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Modelling CSP Plant Scenarios in South Africa

CSP today

CSP Today South Africa 2013

4 February 2013

Paul Gauché, Stefan Pfenninger, Warrick Pierce, Georg F. Schneider, Liam May**, Adriaan J. Meyer***, Theodor W. von Backström and Alan C. Brent*

*Stellenbosch University (SU), *International Institute of Applied Systems Analysis (IIASA) & Imperial College, **GeoSUN Africa, ***UCT & SU*

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Agenda

- About STERG at Stellenbosch University
- **Strategic analysis:** CSP for South Africa's energy system
- **Start now:** R2+/kWh CSP now & baby steps is valuable
- **Extreme scenario:** CSP baseload case
- **Low hanging fruit 1:** Coal augmentation / boosting
- **Low hanging fruit 2:** Peaking CSP replacing OCGTs
- **Longer term:** CSP in a high RE scenario

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www.sun.ac.za/sterg

ABOUT STERG

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STERG – Only formal CSP research group in SA*

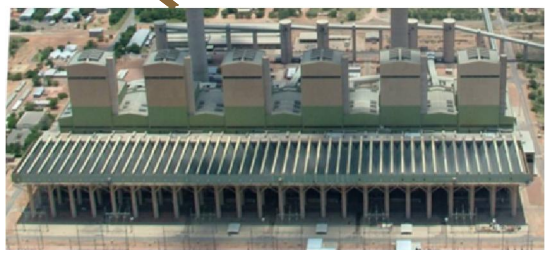
~ 60 Members in January 2013
From/at: SU, UCT, Wits, CSIR, UKZN, NMMU, NWU, Eskom, Sasol, Germany, China, Holland, etc.
Primary grants: DST-NRF, Sasol, Eskom

* At this time at a SA university

Solar thermal history at SU

1980 - 1989	1990 - 1999	2000 – 2009	2010 -

First Parabolic Trough Research



Dry cooling research at SU commences

Solar chimney research at SU commences

RENEWABLE & SUSTAINABLE ENERGY STUDIES

National SANERI/DST RE centre founded

SANERI/DST Solar thermal spoke & Hope project

sasol reaching new frontiers

Sasol researcher

Solar roof lab commissioned

SASTELA

Research and academic committee representative

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Solar resource station at SU

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STERG acceleration

2010	2011	2012	2013 –
7 – 15 people	~ 30 people	~ 45 people	~ 60 people (eish!)

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Solar roof lab expansion (with tower, kiln, etc)

Solar resource station at SU

Eskom chair and centre of excellence

SASEC 1st Southern African Solar Energy Conference

Sasol 40 m² heliostat field

NRF solar thermal spoke 2013 - 17

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STERG R&D overview

STERG – Solar Thermal Energy Research Group

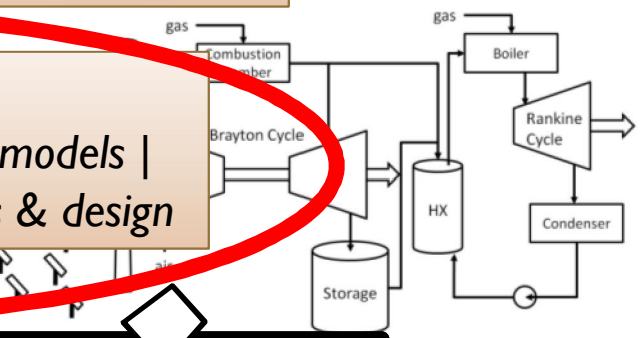
Engineering (ME, EE, others)

Physical, Social, Mathematical, Political, Statistical Sciences, Geography, Philosophy, etc.

Other
Better SWH | Coal power augmentation | other…

SUNSTEL (SU Solar Thermal Electricity Project)
(Primary technologies: SUNSPOT, LFR, Dish)

System R&D
Systems analysis | Plant thermodynamic models | Techno-economic analysis | Plant concepts & design



Solar Resource R&D
Satellite | Ground

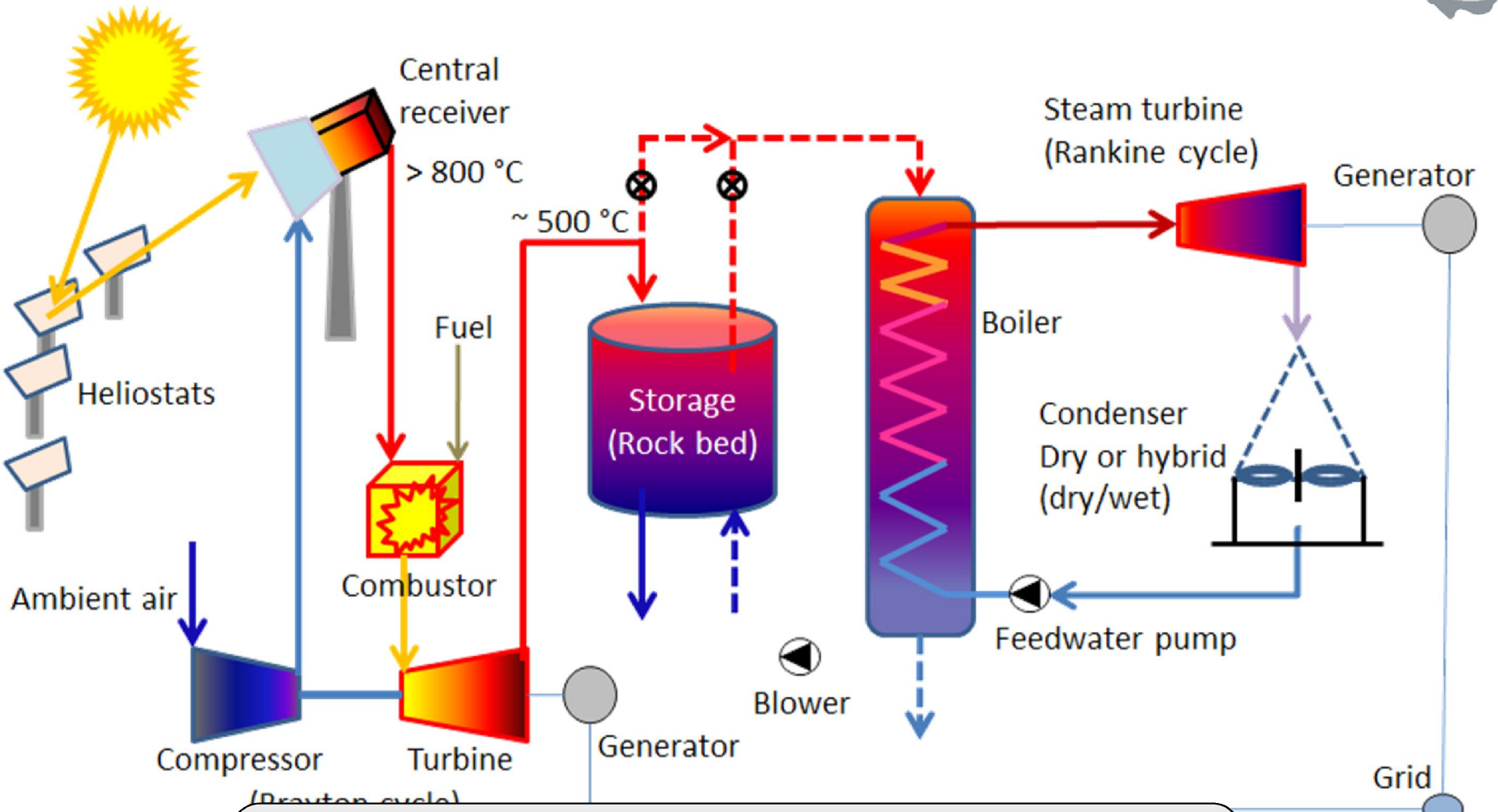
Dry Cooling
Dry | Hybrid | Diurnal etc

Heat Transfer Fluids & Storage
CO_2 | Air | NaK | Salt | Rock | Metal PCM

Heliostats & Receivers
Control | Drives | Optics | Field | Heat Transfer

Italics: On-going R&D

SUNSPOT – primary technology



11+ Projects from distribution to system to components focused on SUNSPOT

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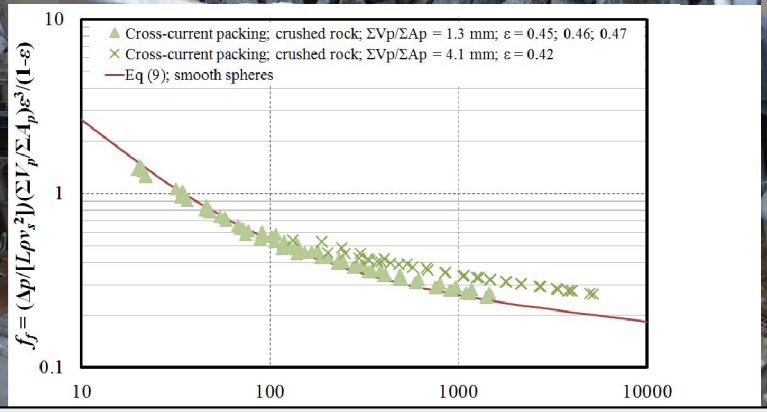
Industrial cooling system performance R&D

Prof HCR Reuter (PrEng, PhD)

Packed bed storage research



Our "**Sauna**". Thermal cycling of 2 – 3 tons of material between 600 °C and ambient.

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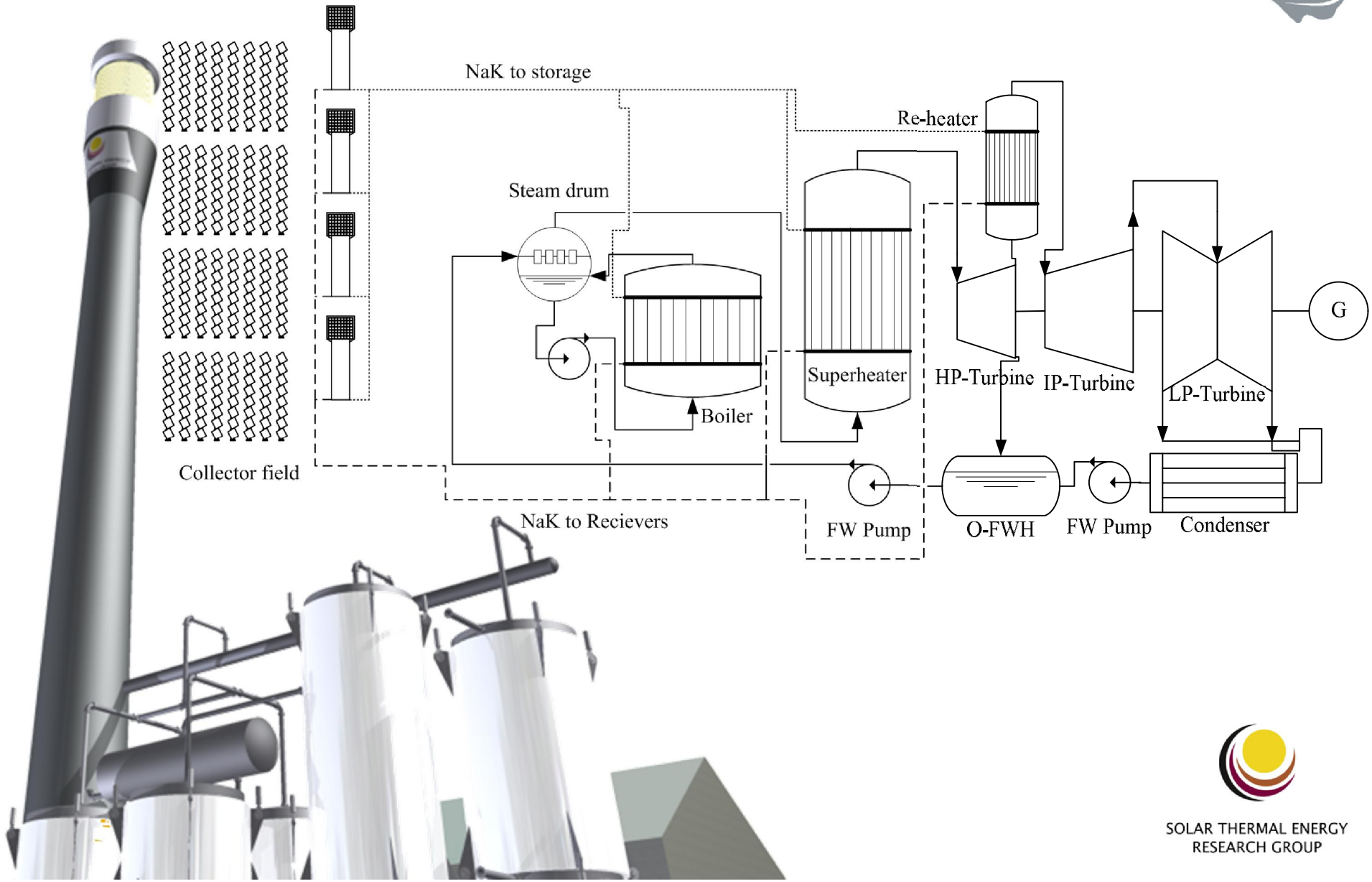
Potential concepts: Metallic phase change material – Direct steam generation from storage



