Power sector effects of different roll-outs of flexible vs inflexible heat-pumps

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Premise and research question

- German government aims for 6 million heat pumps by 2030
- What are the capacity and dispatch effects of a wide roll-out of heat pumps with **100 % renewable** heat and different degrees of **flexibility**?

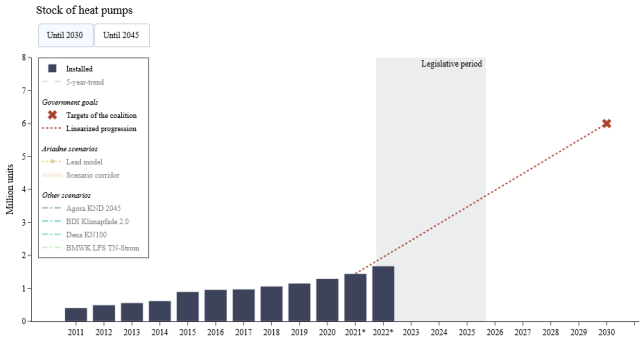


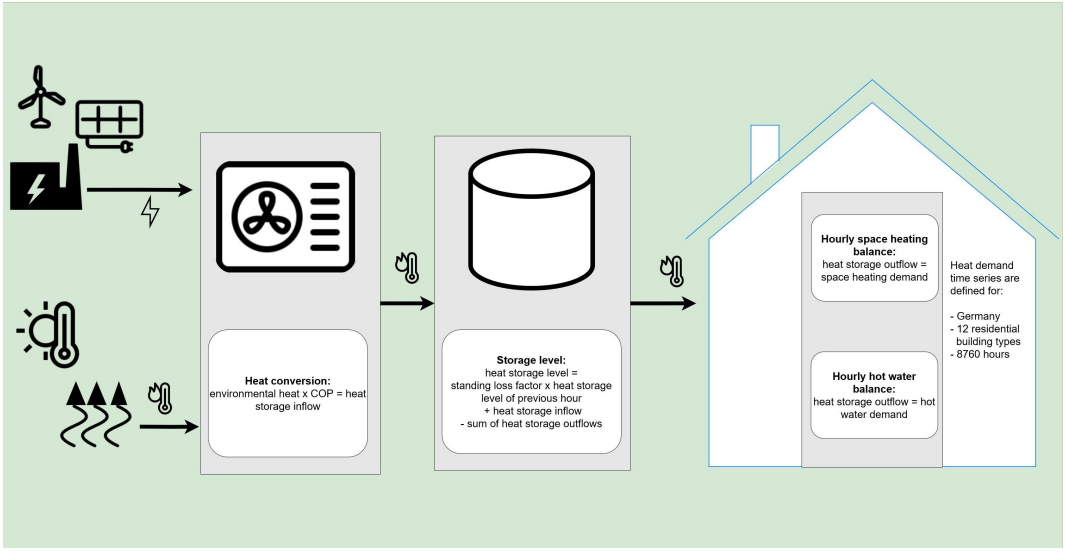
Figure: Source: `https://openenergytracker.org/en/`

Power sector model

DIETER (Dispatch and Investment Evaluation Tool with Endogenous Renewables)

- Capacity expansion model
- System cost minimization
- Linear program
- Full year in hourly resolution
- Implementation in GAMS and Python
- Open source: `https://gitlab.com/diw-evu/dieter_public`
- Sector coupling: e-mobility, hydrogen, **heating**

