SOLAR ENERGY IN THE ELECTRICITY SYSTEM OF SOUTH AFRICA

Linking a Detailed Technology Modelling with a Large-scale Energy System Model

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SOLAR ENERGY IN THE ELECTRICITY SYSTEM OF SOUTH AFRICA

- Introduction
- Approach
- Data analysis (GIS)
- Results for potential and role of RES
- Conclusions

Motivation and objective of this work

Motivation

(1) Renewable energy technologies are attractive alternatives to supply the increasing electricity demand of South Africa (RSA).

(2) Rapid increase of renewable energy technologies lead to an increasing demand for energy system analysis in South Africa.

Objective

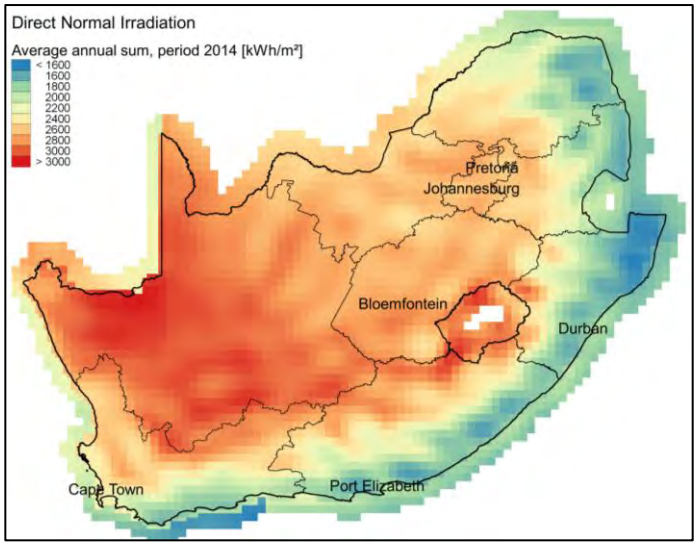
(1) Adaption & testing of energy system model for the RSA electricity system

(2) Evaluation of technology combinations and geographical distribution

Research questions

(1) What are the long-term effects of high share of large-scale RES, (CSP, PV and wind power) on the **South African energy system** in the *cost optimal technology mix*?

(2) How is the potential of solar technologies optimally used in long-term development paths?

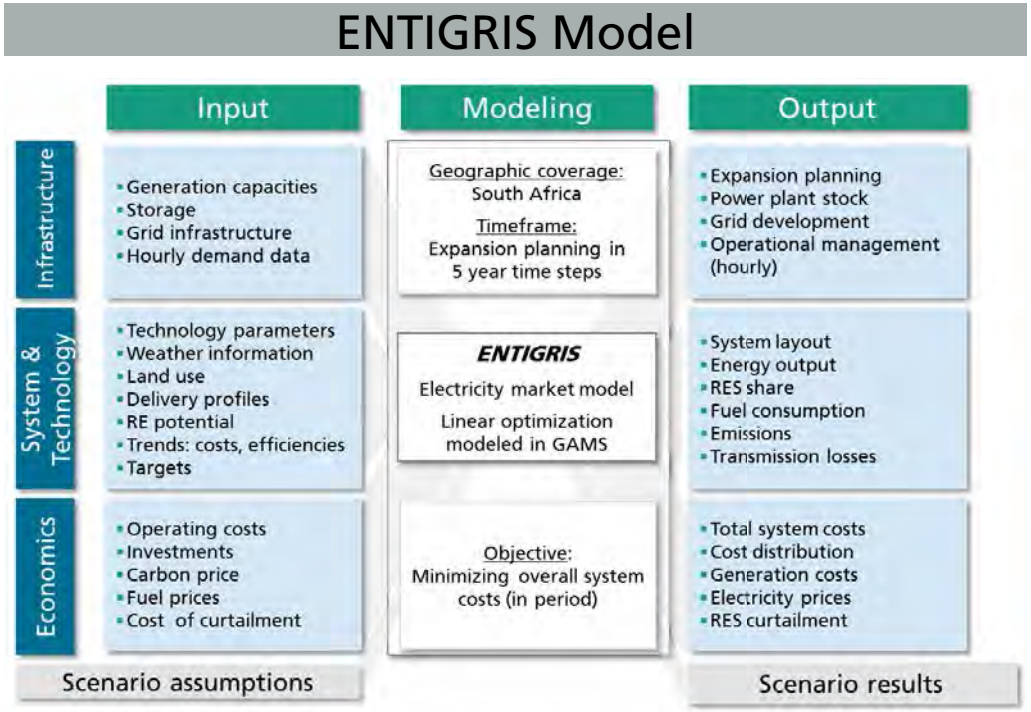


http://reneweconomy.com.au/
http://www.solarfeeds.com/

Selected dataset: NCEP Climate Forecast System Version 2(CFSv2)

Our approach & solution to analyze long-term effects of RES in the electricity system

- Energy system model ENTIGRIS adapted to RSA
- Detailed analysis of CSP, PV and wind potentials with GIS software
- Quantitative model output
- Benefits for new RES plants:
  - ✓ Optimal location planning
  - ✓ Demand and grid considered
  - ✓ Interaction with other technologies



