The cost of undisturbed landscapes

Assessing systemic effects of renewables expansion in Austria

Sebastian Wehrle, Johannes Schmidt

University of Natural Resources and Life Sciences, Vienna

February 25, 2020

NOeG Annual Meeting 2020

Austrian energy policy objectives

according to government programme 2020-2024

- 100%[1] of electricity demand from domestic renewable sources on annual balance by 2030

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

[2]meteorological conditions as in 2016

Austrian energy policy objectives

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- 100%[1] of electricity demand from domestic renewable sources on annual balance by 2030
- additional annual electricity generation of $27\,\mathrm{TW\,h}$ is expected to suffice

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Austrian energy policy objectives

according to government programme 2020-2024

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- additional annual electricity generation of $27\,\mathrm{TW\,h}$ is expected to suffice
- technology-specific additions:

	2018 [GW]	2018[2] [TWh]	Policy [TWh]	2030 [TWh]	2030 [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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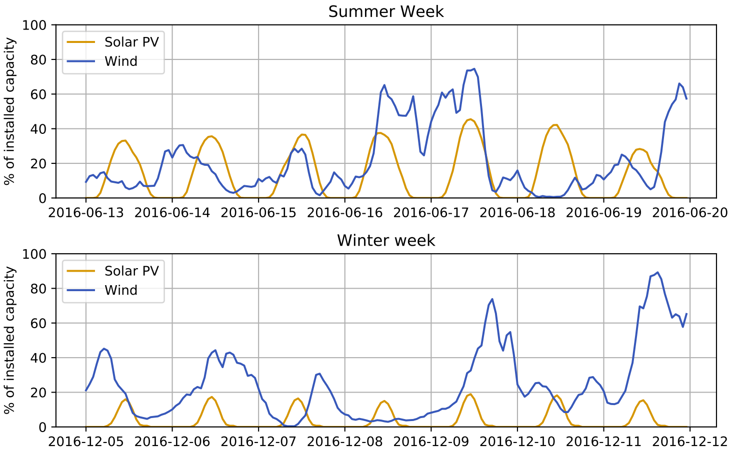
Stylized Facts

- 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



- 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?

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

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

- 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 CO_2 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

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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
   ($\rightarrow$ 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.

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

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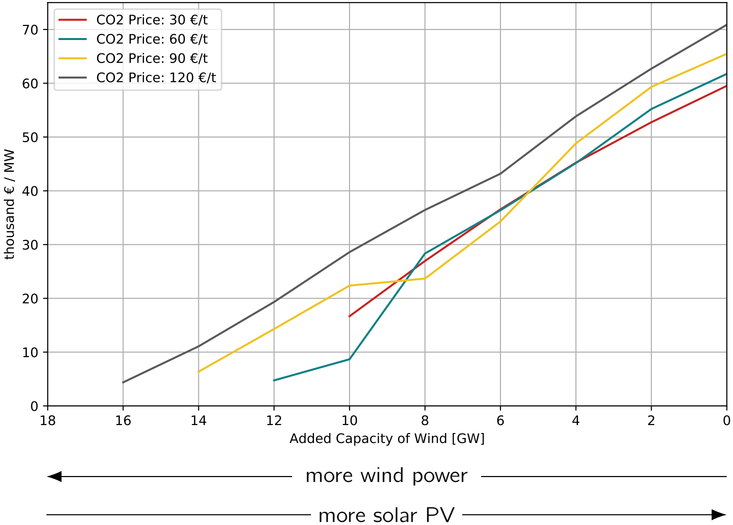

Capital cost of solar PV	630 €/kWp

→ about 2/3 rooftop PV, 1/3 open space PV

wind power and solar PV are substitutes

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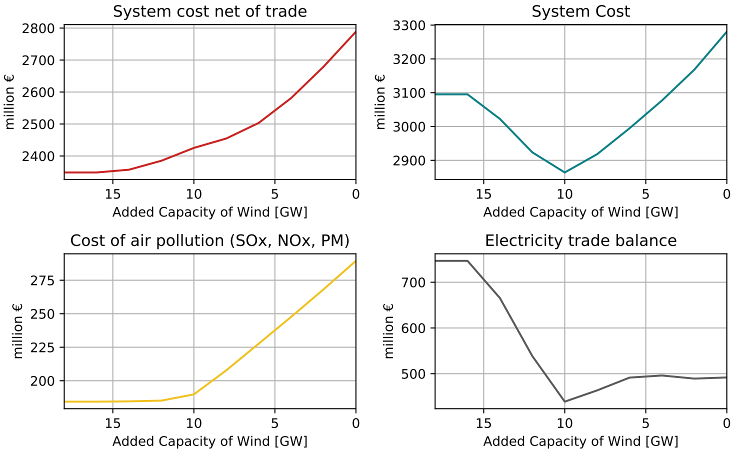
Cost with restricted wind power



