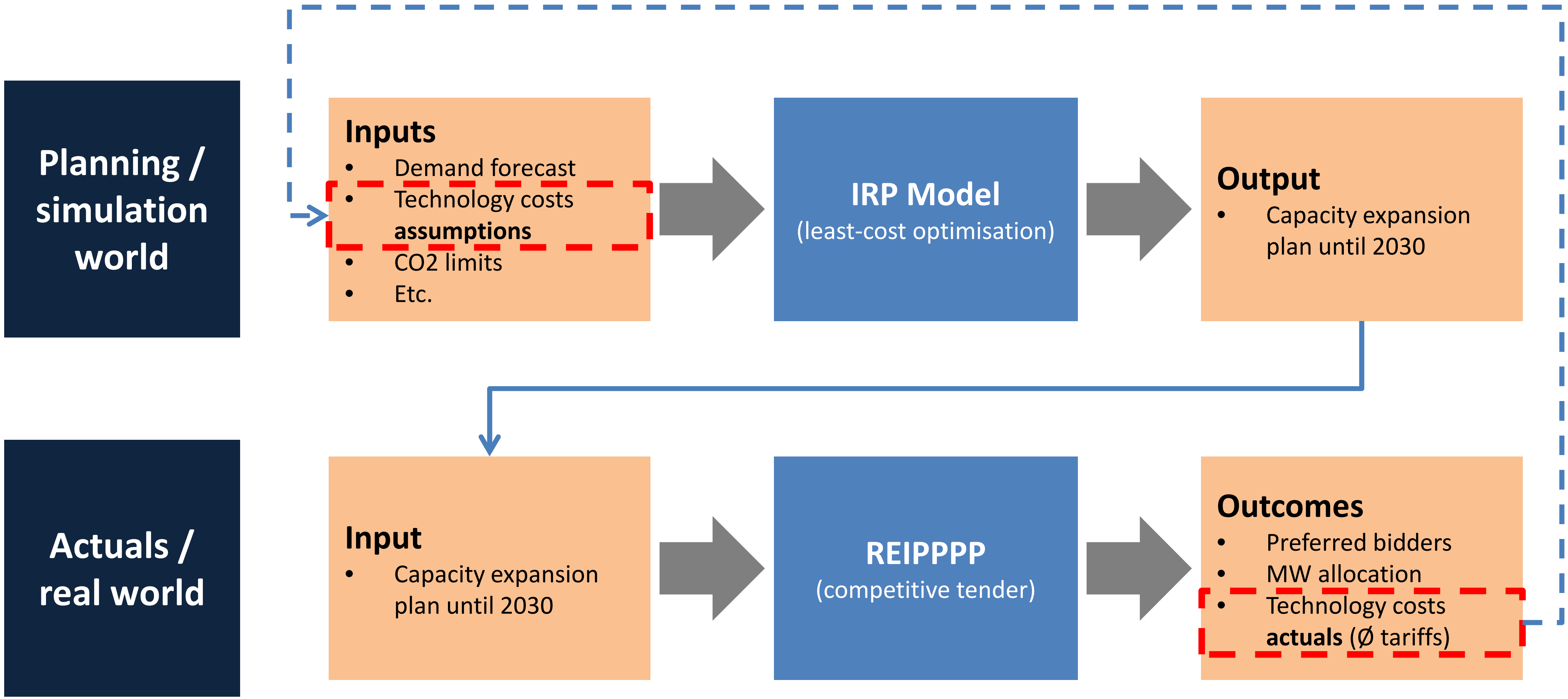
Renewables in South Africa

Wind potential in South Africa

Extreme renewables scenarios

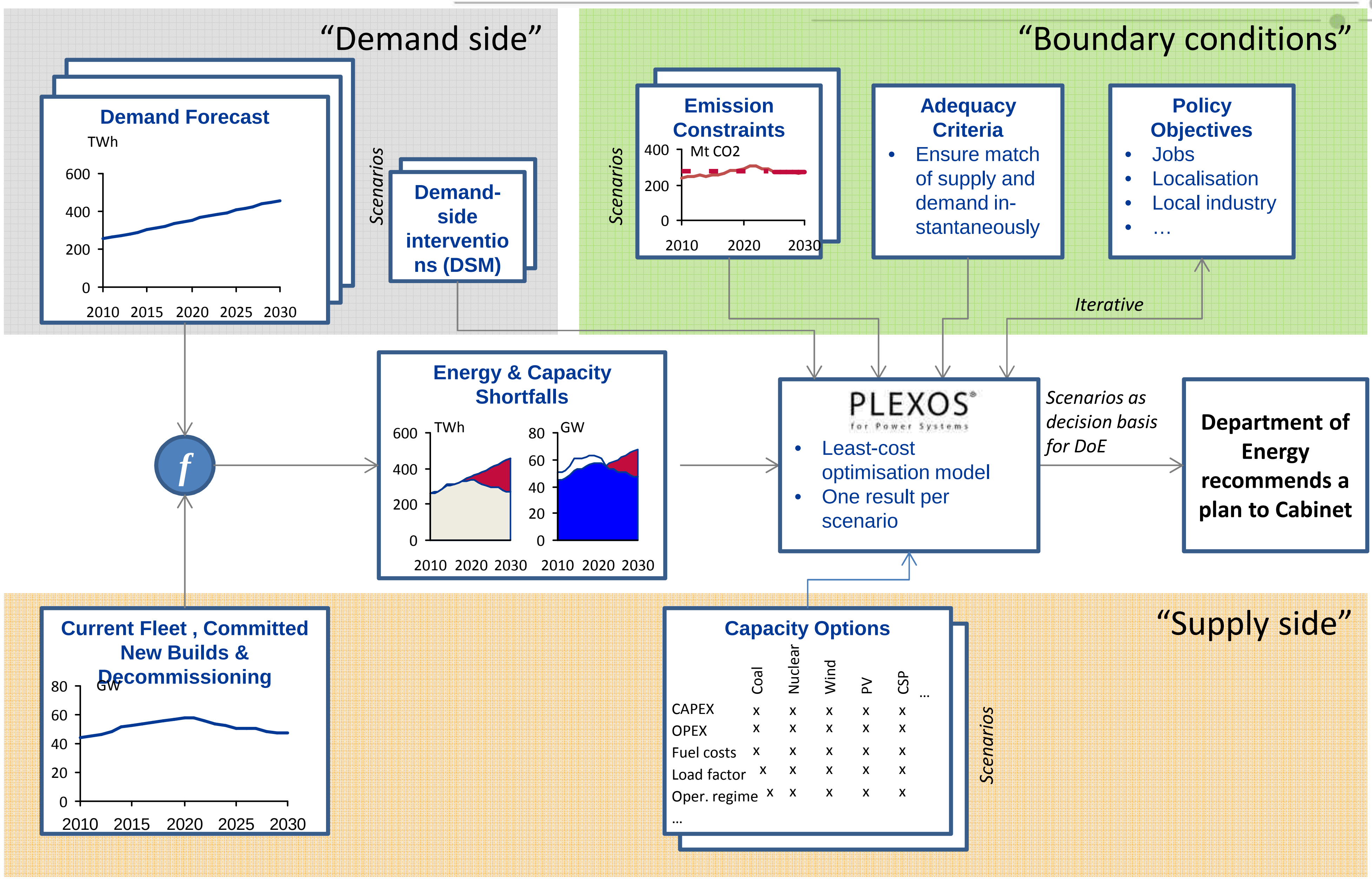
our future through science

In-principle process of IRP planning and implementation



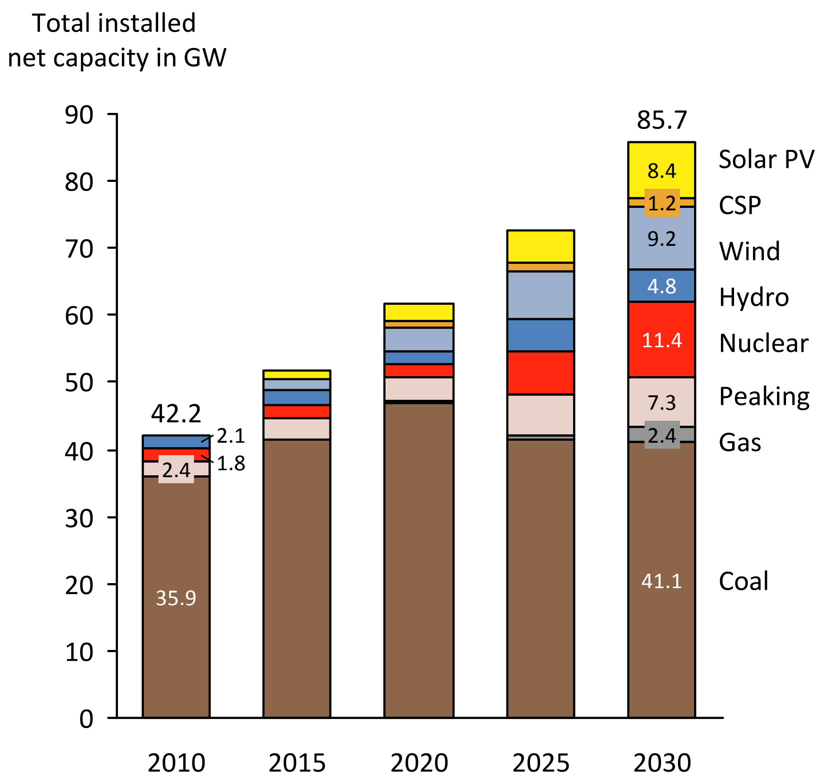
Sources: CSIR Energy Centre analysis

The Integrated Resource Plan tries to balance different objectives through detailed scenario analyses

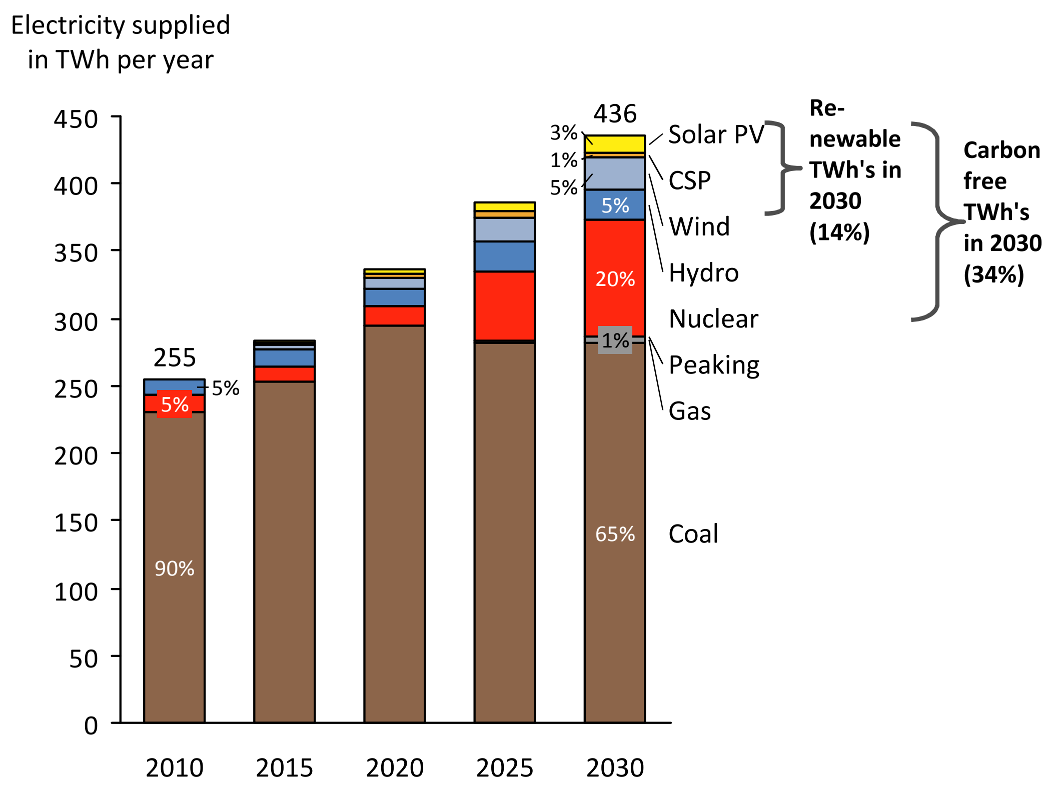


Integrated Resource Plan 2010 (IRP 2010): Plan of the power generation mix for South Africa until 2030

Installed capacity



Energy mix



Share new renewables **0%** → **9%**

Implementation of the IRP is done by Department of Energy through competitive tenders ("REIPPPP" for renewables)

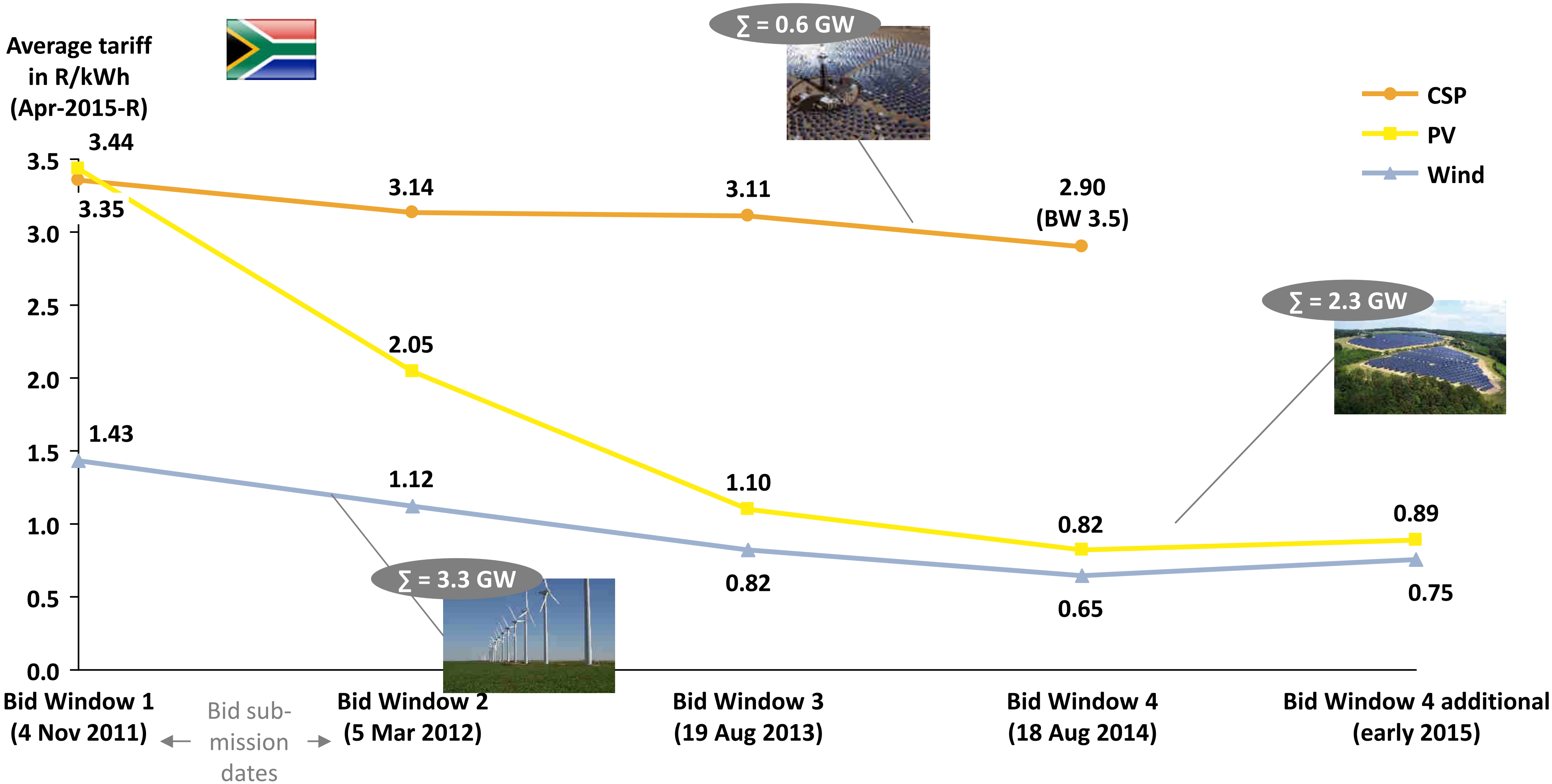
CSIR
our future through science

Note: hydro includes imports from Cahora Bassa

Sources: Integrated Resource Plan 2010, as promulgated in 2011; CSIR Energy Centre analysis

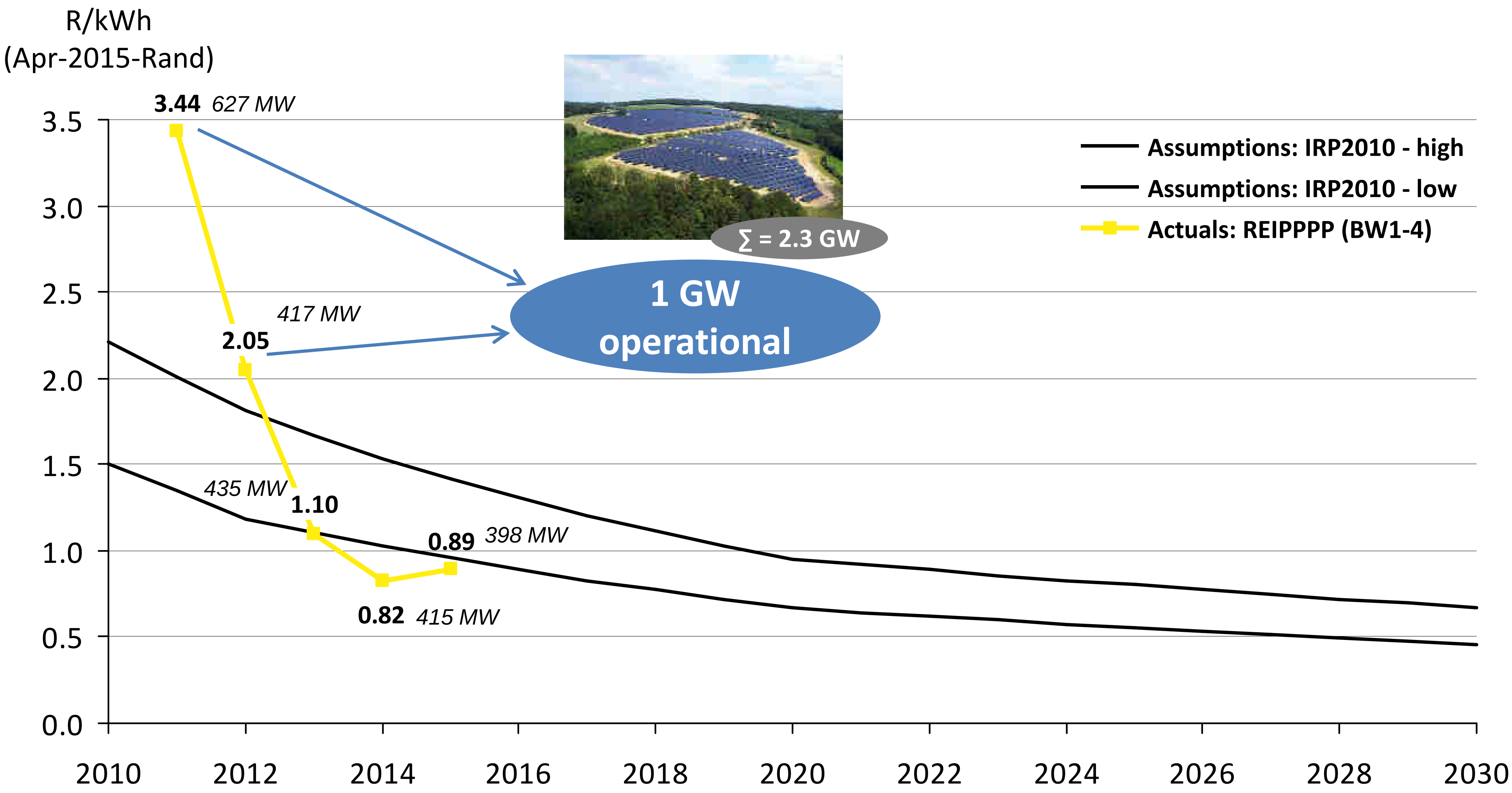
Actual results: new wind/PV projects much cheaper than the first ones

