Assessing systemic effects of renewables expansion in Austria

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Austrian energy policy objectives

according to government programme 2020-2024

• $100\%^1$ of electricity demand from domestic renewable sources on annual balance by 2030

¹excluding system services and industry own consumption. At current levels this equals 10% of consumption, i.e. actual target is around 90%.

²meteorological conditions as in 2016

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- 100%¹ of electricity demand from domestic renewable sources on annual balance by 2030
- additional annual electricity generation of 27 TW h is expected to suffice

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Austrian energy policy objectives

according to government programme 2020-2024

- 100%¹ of electricity demand from domestic renewable sources on annual balance by 2030
- additional annual electricity generation of 27 TW h is expected to suffice
- technology-specific additions:

	2018	2018 ²	Policy	2030	2030
	[GW]	[TWh]	[TWh]	[TWh]	[GW]
Solar PV	1.44	1.23	+11	12.23	14.27
Wind (onshore)	3.05	6.14	+10	16.14	8
Hydro (run-of-river)	5.72	28.34	+5	33.34	6.73

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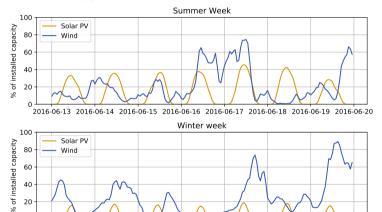
Stylized Facts

- Apart from wind and solar, potentials for renewable electricity generation in Austria largely exhausted
- Under announced policies, solar PV is only large-scale substitute to wind power
- Increasing social conflict around the large-scale expansion of onshore wind power
- Traditional power system models do not account for local negative externalities of renewable energy generators, such as:
 - visual impact on landscape
 - harm to wildlife
 - noise, flickering, glaring

Why wind is not solar

A side note on imperfect substitutes

Aggregate generation profile in Austria



2016-12-05 2016-12-06 2016-12-07 2016-12-08 2016-12-09 2016-12-10 2016-12-11 2016-12-12

- secure system operation requires
 S = D at any point in time
- electricity not easily storable
- grid operators
 »transform«
 electricity feed-in
 to end-use
 electricity

The problem from a social planner's perspective

How to account for local negative externalities in renewables expansion planning?

The cost of undisturbed landscapes

assess energy system effects and costs of substituting wind power with solar PV

The value of undisturbed landscapes

• estimates of the negative external effect of wind turbines reported in literature

Approach

- Resemble Austrian power system in 2030
- include most important electricity trading partner Germany
- set policy target of meeting 90% of demand in 2030 from domestic renewable sources
- incorporate announced electricity system targets for Germany in 2030
 - nuclear phase-out
 - partial coal exit
 - expansion of renewable capacities in line with EEG 2017
- simulate prospective electricity system with medea

Power system model medea

Objective

- minimize total system cost
 - fuel and CO₂ cost
 - O&M cost
 - capital cost

Decision variables

- hourly dispatch
- inter-zonal electricity trade
- investment in power plants, storages, and transmission

Constraints

- market clearing
- capacity constraints
- co-generation & fuel use
- system service requirement
- inter-zonal electricity trade

Economic assumptions

- perfect competition
- perfect foresight
- price-inelastic demand

Resolution

- hours (one year)
- bidding zones
- 41 technologies

Implementation

- linear program
- python & GAMS

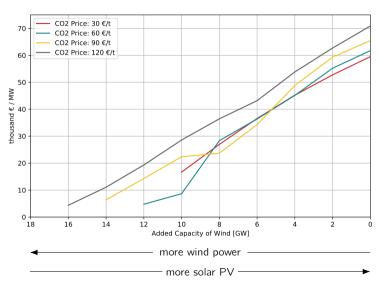
medea is available on github.com/inwe-boku/medea under an open MIT license

Estimating the opportunity cost of wind power

- 1) derive unrestricted optimal deployment of wind and solar power
- 2) restrict deployment of wind power by a small margin(→ solar PV substitutes for wind)
- 3) repeat till no wind power can be deployed

We approximate the cost of undisturbed landscapes (i.e. the forgone value of wind power w) by the change in net cost of the electricity system including air pollution cost c_{net} in response to a change in deployed wind power w, i.e.

$$oc_w = \frac{\Delta c_{net}}{\Delta w}$$

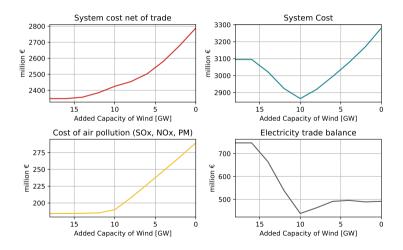


Capital cost | 630 €/kWp of solar PV

 \rightarrow about $^2/_3$ rooftop PV, $^1/_3$ open space PV

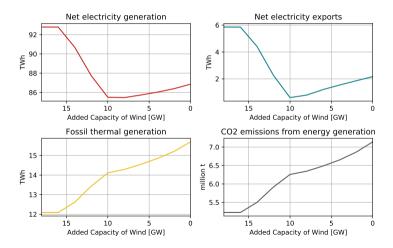
wind power and solar PV are substitutes

Cost with restricted wind power



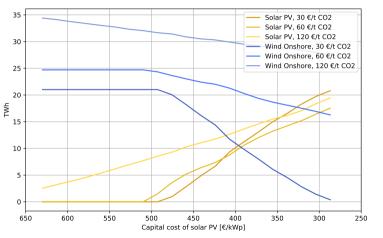
Capital cost of solar PV CO₂ price 90 €/MWh