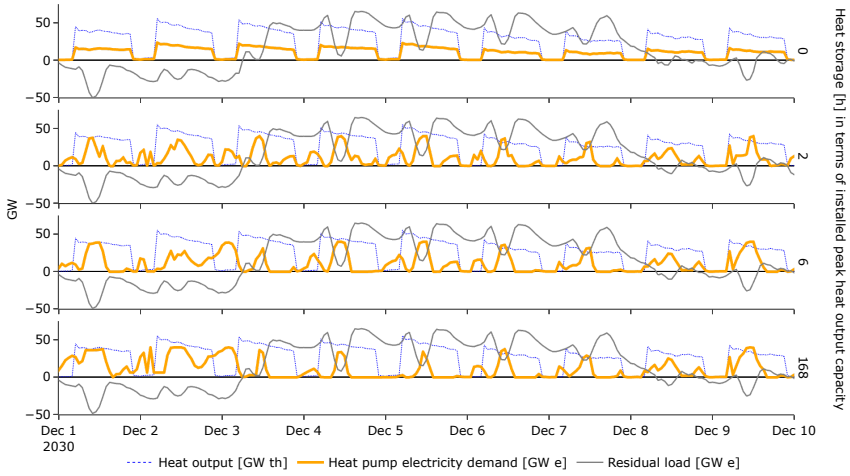
Heating module



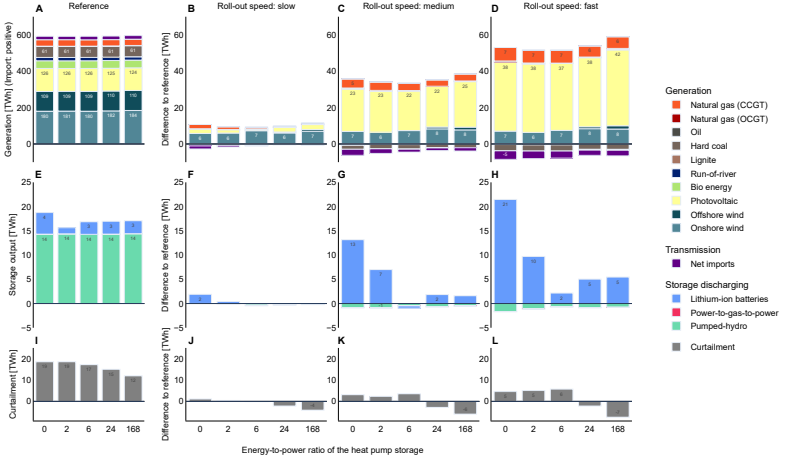
Data & Assumptions

- Heat pump roll-outs: Reference (1.7 Mio), Slow (3.9 Mio), Mid (6.5 Mio), Fast (7.5 Mio)
- Heat storage durations: 0, 2, 6, 24, 168 hours
- Germany (Capacity expansion + dispatch, with heating), Austria, Belgium, Switzerland, Czech Republic, Denmark, France, Luxembourg, Italy, Netherlands, Poland (Dispatch only, no heating)
- 2030 in hourly resolution
- 80 % renewable target in Germany (100 % for heating, yearly balance)
- Load data and capacity bounds: Open Power System Data [3] (`https://open-power-system-data.org/`) and German NDP 2030 [1] for Germany, Ten-Year NDP 2020 [2] for other countries