First four bidding windows' results of Department of Energy's RE IPP Procurement Programme (REIPPPP)



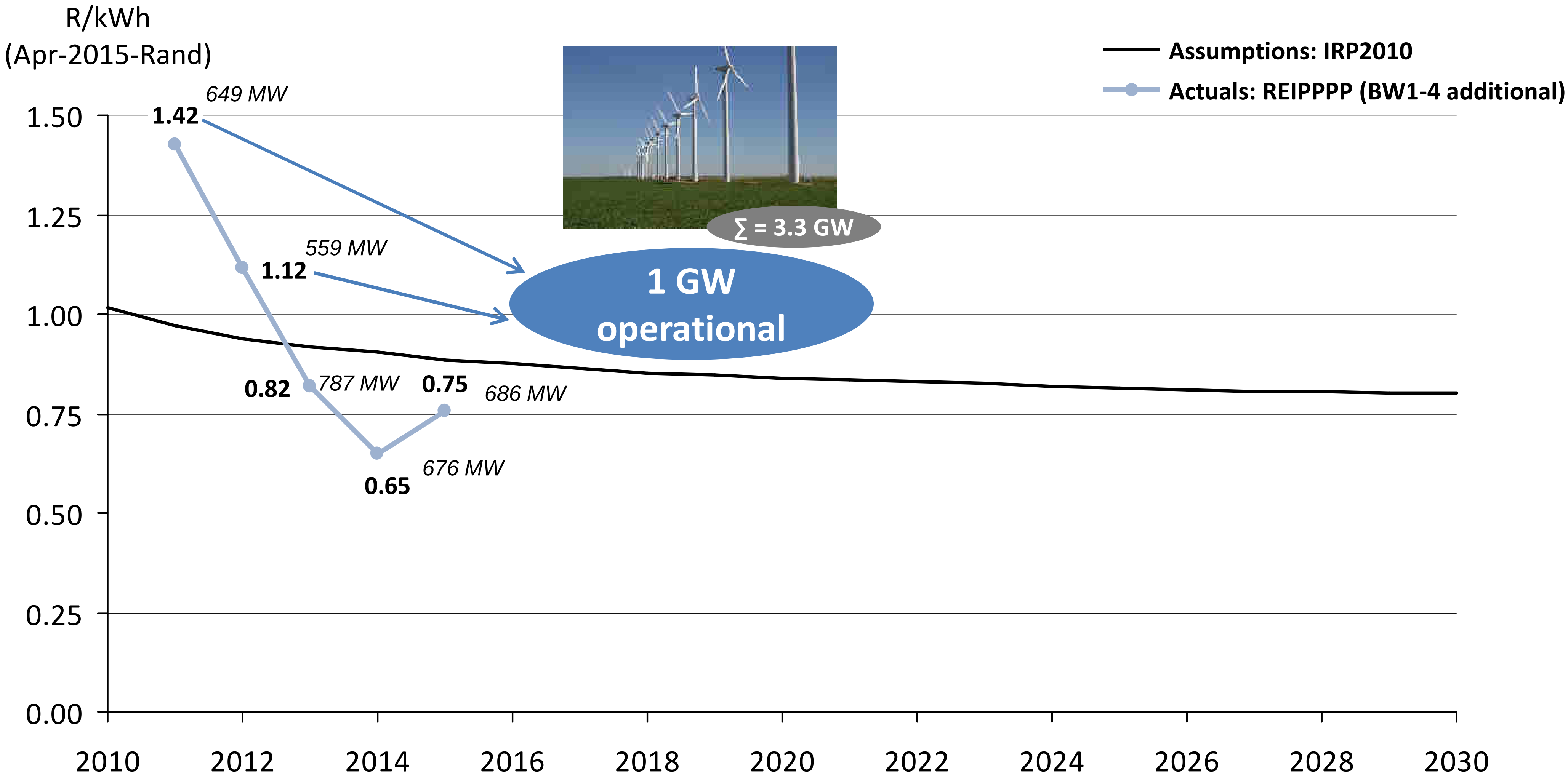
Notes: For CSP Bid Window 3 and 3.5, the weighted average of base and peak tariff is indicated, assuming 50% annual load factor; BW = Bid Window; Sources: Department of Energy's publications on results of first four bidding windows http://www.energy.gov.za/IPP/List-of-IPP-Preferred-Bidders-Window-three-04Nov2013.pdf; http://www.energy.gov.za/IPP/Renewables_IPP_ProcurementProgram_WindowTwoAnnouncement_21May2012.pptx; http://www.ipprenewables.co.za/gong/widget/file/download/id/279; StatsSA on CPI; CSIR analysis

Actual solar PV tariffs quickly approached IRP cost assumptions in first four bid windows & are now below the lowest cost assumptions of IRP



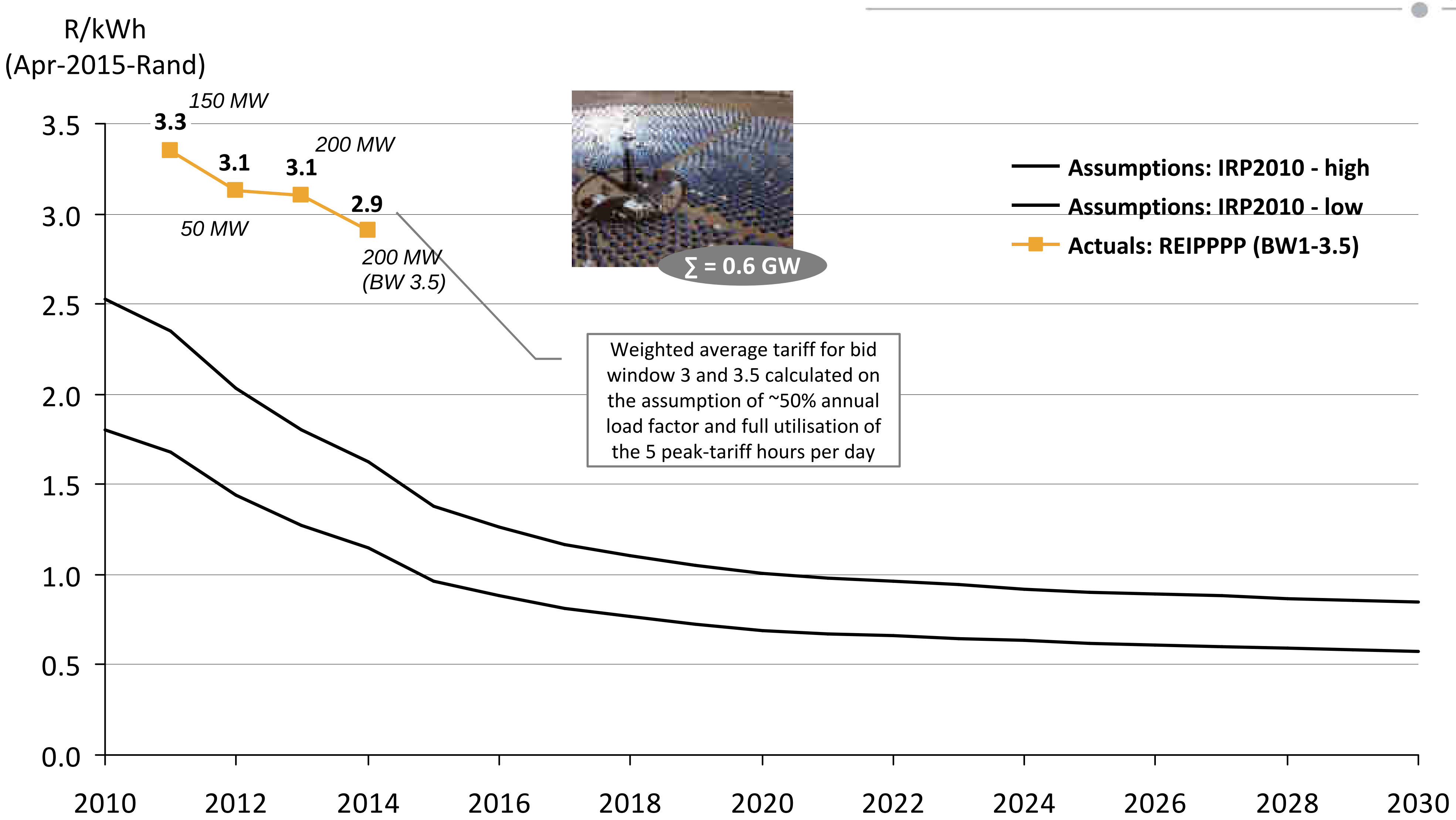
Assumptions: CPI used for normalisation to May-2015-Rand; LCOE calculated for IRP with 8% discount rate (real), 25 yrs lifetime, cost and load factor assumptions as per relevant IRP document; "IRP Tariff" then calculated assuming 80% of total project costs to be EPC costs, i.e. divide the LCOE by 0.8 to derive at the "IRP Tariff"
Sources: IRP 2010; IRP Update; http://www.ipprenewables.co.za/gong/widget/file/download/id/279; CSIR analysis

Actual wind tariffs in bid window three were already at the level that was assumed for 2030 in the IRP, bid window four is significantly below



Assumptions: CPI used for normalisation to May-2015-Rand; LCOE calculated for IRP with 8% discount rate (real), 20 yrs lifetime, cost and load factor assumptions as per relevant IRP document; "IRP Tariff" then calculated assuming 80% of total project costs to be EPC costs, i.e. divide the LCOE by 0.8 to derive at the "IRP Tariff"
Sources: IRP 2010; IRP Update; http://www.ipprenewables.co.za/gong/widget/file/download/id/279; CSIR analysis

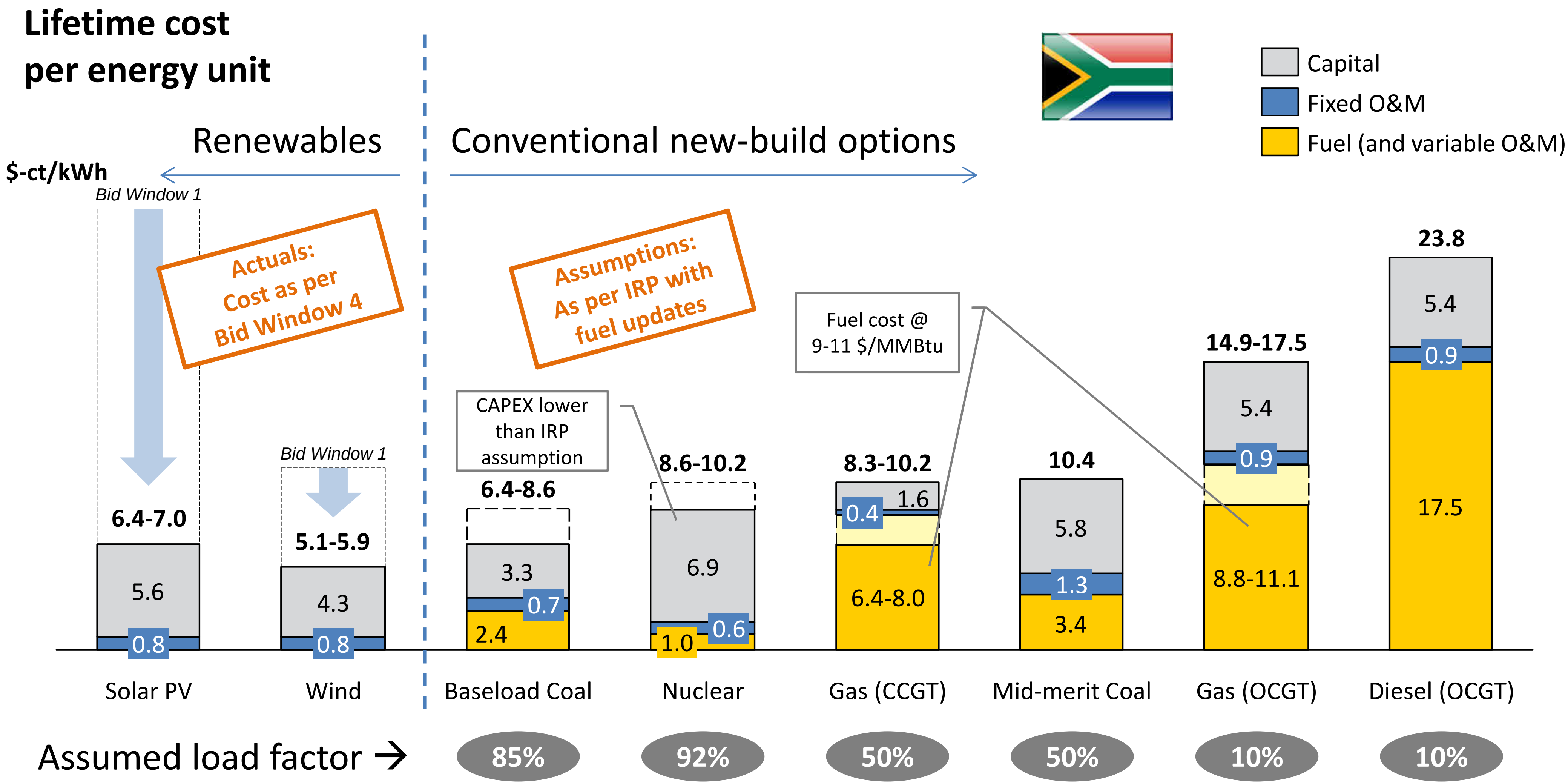
Actual CSP tariffs are declining from bid window one to 3.5, but still well above IRP cost assumptions



Assumptions: CPI used for normalisation to May-2015-Rand; LCOE calculated for IRP with 8% discount rate (real), 30 yrs lifetime, cost and load factor assumptions as per relevant IRP document; “IRP Tariff” then calculated assuming 80% of total project costs to be EPC costs, i.e. divide the LCOE by 0.8 to derive at the “IRP Tariff”

Sources: IRP 2010; IRP Update; http://www.energy.gov.za/IPP/List-of-IPP-Preferred-Bidders-Window-three-04Nov2013.pdf; CSIR analysis

Consequence of renewables' cost reduction for South Africa: Solar PV and wind are the cheapest new-build options per kWh today



Note: Changing full-load hours for conventionals drastically changes the fixed cost components per kWh (lower full-load hours → higher capital costs and fixed O&M costs per MWh); Assumptions: average efficiency for CCGT = 50%, OCGT = 35%; coal = 37%; nuclear = 33%; IRP cost from Jan 2012 escalated with CPI to Jan 2016; assumed EPC CAPEX inflated by 10% to convert EPC/LCOE into tariff; ZAR/USD = 12.8 (2015 average); Sources: IRP Update; REIPPPP outcomes; StatsSA for CPI; Eskom financial reports on coal/diesel fuel cost; CSIR analysis

Agenda

Renewables in South Africa

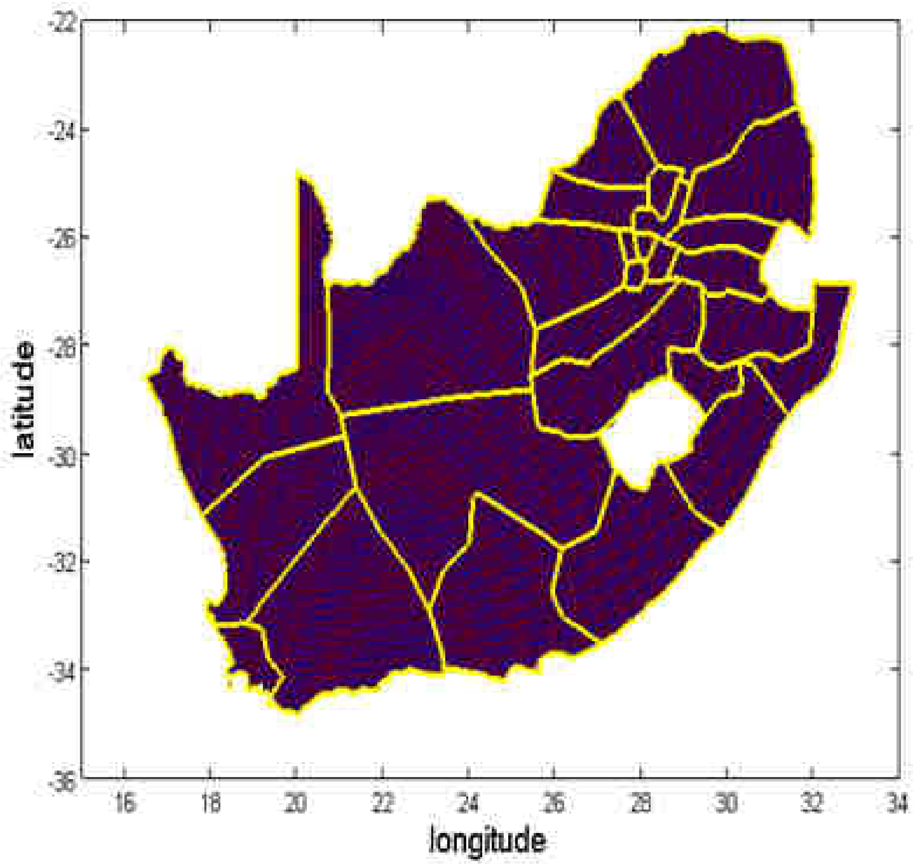
Wind potential in South Africa

Extreme renewables scenarios

our future through science

The so-called WASA model was re-run to cover the entire country

Data sources and characteristics of data used for solar/wind aggregation analysis