More information: https://www.ise.fraunhofer.de/en/business-areas/energy-system-technology/research-topics/energy-system-analysis/energy-system-models-at-fraunhofer-ise/

Model Input

High resolution GIS analysis of suitable areas for RES

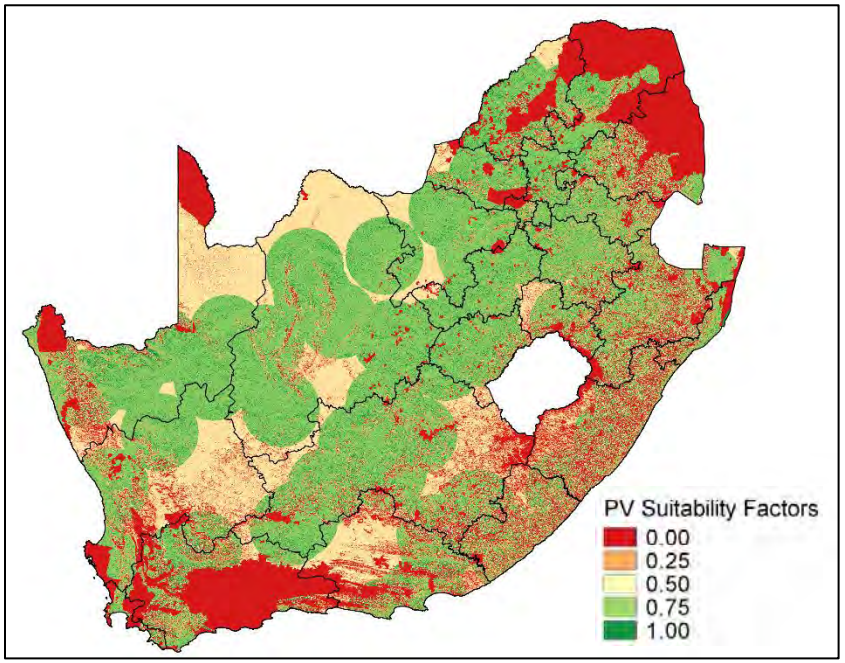
- Identification of suitable areas for solar and wind potentials in a high geographical resolution (250 x 250 m)
- Geographical Information System (GIS) data allows qualitative assessment of suitability for PV, CSP and wind
- Classification through suitability factors

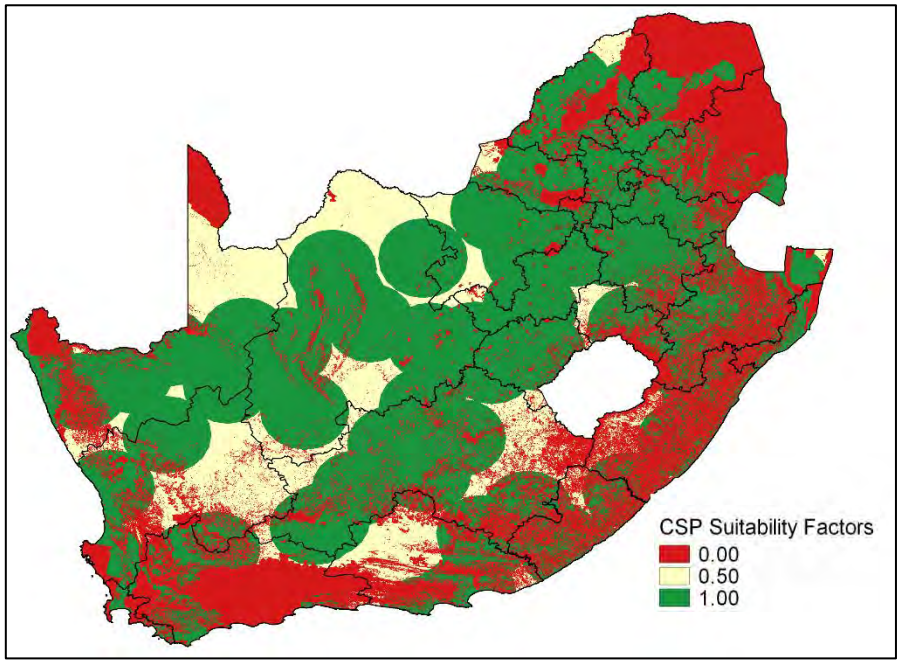
CSP	PV	Wind	Dataset
Elevation, Slope	Elevation, Slope, Aspect	Elevation, Slope	DEM (NASA 90*90 m)
Usable Areas	Usable Areas	Distance to Urban Areas, Usable Areas	Land Cover Dataset (GEOTERRAIMAGE 25*25 m)
Unusable Areas	Unusable Areas	Unusable Areas	World Database of Protected Areas
Distance to Grid	Distance to Grid	Distance to Grid	Electricity Grid (GCCA by ESKOM)