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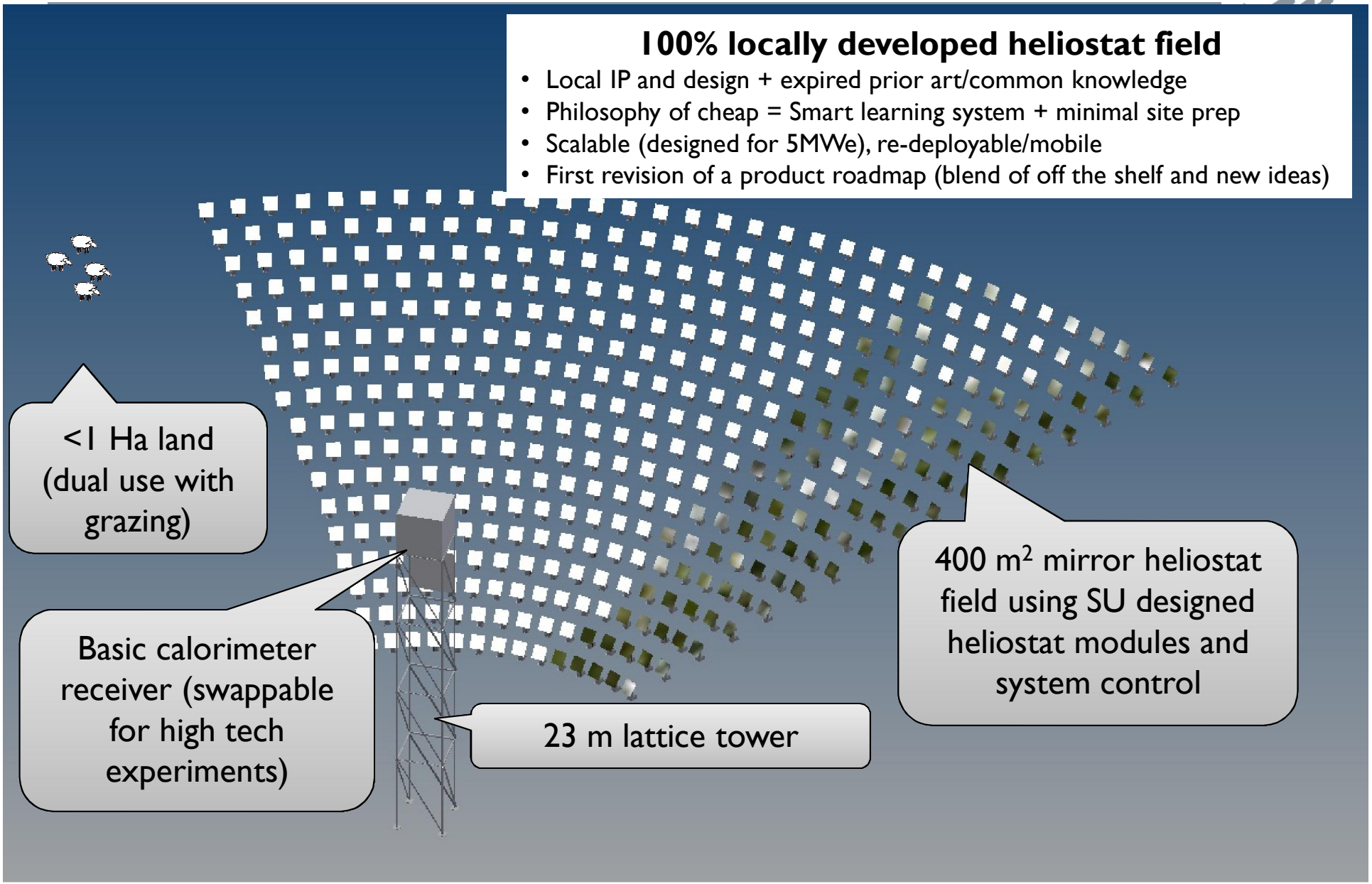
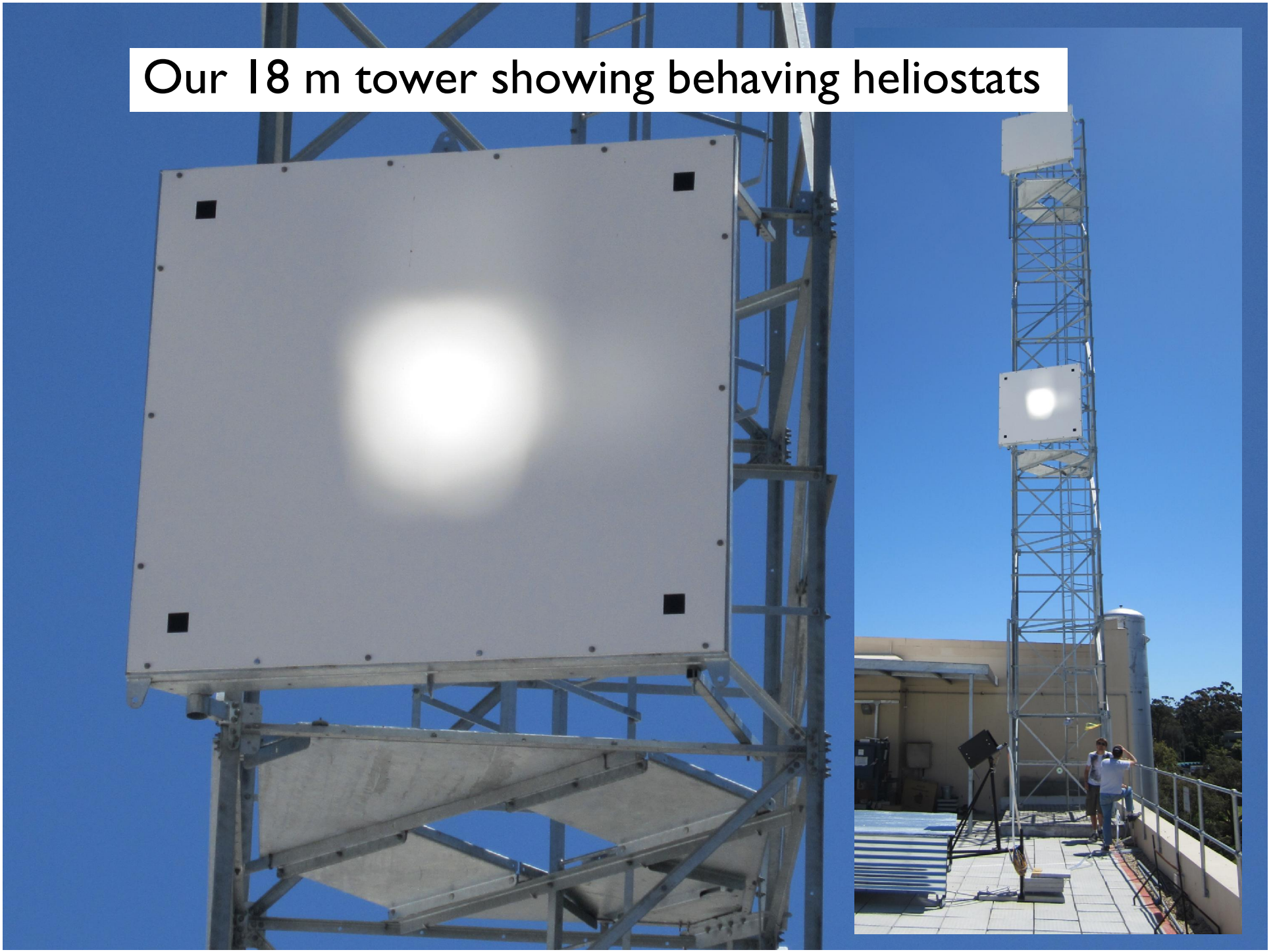
Baby steps towards SUNSPOT – 400m^2 pilot

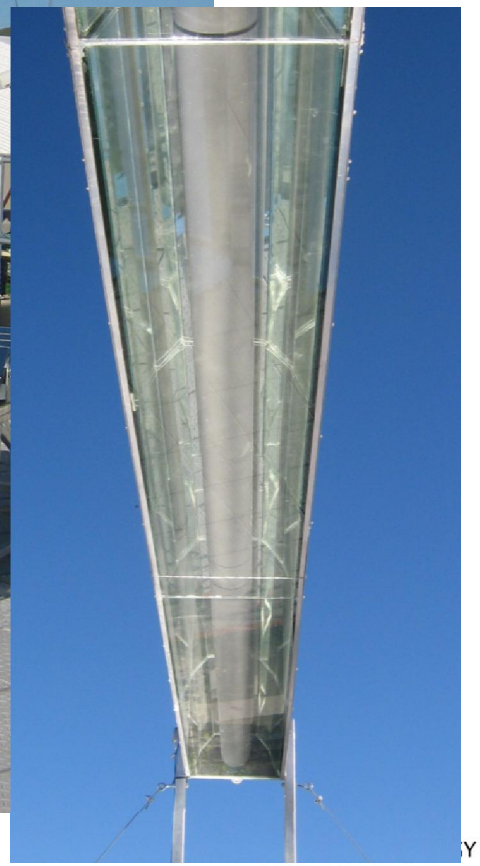


Heliostat prototype in motion

Our 18 m tower showing behaving heliostats



LFR – secondary technology



CSP for South Africa's energy system

STRATEGIC ANALYSIS

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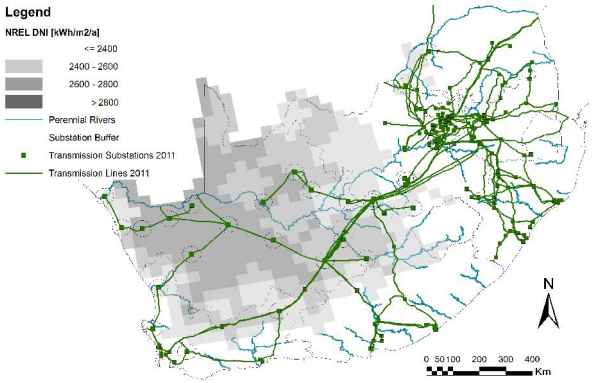
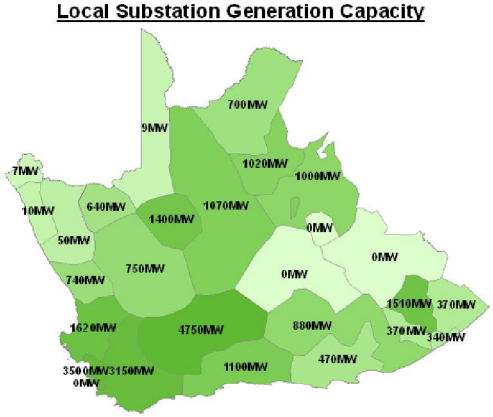
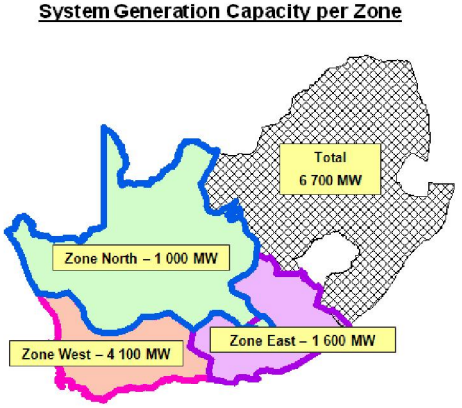
CSP roadmap and resource

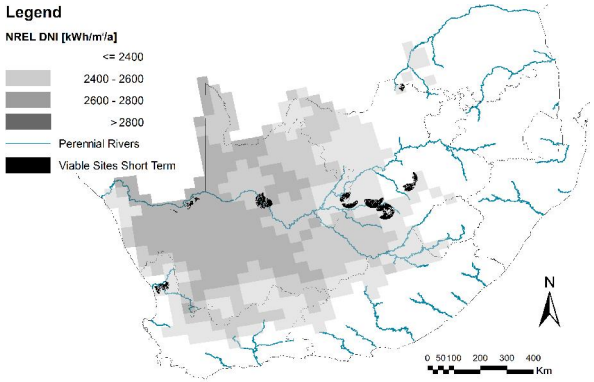
- Work by STERG and CRSES
- Contributors: Riaan Meyer, Tom Fluri, others



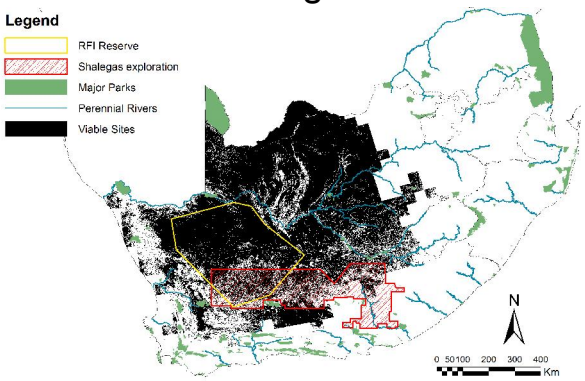




Viable short term sites



Viable long term sites



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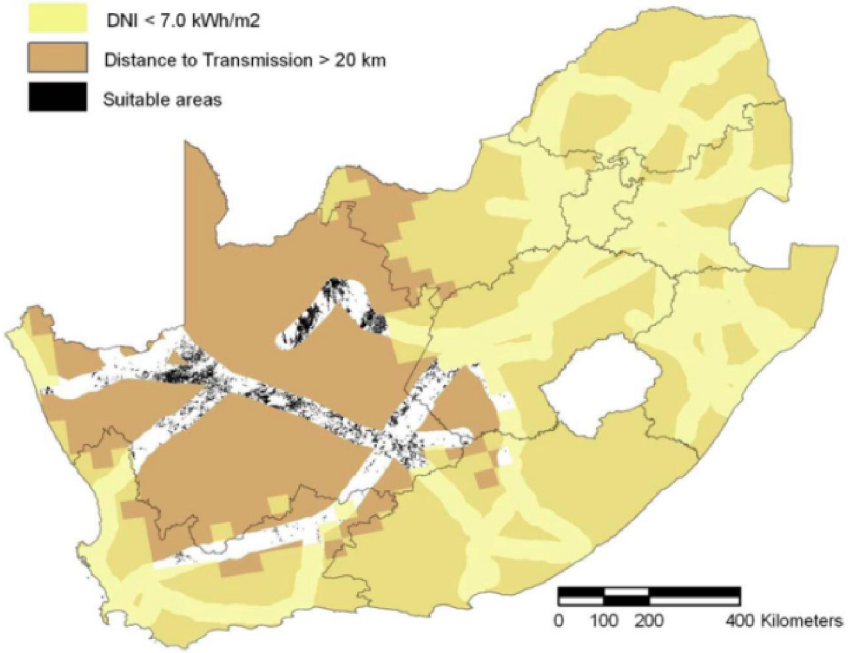
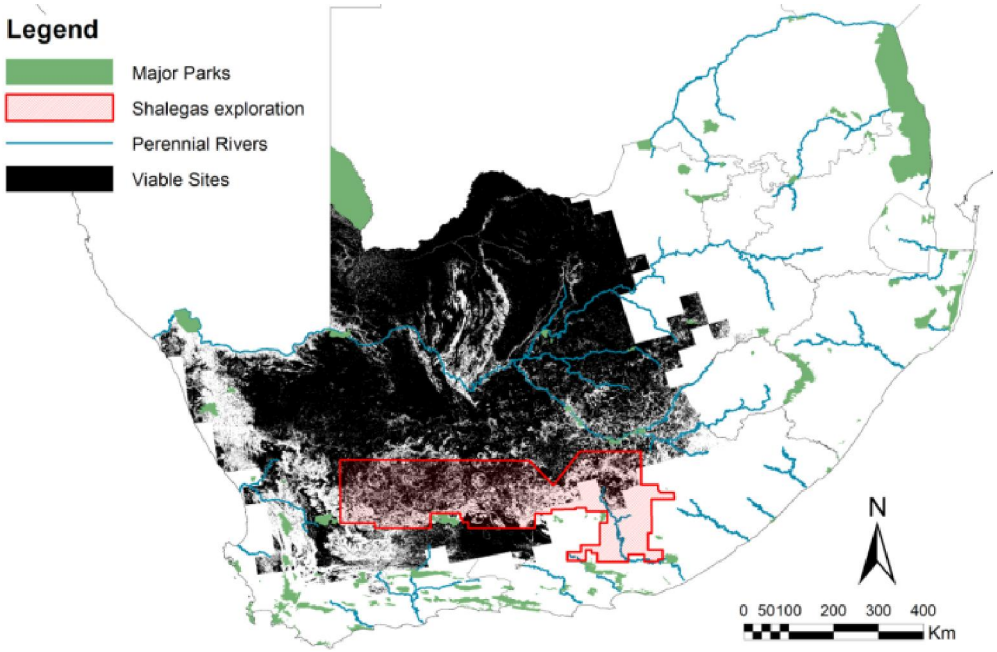
Prior work on SA CSP potential