Grid squares of the numerical weather model „NWM pixel“

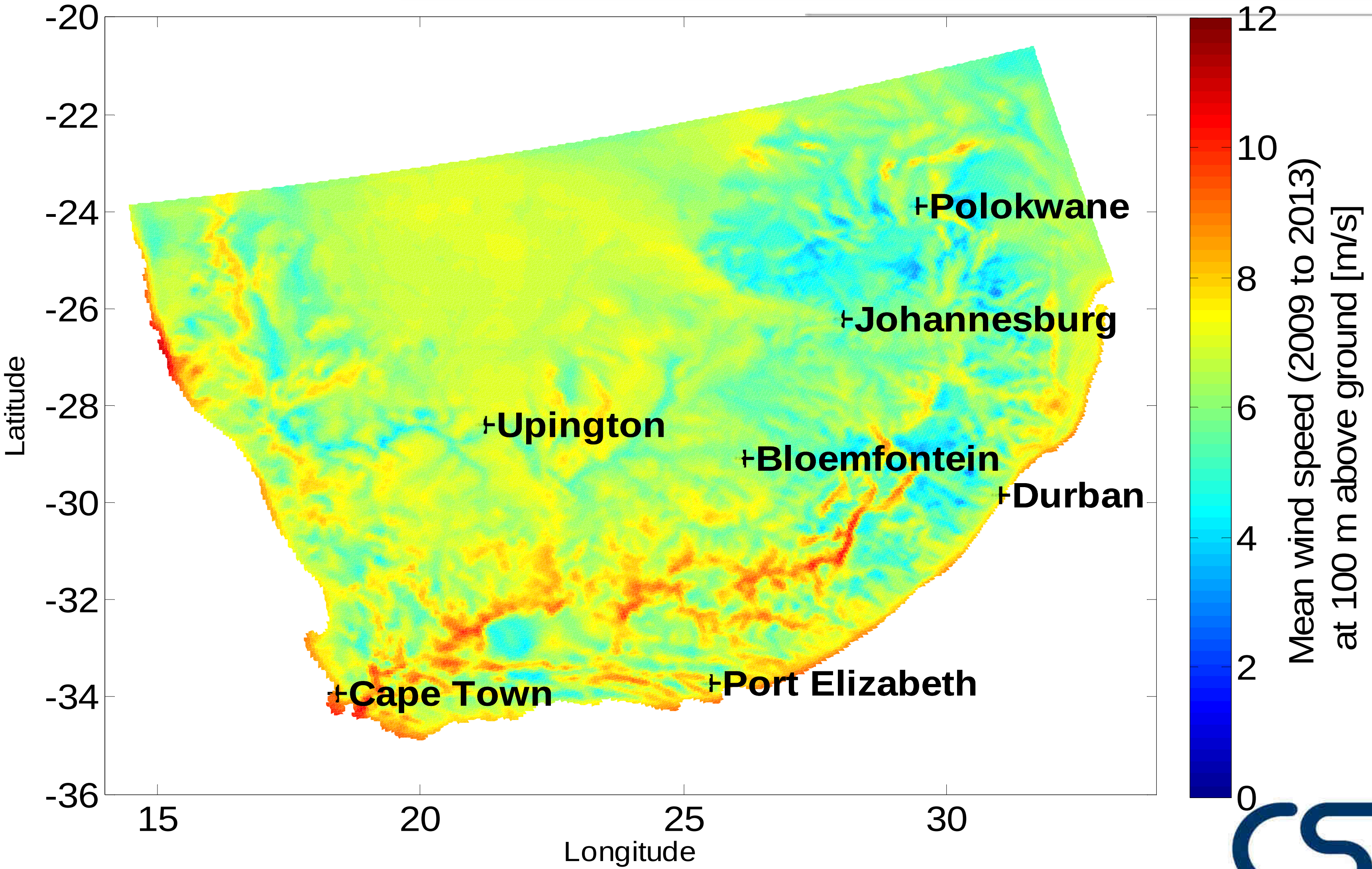
Raw data from →	WASA	SODA
Variables	v, T	I
Height levels [m]	2 (T), 50, 80, 100, 150 (v)	2
Temporal coverage	2009 to 2013	2010 to 2012
Temporal resolution	15 min	15 min
Spatial coverage	South Africa	South Africa
Spatial resolution	5 km x 5 km → 47 522 pixels	0.2° x 0.2° (approx. 5 km x 5 km)

our future through science

Sources: Wind and Solar Aggregation Study, commissioned by the CSIR, SANEDI and Eskom, executed in collaboration with Fraunhofer IWES

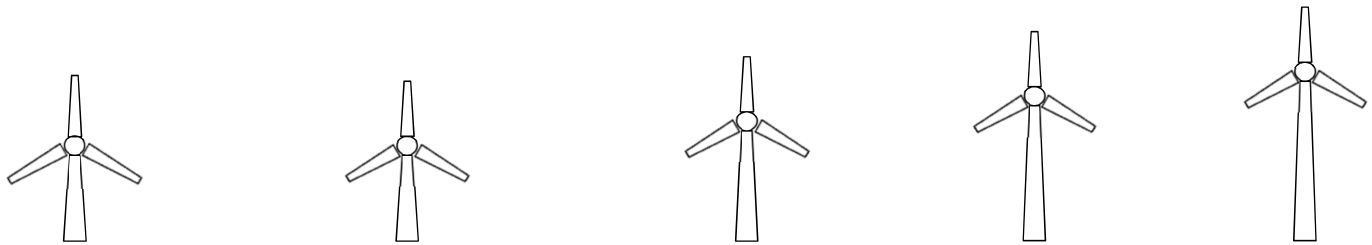
South Africa has wide areas with > 6 m/s average wind speed @ 100 m

Average wind speed at 100 meter above ground for the years from 2009-2013 for South Africa



our future through science

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

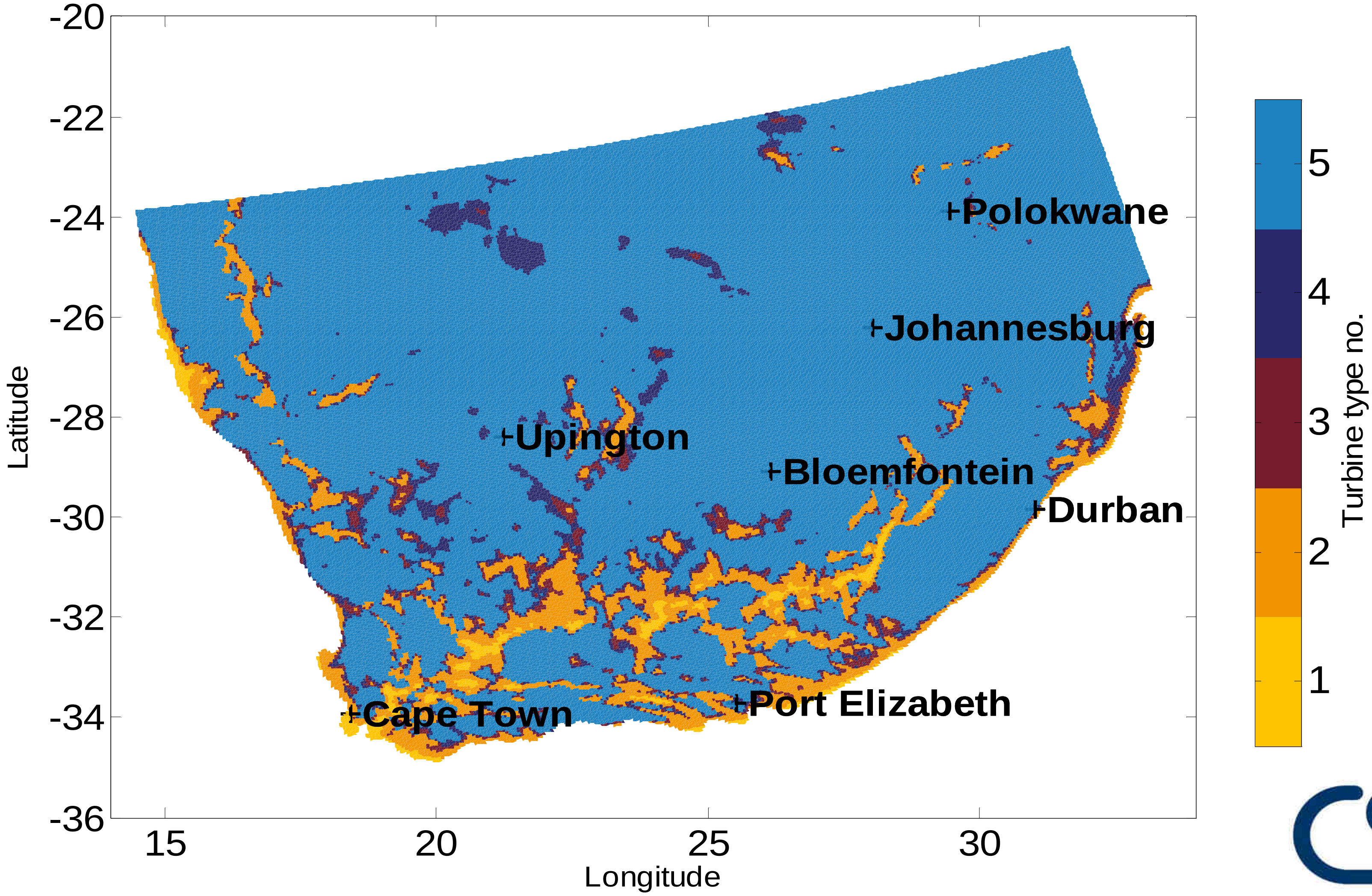


Turbine type no.	1	2	3	4	5
Nominal power [MW]	3	2.2	2.4	2.4	2.4
Selection criterion	$\bar{v}_{80m} > 8.5\frac{m}{s}$	$\bar{v}_{80m} < 8.5\frac{m}{s}$ and $\bar{v}_{100m} > 7.5\frac{m}{s}$	$\bar{v}_{100m} < 7.5\frac{m}{s}$	$\bar{v}_{120m} < 7.5\frac{m}{s}$	$\bar{v}_{140m} < 7.5\frac{m}{s}$
Blade diameter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

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

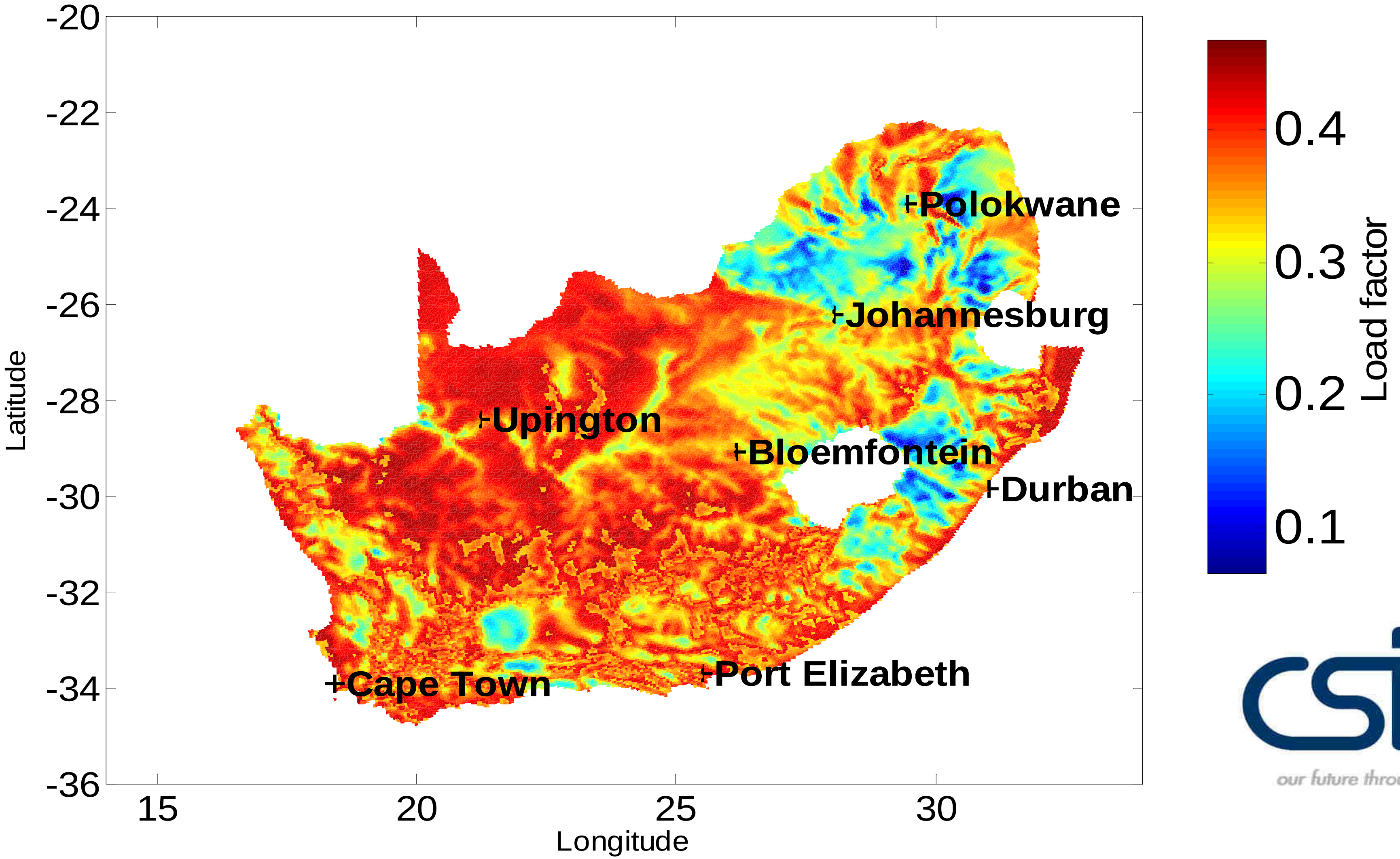
CSIR
our future through science

Turbine types : Distribution according to mean wind speeds



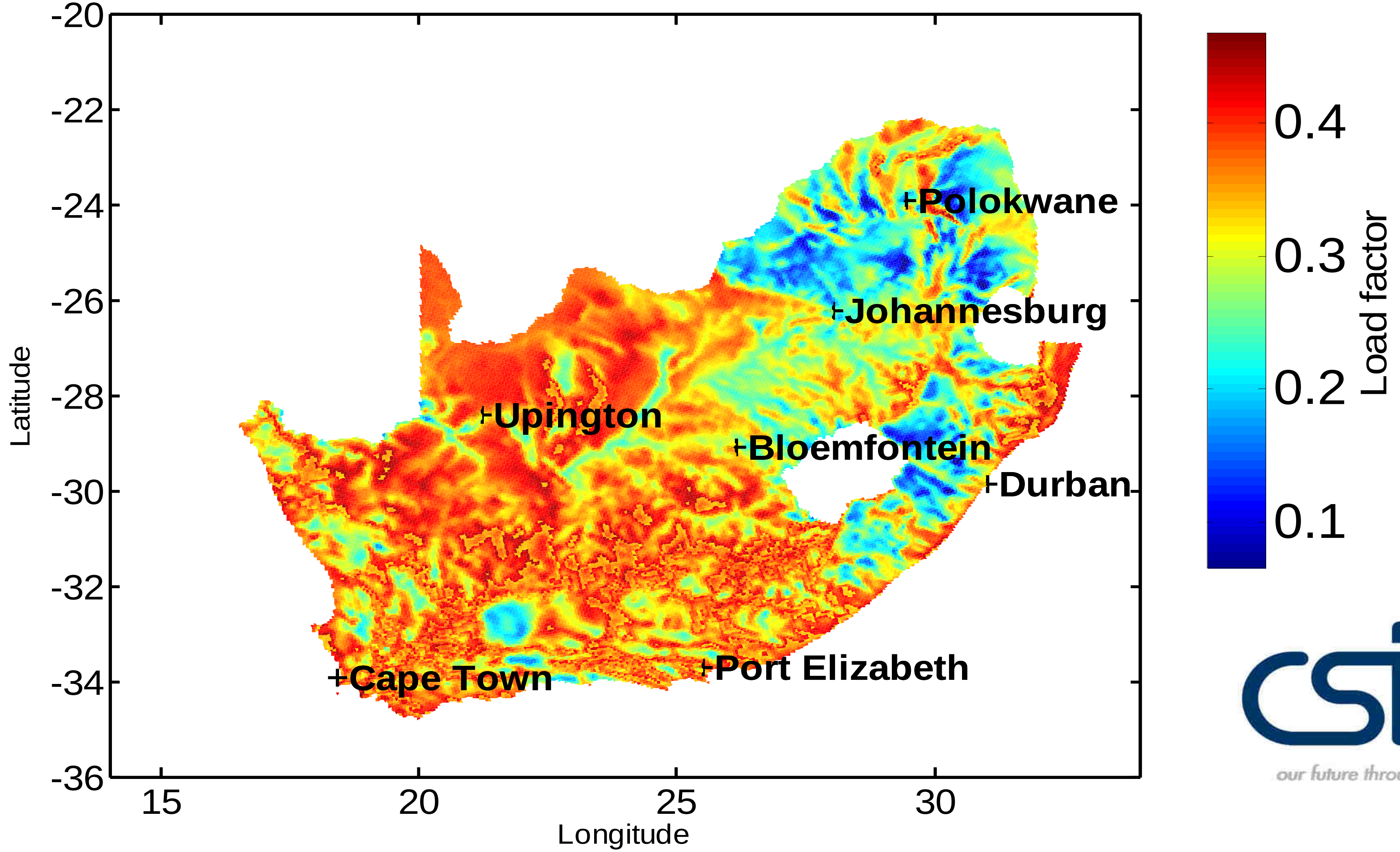
Placing a wind farm of best suited turbine type (1, 2, 3, 4 or 5) in each pixel shows: more than 30% load factor achievable almost everywhere