High resolution GIS analysis for solar potential

Aspect, slope and grid access to identify solar sites

Slope in Degrees	PV Factors		Aspect in Degrees									
			North		East		South		West			North
	min		0	22.5	45	90	135	180	225	270	315	337.5
		max	22.5	45	90	135	180.0	225.0	270.0	315.0	337.5	360.0
	0	2	1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1
	2	5	1	0.8	0.7	0.25	0.25	0.25	0.25	0.7	0.8	1
	5	15	1	0.8	0.5	0	0	0	0	0.5	0.8	1
	15	30	0.5	0.5	0	0	0	0	0	0	0.5	0.5





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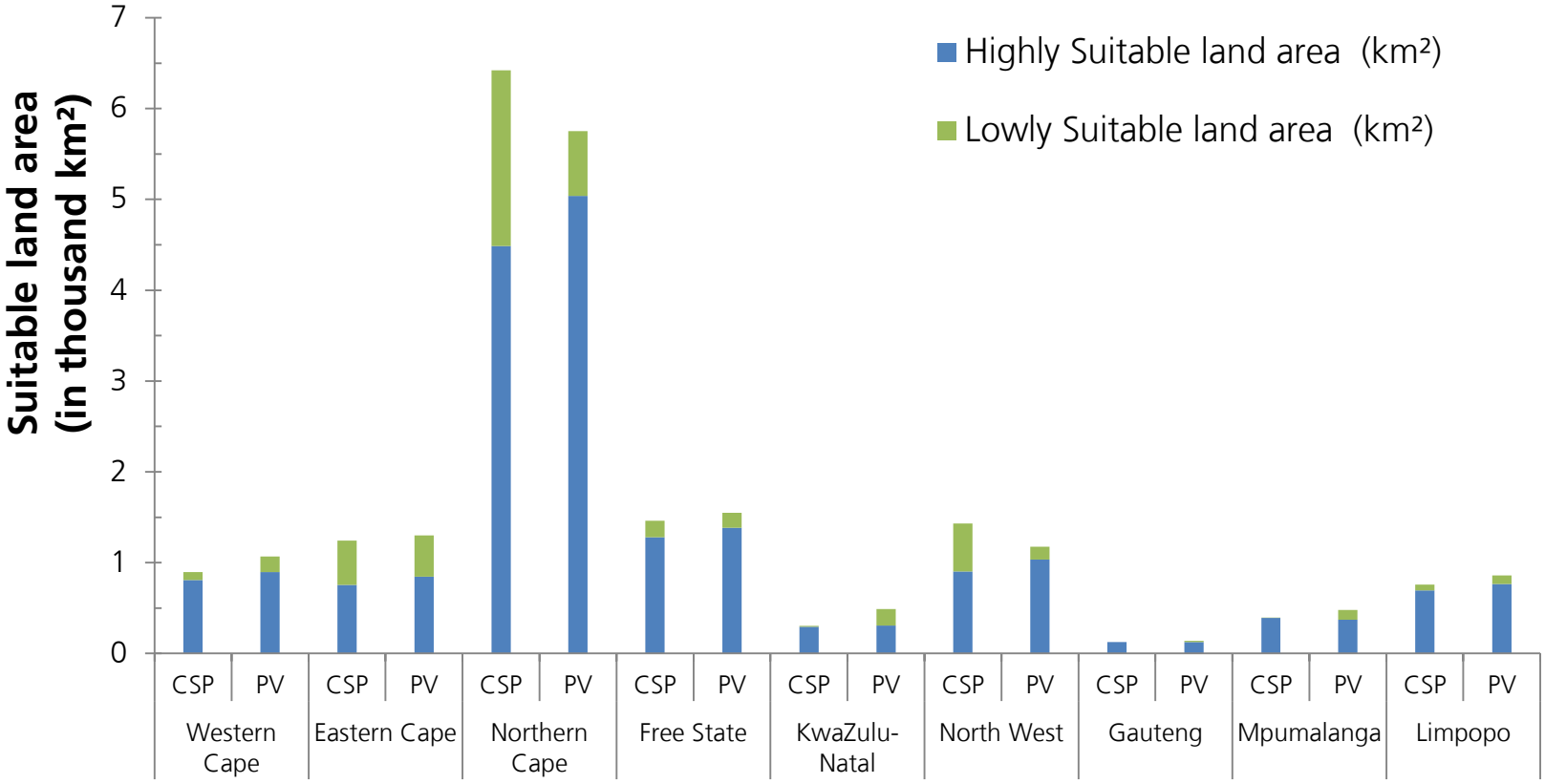
High resolution GIS analysis for solar potential

Provincial power generation potential for the implementation of large-scale solar power plants



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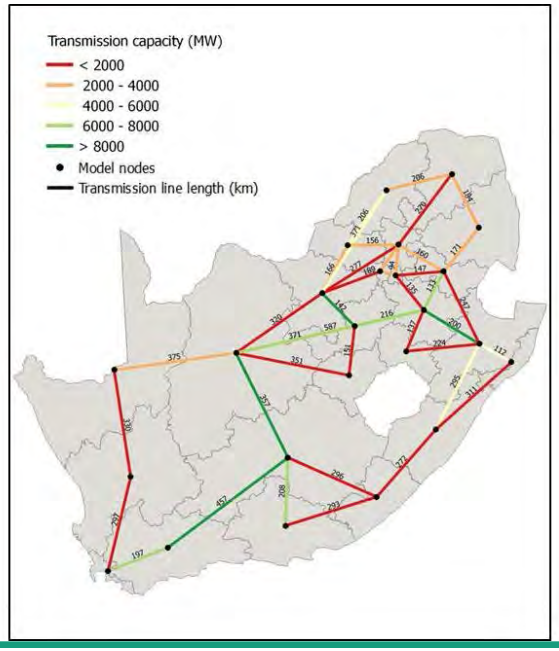
Data input for energy system model ENTIGRIS

