African Utility Week

Combined wind and solar feed-in to the grid

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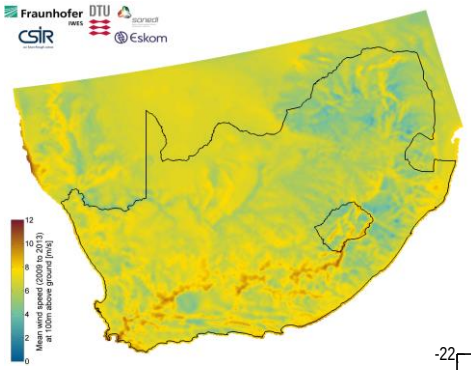
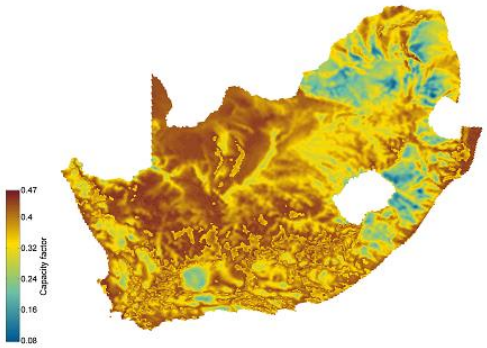
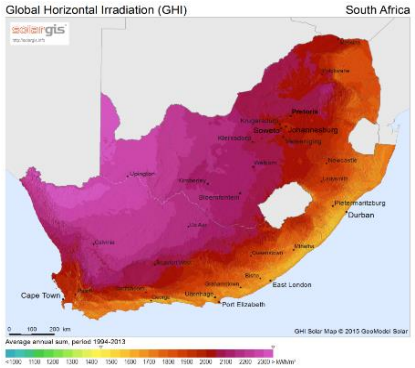
PRESENTATION AGENDA

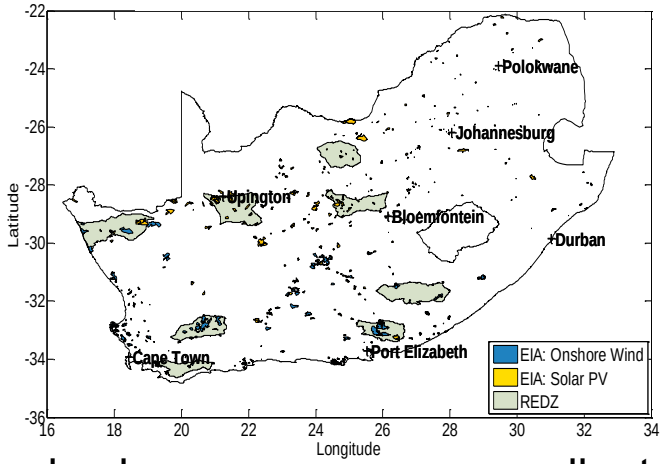
- South African wind and solar resources
- Case study on wind and solar PV combination
- Energy system design – the traditional vs new philosophy
- Changes in the Energy System – energy transition
- VRE integration – the conservative approach
- VRE integration – the optimal approach
- VRE curtailment analysis
- VRE integration grid analysis
- Conclusion

SA WIND AND SOLAR RESOURCES



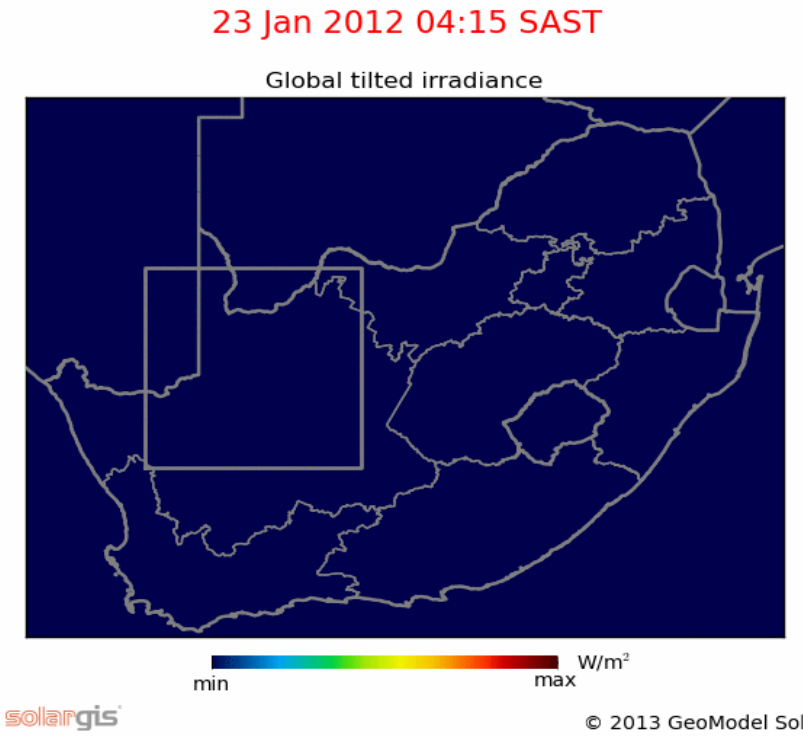


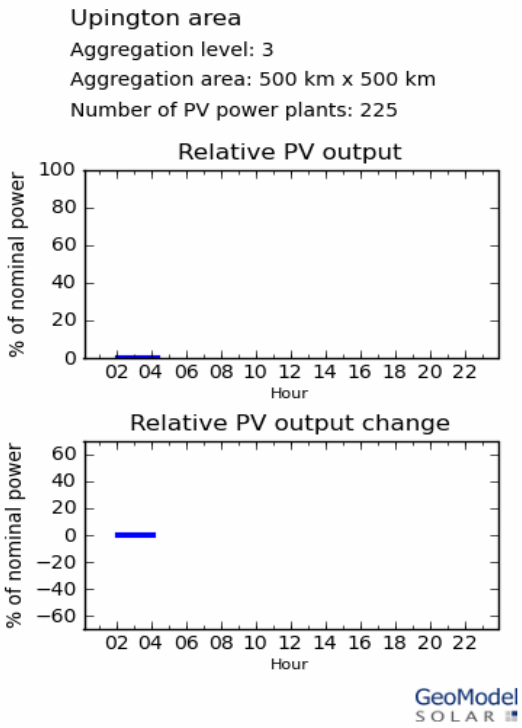


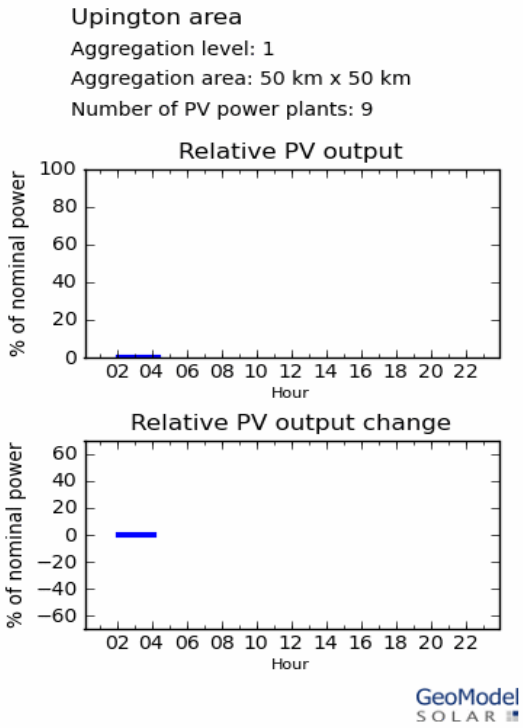


- South Africa's wind and solar resources are excellent countrywide.
- EIA applications: estimated Wind (90), PV(330); land use is roughly 1.21% of SA land
- REDZ: estimated Wind (530 GW), PV (1780 GW); land use is roughly 4.4% of SA land

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







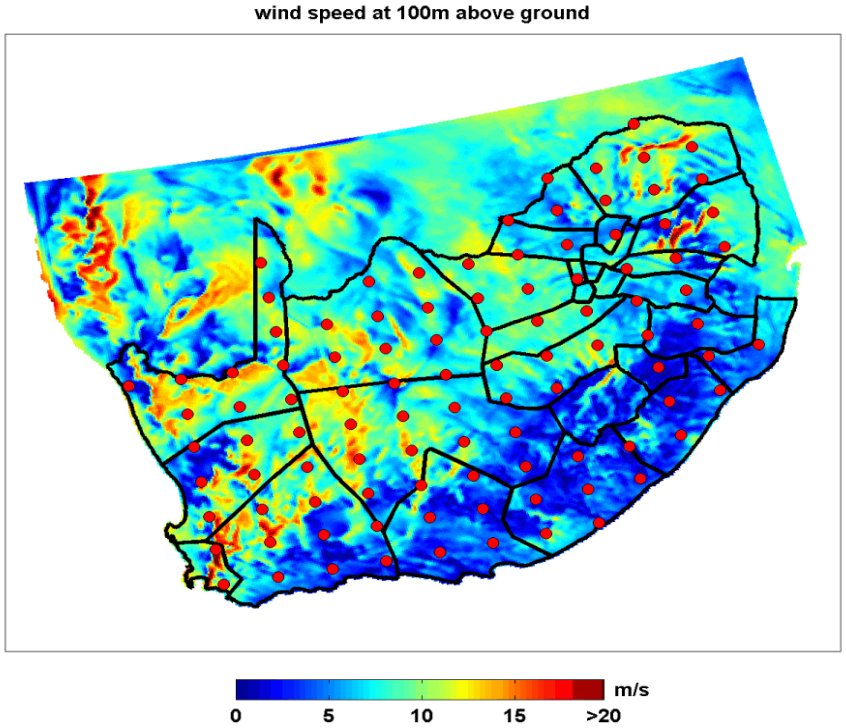
Widespread spatial distribution makes aggregated PV power output very predictable and smooth

Source: Cloud Cover study commissioned by Eskom done by GeoModel Solar and University of Stellenbosch (CRSES)

