LCOE estimation in Aggregated Wind/PV study

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+CSIR – Energy Centre

Content

- Main findings of the Aggregation study
- data base of Aggregation study
- comparison to ground based measurments and model data
- Results of the diffrent bid windows as comparison
- LCOE calculation of Aggregation study
- The meaning of LCOE
- Limitation of LCOE
- Other aspects not included in LCOE
- summary (1-2 slide)

Executive Summary

CSIR, SANEDI, Eskom and Fraunhofer IWES conducted a study to holistically quantify

- the wind-power potential in South Africa and
- the portfolio effects of widespread spatial wind and solar power aggregation in South Africa

Wind Atlas South Africa (WASA) data was used to simulate wind power across South Africa

Key result: South Africa exhibits world-class conditions to introduce very large amounts of variable renewables into the electricity system

- Both solar and wind resources are world class: solar PV and wind turbines are therefore very low-cost bulk energy providers in South Africa already today
- Both solar and wind supply have very low seasonality in South Africa
- Very wide-spread interconnected electricity grid enables spatial aggregation to reduce volatility
- South Africa is a very large country with low population density: space is not a constraint
- Turbines widely dispersed: Even 50% wind energy share does not create short-term volatility

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Acknowledgements and contributions

Working group:

SAWEA

SAPVIA

DoE IPP Office

GIZ SAGEN

DoE

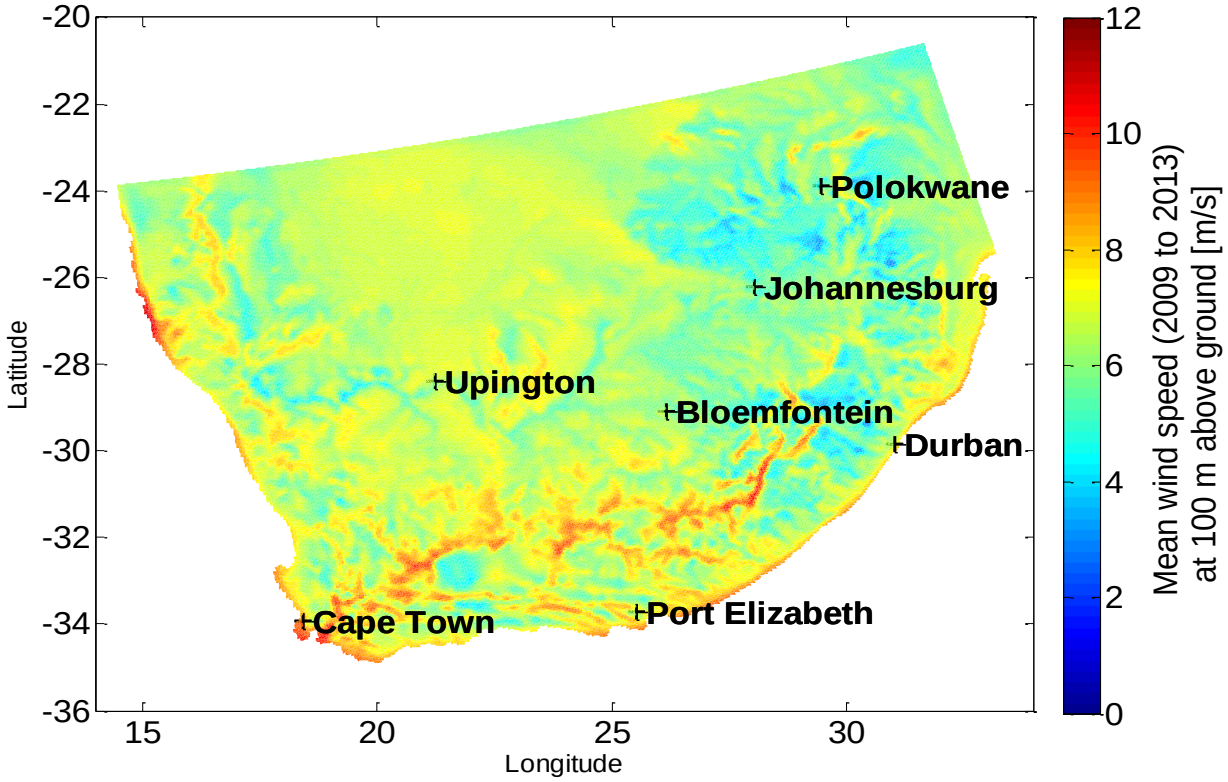
DANIDA/DoE

Energy Exemplar

Study was conducted from early 2015 to March 2016

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

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



5x5km resulution, 2009-2013 data

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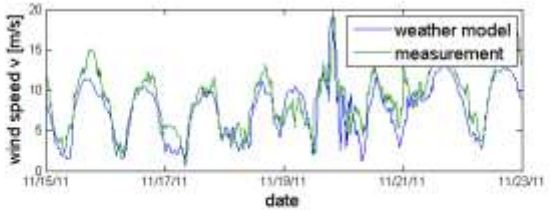
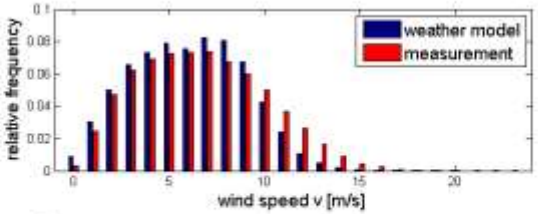
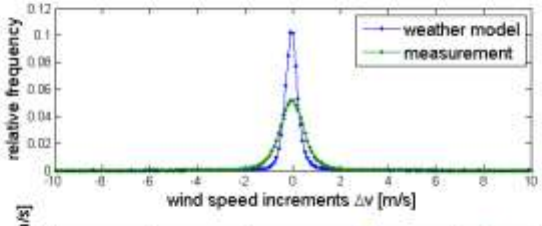
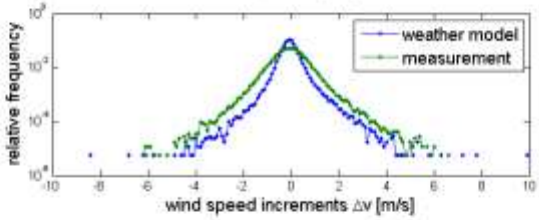
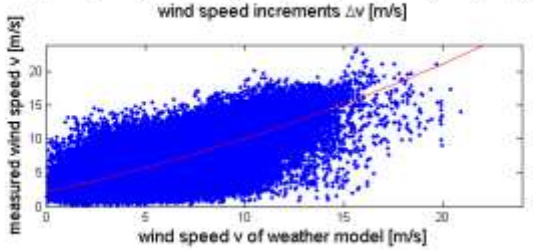
Comparison of Model Date show devaitons of 0-10% depending on site and complexity











