A GIS-BASED ECONOMIC ASSESSMENT OF WIND ELECTRICITY CONSIDERING LAND USE RESTRICTIONS

SWEDISH CASE

Shahid Hussain Siyal
siyal@kth.se

www.desa.kth.se
Division of Energy System Analysis, KTH

OUTLINES

- Introduction
- Specific questions
- Methodology
- Results
- Conclusions

INTRODUCTION

Sweden´s status in Europe

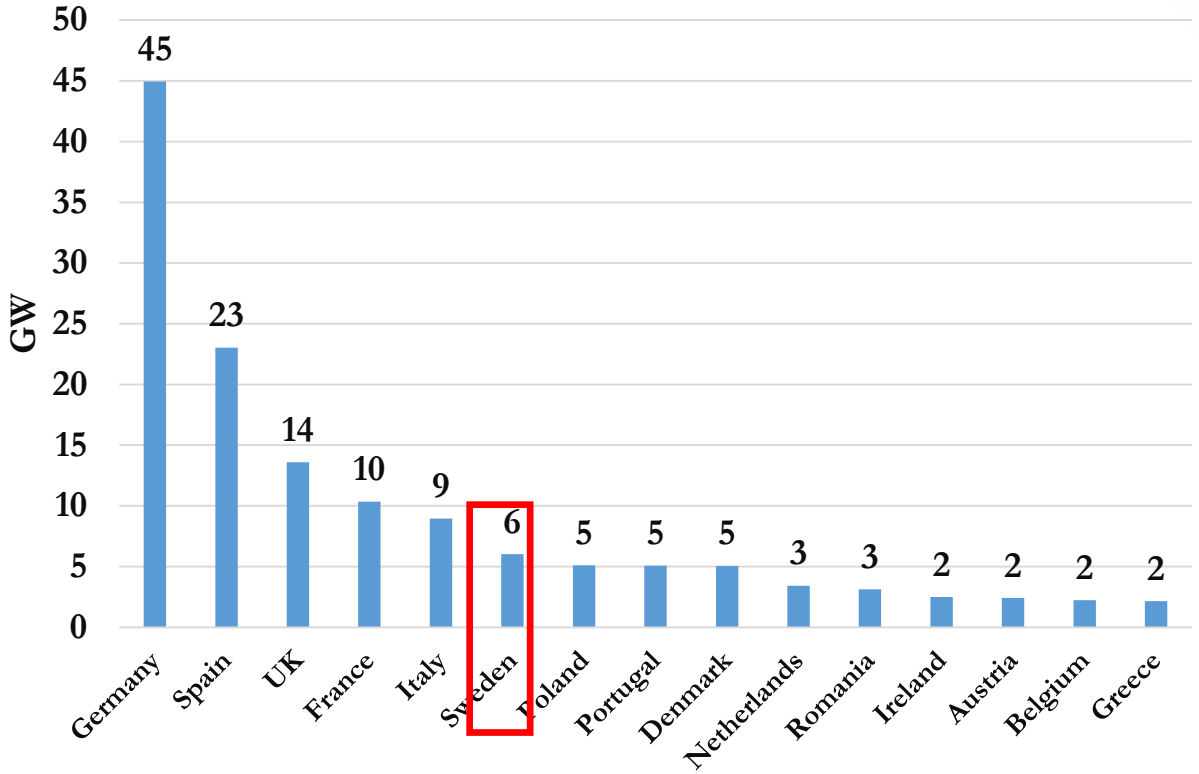

Fig: Top 15 wind power capacities in Europe, 2015*.

