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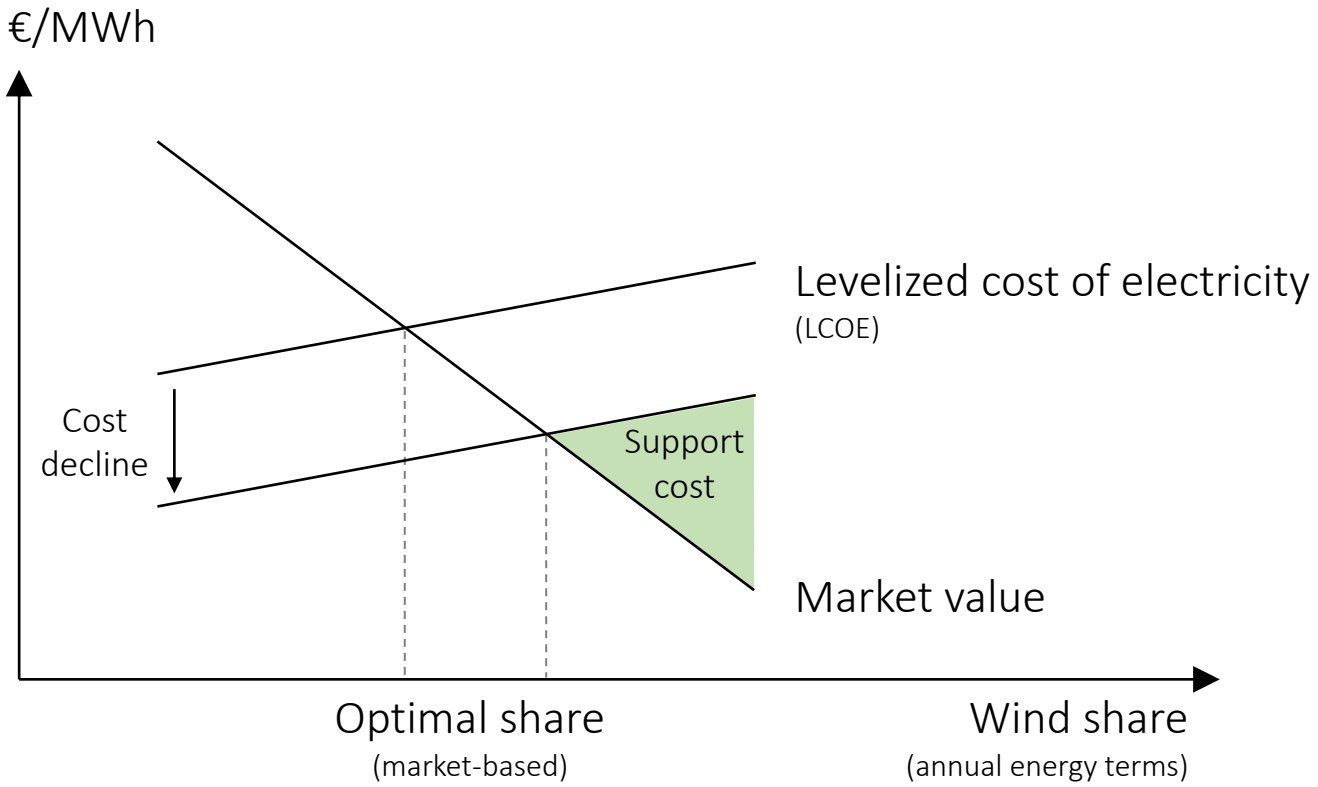
How flexible electricity demand stabilizes wind and solar market values: The case of hydrogen electrolyzers

(link to published working paper)

Oliver Ruhnau
ruhnau@hertie-school.org

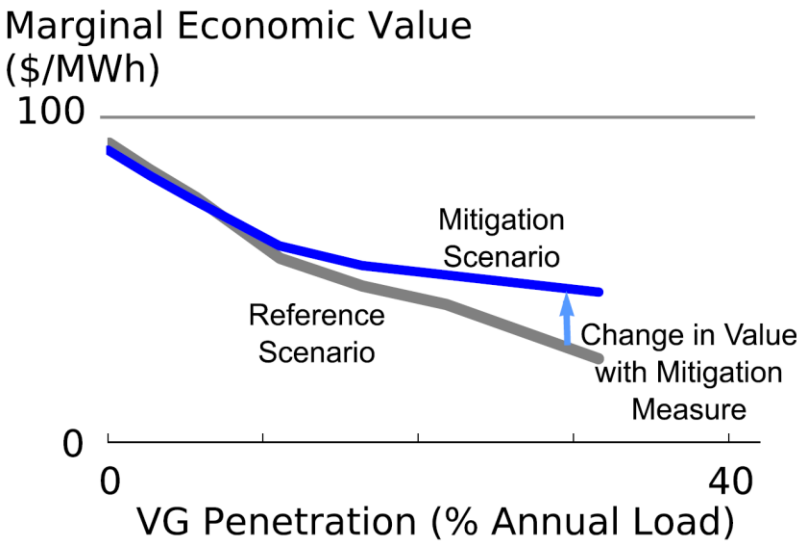
Hertie School

Market integration of variable renewable energy sources

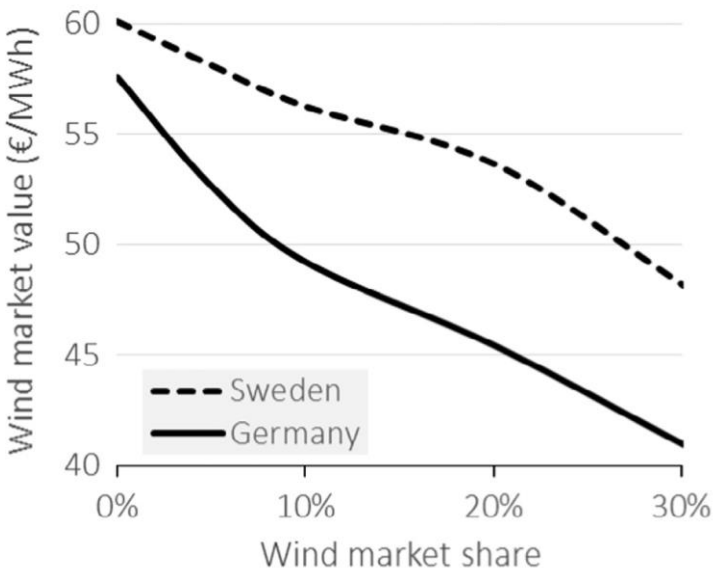


- Can renewables earn back their fixed costs on the free market?
- Will there be an ongoing need for renewable support schemes?