	weather model	met mast no.3
$\bar{v}_{3a}[m/s]$:	6.56	7.17
$\sigma(v)[m/s]$:	2.94	3.33
$\sigma(\Delta v)[m/s]$:	0.42	0.69

correlation coefficient: 0.74465

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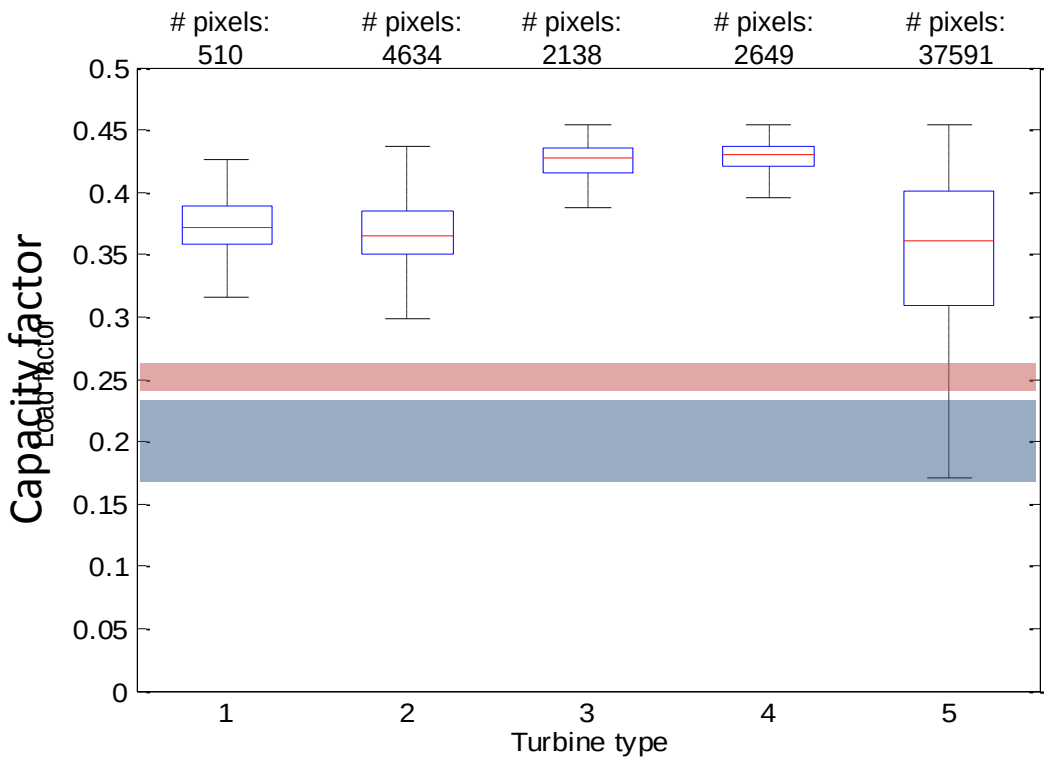
Achievable load factors in all turbine categories significantly higher than actual load factors in leading wind countries

Load factors by turbine type across all 50 000 pixels for South Africa for years 2009-2013

- Years: 2009-2013



Actuals Spain (installed capacity: ~23 GW)

Actuals Germany (installed capacity: ~46 GW)

