Smoothing out the Volatility of South Africa's Wind and PV Energy Resources

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Agenda

Background

Objectives of the wind and PV resource aggregation study

Study progress to-date and Port Elizabeth case study

Animated/interactive GUI (wind/PV/Residual load) in the proposed REDZ

Acknowledgements and collaborations

Next steps

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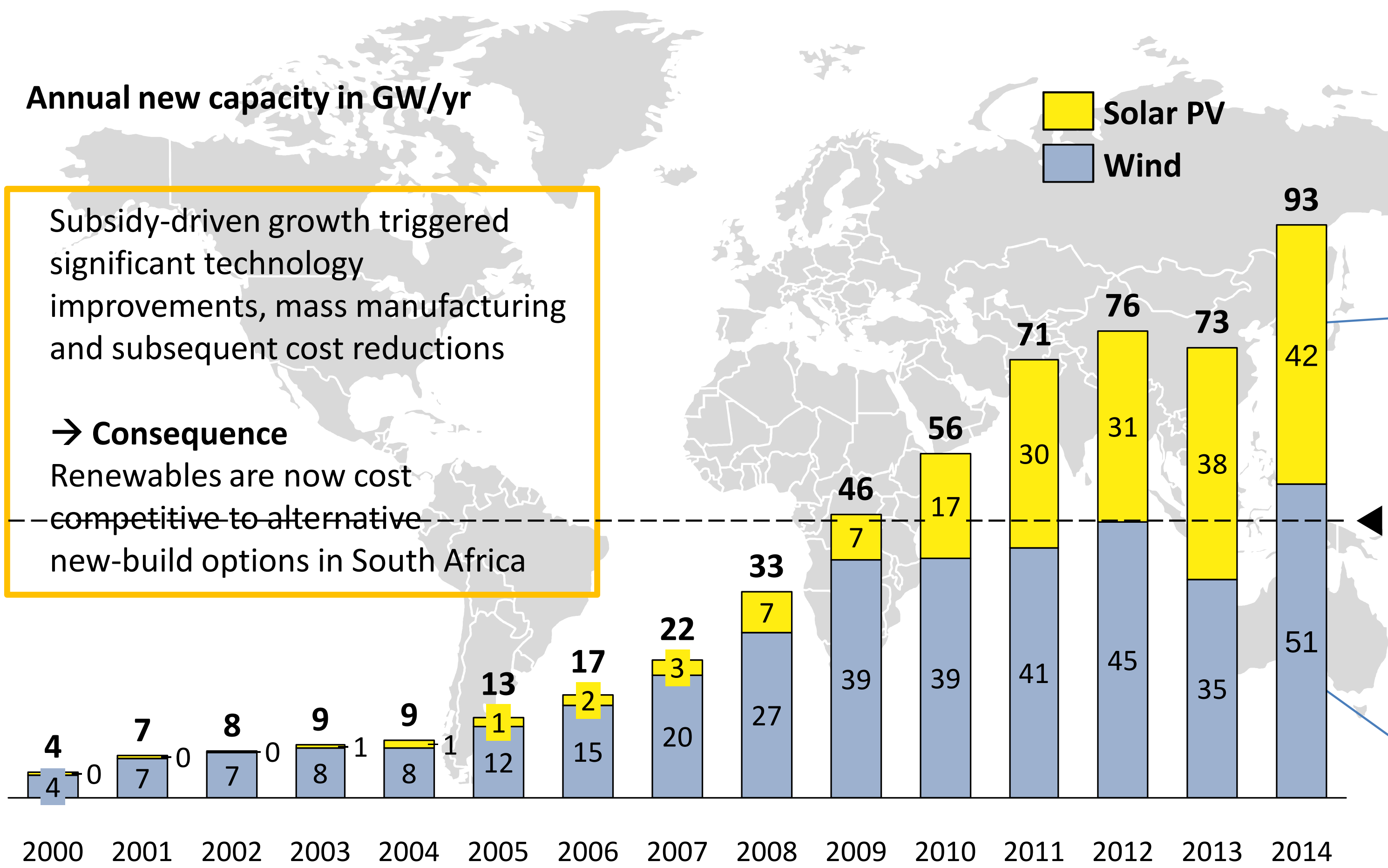
Last year alone, 93 GW of wind and solar PV were installed globally



Subsidy-driven growth triggered significant technology improvements, mass manufacturing and subsequent cost reductions

→ **Consequence**
Renewables are now cost competitive to alternative new-build options in South Africa

This is all very new: Almost 90% of the globally existing PV capacity was installed during the last five years alone!

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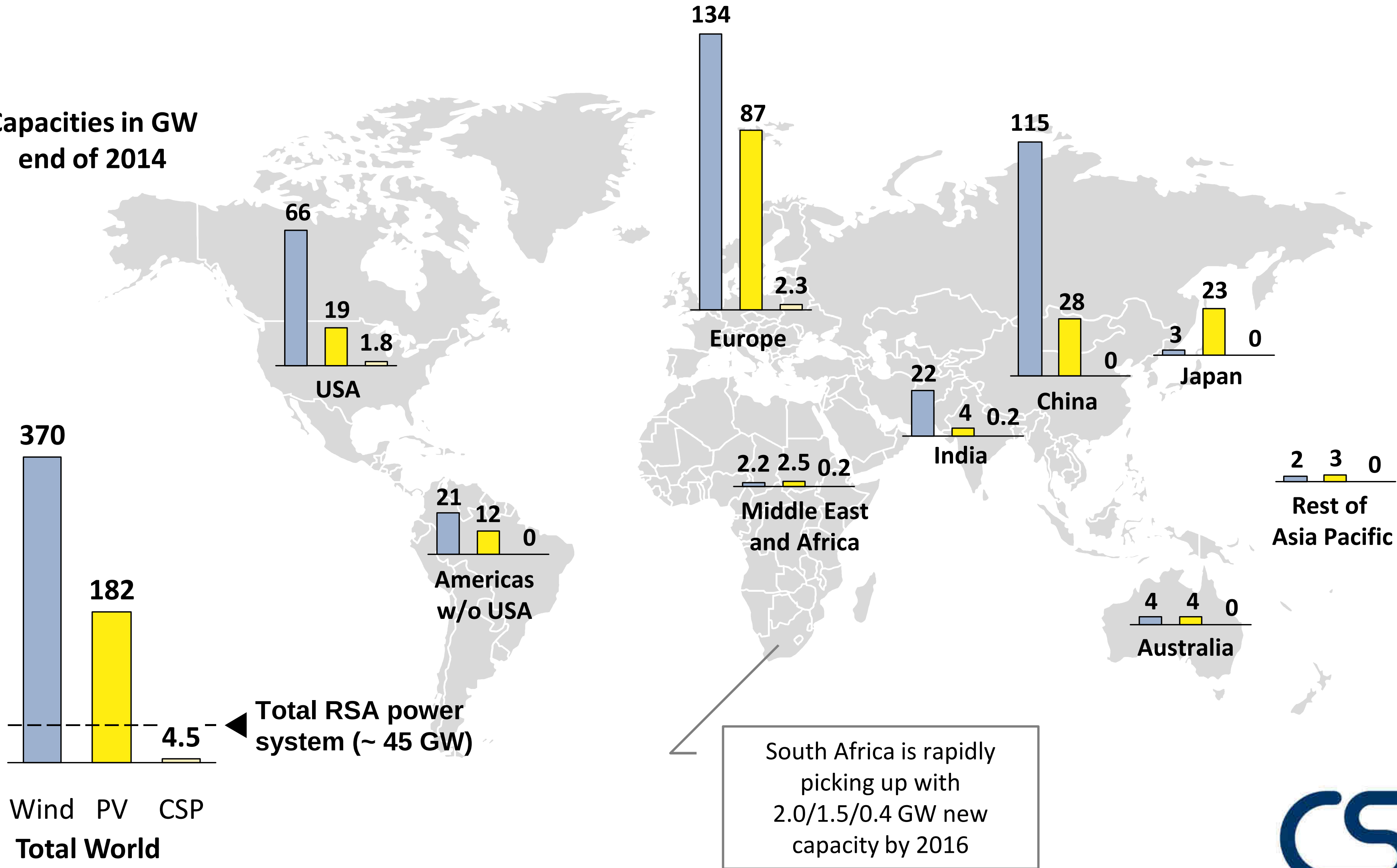
Sources: International Energy Outlook of the EIA; GWEC; EPIA; CSIR analysis

Until today, renewables were mainly driven by the US, Europe and China – South Africa picking up



Sources: GWEC; EPIA; CSPToday; CSIR analysis

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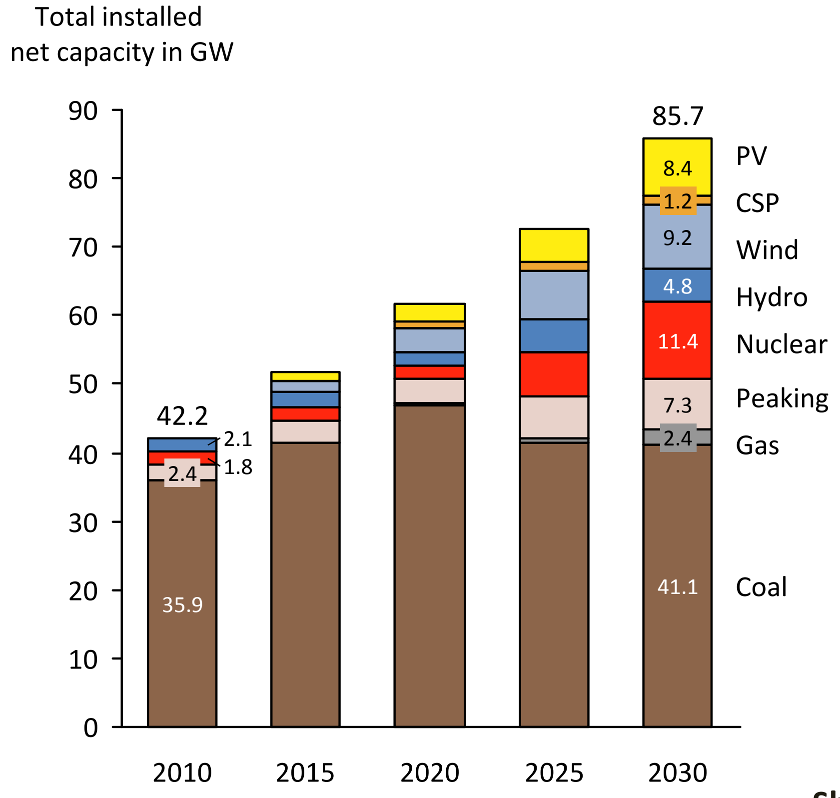
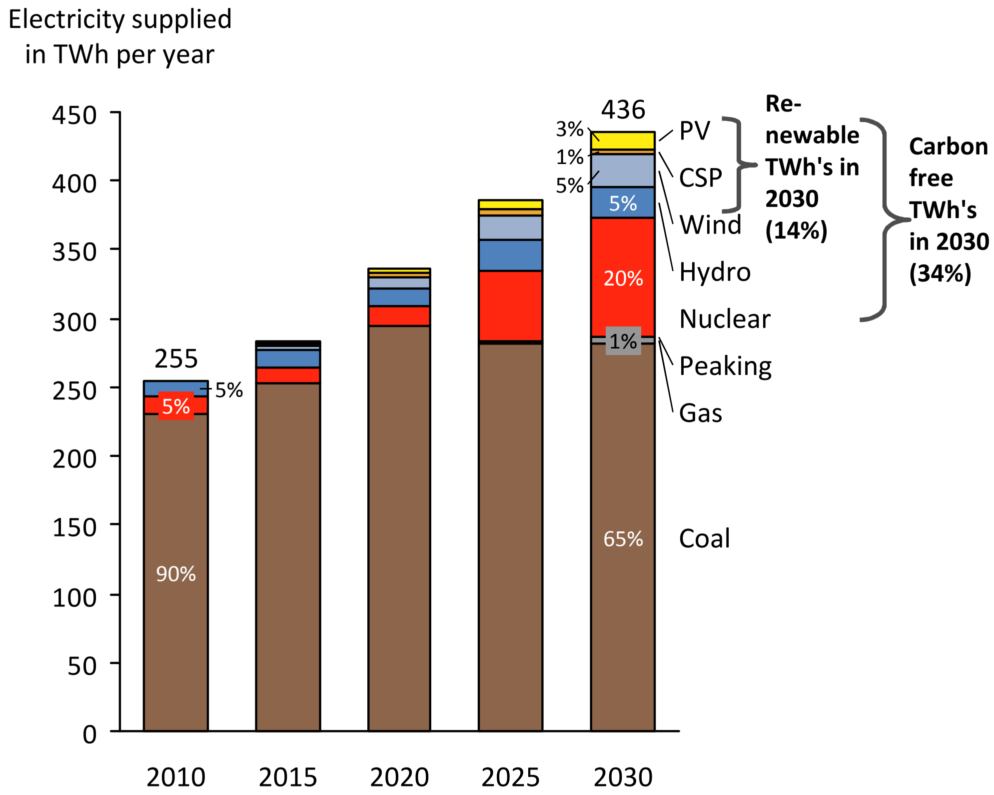
Integrated Resource Plan 2010 (IRP 2010): Plan of the power generation mix for South Africa until 2030

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)