Capital cost of solar PV	630 €/kWp
CO_2 price	90 €/MWh

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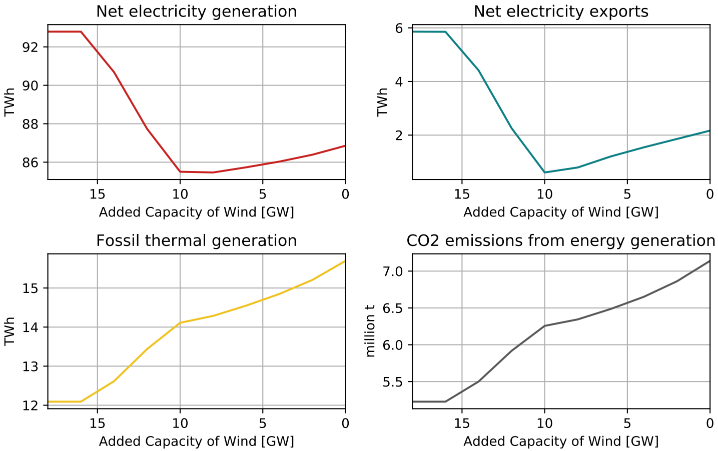
System operation with restricted wind power



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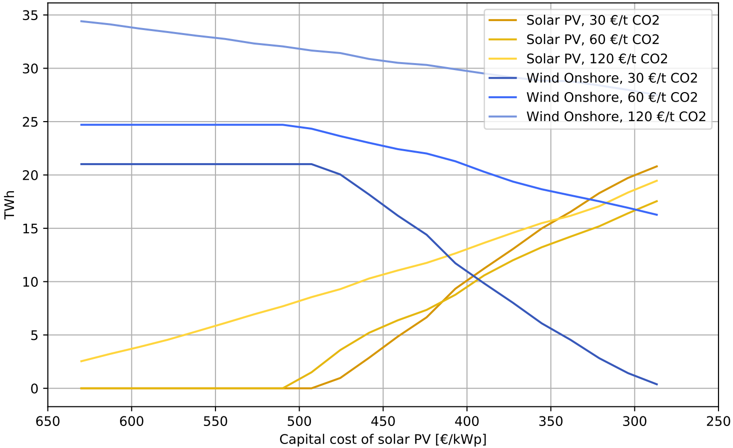
Sensitivity to capital cost of solar PV



Capital cost estimates for solar PV in 2030

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

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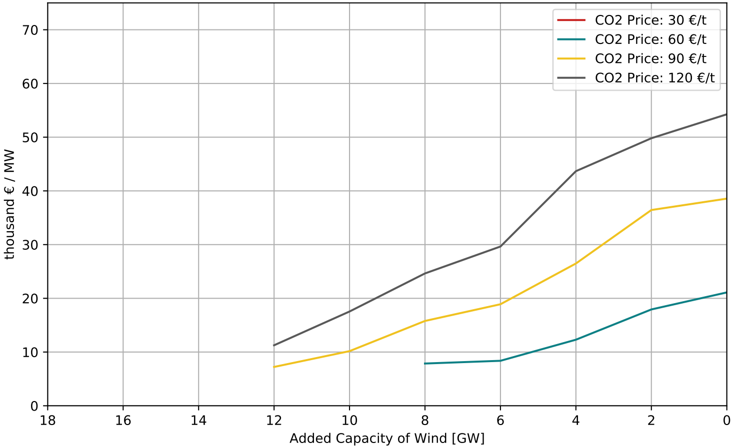
Sensitivity to capital cost of solar PV



Capital cost of solar PV	280 €/kWp

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- 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 CO_2 emissions at 30 €$/\mathrm{MWh}$ or lower, onshore wind power can be substituted by open-space utility-scale solar PV at little loss
- CO_2 valuation above 30 €$/\mathrm{MWh}$ 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

We gratefully acknowledge support from the European Research Council
(“reFUEL” ERC-2017-STG 758149).

reFUEL

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Unconstrained deployment of wind and solar power

Results for Austria

Added Solar PV	0.0	TWh
Added Wind	31.0	TWh
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	TWh
Curtailment	2.4	TWh
Net exports	5.9	TWh
Wholesale electricity price	56.05	€/MWh

Capital cost of solar PV	630	€/kWp
CO_2 price	90	€/MWh

[3] excluding cost for domestic transmission and distribution grids

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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%

[4] DID . . . difference-in-differences, SAR . . . spatial autoregressive, SFE . . . spatial fixed effects
[5] d . . . distance, v . . . visibility

Compensating for local negative externalities

An example

OC of wind turbines in Austria

oc_w [€ MW^{-1}a^{-1}]	δ	NPV oc_w [€ MW^{-1}]	NPV oc_w [€ turbine^{-1}]
40 000	0.05	563 758	1 973 152
40 000	0.03	696 526	2 437 841
10 000	0.05	140 939	493 288
10 000	0.03	171 131	609 460

Property value loss in Germany

	value €	impact %	loss €
mean	273 786	0.06	16 427
mean	273 786	0.10	27 379
mean + 1 s.d.	476 923	0.06	28 615
mean + 1 s.d.	476 923	0.10	47 692

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