Map of achievable average load factors for 2009-2013 for turbine types 1-5



Even when placing only high-wind-speed turbine types (1, 2, 3) in each pixel shows: more than 30% load factor achievable in wide areas

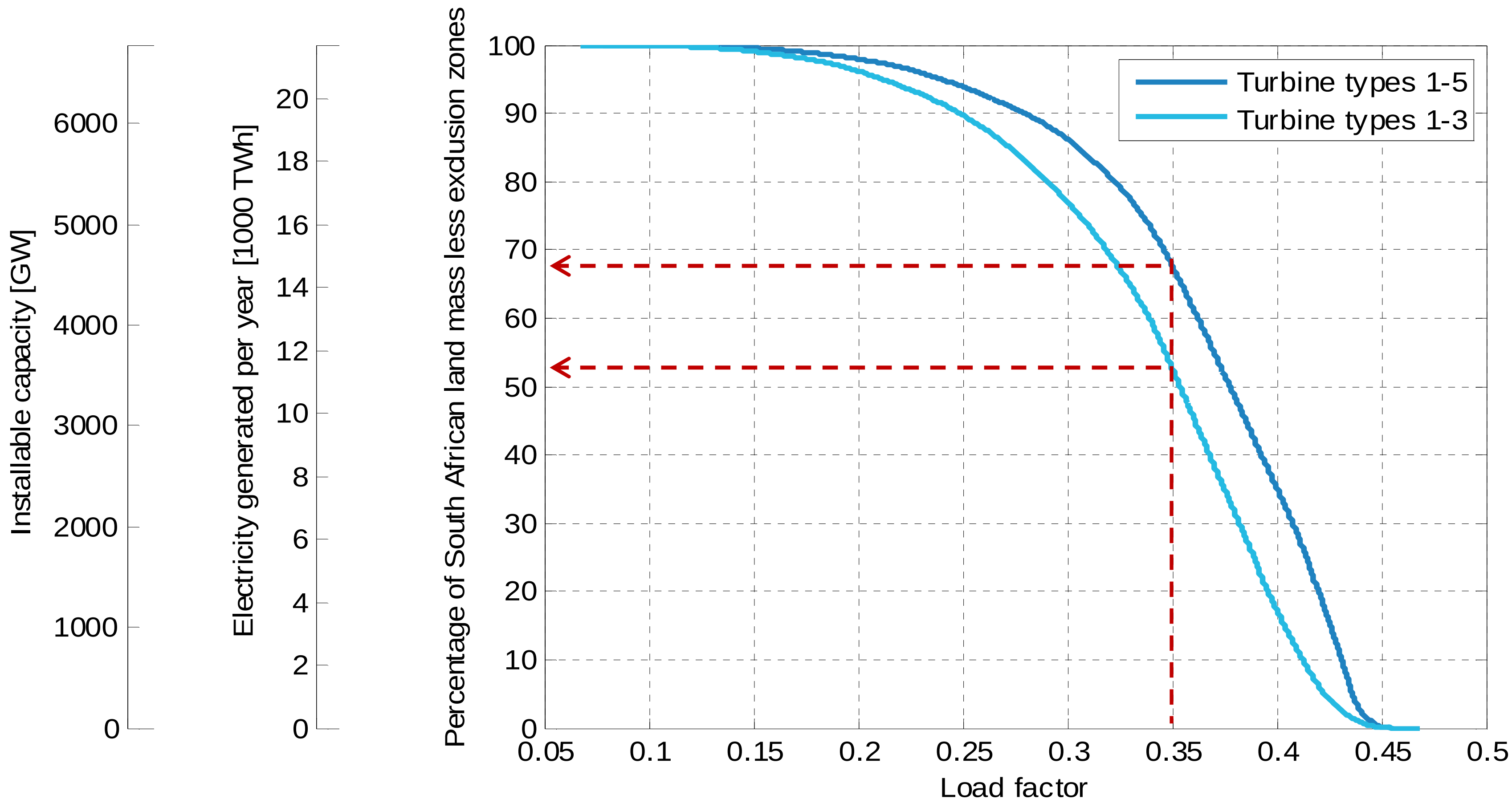
Map of achievable average load factors for 2009-2013 for turbine types 1-3



our future through science

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

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

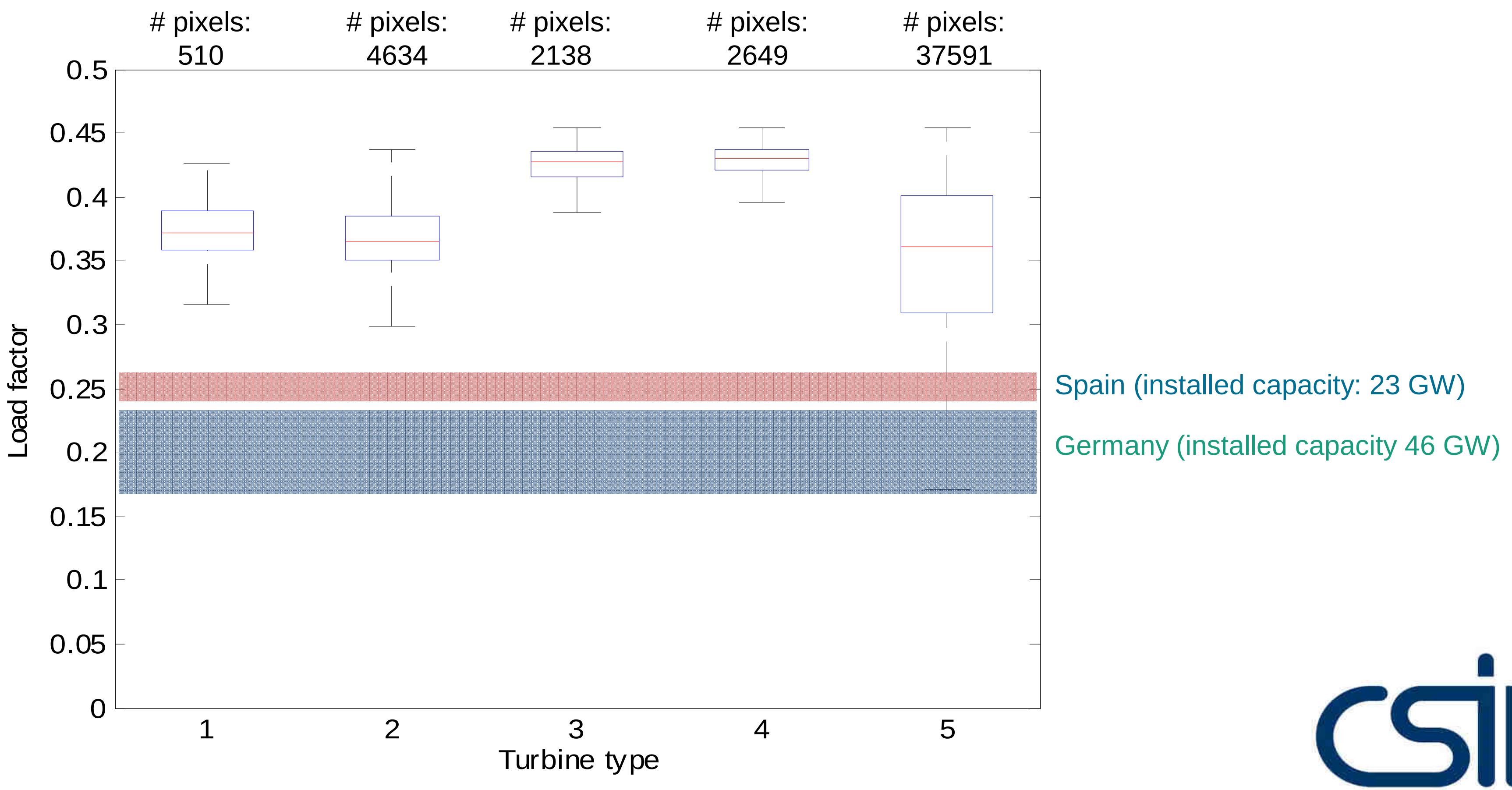


→ Installing turbine type 4 and 5 will cause higher costs but also increase load factors and electricity yield whilst consuming the same area

our future through science

Achievable load factors in all turbine categories significantly higher than in leading wind countries

Achievable load factor distribution per pixel per turbine type



Methodology to derive relative LCOE per pixel

Relative wind farm cost
Turbine type 5 is approximately
25% more expensive than turbine type 1

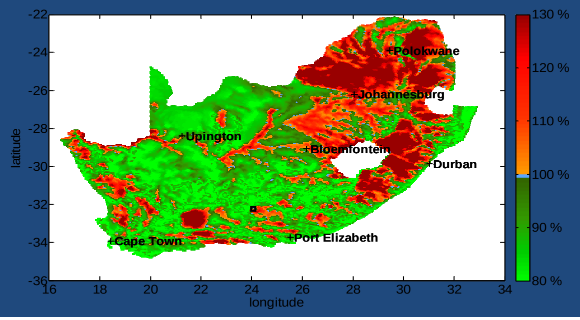
Capex: 80% of overall costs
→ LCOE of turbine type 5 is approximately 20% higher than turbine type 1 (for the same load factor)

Map of relative LCOE (for the same load factor)

Reference pixel
Turbine 1, load factor ~30%

For every pixel: determine load factor multiplier

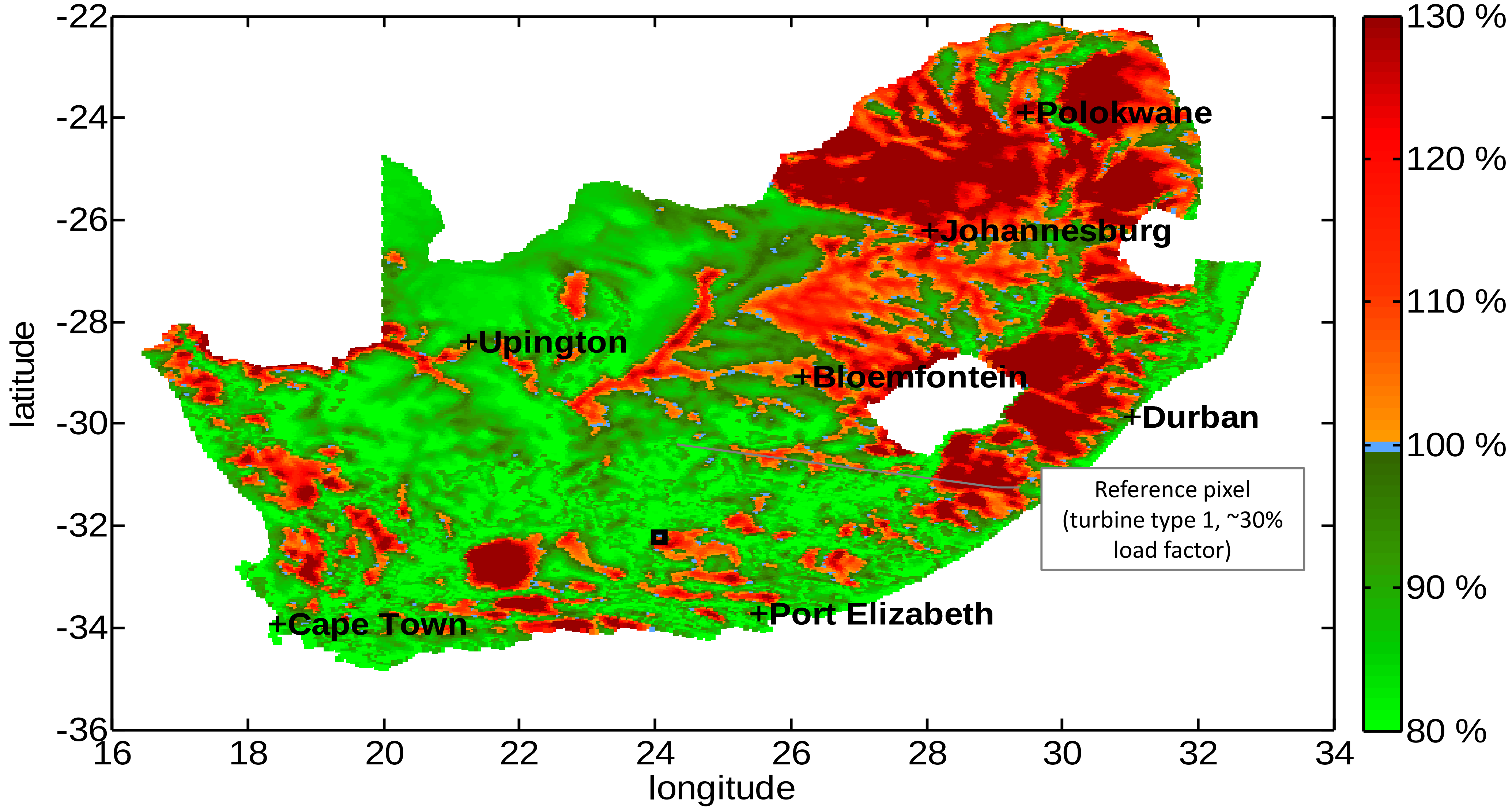
Relative LCOE by multiplying costs with scaled load factors



our future through science

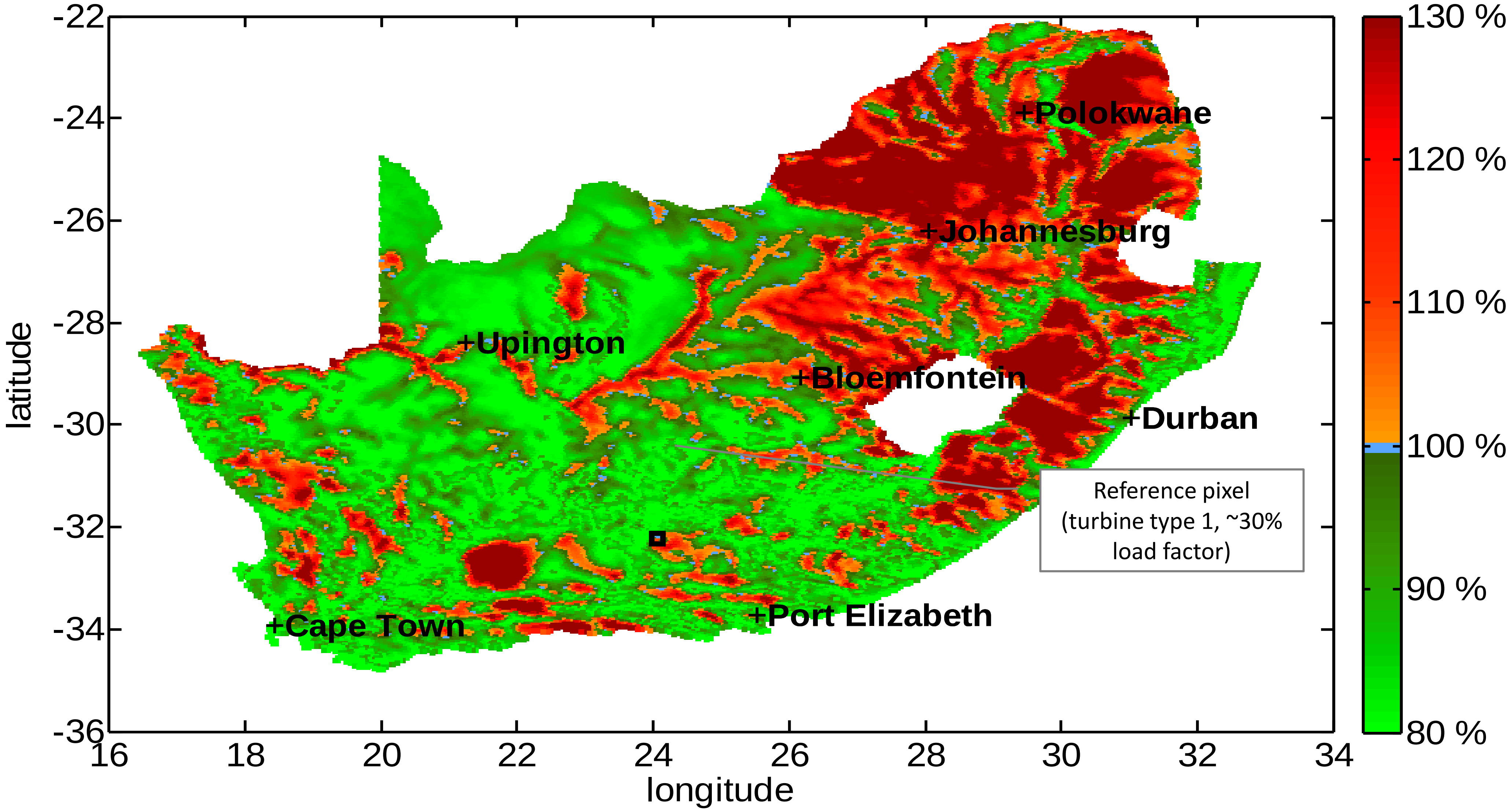
Large parts of RSA can achieve LCOE well below reference