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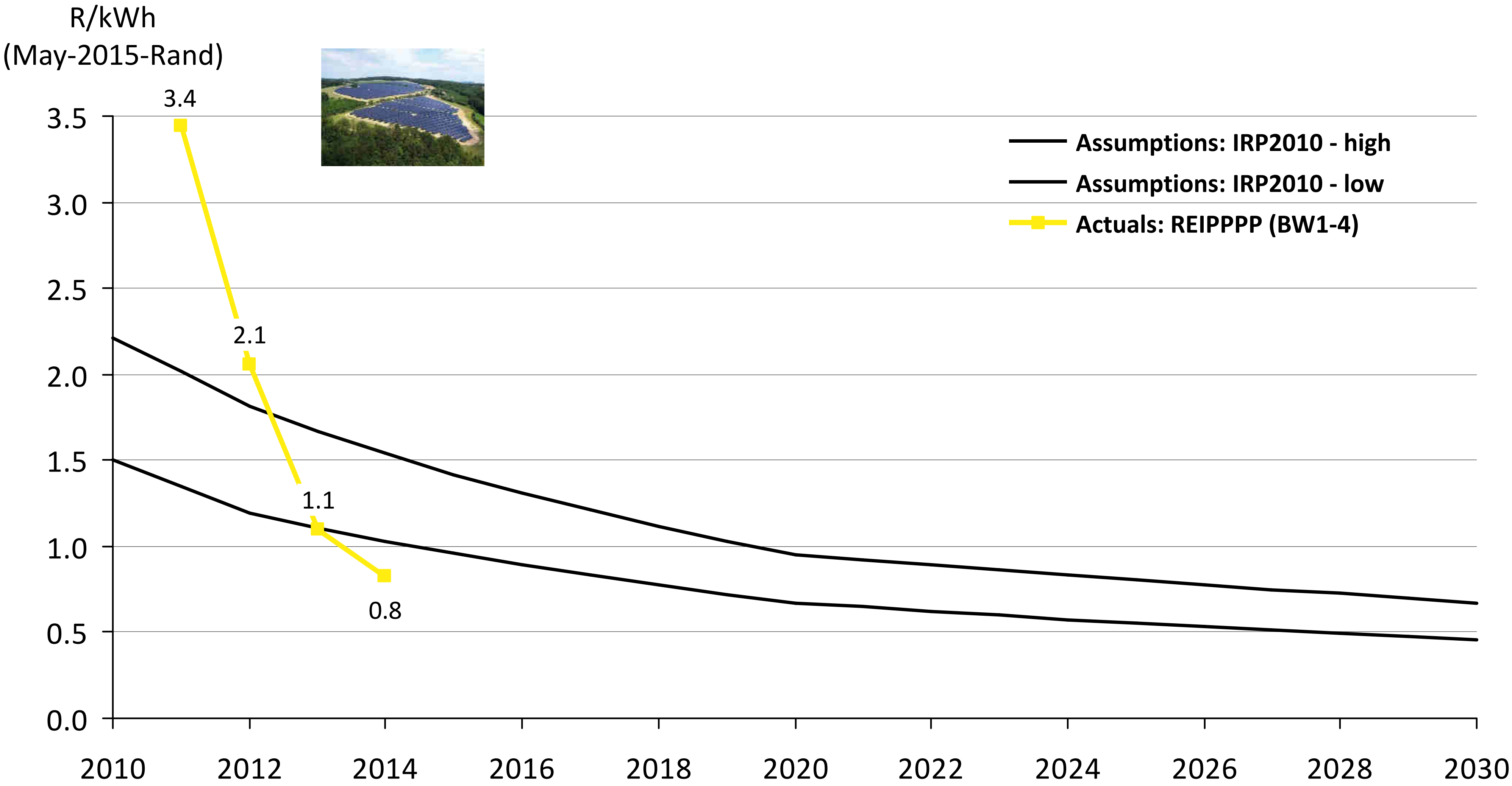
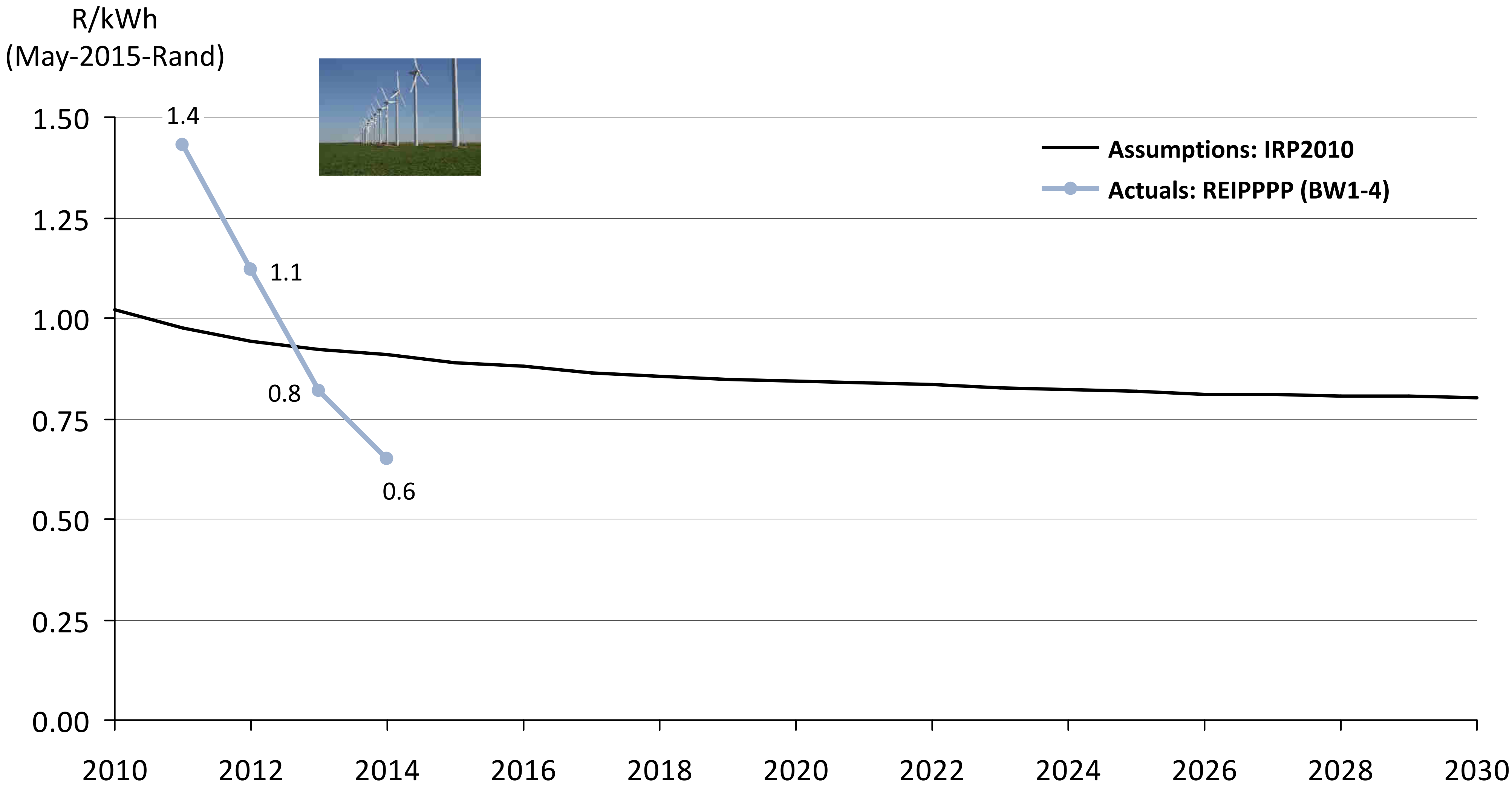
Note: hydro includes imports from Cahora Bassa
Sources: Integrated Resource Plan 2010, as promulgated in 2011; CSIR Energy Centre analysis

Actual PV tariffs quickly approached IRP cost assumptions in first four bid windows and 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 Energy Centre analysis

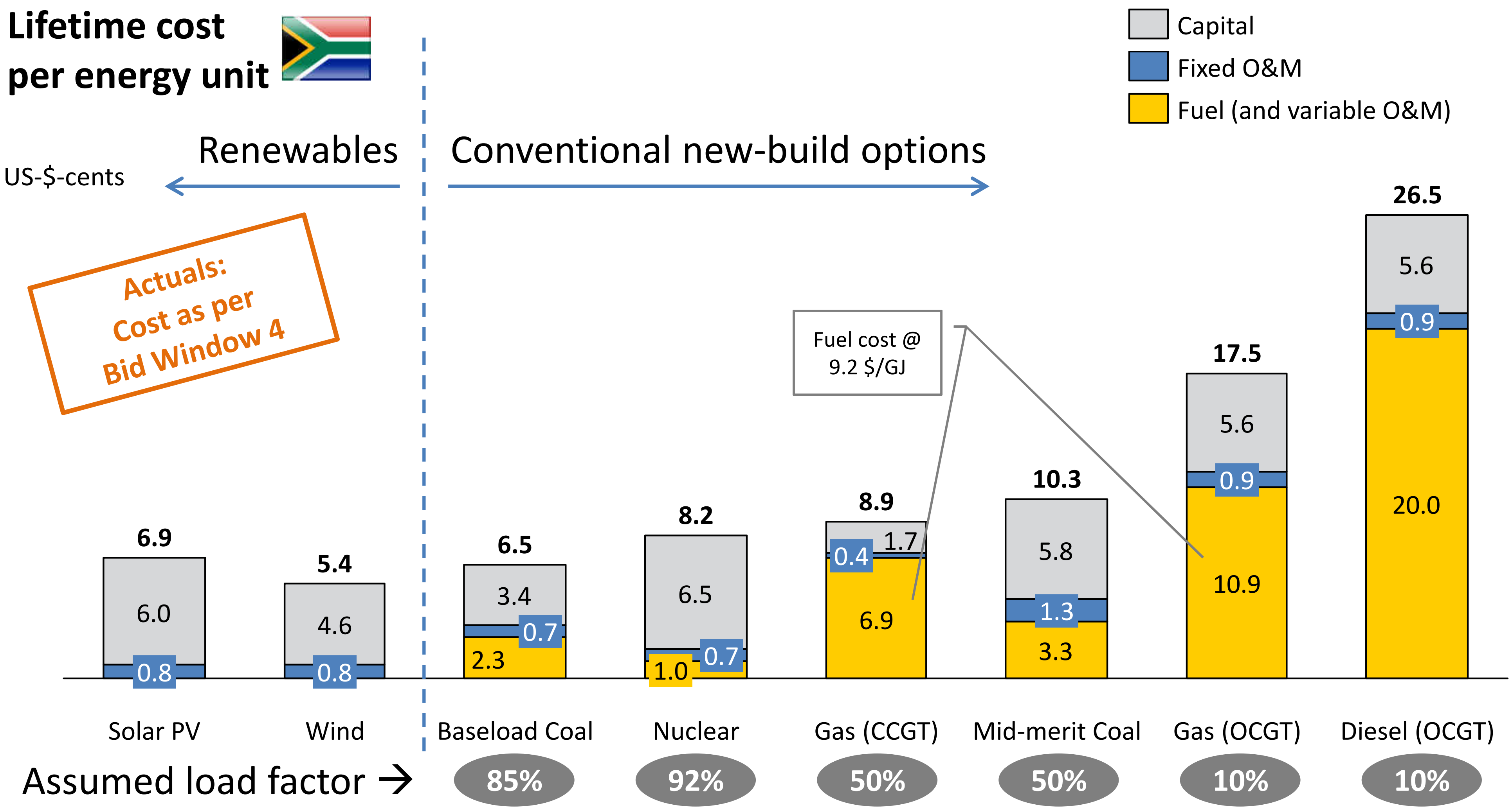
Actual wind tariffs in bid window three were already at the level that was assumed for 2030 in the IRP, bid window four is significantly below



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 Energy Centre analysis

Consequence of renewables' cost reduction: Solar PV & wind cheapest new-build options per kWh in South Africa

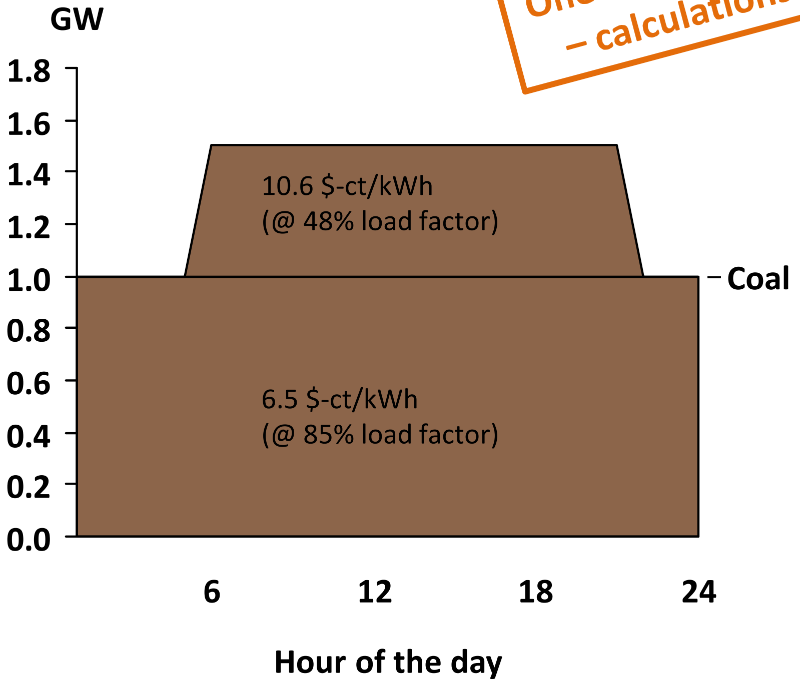


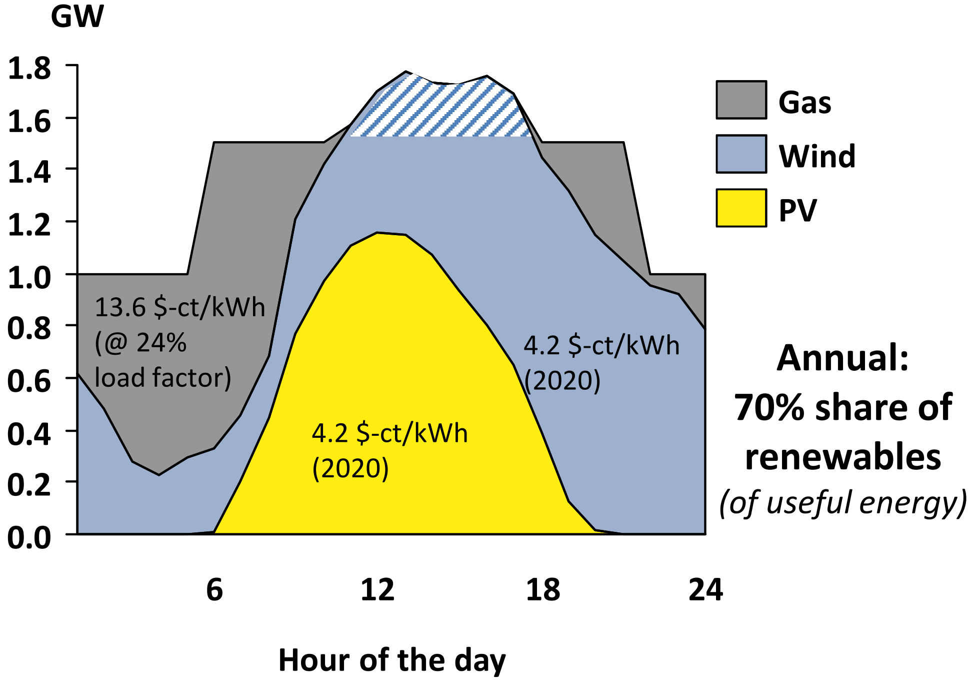
Note: Changing full-load hours for conventionals drastically changes the fixed cost components per kWh (lower full-load hours → higher capital costs and fixed O&M costs per MWh); Assumptions: average efficiency for CCGT = 50%, OCGT = 35%; coal = 37%; nuclear = 33%; IRP cost from Jan 2012 escalated with CPI to May 2015; assumed EPC CAPEX inflated by 10% to convert EPC/LCOE into tariff; CSP: 50% annual load factor and full utilisation of the five peak-tariff hours per day assumed to calculate weighted average tariff from base and peak tariff

Sources: IRP Update; REIPPPP outcomes; StatsSA for CPI; Eskom financial reports on coal/diesel fuel cost; CSIR analysis

By 2020, a mix of PV, wind and flexible gas (LNG-based) costs the same as new coal, even without any value given to excess wind/PV energy

One illustrative winter day in display – calculations done for a full year





Annual:
70% share of renewables
(of useful energy)

Technology:	Coal base / coal mid-merit
Size:	1.18 / 0.56 GW
Energy:	11.1 TWh/yr
Weighted cost:	**7.3 $-ct/kWh**
CO2:	~0.95 kg/kWh

Technology:	PV / wind / gas
Size:	1.5 / 2.0 / 1.61 GW
Energy (useful):	11.1 TWh/yr
Energy (total):	3.6 / 5.3 / 3.2 TWh/yr = 12.1 TWh/yr
Weighted cost:	**7.3 $-ct/kWh** *(per useful energy, i.e. no value given to excess)*
CO2:	~0.18 kg/kWh (per useful energy)

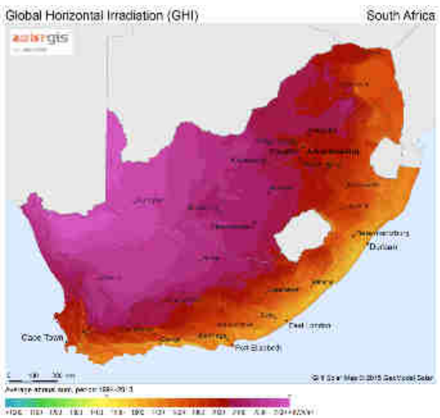
South Africa has abundant solar and wind resources