System operation with restricted wind power





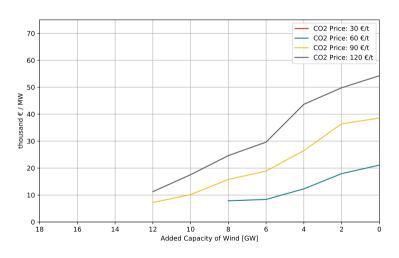
Sensitivity to capital cost of solar PV



Capital cost estimates for solar PV in 2030

Small-scale	830 €/kWp
rooftop	
Utility-scale	280 €/kWp
open space	

Sensitivity to capital cost of solar PV



Capital cost | 280 €/kWp of solar PV

Discussion of results

- Renewable resource quality held constant as capacity is expanded
- Sub-national electricity transmission and distribution grids neglected
- Technical operation of generators not fully represented (e.g. no unit commit, simplified balancing)
- Electricity market-splitting has increased market concentration
- Announced policy necessarily turns Austria into a net exporter of electricity
 - → "loop-flows" potentially avoided
 - → artificial transmission restriction between DE and AT could be eliminated

Conclusions

- If we value CO₂ emissions at 30 €/MWh or lower, onshore wind power can be substituted by open-space utility-scale solar PV at little loss
- CO₂ valuation above 30 €/MWh or a preference for rooftop PV allows for gains to be made from wind power deployment
- Gains from wind power could be used to compensate the ones affected by local negative externalities of wind turbines
- Complementing our analysis with spatially resolved estimates of wind turbine impacts, one could derive a spatially explicit plan for the socially optimal expansion of wind power in Austria

Thank you!

https://refuel.world https://github.com/inwe-boku/medea sebastian.wehrle@boku.ac.at





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Unconstrained deployment of wind and solar power

Results for Austria		
Added Solar PV	0.0	TWh
Added Wind	31.0	TW h
System Cost ³	3095.2	M€
Trade balance	746.8	M€
Cost of air pollution	184.4	M€
CO ₂ emissions	5227.3	kt
Electricity generation	92.8	TW h
Curtailment	2.4	TWh
Net exports	5.9	TW h
Wholesale electricity price	56.05	€/MWh

Capital cost	630	€/kWp
Capital cost of solar PV		
CO ₂ price	90	€/MWh

³excluding cost for domestic transmission and distribution grids

The value of undisturbed landscapes

Local Negative Externalities of Wind Turbines

Authors	Country	Sample	Framework ⁴	Impact Proxy ⁵	Estimated Impact
Heintzelmann and Tuttle, 2012	USA, NY	2000 - 2009	hedonic, SFE	d	-3.6% to -9.6%, insignificant
Jensen et al., 2014	DNK	2000 - 2011	hedonic, SAR	d, v	-4.35%
Lang et al., 2014	USA, RI	2000 - 2013	DID	d, v	insignificant
Gibbons, 2015	GBR, EAW	2000 - 2011	DID	d, v	-6%
Hoen et al., 2015	USA	1996 - 2011	DID	d	insignificant
Dröes and Koster, 2016	NED	1985 - 2011	DID	d	-1.4%
Sunak and Madlener, 2016	GER, NRW	1992 - 2010	DID	V	−9% to −14%
Jensen et al., 2018	DNK	-	hedonic, SAR	d, # of turbines	-0.2% to -1.1%
Kussel et al., 2019	GER	2007 - 2015	DID	d	-6.0%

⁴DID ... difference-in-differences, SAR ... spatial autoregressive, SFE ... spatial fixed effects

⁵d . . . distance, v . . . visibility

Compensating for local negative externalities

An example

l value l impact l loca

OC of wind turbines in Austria

Property value loss in Germany

$[\in MW^{-1}a^{-1}]$	δ	NPV oc_w [\in MW $^{-1}$]	NPV <i>oc_w</i> [€ turbine ⁻¹]	
40 000	0.05	563 758	1 973 152	mean
40 000	0.03	696 526	2 437 841	mean
10 000	0.05	140 939	493 288	mean + 1 s.d.
10 000	0.03	171 131	609 460	mean + 1 s.d.

value	ппрасс	1055
€	%	€
273 786	0.06	16 427
273 786	0.10	27 379
476 923	0.06	28 615
476 923	0.10	47 692
	€ 273 786 273 786 476 923	€ % 273 786 0.06 273 786 0.10 476 923 0.06

Compensation potential

OC _w	δ	value	impact	# property owners
40 000	0.05	273 786	0.06	120
40 000	0.05	273 786	0.10	72
40 000	0.03	476 923	0.06	69
40 000	0.03	476 923	0.10	41
10 000	0.03	476 923	0.10	18