



Value of Power-to-Gas as a Flexibility Option in Integrated Electricity and Hydrogen Markets

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Outline

1. Background

- Role of hydrogen in energy transition policies
- Research questions

2. Value of power-to-gas to provide flexibility

- Measurement of value of flexibility: price-duration curves and welfare effects
- Design of simulation model of integrated electricity and hydrogen markets
- Model calibration and scenario definitions
- Results
 - without external hydrogen demand
 - with large external hydrogen demand

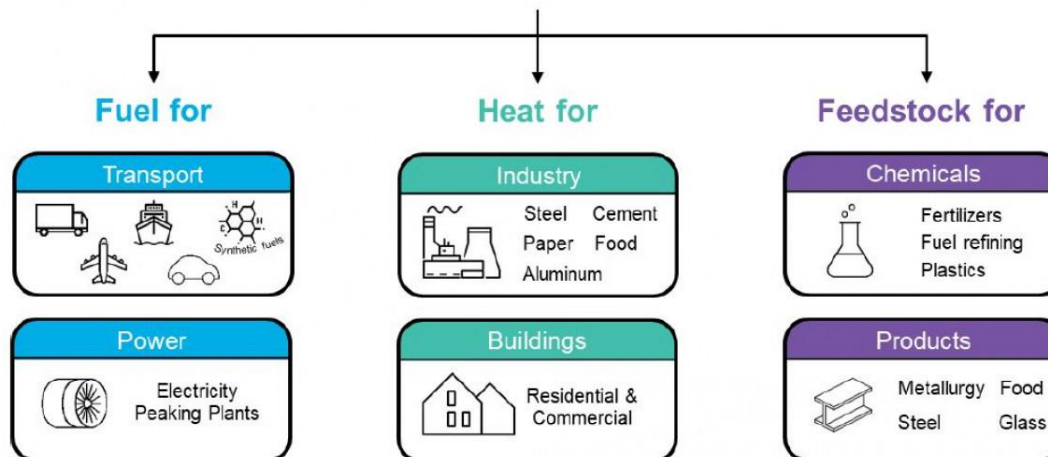
3. International spill-over effects of hydrogen policies

- Method: simulation model of internationally integrated markets
- Model calibration and definition of policy variants
- Results

Background

Many countries, in Europe and elsewhere, have formulated ambitious objectives for hydrogen

Hydrogen is seen as THE alternative energy carrier to reduce carbon emissions, as it can be used in different ways: as fuel, heat and feedstock



Source: BloombergNEF

Hence, Power-to-Gas (PtG) may provide large flexibility to systems to reduce carbon emissions

1. Flexibility to the electricity market (= time flexibility)

- using electricity to make hydrogen when electricity price is low
- generating electricity by using hydrogen when electricity price is high

2. Flexibility to users of energy (= end-use flexibility)

using hydrogen to replace fossil fuels in industry, transport or households

3. Flexibility to countries (= locational flexibility)

importing hydrogen from other countries to realize national climate objectives

Because of the potential benefits, many countries want to promote the PtG business

Research Question

What is the economic value of the flexibility of PtG in a system with high shares of renewable?

Method and outline presentation

In order to answer this question, we developed a simulation model of integrated electricity and hydrogen markets and we use this model to determine the welfare effects

First, we analyse the potential impact of PtG in an electricity market with high shares of renewables without interaction with external demand for hydrogen

Next, we add integration of both markets (i.e. sector coupling of electricity and hydrogen markets) and explore to what extent the end-use flexibility affects the value of time flexibility

Finally, we add more countries with national policies to promote PtG and determine the welfare effects



Value of power-to-gas to provide flexibility

This part of presentation is based on

Li, X., & Mulder, M. (2021).

Value of power-to-gas as a flexibility option in integrated electricity and hydrogen markets.

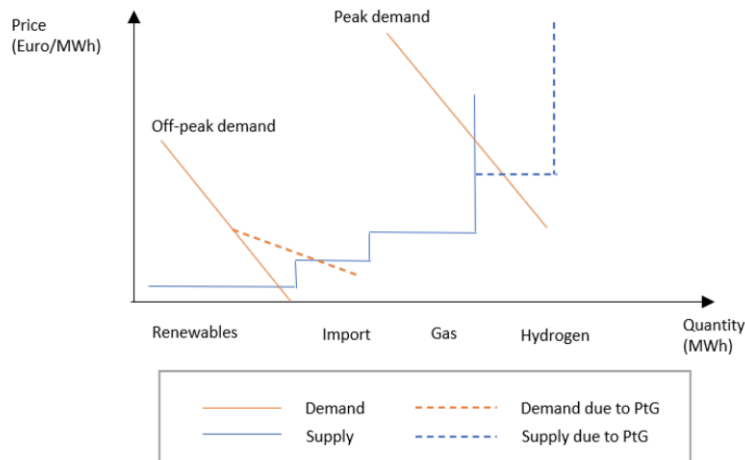
Applied Energy, 304, [117863].

<https://doi.org/10.1016/j.apenergy.2021.117863>

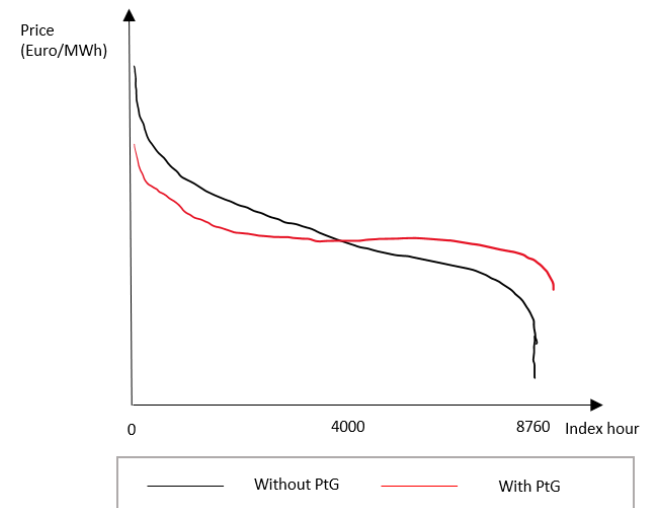
Flexibility offered by PtG to electricity market dominated by renewables

How can PtG provide flexibility to the electricity market?