Sweden´s wind energy progress

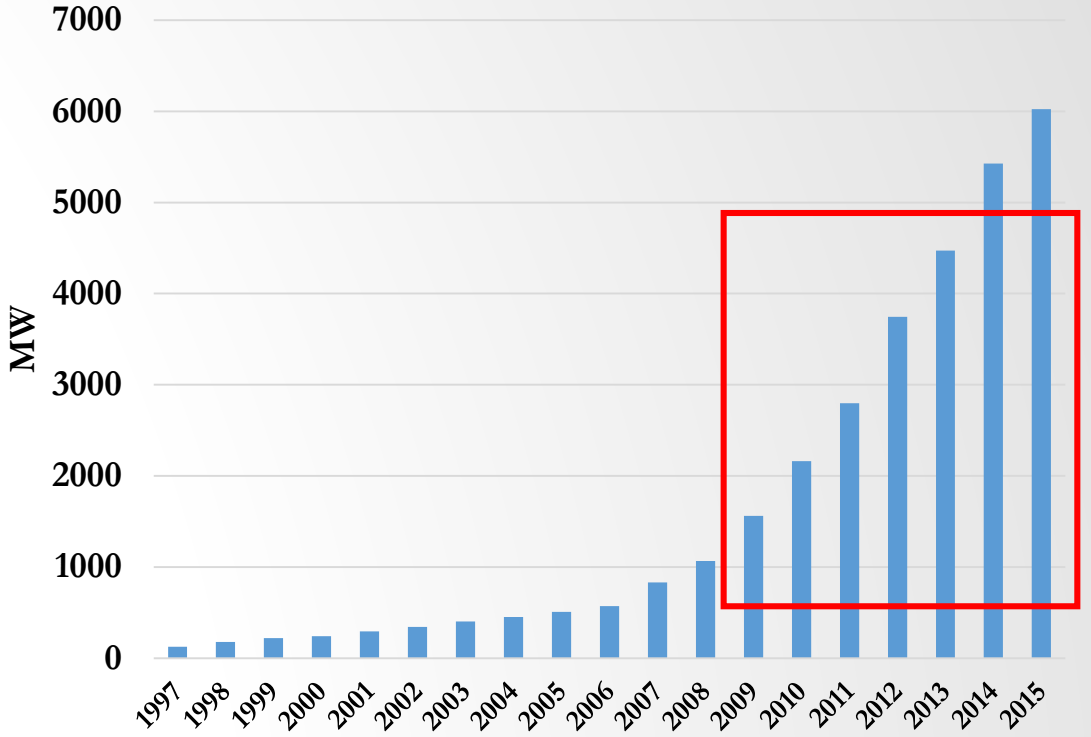

Fig: Wind power progress in Sweden, 1997-2015 **.

* Data source: GWEC, 2015

*'Data sourcehttp://www.thewindpower.net/index.php

INTRODUCTION

Sweden´s status now:

Total wind electricity till 2015:

- ✓ Total 16 TWh (11% of total 150 TWh generation)
- ✓ 6000 MW onshore, 200 MW offshore

Future targets:

Wind energy targets:

- ✓ 30 TWh by year 2020
  - 20 TWh onshore
  - 10 TWh offshore

SPECIFIC QUESTIONS

Spatial assessment of wind energy economic indicators in each county:

- Wind electricity (WE)
- Cost of wind electricity (COE)
- Simple payback period (SPB)
- Net present value (NPV)
- Annual saving (AS)

TOOL

How were specific questions answered?

ArcGIS Tool

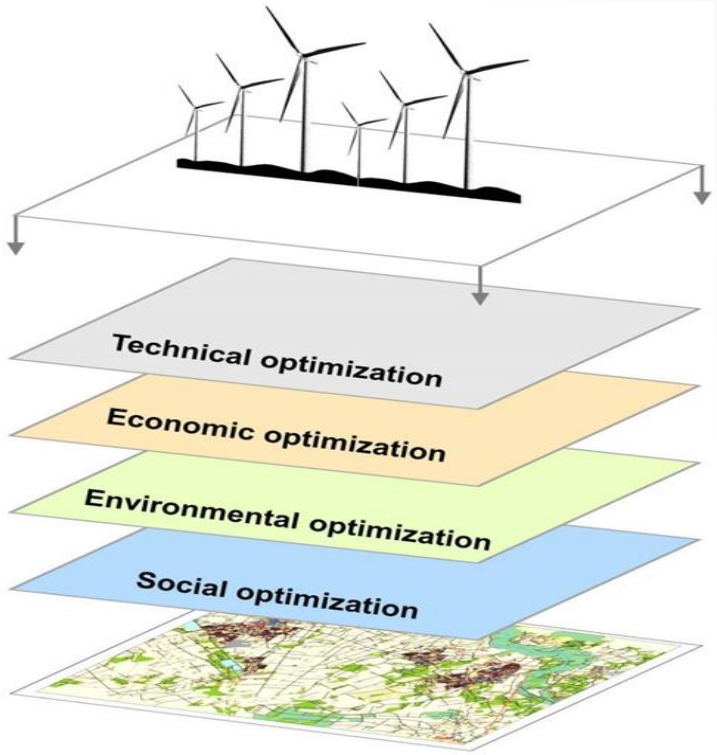

Fig: GIS-based wind power decision support system

GIS-BASED METHODOLOGY

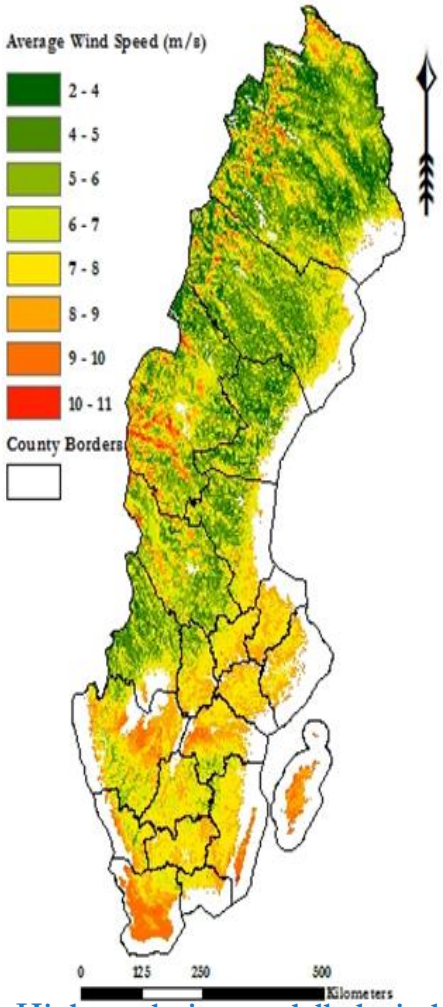

Fig: High resolution modelled wind speed. SEA 2014.

In total 435,000 grid cells were analyzed throughout Sweden. Each grid cell sized (1km x 1km).