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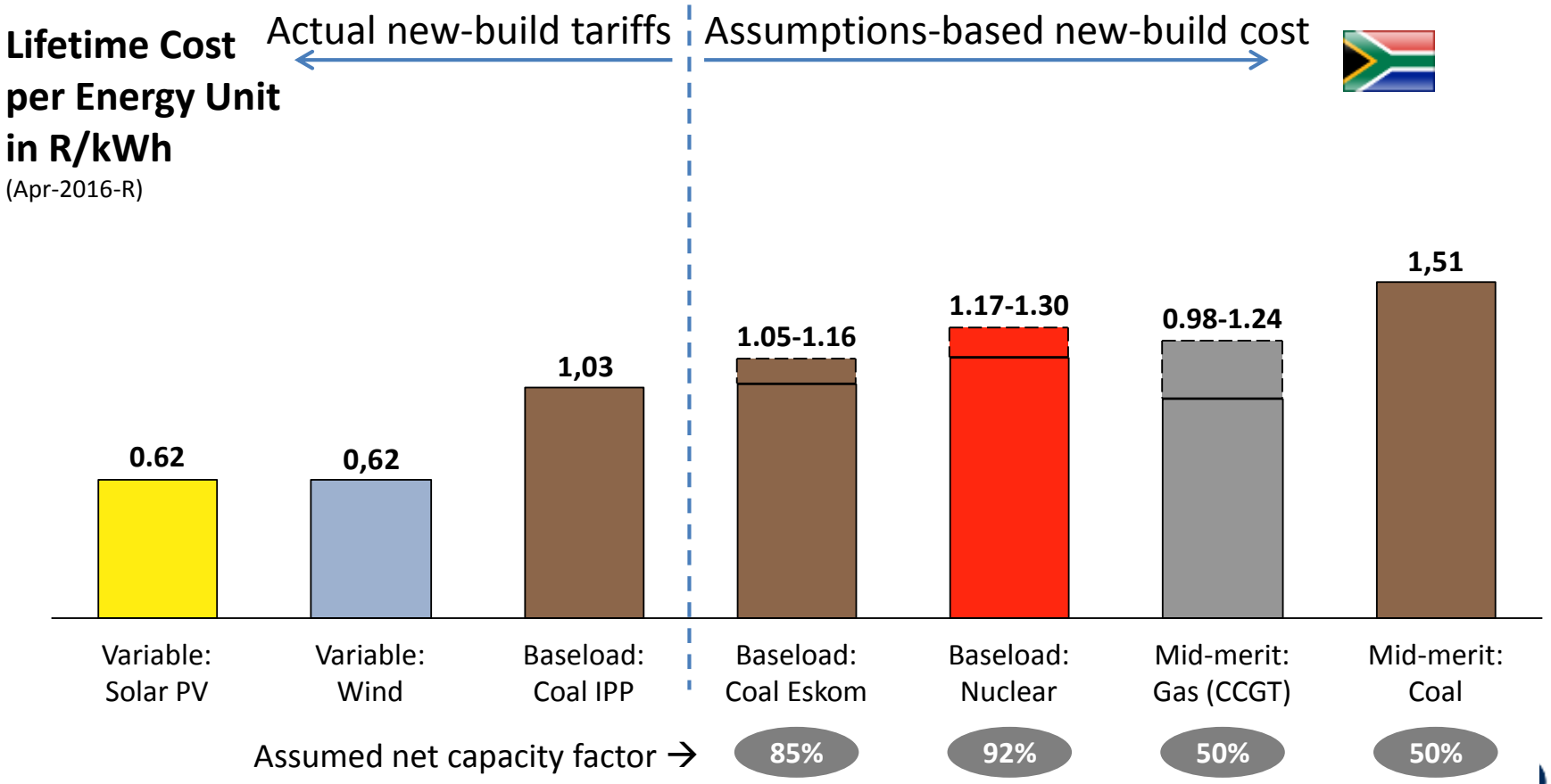
Consequence of renewables' cost reduction for South Africa: Solar PV and wind are 40% cheaper than new baseload coal today



Note: Changing full-load hours for conventional 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 Apr-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 & nuclear cost; CSIR analysis

LCOE what does it mean?

- It's a means to compare energy production per cost for different technologies and different life spans

- Energy specific present value of lifetime costs

$$\text{LCOE} = \frac{Lifetime\ costs}{Energy\ production} = \frac{\sum_t^n \frac{CAPEX_t + OPEX_t + FUEL_t - INCENTIVE_t}{(1+r)^t}}{\sum_t^n E_t}$$

For a single wind turbine:

$$E = 8760 \varphi_{losses} \sum_{i=1}^{N} P(u_i) \cdot f(u_i)$$

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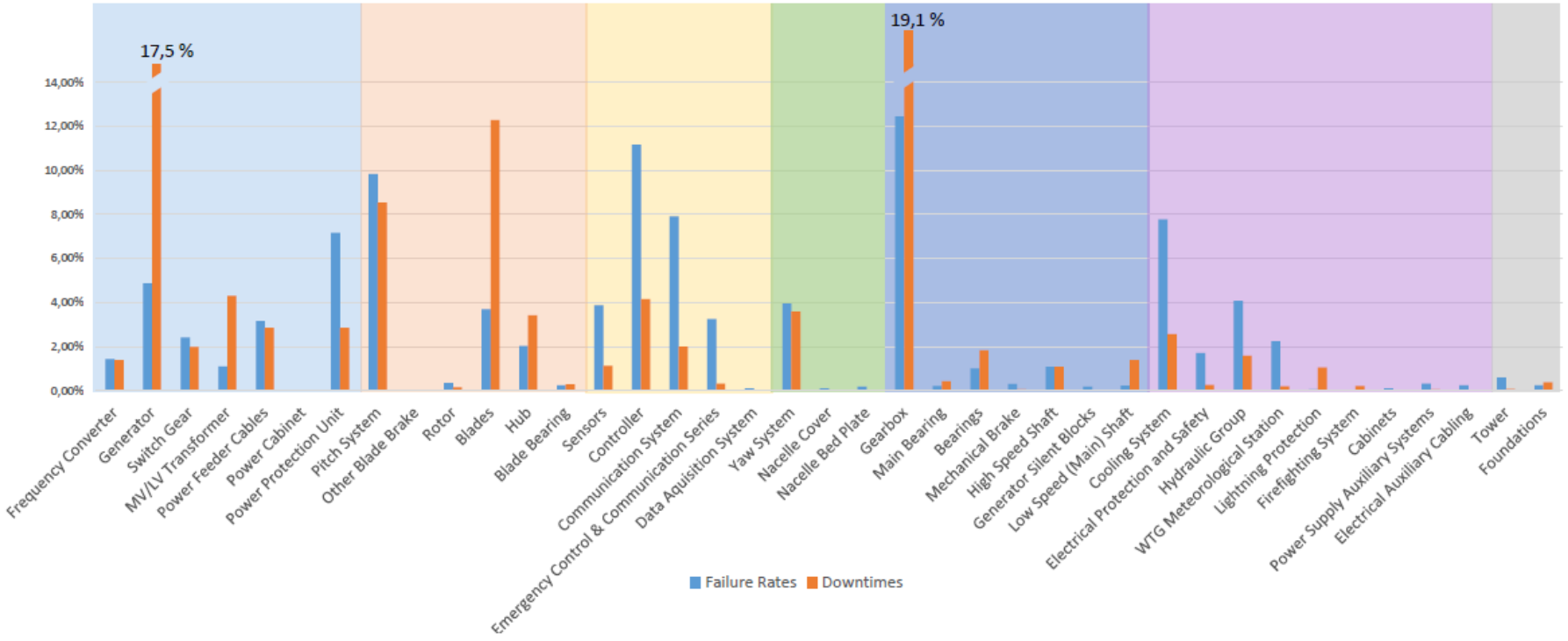
Limitations of LCOE - CAPEX

