Impact of CO_2 prices on the design of a highly decarbonised coupled electricity and heating system in Europe

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Agenda

Introduction

Methodology

Results

Conclusions

Future work

Introduction

Introduction

- Limit the increase of global average temperature to 2 °C
- CO_2 emissions reduction by 80%-95% in 2050 compared to 1990[1]
- The major future renewable energy: wind and solar energy
- Drastically reduction of CO_2 emissions not only in the electricity sector[2]

[1] European Union, *A Roadmap for moving to a competitive low carbon economy in 2050.*

[2] *National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism, European Environment Agency.*

Research questions

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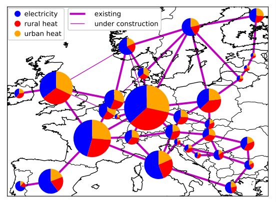
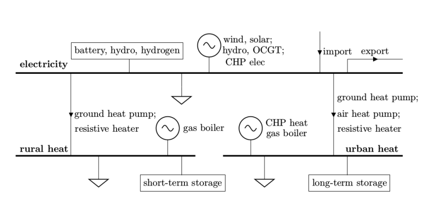
- What are the cost-optimal system configurations under specific CO_2 emission reductions?

Methodology

Methodology: PyPSA Model[3]

Electricity and heating coupled, hourly-resolved one-node-per-country





[3] Brown, Hörsch, and Schlachtberger, "PyPSA: Python for Power System Analysis".

Methodology: Optimisation

- A techno-economical joint optimisation problem
- Technical and physical constraints, assuming perfect competition and foresight
- Renewable self-sufficient for individual country: weakly homogeneous layout

$$\min_{\substack{G_{n,s},E_{n,s},\\ F_{\ell},g_{n,s,t}}} \left[\sum_{n,s} c_{n,s} \cdot G_{n,s} + \sum_{n,s} \hat{c}_{n,s} \cdot E_{n,s} + \sum_{\ell} c_{\ell} \cdot F_{\ell} + \sum_{n,s,t} o_{n,s,t} \cdot g_{n,s,t}\right]$$

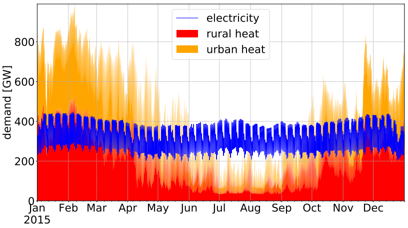
sub. to

$$\sum_{s} g_{n,s,t} + \sum_{\ell} \alpha_{n,\ell,t} \cdot f_{\ell,t} = d_{n,t} \quad \leftrightarrow \quad \lambda_{n,t} \qquad \forall\, n,t$$

$$g_{i,VRES}^{gross} = \gamma_{i}^{gross} \sum_{t,n \in i} d_{n,t} \qquad \forall i$$

Methodology: Data

- Electricity demand is from ENTSO-e
- Heat demand is modelled by Heating Degree Hour (HDH)
- Heating bus is separated proportionally into rural and urban heat



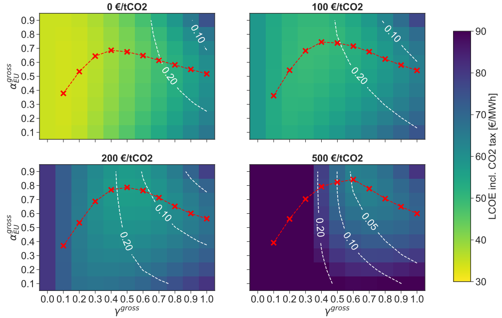
Methodology: Data

- Electricity demand is from ENTSO-e
- Heat demand is modelled by Heating Degree Hour (HDH)
- Heating bus is separated proportionally into rural and urban heat
- Wind and solar capacity factors are calculated based on reanalysis dataset (CFSR) through REatlas
- The geographical potentials of wind and solar are estimated