Aggregation across entire country: wind output very smooth

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

14 Jan 2012 23:45 SAST



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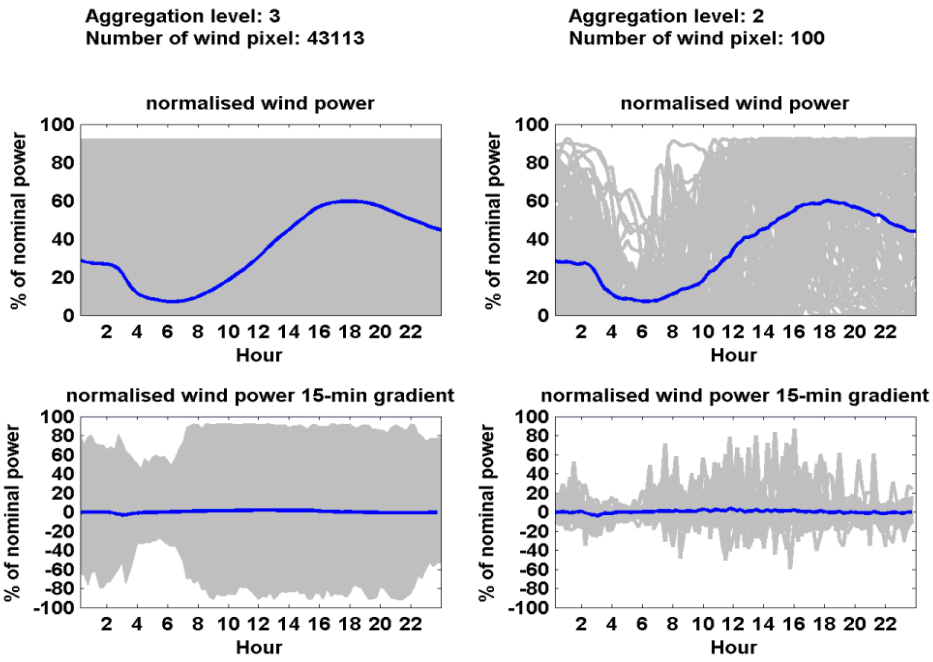
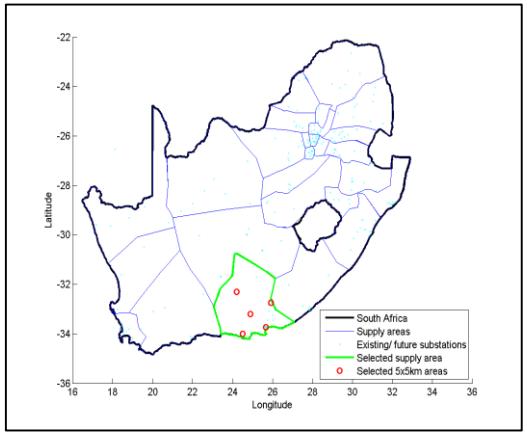
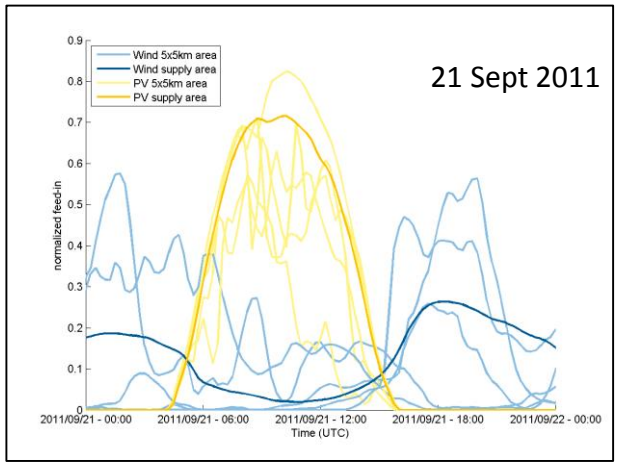
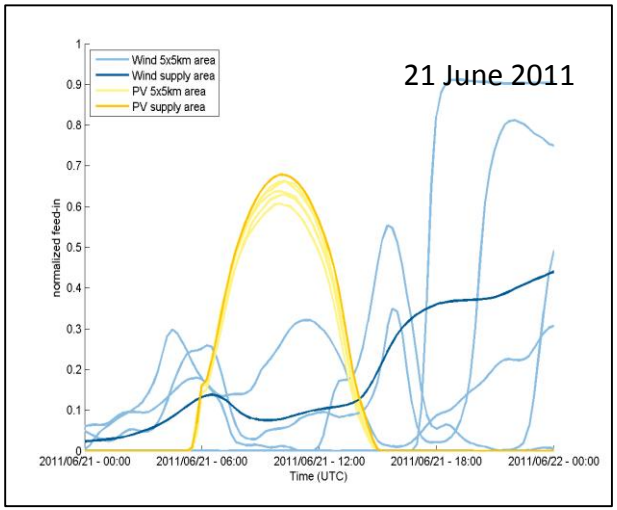


WIND AND SOLAR PV COMBINATION

Port Elizabeth Area case study





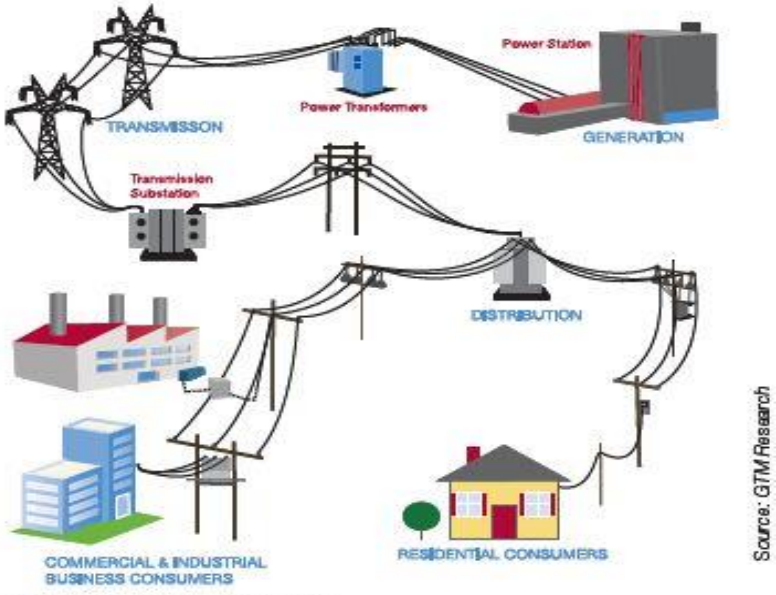


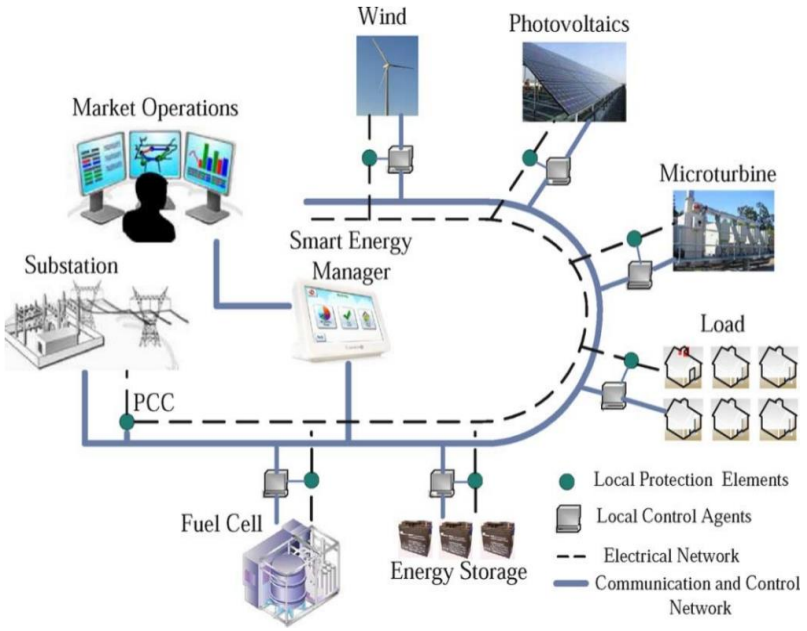
- Individual plants have high ramp rates
- Individual plant power output very volatile; low predictability
- Area (aggregated) output is much smoother with low ramp rates
- Aggregated plant output is more predictable
- Wind and solar PV output are complimentary, peaking at different times

ENERGY SYSTEM DESIGN - TRADITIONAL

YESTERDAY – centralised power system, fossil fuel driven, long lead times to build

TOMORROW – distributed (local), smart, clean power, short lead times to build



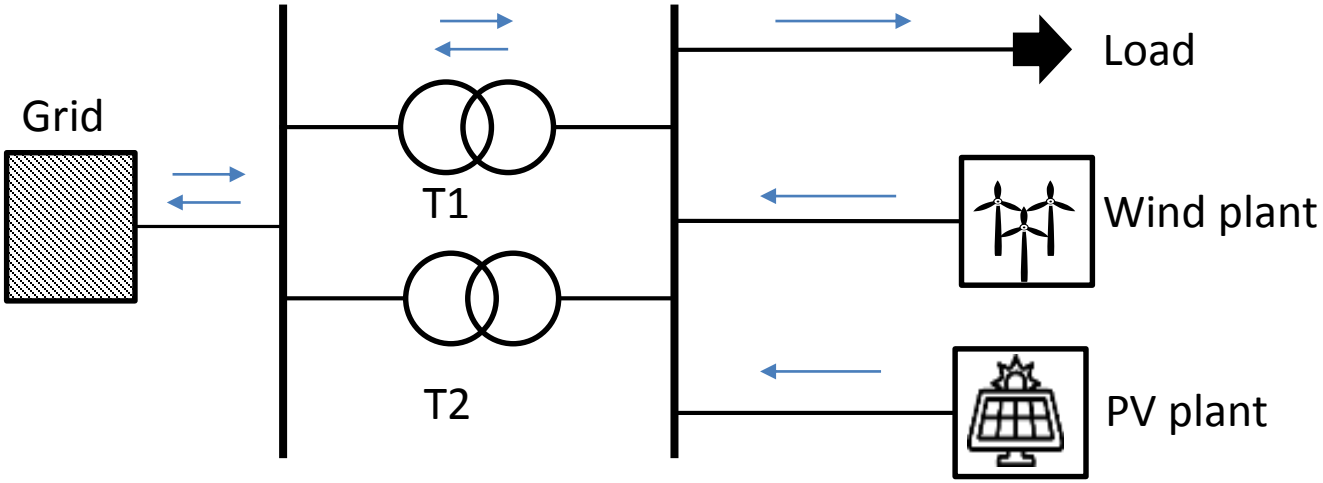


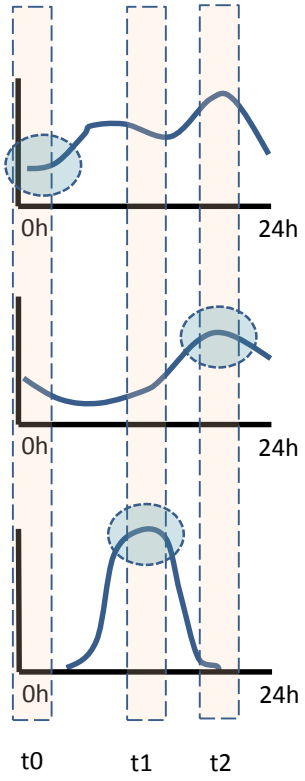
Source: J. N. Edward, A. Ramadan, El-Shatshat, "Multi-Microgrid Control Systems (MMCS)," IEEE Power and Energy Society General Meeting, 25-29 July 2010, pp. 1-6; CSIR analysis.