- during offpeak demand, more demand from PtG
- during peak demand, more supply from PtG



As a result, price duration curve changes



The value of flexibility can be measured by changes in welfare

Change in electricity price affects

- consumer surplus electricity consumers
- producer surplus electricity producers

If integrated with hydrogen market, this change also affects

- consumer surplus hydrogen consumers
- producer surplus hydrogen producers

In order to determine value of flexibility of PtG, we calculate the welfare effects of adding PtG for different groups

The expected welfare effects are related to the expected changes in the price-duration curves

Impact of more renewables on electricity price duration curves

- Much steeper price duration curves

Impact of PtG when there are more renewables

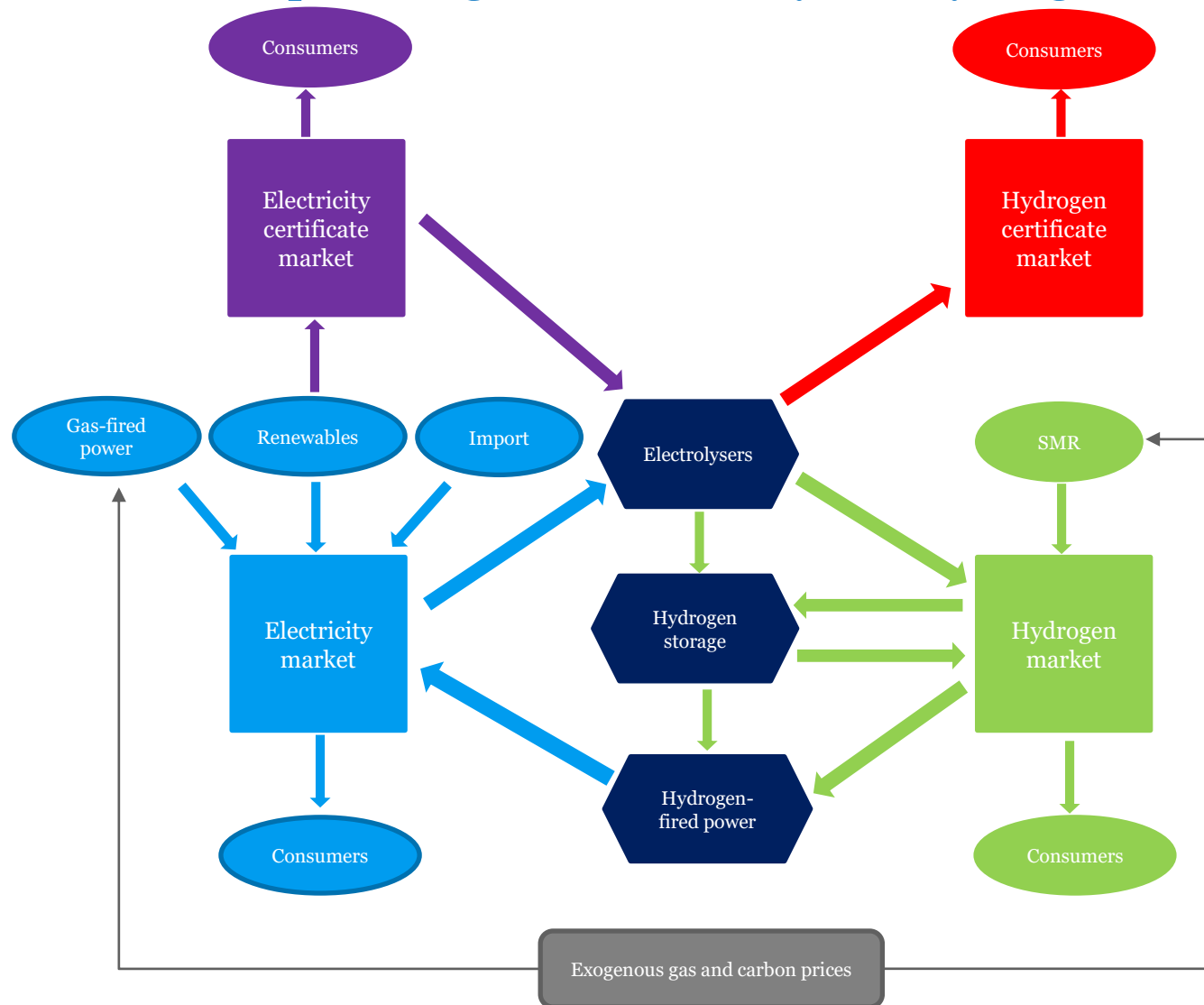
- PtG can flatten the price duration curve

Impact of external hydrogen demand

- PtG can not flatten the price duration curve too much because other sectors compete for hydrogen

We estimate these effects by simulating integrated electricity and hydrogen markets, calibrated on the Dutch market

Setup of integrated electricity and hydrogen market



Modelling of markets by simulating hourly market equilibria

- **Market participants** - producers and consumers in all markets– maximize their profits and utilities to derive their supply and demand functions
- **Equilibrium prices** clear each market at the points where the demand equals the supply
- **Prices of gas and carbon** are exogenous (based on actual values in 2019)
- **Prices of electricity, hydrogen, and certificates** are endogenous

Scenario dimesions:

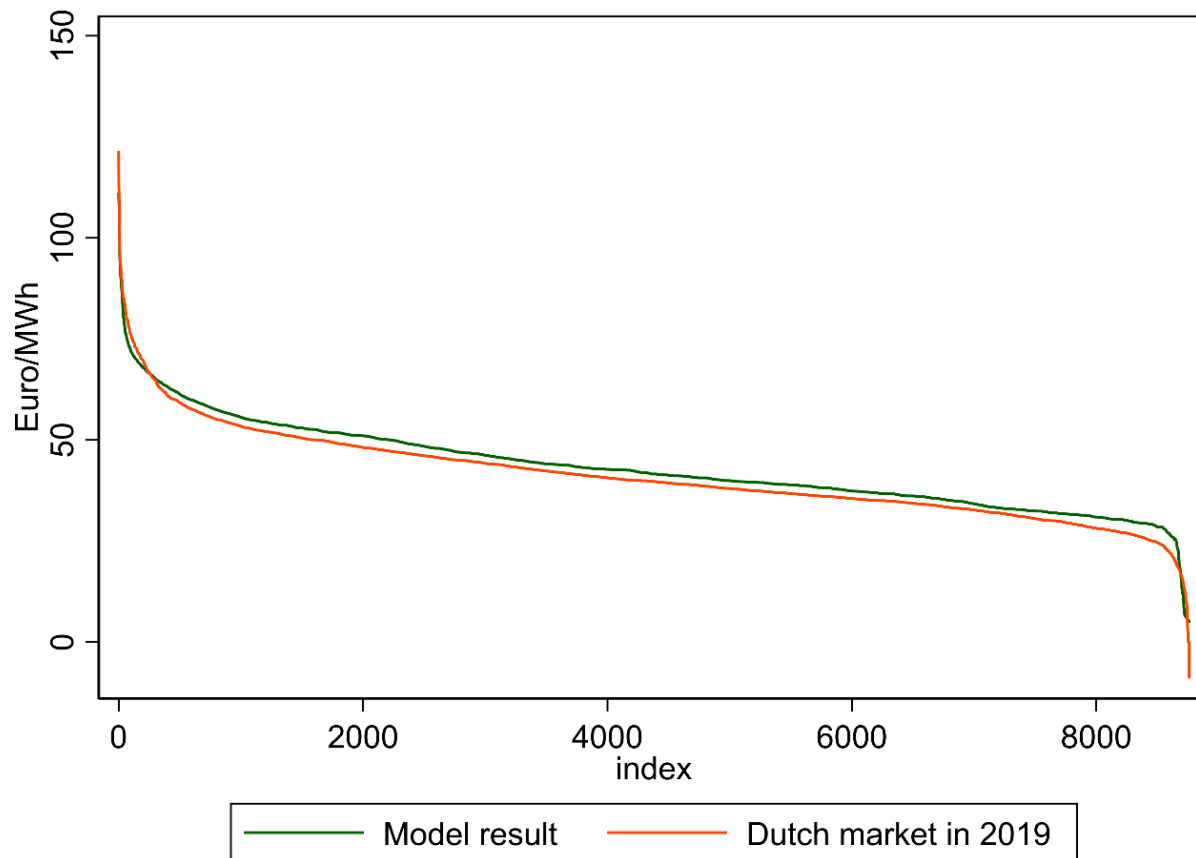
1. PtG capacity and
2. External hydrogen demand

<div>Capacity of PtG</div> <div>Industrial hydrogen demand</div>	No PtG	Low PtG Electr : 1580 MW H2-fired: 1582/2 MW Storage: 1580x20 MW	High PtG 5xlow
No			
Low (250 MWh at price 45 euro/MWh)			
High (2500 MWh at price 45 euro/MWh)			

Model Calibration

Model is calibrated to roughly reflect Dutch power market outcomes

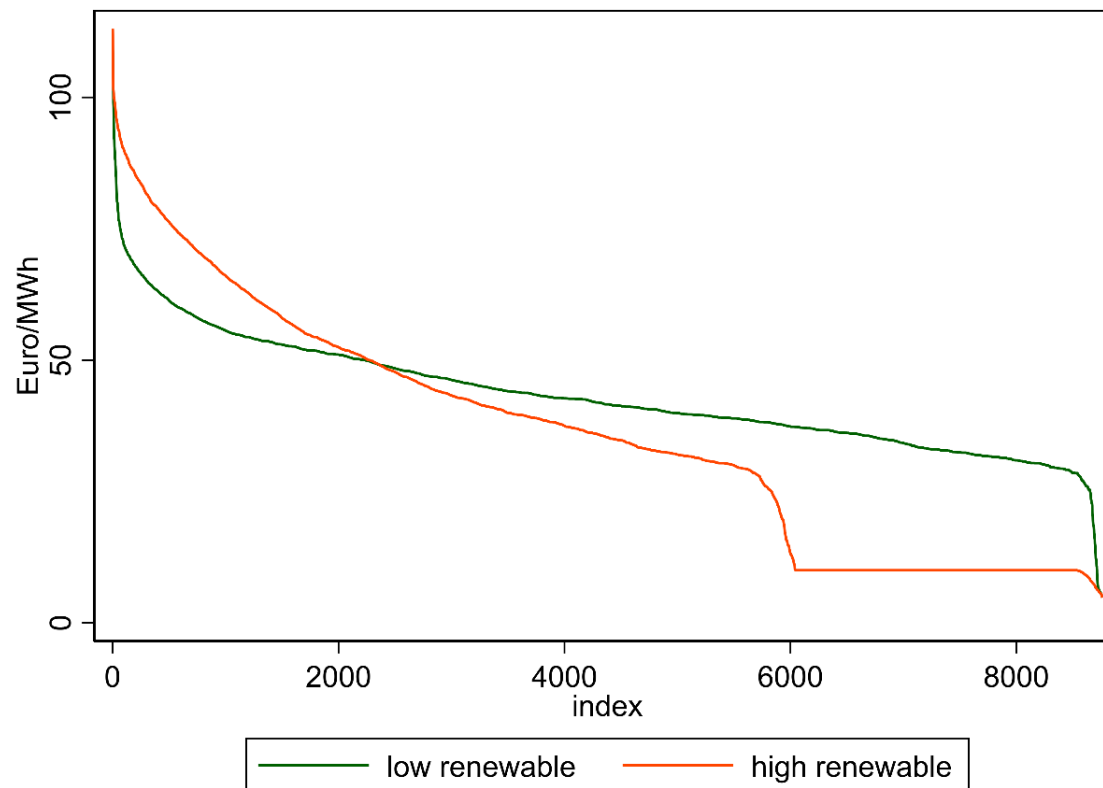
Price duration curves of electricity prices in Netherlands,
Actual in 2019 and model result



Model results:

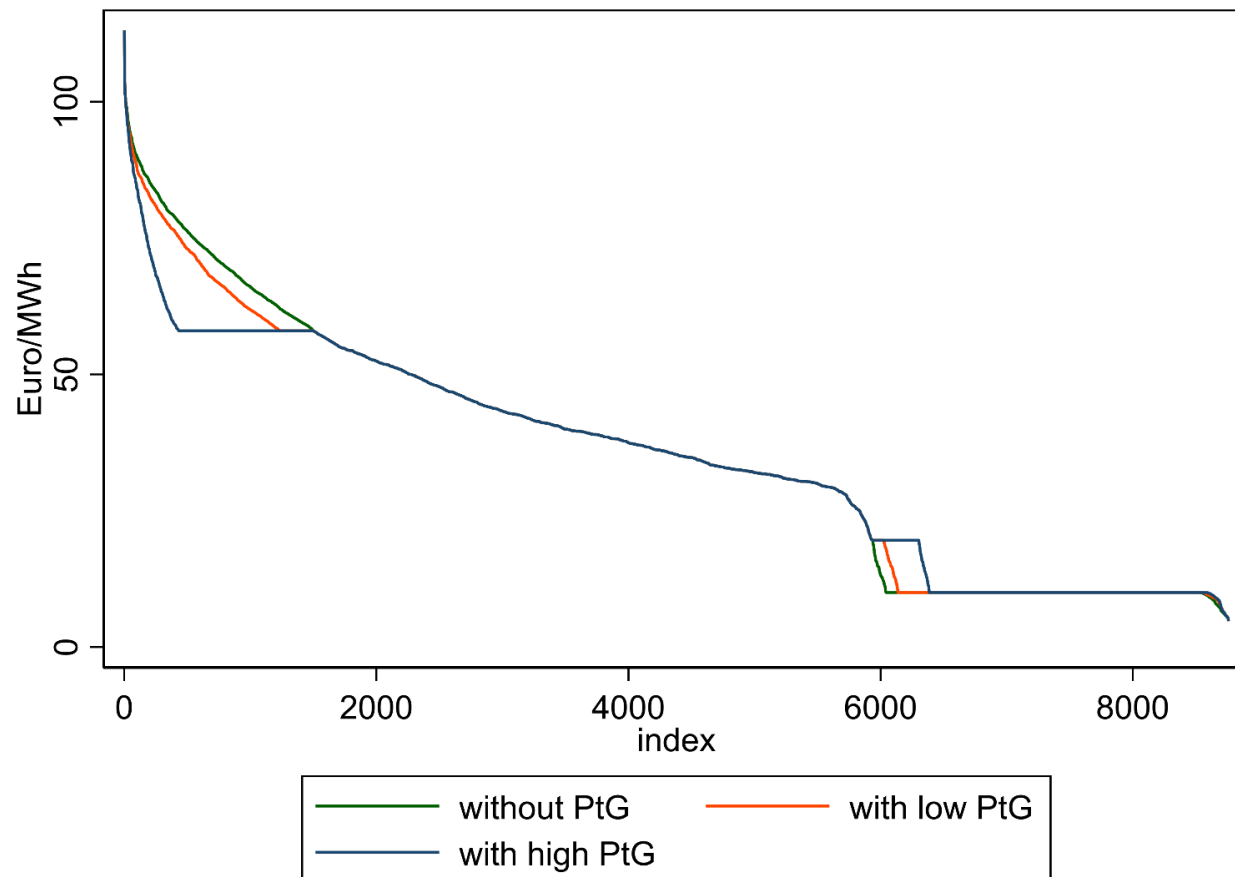
first: what is impact of renewables on price volatility?

Electricity prices are more volatile with high share of renewables, which is reflected by the steeper price-duration curve



Model result: what is impact of PtG on price volatility?

The more PtG capacity, the lower number of hours with very high prices and also less hours with very low prices

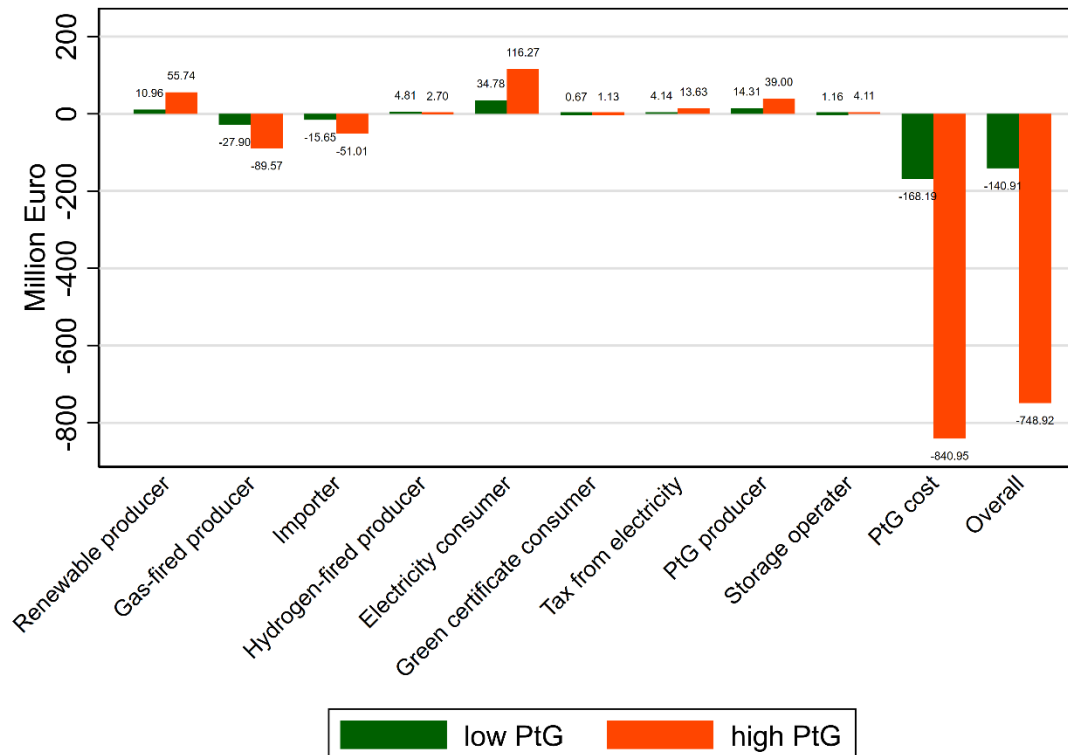


Annual utilization of PtG per scenario

	Electrolysers		Hydrogen-fired power plants	
	Operating hours	Capacity factor	Operating hours	Capacity factor
Low PtG	789	0.08	862	0.08
High PtG	772	0.06	1197	0.06