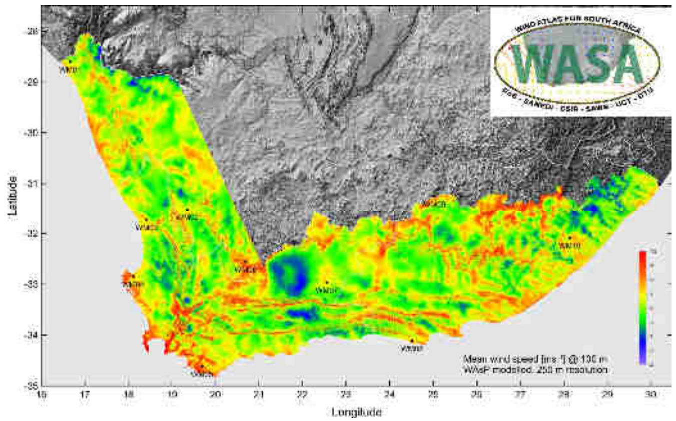
South Africa has some of the world's best solar and excellent wind resources, that until today are largely untapped

The Integrated Resource Plan 2010 plans for 8.4 GW of PV and 9.2 GW of wind by 2030 in South Africa

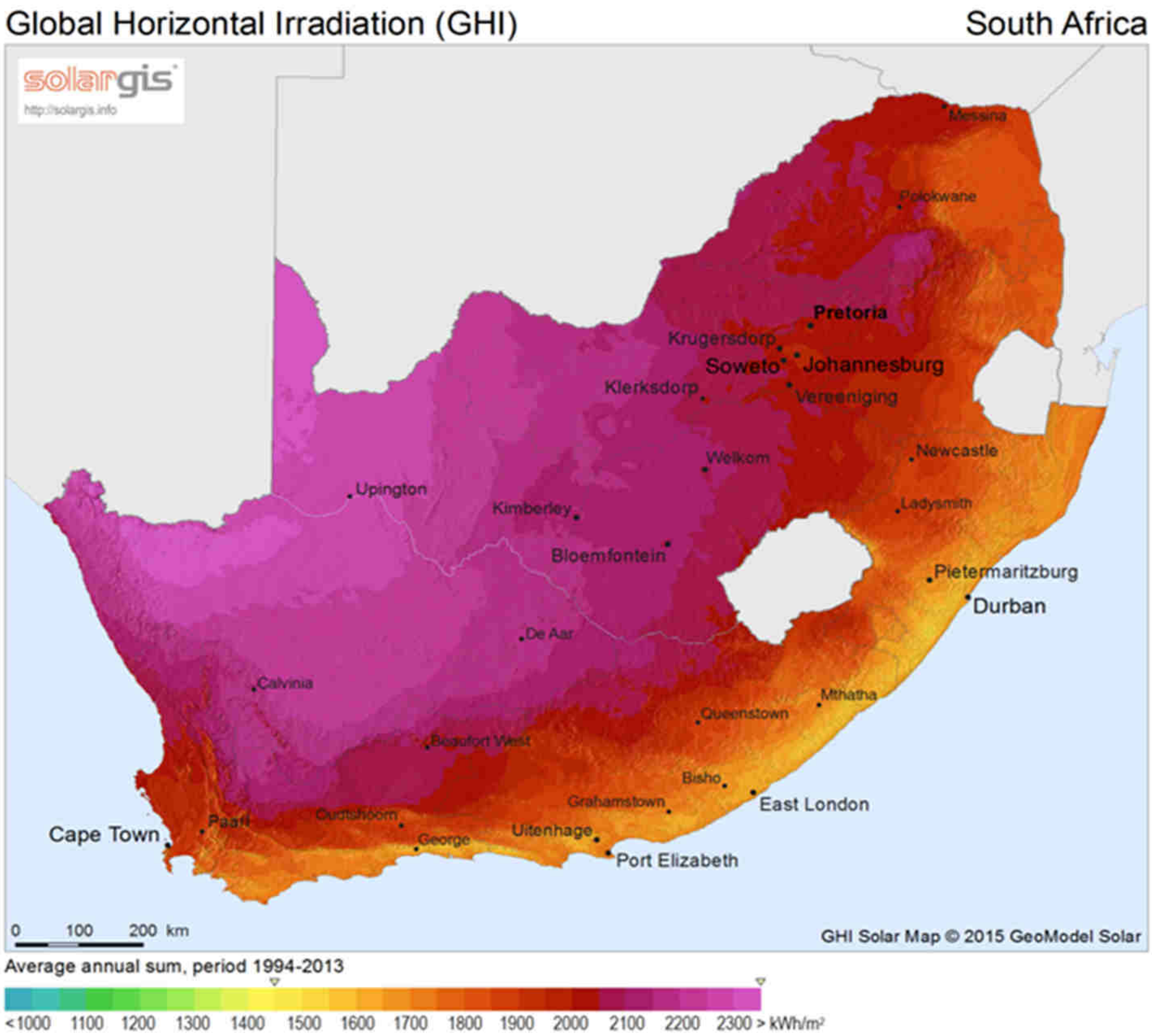
These targets which were developed five years ago are far below potential

Cost not a barrier anymore: new wind now costs 0.6 R/kWh (< 5 $ct/kWh) and new solar PV costs 0.8 R/kWh (6 $ct/kWh), based on actual PPA tariffs

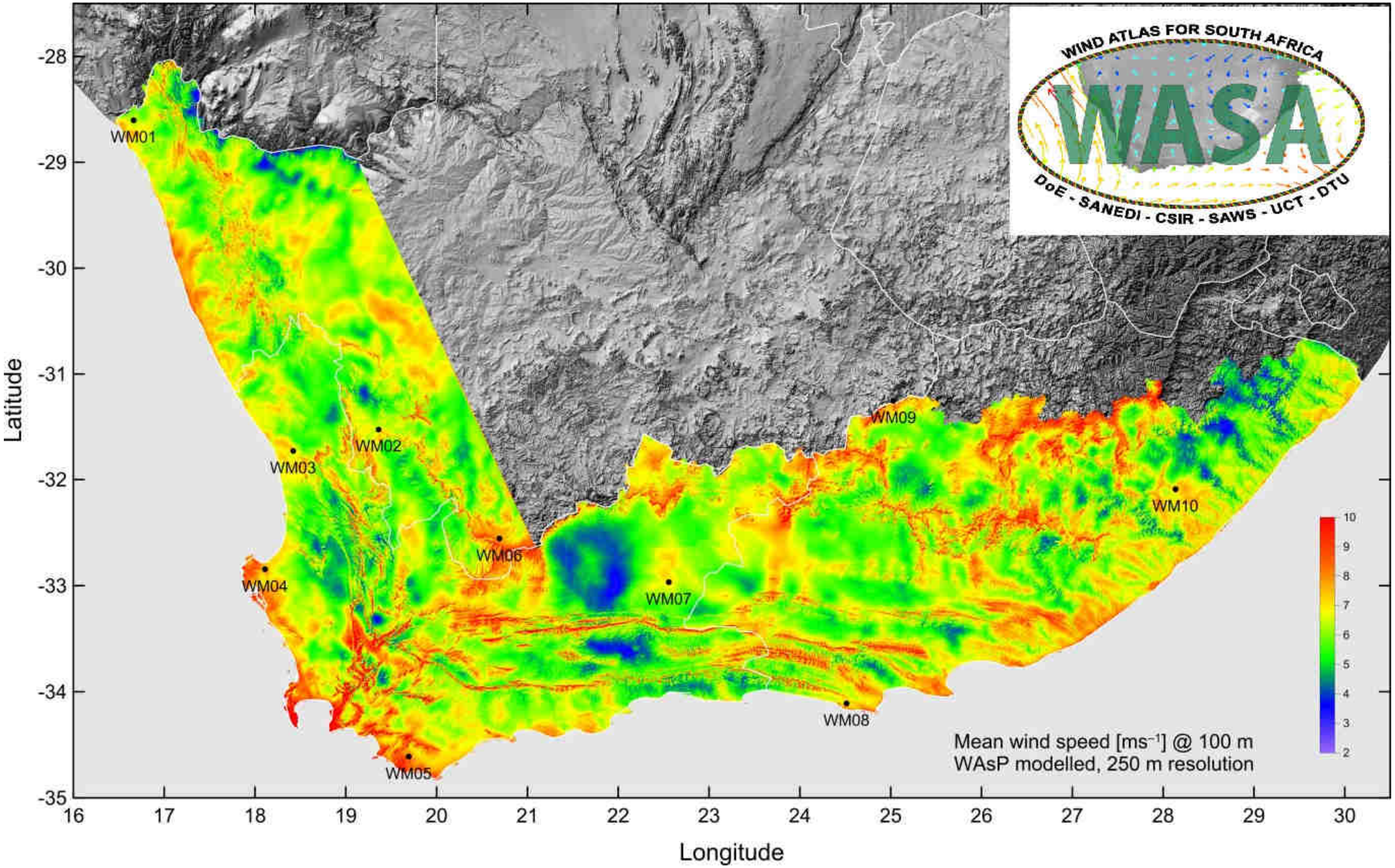




Solar PV resource in South Africa



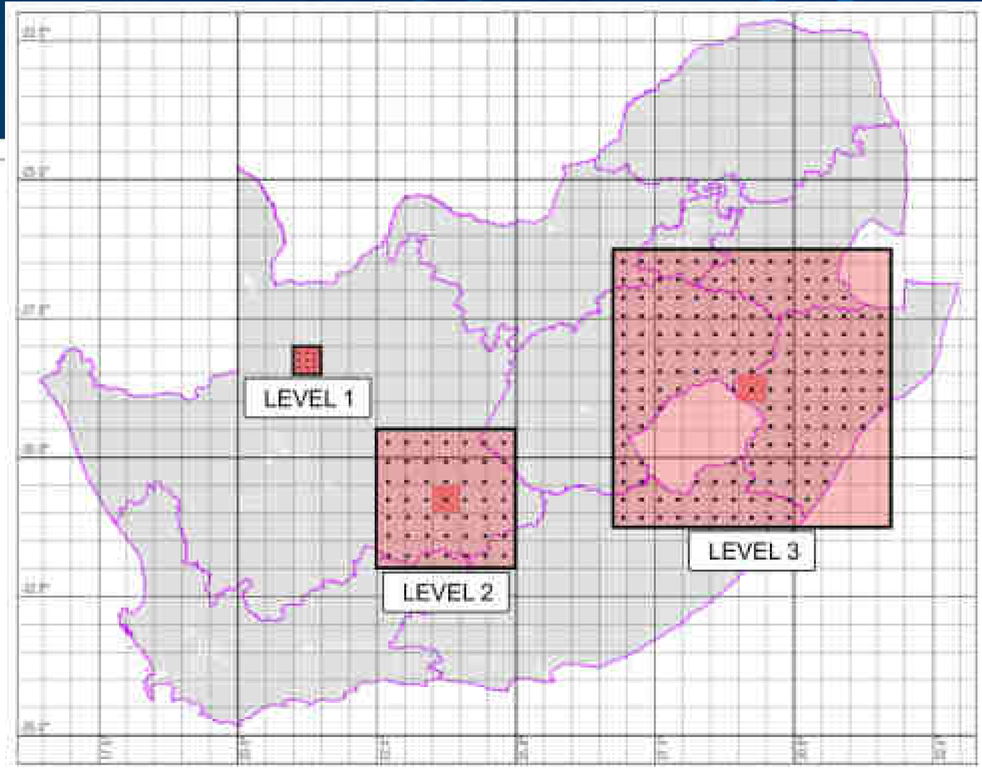
Wind energy resource in South Africa



Definition of aggregation levels

Regularly distributed power plants

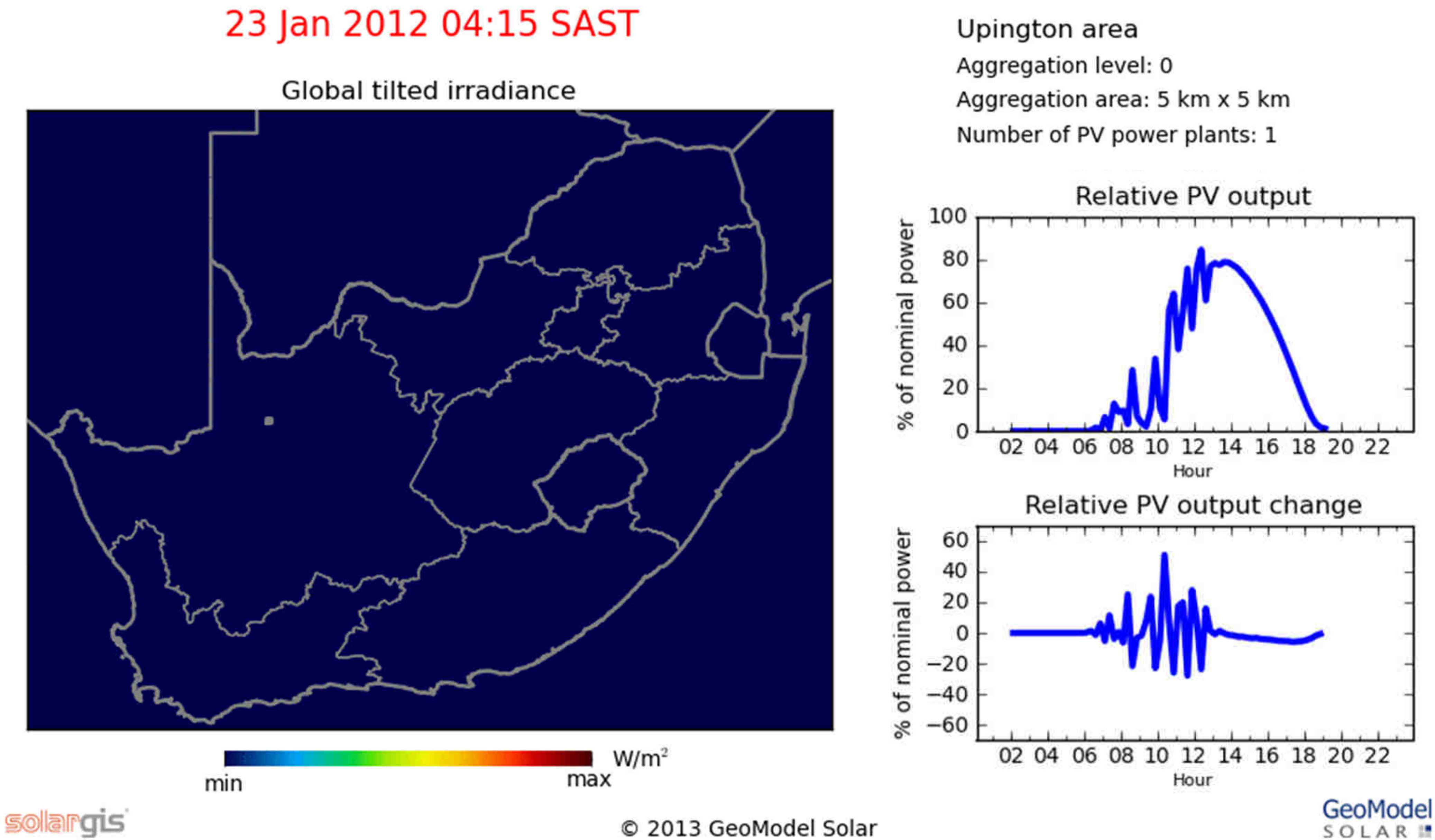
Equally-sized



Aggregation level	Size of square: Arc-degrees in the database	Size of square: Approximation in km	Number of power plants
Level 0	0.05°	5 x 5	1
Level 1 (reference)	0.5°	50 x 50	9 (3 x 3)
Level 2	2.5°	250 x 250	49 (7 x 7)
Level 3	5.0°	500 x 500	225 (15 x 15)