CHANGES IN THE ENERGY SYSTEM

Traditional view of the energy system	New approaches to energy systems
Large centralised generation	Small decentralised generation
Base load generation (less flexible)	Flexible generation (baseload in irrelevant)
Centralised grid design with transmission as backbone	Microgrids or minigrids are the building blocks of the grid
Consumers	Prosumers
Load	**Residual load (i.e. load – variable RE)**
Communication and control at transmission level	Distribution grid and customer levels are driven by smart systems; ICT central to the energy system
Unidirectional power flow	Bidirectional power flow
Electricity price largely depends on energy charge	Capacity charge is larger portion of the electricity price
Generation is largely owned by large corporations or the state	Community trusts and cooperatives can own distributed generation
Bulk power from centrally dispatched power plants	**Bulk power from self/weather dispatched power plants (i.e. wind and solar)**

VRE INTEGRATION – CONSERVATIVE





A: VRE generation = $PV_{max\,(t1)} + Wind_{max\,(t2)}$

B: VRE generation = $PV_{max\,(t1)} + Wind_{max\,(t2)} + Load_{min(t0)}$

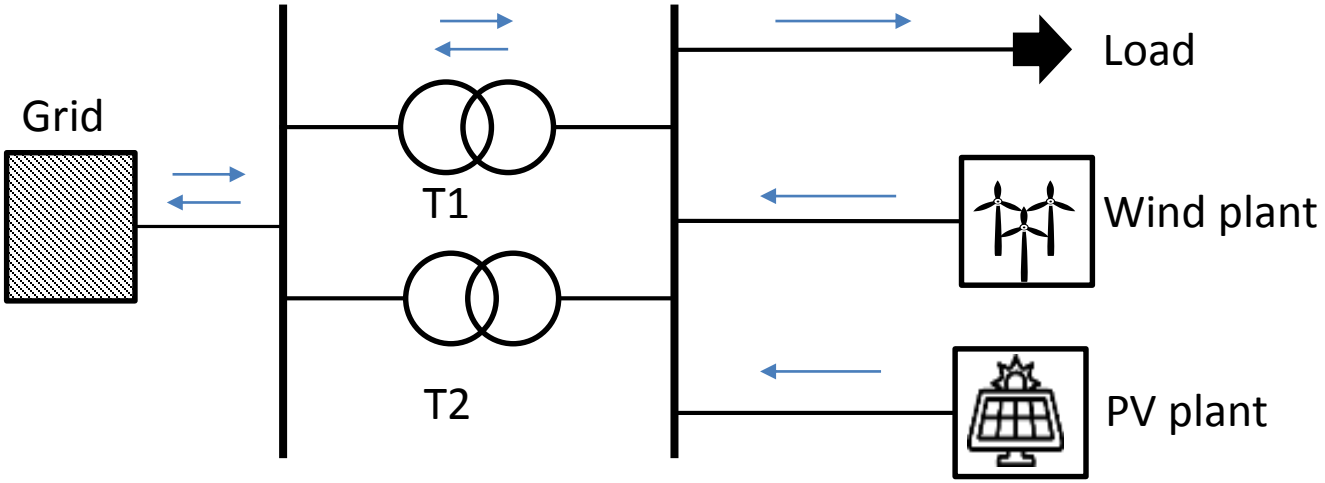
C: VRE generation = $(PV_{t1} + Wind_{t1})_{max} + Load_{min(t0)}$

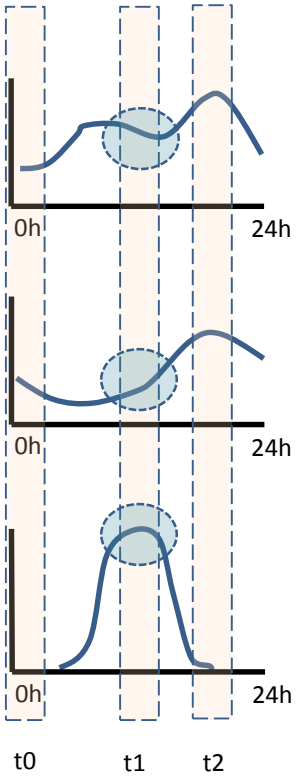
A: Load not considered, therefore transformation capacity is the limitation

B: Load considered, but no diversity for generation and load

C: Diversity for generation only, load diversity not considered

VRE INTEGRATION – OPTIMAL APPROACH





VRE generation = PV $_{(t1)}$ + Wind $_{(t1)}$ + Load $_{(t1)}$

- **Generation and load diversity taken into account all the time, therefore more PV and Wind capacity that can be added far exceed the transformation capacity.**
- **Even if load is zero, PV and Wind diversity results in their capacities exceeding the transformation capacity.**

VRE CURTAILMENT ANALYSIS – RESEARCH QUESTIONS

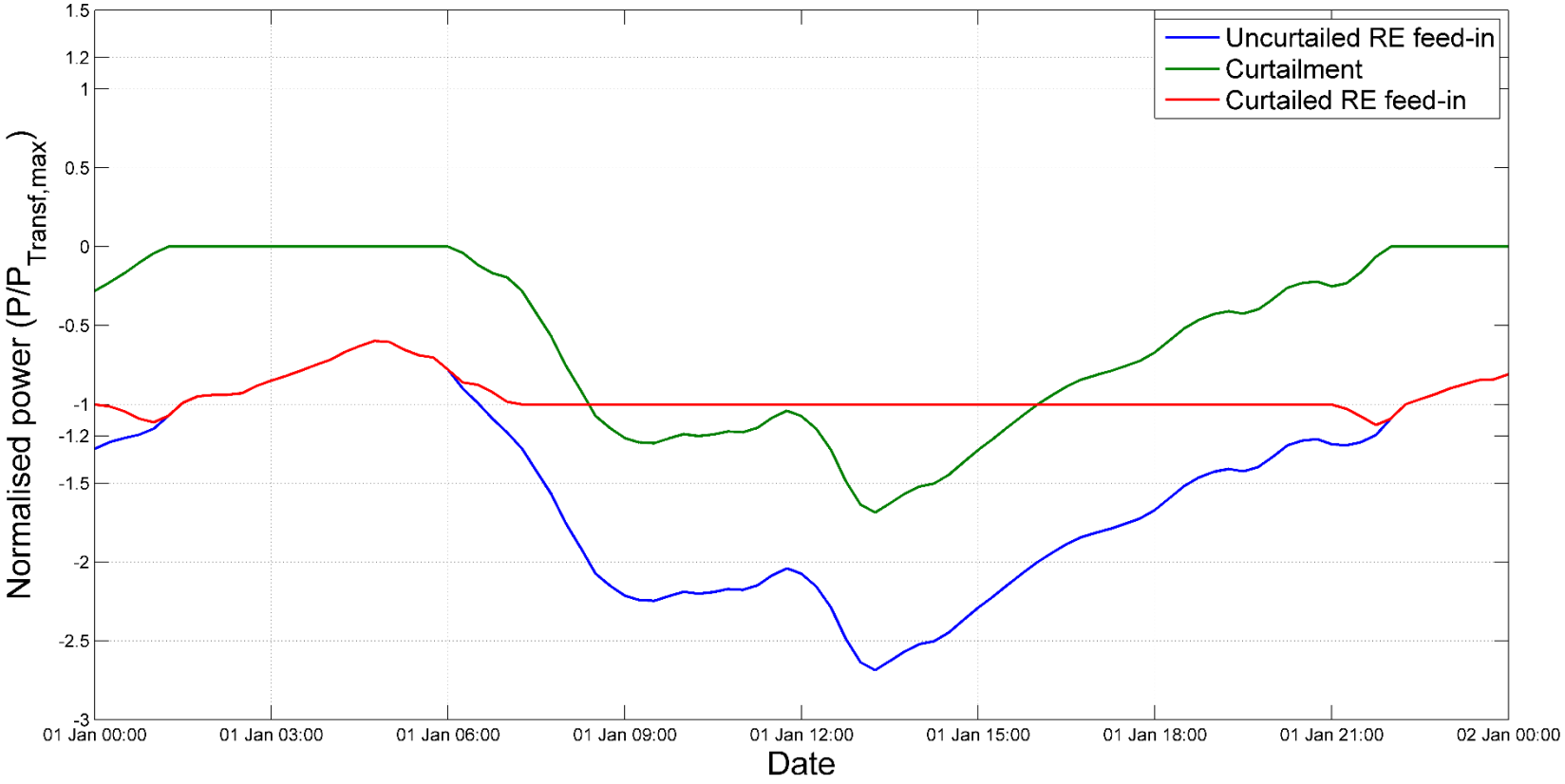
- How much VRE might be installed at substation level?
  - Should it be 100% of transformer capacity or more?
- How to estimate the installable capacity countrywide?