- CSP potential has been investigated by Fluri (short term) and Meyer & van Niekerk (longer term)





- Short term multi-constraint potential (500GWe+) vastly exceeds current or future electricity needs
- This work extends previous work to explore full potential of dispatchability

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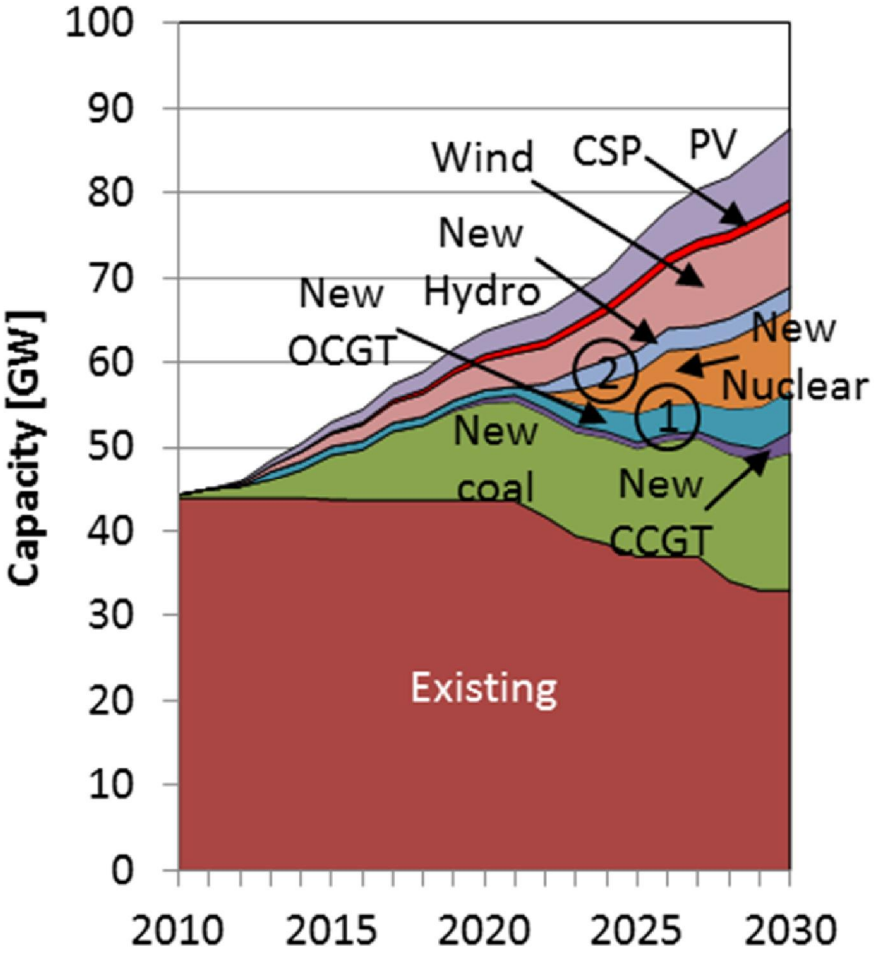
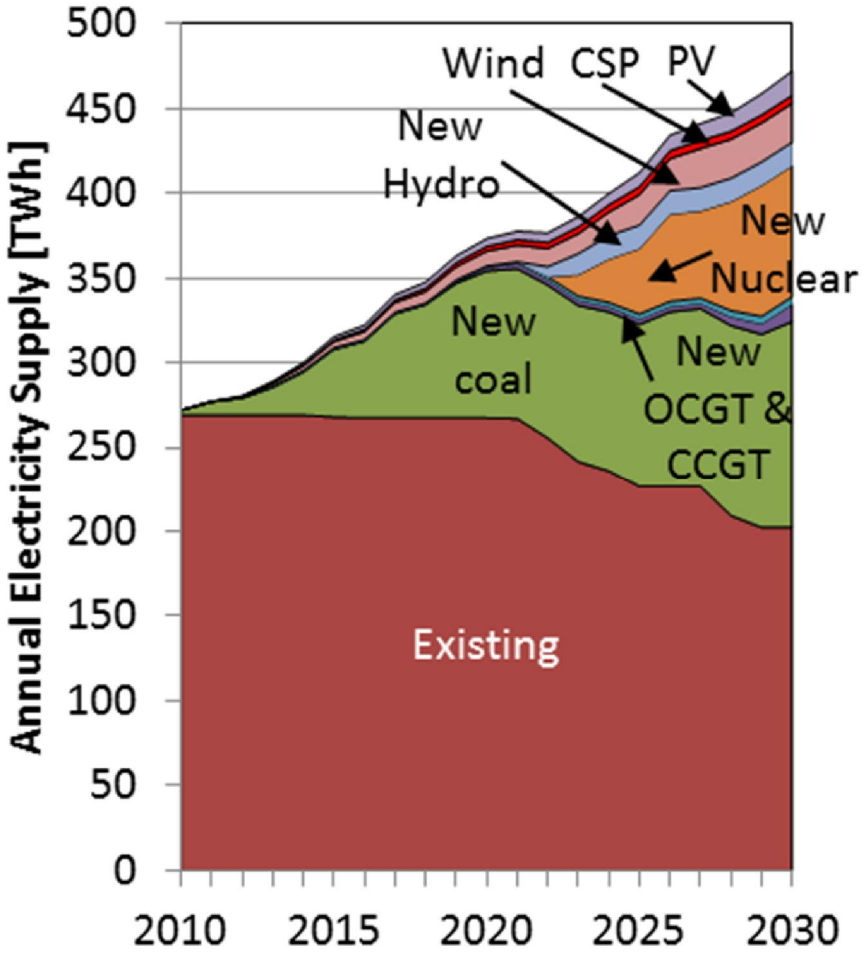
IRP2010 summary

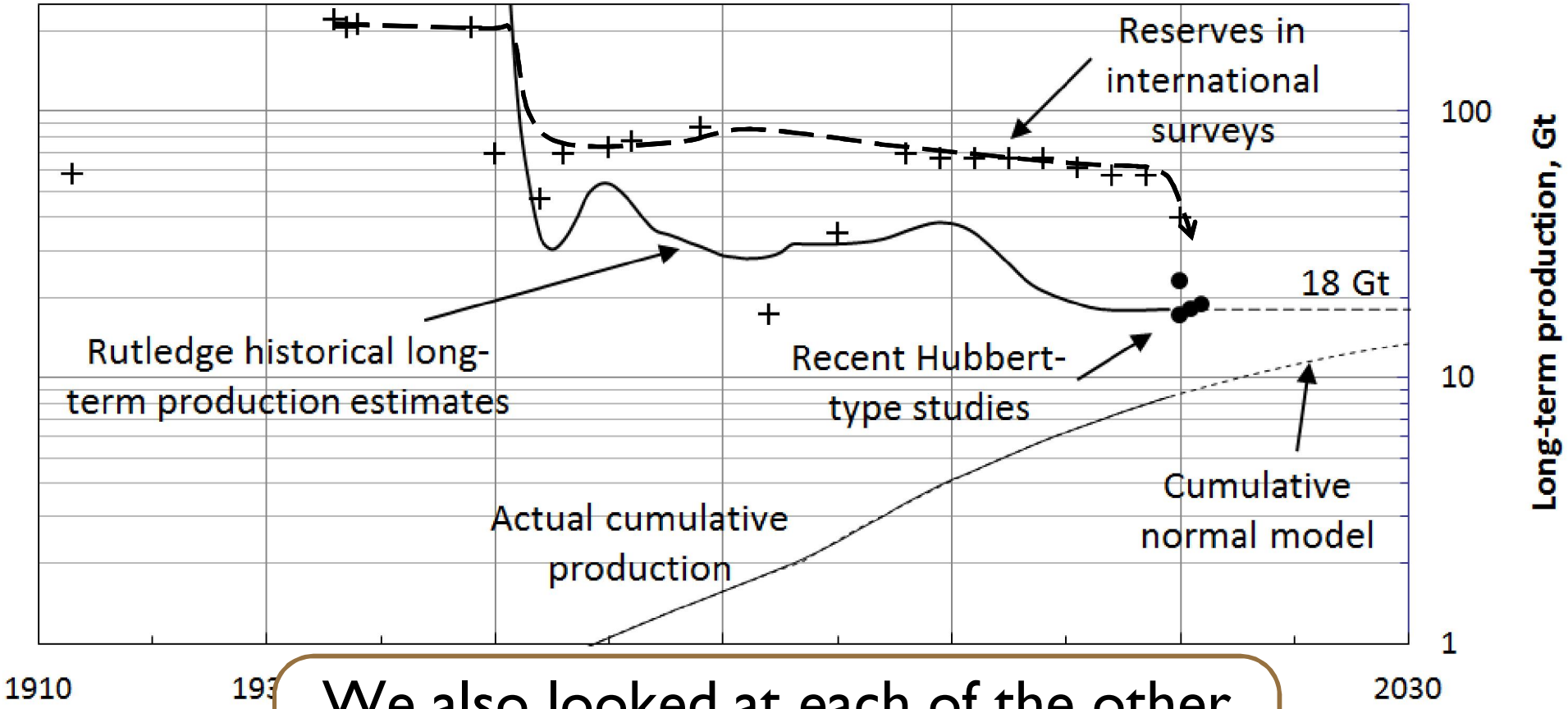
Capacity



Electricity produced



South African coal analysis



We also looked at each of the other major energy sources in the IRP and came up with the following…

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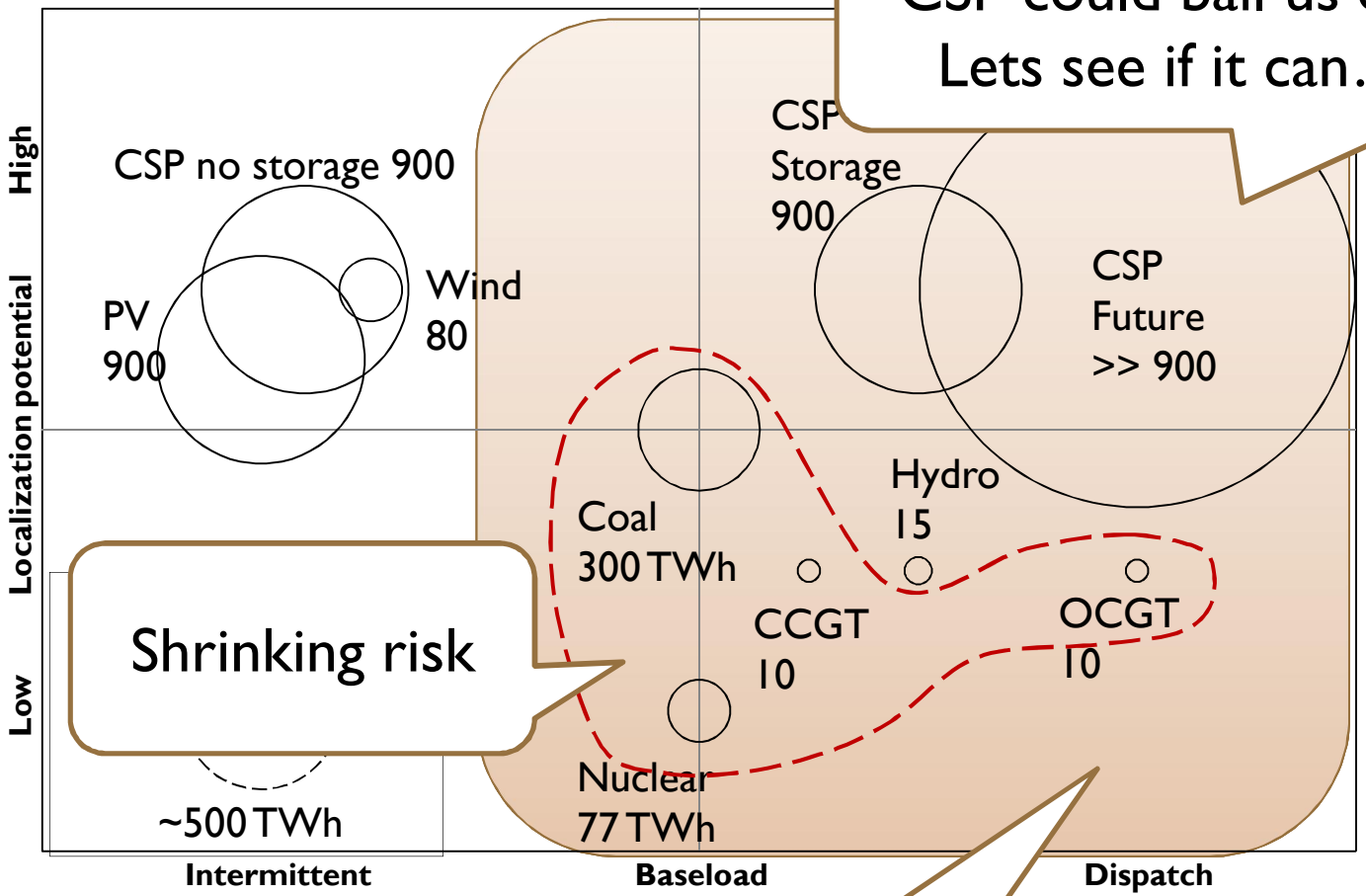
Making sense of our options