- In the scenario of high PtG, the utilization of PtG remains almost the same as in the scenario of low PtG
- In both scenarios, the capacity factor of PtG is quite low, which is due to the assumption that the hydrogen storage operator only buys hydrogen at a price below the marginal cost of SMR hydrogen

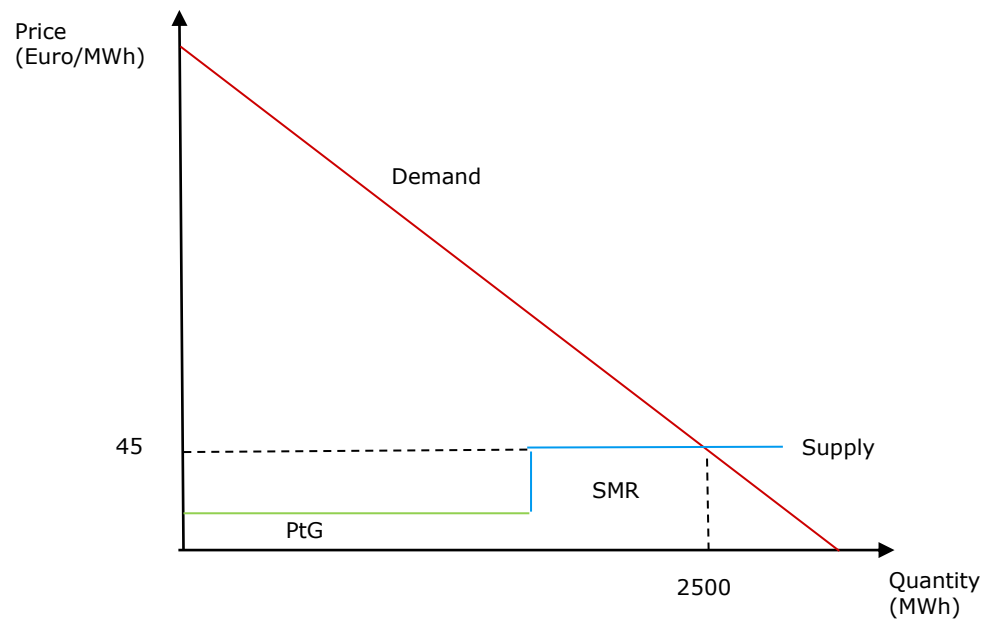
Overall welfare impact of PtG



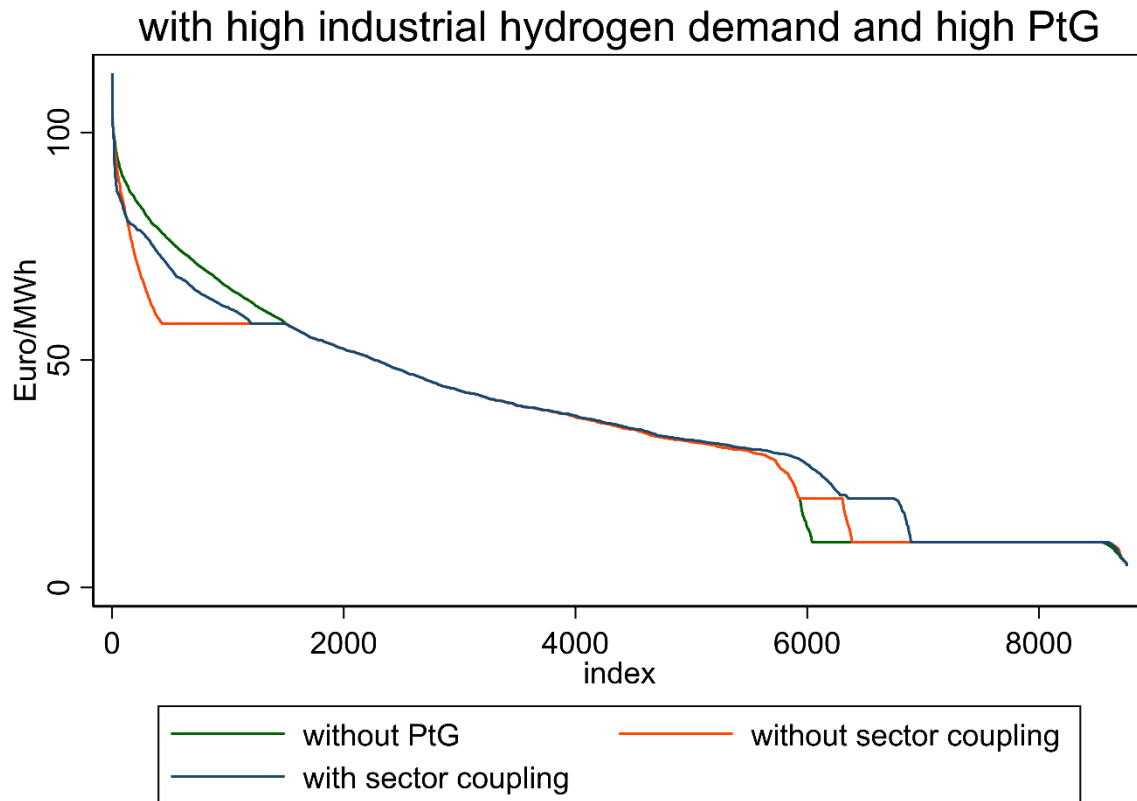
- Overall welfare is negative due to high fixed cost of PtG
- The **winners** include renewable producers because of fewer hours of low prices, and electricity consumers because of fewer hours of high prices
- The **losers** include gas-fired producers because of fewer hours of high prices, and importers because of smaller arbitrage room

Next question:

what happens if we add sector coupling?
(i.e. high industrial hydrogen demand)