Additional aspects:

- Each transmission substation has a certain rated capacity in MW (maximum evacuation)
- Each solar PV/wind project has a certain rated capacity in MW (maximum output)
- Status quo: solar PV/wind projects can connect to a certain substation up to the point that the sum of the rated solar PV/wind capacity equals the rated capacity of the substation
- Solar PV and wind projects' power output however is generally not highly correlated
- This means that the sum of rated solar PV and wind capacity at a substation could be higher than the rated capacity of the substation without running into excess power situation often
- This effect was analysed and the potential over-installation capacity of solar PV and wind was quantified for all substations across South Africa

FEED IN AND CURTAILMENT

- If feed-in exceeds transformer capacity, VRE feed in is curtailed
- Overload up to 20% can be accepted up to 45 minutes
- For the study a conservative approach was chosen: no overload is accepted



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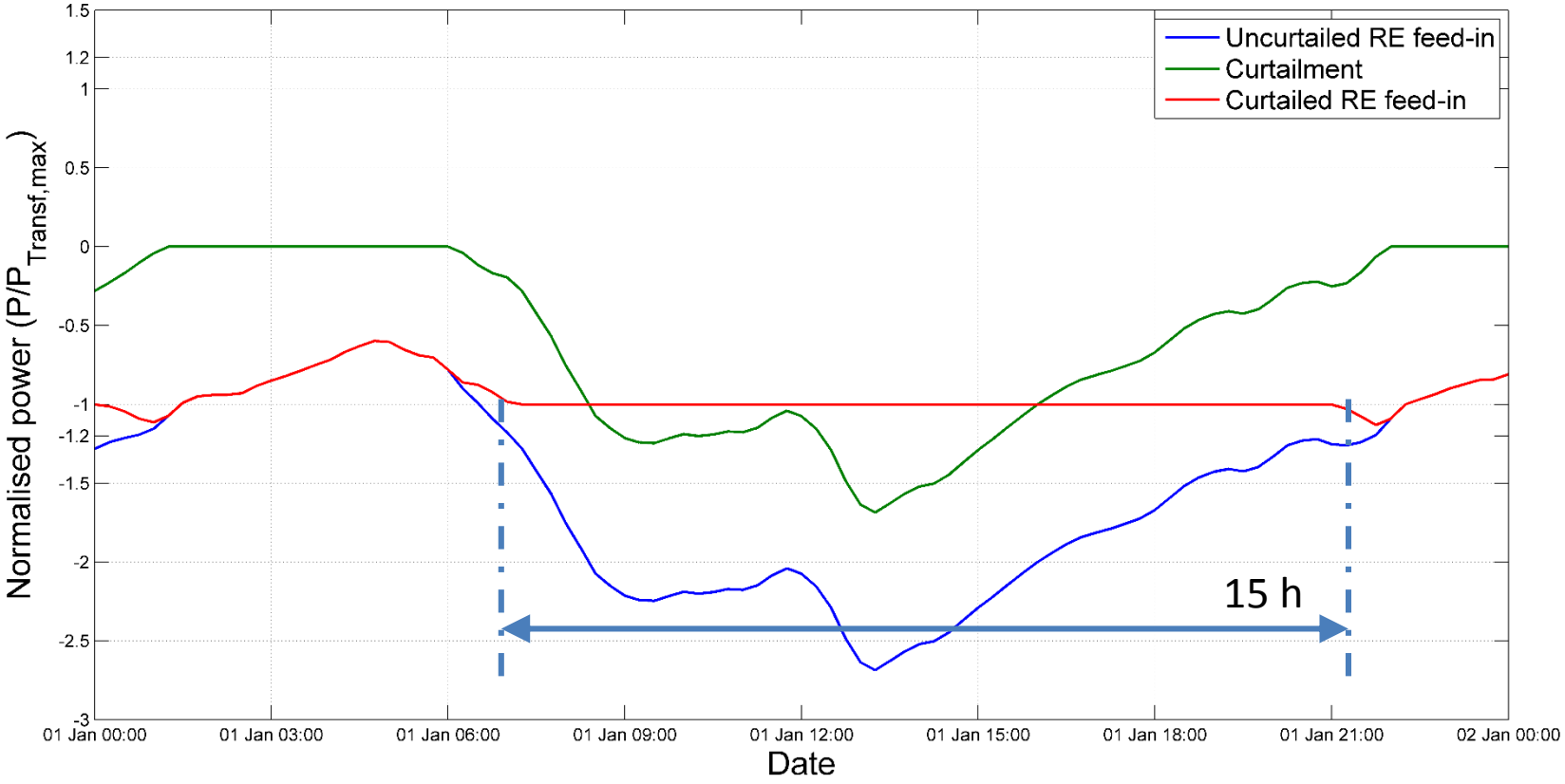
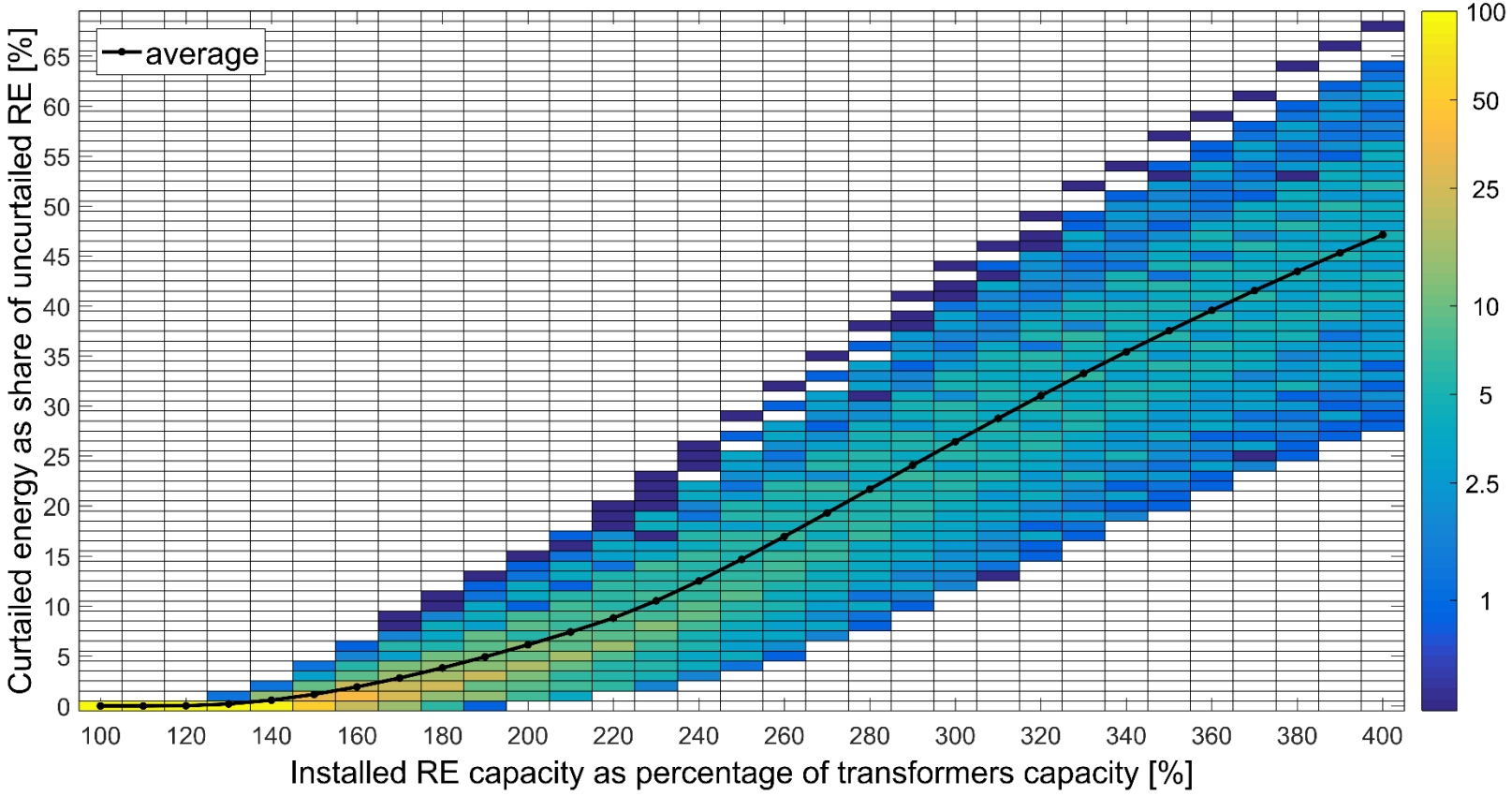


UP TO 20% OVER-INSTALLATION IS POSSIBLE WITHOUT CURTAILING ENERGY

– FOR THE MOST CONSERVATIVE APPROACH (NO DEMAND CONSIDERED)



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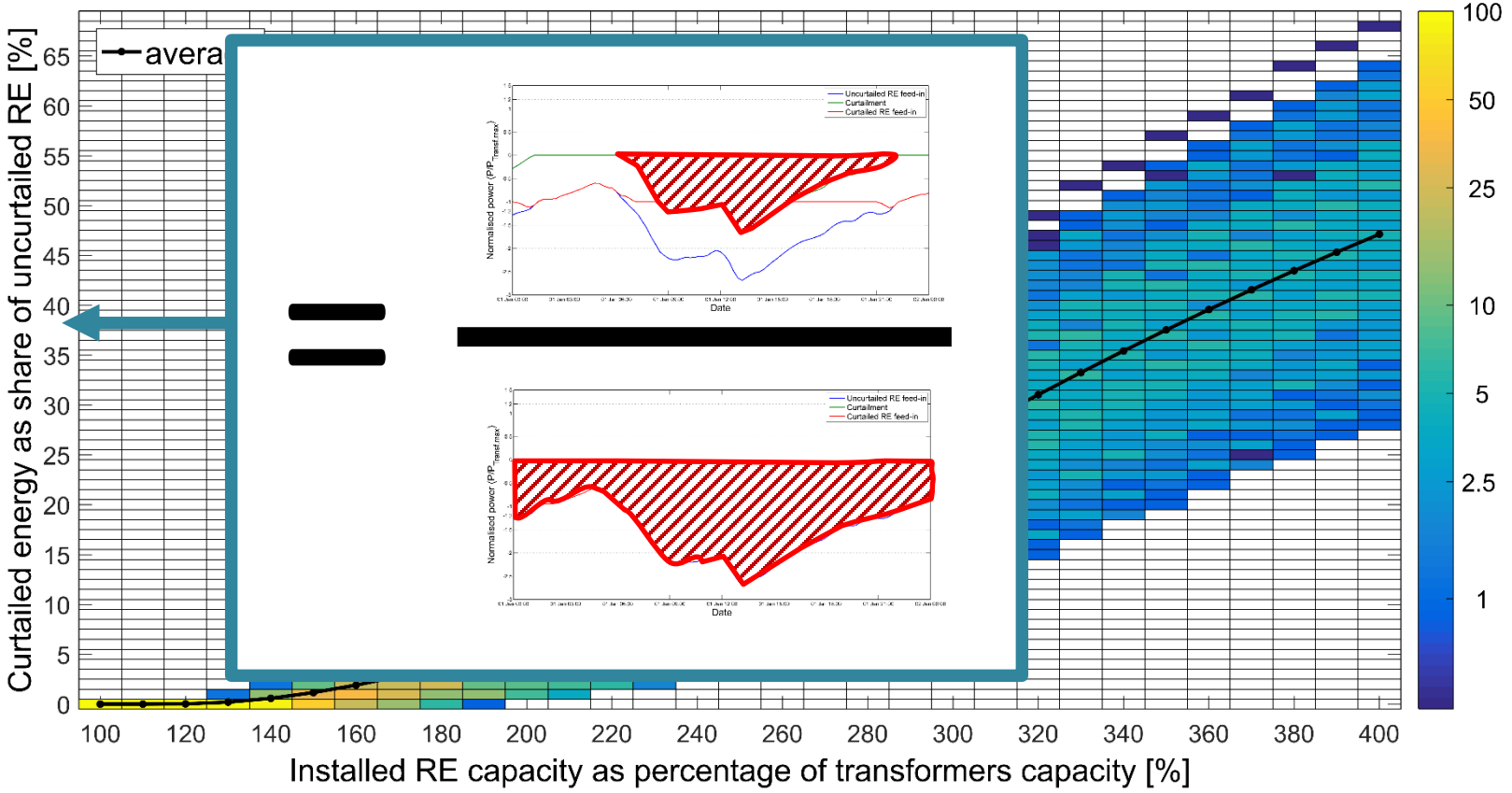