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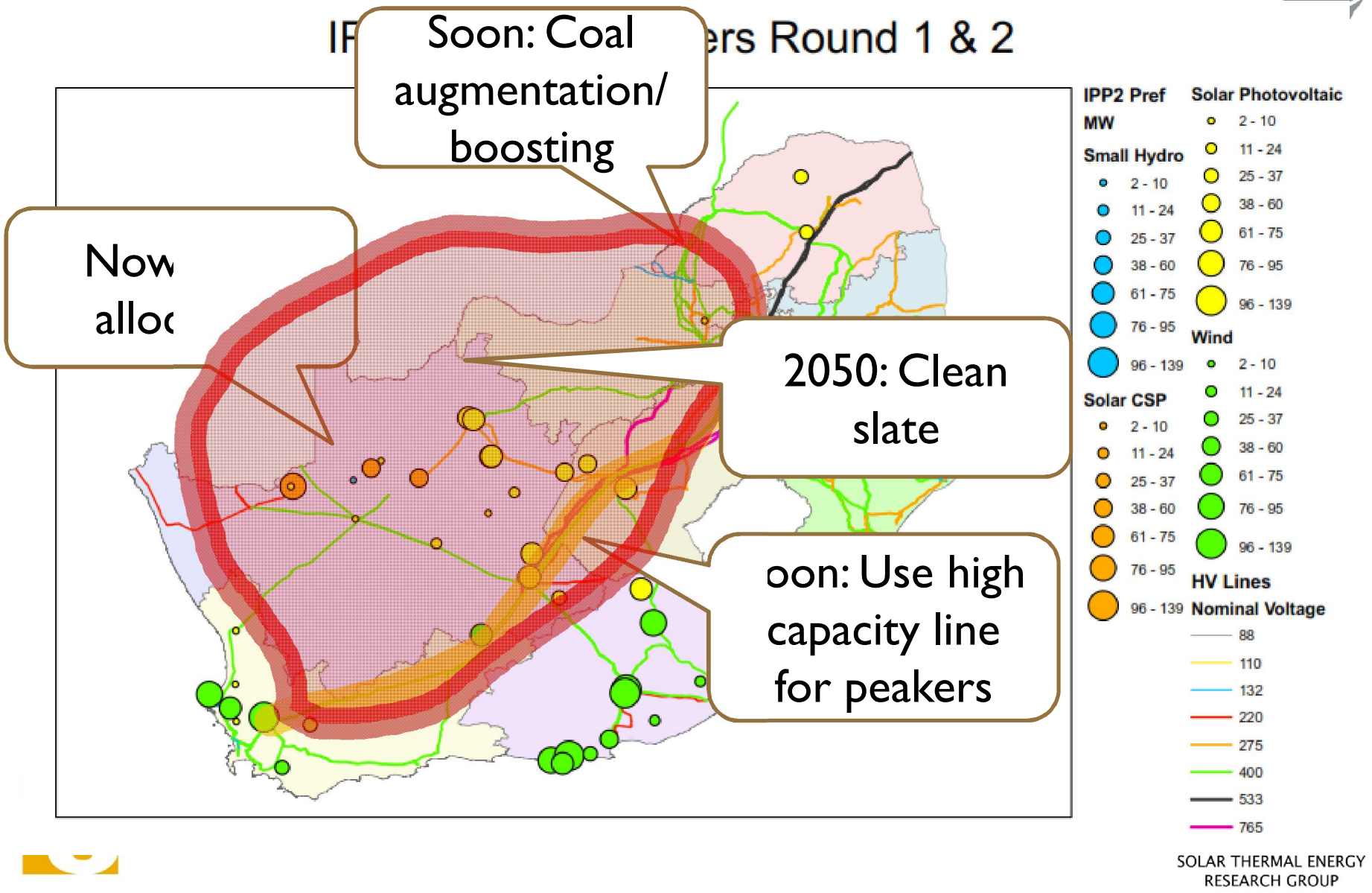
CSP alternatives: Now to 2050 and beyond



R2+/kWh CSP now & baby steps is valuable

START NOW

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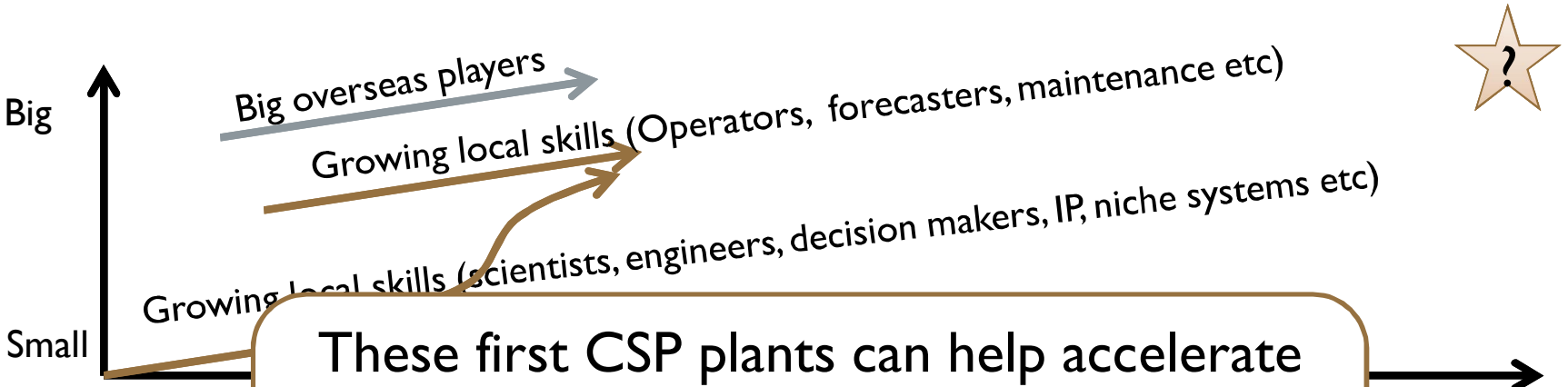
Recap of CSPToday 2012 Joburg

- If there is a chance my holistic energy view is plausible…
- Our transition needs to be radical
- We need local baby steps to get ready for a high RE scenario
- We also need the bigger proven players in now to get on the grid.



These first CSP plants can help accelerate growing local skills, industry prep & we will quickly "know what we don't know"
BUT this needs to be part of the program

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CSP baseload case

EXTREME SCENARIO

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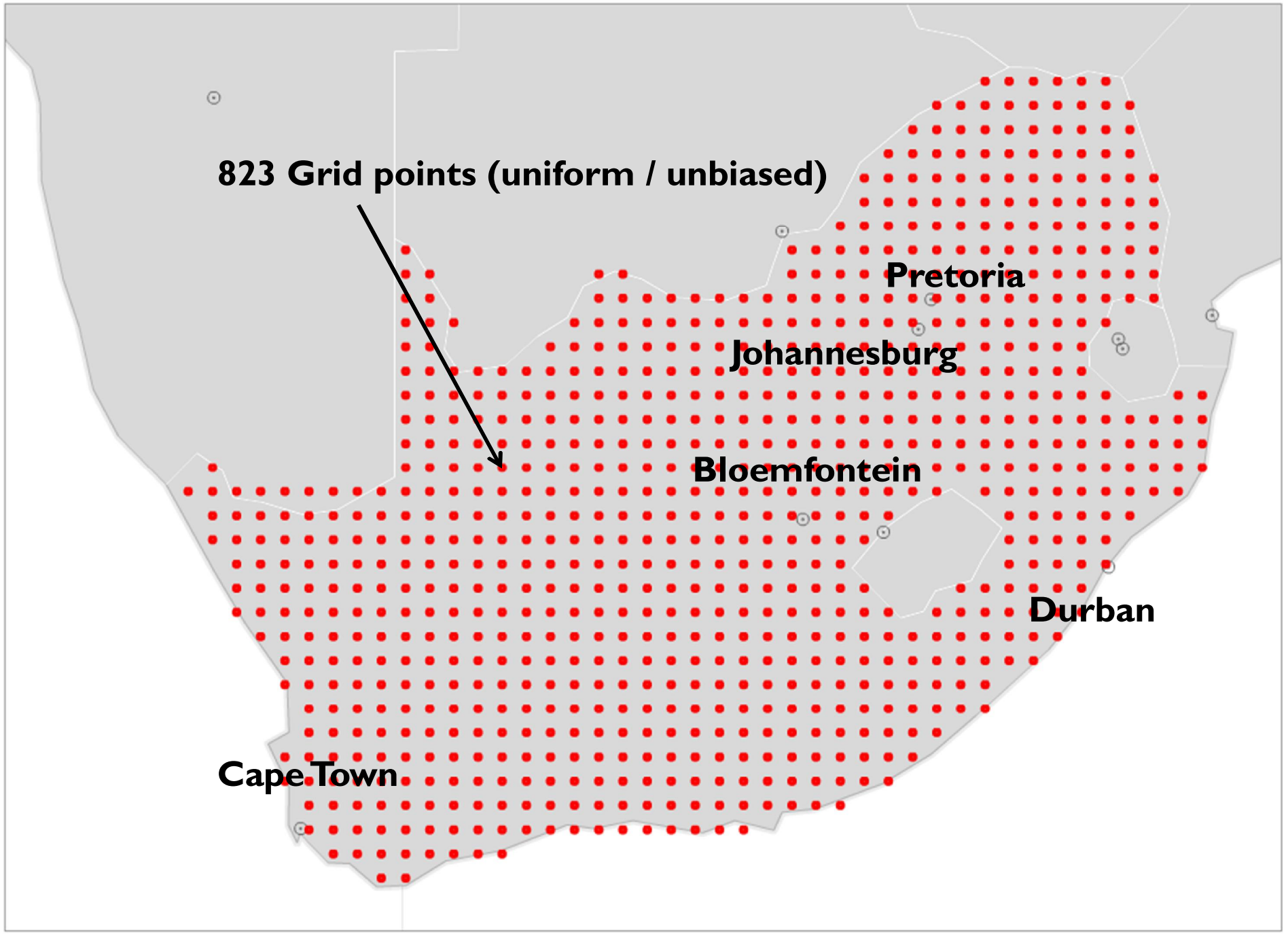
Method: Plant

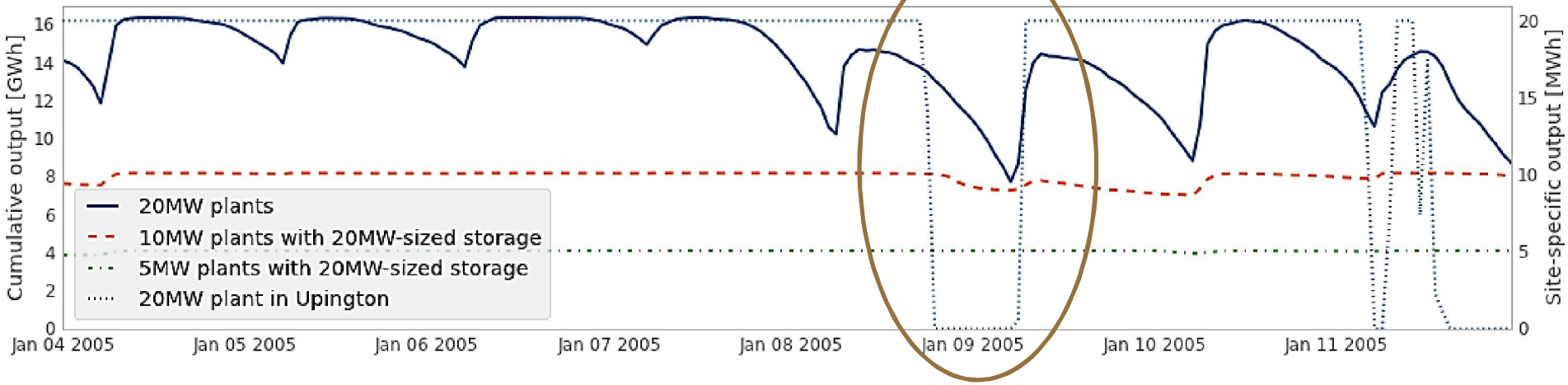
- Based on the Gemasolar plant
- Approximated optical performance + Chambadal-Novikov engine (modified Carnot) + inertia capacitance + storage capacitance
- Model validated using
  - eSolar measured data (Gauché et al. SolarPACES 2011)
  - NREL predicted annual electricity generation for this plant (110 vs. 115 GWh/yr)

Item	Value
Country, Region	Spain, Seville Andalucía
Location	37°33′ 44.95″ North, 5°19′ 49.39″ West
Land area	195 Ha
Solar resource	2,172 kWh/m^2/yr
Electricity Generation	110 GWh/yr (planned)
Cost	230,000,000 Euro
O&M jobs	45
Heliostat aperture area	304,750 m^2
Number of heliostats	2,650
Heliostat size	120 m^2
Tower height	140 m
Heat transfer fluid	Molten salt
Receiver outlet / inlet temperature	565 °C / 290 °C
Turbine capacity (gross)	19.9MWe
Cooling	Wet
Storage	2 tank, 15 hours