Results: Exemplary electricity draw of heat pumps

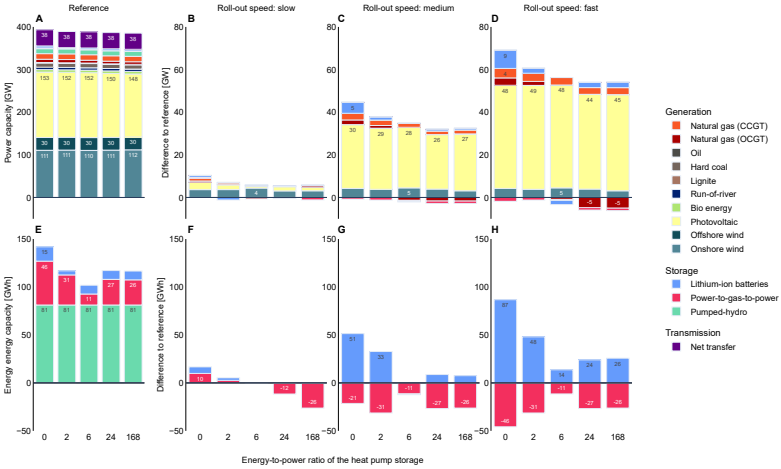


Results: Yearly electricity generation



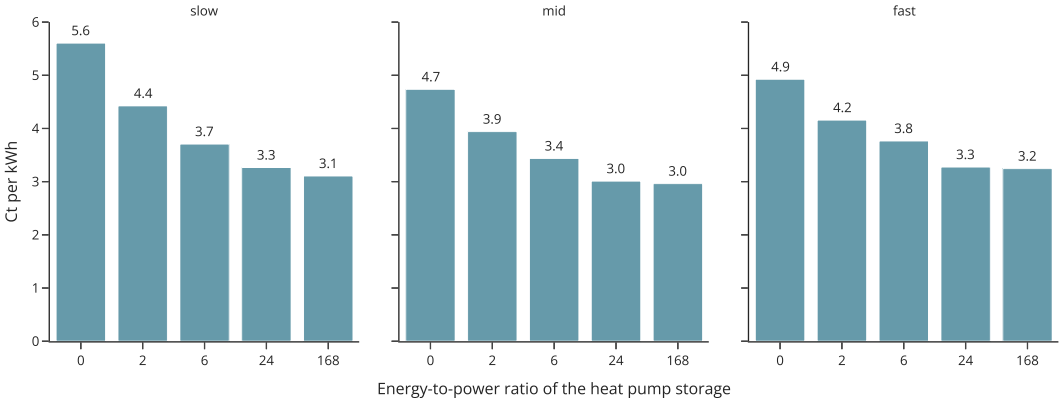
Absolute values in the reference scenarios (Panels A & E) and changes due to heat pump roll-out and heat storage sizes.

Results: Capacity investments



Absolute values in the reference scenarios (Panels A & E) and changes due to heat pump roll-out and heat storage sizes.

Results: Additional system costs per heating energy provided

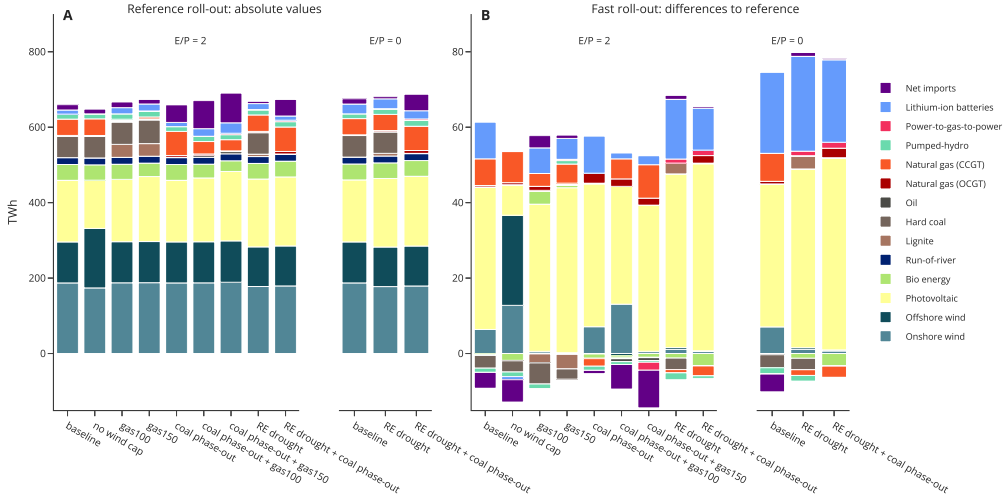


Sensitivities

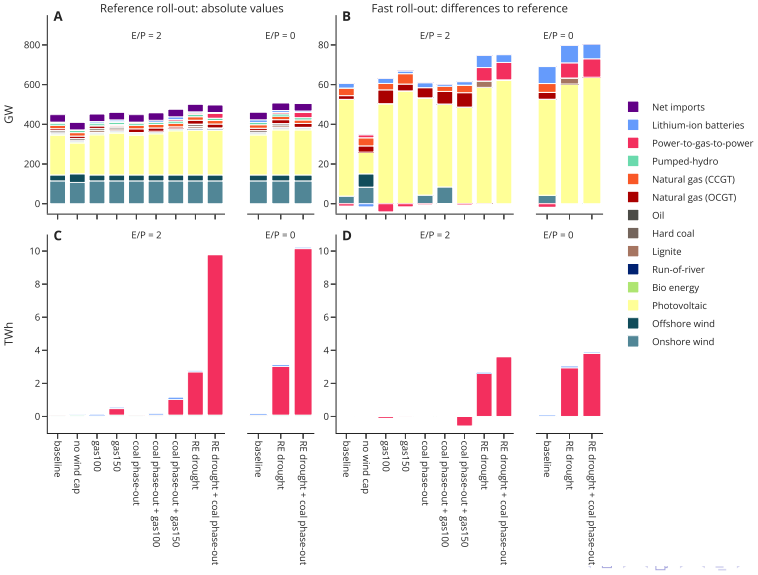
Table: Overview of sensitivity analyses

	Name	**Description**
1	*no wind cap*	No upper capacity on capacity on- and offshore wind investment in Germany.
2	*gas100*	Natural gas price set to 100 EUR/MWh.
3	*gas150*	Natural gas price set to 150 EUR/MWh.
4	*coal phase-out*	No coal-fired plants allowed to operate by 2030.
5	*coal phase-out + gas100*	Combination of 2 and 4.
6	*coal phase-out + gas150*	Combination of 3 and 4.
7	*RE drought*	All renewable energy capacity factors in one winter week are set to zero.
8	*RE drought + coal phase-out*	Combination of 4 and 7.