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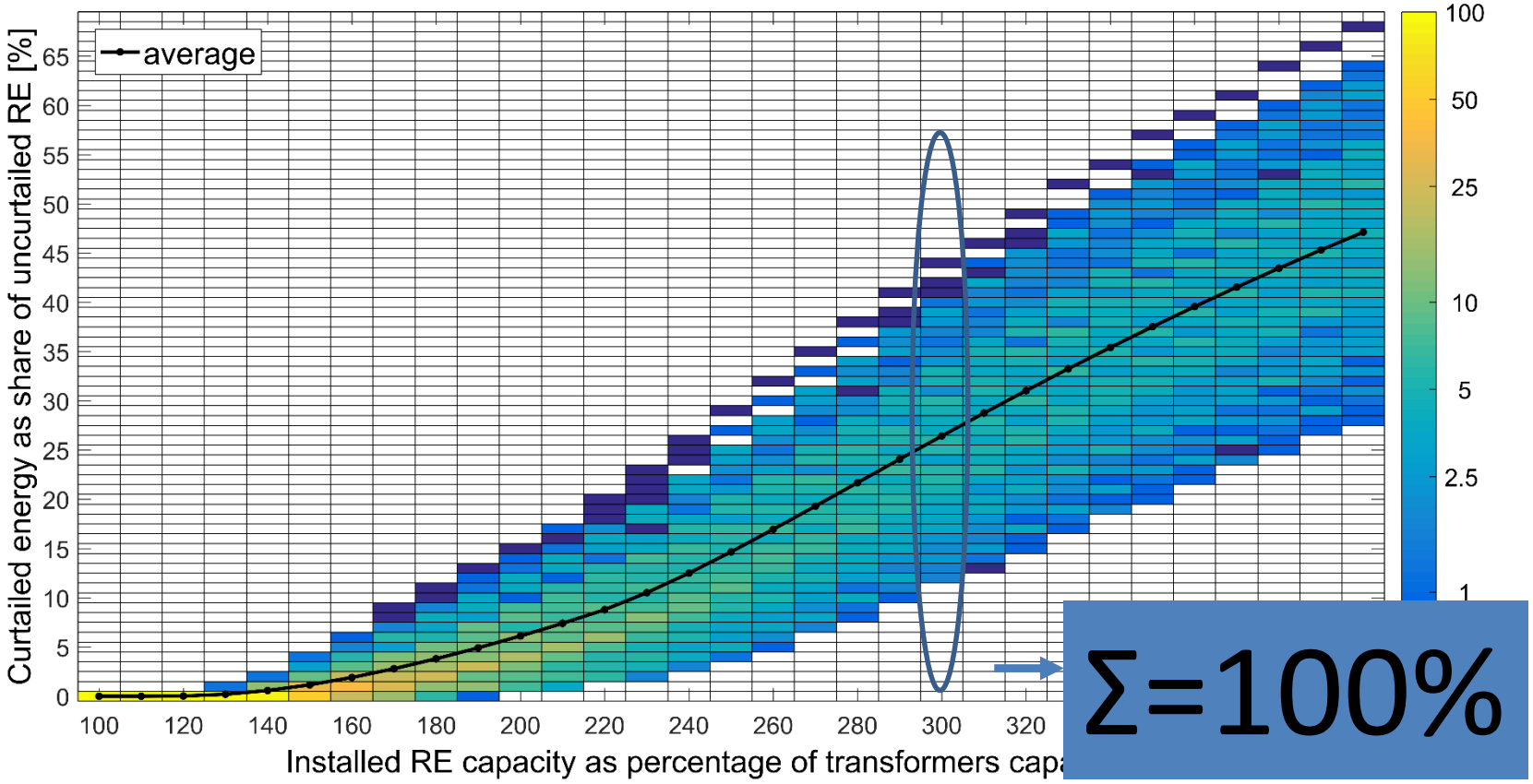
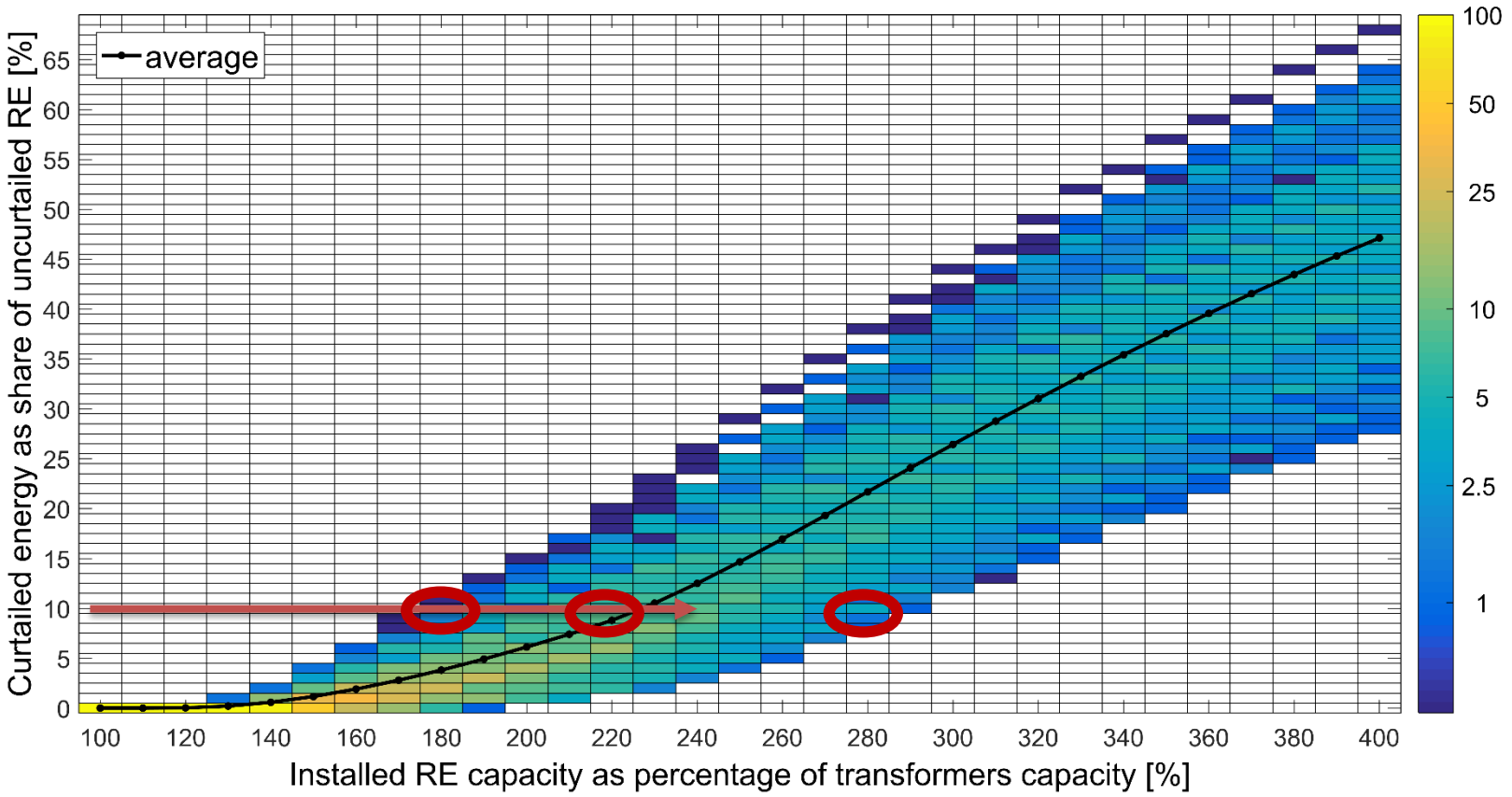
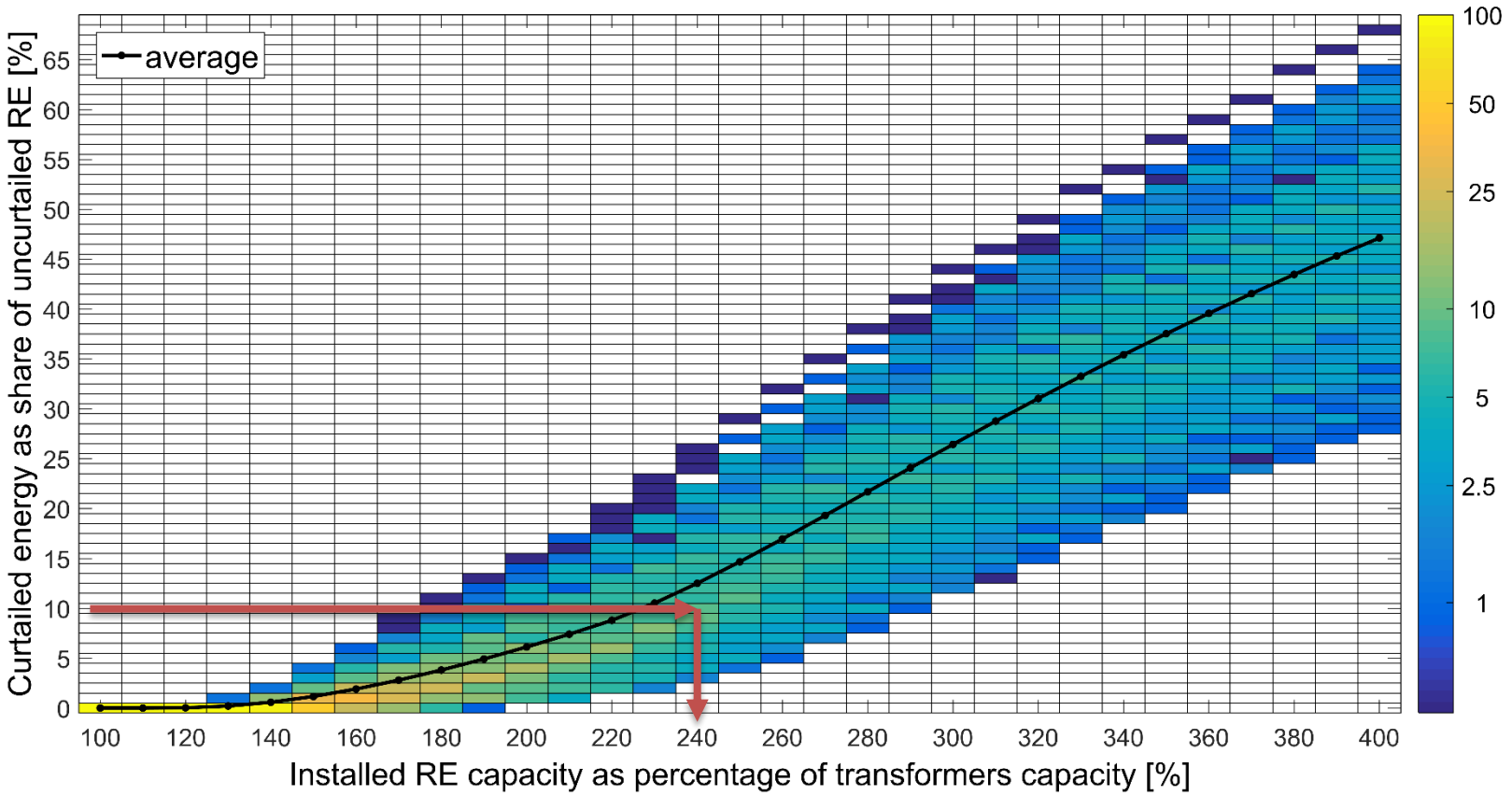