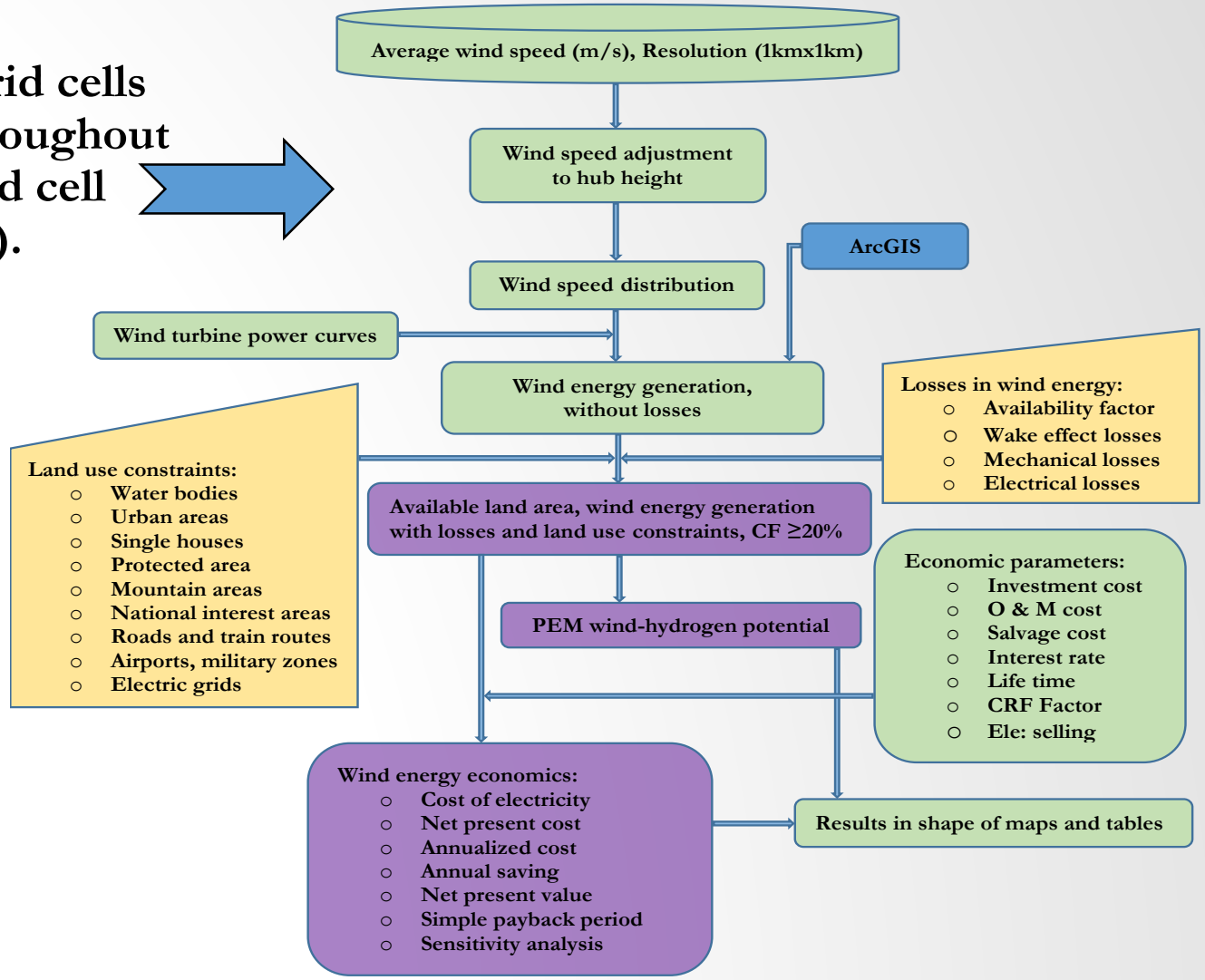

Fig: Combined methodology, Paper 1, 2 and 3.

GIS METHODOLOGY-LAND USE RESTRICTIONS

Table: Land use Restrictions/Constraints.

Land use Restrictions	Buffer zone	Restriction Scenario 1	Restriction Scenario 2
National roads	200 m	Yes	Yes
Railroads	200 m	Yes	Yes
Electricity grid (national and regional)	200 m	Yes	Yes
Airports	2500 m	Yes	Yes
Military zones	-	Yes	Yes
Lakes, watercourses and shorelines	100 m	Yes	Yes
Urban areas	1000 m	Yes	Yes
Single residential houses and churches	500 m	No	Yes
Protected areas	-	No	Yes
Areas of national interest for nature, culture and recreation values	-	No	Yes