- GIS data -> RES potentials
- Existing power plants and lifetime
- Existing power grid and demand regions (simplified)



- Cost and technology data

	investment cost US$/KW			
Technology	2020	2030	2040	2050
Biomass	2.820	2.651	2.491	2.341
Gas	960	960	960	960
Wind	1.488	1.418	1.352	1.290
Coal	1.680	1.680	1.680	1.680
PV	900	720	566	510
Oil	480	480	480	480
Nuclear	7.200	7.200	7.200	7.200
CSP +8h	5.417	4.143	3.684	3.043

Gas price: 25 $/MWh, coal price: 10$/MWh

Remark: Changes compared to presentation at Solarpaces: higher CSP cost, more modeling hours

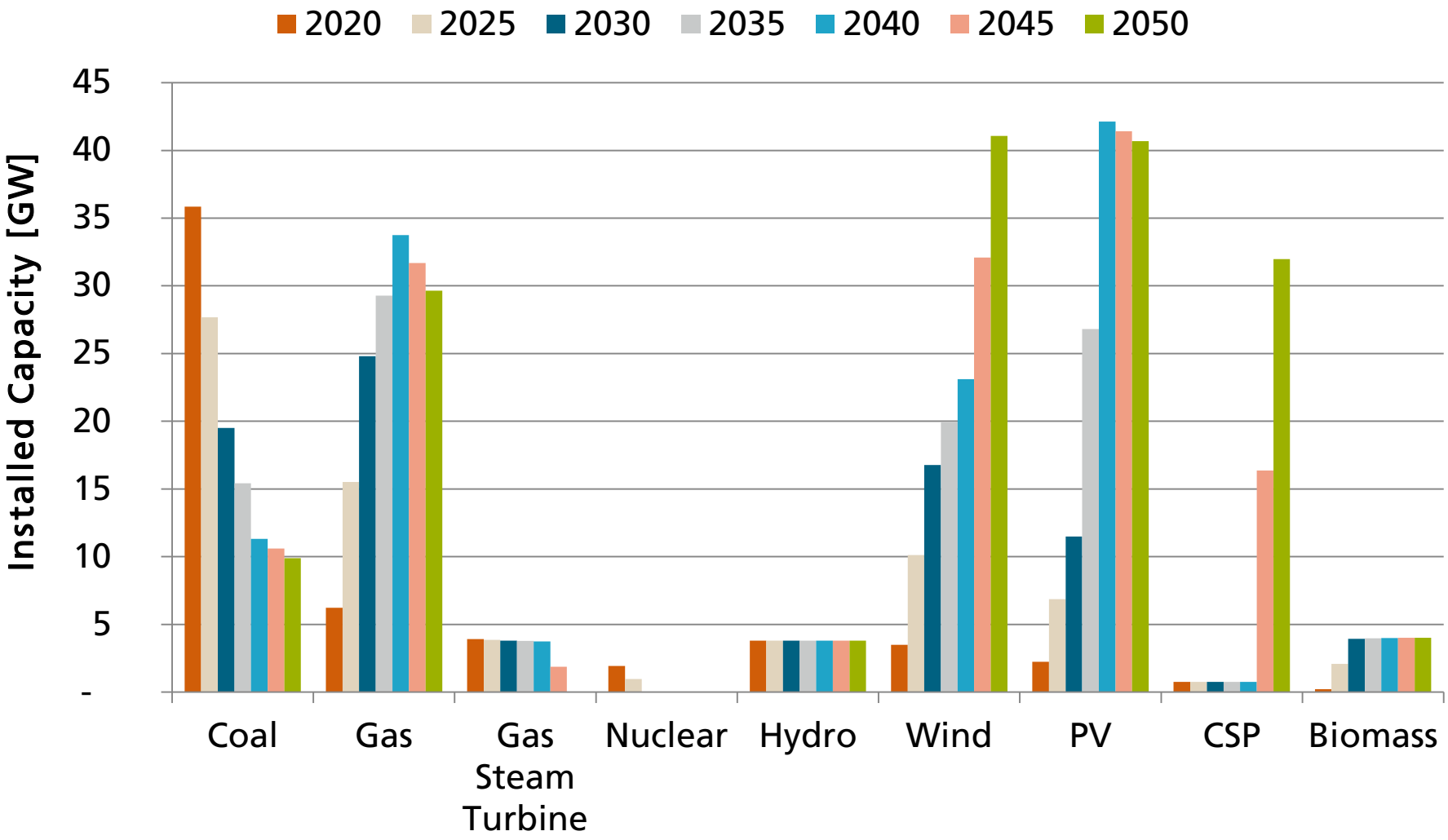
Modelling the South African energy future
Test scenarios and their description