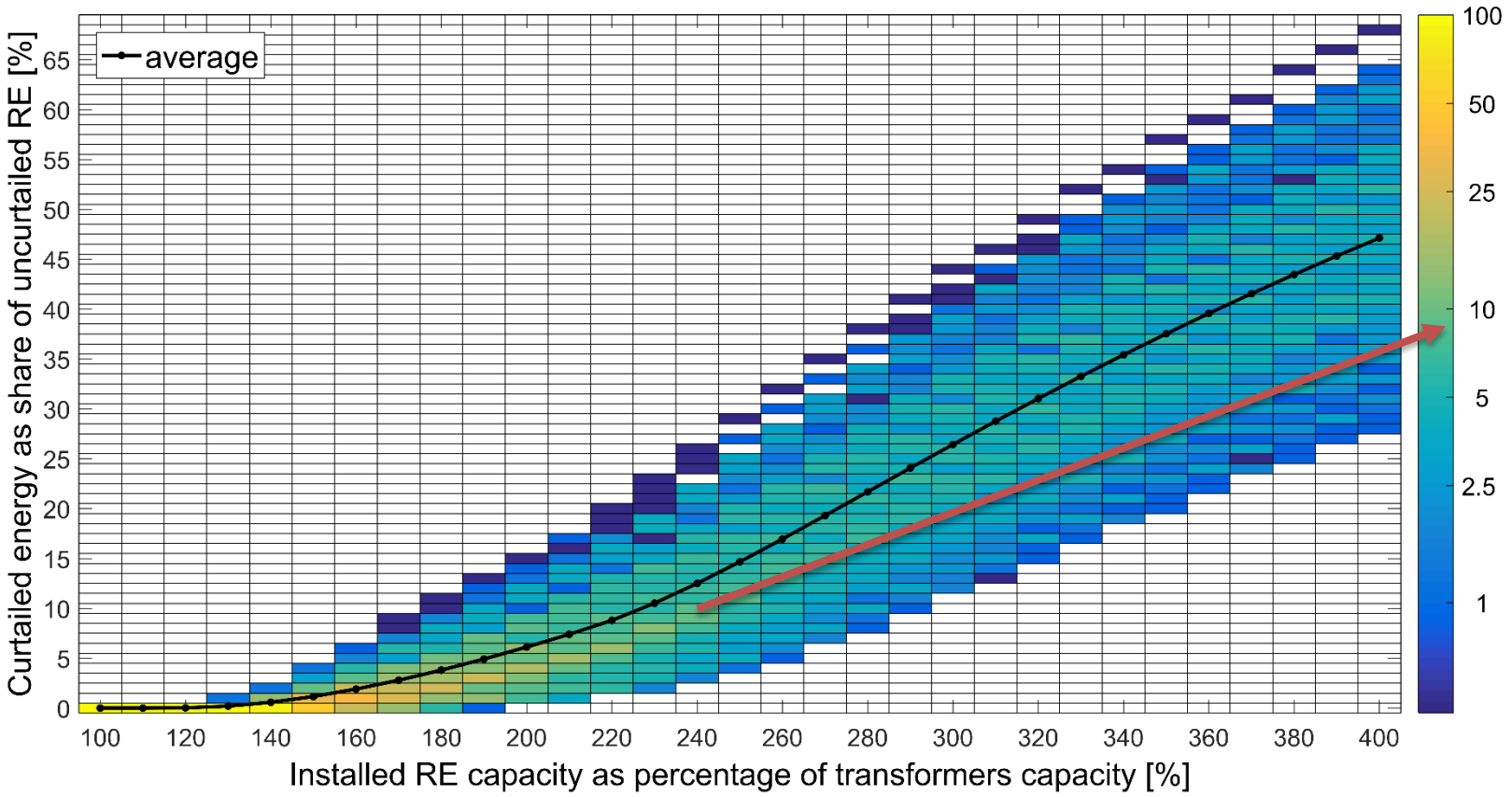
10% CURTAILMENT



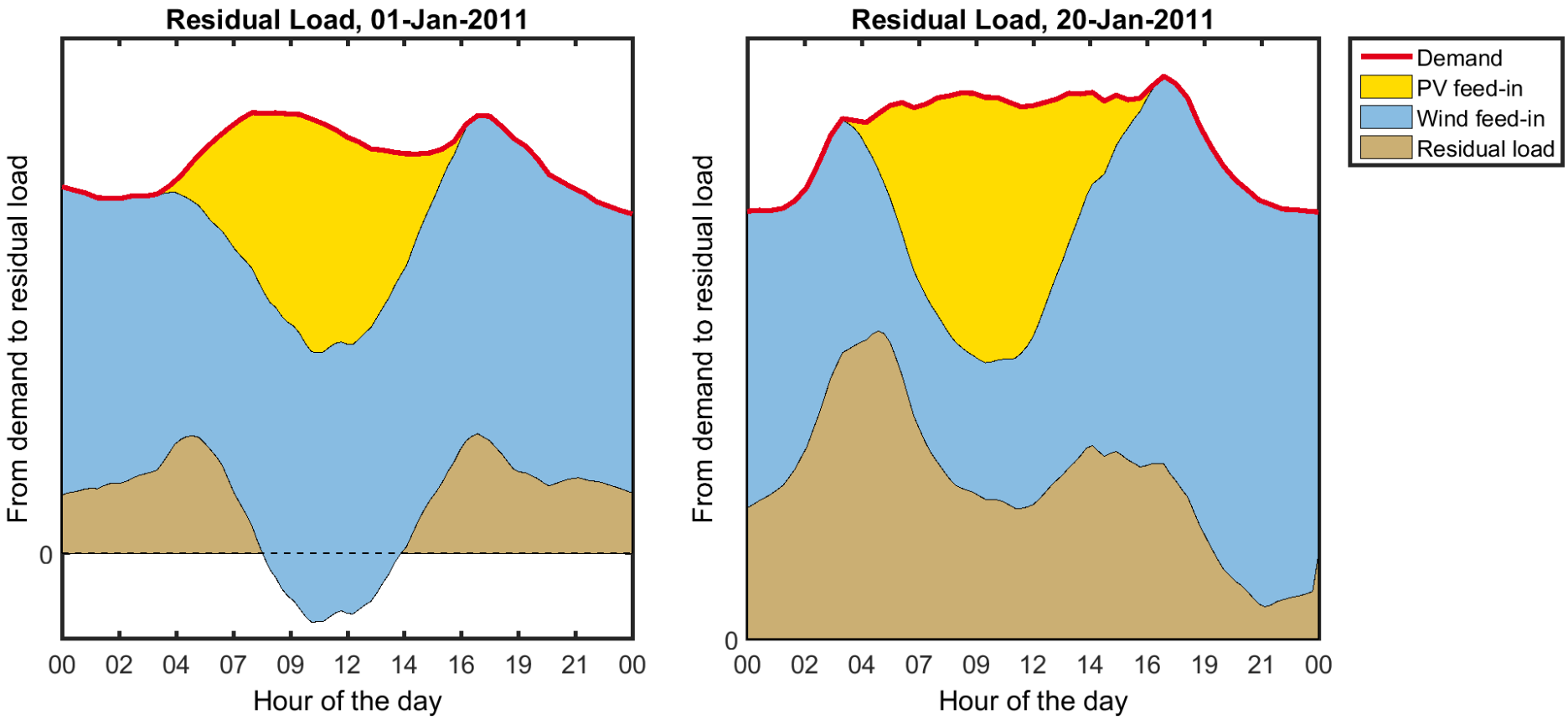
10% CURTAILMENT @ 240% RE CAPACITY



10% CURTAILMENT @ 240% RE CAPACITY
10% PROBABILITY

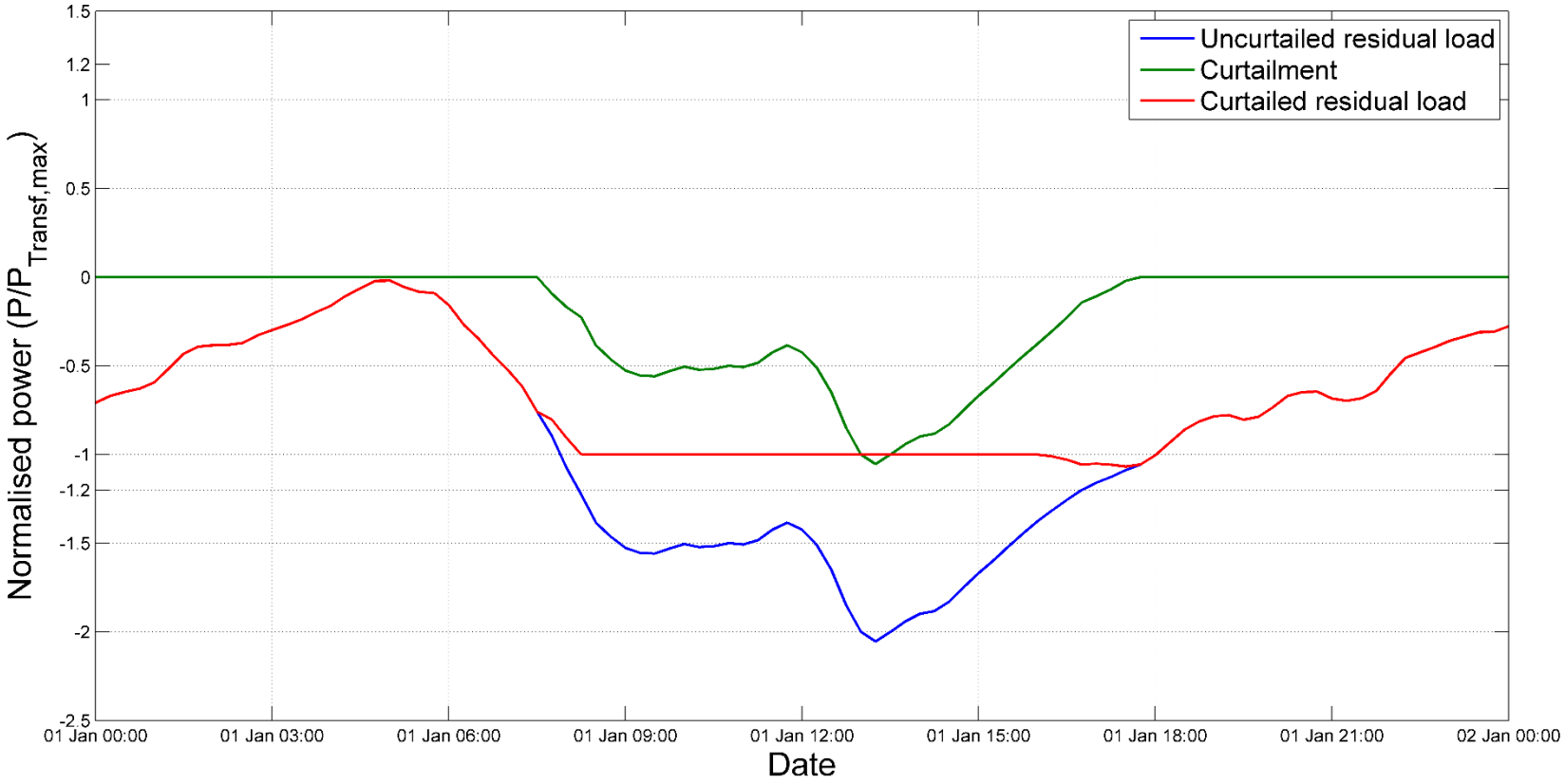


NOT FEED-IN BUT RESIDUAL LOAD MATTERS