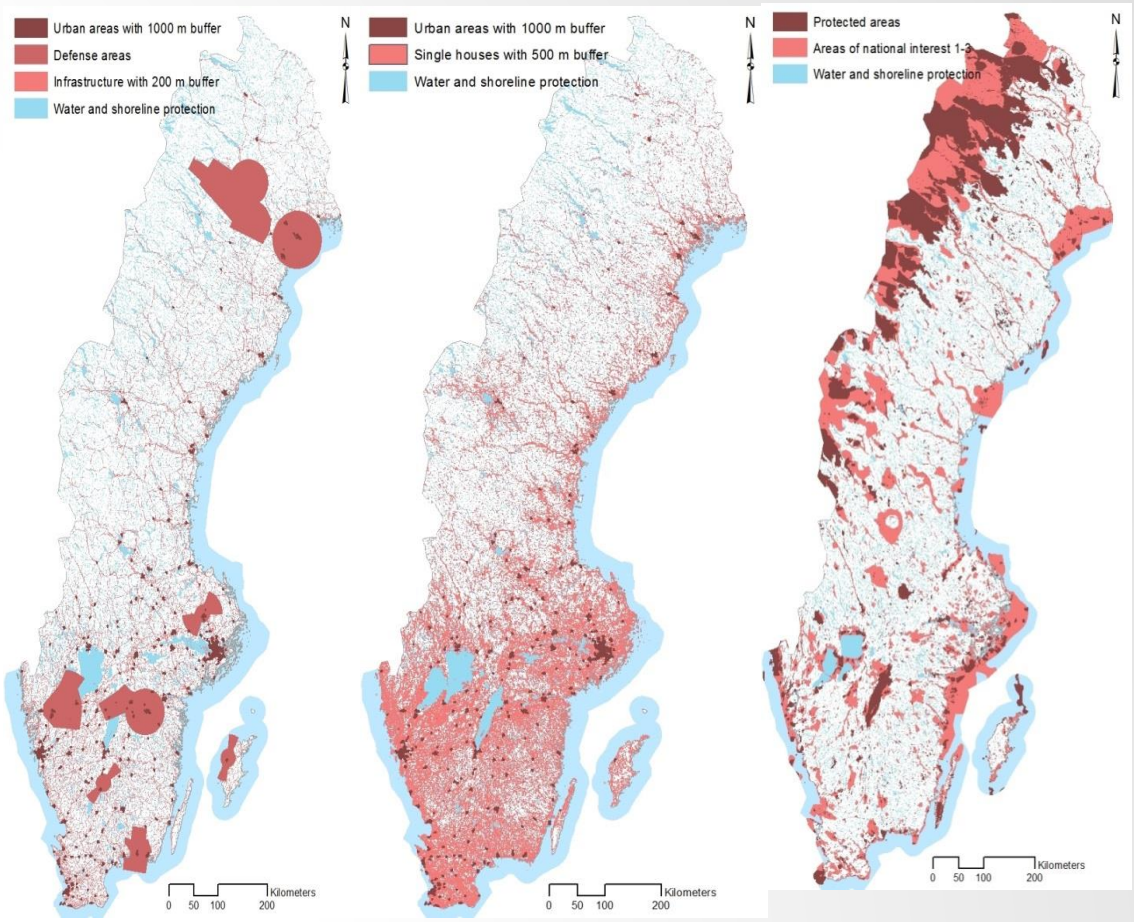

Fig: Urban areas with buffer zones, defence areas and safety zones to infrastructure (left). Urban areas and single residential houses and churches with buffer zones (Centre). Protected areas and areas of national interest for: 1) nature, 2) culture and 3) recreation values (right)

GIS METHODOLOGY - ADDITIONAL RESTRICTIONS

- ✓ Areas with elevation more than 2000 m were excluded due to following reasons.
- ✓ Electrical, mechanical and transmission losses were assumed to be approx. 17%.
- ✓ Grid cell having wind speed less than 4.5 m/s were excluded from the analysis
- ✓ Grid cell having capacity factor less than 20% were excluded from the analysis.

GIS METHODOLOGY

$$f(U) = \frac{\pi}{2} * \frac{U}{U_{mean}^2} * \exp\{-\frac{\pi}{4}\left(\frac{U}{U_{mean}}\right)^k\}$$

$$E_T = \mu * T \int_{U=0}^{U=cut_{out}} P(U) * f(U)dU \approx \mu * T \sum_{\text{wind class}} P(U) * f(U)$$

GIS METHODOLOGY

- $\mathrm{COE} = \frac{\mathrm{AC}}{\mathrm{E_T}}$

$$\mathrm{NPC} = \mathrm{I_C} + \mathrm{O\&M_{WP}} + \mathrm{S_C}$$

$$\mathrm{AC} = \mathrm{NPC} * \mathrm{CRF}(\mathrm{i}, \mathrm{T_P})$$

$$\mathrm{CRF}(\mathrm{i}, \mathrm{n}) = \{\mathrm{i}\,(1+\mathrm{i})^{\mathrm{n}}\} \div \{(1+\mathrm{i})^{\mathrm{n}} - 1\}$$

- $\mathrm{NPV} = \mathrm{E_{SP}} * \mathrm{E_T}\left[\frac{(1+\mathrm{i})^{\mathrm{n}}-1}{\mathrm{i}\,(1+\mathrm{i})^{\mathrm{n}}}\right] - \mathrm{I_C}\left[1 + \mathrm{O\ \&\ M_{WE}}\left(\frac{(1+\mathrm{i})^{\mathrm{n}}-1}{\mathrm{i}\,(1+\mathrm{i})^{\mathrm{n}}}\right)\right]$
- $\mathrm{AS} = (\mathrm{E_T} * \mathrm{E_{SP}}) - (\mathrm{E_T} * \mathrm{O\&M_{WE}})$
- $\mathrm{PBP} = \frac{\mathrm{I_C}}{\mathrm{AS}}$