Existing literature on mitigating the value decline



Mills and Wiser (2015)



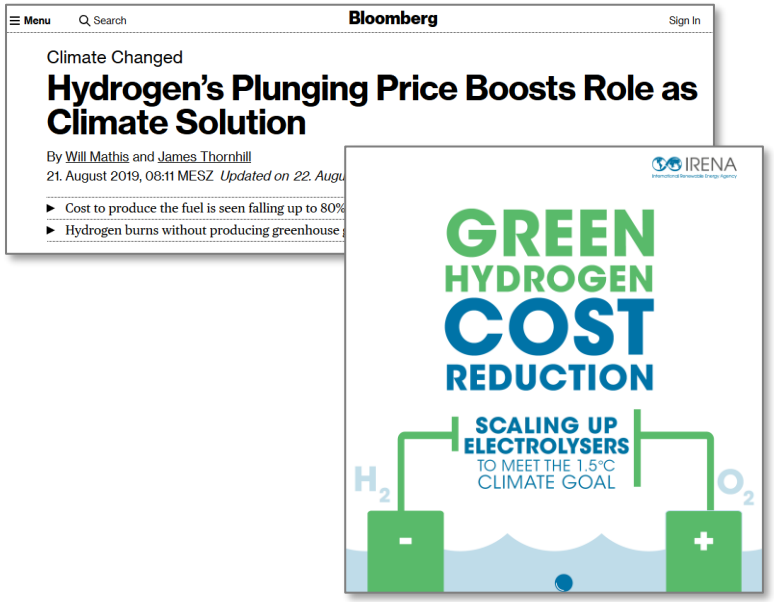
Hirth (2016)

- Known options to slow down declining market values: storage, transmission, "low wind speed" turbines, …
- Nothing has yet been found that can permanently stop the decline

Green hydrogen

Political attention

Costs may also decline

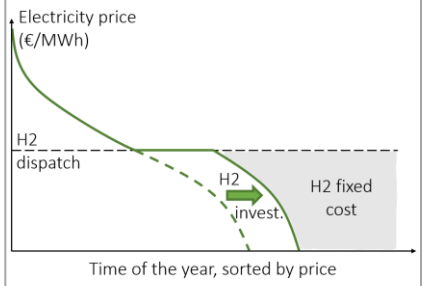


- So far: competitiveness of green hydrogen as a function of renewables
- This study: competitiveness of renewables as a function of green hydrogen

Agenda

Research question:
How can flexible hydrogen electrolyzers stabilize renewable market values?

Theoretical framework

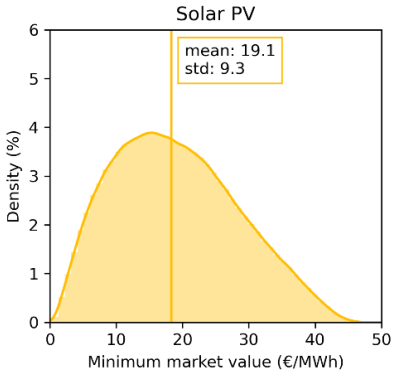


Analytical formula

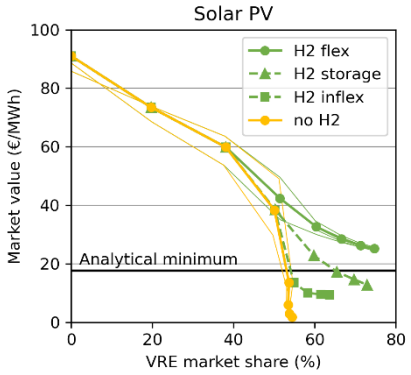
In the long-term equilibrium:

$$value_{RE,min} = f(H2)$$

Monte Carlo analysis

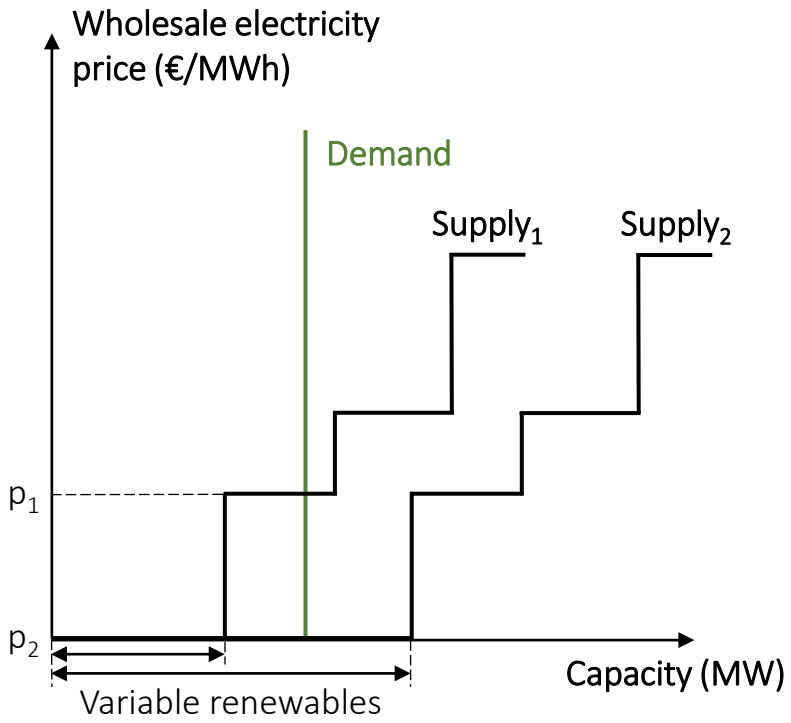


Electricity market model



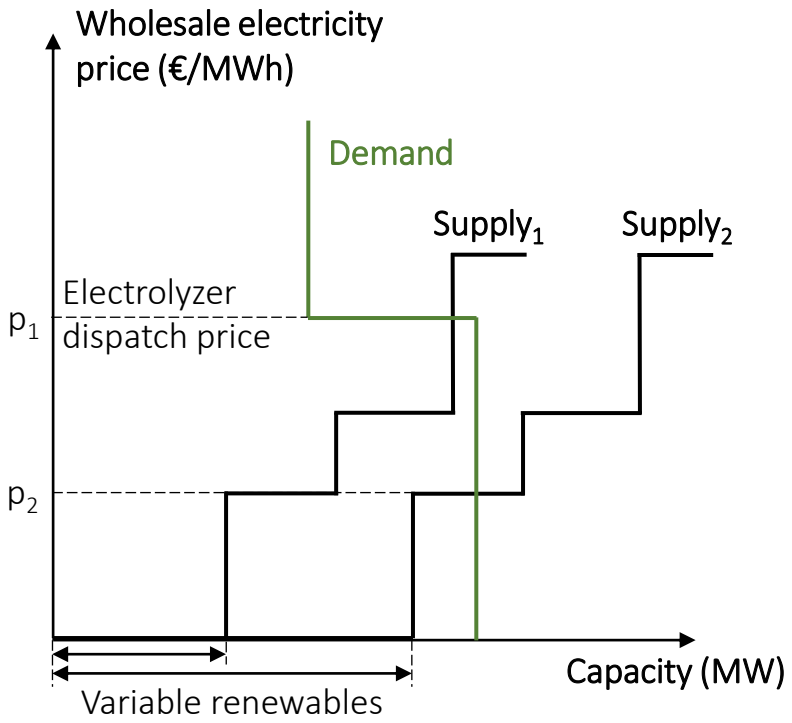
Policy implications and conclusions

Merit order model with renewables



- Power prices equal the variable costs of the marginal generator – except for scarcity prices.
- When available, variable renewables depress market prices – possibly to zero.