Results

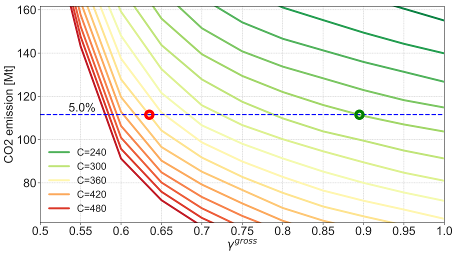
Results I: LCOE for configuration sweep

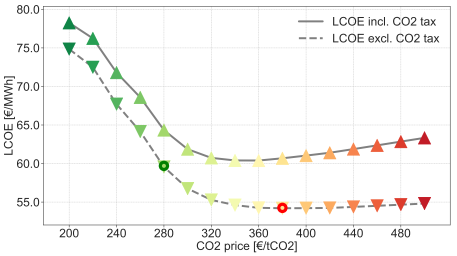
- High VRES penetrations do not necessarily lead to low CO_2 emissions
- The CO_2 price has limited impact on the cost-optimal wind/solar mix



Results II: Target configuration

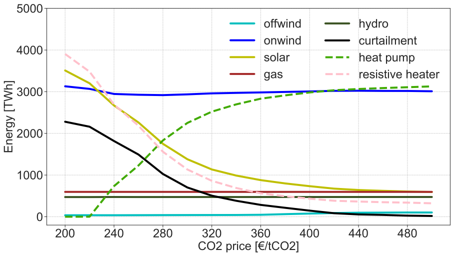
- The minimum of LCOE excl. CO_2 tax determines the cost-optimal configuration
- The LCOE shows low sensitivity around the optimum

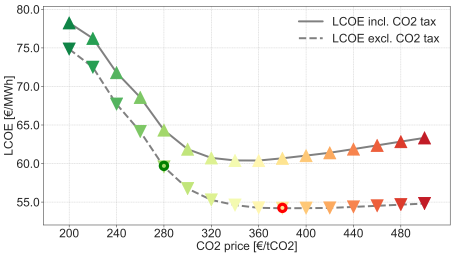




Results II: Target configuration

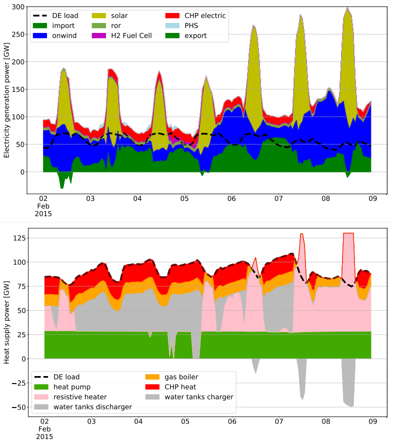
- The minimum of LCOE excl. CO_2 tax determines the cost-optimal configuration
- The LCOE shows low sensitivity around the optimum
- A higher CO_2 price curtails less VRES and utilises VRES more efficiently
- The high CO_2 price forces the choice of expensive heat supply





Results III: Germany dispatch time series

5%, 280 €/tCO_2



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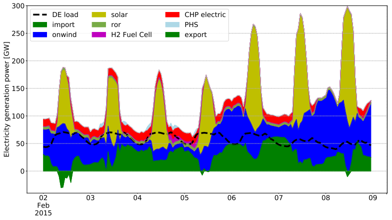