- Limitations per LCOE parameter specific to wind turbines
- $CAPEX_t$ – mostly only initial investment cost, excludes large component/system failures[1] e.g. gearbox, generator or pitch system



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URL: http://iopscience.iop.org/article/10.1088/1742-6596/753/7/072027

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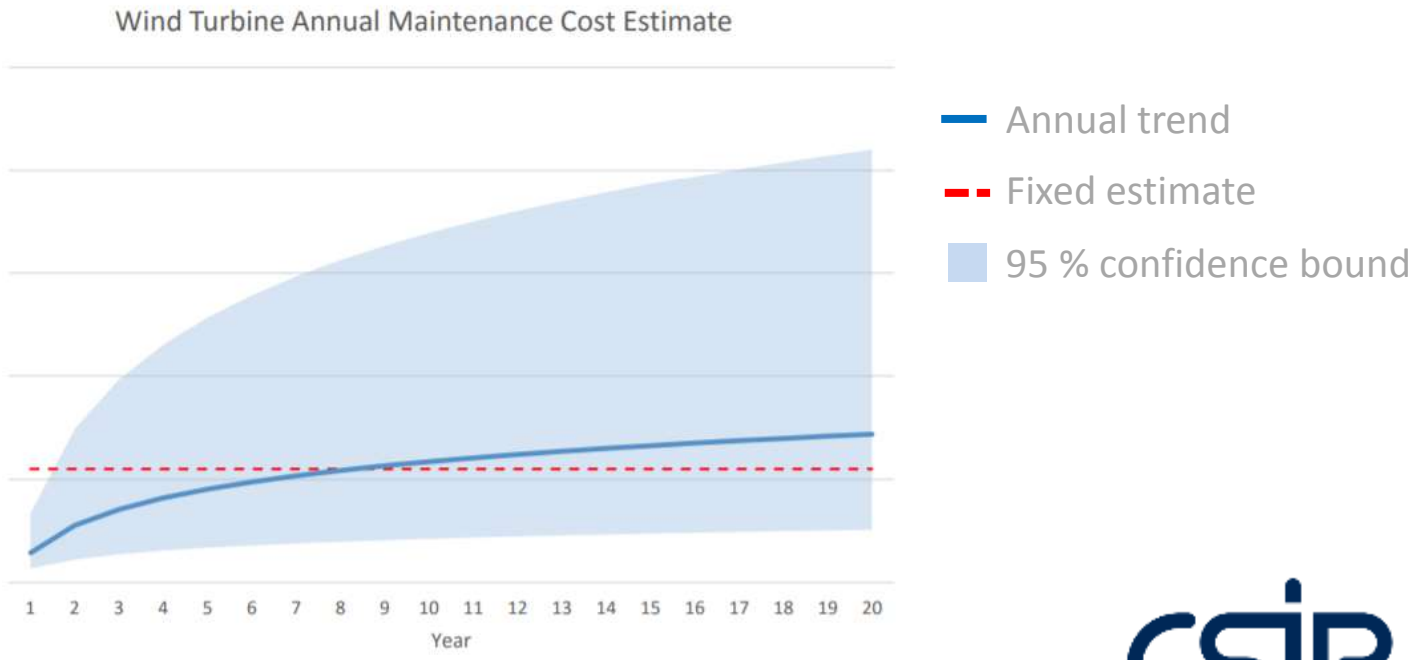
Limitations of LCOE - OPEX

- $OPEX_t$ – involves scheduled "fixed" operation and maintenance costs, excluding:

- unforeseen[2] "variable" maintenance
- system integration[3] cost to ensure stability and recovery



2. Einarsson, S. 2016. Wind turbine reliability modeling. MSc thesis, Raykjavík University. URL:https://skemman.is/bitstream/1946/25747/1/Wind%20Turbine%20Reliability%20Modeling_Einarsson.pdf
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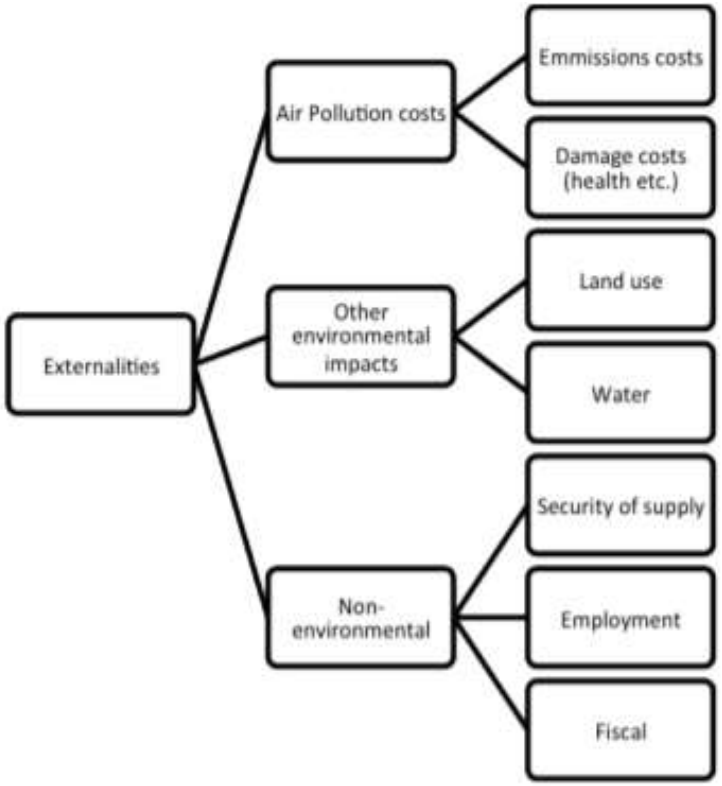
Limitations of LCOE - Incentives

- $INCENTIVE_t$ – involves tax reductions and externalities[4]

- is it not sure if tax reductions are constant for the lifetime of project
- the gain from externalities (+) such carbon credits is also temporal