Relative LCOE across South Africa when installing turbine types 1 to 5



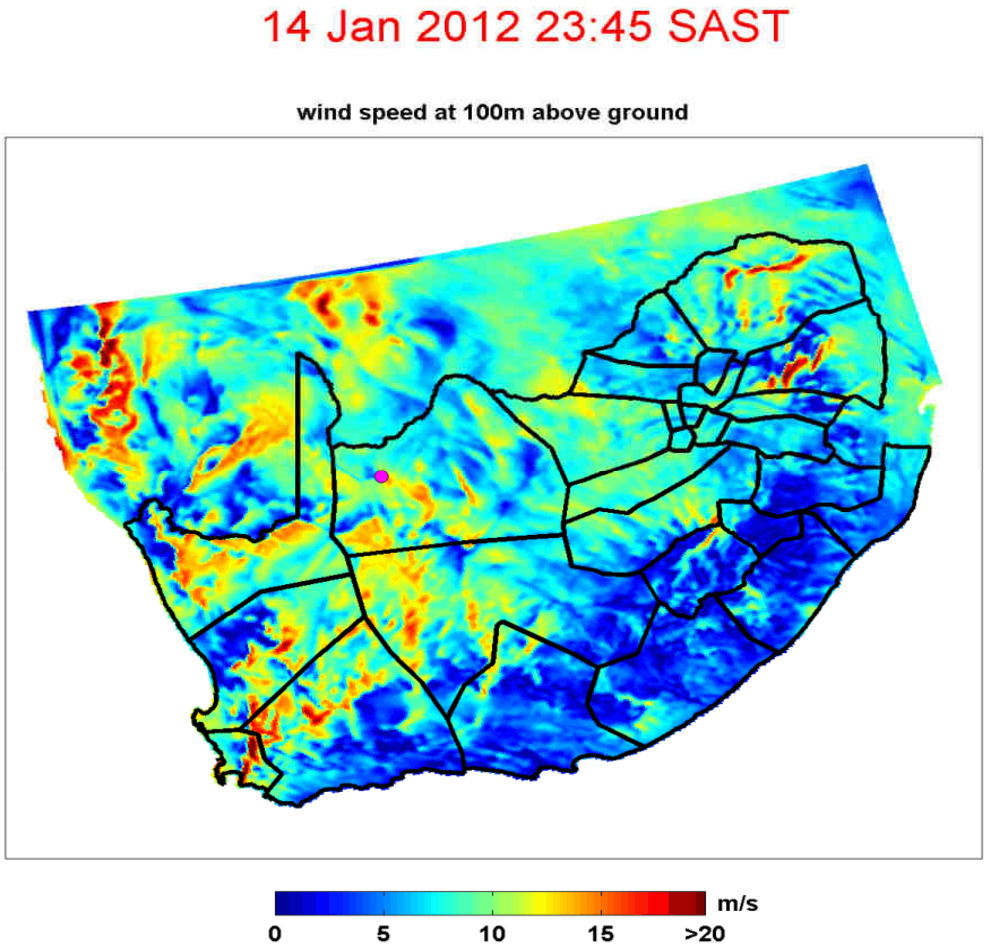
Large parts of RSA can achieve LCOE well below reference

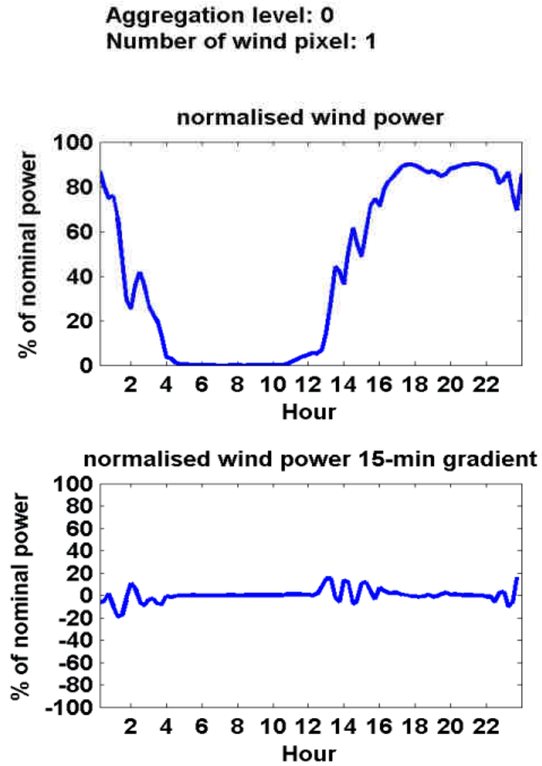
Relative LCOE across South Africa when installing turbine types 1 to 3 only (i.e. type 3 at 4/5 pixels)



A single wind farm changes its power output quickly

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





Fraunhofer IWES

WASA

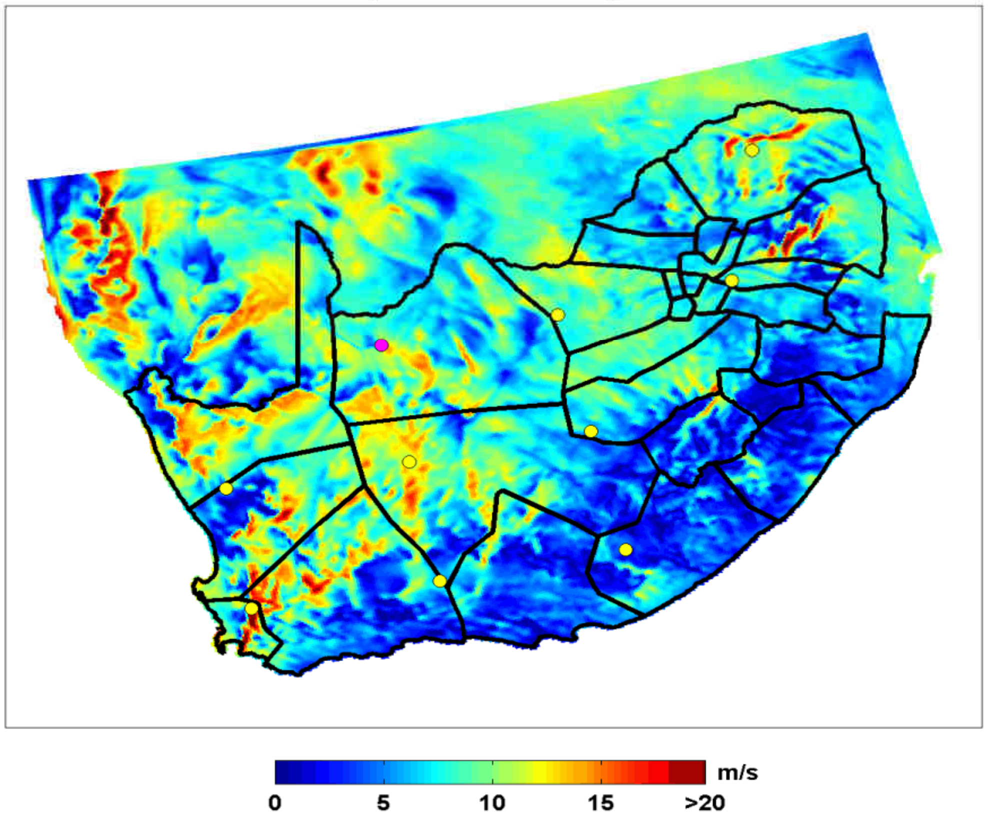
CSIR our future through science

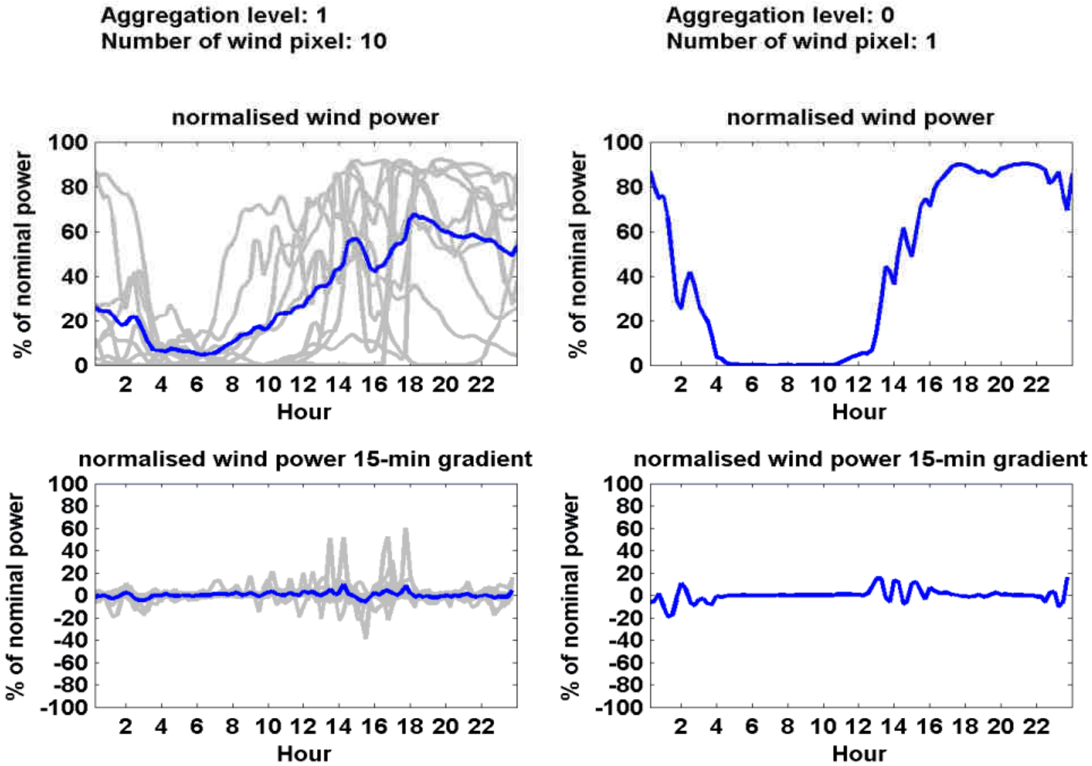
Aggregating just 10 wind farms’ output reduces short-term fluctuations

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

14 Jan 2012 23:45 SAST

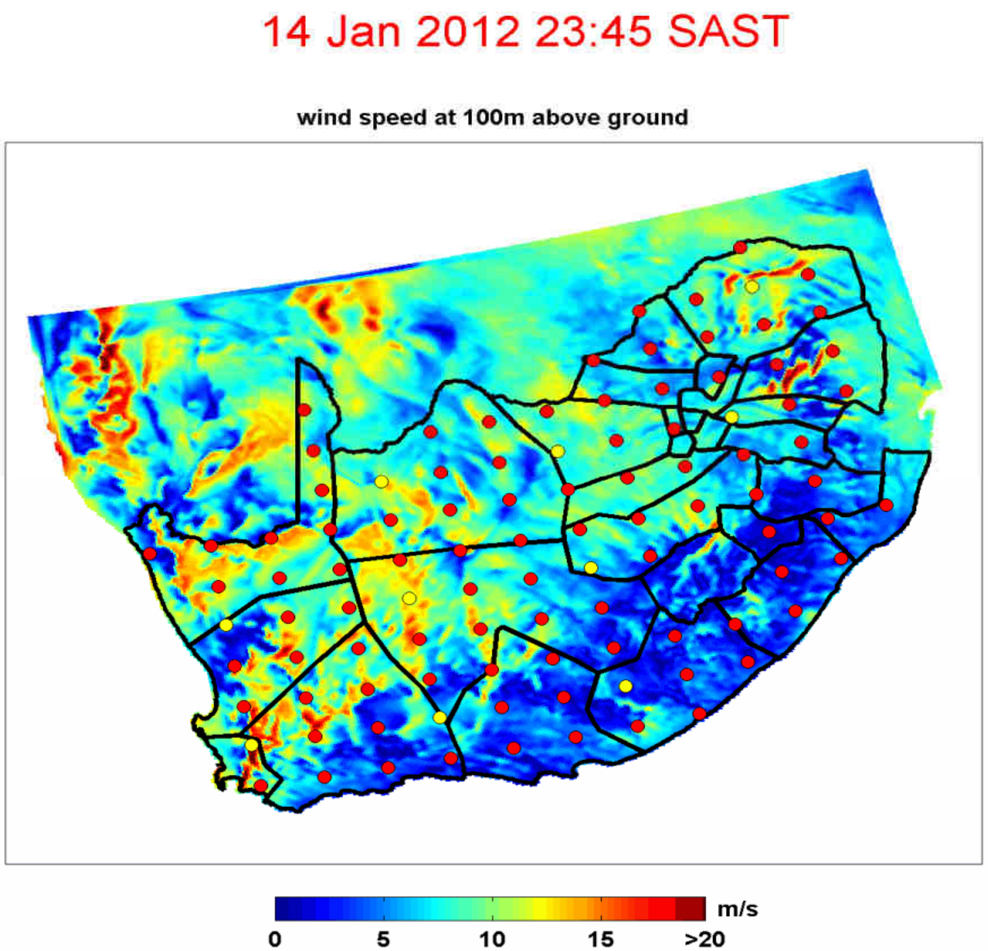
wind speed at 100m above ground

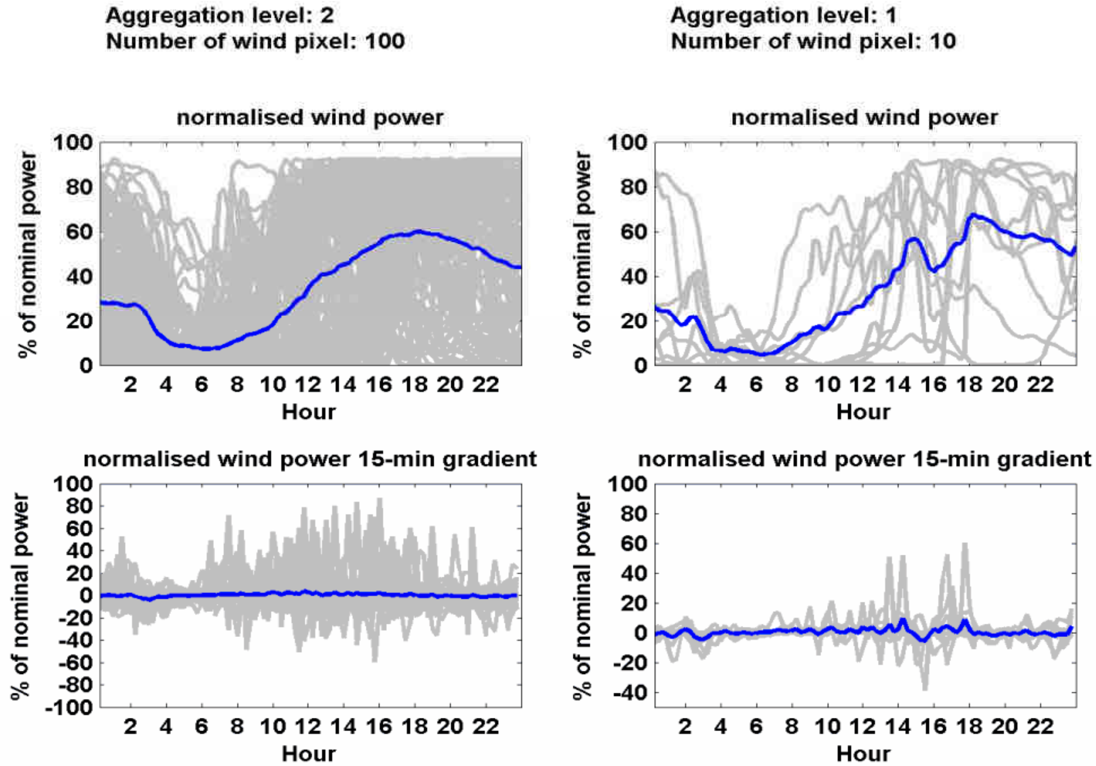




Aggregating 100 wind farms: 15-min gradients almost zero

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





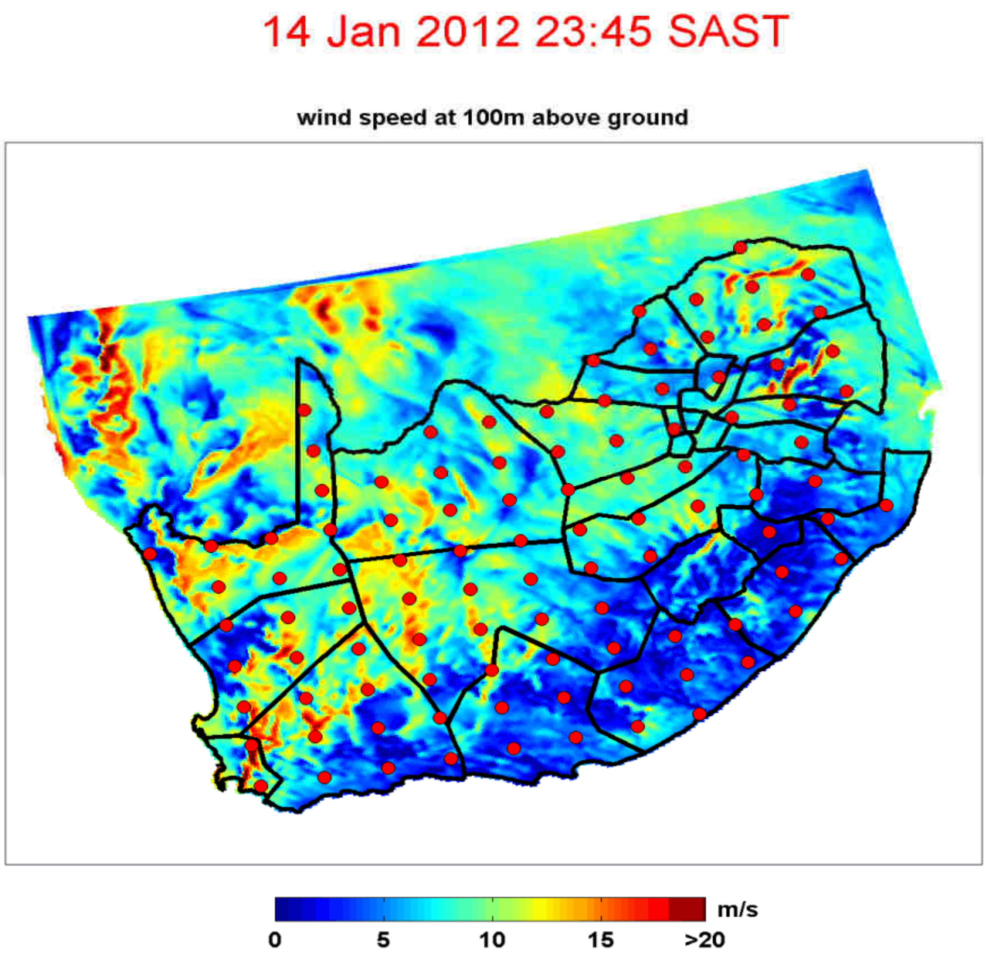
Fraunhofer IWES

WASA

CSIR
our future through science

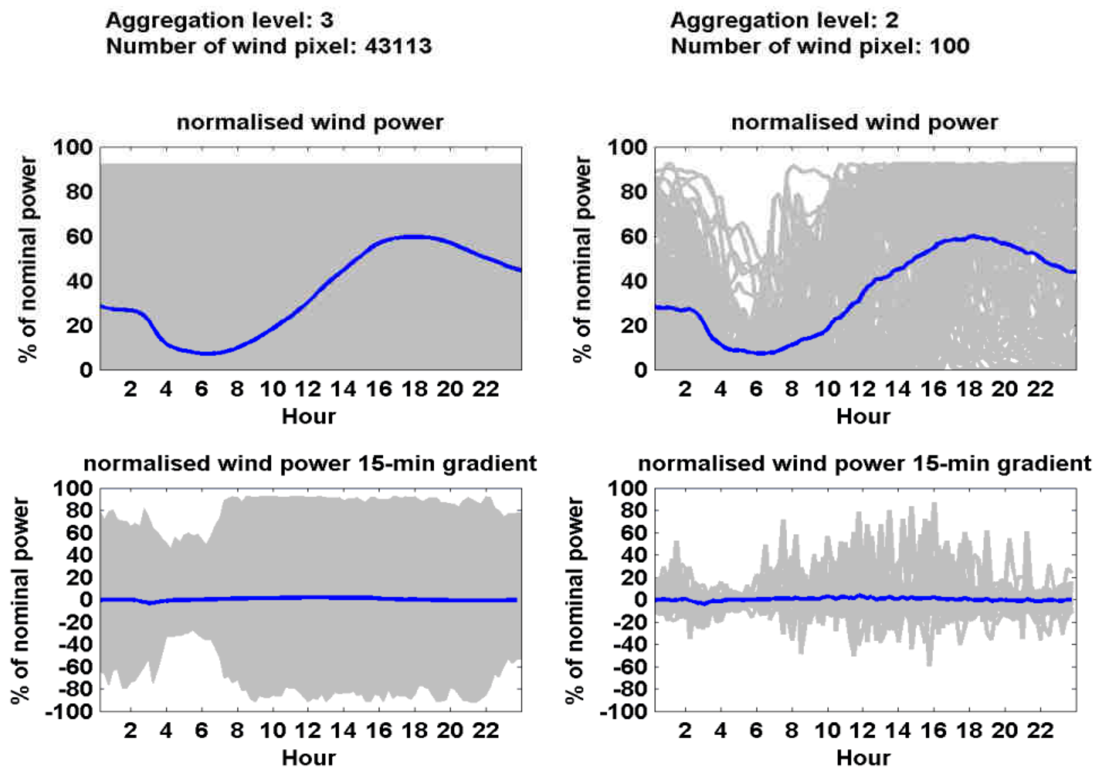
Aggregation across entire country: wind output very smooth