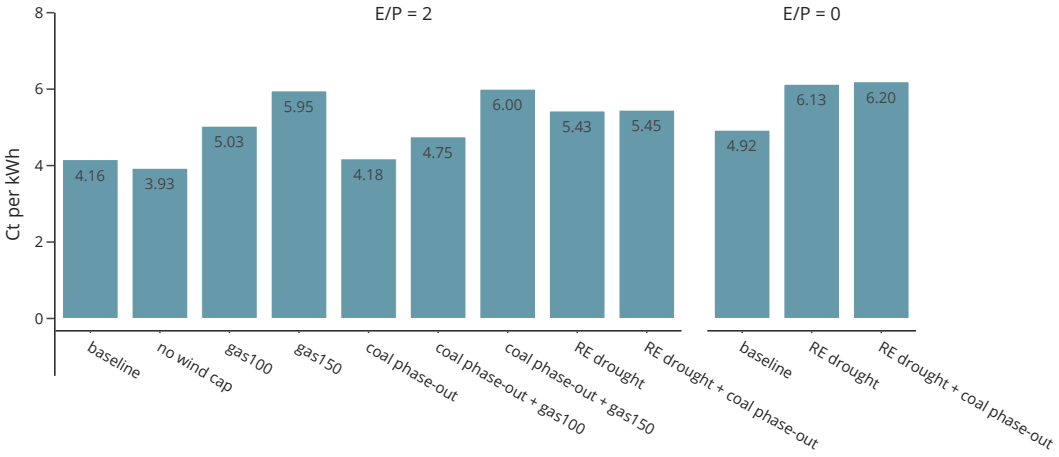
Sensitivities: Yearly electricity generation



Sensitivities: Capacity investments



Sensitivities: Additional system costs per heating energy provided



Conclusions

- Ambitious heat pump roll-out requires additional solar PV capacity in Germany
- Seasonal mismatch of PV generation and heat demand can be mitigated via the European interconnection.
- Results are driven by the renewable target in the heating sector and the expansion limit of wind power
- The need for additional firm capacities is limited
- Already small buffer heat storage enables heat pumps to align electricity consumption better with the residual load.
- Thermal storage reduces the need for electricity storage
- Flexible heat pumps have power sector benefits, but the effects of inflexible heat pumps are also manageable.

Thank you for your attention.

Working paper

Flexible heat pumps: must-have or nice to have in a power sector with renewables?
Alexander Roth, Dana Kirchem, Carlos Gaete-Morales, Wolf-Peter Schill (2023)
`http://arxiv.org/abs/2307.12918`

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KOPERNIKUS Ariadne PROJEKTE
Die Zukunft unserer Energie

Federal Ministry of Education and Research

References

[1] Bundesnetzagentur (2018). Genehmigung des Szenariorahmens 2019-2030. Technical report.

[2] ENTSOE (2018). TYNDP 2018. Project Sheets. Technical report.

[3] Wiese, F., Schlecht, I., Bunke, W.-D., Gerbaulet, C., Hirth, L., Jahn, M., Kunz, F., Lorenz, C., Mühlenpfordt, J., Reimann, J., and Schill, W.-P. (2019). Open Power System Data – Frictionless data for electricity system modelling. *Applied Energy*, 236:401–409.

Capacity assumptions

Table: Assumptions on capacity bounds [in GW]