- The following assumptions were applied to all scenarios:
  - IRP-2013 plan for lifetime extension of existing power plants was not taken into account
  - No limitations in commissioning and decommissioning of capacities

Scenario	RE generation targets 2020-2030-2040-2050	Annual growth of electricity consumption	Higher Costs for Suitability Class 0.5
RES Scenario	**10-30-50-80**	**1,8 % - 2030** **1,3 % - 2050**	**Yes**
Cheap potentials	10-30-50-80	1,8 % - 2030 1,3 % - 2050	**No**
Business as usual	10-30-**30-30**	1,8 % - 2030 1,3 % - 2050	Yes
High energy demand	10-30-50-80	**3,5 % - 2035** **1,8 % - 2050**	Yes

Test results of the RES scenario

Strong increase of RES in the electricity system



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Comparison of IRP targets and RES scenario in 2030

Power plant type	Base Case IRP Update 2013		RES Scenario
	[MW]	[%]	[MW]
Coal	38,680	47.6	19,500
Gas	7,680	9.5	**24,800**
Gas Steam Turbine	3,550	4.4	3,800
Nuclear	6,660	8.2	-
Hydro	3,690	4.5	3,800
Wind	4,360	5.4	**16,800**
PV	9,770	12.0	11,500
CSP	3,300	4.1	**750**
Biomass	640	0.8	4,000
Total	81,230	100.0	84,950

Higher flexibility is needed

Wind is preferred

Depending on cost of CSP, role of coal/gas

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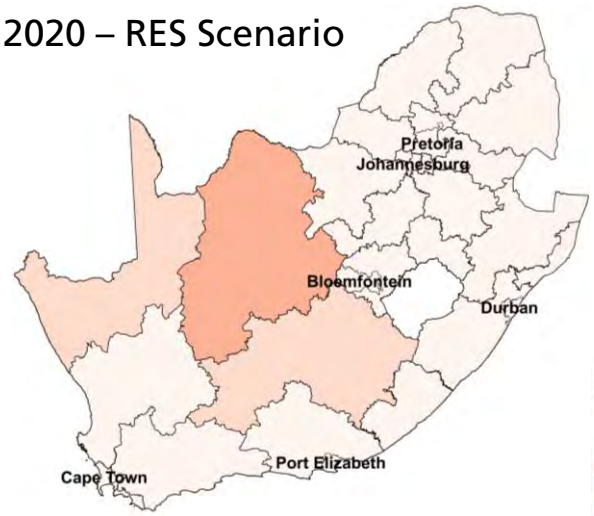
Test of other scenario assumption on results

- **Cheap potentials**
  - Larger distance between power plants and demand
- **Business as usual**
  - Higher share of coal and gas, but flexible gas is preferred with 30% RES
- **High energy demand**
  - Similar share of each technology but larger capacities
- **Low CSP cost**
  - Increasing share of CSP (see results at SOLARPACES)

Geographical analysis shows region with increasing PV and wind capacity by 2050

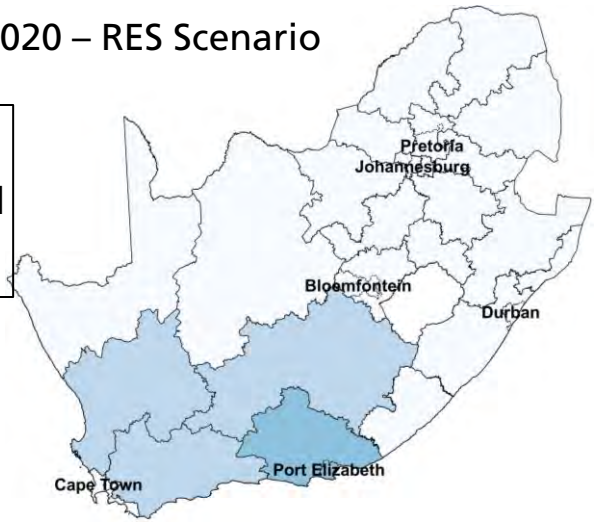
PV 2020 – RES Scenario

Sites with high solar radiation



Wind 2020 – RES Scenario

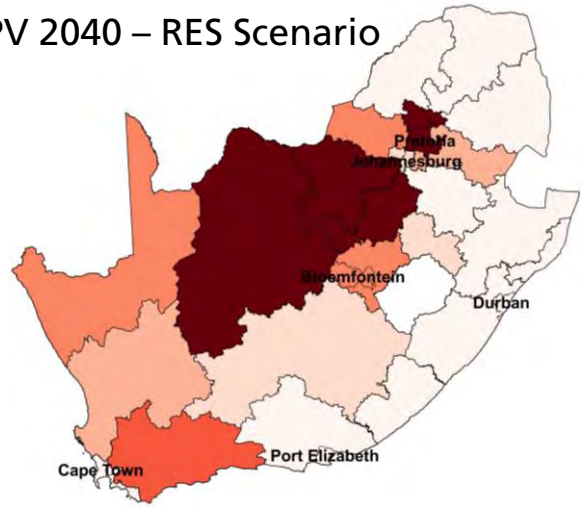
Sites with high wind resource



Installed Capacity [MW]