4. Roth, I.F. and Lambs, L.L. 2004. Incorporating externalities into a full cost approach to electric power generation life-cycle costing. *Energy*, 29, pp. 2125-2144

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Limitations of LCOE - Energy

- $Energy_t$ - inaccuracies in wind turbine / farm losses estimations
  - no inclusion off daily generation cycles

$$E_t = 8760 \ \varphi_{losses} \sum_{i=1}^{N} P(u_i) \cdot f(u_i)$$

Aerodynamic conversion:
- turbulence
- stability - shear
- inflow angle – topography
- wakes

Electro-mechanical conversion:
- yield degradation over lifetime

Grid transmission:
- transmission decoupling
- weak connections

Power curve[5,6]:
- up to 20 % variation about mean "warranted" curve
- wind turbines mostly underperforming
- variation increases from 60 % $P_{nominal}$ towards 100 % $P_{nominal}$

Wind climate:
- measurement inaccuracies
- microscale modelling simplifications
- final wind turbine siting

5. Heller, A. 2014. Predictiong wind power with greater accuracy. Lawrence Livermore National Laboratory paper. URL: https://str.llnl.gov/content/pages/april-2014/pdf/04.14.1.pdf
6. Anonymous. 2012. WTG Performance Measurement and AEP assessment with LiDAR. Sun & Wind Energy article . URL: http://energy2909.rssing.com/chan-25334245/all_p32.html

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Limitations of LCOE - Rates

- *Rates* – discount rates applied are usually fixed

- accurate estimation of discount rates are required

- Bottom-line: a LCOE range per technology with the inclusion of the above must be considered
- Lowering LCOE per generation unit does not necessarily yield the lowest system LCOE
- Wind turbines/farms are part of a system
- System LCOE is sensitive to RE penetration level
- Higher wind penetration (aggregated or not) will require mid-merit storage or flexible loads (e.g. desalination)

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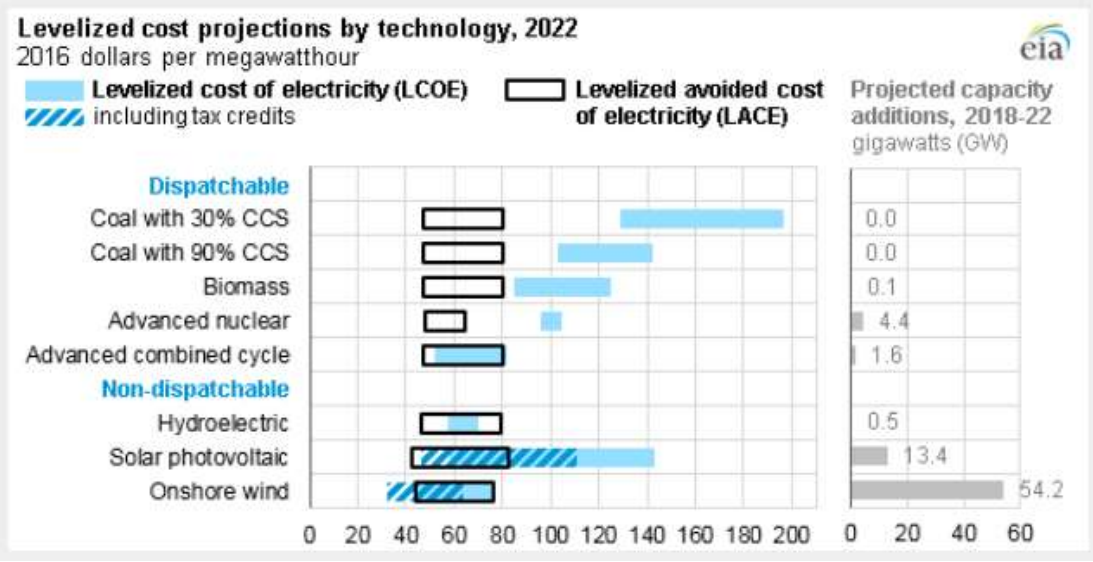
LACE – Levelised Avoided Cost of Energy

- LACE[7] – a LCOE supportive indicator of cost to grid to generate the power that is otherwise displaced by a new project – if LACE > LCOE – more competive
- Meaning: cost of boosting/modifying existing generation to meet load targets – system cost approach



7. U.S. Energy Information , Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2017. URL: www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

LACE – Levelised Avoided Cost of Energy

- Estimating LACE

$$LACE = \frac{\sum_t^n marginal\ generation\ price(t) \cdot h_{dispatched} + CAPEX \cdot Credit}{AEP_{expected}}$$

where:

t – time period

n - number of periods

marginal generation price – cost of serving load to meet demand per period

$h_{dispatched}$ – estimated number of hours

CAPEX – value of system meeting reliability margin

Credit – ability of unit to provide system reserves

Methodology to derive relative LCOE per pixel

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

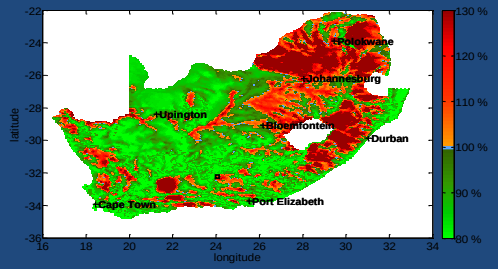
Capex: 80% of overall costs
→ LCOE of turbine type 5 is approximately 20% higher than turbine type 1 (for the same load factor)