Merit order model with renewables *and electrolyzers*



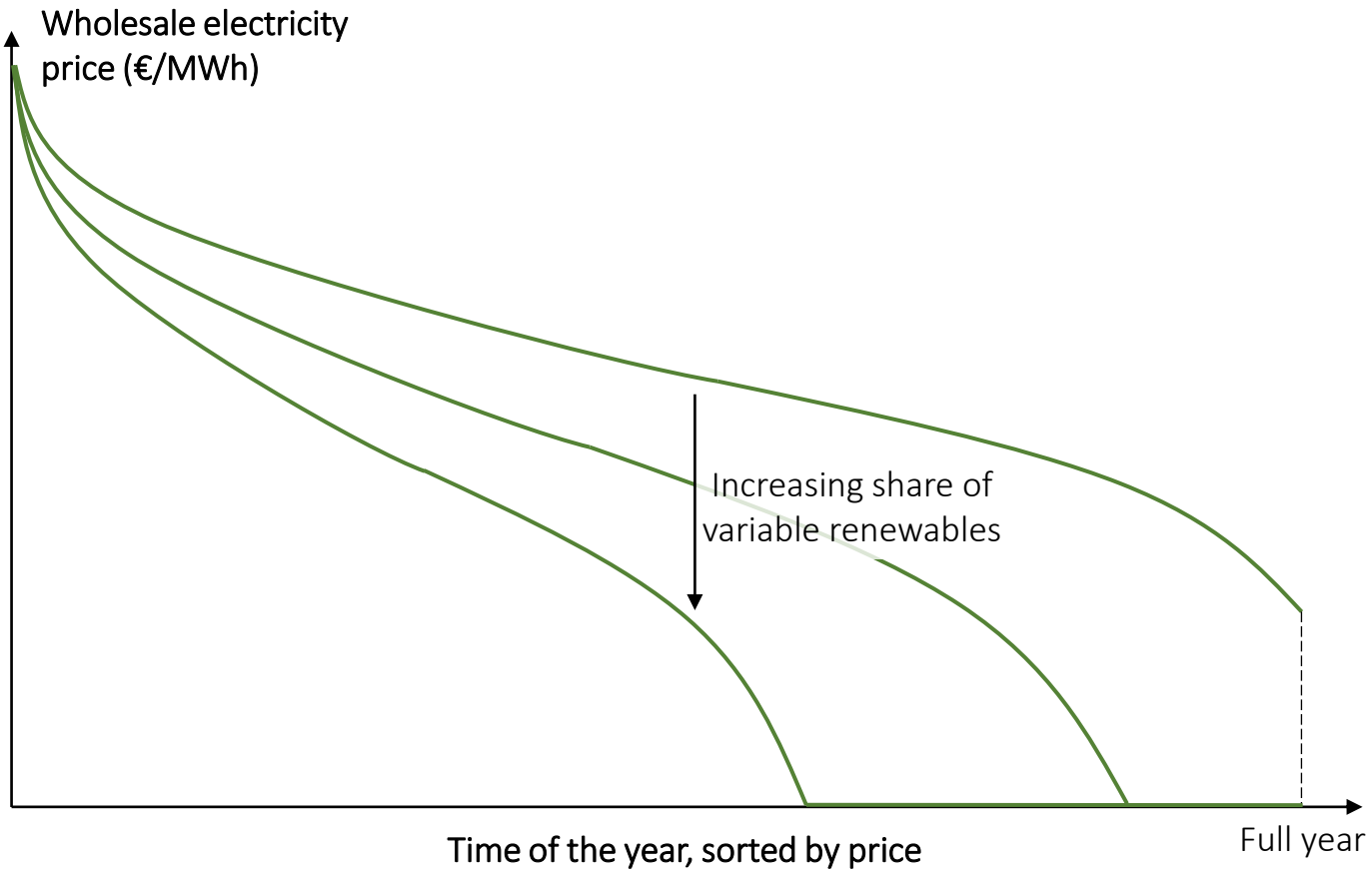
Simplification:
constant hydrogen price

$$P_{dispatch} = \left(P_{H2} - C_{OPEX,var}\right) \cdot \eta - C_{sup}$$

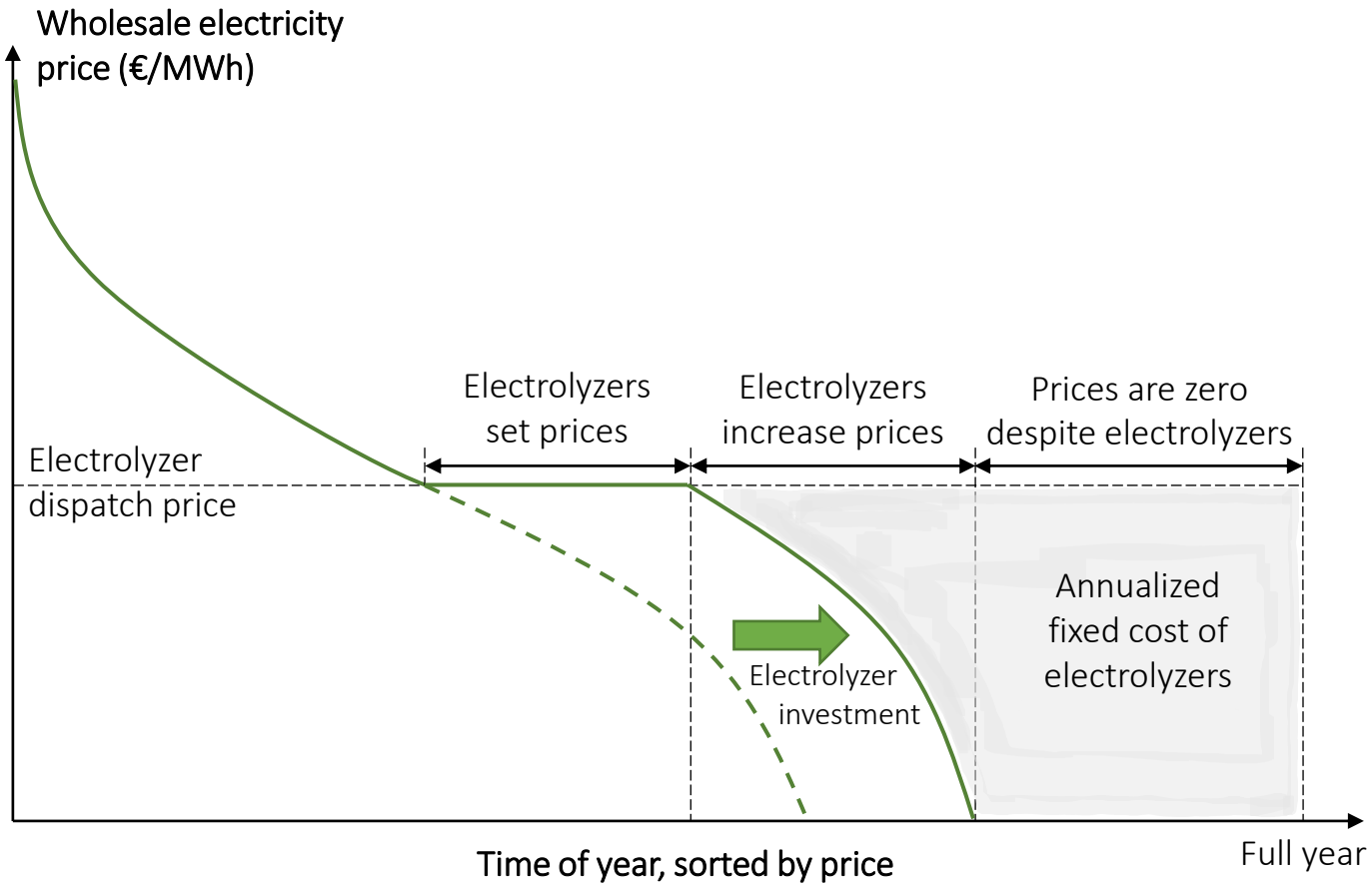
- Dispatch if electricity price is below product revenues (for hydrogen) minus variable cost per MWh_{el}.
- Electrolyzers can increase or even set the electricity price.