RESIDUAL LOAD = DEMAND – VRE FEED-IN



CURTAILMENT OF RESIDUAL LOAD IS KEY

- Residual load (consumption at substation level minus VRE feed-in) has to be investigated



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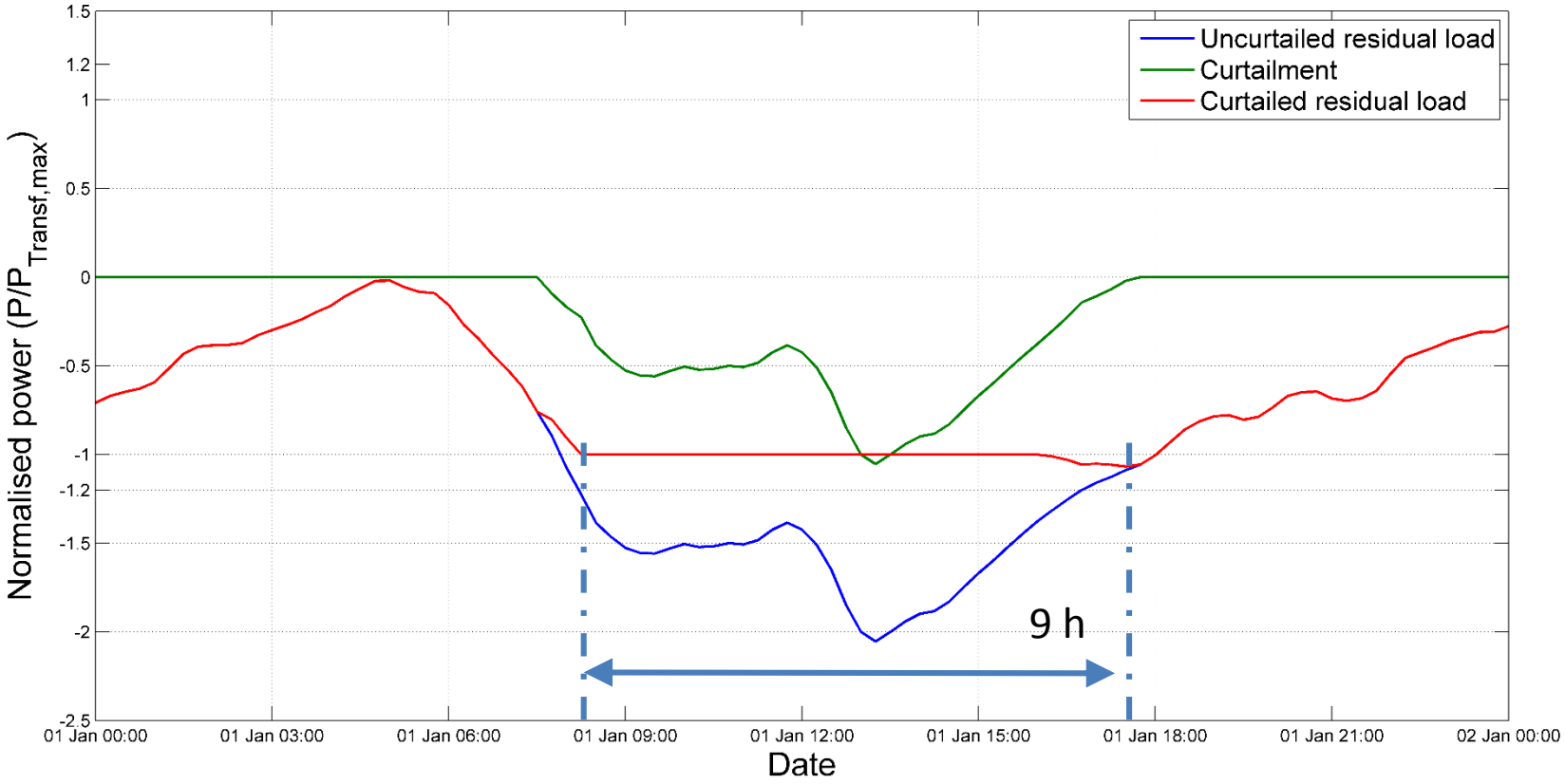
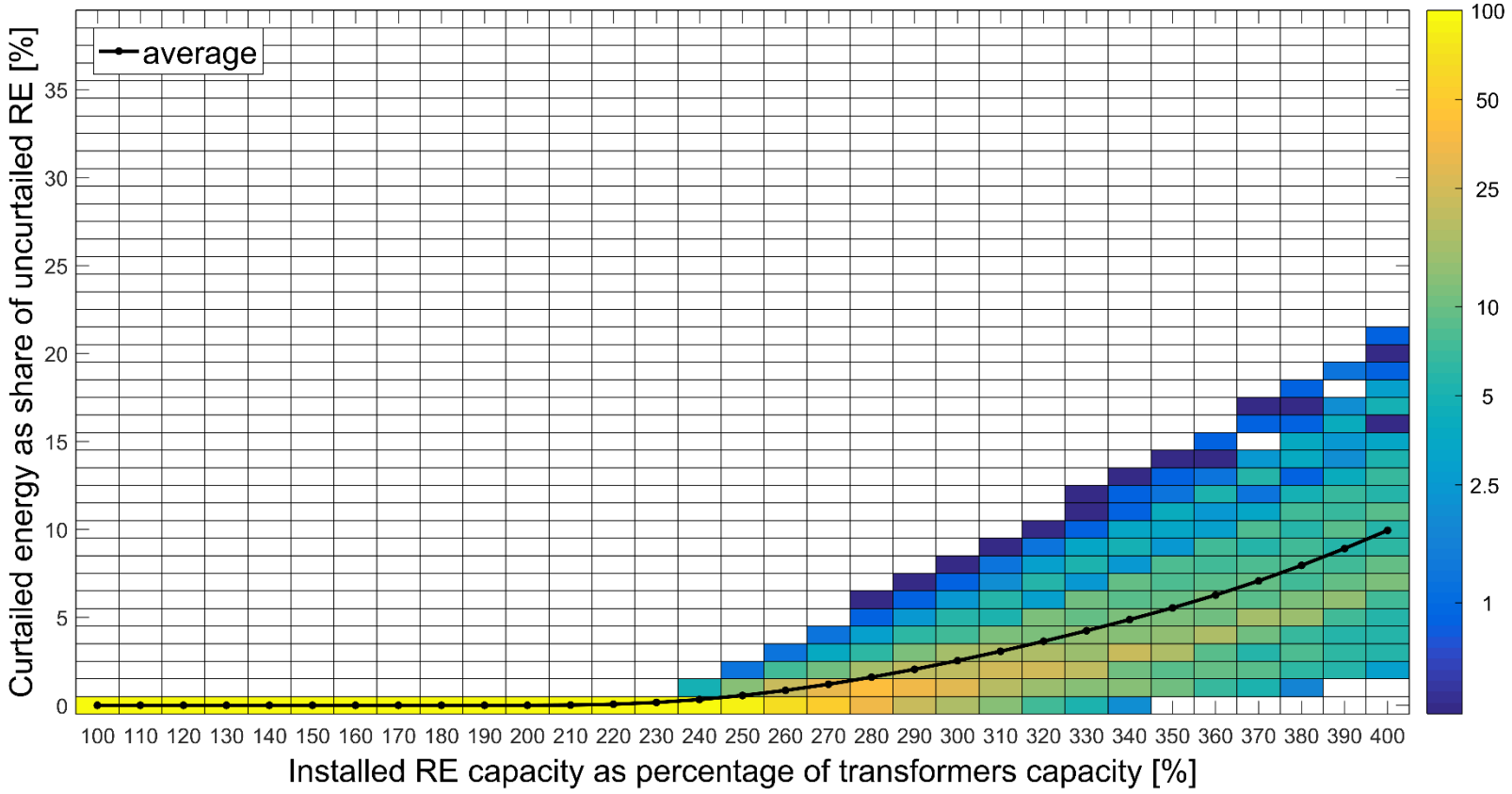