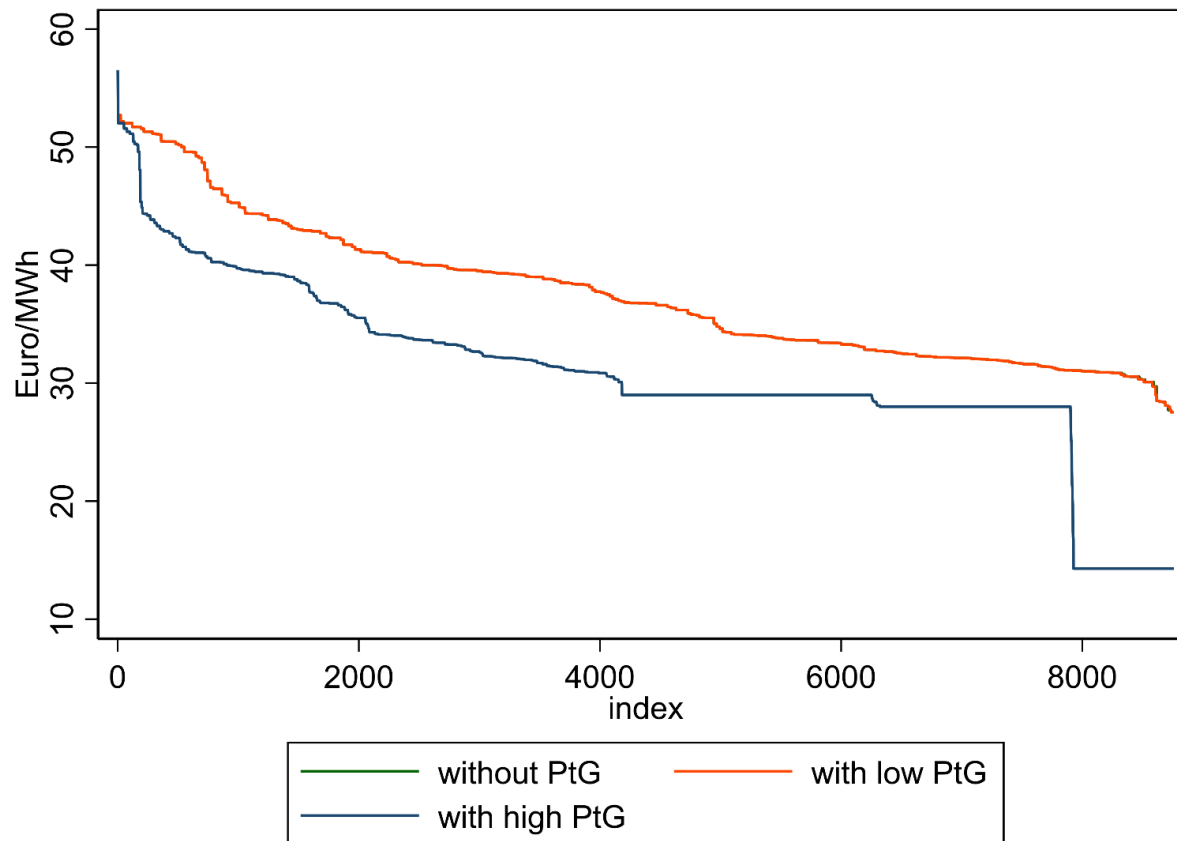


Impact of PtG on electricity price duration curve



- Compared to no sector coupling, there is less impact of PtG on the price duration curve in high price periods
- This means: with high external demand for hydrogen, value of PtG for providing time flexibility reduces

Impact of PtG on hydrogen price duration curve



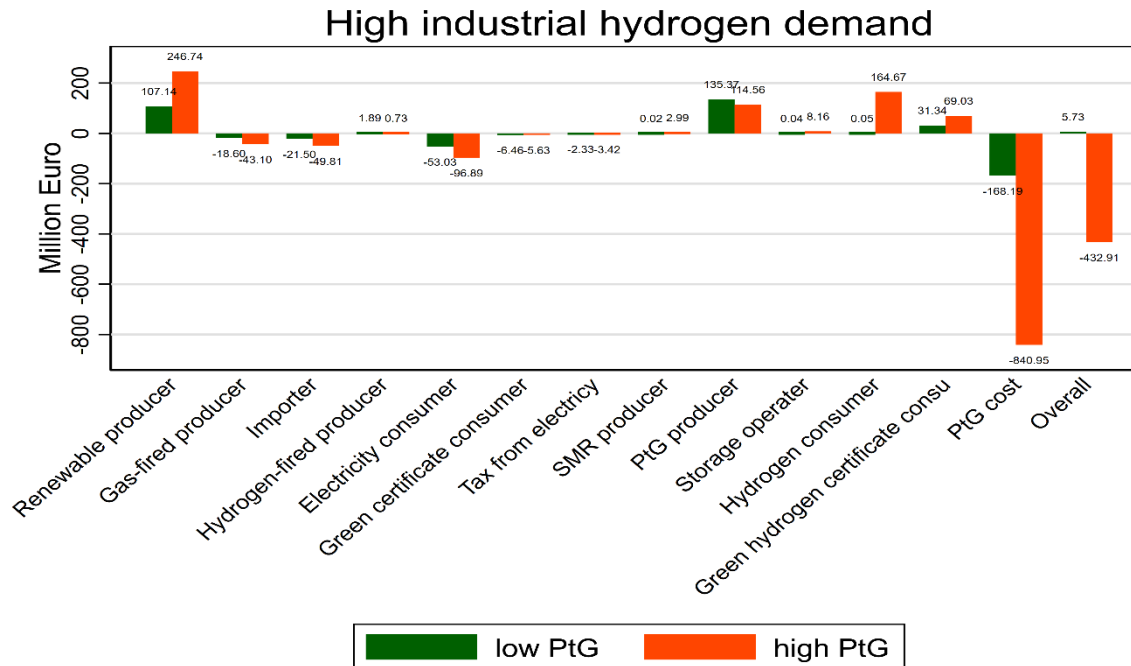
- With high capacity, PtG reduces hydrogen prices significantly
- With low capacity, PtG alone cannot meet the high hydrogen demand, hence, SMR is still the price setter

Annual utilization of PtG per scenario

	Electrolysers				Hydrogen-fired power plants			
	Operating hours		Capacity factor		Operating hours		Capacity factor	
	with coupling	without coupling	with coupling	without coupling	with coupling	without coupling	with coupling	without coupling
Low PtG	4190	789	0.39	0.08	637	862	0.06	0.08
High PtG	3925	772	0.22	0.06	843	1197	0.03	0.06

- Compared to no sector coupling, the capacity factor of electrolyser in both scenarios is higher
- In both scenarios, the utilization of hydrogen-fired power plants remains quite low because of high hydrogen prices driven by high hydrogen demand