$P_{dispatch}$	Dispatch price (€/MWh_{el})
P_{H2}	Hydrogen price (€/kg_{H2})
$C_{OPEX,var}$	Variable operational cost (€/kg_{H2})
η	Electrolyzer efficiency (kg_{H2}/€/MWh_{el})
C_{sup}	Demand supplement on wholesale electricity prices (€/MWh_{el})

Price duration curve with renewables



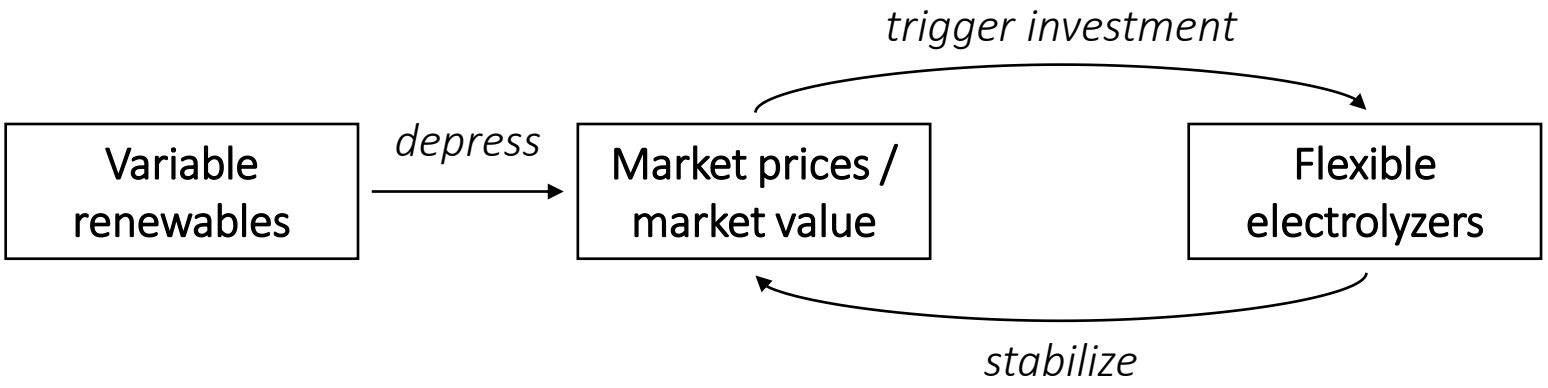
Price duration curve with renewables *and electrolyzers*



Electrolyzers will be installed until the annual margin equals annual fixed cost.

The argument

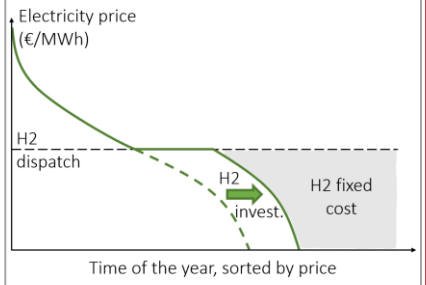
Flexible electrolyzers balance the value decline of variable renewables:



Agenda

Research question:
How can flexible hydrogen electrolyzers stabilize renewable market values?

Theoretical framework



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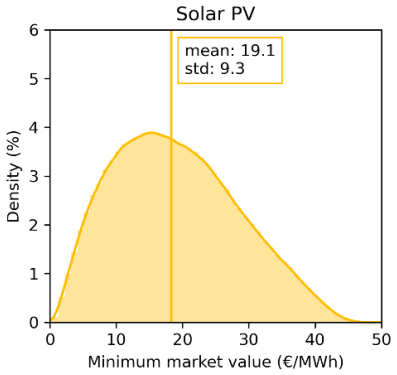