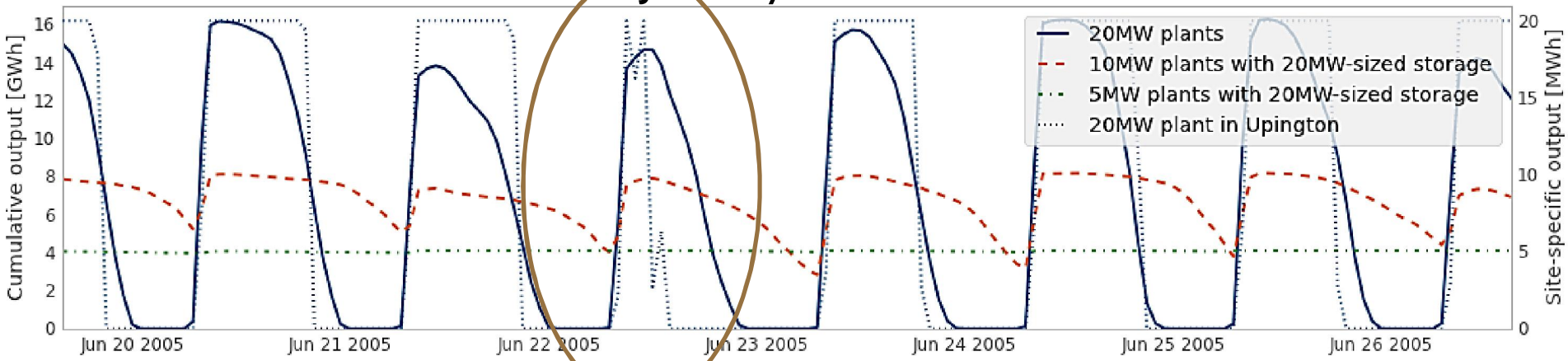

823 Grid points (uniform / unbiased)
Pretoria
Johannesburg
Bloemfontein
Durban
Cape Town

Results and analysis: Time plots

8 January days



8 June days



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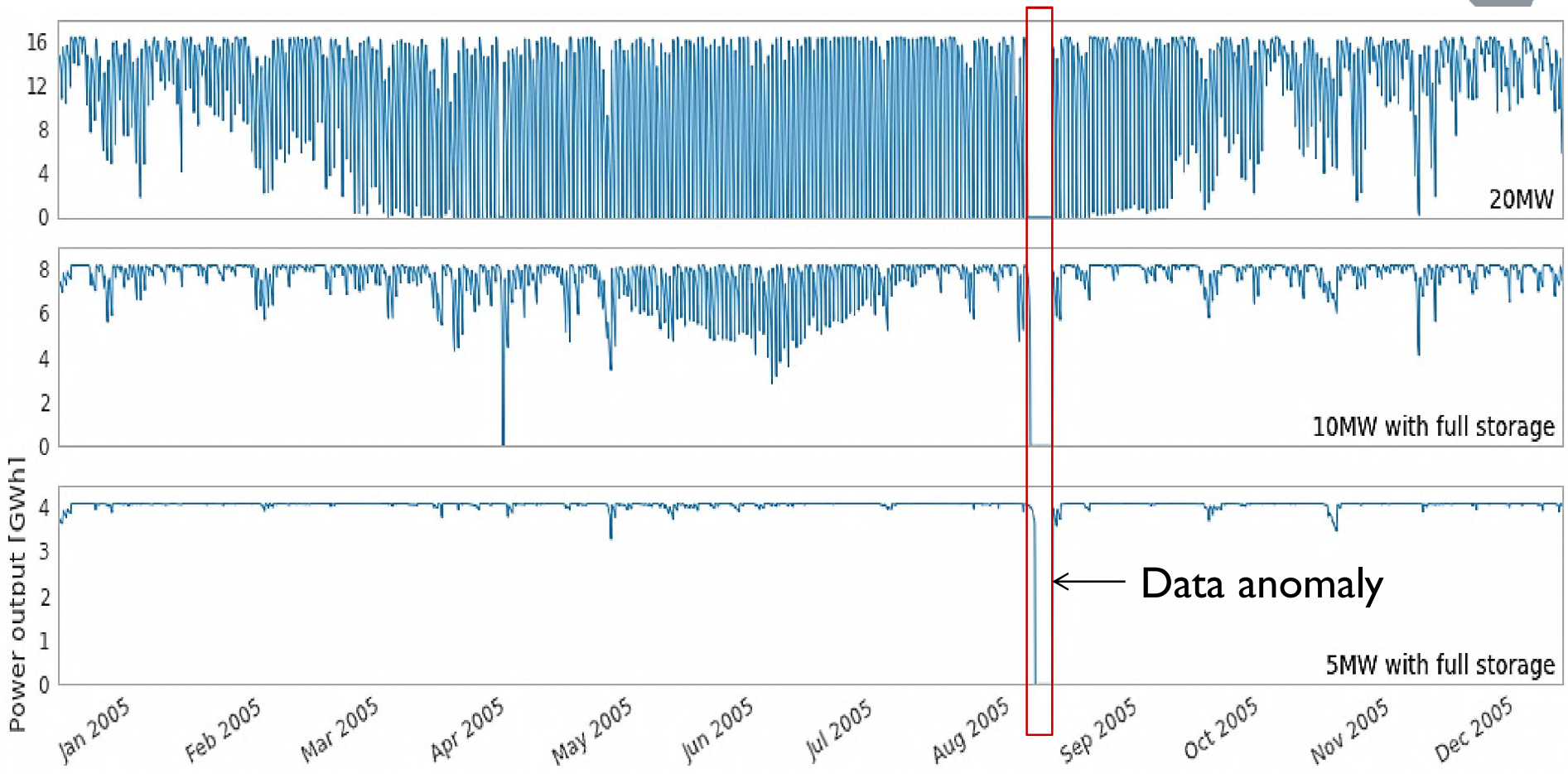
Results and analysis: Time plots



1 out of 4 plants running at a time practically demonstrates baseload – our first dispatch test

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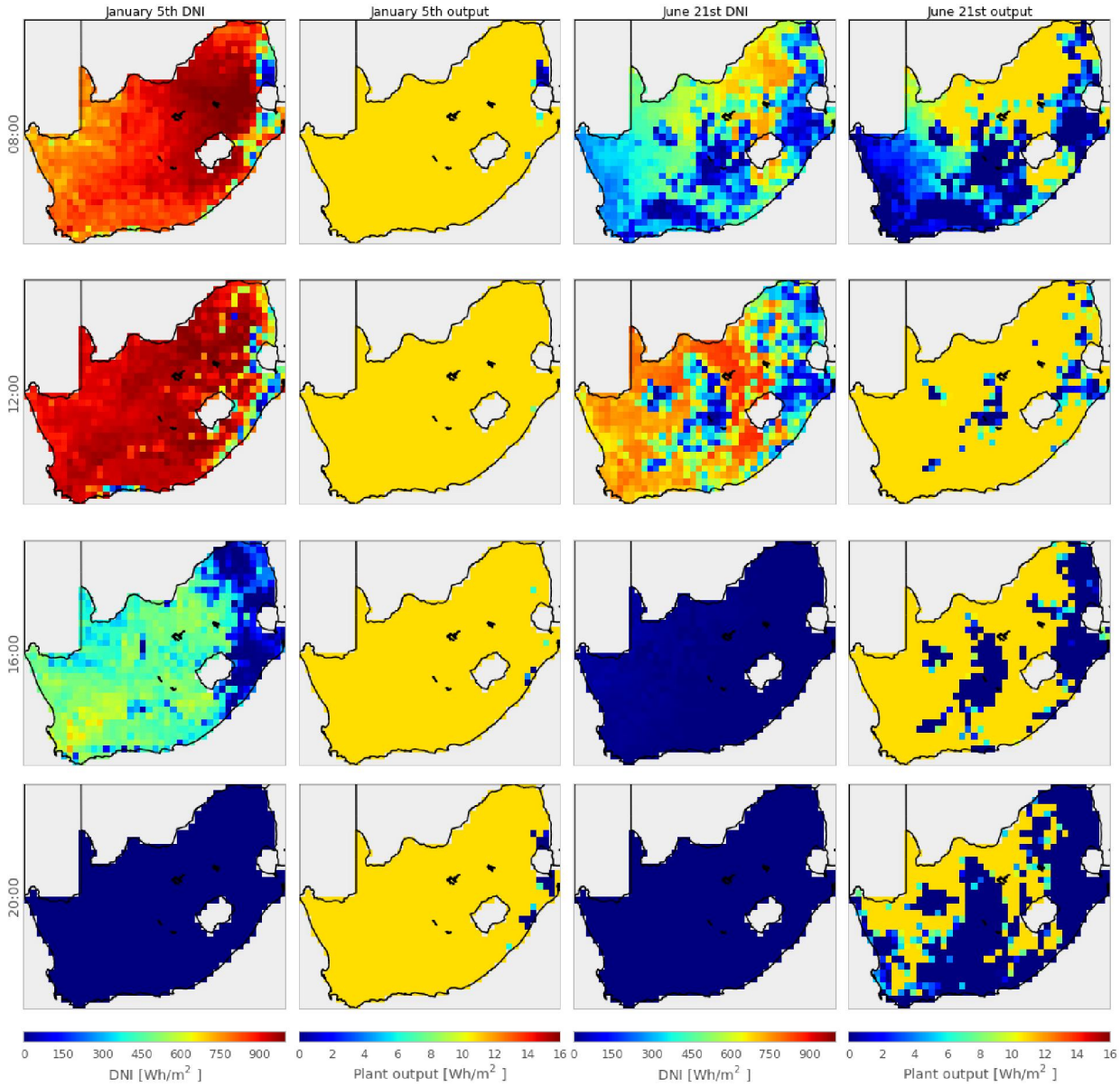
Results and analysis: Spatial

january.mp4

june.mp4



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SAPG (Solar assisted power generation) / Coal augmentation / Boosting

LOW HANGING FRUIT I

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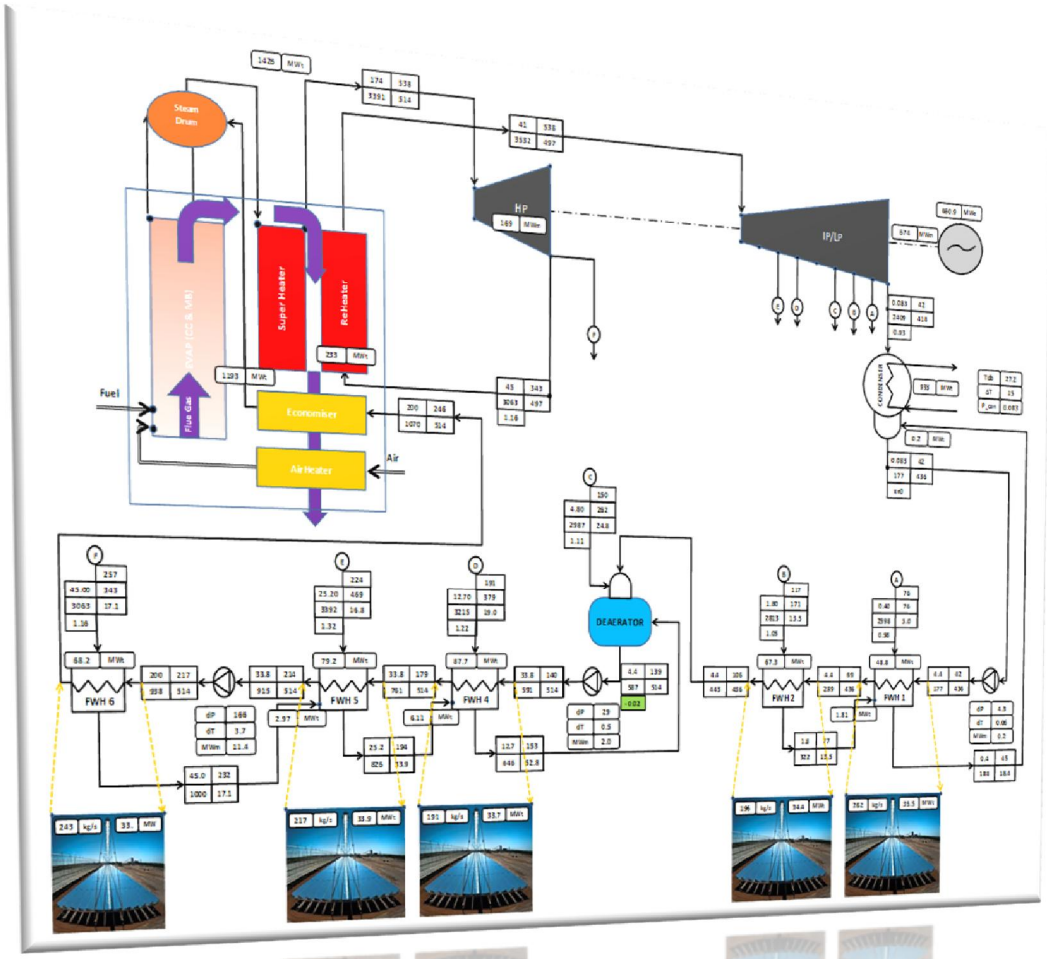
Solar assisted power generation (SAPG)



- preheating of boiler feedwater
- compliment extracted turbine steam with solar heat
- efficient use of low to medium temperature solar heat (less than 250°C) for power generation

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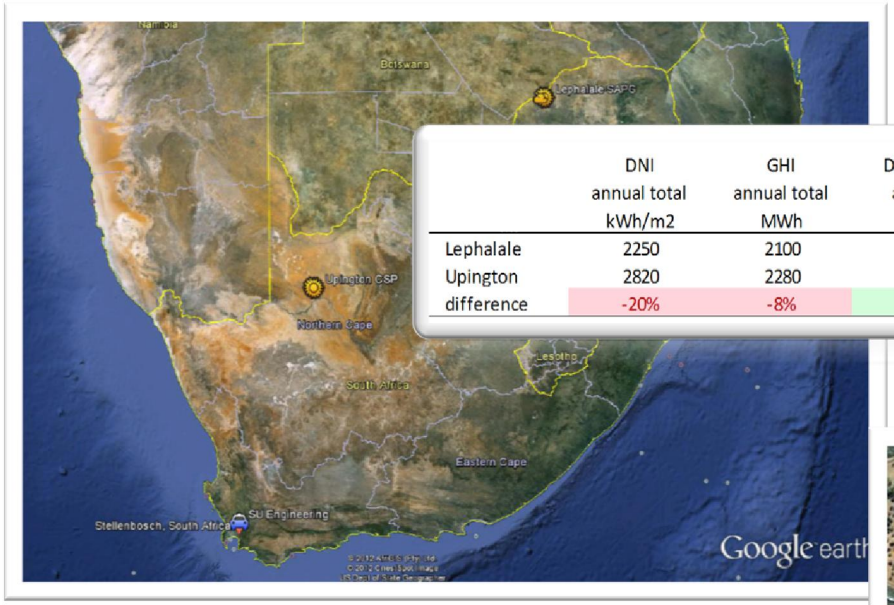
SAPG vs stand-alone CSP