UP TO 230% INSTALLED VRE CAPACITY (50% PV, 50% WIND) NO CURTAILMENT IS NEEDED (THREE YEARS AVERAGE)

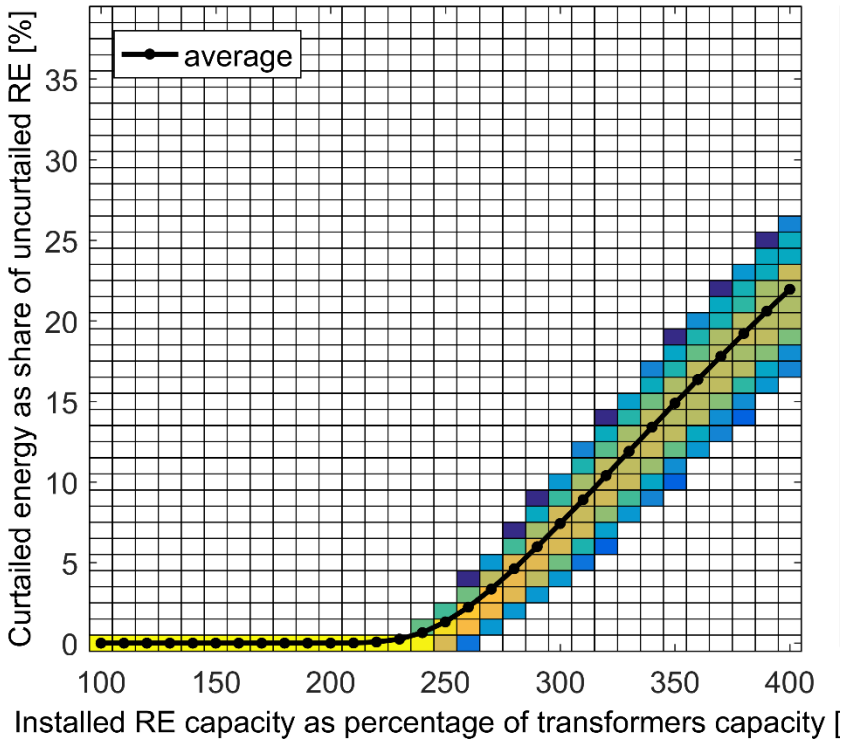


INSTALLABLE CAPACITY COUNTRY WIDE

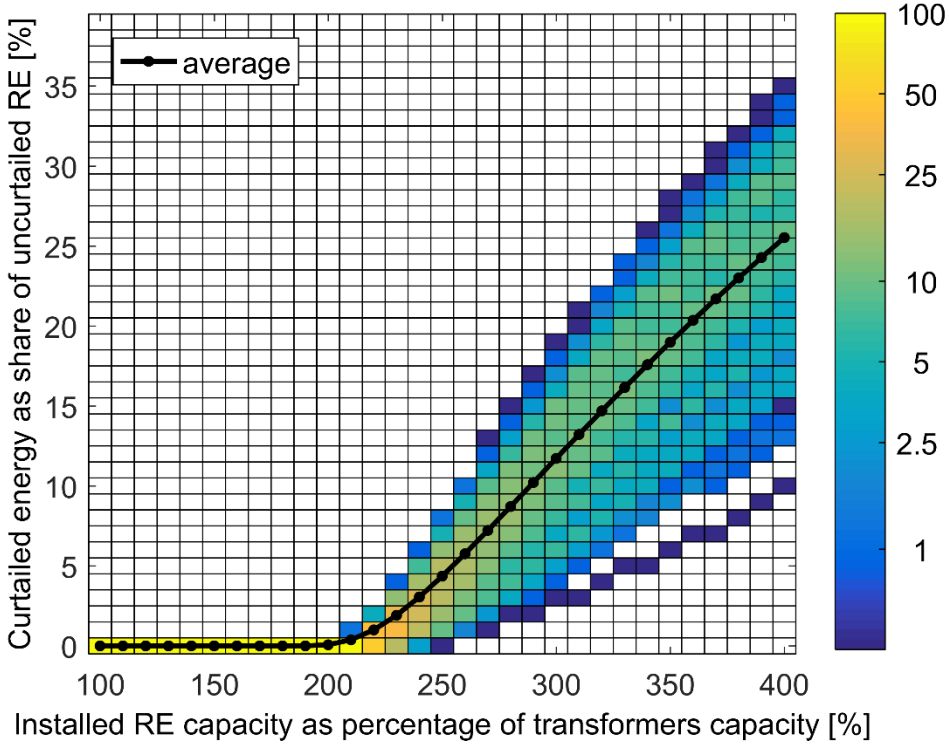
	Curtailed annual energy per total solar/wind energy	Minimum installable solar/wind power per substation capacity	Average installable solar/wind power per substation capacity	Maximum installable solar/wind power per substation capacity
Only Feed-in 50% wind	0%	120%	120%	340%
	5%	140%	190%	Not evaluated yet
	10%	180%	290%	Not evaluated yet
Feed-in and load (residual load) 50% wind	**0%**	**230%**	**240%**	**340%**
	5%	**280%**	**340%**	**Not evaluated yet**
	10%	**320%**	**400%**	**Not evaluated yet**

CHANGING THE PV/WIND RATIO

10% wind / 90% PV capacity



90% wind / 10% PV capacity



INSTALLABLE CAPACITY COUNTRY WIDE

	Curtailed annual energy per total solar/PV energy	Minimum installable solar/wind power per substation capacity	Average installable solar/wind power per substation capacity	Maximum installable solar/wind power per substation capacity
Feed-in and load (residual load) Wind 10%	0%	230%	230%	260%
	5%	270%	280%	310%
	10%	300%	320%	350%
Feed-in and load (residual load) Wind 50%	**0%**	**230%**	**240%**	**340%**
	5%	**280%**	**340%**	**Not evaluated yet**
	10%	**320%**	**400%**	**Not evaluated yet**
Feed-in and load (residual load) Wind 90%	0%	200%	200%	250%
	5%	240%	260%	340%
	10%	260%	290%	400%

VRE CURTAILMENT ANALYSIS RESULTS

- 120% VRE capacity compared to transformer capacity can be installed at substation level for feed-in only without curtailment
  (20% additional VRE capacity compared to transformer capacity can be installed)

- About 230% VRE Capacity compared to transformer capacity can be installed at substation level considering a share of 50% PV and 50% wind

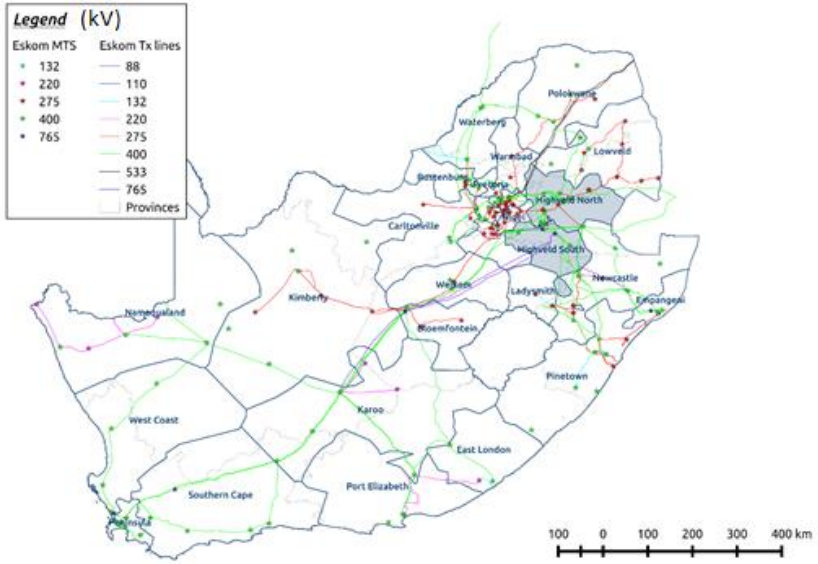
- Solar and wind both meet the demand well, even solely

- Solar is more consistent over time and substations than wind, thus results are less variable

- For the same installed capacity, the energy generation from wind is usually greater than that of solar PV as wind power plants are able to reach higher capacity factors and they can generate 24/7

COUNTRYWIDE MORE THAN 350 GW VRE CAPACITY CAN BE INSTALLED WITHOUT CURTAILMENT

- Evaluation done for 376 transmission transformers
- Average power 377 MVA
- Total transformer capacity 142 GW
- Total installable VRE capacity without curtailment: 377 GW



CONCLUSION

- The excellent wind and solar PV resources in South Africa provide a basis for larger shares in the future energy mix
- Spatial aggregation of wind and solar resources reduces variability and thus increases predictability
- Wind and solar resource profiles are complimentary, which makes them an ideal combination
- At least 20% additional wind/PV power can be installed per substation without any curtailment of wind/PV power (90% with 5% curtailment) – no load considered, thus conservative
- Considering load this value increases to 130% (180% with 5% curtailment)
- A better simulation of overload and allowable overload situations considering ambient temperature etc. should be carried out to refine the installable capacity results
- The special situation at that particular node, e.g. local load, grid stability on site etc., should be investigated further.

African Utility Week

Energy Revolution Africa

Thank you!

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