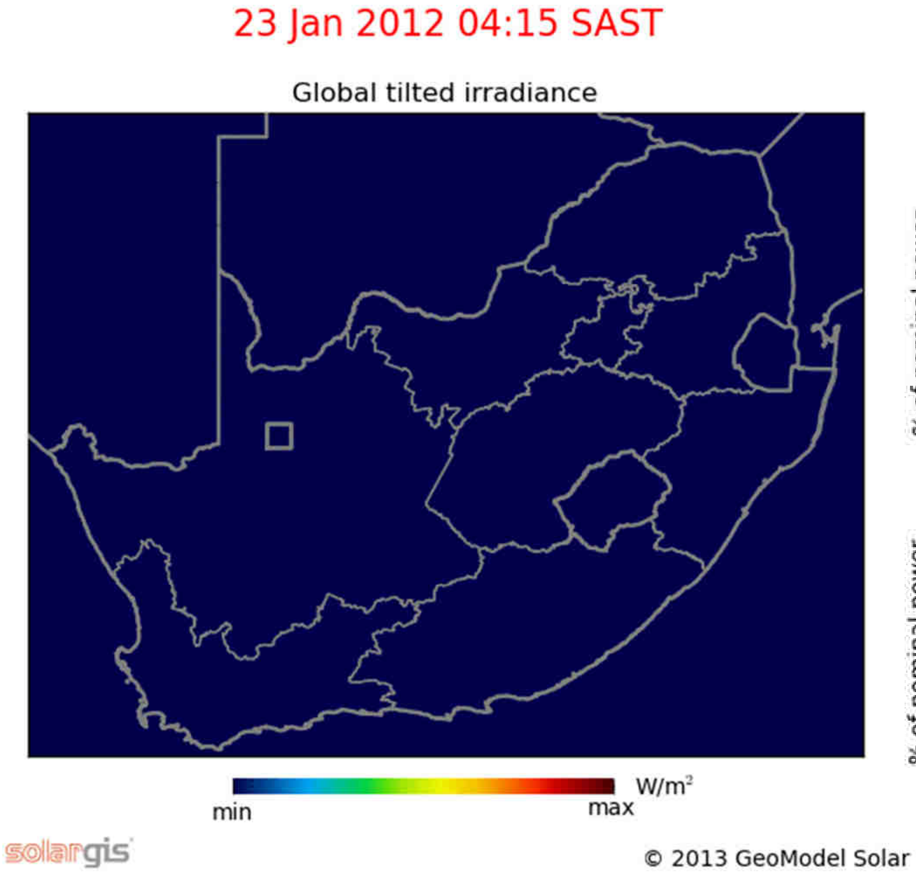
Source: Cloud Cover study commissioned by Eskom

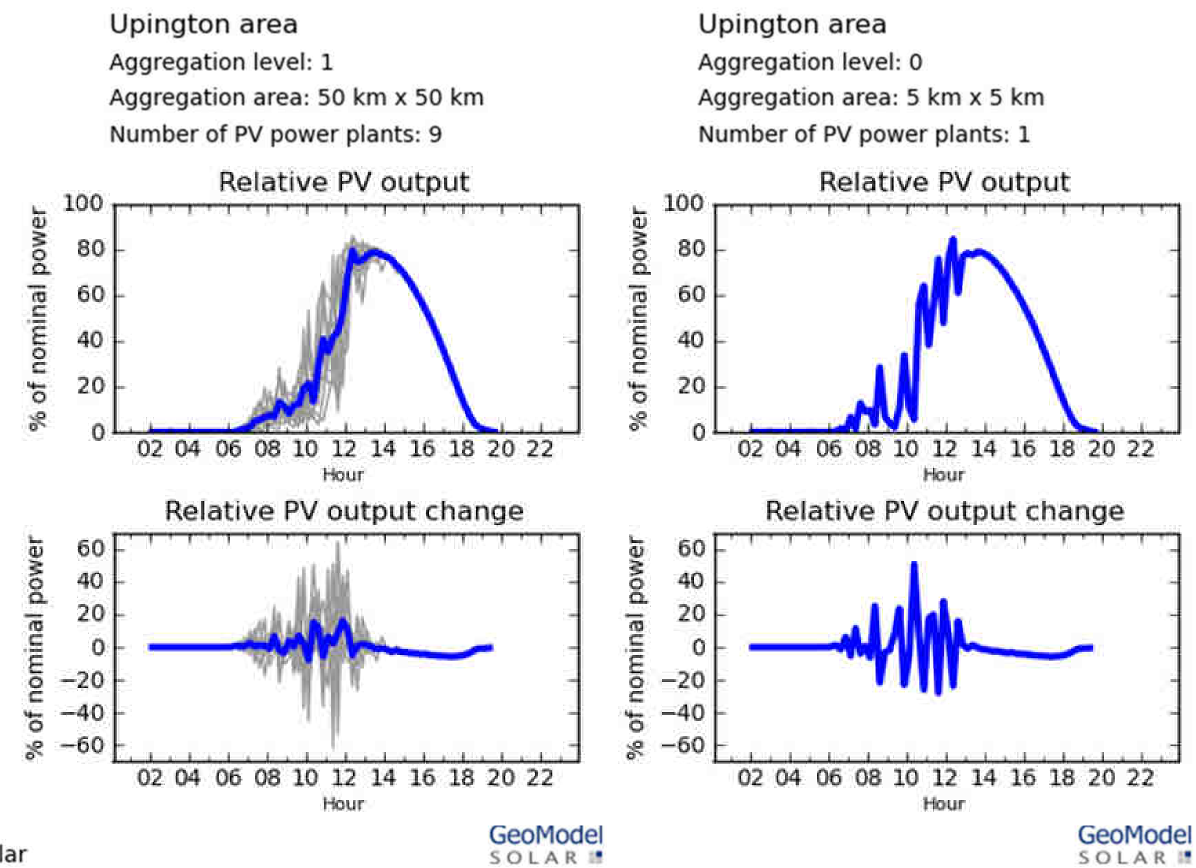
Cloud impact on PV:
A single PV plant's power output has very high fluctuations



Source: Cloud Cover study by Stellenbosch and GeoModel Solar, conducted on behalf of Eskom

Aggregating only 9 PV plants in a relatively small area already reduces fluctuations significantly





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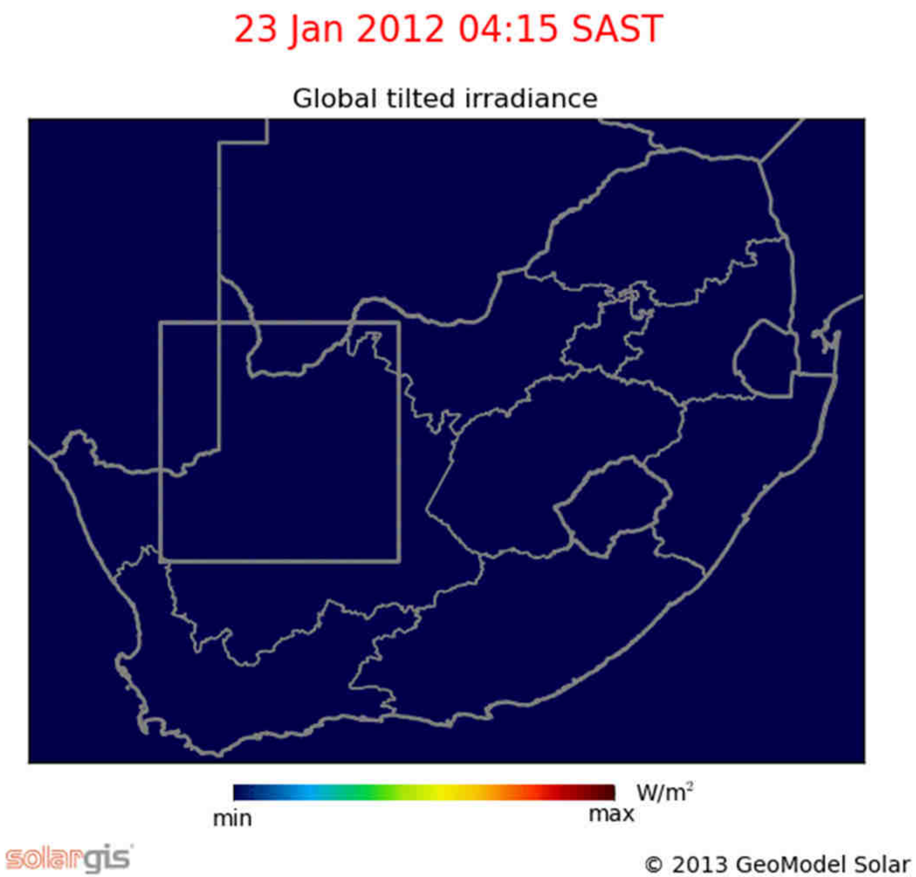
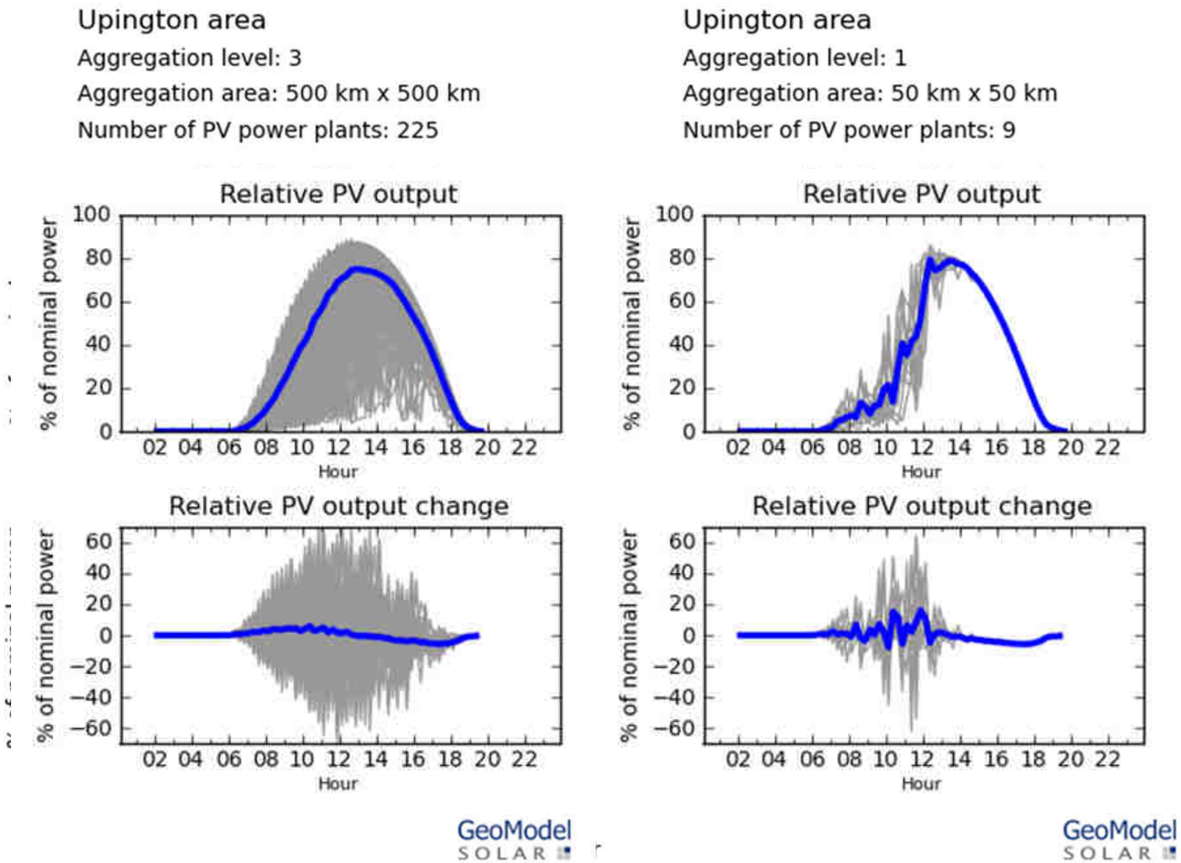
Source: Cloud Cover study by Stellenbosch and GeoModel Solar, conducted on behalf of Eskom

Aggregating 225 PV plants over 500 x 500 km reduces short-term fluctuations to almost zero





Widespread spatial distribution makes aggregated PV power output very predictable and smooth

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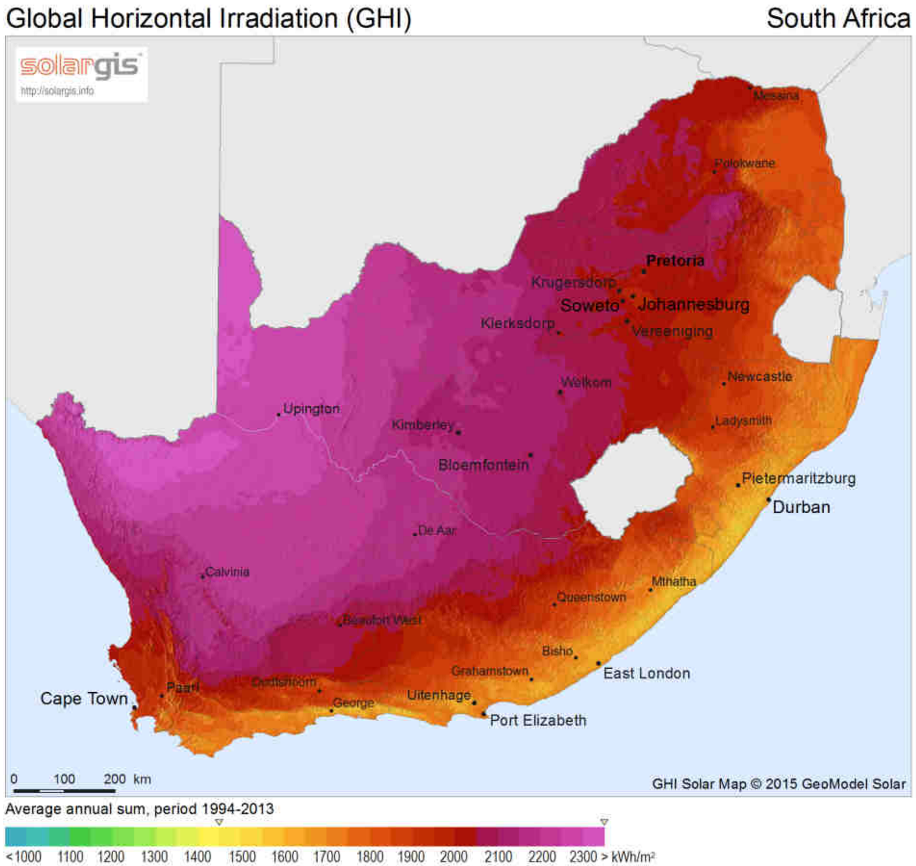
Source: Cloud Cover study by Stellenbosch and GeoModel Solar, conducted on behalf of Eskom

South Africa has almost 2-times the solar resource as Germany, where PV is close to cost competitiveness

Solar resource in South Africa…



SA's planned PV capacity by 2030: 8.4 GW target too low

… as compared to Germany

Germany's status today: almost 40 GW PV installed capacity (roughly one Eskom)

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Wind and solar aggregation study: Main objective to quantify the effects of spatial distribution on output

Increase the fact base and understanding of aggregated wind and PV power profiles for different spatial distributions in South Africa

Generate data sets that can be used for various studies (IEP, IRP, TDP, SEA etc.)