- < 250
- 250 - 499
- 500 - 999
- 1,000 - 1,999
- 2,000 - 2,999
- 3,000 - 3,999
- 4,000 - 4,999
- > 4,999

PV 2040 – RES Scenario



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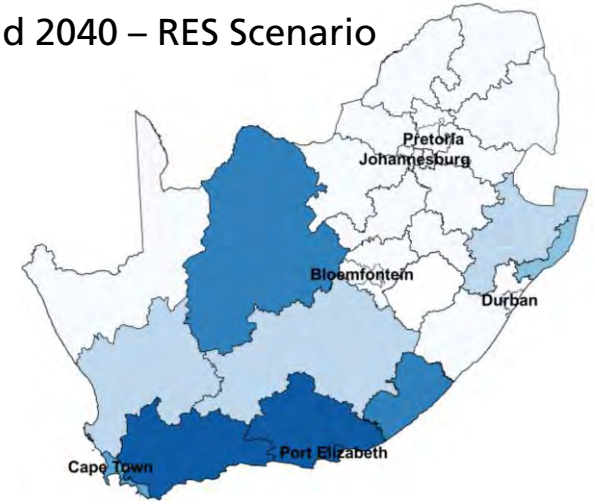
Wind 2040 – RES Scenario



Close to demand

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Potential model improvements and system requirements

- Specific project constraints by South Africa: Only very specific area for Wind energy (-> in GIS analysis)
- Cost of coal vs cost of gas
- Additional operational constraints or technology options
- Batteries have not been adapted from European model version so far.
- Neighboring countries
- Use of specific policy targets (only general scenarios are tested)
- …

Summary and conclusions

- ENTIGRIS model was adapted to South Africa
- A first set of parameters and assumptions is tested in this paper
  - We showed interaction between coal and gas
  - Geographical distribution of new sources
- Demand structure, grid access and land use have a strong impact on technology expansion
- Site potentials not necessarily dominated by solar resource

Outlook

- Improved solar potential analysis of South Africa at the Fraunhofer ISE takes the water availability at every location into account
- With the available tools we can perform further analyses for other scenarios (sensitivities) / countries

Thank you for your kind attention!

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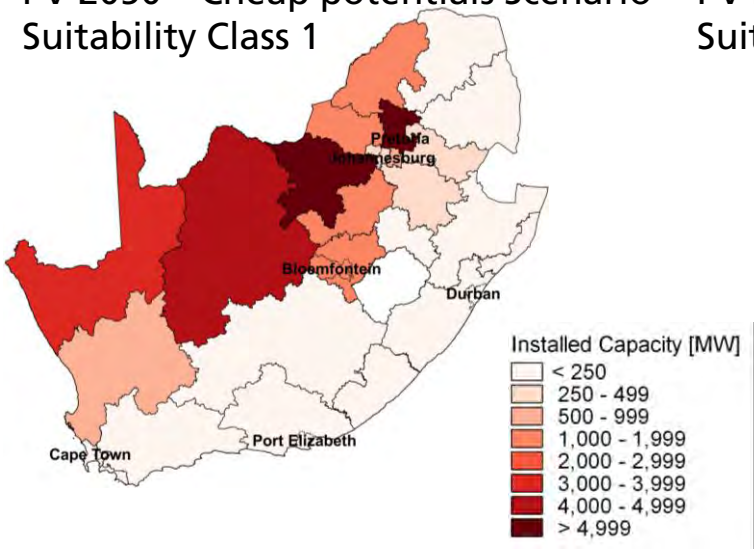
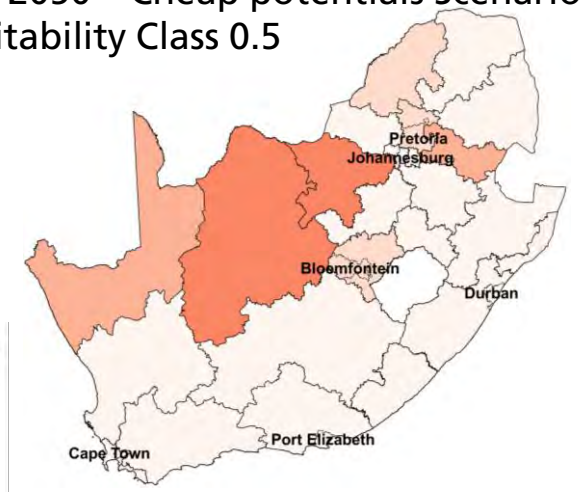
Sensitivity analysis for potential locations