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



Fraunhofer IWES

WASA



CSIR
our future through science

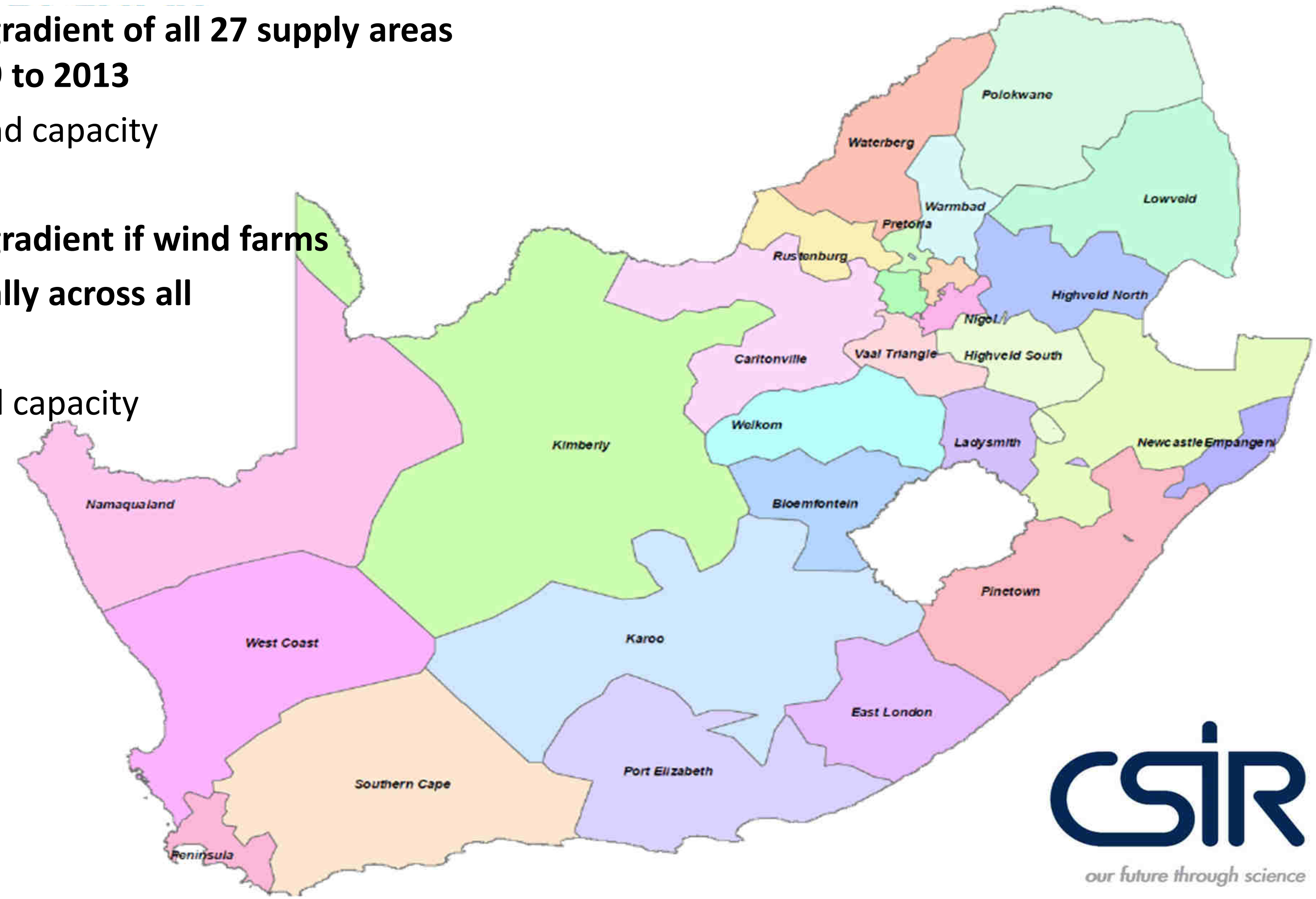
Distributing wind farms widely reduces short-term fluctuations

Minimum 15-minute gradient of all 27 supply areas individually from 2009 to 2013

→ 75% of installed wind capacity

Minimum 15-minute gradient if wind farms are distributed optimally across all 27 supply areas

→ 4% of installed wind capacity



our future through science

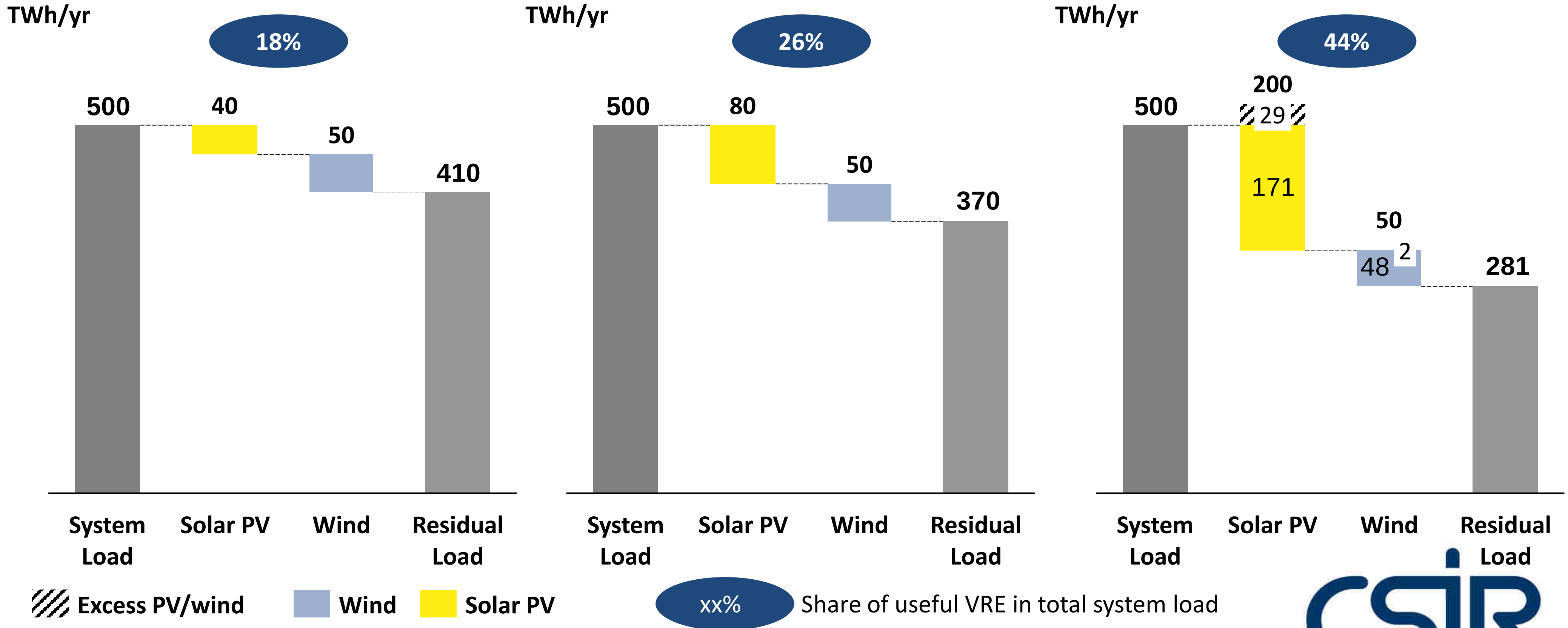
Excess energy is mainly caused by high solar PV shares

Generated solar PV and wind energy and split into useful and excess for different VRE penetrations

Low PV / low wind
Load: 500 TWh/yr
PV: 40 TWh/yr
Wind: 50 TWh/yr

Medium PV / low wind
Load: 500 TWh/yr
PV: 80 TWh/yr
Wind: 50 TWh/yr

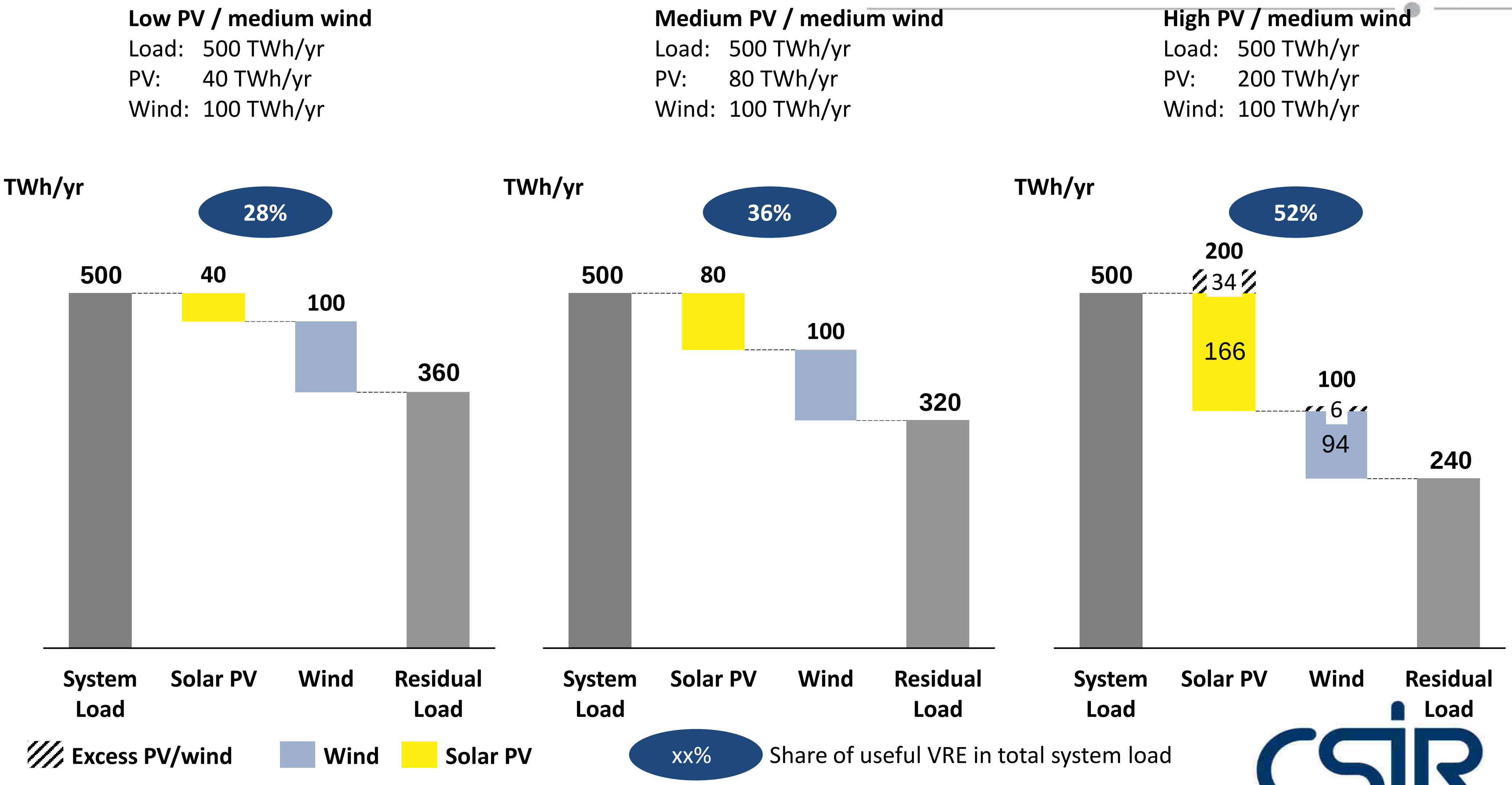
High PV / low wind
Load: 500 TWh/yr
PV: 200 TWh/yr
Wind: 50 TWh/yr



our future through science

2x wind (50 to 100 TWh/yr): almost no effect on excess energy

Generated solar PV and wind energy and split into useful and excess for different VRE penetrations



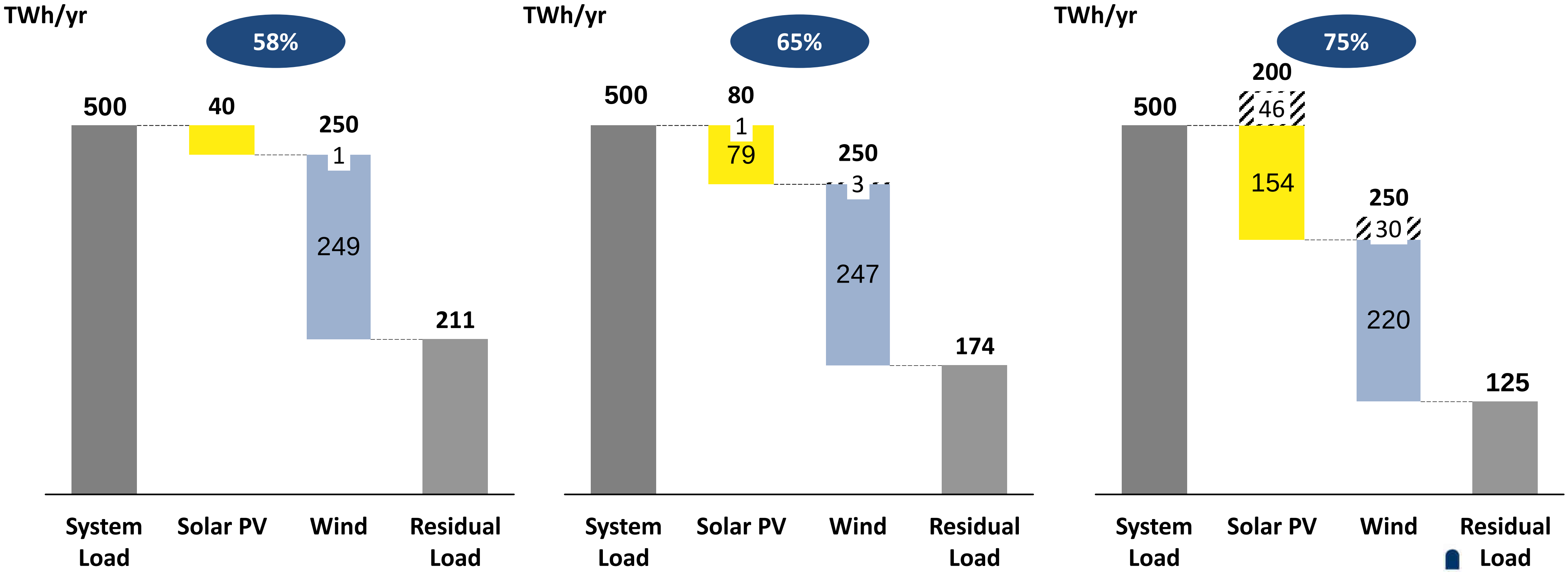
65% VRE share achievable with almost no excess energy

Generated solar PV and wind energy and split into useful and excess for different VRE penetrations

Low PV / high wind
Load: 500 TWh/yr
PV: 40 TWh/yr
Wind: 250 TWh/yr

Medium PV / high wind
Load: 500 TWh/yr
PV: 80 TWh/yr
Wind: 250 TWh/yr

High PV / high wind
Load: 500 TWh/yr
PV: 200 TWh/yr
Wind: 250 TWh/yr



Excess PV/wind   Wind   Solar PV

xx% Share of useful VRE in total system load

CSIR our future through science

Electricity surpluses: 65% energy share of solar PV/wind does not cause significant excess electricity

Electricity storage with the purpose to <u>absorb excess electricity</u> is only required at very high shares of VRE