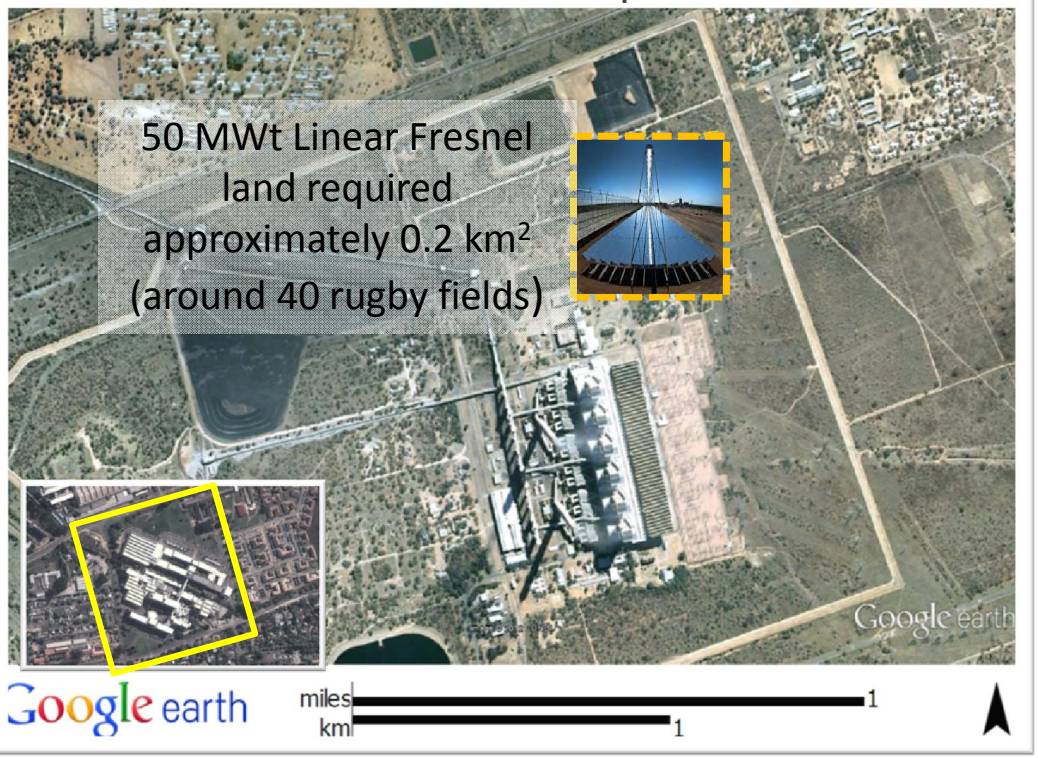


	DNI annual total kWh/m2	GHI annual total MWh	Dry bulb T average °C
Lephalale	2250	2100	19.9
Upington	2820	2280	21.5
difference	-20%	-8%	-1.6

site locations

- SAPG : Lephalale (home to Matimba and Medupi power stations)
- stand alone CSP – Upington (solar park) 20% more annual total DNI

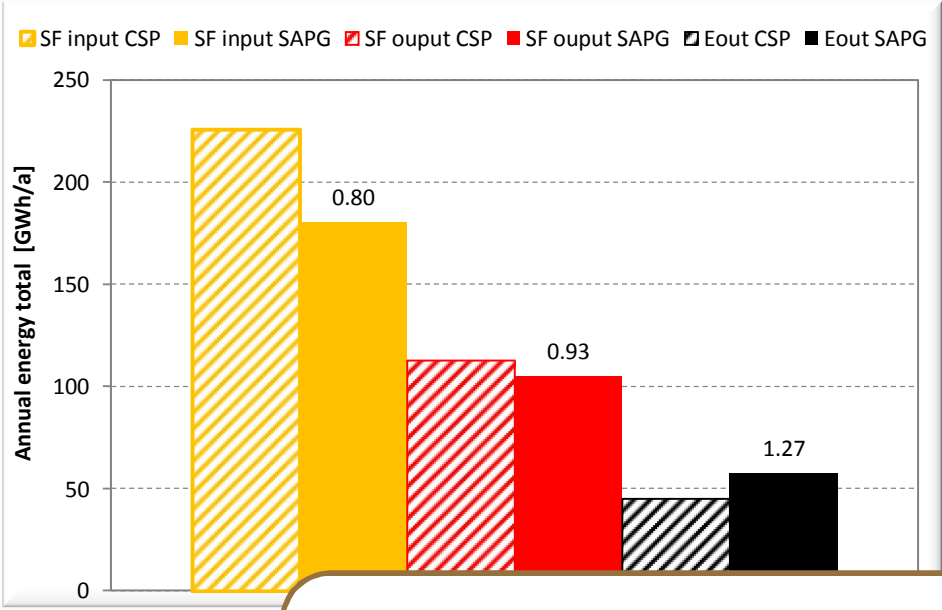
aerial view of Matimba power station



land footprint

- low energy density compared to coal
- land availability might be limiting factor

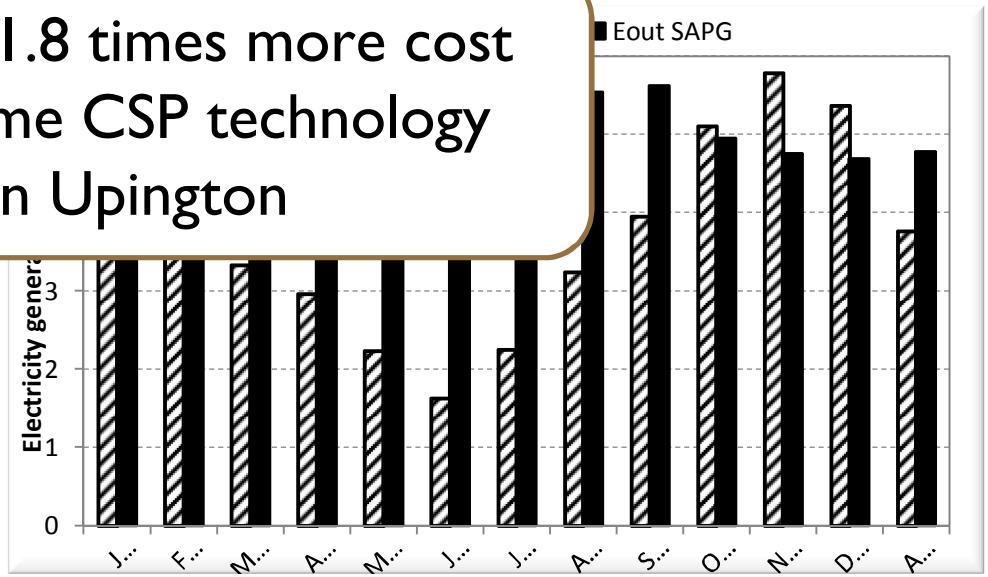
Results – SAPG vs stand-alone CSP



- Upington ('solar park') CSP vs Lephalale (Matimba and Mudupi) SAPG
- based on PT technologies with same power block performance, annual simulations
- SAPG 1.27 times more electricity into the grid
- If SAPG cost taken as 72% of stand-alone CSP => 1.8 times more cost effective solution

SAPG in Lephalale is 1.8 times more cost effective than the same CSP technology stand-alone in Upington

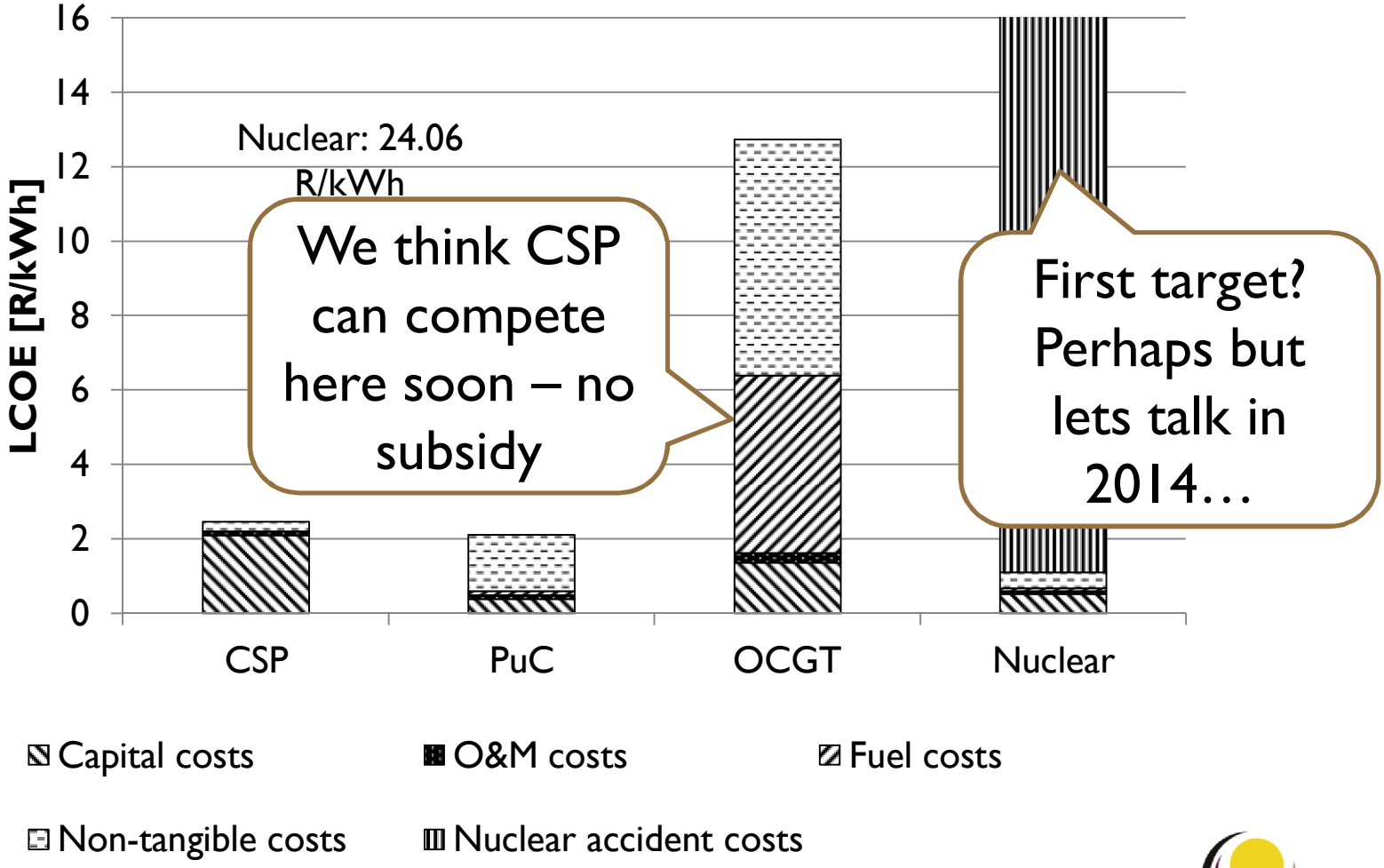
- better pe
  months (
- other benefits: existing infrastructure and zoning (EIA), storage capabilities, scale, vicinity to loads and manufacturing industry



Peaking CSP replacing OCGTs

LOW HANGING FRUIT

Costs of non intermittent technologies in SA*



** A work in progress. Tangible costs for comparison only*
Intangible and nuclear accident costs can be ignored for this presentation

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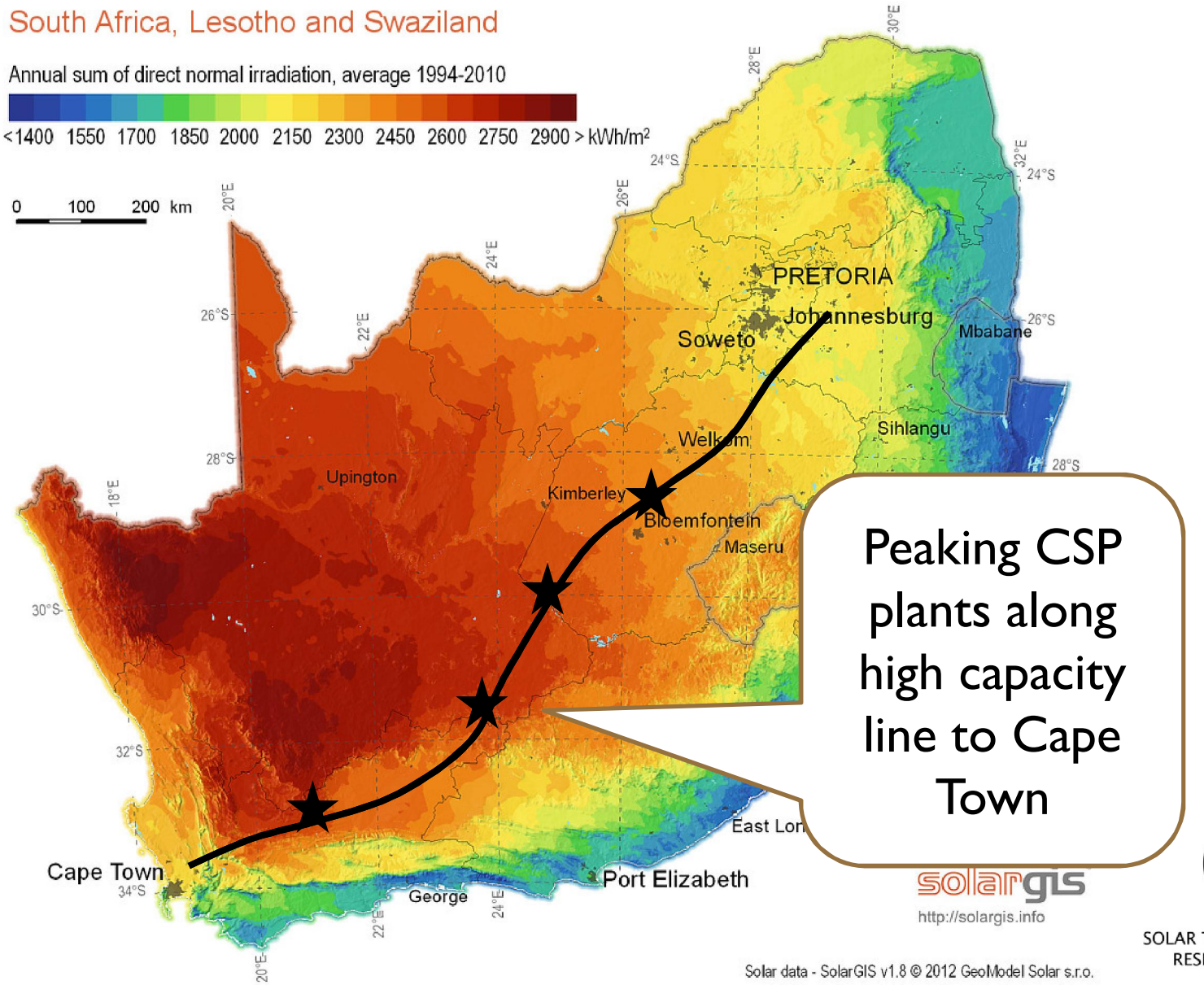
The idea