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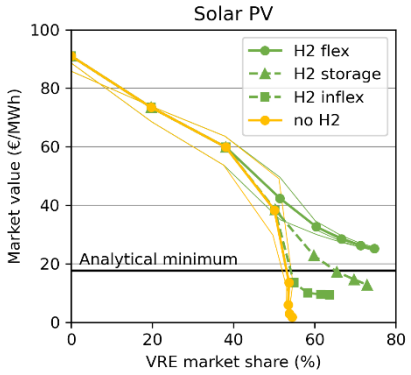
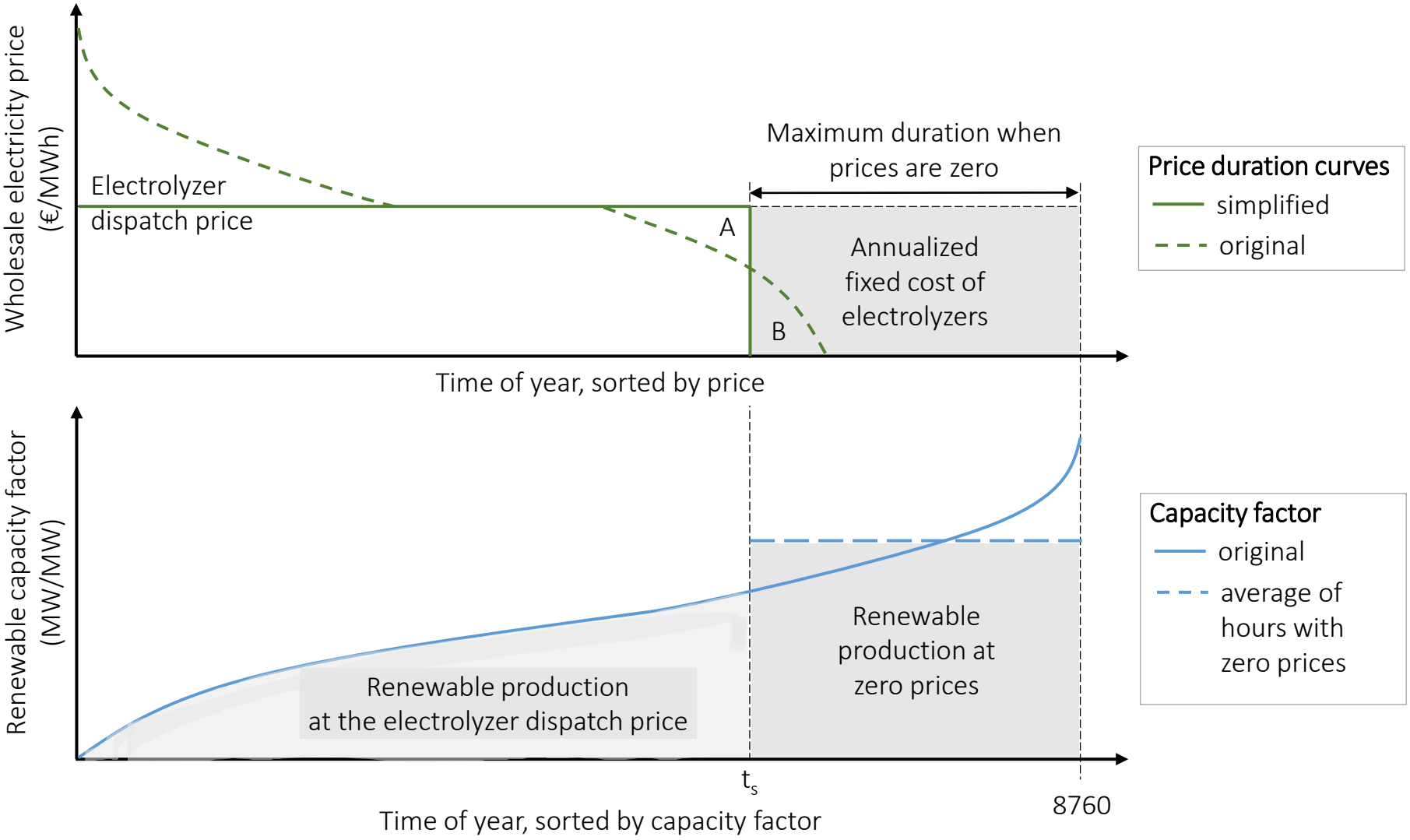


Policy implications and conclusions

Two conservative assumptions



Result: an analytical formulat for the minimum market value of renewables

$$value_{RE,min} = P_{dispatch} - \frac{\overline{RE_Z}}{\overline{RE}} \cdot \frac{AFC}{8760}$$

$P_{dispatch}$	Dispatch price of electrolyzers (€/MWh$_{el}$)
AFC	Annualized fixed cost of electroylzers (€/MWel)
$\overline{RE}$	Annual average renewable capacity factor (1)
$\overline{RE_Z}$	Average renewable capacity factor during zero-price hours (1)

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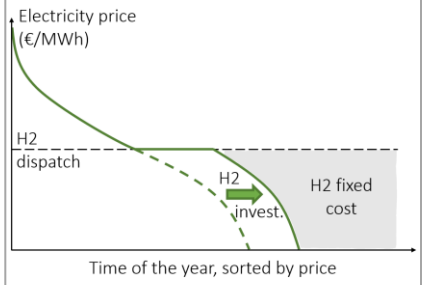

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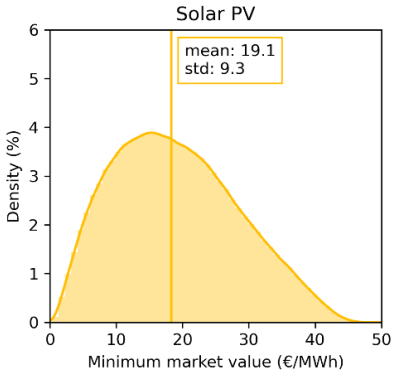

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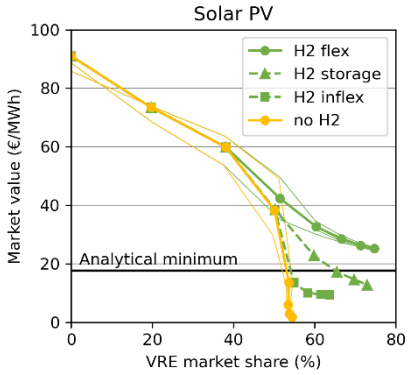


Policy implications and conclusions

Input: 2050 scenarios

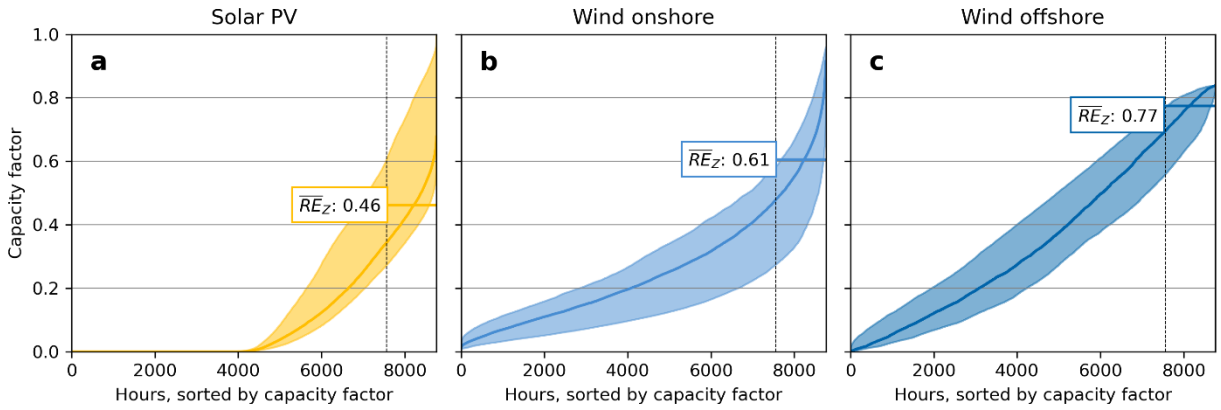
Parameter	Unit	Sensitivity range	Source(s)
General			
Interest rate, i	%/a	4…10	
Hydrogen price, P_{H2}	€/kg$_{H2}$	1.5…2.5	19,21
Hydrogen electrolyzers			
CAPEX, C_{CAPEX}	€/kW$_{el}$	100…800	17–19
Fixed OPEX, $c_{OPEX,fix}$	% of CAPEX	2	22
Variable OPEX, $C_{OPEX,var}$	€/kg$_{H2}$	0.1	21
Lifetime, T	a	20…30	21,22
Efficiency, η	kg$_{H2}$/MWh$_{el}$	20…22	19