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



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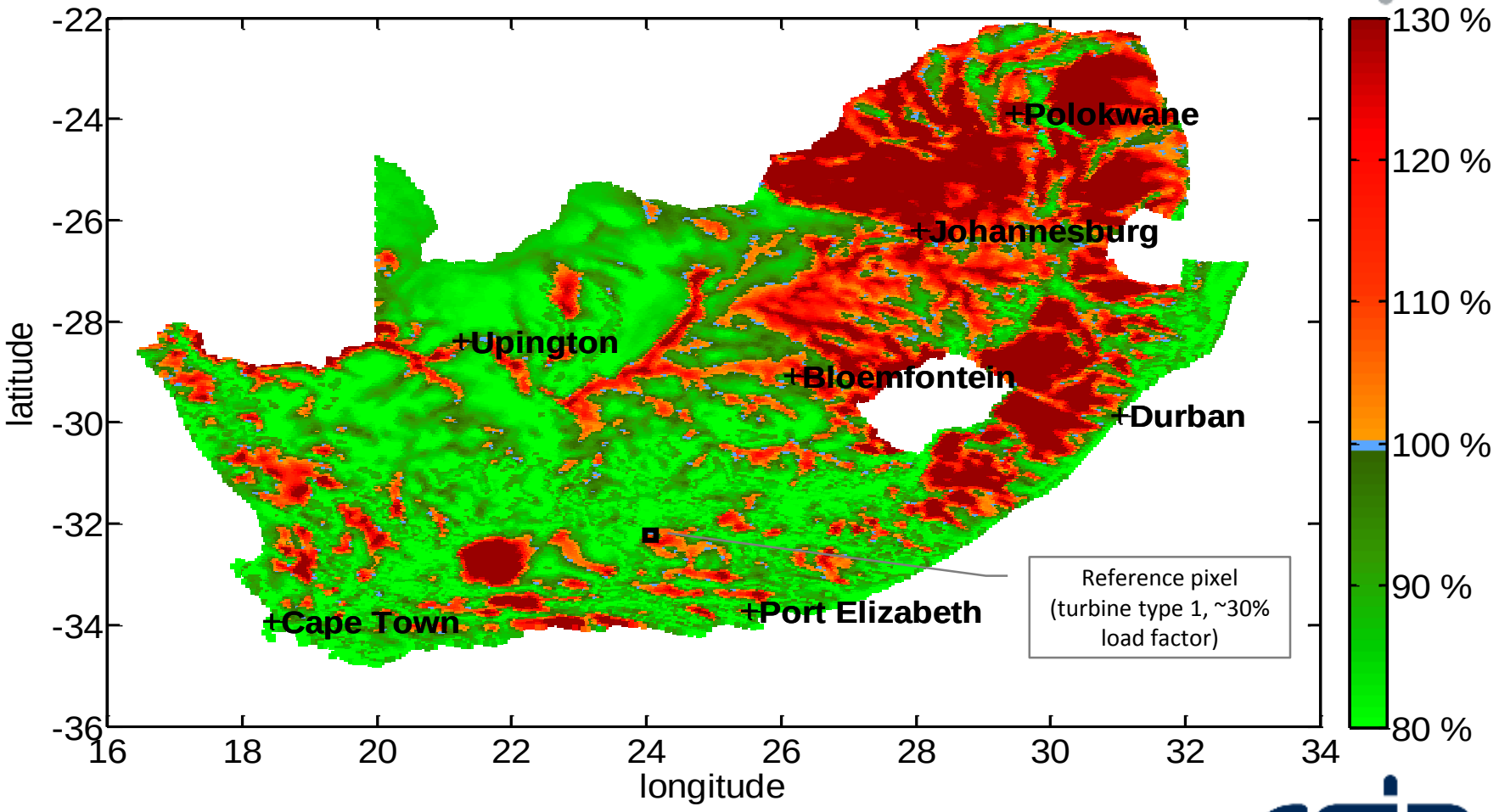
Large parts of RSA can achieve LCOE well below reference

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



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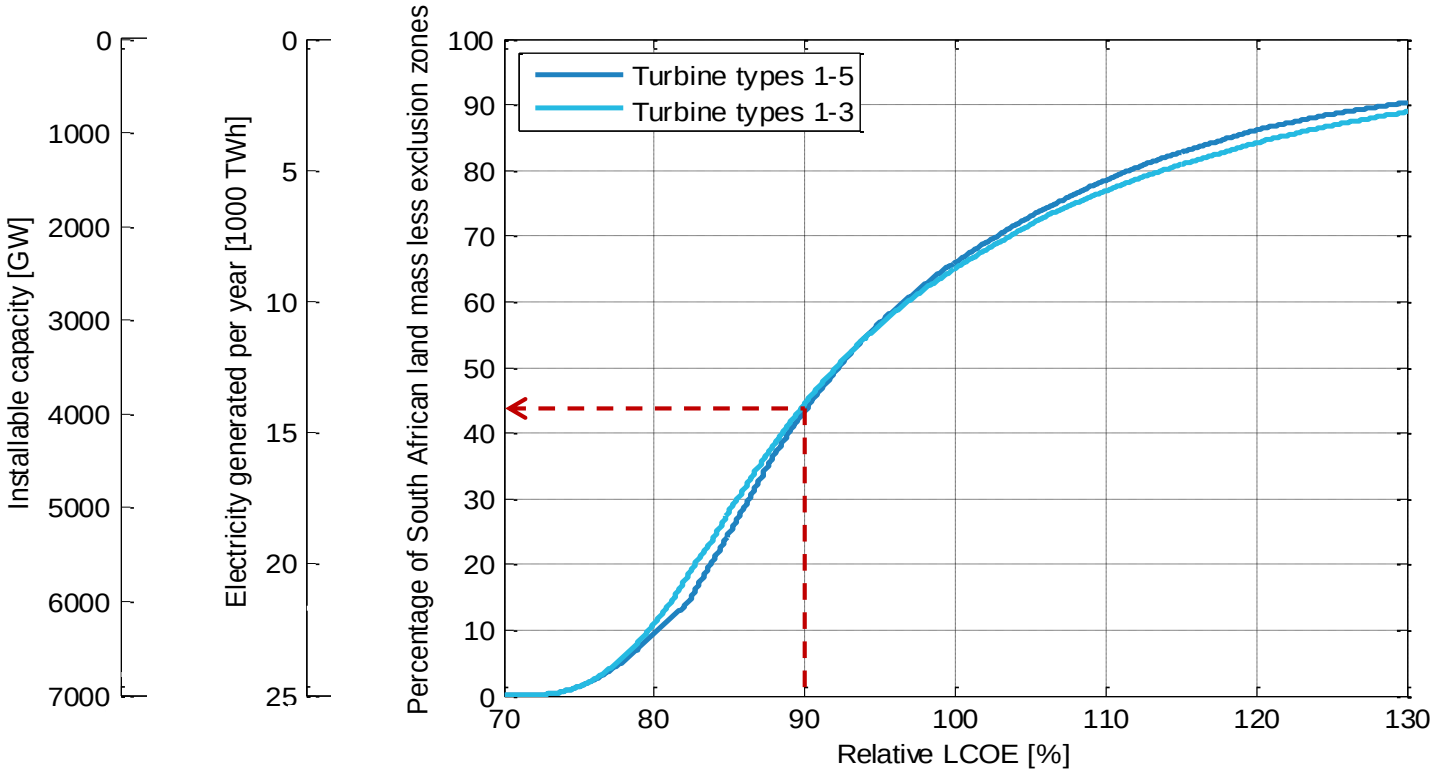
Large parts of the South African suitable land (entire land mass less exclusion zones) can achieve low wind LCOEs