South Africa, Lesotho and Swaziland
Annual sum of direct normal irradiation, average 1994-2010
<1400 1550 1700 1850 2000 2150 2300 2450 2600 2750 2900 > kWh/m²
0 100 200 km
PRETORIA
Johannesburg
Soweto
Mbabane
Welkom
Sihlangu
Upington
Kimberley
Bloemfontein
Maseru
East Lon
Cape Town
George
Port Elizabeth
Peaking CSP plants along high capacity line to Cape Town
solargis
http://solargis.info
Solar data - SolarGIS v1.8 © 2012 GeoModel Solar s.r.o.
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Results

Truth is somewhere between R1.50/kWh* – R5.00/kWh*
<u>Bonus</u>: No fuel price volatility

Watch this space for our results in 2013…

* Excludes learning rate improvements

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CSP in a high RE scenario

LONGER TERM

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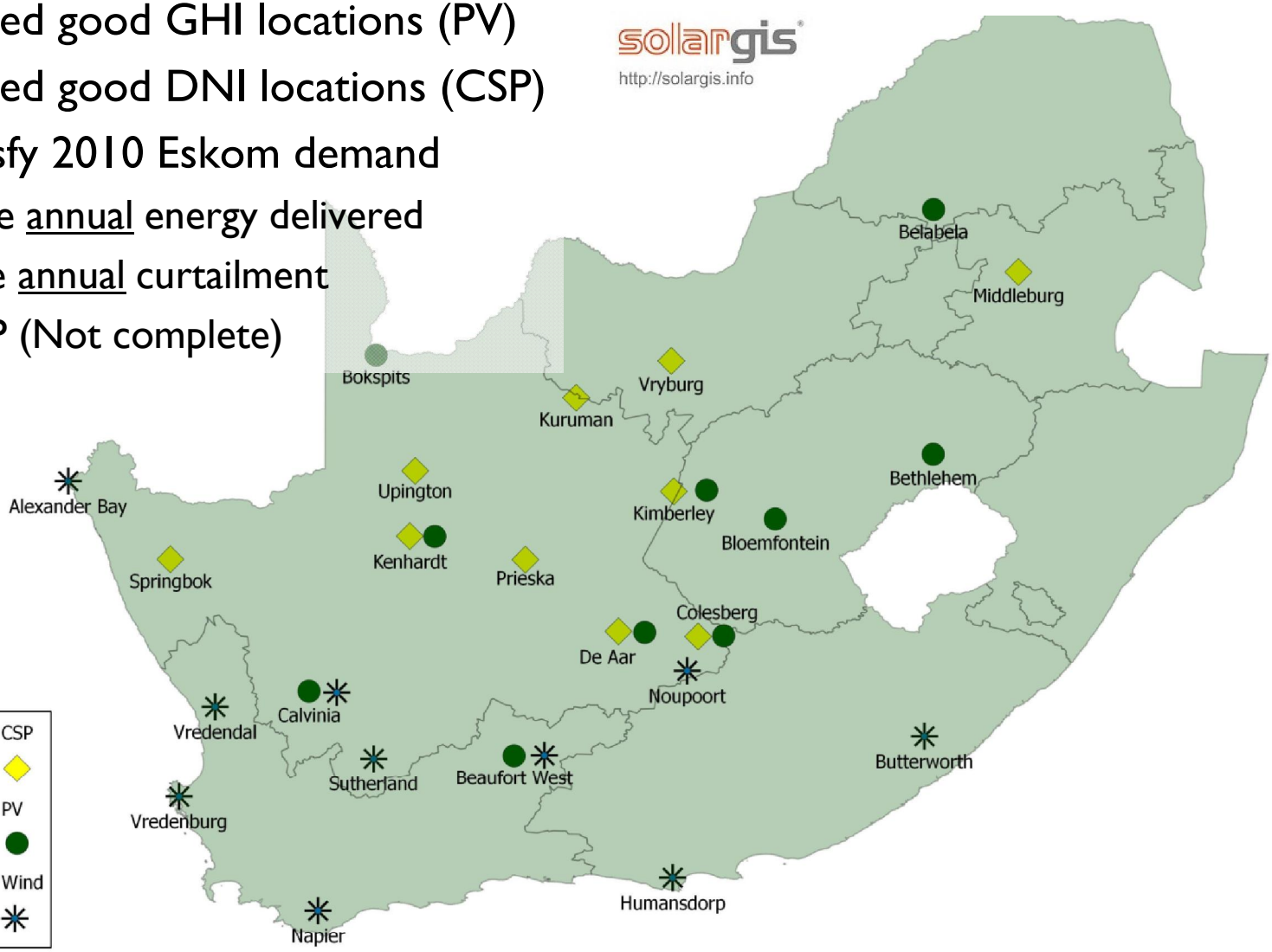
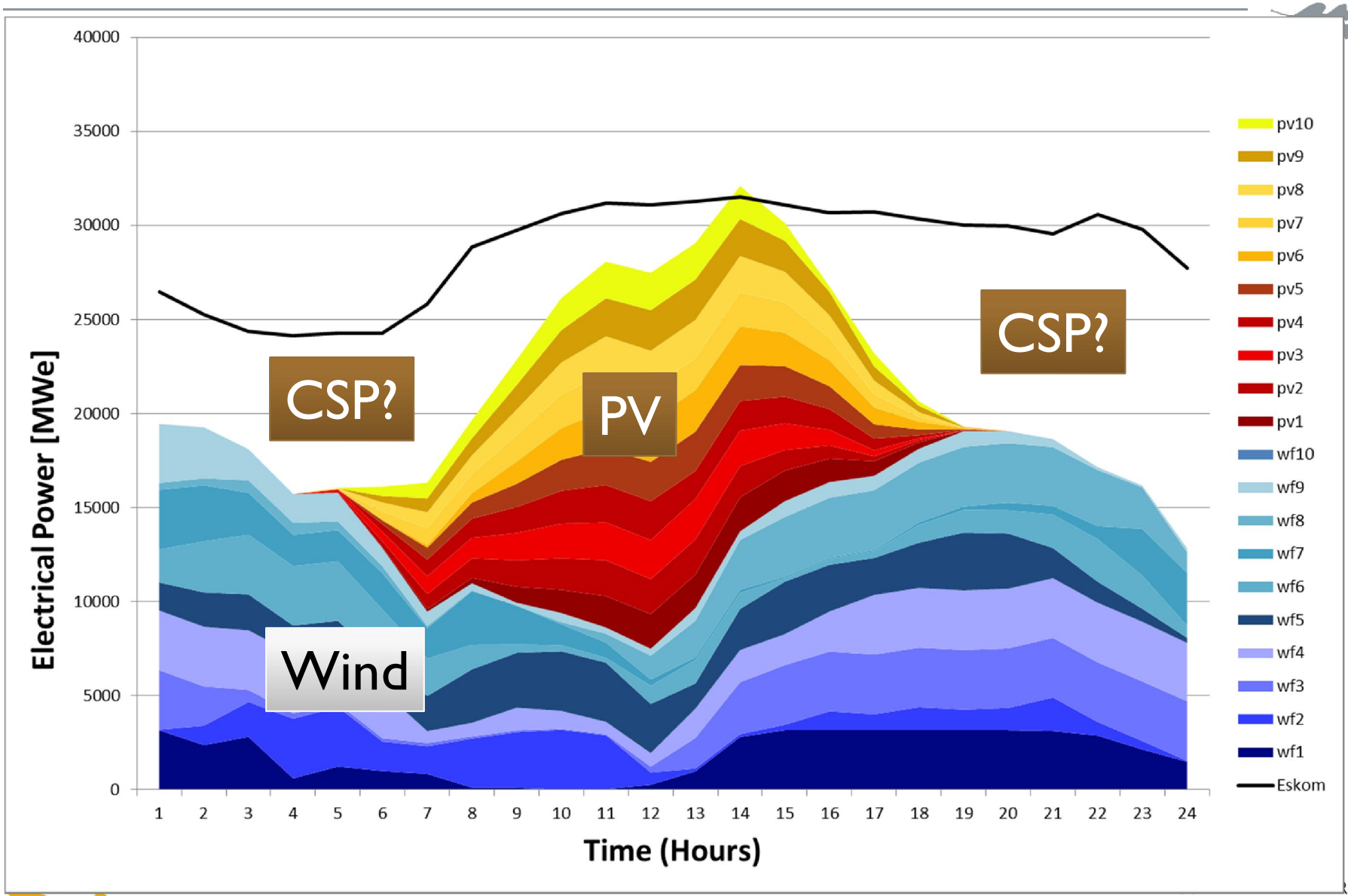
Methodology

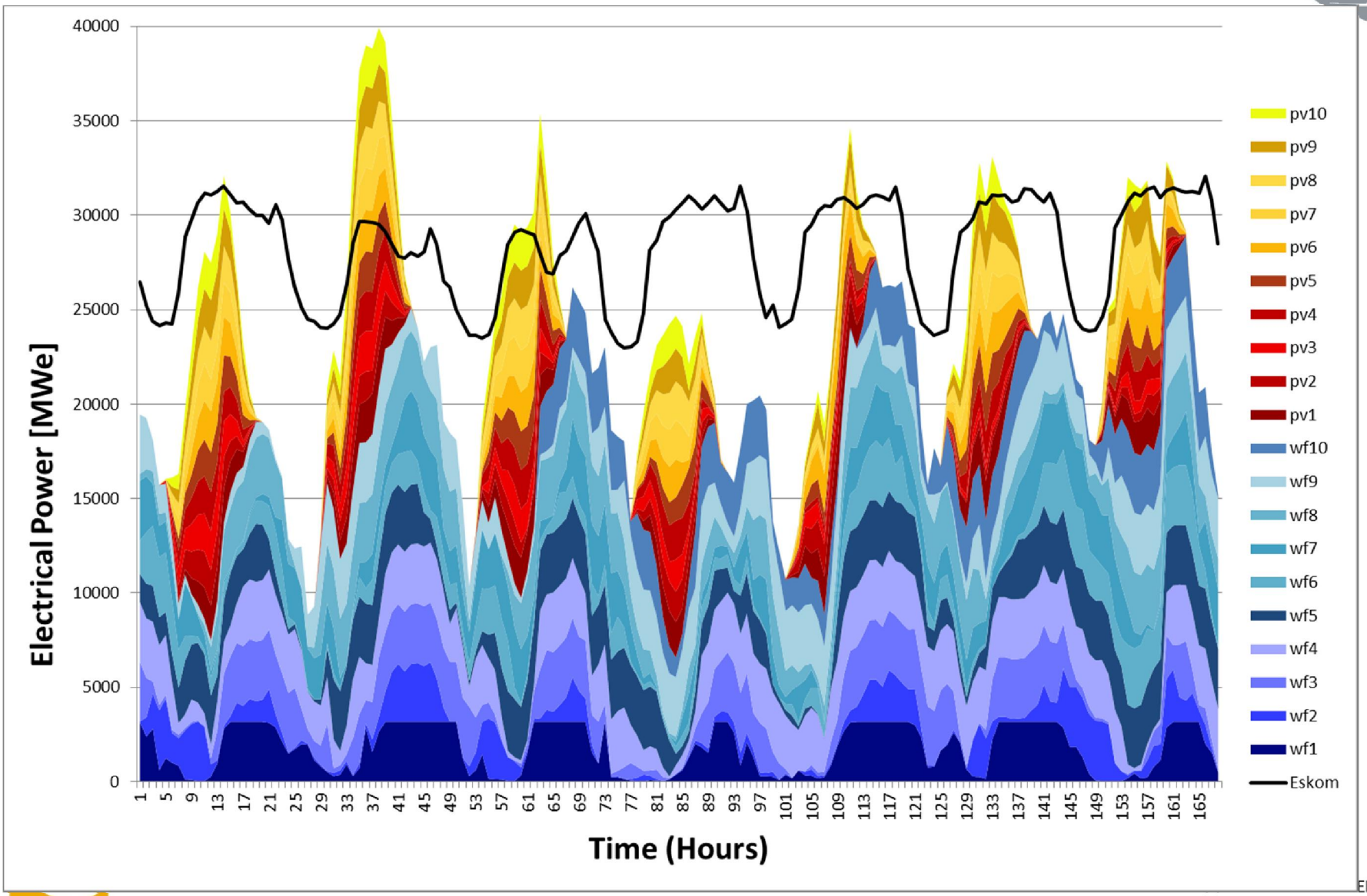
- 10 key points of new wind atlas
- 10 distributed good GHI locations (PV)
- 10 distributed good DNI locations (CSP)
- Aim to satisfy 2010 Eskom demand
  - Maximize annual energy delivered
  - Minimize annual curtailment
  - Add CSP (Not complete)