Overall welfare impact of PtG



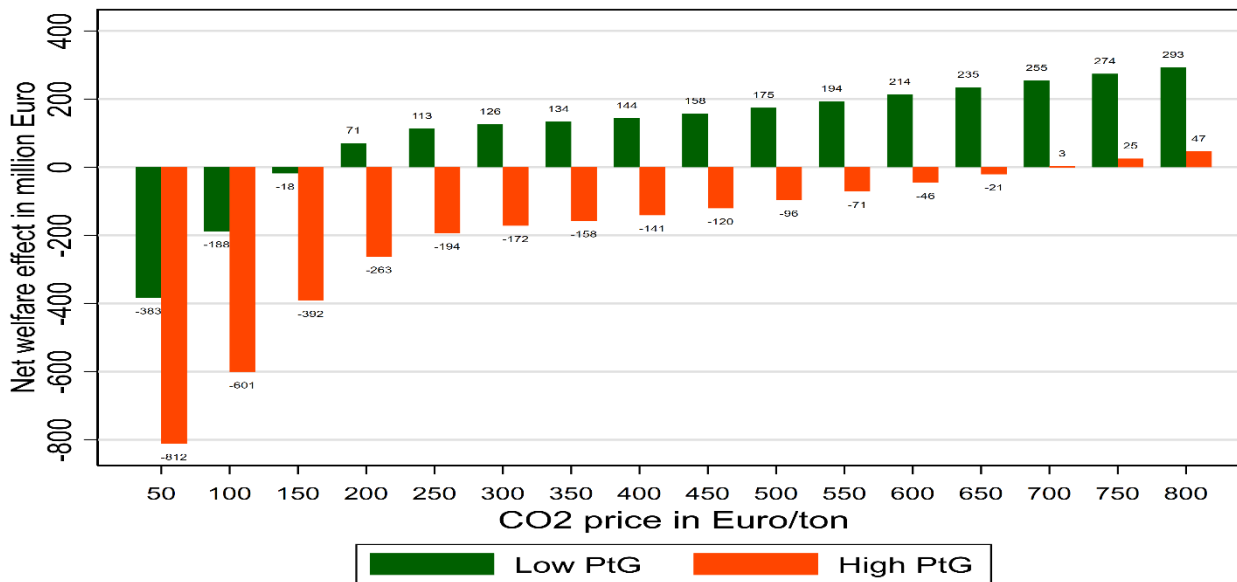
- The **winners** include renewable producers because of fewer hours of low prices, and hydrogen consumers because of fewer hours of high prices
- The **losers** include gas-fired producers because of fewer hours of high prices, electricity consumers because of higher average price, and importers because of smaller arbitrage room
- The overall welfare depends on the size of PtG

The implicit welfare loss of promoting hydrogen

- Under current market conditions, hydrogen is much more expensive than gas
- To promote hydrogen, governments levy a heavy tax on gas or give a subsidy to hydrogen to incentivize consumers to shift their consumption from cheap gas to expensive hydrogen, which leads a welfare loss
- When this loss is taken into account, the welfare effect of PtG is lower than its cost even in the scenario of high hydrogen demand with carbon price is included

How to make investments in PtG break even, when the implicit welfare loss of promoting hydrogen is counted?

- Higher carbon price



In case of high capacity of PtG, the carbon price should be at least 700 euro to make investments break even

Other option to make PtG break even is to improve efficiency

- Cost reduction of PtG (or efficiency improvement)

Efficiency of electrolyzers	Cost of PtG reduced by					
	0%(current level)	10%	20%	30%	40%	50%
0.7(current level)	650-700	500-550	300-350	200-250	150-200	100-150
0.8	550-600	400-450	200-250	150-200	150-200	100-150

Table 8: Break even CO₂ price (Euro/ton) for high installation PtG with different levels of cost reduction and efficiency in the scenario of high renewables and high industrial hydrogen demand

Break-even carbon price is reduced to about 150 euro/ton when the investments costs are reduced by 50% and the efficiency increased to 80%

Conclusions

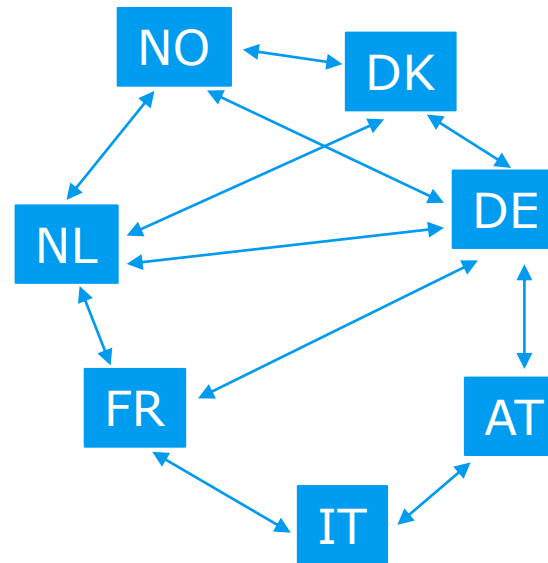
- More renewables result in steeper price-duration curve
- PtG makes the price duration curve flatter
- Taking investment costs into account, the welfare effects of PtG are positive only in the scenario of high renewables and high industrial hydrogen demand. But some groups are harmed by PtG, such as electricity consumers, gas-fired generators, and electricity importers
- However, including the welfare loss due to shifting gas consumption to more expensive hydrogen, PtG does not lead to an overall positive welfare
- To neutralize the negative welfare effect of PtG, CO₂ price at least 150-200 euro/ton is needed for low installation and 650-700 euro/ton for high installation
- In case there is a high hydrogen demand from other sectors (industry, transport), then the economic value of electrolyzers to provide flexibility is reduced... so, both objectives cannot be realized simultaneously



International spillover effects of national hydrogen policies

This is work in progress

Model (what's new compared to the previous one)



- More countries are included in integrated electricity and hydrogen markets
- Same types of participants in each country
- Electricity can be traded between neighboring countries without costs but with cross-border transport capacity constraints based on actual data
- Hydrogen can be traded between any two countries with transportation costs (3 euro/MWh/1000KM) and capacity constraints (100 MW)