Resulting in:

- Confidence in integrating higher renewables shares
- Optimal mix of wind and PV, to minimise cost and maintain grid stability easier

Transfer of knowledge and skills on utilising wind data in energy-planning activities

The study is currently being conducted for South Africa

- Wind and solar data sets covering the entire country
- 5x5 km spatial resolution, 15-minute time resolution, 5 years of data
- Spatial load data for the entire country

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Visit by CSIR/Eskom/UCT to Fraunhofer IWES

7 guests from 17.8.2015 to 11.9.2015

<u>Topics</u>

- Collaborative project work
- Workshops
  - WindPRO course
  - Micro-scale wind modelling workshop
  - Presentation of a virtual power plant (Kombikraftwerk)
- Excursions
  - 200m met mast
  - Wind farm

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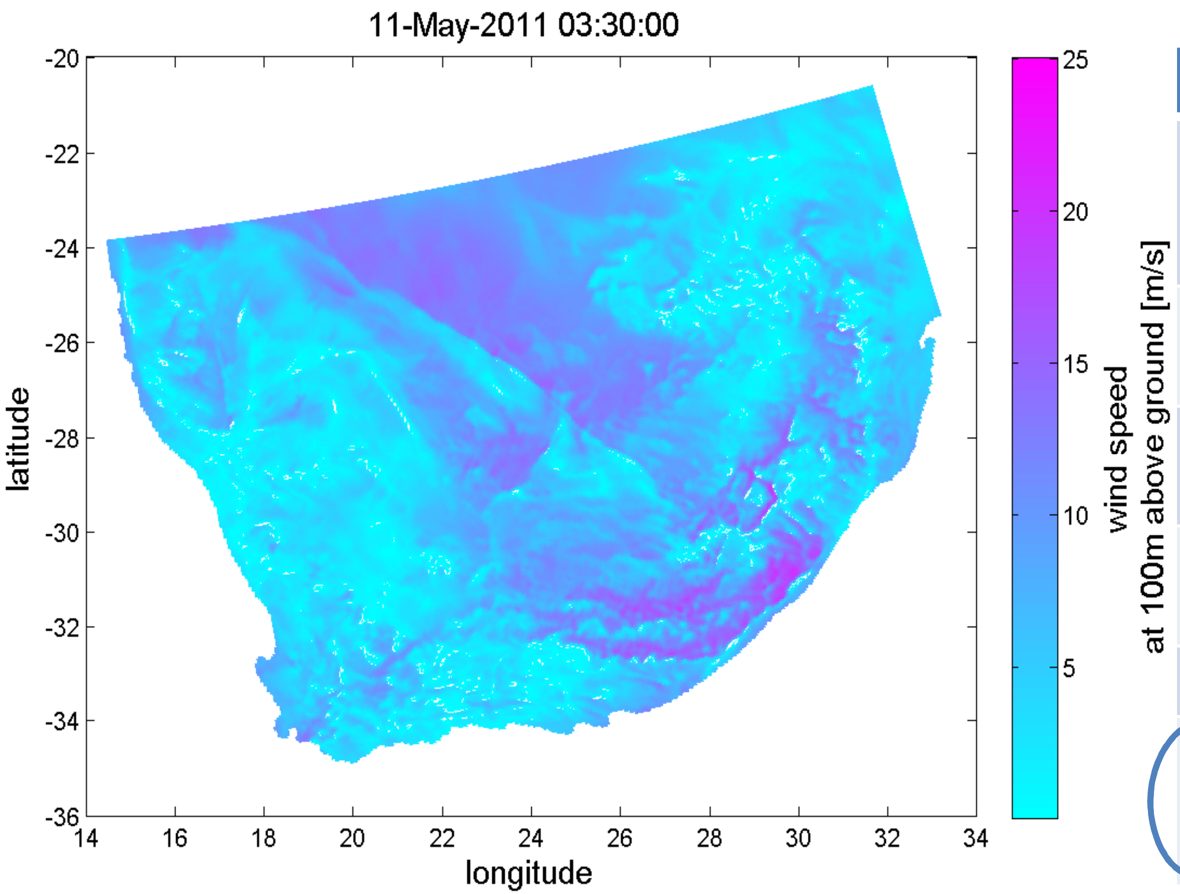
Processed weather data



	WASA	SODA
Variables	Wind speed v TKE Temperatur T	Solar irradiation
Height levels [m]	2 (T), 50, 80, 100, 150 (v)	2
Temporal coverage	2009 to 2013	2010 to 2012
Temporal resolution	15min	15min
Spatial coverage	South Africa	South Africa
Spatial resolution	5km x 5km → 47522 grid squares	0.2° x 0.2°

usefulness will be analysed

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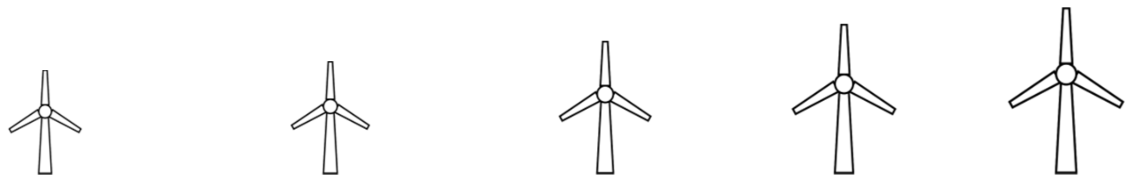
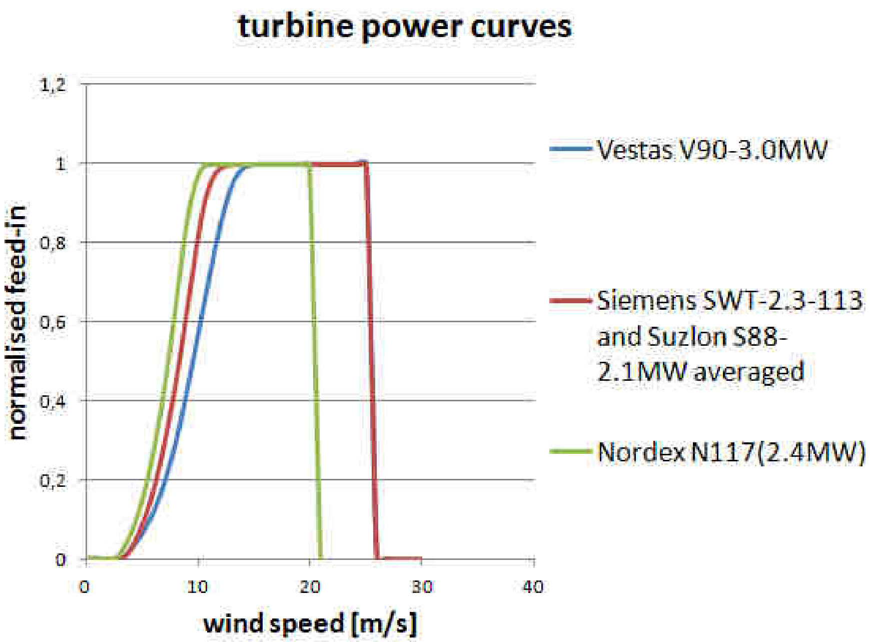
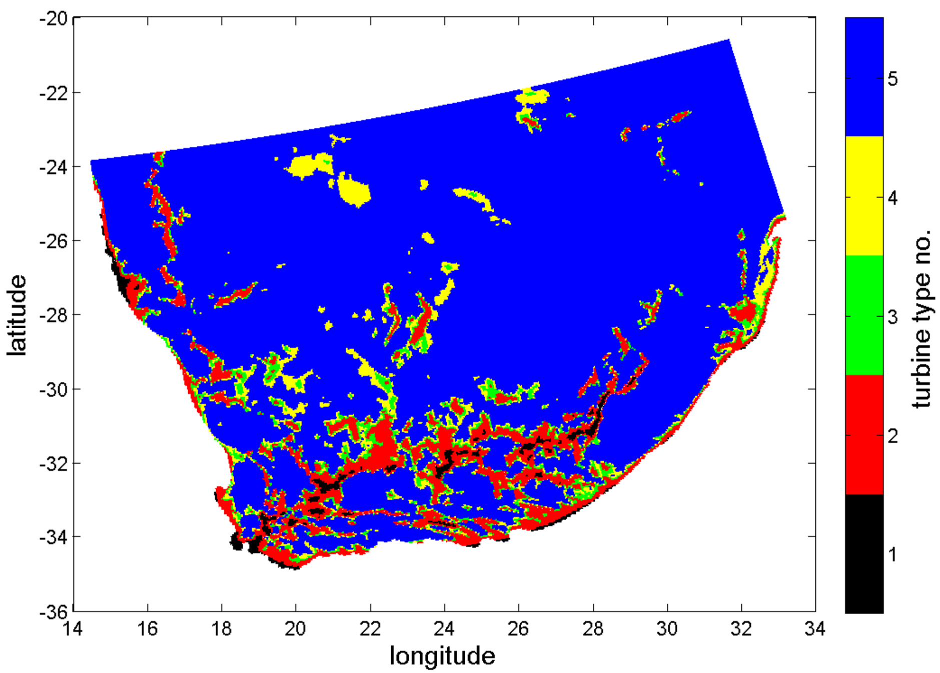
Turbine definition and positioning

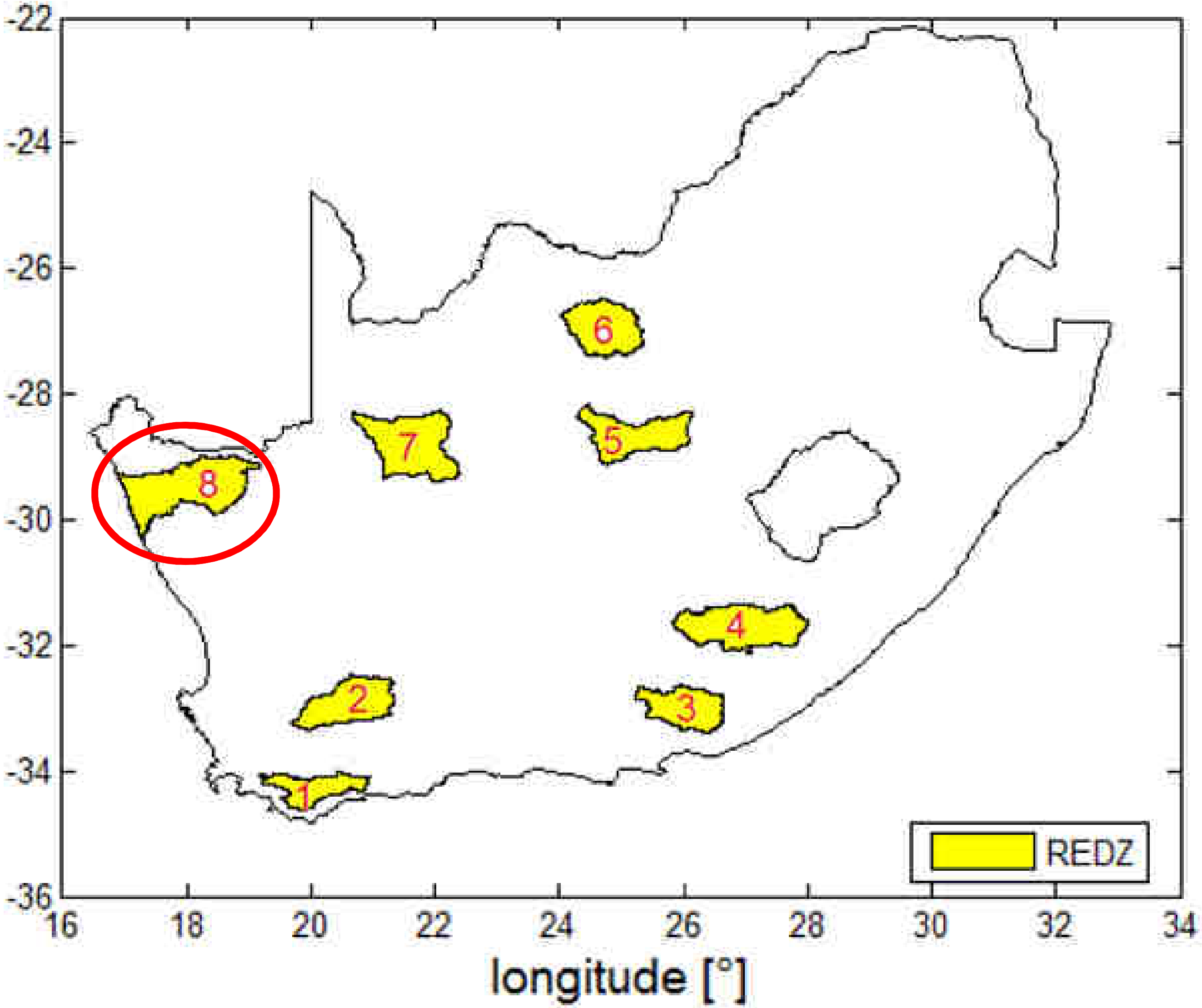


Hub height [m]	80	80	100	120	140
Installed capacity [MW]	3	2.2	2.4	2.4	2.4
Selection criterion	$v_{80m}>0$	$v_{80m}<8.5$	$v_{100m}<7.5$	$v_{120m}<7.5$	$v_{140m}<7.5$
Turbine type	Vestas V90-3.0MW	Siemens SWT-2.3-113 and Suzlon S88-2.1MW averaged	Nordex N117(2.4MW)	Nordex N117(2.4MW)	Nordex N117(2.4MW)
Turbine type no.	1	2	3	4	5





Renewable Energy Development Zones (REDZ)