Table: Input values adopted from published literature

Input parameter (Notation) (Unit)	Quantity
Initial investment cost (I_C) (USD/kW)	1500
Wind power operation and maintenance cost ($O\&M_{WP}$) in (USD/kW)	25% of ($I_C \div T_P$)
Interest rate (i) in (%)	4
Salvage cost (SC) in (USD/kW)	10% of (I_C)
Lifetime of wind energy system (T_P) in (years)	20
Wind electricity operation and maintenance cost ($O\&M_{WE}$) in (USD/kWh)	0.028
Total number of years fixed for investment recovery (n) in (years)	20

Table: Abbreviation elaboration

Abbreviation and full form	Unit
COE=Cost of electricity	USD/MWh
AC=Annualized cost	USD/year
E_T=Annual expected wind electricity	MWh/year
NPC=Net present cost	USD
CRF=Capital Recovery Factor	Ratio
NPV=Net present value	USD
AS=Annual saving	USD/year
E_{SP}=Electricity selling price	USD/MWh
PBP=Payback period	years
I_C=Initial investment cost	USD/kW

RESULTS

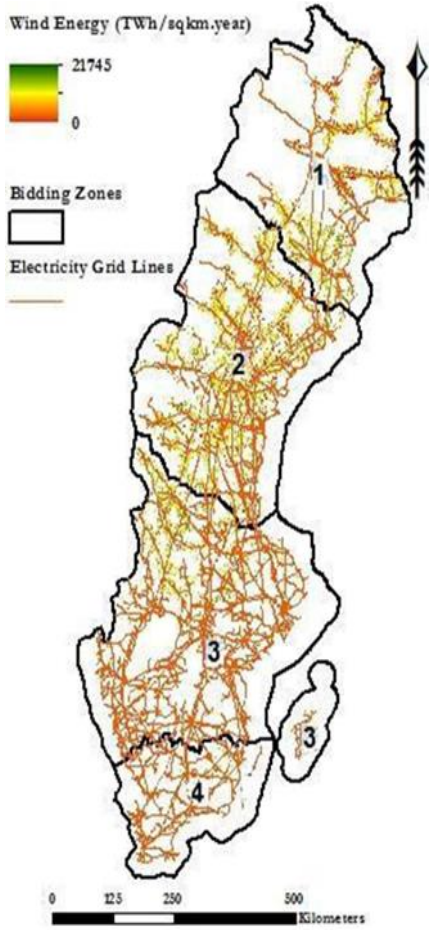

Table: Wind energy potential in each county, considering grid cells having 60% and 80% availability, making clusters of at least 3 km^2 and 5 km^2 within 10 kilometres range of national or regional electricity grids.

County/län	Total wind energy (TWh) in grid cells having 60% availability making clusters of 3 km^2	Total wind energy (TWh) in grid cells having 80% availability making clusters of 3 km^2	Total wind energy (TWh) in grid cells having 80% availability making clusters of 5 km^2
Stockholm	1	0	0
Uppsala	4	1	1
Södermanland	1	0	0
Östergötland	2	0	0
Kronoberg	3	1	1
Kalmar	4	1	1
Gotland	2	0	0
Blekinge	0	0	0
Halland	1	0	0
Värmland	22	8	8
Örebro	7	2	1
Västmanland	7	2	1
Kopparberg	57	22	20
Gävleborg	36	12	11
Västernorrland	50	23	21
Jämtland	96	42	39
Västerbotten	101	45	42
Norrbotten	90	46	44
Skåne	0	0	0
Jönköping	1	0	0
Västra Götaland	2	0	0
Sweden	**487**	**205**	**190**

Fig: Wind energy distribution in Sweden (TWh/sqkm.year) in grid cells having 80% availability, in clusters of at least 3 km^2 and lying within 10 km of national and regional electric grids.