Excess electricity at very high shares of VRE is mainly driven by solar PV

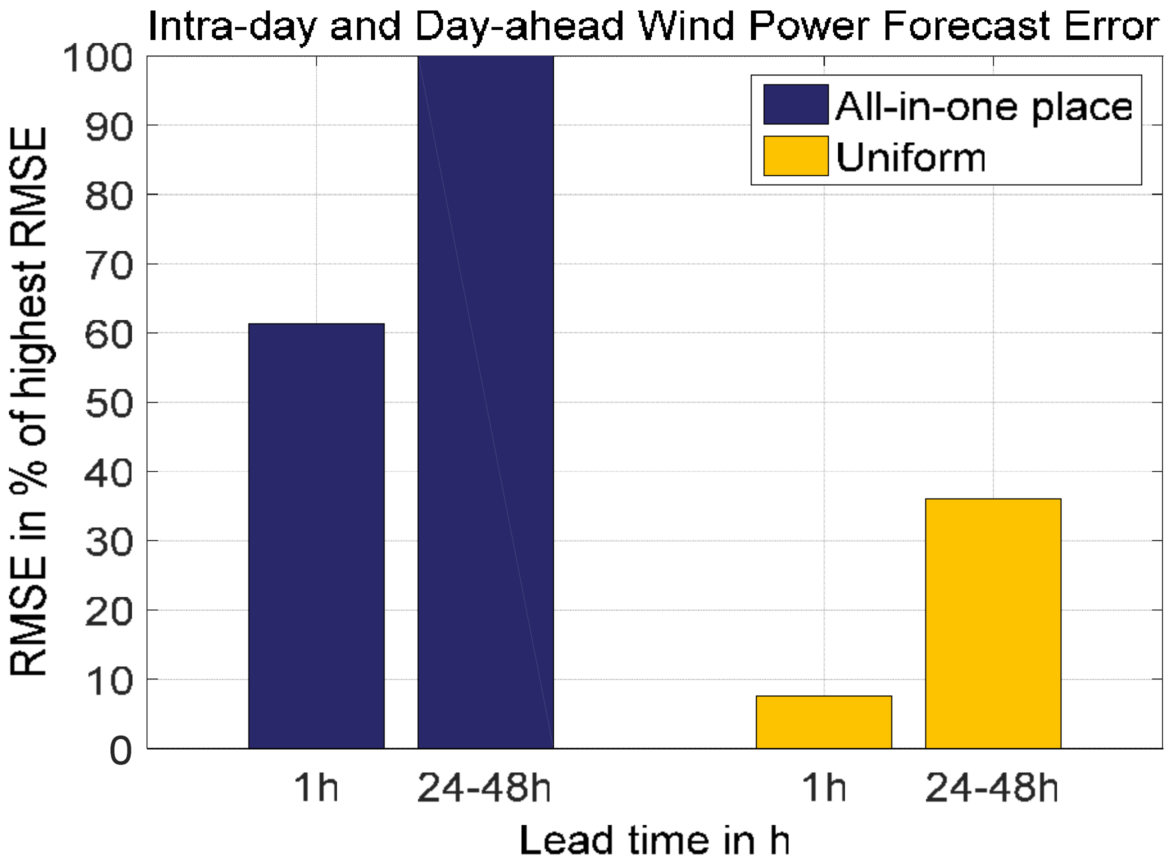
- Up to a certain energy share, solar PV does not cause excess electricity
- Beyond that threshold, solar PV causes large amounts of excess electricity because of the skewed supply pattern of solar PV (daytime only)
- Wind supply is more volatile, but on average better distributed over the full 24 hours of the day
- Very high shares of wind energy can be achieved without any significant amounts of excess electricitiy (assuming the wind farms are distributed widely across the country)

For example for 65% VRE share (80 TWh PV and 250 TWh wind, grid-focused distribution, 500 TWh/yr system load), excess electricity is only 1.2% of total solar PV/wind energy produced

Side note: in the 65% VRE case, the entire residual load‘s fluctuations can be balanced by a conventional fleet that has a fuel-storage capacity of 48 days of the average power output
(Eskom currently stocks coal on average for the entire fleet for 57 days)

Uniform distribution of wind turbines leads to ~85% lower forecast error for intra-day and ~60% lower for day-ahead

Years considered: 2009-2013



Agenda

Renewables in South Africa

Wind potential in South Africa

Extreme renewables scenarios

our future through science

Thought experiment: Build a new power system from scratch

Base load: 8 GW

→ Annual demand: 70 TWh/yr (~30% of today's South African demand)

Questions:

- Technical:
  Can a blend of wind and solar PV, mixed with flexible dispatchable power to fill the gaps supply this?
- Economical: If yes, at what cost?

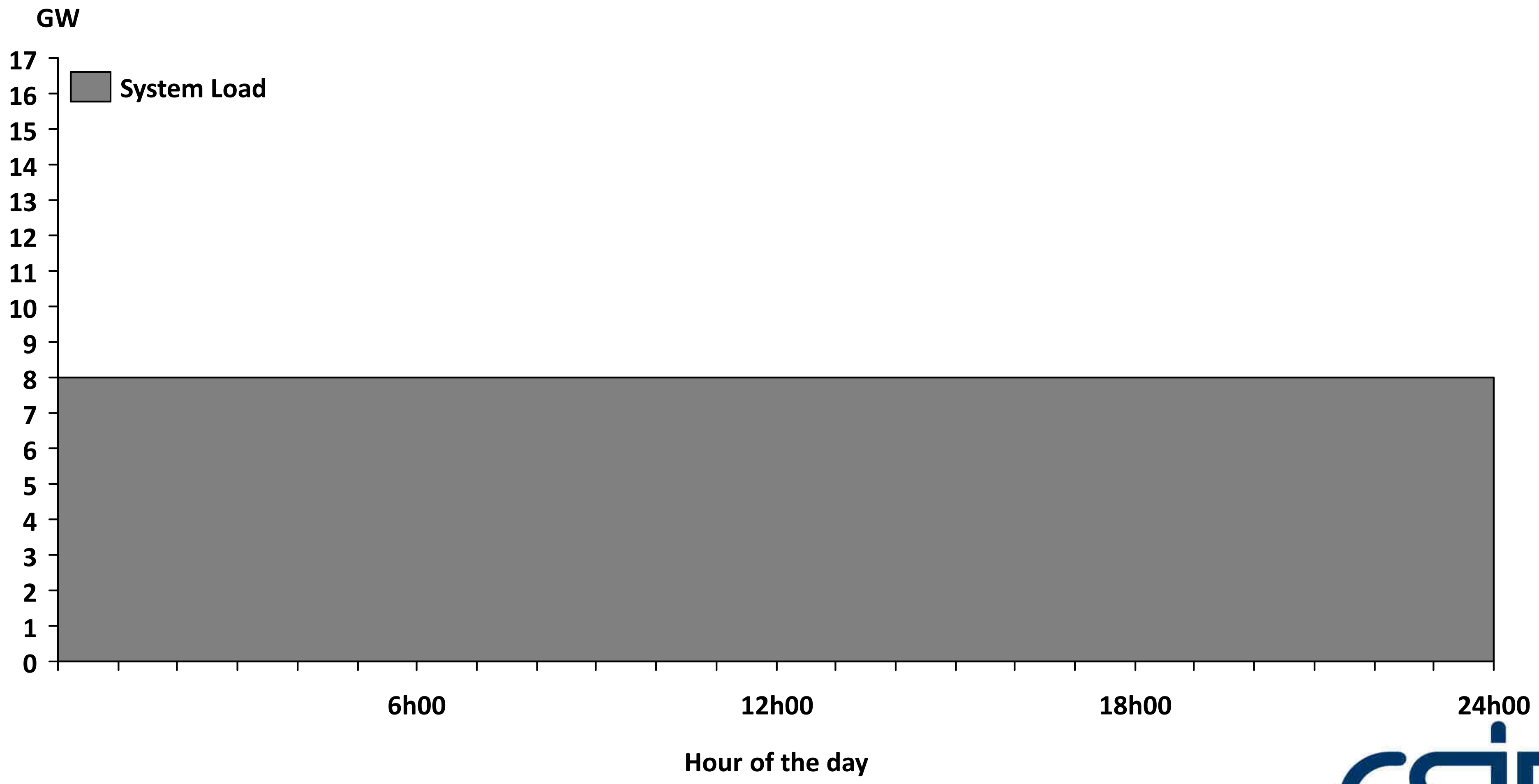
Assumptions/approach

1. 15 GW wind @ 5.1 $-ct/kWh (Bid Window 4 average tariff)
2. 7 GW solar PV @ 6.4 $-ct/kWh (Bid Window 4 average tariff)
3. 8 GW flexible power generator to fill the gaps @ 16.4 $-ct/kWh (e.g. high-priced gas @ 11.6 $/MMBtu)

- Hourly solar PV and wind data from recent CSIR study, covering the entire country
  - Check out the results: www.csir.co.za/Energy_Centre/wind_solarpv.html
- Hourly simulation of supply structure for an entire year

Notes: ZAR/USD = 12.8 (2015 average)
Sources: IRP; REIPPPP outcomes; CSIR analysis

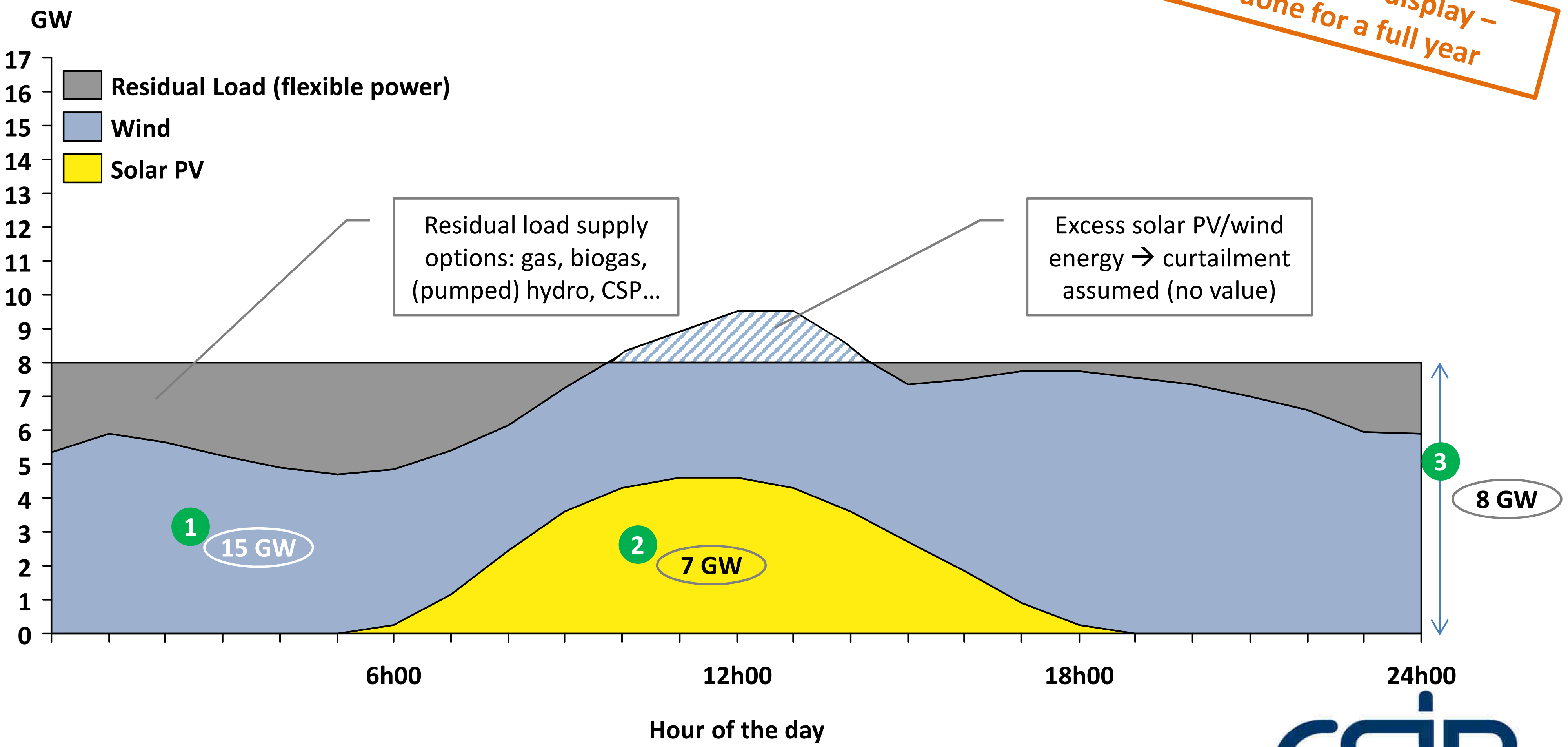
Thought experiment: assumed 8 GW of true baseload



Sources: CSIR analysis

A mix of solar PV, wind and flexible power can supply this baseload demand in the same reliable manner as a base-power generator

One illustrative day in display – simulation done for a full year



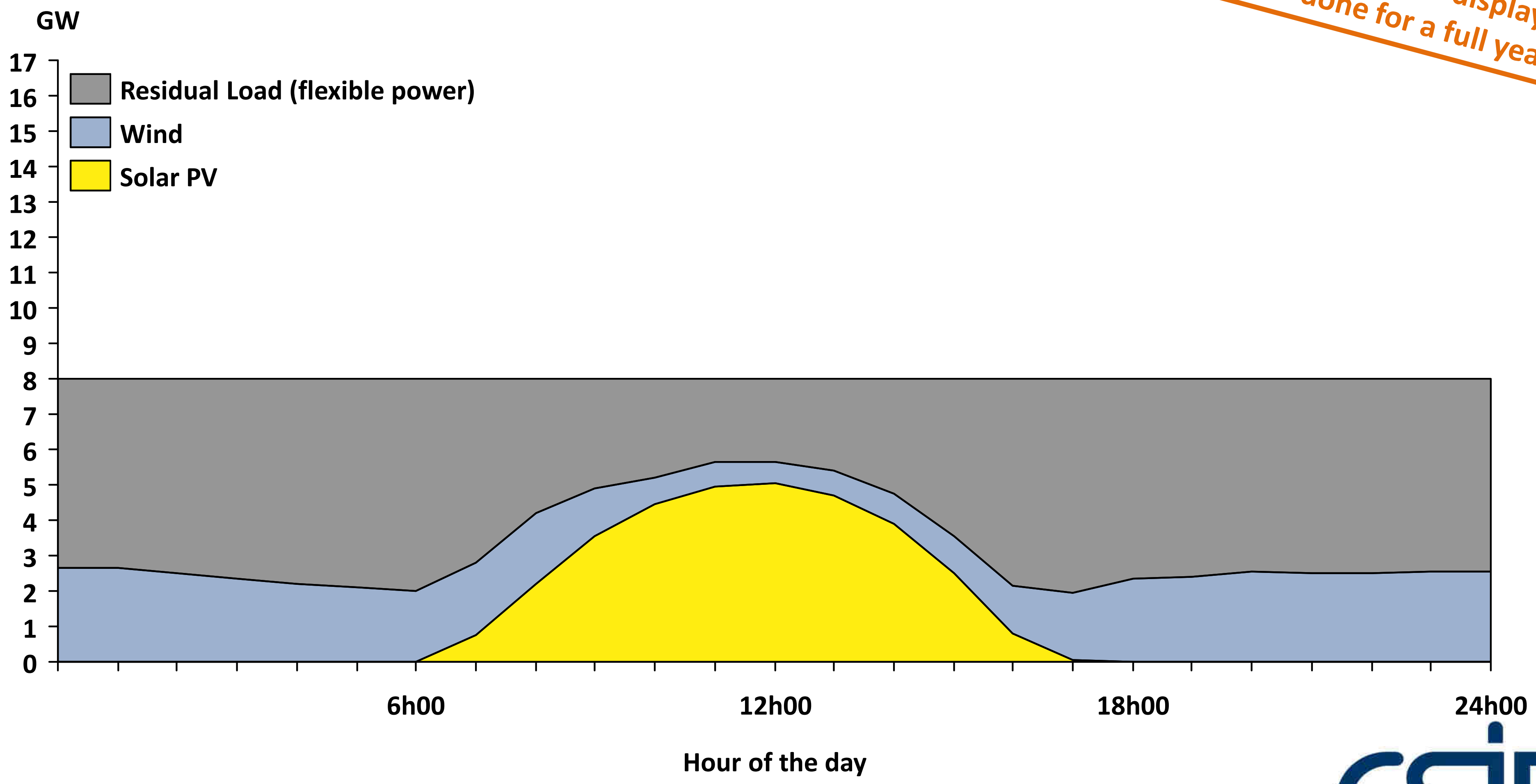
Total installed capacity: 30 GW to supply 8 GW baseload – does this make sense? Yes, it's about energy, not capacity!