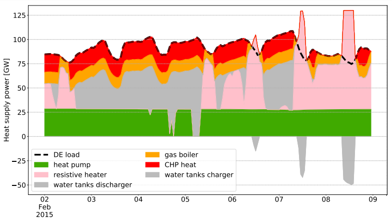

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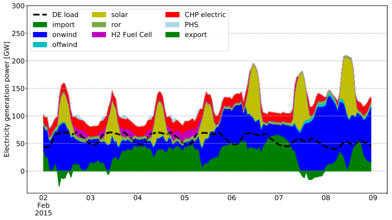
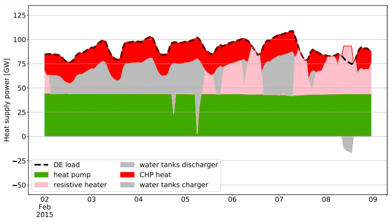
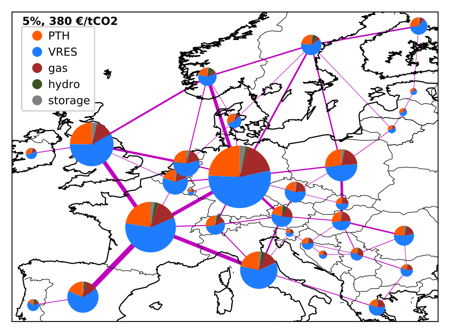
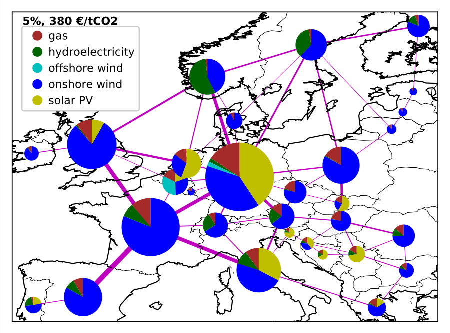




System cost

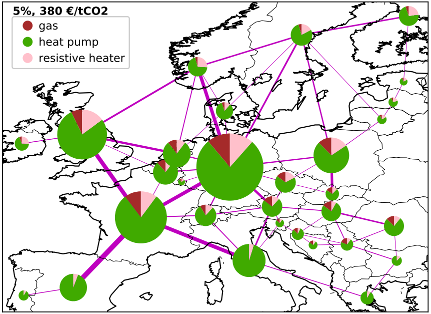


Primary energy

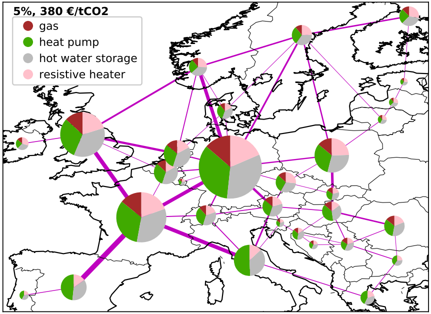


Results IV: Spatial distribution

Thermal energy



Thermal capacity



Results V: Aggregated system configurations

Transmission volume	Optimal volume			Todays volume		
Emission level	20%	10%	5%	20%	10%	5%
Transmission volume	141	176	196	32	32	32
CO_2 price	160	260	380	200	320	580
Penetration	0.46	0.57	0.64	0.5	0.64	0.7
Wind/solar mix	0.77	0.8	0.8	0.73	0.74	0.79
LCOE excl. CO_2 tax	43.2	49.8	55.4	45.4	53.9	60.9
Resistive heater	307	389	464	434	581	673
Heat pump	69	113	148	67	103	143
CHP	363	243	165	464	336	268
Hot water tank	7,768	27,823	91,796	17,232	57,818	156,753

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- What are the cost-optimal system configurations under specific CO_2 emissions?

- Only installing high capacities of renewable is not enough
- A significantly high CO_2 price is required to disincentivise gas usage
- The flatness around cost-optimal CO_2 price allows flexibilities

Future work

Motivation

Cost optimal scenarios depend on the specific input data

Potential climate change may change the future demand profile

Evaluate the robustness of target configurations

Scenarios

Temperature increase influences the heat and cooling demand

Retrofitting may lower the heat demand

Cost parameter

Possible demand-side management

Motivation

Seek the robust build-up of renewable capacities

Analyse the required levels of economic instruments

Make sure that the transmission capacities could fulfill the need of expanding renewable

Methodology

Logistic growth for renewable capacities

Constrain the CO_2 emissions as a function of time

Understand the next feasible investments in decarbonisation

Thanks for your attention.

References

Brown, T., J. Hörsch, and D. Schlachtberger. "PyPSA: Python for Power System Analysis". In: *Journal of Open Research Software* 6.4 (1 2018). DOI: 10.5334/jors.188. eprint: 1707.09913. URL: https://doi.org/10.5334/jors.188.

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