→ A relative LCOE of 90% or less can be achieved at 44% of the South African land mass (less exclusion zones); 100% benchmark is a high-wind-speed pixel

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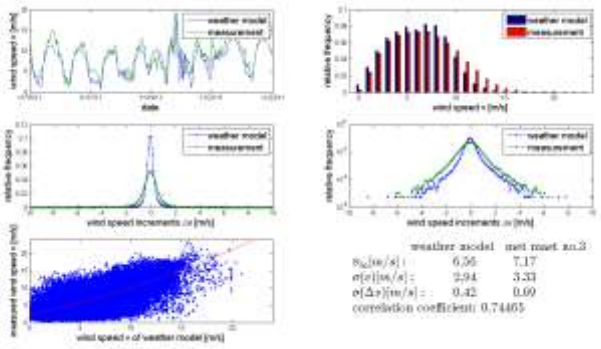
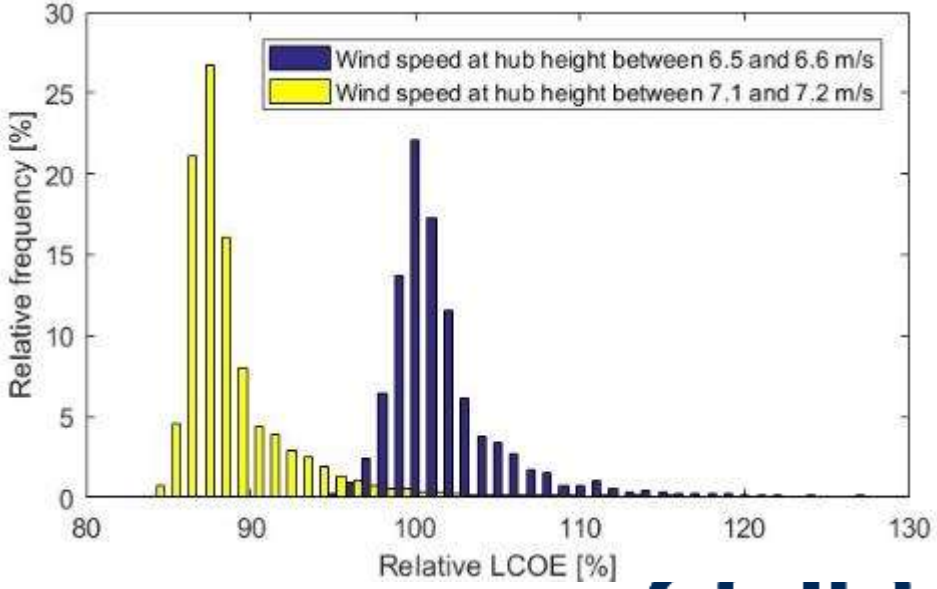


Mean LCOE for 6,56 m/s: 102%
LCOE Mean LCOE for 6,56 m/s: -: 89%

→ Deviation 15%



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Low deviationsof LCOE of ground based and modell data

Met Mast	Wind speed ma	Wind speed Mod	Deviatio	LCOE mittel Ma	LCOE mittel Mod	Deviation
1	6,2	6,1	2%	112,3	115,8	-3%
2	6,9	6,2	10%	94,9	111,2	-15%
3	6,6	7,2	-8%	102,0	89,0	15%
4	6,6	6,7	-2%	101,7	98,9	3%
5	7,5	8,5	-12%	83,2	84,6	-2%
6	8,2	7,4	11%	76,7	83,1	-8%
7	7,0	7,0	1%	91,5	92,3	-1%
8	7,5	7,4	1%	86,6	82,6	5%
9	8,2	8,0	3%	78,1	79,7	-2%
10	6,5	6,5	0%	102,8	102,7	0%
	7,116518632	7,099264514	0%	93,0	94,0	-1%