Monte Carlo: uniform distribution within the sensitivity range

Demand supplement on wholesale electricity prices: €0 MWh^{-1}

Monte Carlo: random selection

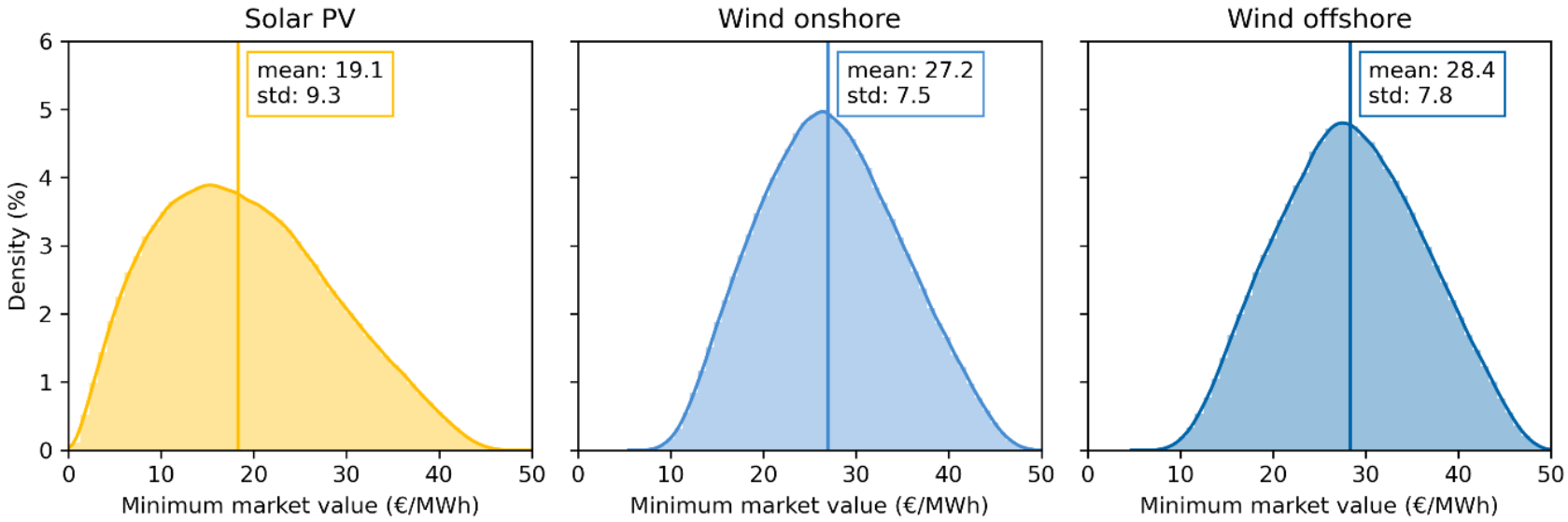
Renewable profiles



Year 2050, 34 European countries, 10 weather years (Source: METIS Project)

Results: density functions

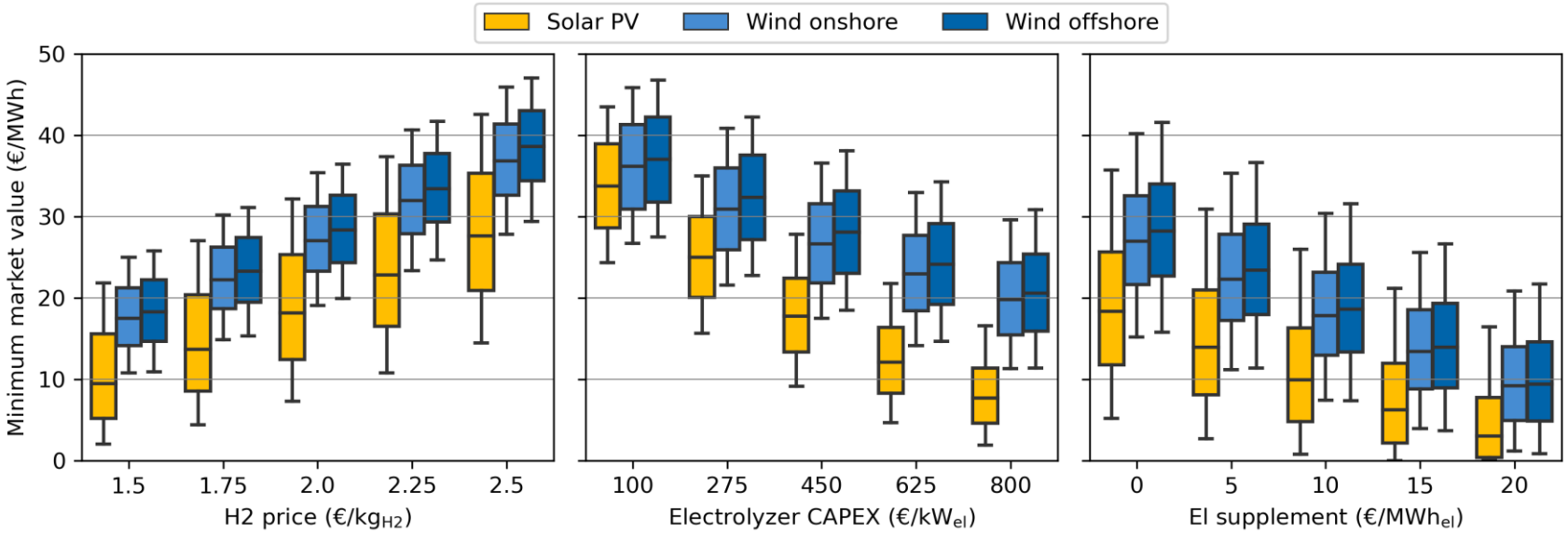
N = 1m each



- Estimates are significantly above zero
- For Solar PV and onshore wind power, the minimum market values are in the range of projected levelized cost (€14–50 MWh^{-1} and €20–30 MWh^{-1})
- For offshore wind power, minimum market values are slightly below cost (€30–70 MWh^{-1})