RESULTS

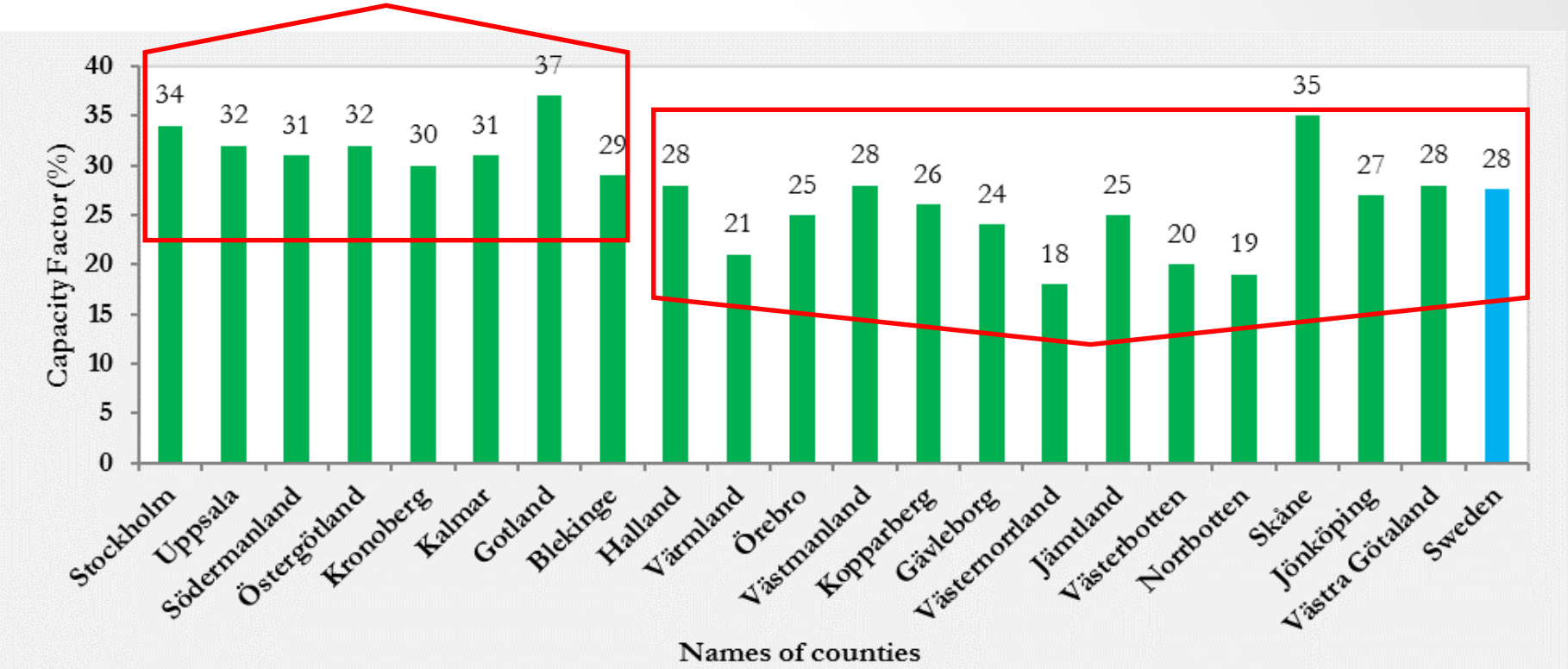

Fig: Average capacity factor for wind power of each Swedish county on the basis of Restriction Scenario 2 and within 10 km of grid restriction.

RESULTS

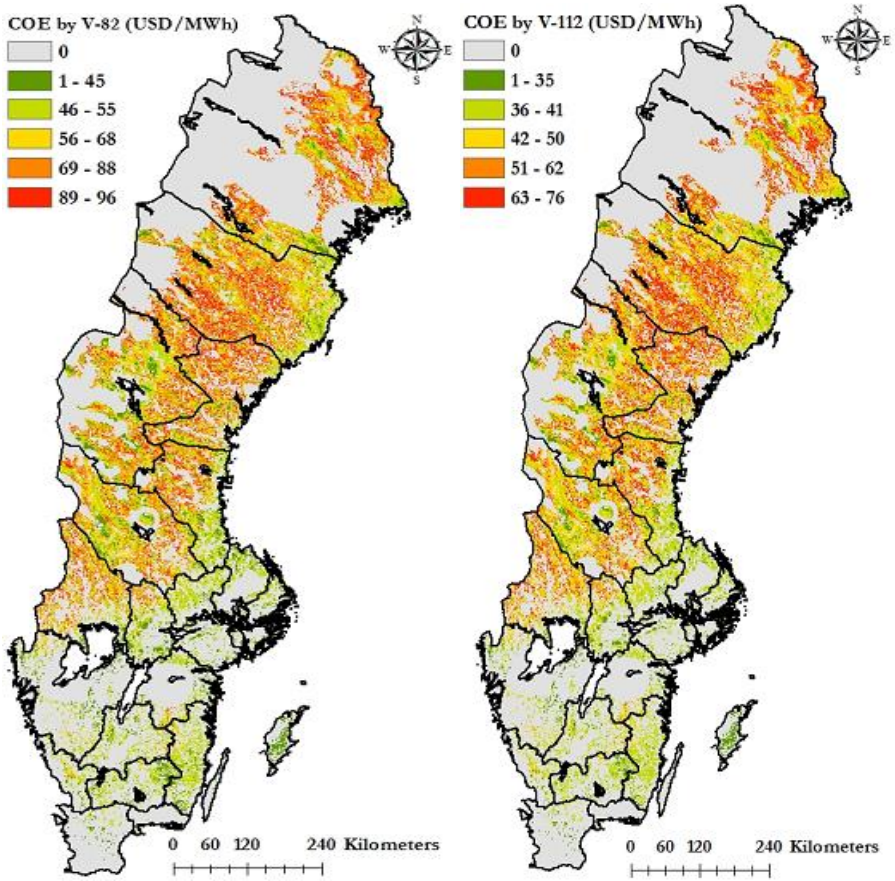

Fig: Spatial distribution of the cost of electricity achievable in each 1kmx1km sized grid cell by V-82 (left) and V-112 (right).