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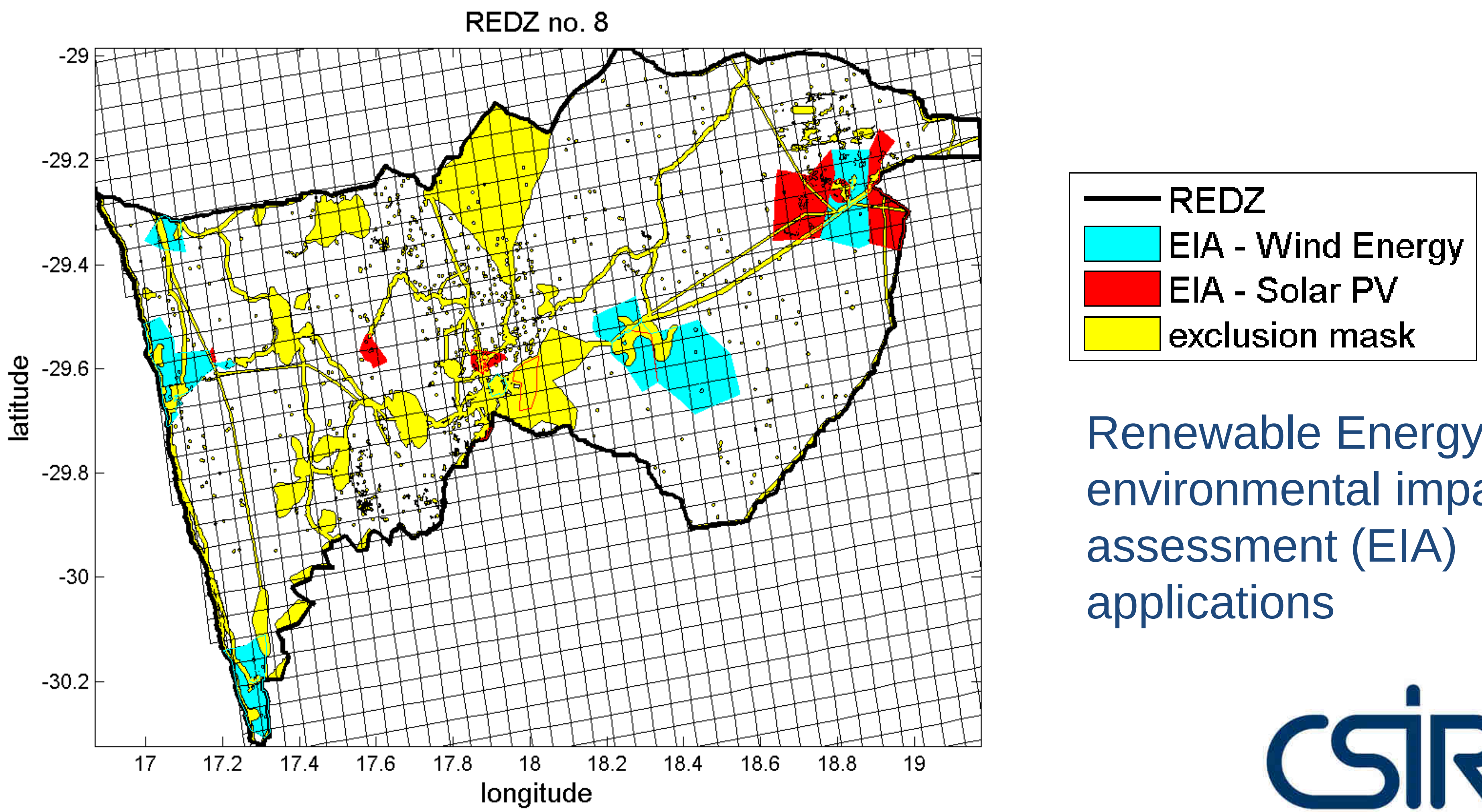
EIA applications and exclusion zones



Renewable Energy environmental impact assessment (EIA) applications

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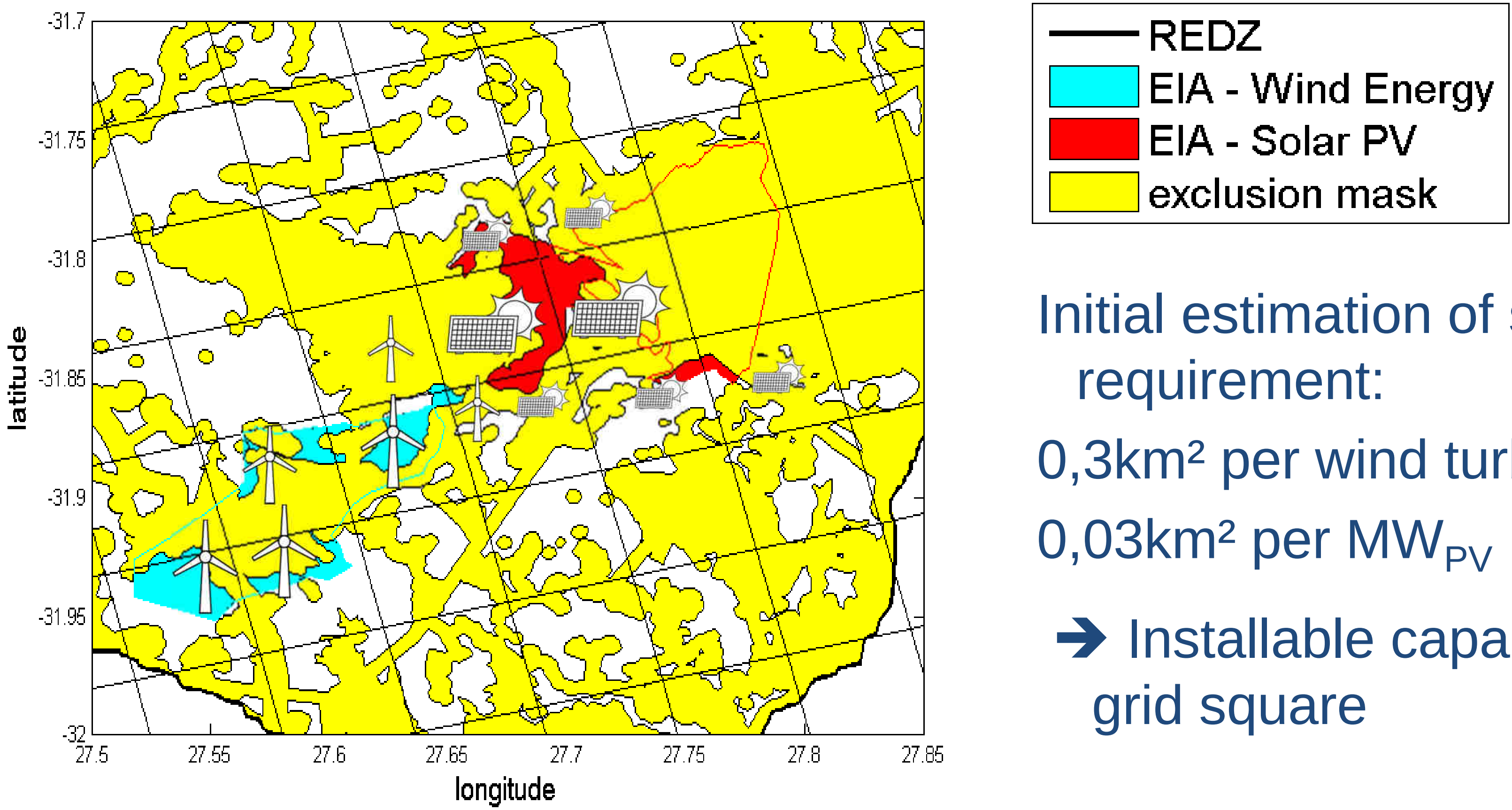
Static wind power and PV scenario



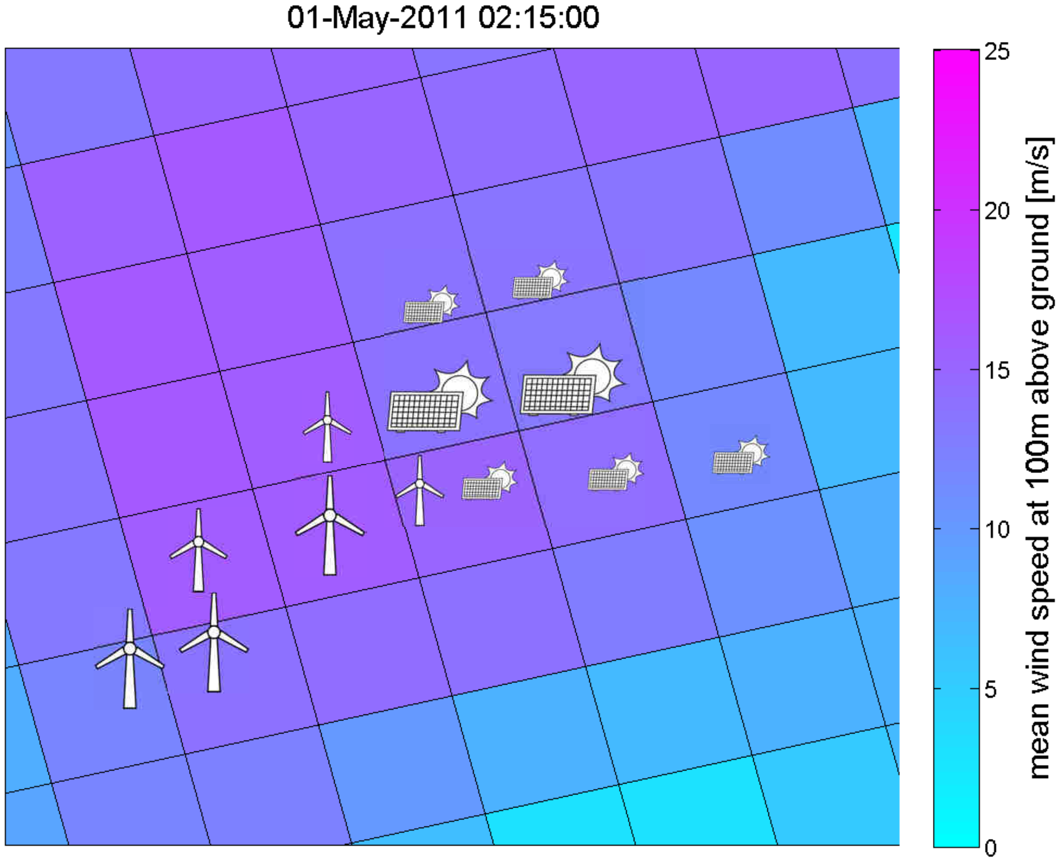
Initial estimation of space requirement:

0,3km² per wind turbine

0,03km² per MW_{PV}

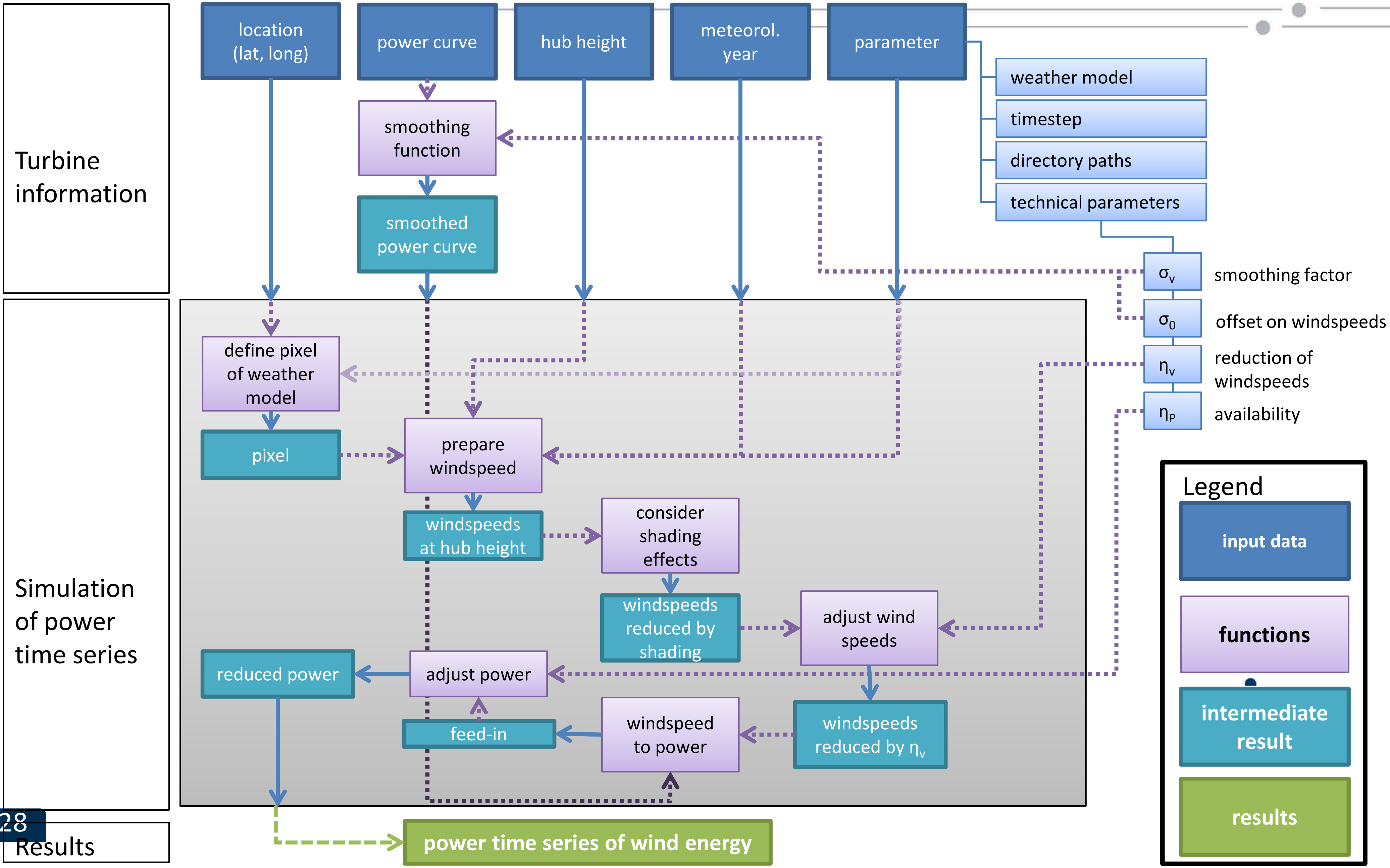
➔ Installable capacity per grid square

Dynamisation via historical weather data

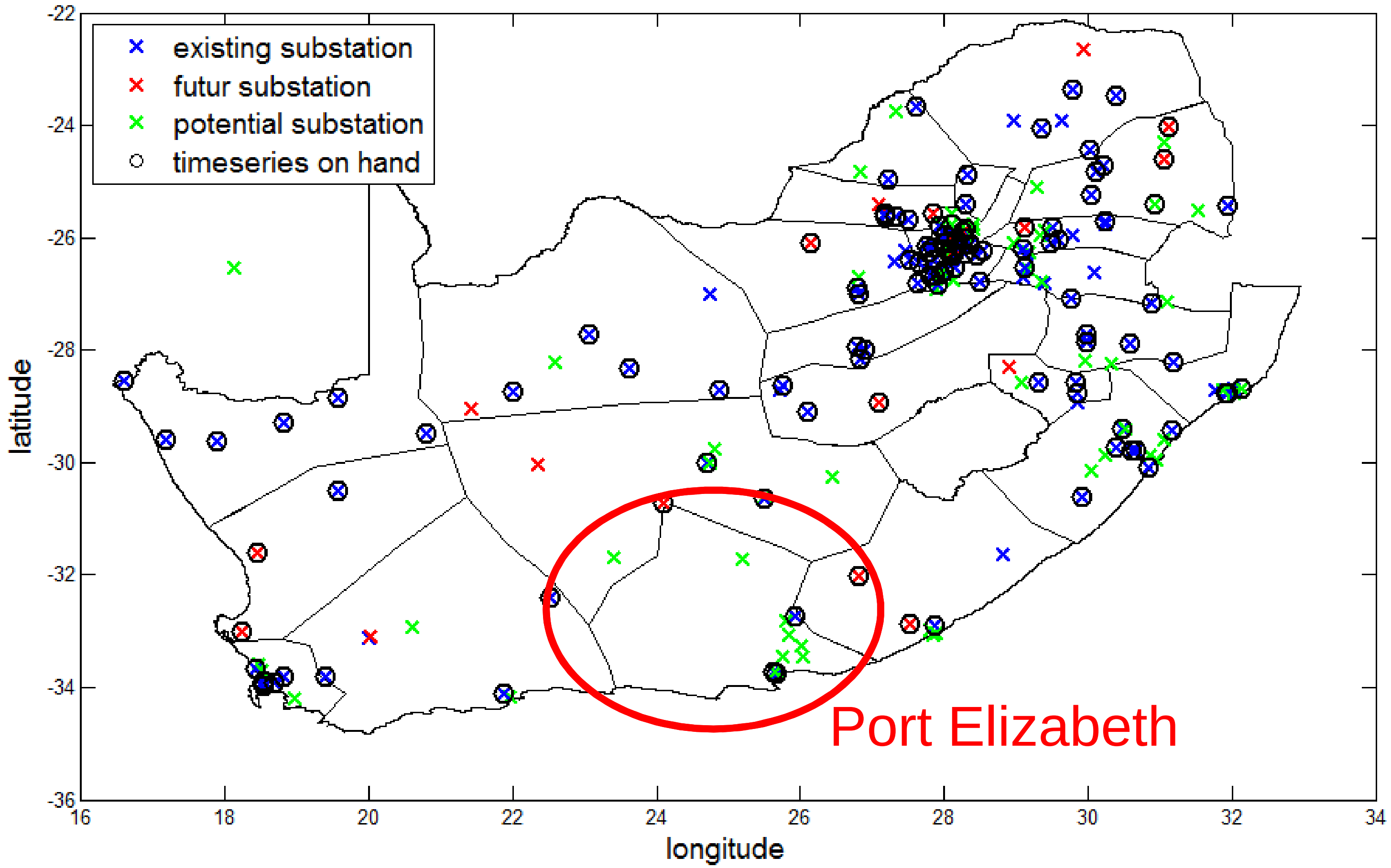


Electrical power feed-in via physical models (e.g. turbine power curves, hub heights, etc.)