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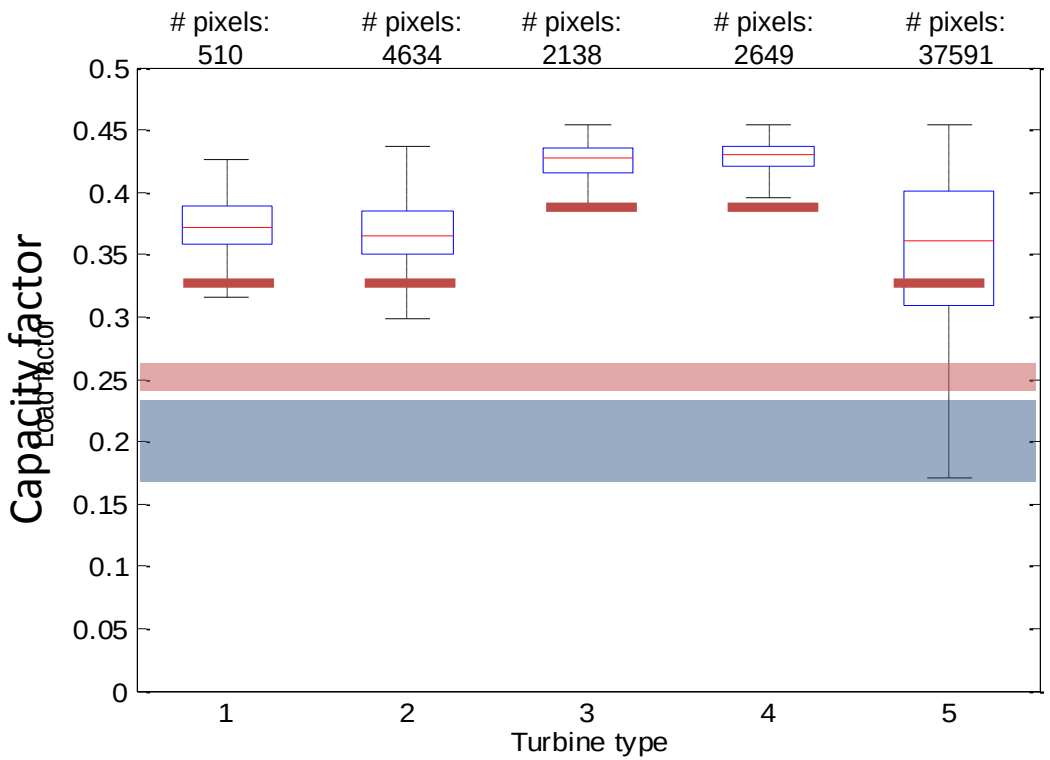
Even considering 15% lesse Capacity factor: still good situations

- Years: 2009-2013



Actuals Spain (installed capacity: ~23 GW)

Actuals Germany (installed capacity: ~46 GW)

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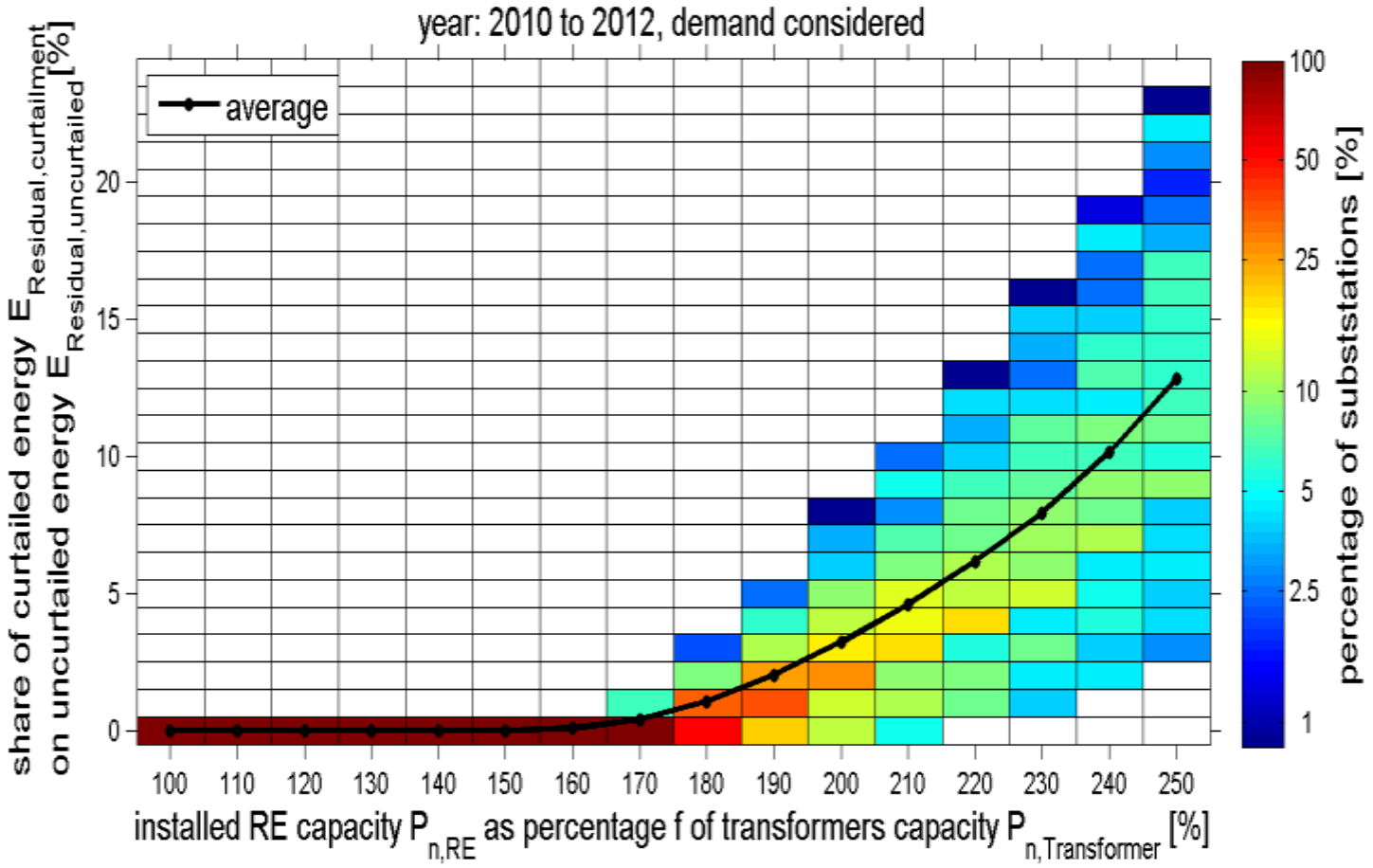
System perspective: possible overrating of transmissions substations



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Conclusion

- LCOE based on model data suitable for system studies
- For bankable export opinions other methods should be used
- SA have some of the world‘s best sites
- Extension on transmission level is not first issue
- General analysis of distribution grids was not part of the analysis
- Important to keep market up an running

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Thank you

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