Country	Germany		Austria	Belgium	Switzerland	Czech Republic	Denmark	France	Luxembourg	Italy	Netherlands	Poland
Technology	**Lower**	**Upper**	**fixed capacities**									
Run-of-river hydro	5.60	5.60	6.14	0.15	4.11	0.40	0	13.64	0.05	5.64	0.05	0.54
Nuclear	0	0	0	0	1.19	4.04	0	58.21	0	0	0.49	0
Lignite	0	0 / 9.3	0	0	0	3.89	0	0	0	0	0	6.32
Hard coal	0	0 / 9.8	0	0.62	0	0.37	0.77	0	0	0	0	9.88
Natural gas (CCGT)	0	17.60	2.82	7.61	0	1.35	0	6.55	0	38.67	8.65	5.00
Natural gas (OCGT)	0	19.60	0.59	1.08	0	0	0	0.88	0	5.40	0.64	0
Oil	0	1.20	0.17	0	0	0.01	0	0	0	0	0	0
Other	0	0	0.95	1.32	0.89	1.23	0.24	1.87	0.03	5.99	3.77	6.82
Bio energy	6.00	6.00	0.60	0.21	1.20	1.06	0.67	2.56	0.05	4.93	0.54	1.41
Onshore wind	56.00	115 / +Inf	10.00	5.93	1.25	3.00	5.48	44.11	0.35	19.05	8.30	11.28
Offshore wind	7.77	30 / +Inf	0	4.30	0	0	4.78	3.00	0	0.60	6.72	0.90
Solar PV	59.00	+Inf	15.00	13.92	11.00	10.50	4.75	42.63	0.25	49.33	15.46	12.19
Lithium-ion batteries												
... power in/out	0	+Inf	0.53	0.90	0.39	0.50	0.44	3.10	0.06	1.56	0.75	0.25
... energy [GWh]	0	+Inf	0.53	0.90	0.39	0.50	0.44	3.10	0.06	1.56	0.75	0.25
Power-to-gas-to-power												
... power in/out	0	+Inf	0	0	0	0	0	0	0	0	0	0
... energy [GWh]	0	+Inf	0	0	0	0	0	0	0	0	0	0
Pumped hydro storage												
... power in/out	11.60	11.60	5.70	1.40	3.99	1.16	0	3.50	1.31	11.90	0	1.50
... energy [GWh]	81.20	81.20	39.88	9.77	27.92	8.11	0	24.50	9.17	83.29	0	10.51
Reservoirs												
... power out	2.94	2.94	7.83	0	8.15	1.17	0	10.09	0	13.07	0	0.36
... energy [TWh]	0	0	15.66	0	16.30	2.34	0	20.19	0	26.13	0	0.73
Electrolysis	10	10	0	0	0	0	0	0	0	0	0	0

Cost and technology assumptions

Table: Electricity storage

Technology	Interest rates	Lifetime [years]	Availability	Overnight costs energy [1000 EUR]	Overnight costs charging power [1000 EUR]	Overnight costs discharging power [1000 EUR]	Efficiency charging	Efficiency discharging	Marginal costs charging [EUR]	Marginal costs discharging [EUR]
Li-ion battery		20	0.98	142	80	80	0.96	0.96	0.5	0.5
Pumped hydro	0.04	80	0.89	10	550	550	0.97	0.91	0.5	0.5
Power-to-gas-to-power		25	0.95	2	550	435	0.73	0.42	0.5	0.5

Table: Electricity generation

Technology	Interest rates	Lifetime [years]	Availability	Overnight costs [1000 EUR]	Fixed costs [1000 EUR]	Efficiency	Carbon content [t/MWh]	Fuel costs [EUR/MWh]
Run-of-river	0.04	50	1.00	3,000	30	0.90	0.00	0
Nuclear		40	0.91	6,000	30	0.34	0.00	3.4
Lignite		35	0.95	1,500	30	0.38	0.40	5.5
Hard coal		35	0.96	1,300	30	0.43	0.34	8.3
Closed-cycle gas turbine		25	0.96	800	20	0.54	0.20	30.0
Open-cycle gas turbine		25	0.95	400	15	0.40	0.20	30.0
Oil		25	0.90	400	6.7	0.35	0.27	29.0
Other		30	0.90	1,500	30	0.35	0.35	18.1
Bioenergy		30	1.00	1,951	100	0.49	0.00	32.5
Wind onshore		25	1.00	1,182	35	1.00	0.00	0
Wind offshore		25	1.00	2,506	100	1.00	0.00	0
Solar photovoltaic		25	1.00	400	25	1.00	0.00	0

Green Hydrogen

- Hydrogen demand $h2^{demand}$ of 28 TWh has to be covered by electrolysis over the course of a year (Equation 1)
- Temporally flexible hydrogen demand (unlimited hydrogen storage)
- Investments into electrolysis capacity are modeled endogenously (Equation 3)

$$h2^{demand} = \sum^{h} H2_h^{prod} \tag{1}$$

$$H2_h^{prod} = H2_h^{elec} \times 0.71 \tag{2}$$

$$H2_h^{elec} \leq INV^{H2} \tag{3}$$