Model of wind power simulation



Transmission grid topology



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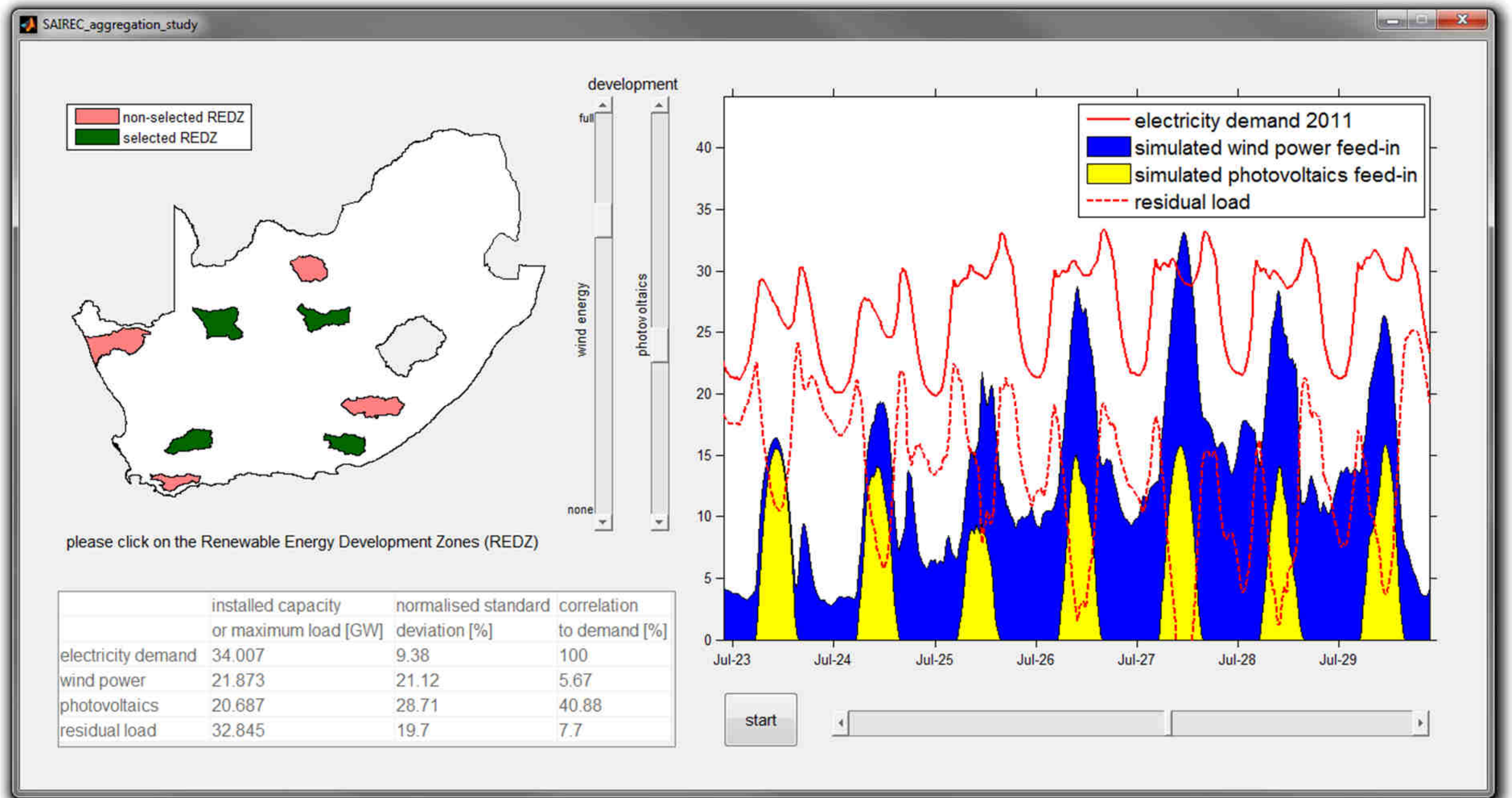
Animated graphical user interface



	installed capacity or maximum load [GW]	normalised standard deviation [%]	correlation to demand [%]
electricity demand	34.007	9.38	100
wind power	21.873	21.12	5.67
photovoltaics	20.687	28.71	40.88
residual load	32.845	19.7	7.7

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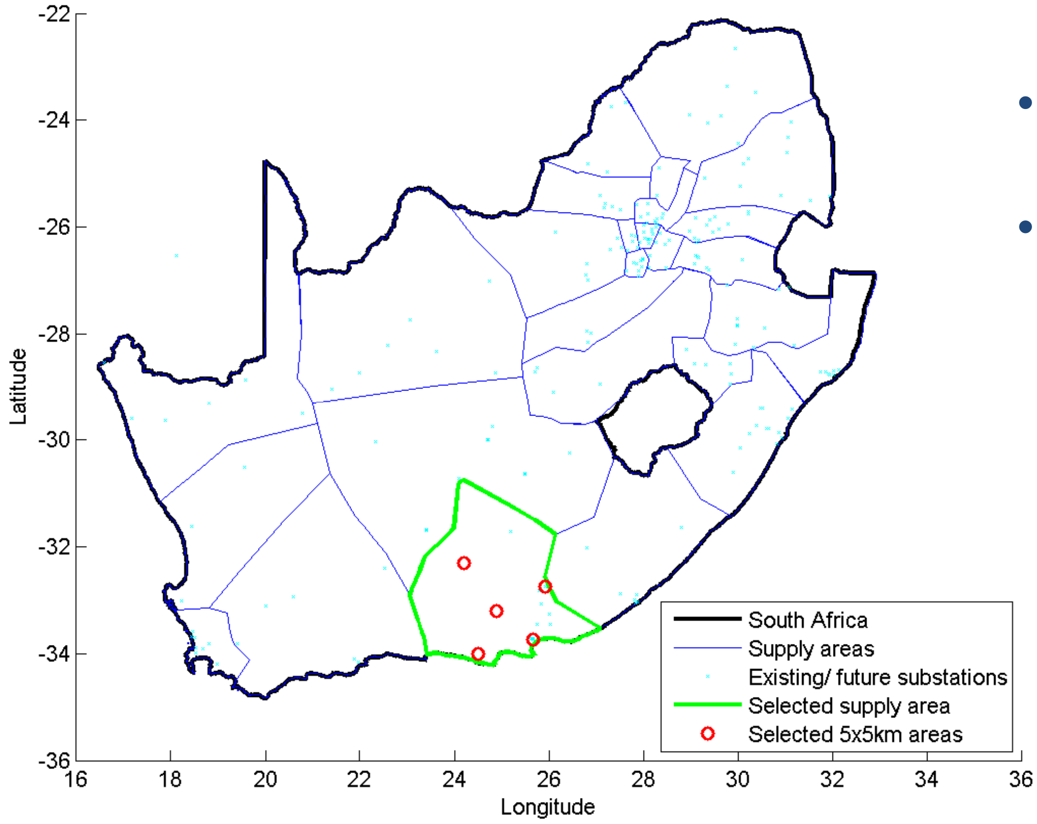
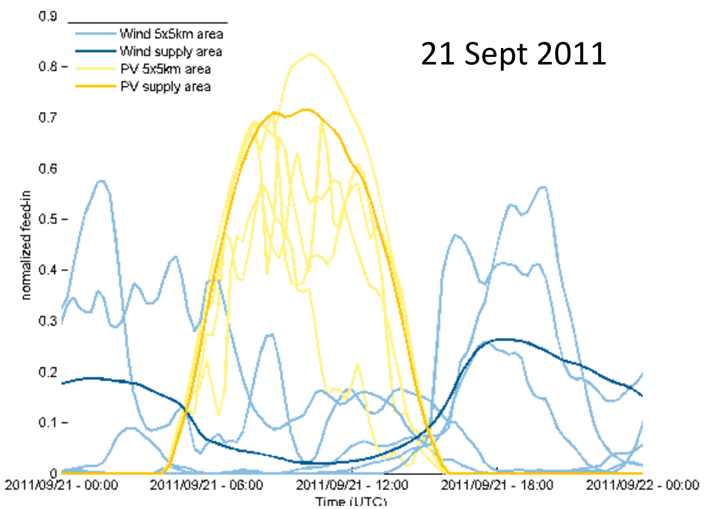
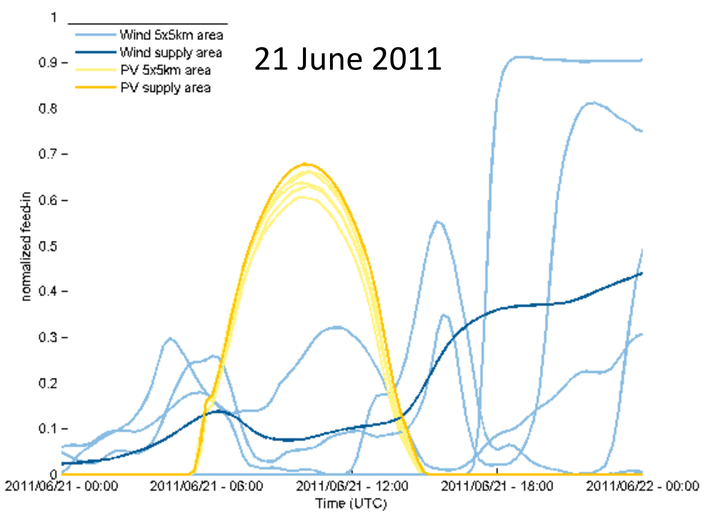
Preliminary study for the Port Elizabeth area



- Five areas/sites (5x5km each) selected as generation sources
- 2011 Wind (WASA) and solar PV profiles (Geomodel Solar) used

First results show on two specific days how volatility of wind and solar reduces with spatial aggregation





- Individual plants have high ramp rates
- Individual plant power output very volatile; low predictability

- Area (aggregated) output is much smoother with low ramp rates
- Aggregated plant output is more predictable

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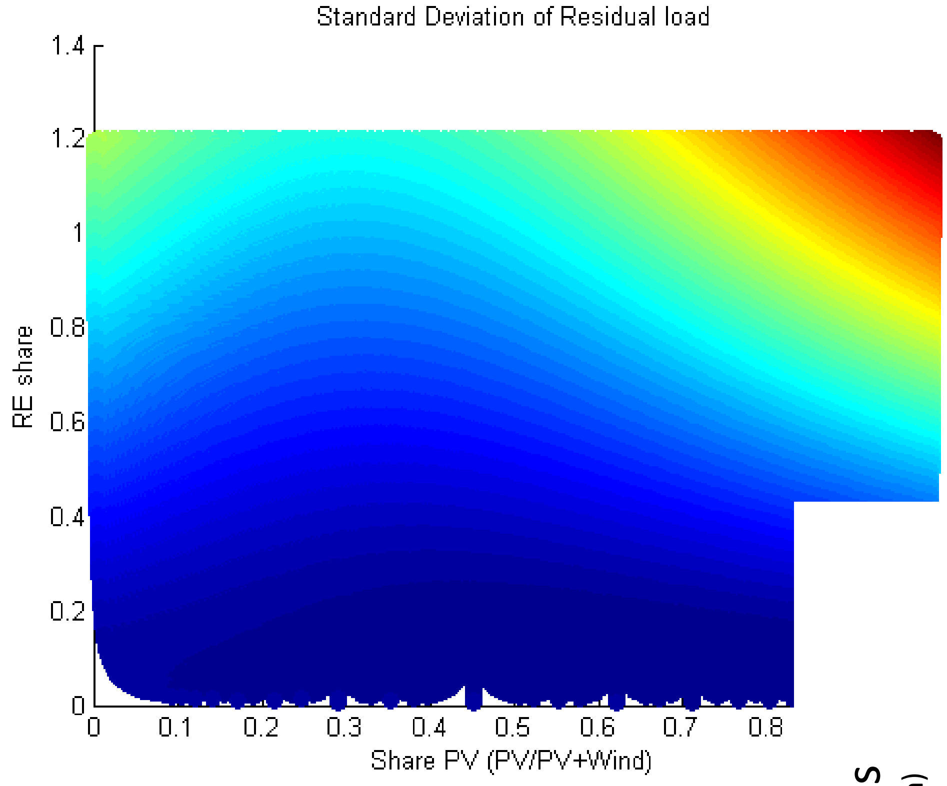
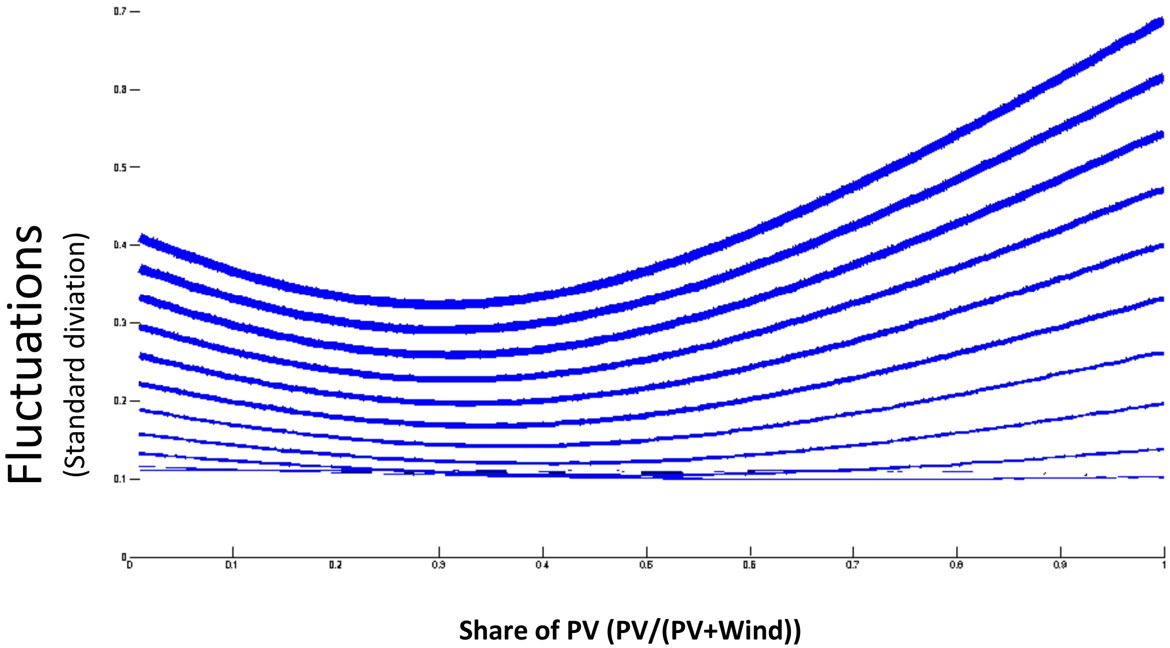
Preliminary results:
Optimisation of fluctuations for PE region suggests mix of wind and PV