PV 2050 – Cheap potentials Scenario Suitability Class 1

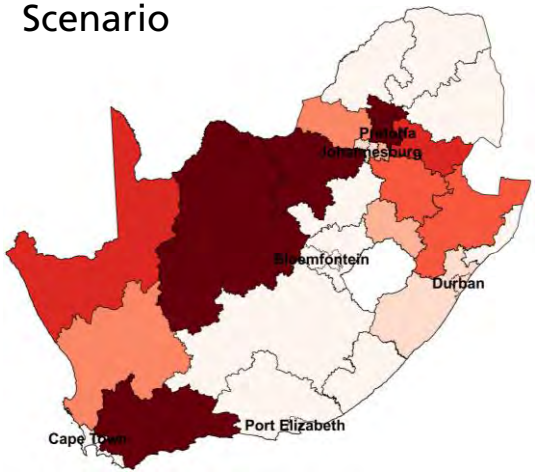


PV 2050 – Cheap potentials Scenario Suitability Class 0.5

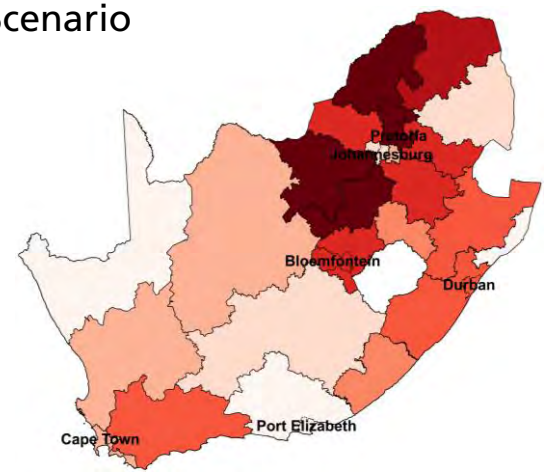


If grid costs are low, higher distance between plants and demand

PV 2050 – Business as usual Scenario



PV 2050 – High energy demand Scenario



High demand = more plants and more distance

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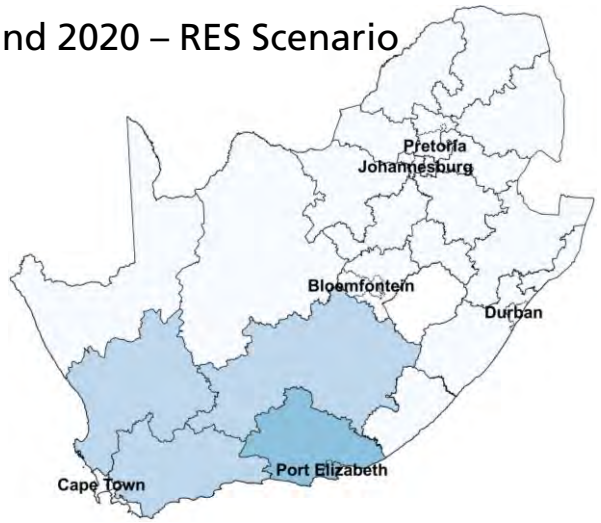
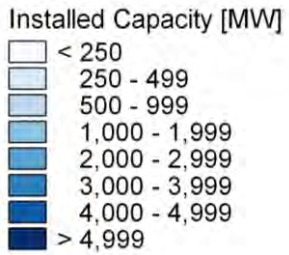
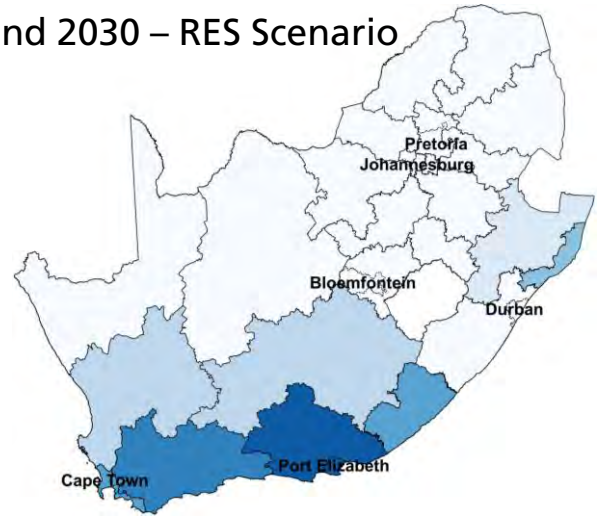
Geographical analysis shows region with increasing Wind capacity by 2050