Sources: CSIR analysis

On a low-wind day the residual load is large

Simulated solar PV and wind power output for a 7 GW PV and 15 GW wind fleet on a day in May

One illustrative day in display – simulation done for a full year

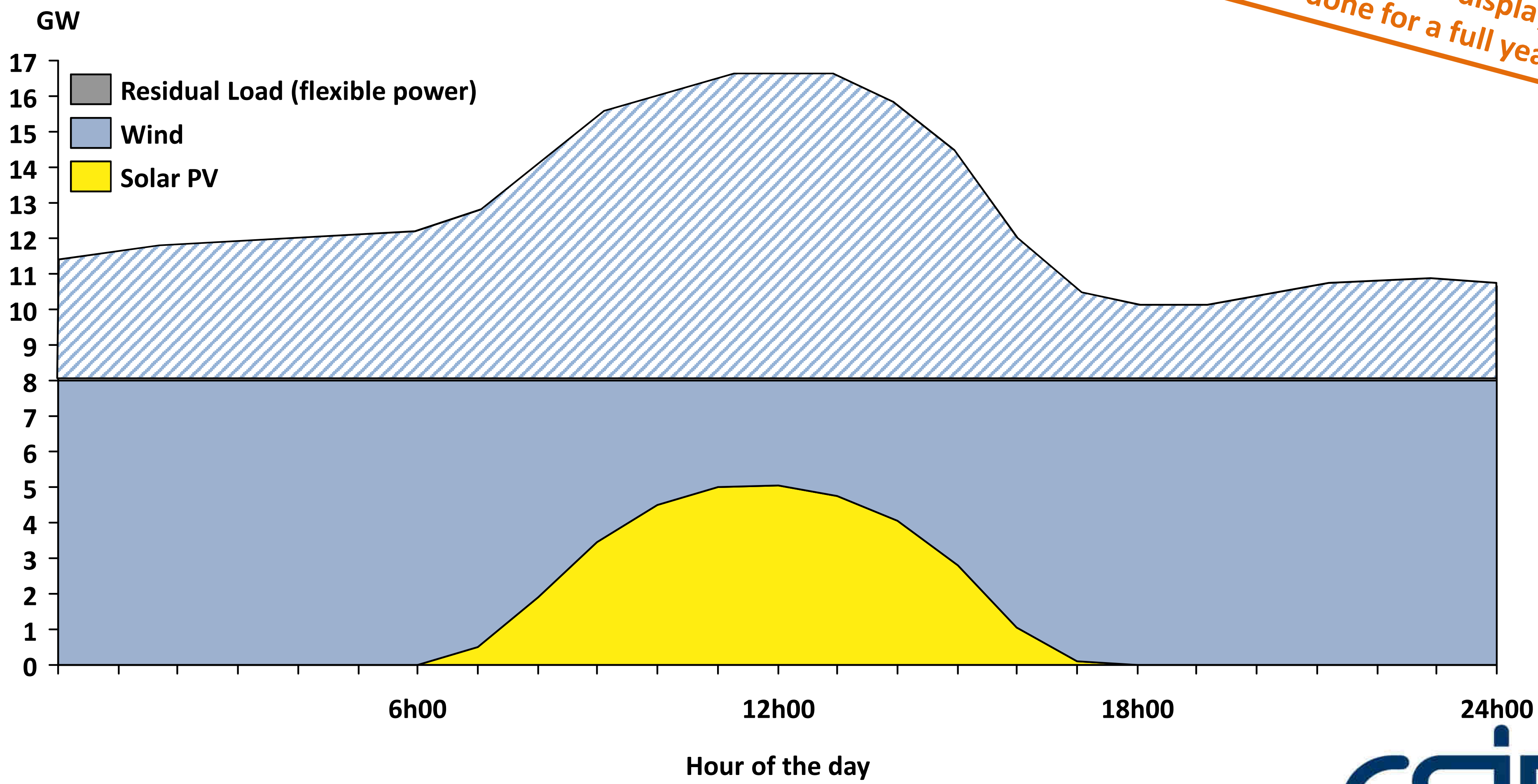


Sources: CSIR analysis

On a sunny and windy day, excess energy from PV and wind is large

Simulated solar PV and wind power output for a 7 GW PV and 15 GW wind fleet on a day in July

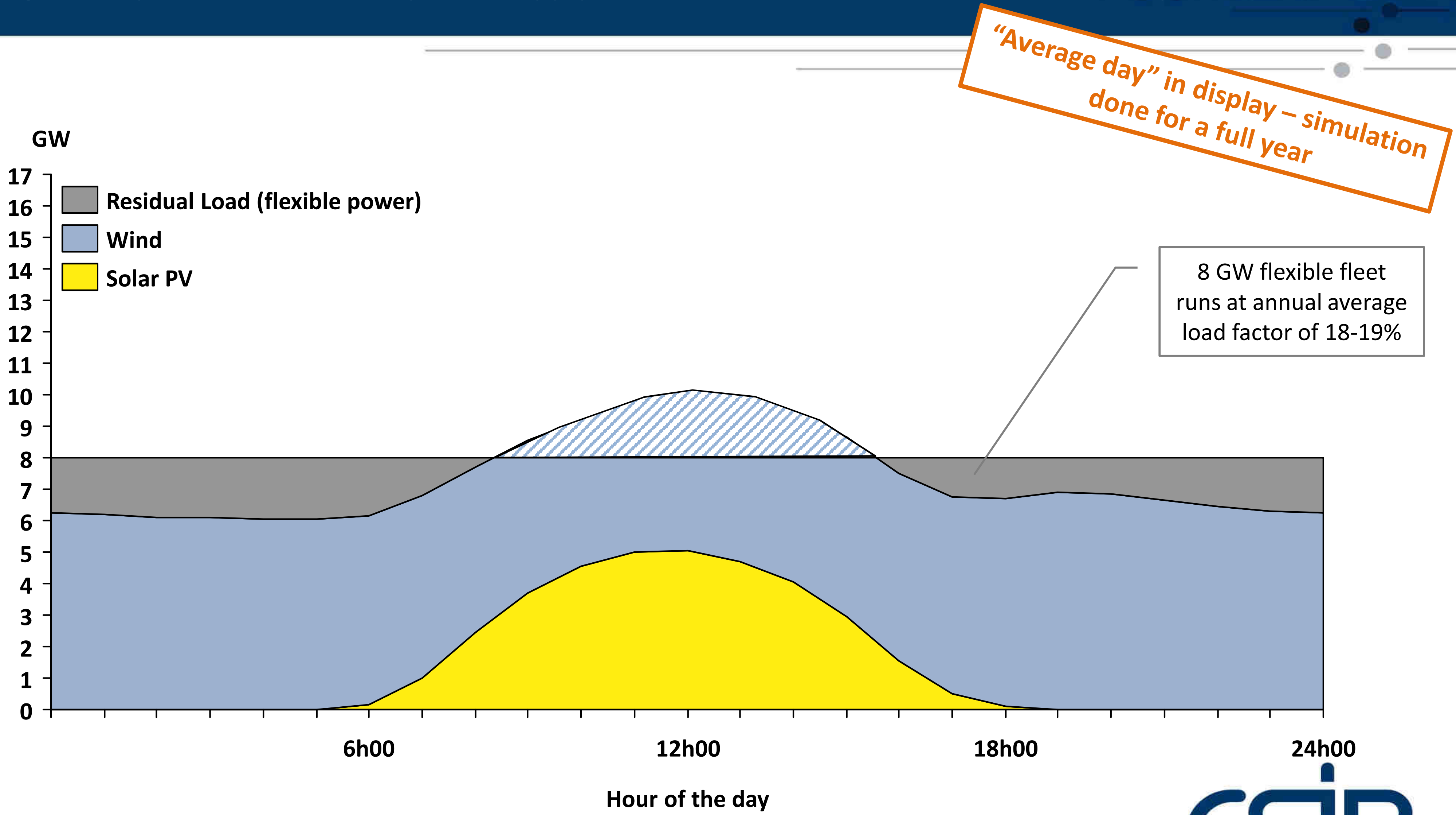
One illustrative day in display – simulation done for a full year



Sources: CSIR analysis

On average, solar PV and wind supplies 82% of the total demand

Average hourly solar PV and wind power supply calculated from simulation for the entire year



Sources: CSIR analysis

Technical feasibility in two key dimensions – detailed analyses required

Ramping

- Max ramp of residual load: 2.8 GW/h → 35% of installed flexible capacity per hour
- Min ramp of residual load: -3.1 GW/h → 39% of installed flexible capacity per hour

→ Open-Cycle Gas Turbines can ramp up from cold start to 100% output in less than 1 hour

→ Open-Cycle Gas Turbines can ramp down from 100% output to zero in less than 1 hour

Fuel-storage

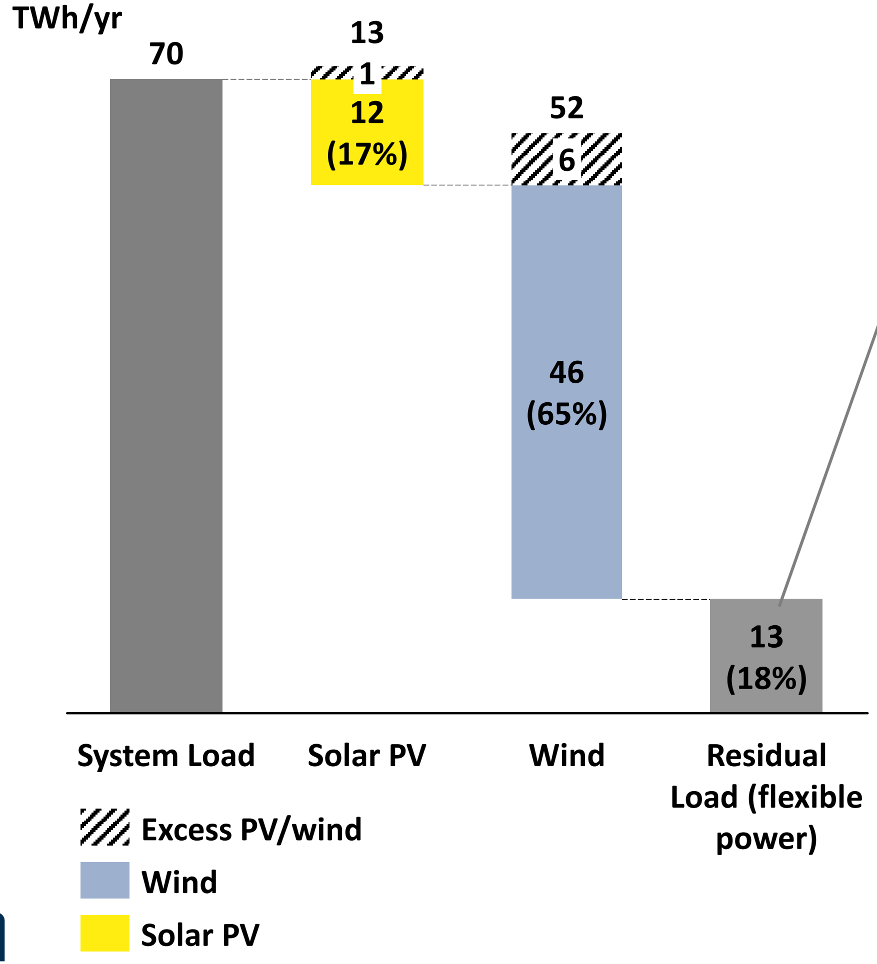
- The flexible power generator of 8 GW installed capacity requires fuel storage for a maximum of 9 days

→ Eskom currently stocks coal at power stations for more than 50 days on average

→ Buffer capacity of a LNG landing terminal is 4-6 weeks at the minimum

CSIR
our future through science

Mix of solar PV, wind and expensive flexible power costs 7.9 $-ct/kWh (excess thrown away) – same level as alternative baseload new-builds



Requires approx. 30 TWh/yr of natural gas → 2 mmtpa of LNG-based natural gas

New-build coal: 6.4-8.6 $-ct/kWh

$$\frac{13\text{ TWh/yr} * 6.4\text{ \$-ct/kWh} + 52\text{ TWh/yr} * 5.1\text{ \$-ct/kWh} + 13\text{ TWh/yr} * 16.4\text{ \$-ct/kWh}}{70\text{ TWh/yr}} = 7.9\text{ \$-ct/kWh}$$

- No value given to 7 TWh/yr of excess energy (bought and "thrown away")
- Bid Window 4 costs for PV/wind (no further cost reduction assumed)
- Very high cost for flexible power of 15.0 $-ct/kWh assumed

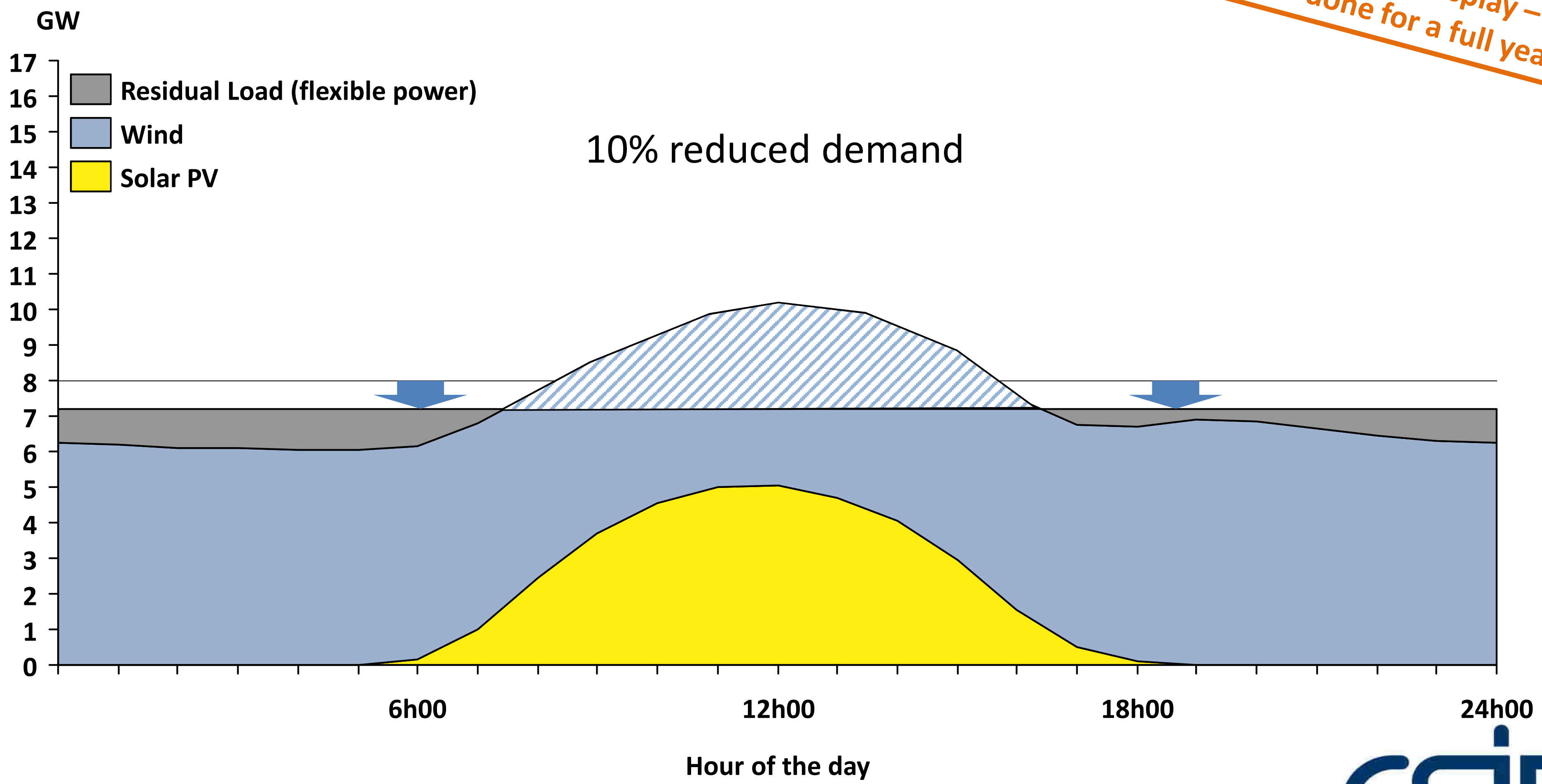
CSIR our future through science

Sources: CSIR analysis

10% less load: excess energy increases, need for flexible power reduces

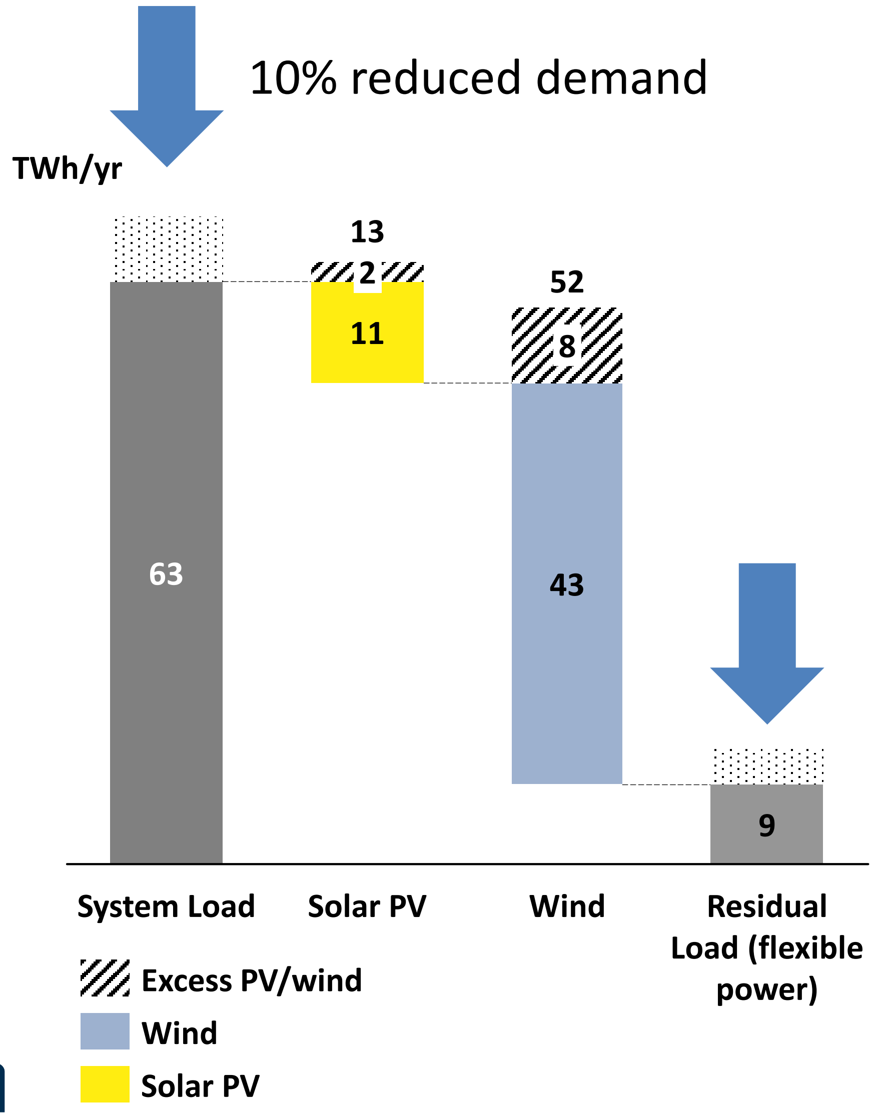
Average hourly solar PV and wind power supply calculated from simulation for the entire year

"Average day" in display – simulation done for a full year



Sources: CSIR analysis

Low sensitivity to changes in demand (-10%): unit cost stays constant



13 TWh/yr * 6.4 $-ct/kWh
+ 52 TWh/yr * 5.1 $-ct/kWh
+ ~~13~~ 9 TWh/yr
* ~~16.4~~ 17.3 $-ct/kWh
――――――――――――――― = 7.~~9~~8 $-ct/kWh
~~70~~ 63 TWh/yr

- No value given to 7 TWh/yr of excess energy (bought and "thrown away")
- Bid Window 4 costs for PV/wind (no further cost reduction assumed)
- Very high cost for flexible power of 16.5 $-ct/kWh assumed

CSIR our future through science

Sources: CSIR analysis

What we learned from having high-fidelity wind data available

Before high-fidelity data collection …	… and after
Wind resource in South Africa is not good	Wind resource in South Africa is on par with solar
There is not enough space in South Africa to supply the country with wind power	>80% of the country’s land mass has enough wind potential to achieve 30% load factor or more
Wind power has very high short-term fluctuations	On portfolio level, 15-minute gradients are very low
Wind power has no value because it is not always available	On average, wind power in South Africa is available 24/7 with higher output in evenings and at night; in a mix with expensive flexible power it is cheaper than dispatchable alternatives

… analyses to be continued

Ke a leboha

ndza Khensa

Enkosi

Ngiyathokoza

Thank you!

Ke a leboga

Ndi a livhuha

Dankie

Ngiyabonga

CSIR

our future through science