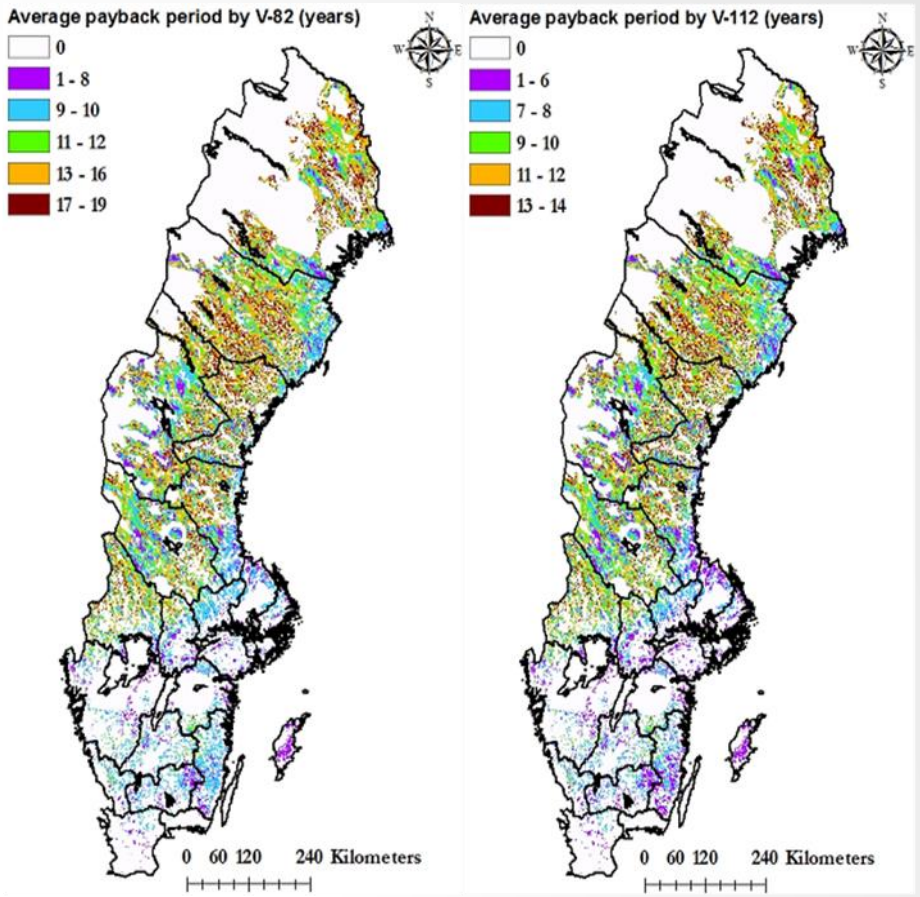

Fig: Spatial distribution of simple payback period achievable in each 1kmx1km sized grid cell by V-82 (left) and V-112 (right).

RESULTS

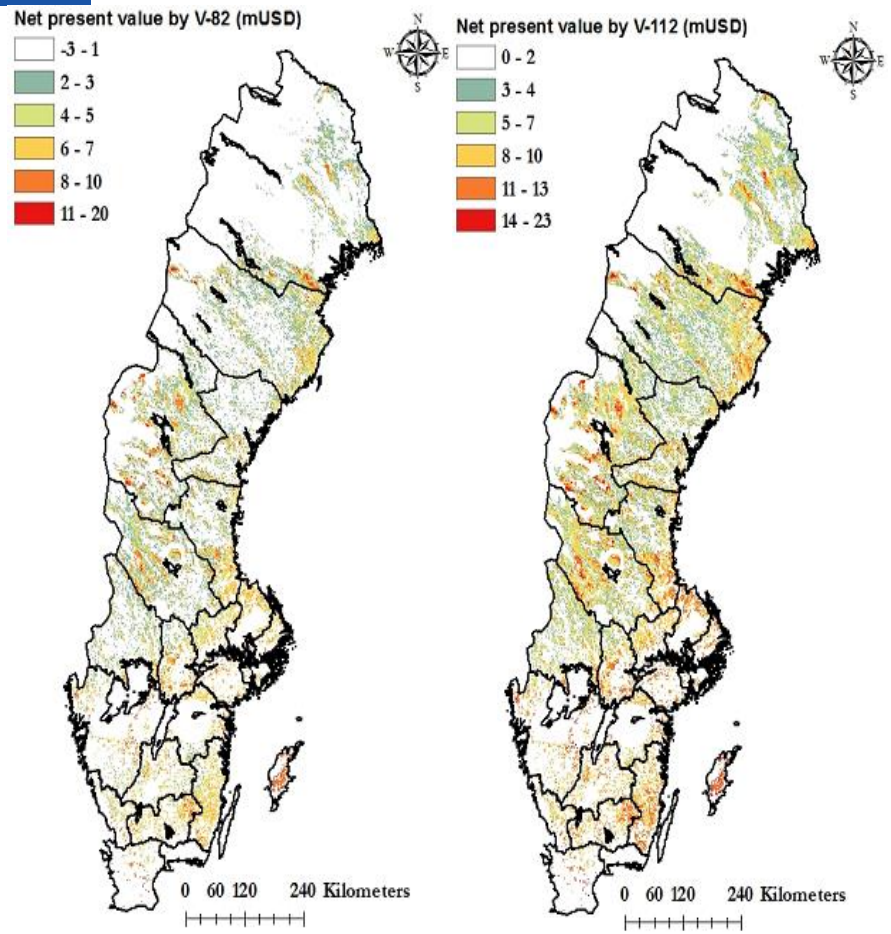

Fig: Spatial distribution of net present value achievable in each 1kmx1km sized grid cell by V-82 (left) and V-112 (right).