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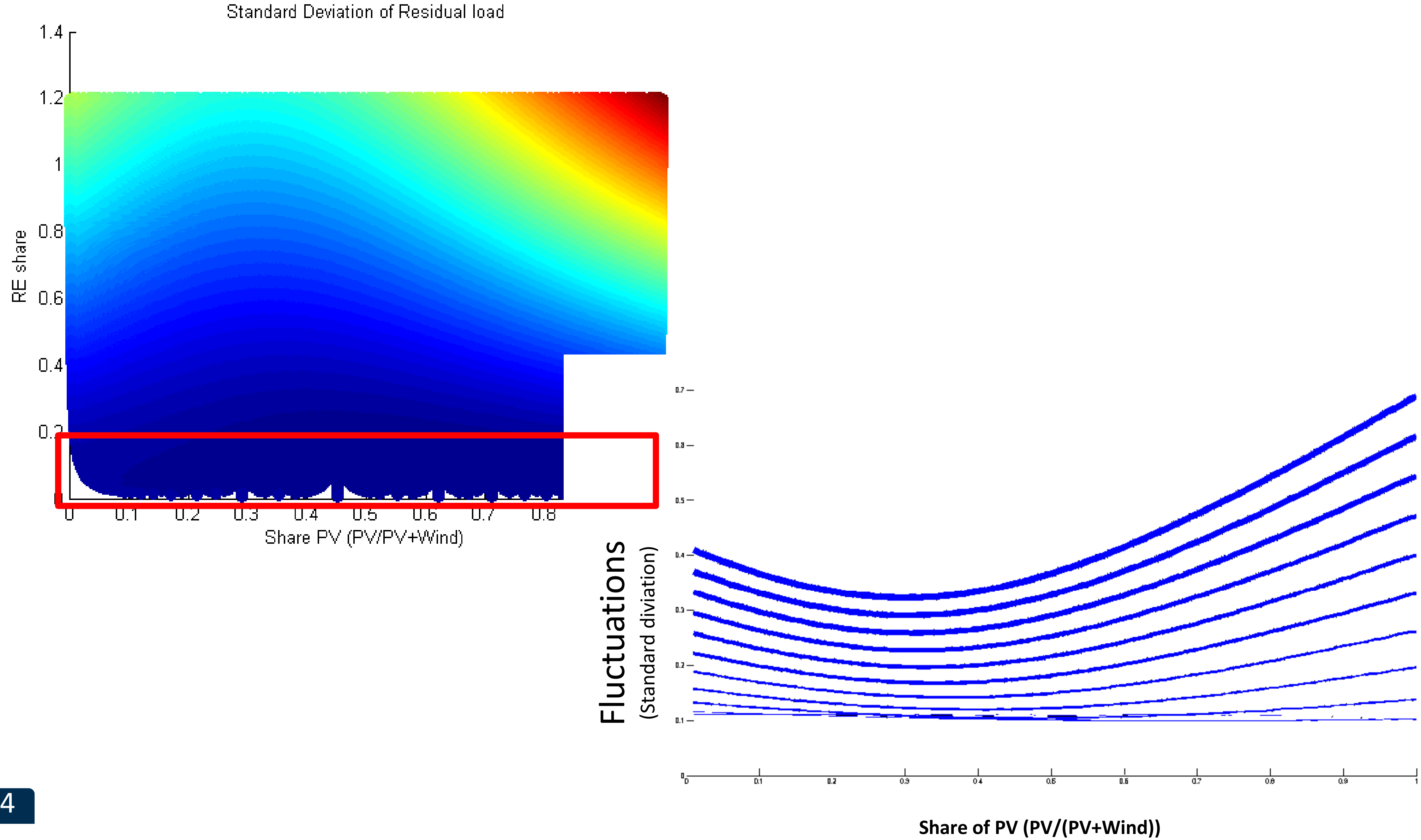
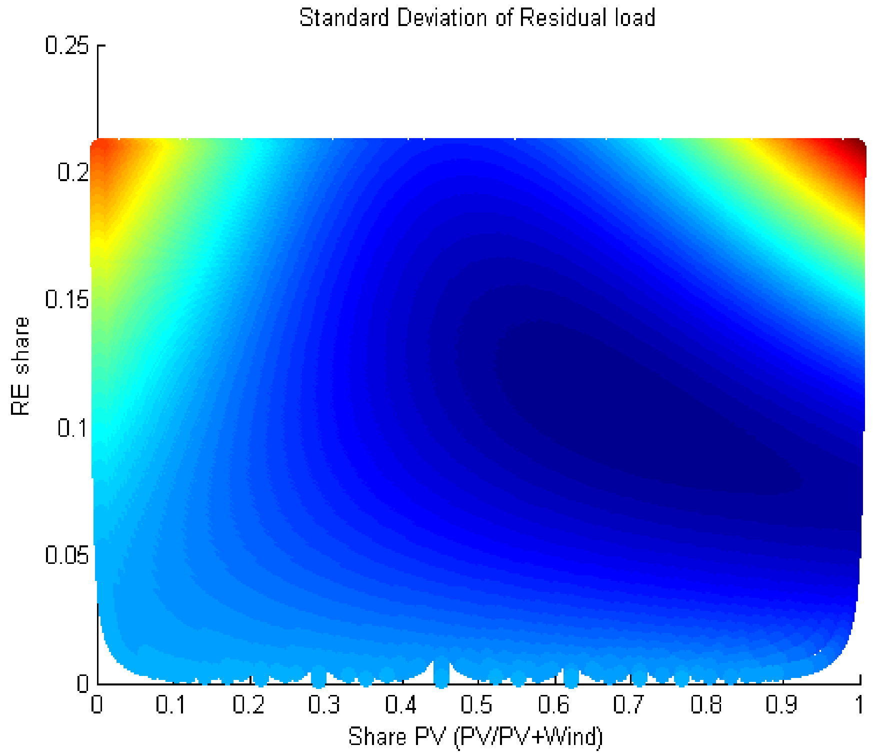
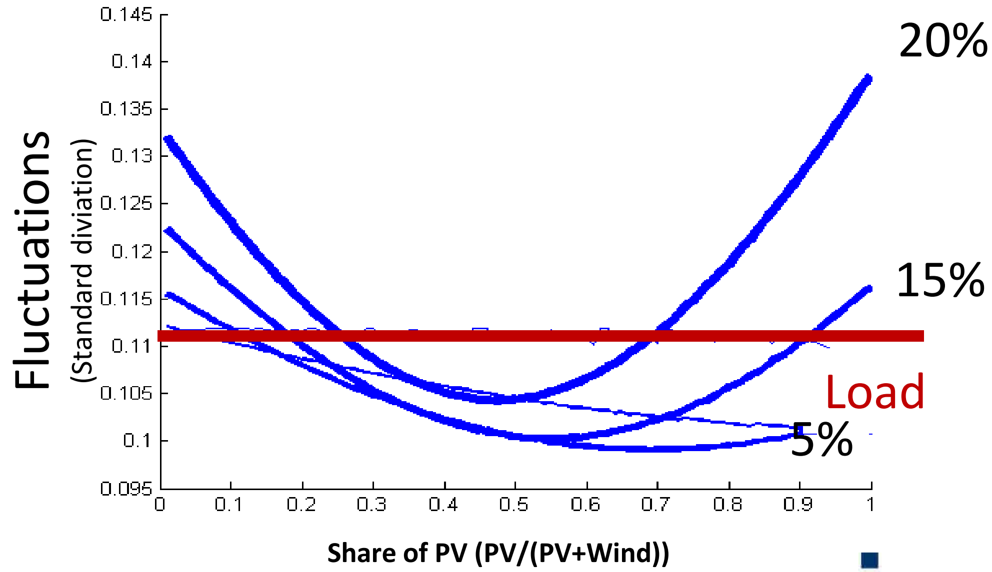


Preliminary results:
First renewables capacities decrease the fluctuations in the load





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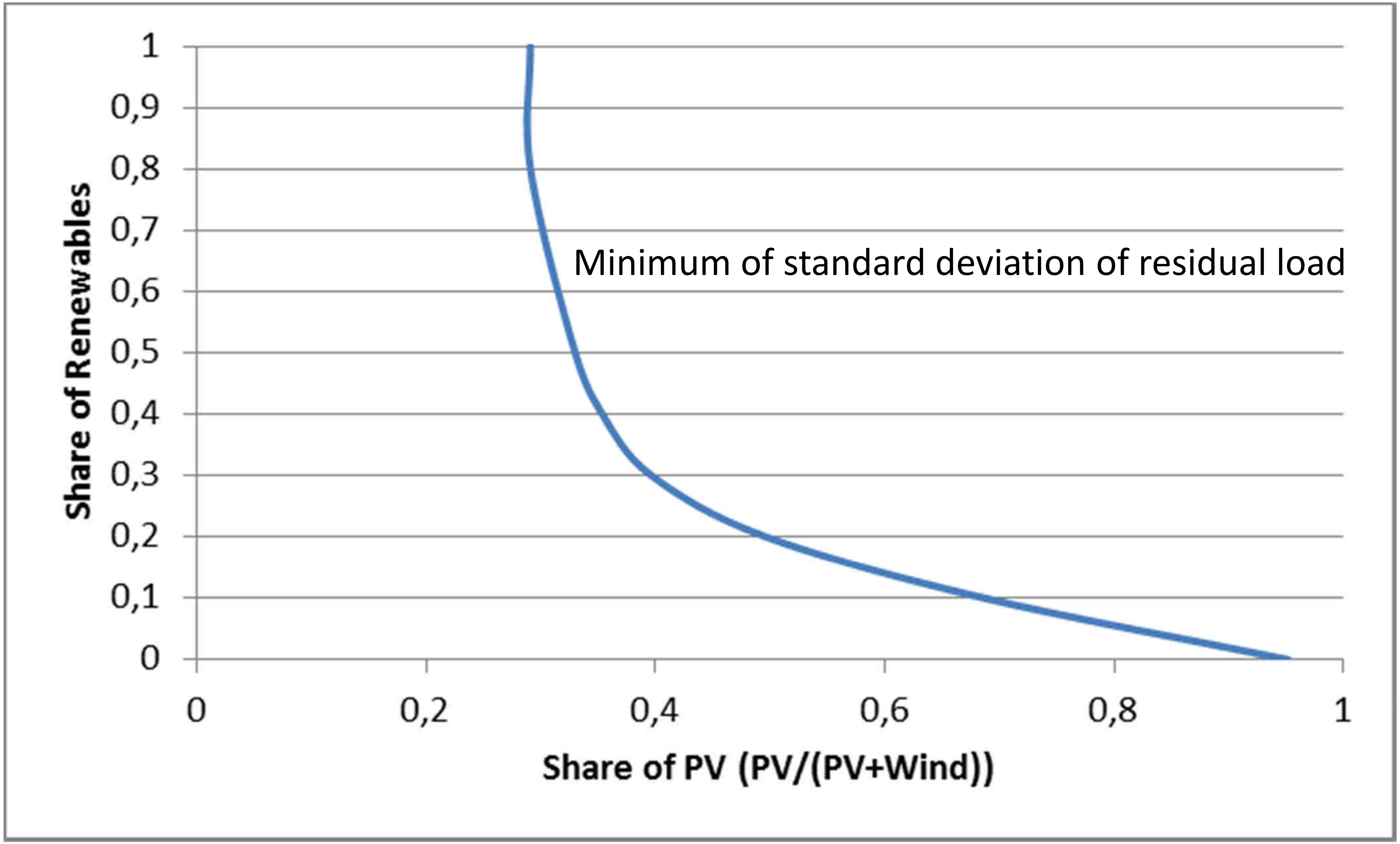
Preliminary results:
Optimal mix of PV and wind based on reducing standard deviation



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Acknowledgements and contribution

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Next steps

Analysis for the for 27 load areas covering the whole country

Include the load profile in the analysis to determine the residual load (Load – PV – Wind) – Done!

Estimate the resource potential

Country wide analysis for different shares of wind and PV

Determine residual metrics that can be used to determine the capability of conventional plants

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Scenario development

Wind energy scenarios

- "Scientific" (all land mass minus exclusion areas)
  - Uniform resource distribution
  - All-in-one-place
  - 2-3 distributions between uniform and all-in-one-place
  - “Optimised” resource distribution (objective function(s) to be determined)
- EIA-focused resource distribution
- REDZ-focused resource distribution (see animation)
- Grid-today-focused resource distribution; TDP grid will be used.
- Grid-in-future-focused resource distribution; year 2024 as per TDP will be used
- Population-density resource distribution
- High-wind-speed resource distribution
- All scenarios for three different constant-energy-supply levels of wind energy: 50, 100, 250 TWh/yr

PV scenarios

- 30% of PV capacity in high-solar areas (as per EIAs), 70% scaled with population density
- 2-3 additional extreme PV scenarios, e.g. 50/50 in Cape Town/Durban vs. all in one spot

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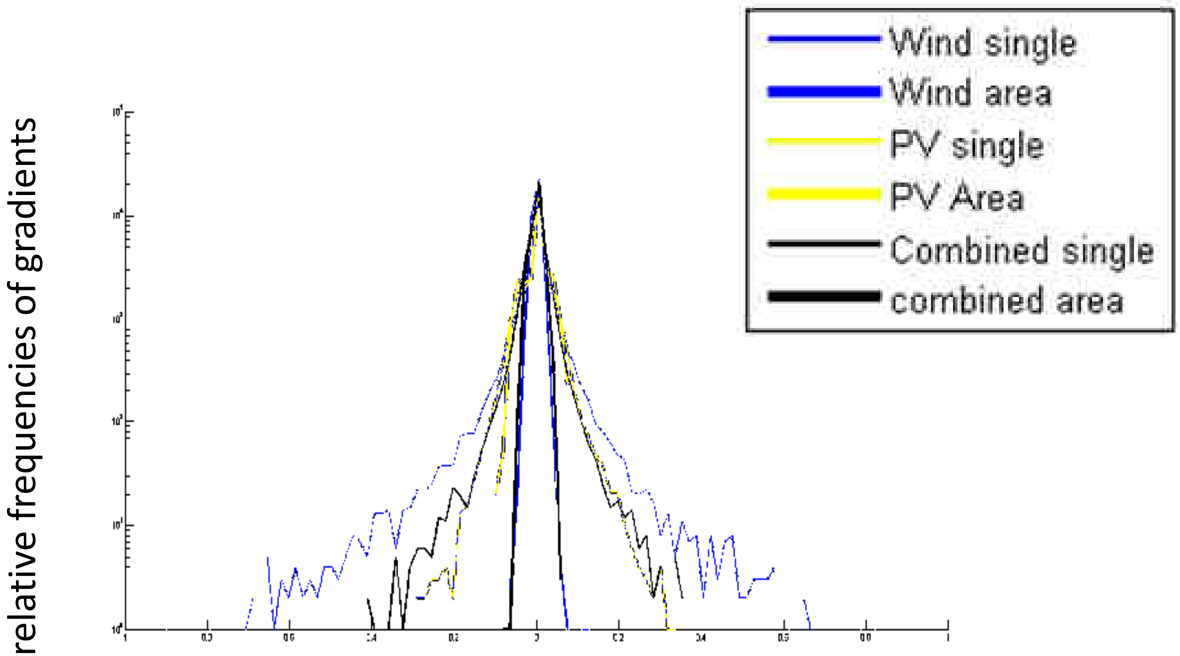
Quantification of aggregation effects

Analysis of the

scenarios in terms o

- power gradients
- power predictability
- power availability



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