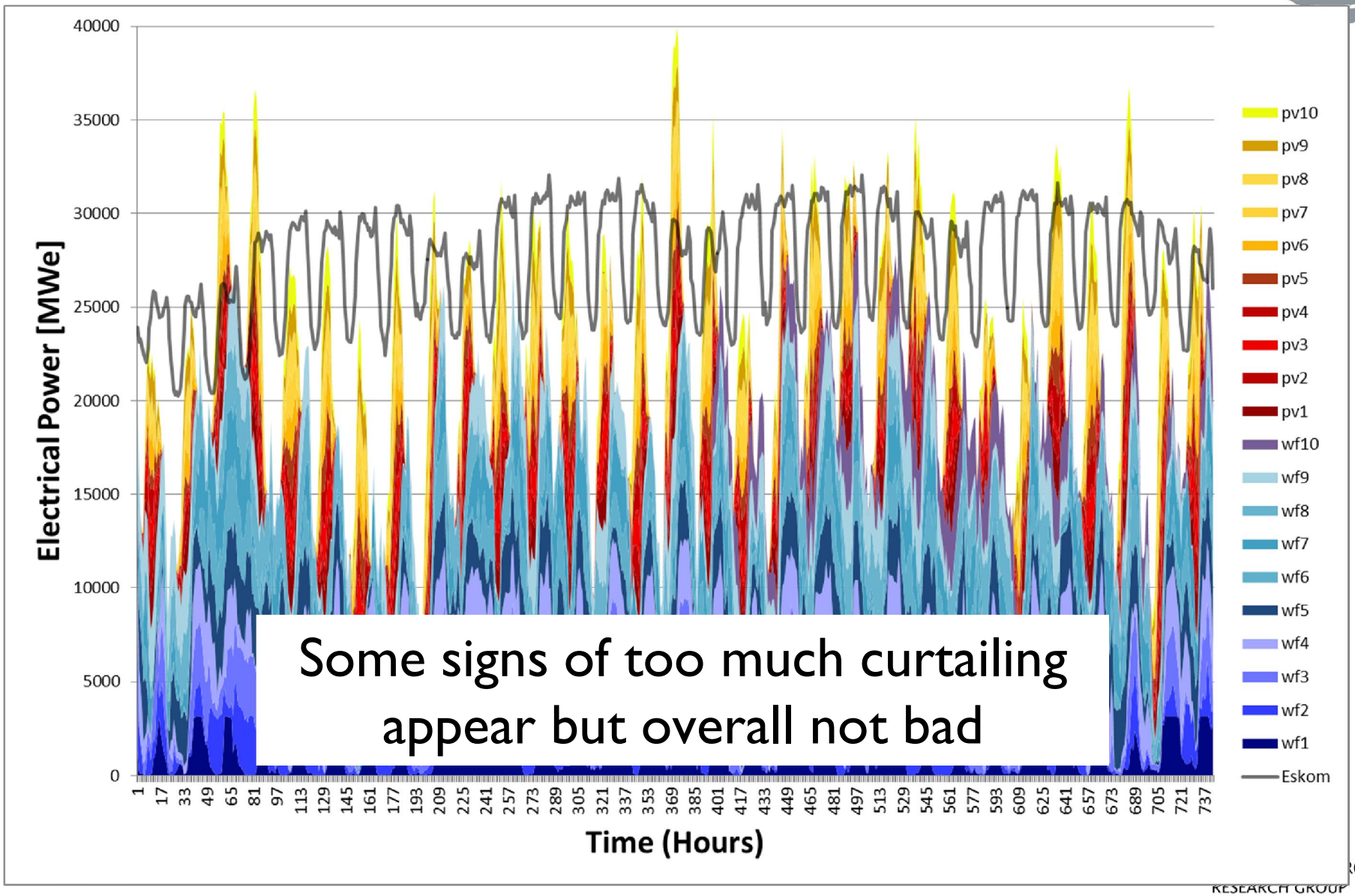
1 Summer day (15 January)



1 Summer week

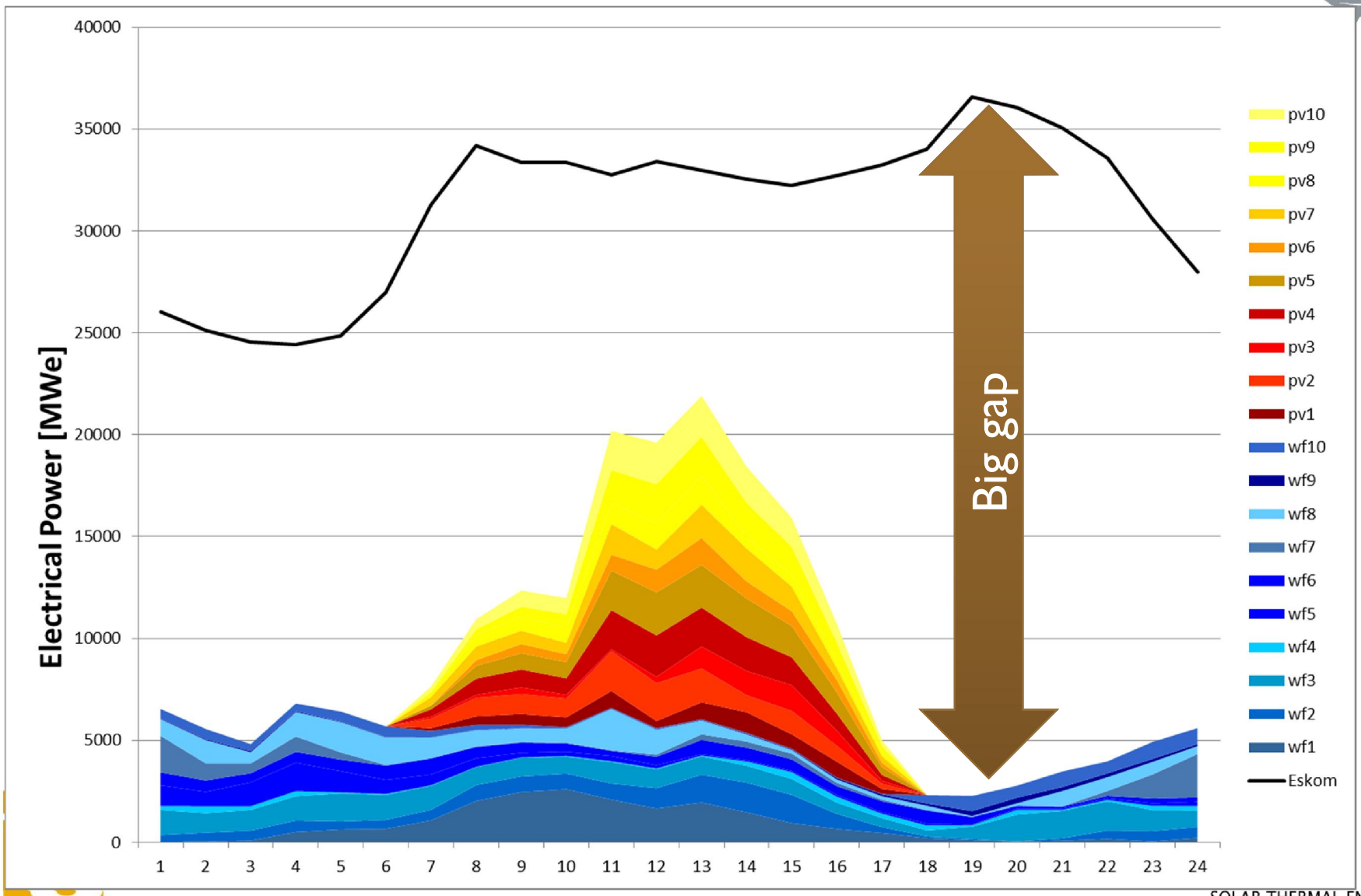


I Summer month (January)

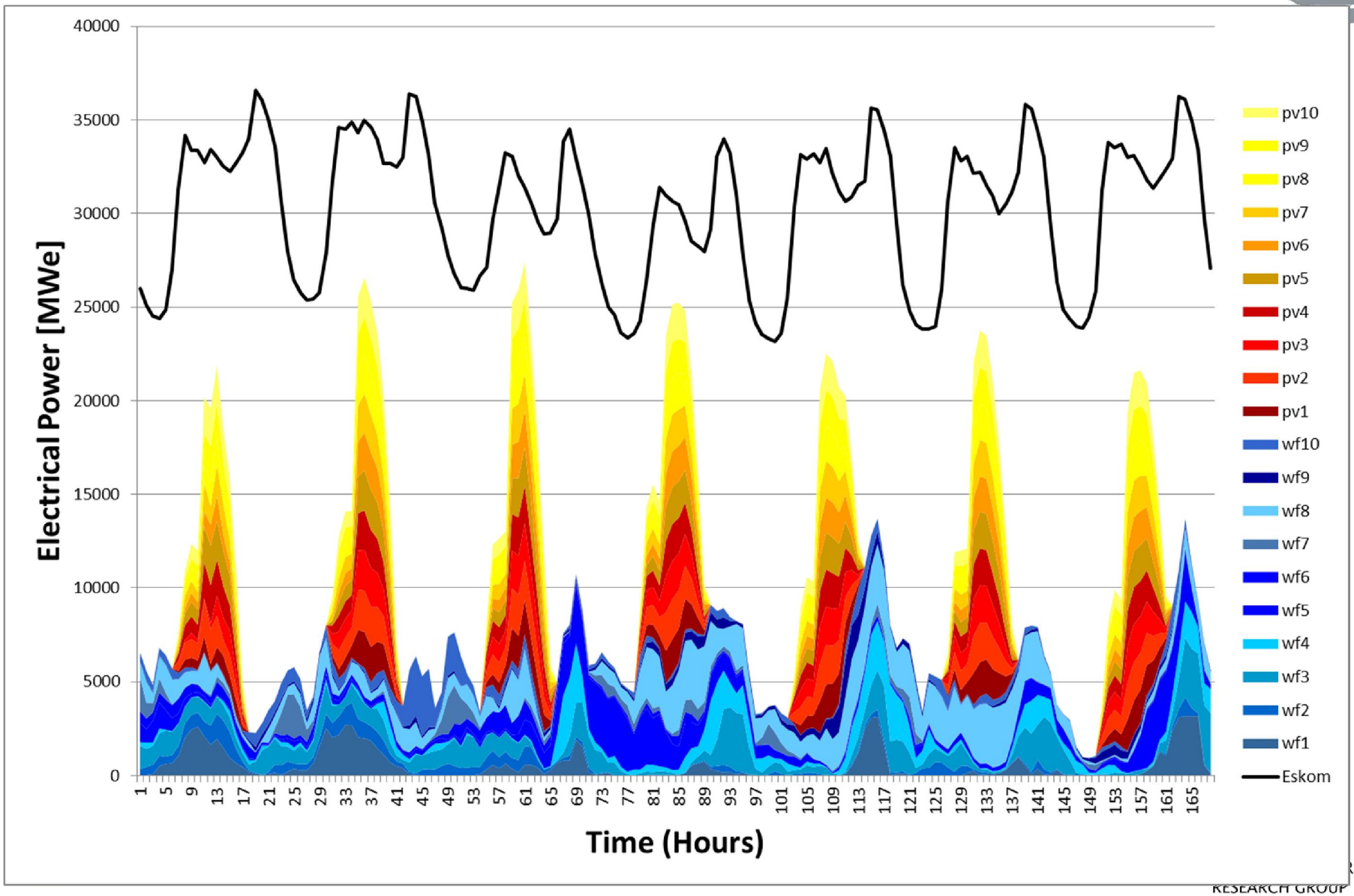


Summer is wonderful!

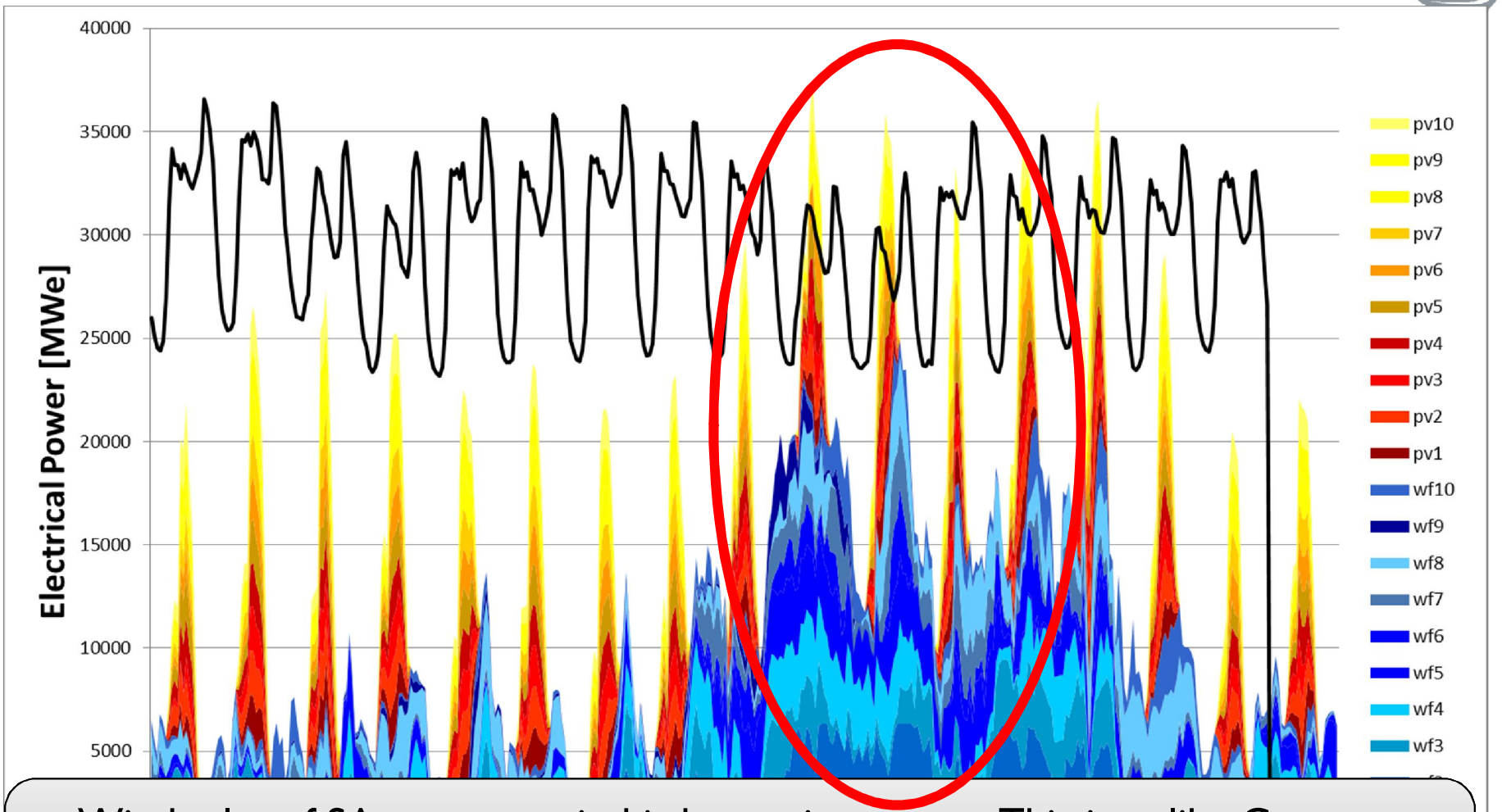
1 Winter day (15 July)



1 Winter week



1 Winter month (July)



Wind atlas of SA suggests wind is better in summer. This is unlike Germany where wind and PV are quite complimentary by season.
Even then, some days actually cause curtailment

Oops

Implications:*

1. Wind+PV+CSP will result in a seasonally lopsided system. Perhaps do plant scheduled maintenance in summer?
2. Perhaps more so than recent German studies, a 100% RE system is too costly. Optimum is probably ~ 80% RE in a future of high fuel costs.
3. Note that a high RE scenario forces low capacity factors on fossil or nuclear. Need to plan for fast start-up fossil systems like peakers.

**This is speculation – modelling incomplete*

Wrapup

SOLAR THERMAL ENERGY RESEARCH GROUP

UNIVERSITEIT STELLENBOSCH UNIVERSITY

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Thank you!

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