Results: sensitivity

N = 100k each



Minimum market values…

…increase with hydrogen prices

…decrease with electrolyzers' CAPEX

…decrease with the demand supplement on wholesale electricity prices

Simplistic approach

Strengths

- Understanding the competitiveness of renewables as a function of flexible hydrogen electrolysis
- Agnostic about many power system parameters (demand, supply, storage); hence results can easily be generalized

Limitations

- Minimum market value, not the actual market value
- No other flexibility options (in particular, no other flexible demand)
- Constant hydrogen price
- Unrestricted transmission between renewables and electrolyzers
  (neglects tradeoff between transmitting electricity vs. transmitting hydrogen)

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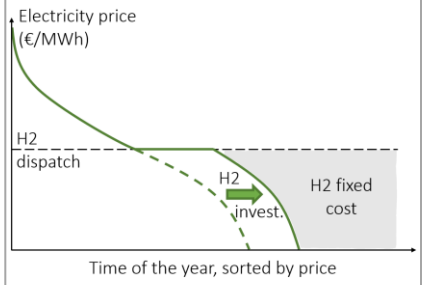
Theoretical framework



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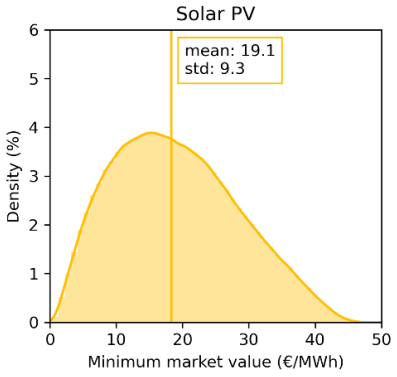

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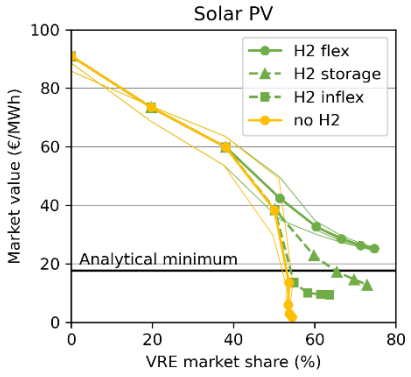


Policy implications and conclusions

Method

Electricity market model EMMA

- Long-term equilibrium: green-field investment + dispatch
- Exogenous wind and solar investment
- New: endogenous electrolyzer investment + dispatch

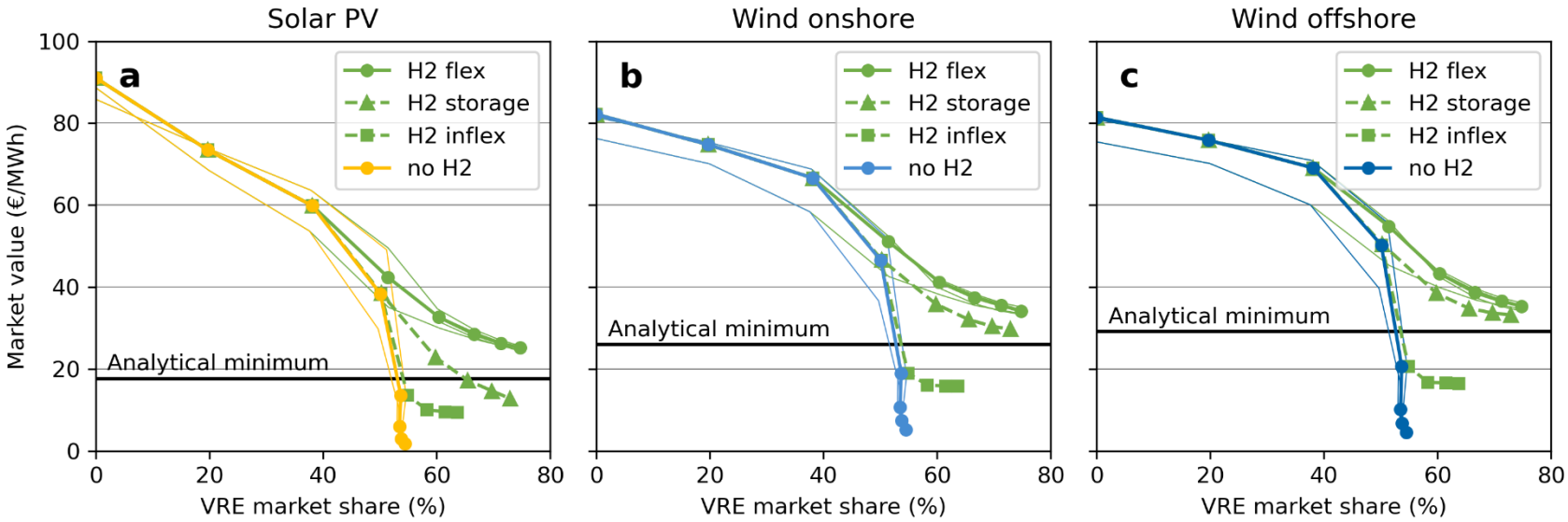
Fixing the uncertain parameters from before

- Center estimates of the hydrogen parameters (2 €/t_{H2}, 450 €/kW_{el})
- Renewable profiles for Germany + 4 neighbors in 2050 (weather year 2010)

Three scenarios

- *H2 flex*: constant hydrogen price (as before) → perfectly flexible electrolyzers
- *H2 storage*: constant hydrogen supply → flexibility comes at the cost of H_2 storage
- *H2 inflex*: constant hydrogen supply, no storage → perfectly inflexible electrolyzers

Results: hydrogen electrolyzers stabilize market values



- *no H2:* market values fall close to zero
- *H2 flex:* market values converge well above the analytical minimum
- *H2 storage:* market values decrease further but they still seem to converge
- *H2 inflex:* significantly lower market values

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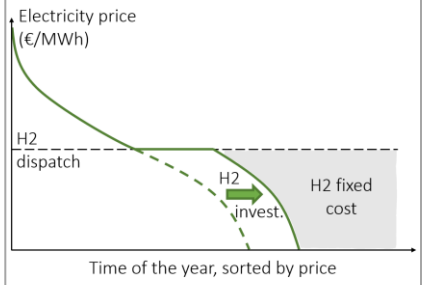

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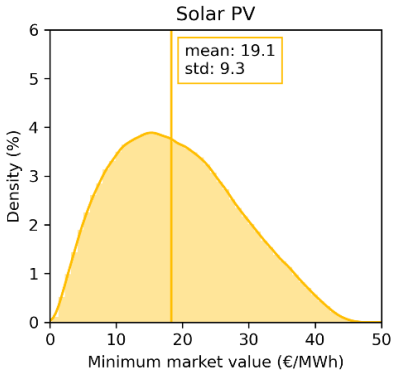