Wind 2020 – RES Scenario

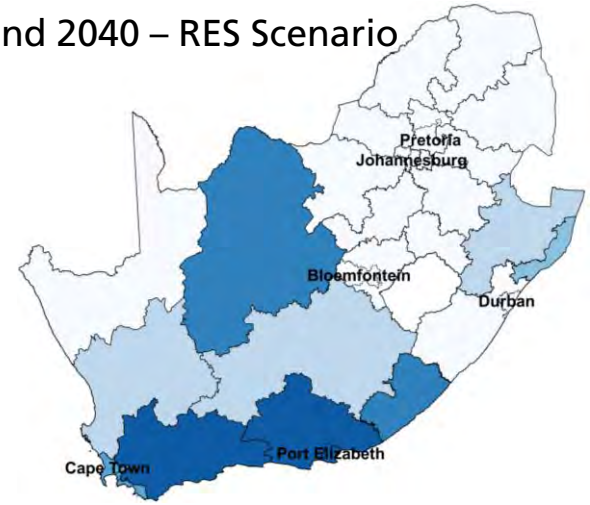




Wind 2030 – RES Scenario

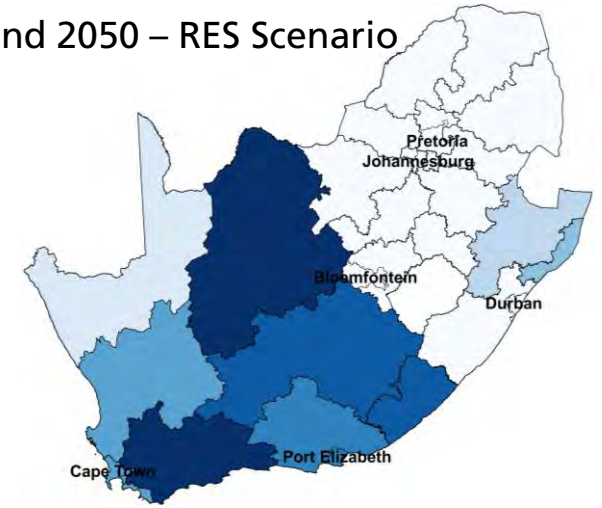


Wind 2040 – RES Scenario



Wind 2040-50
moderate suitability class

Wind 2050 – RES Scenario



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Geographical analysis shows region with increasing CSP capacity by 2050

CSP 2020-2040 – RES Scenario

Sites with high solar radiation

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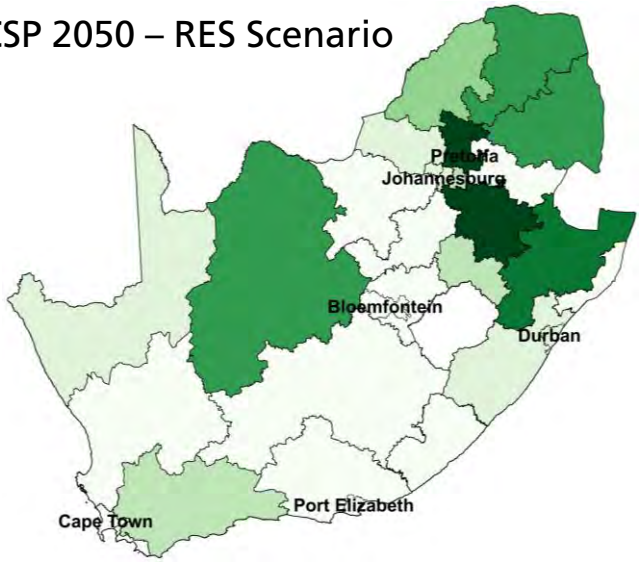
CSP 2050 – RES Scenario



Close to demand

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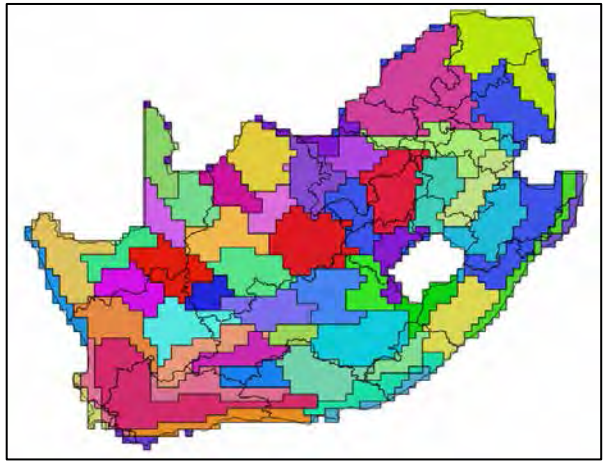
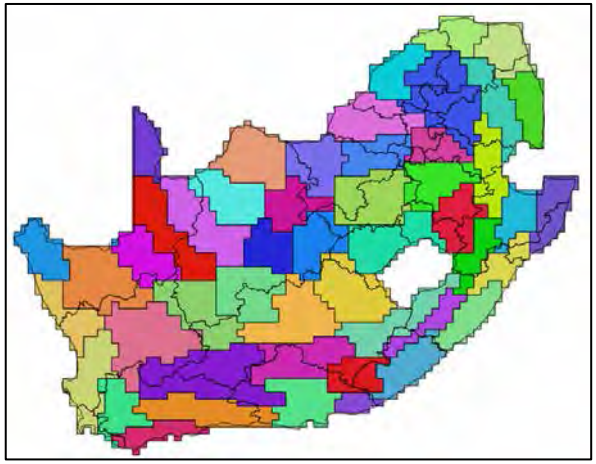
GIS-based electricity generation potential analysis
Cluster analysis of spatial-temporal time series

- Selected dataset: NCEP Climate Forecast System Version 2(CFSv2)
  - Raster cell size of approx. 20 km x 20 km
  - Approx. 7.500 time series for South Africa
  - Hourly wind speed data (10m height) / Hourly global radiation data
- Reduction of spatial-temporal time series
  - Cluster algorithm by Ward (1963) defines 50 cluster per technology

Cluster for wind time series



Cluster for PV time series



Cluster for CSP time series