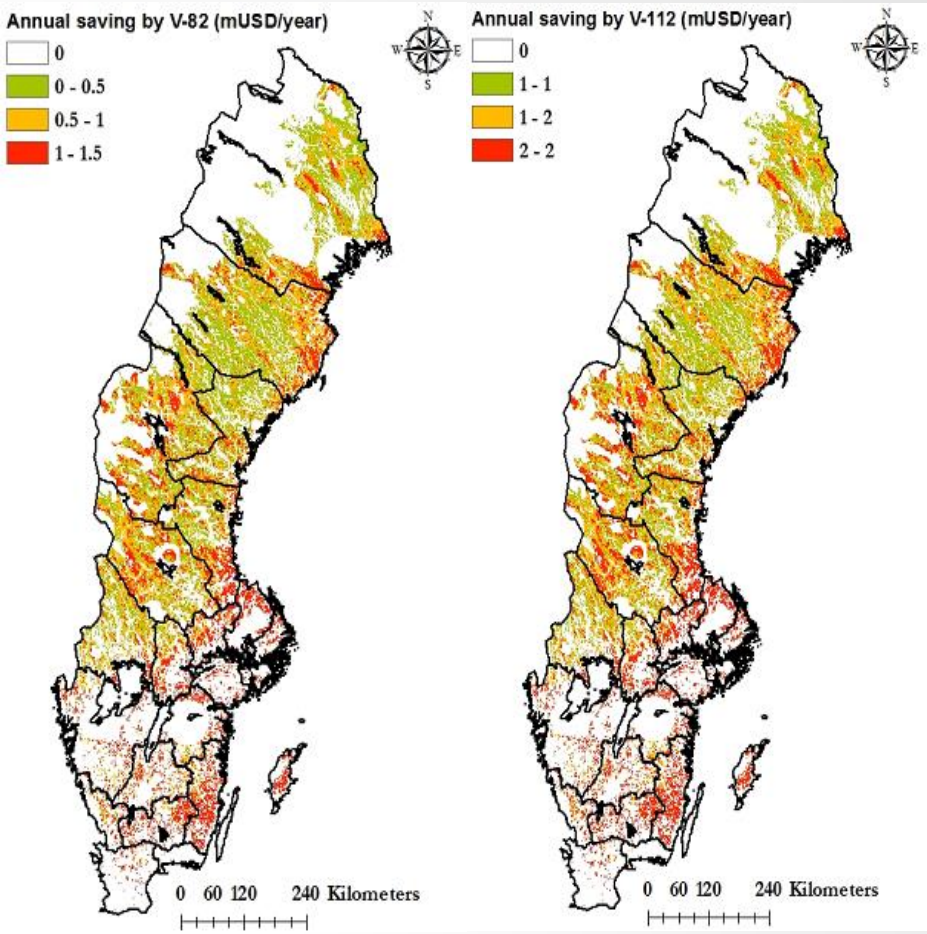

Fig: Spatial distribution of annual saving achievable in each 1kmx1km sized grid cell by V-82 (left) and V-112 (right).

RESULTS

Table: Total annual saving and net present value achievable by V-82 and V-112 in each county.

Region Name	County Name	Total annual saving (bUSD/year)		Total net present value (bUSD)	
		V-82	V-112	V-82	V-112
Southern Region	Blekinge	0.1	0.2	1	1
	Gotland	1	1	9	12
	Halland	1	1	7	11
	Jönköping	2	3	15	25
	Kalmar	4	5	25	41
	Kronoberg	3	3	18	30
	Örebro	3	4	17	31
	Östergötland	2	2	12	20
	Skåne	1	1	5	8
	Södermanland	1	1	7	11
	Stockholm	1	1	7	11
	Uppsala	2	2	12	19
	Värmland	6	8	18	53
	Västmanland	2	3	15	26
	Västra	3	4	19	33
Sub Total # 1		*32*	*39*	*187*	*332*
Central Region	Gävleborg	8	10	34	77
	Jämtland	18	23	66	163
	Kopparberg	12	16	50	116
	Västernorrland	9	11	18	68
Sub Total # 2		*47*	*60*	*168*	*424*
Northern Region	Norrbotten	18	24	35	141
	Västerbotten	22	28	54	177
Sub Total # 3		*40*	*52*	*89*	*318*
Sweden Total # 1, 2 and 3		**119**	**151**	**444**	**1074**

CONCLUSIONS

- **Central** and **Southern Sweden** provides less available land. However, experiences **higher wind speeds** ranging between **7 to 11 m/s** (in contrast to the northern region: **4 to 7m/s**).
- The total economically exploitable wind energy potential is estimated at **190 TWh/year**, whereas, present wind electricity generation is only **19 TWh.**
- **Central** and **southern** regions of the country could offer wind electricity at a range of **35-65 USD/MWh,** depending on the wind speed limit and the type of wind turbine used. This leads to **high NPV** and significant **annual savings**.
- The national electricity grid should be improved and extended accordingly in order to be able to absorb the fluctuation of the incoming wind energy on large scale . With the current status, the Swedish grid can only absorb **45 TWh** of wind energy.

READING FOR MORE DETAILS

Energy Conversion and Management

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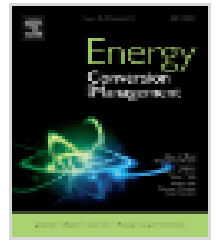

Mapping key economic indicators of onshore wind energy in Sweden by using a geospatial methodology

Shahid Hussain Siyal · , Dimitris Mentis, Mark Howells

Thank you for your Attention !