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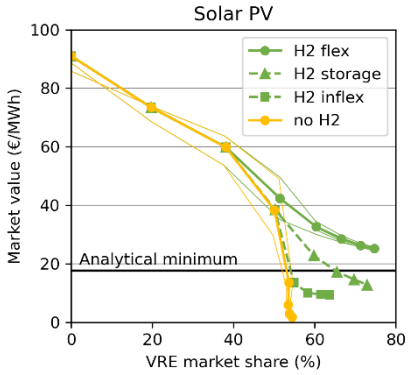
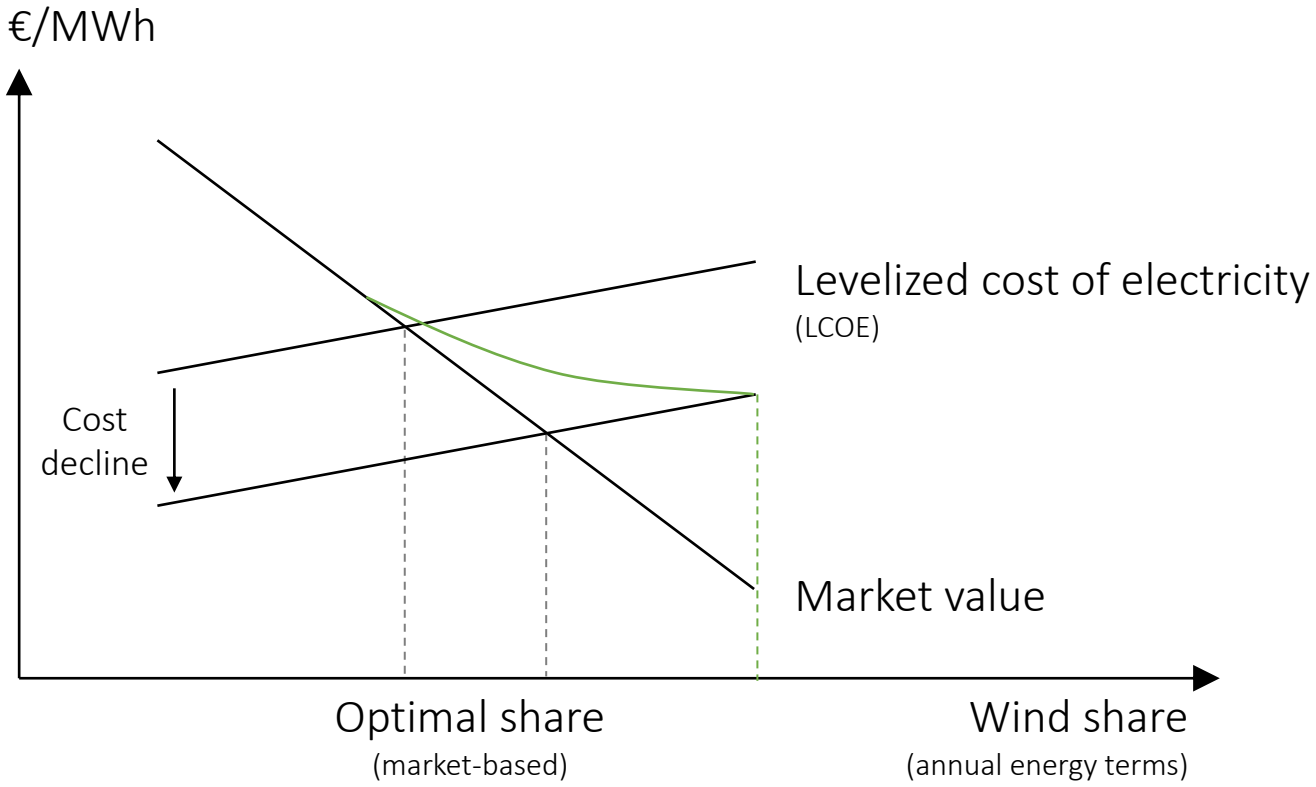


Policy implications and conclusions

Conclusions on market-based renewables



- Stabilizing market values mean higher optimal shares of wind and solar
- These may be reached in competitive markets without direct policy support
- Regulation may still play a role (e.g., supplement on wholesale prices)

Conclusions on flexible electricity demand

Flexible electricity demand is crucial when analyzing variable renewables

Hydrogen electrolysis…

- …may also be feasible on a market basis, triggered by renewables
- …is an ideal type of flexible electricity demand with distinct characteristics

Other flexible electricity demand…

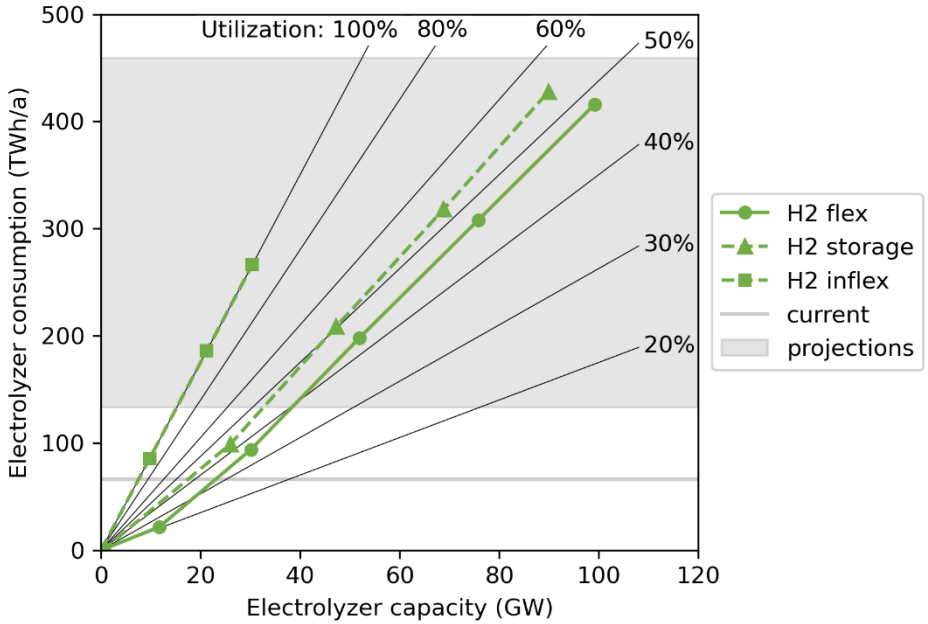
- …may be analyzed using and adjusting the presented framework
- …will compete with hydrogen electrolyzers for using renewable electricity and jointly contribute to stabilizing the market value of renewables

Thank you!

I am looking forward to your questions and feedback now and via ruhnau@hertie-school.org

Link to published working paper

Back-up: details on electrolyzers



- For perspective: today's German hydrogen consumption is 55 TWh; by 2050, the hydrogen demand is estimated to increase to 110-380 TWh (BMWi 2020)
- Flexible operation means low utilization (40-55%) but higher overall hydrogen production