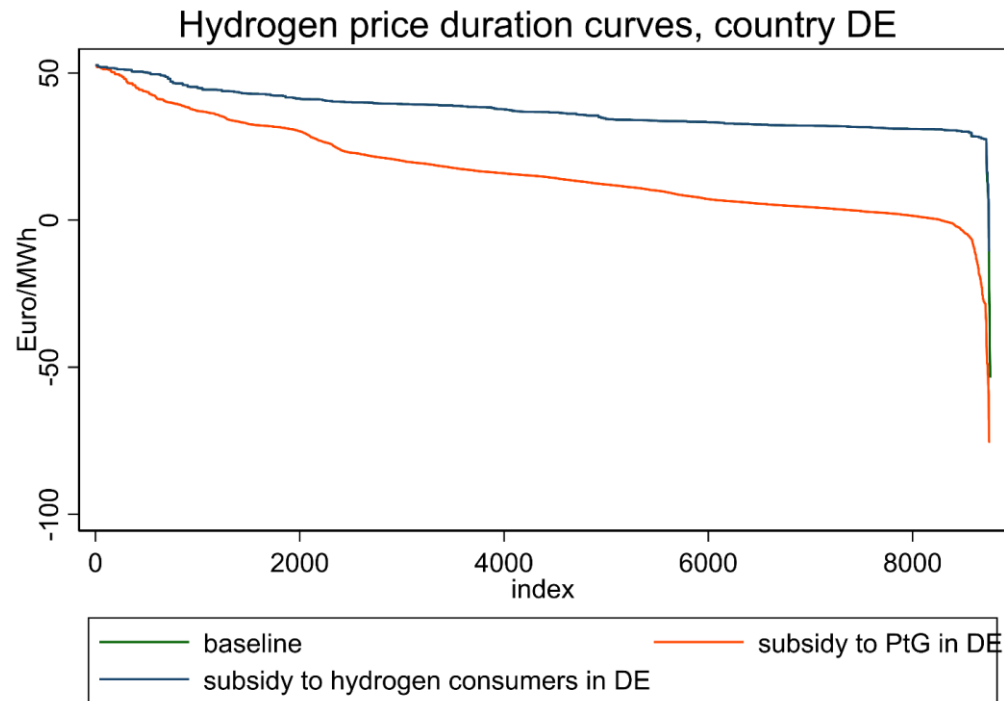
Policy variants

- Subsidy to PtG producers
- Subsidy to hydrogen consumers (can be either blue or green)
- The subsidy to PtG is calculated at the level making PtG competitive with SMR hydrogen and the same level is applied to hydrogen consumers
- We study the spillover effect of a country's hydrogen policy
 - We focus on a policy that Germany subsidizes its PtG producers or hydrogen consumers at 65 euro per MWh hydrogen



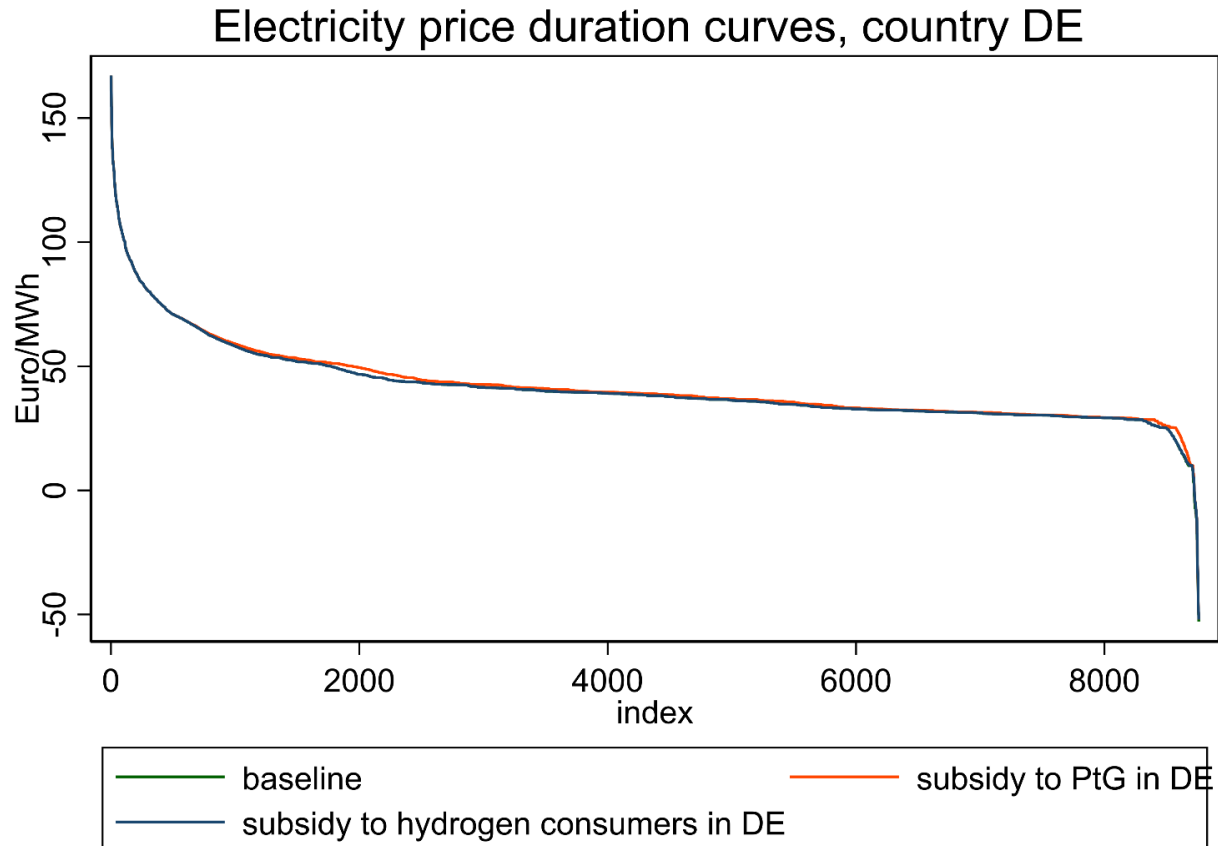
Results of German hydrogen policies

Impact of PtG on hydrogen price duration curve



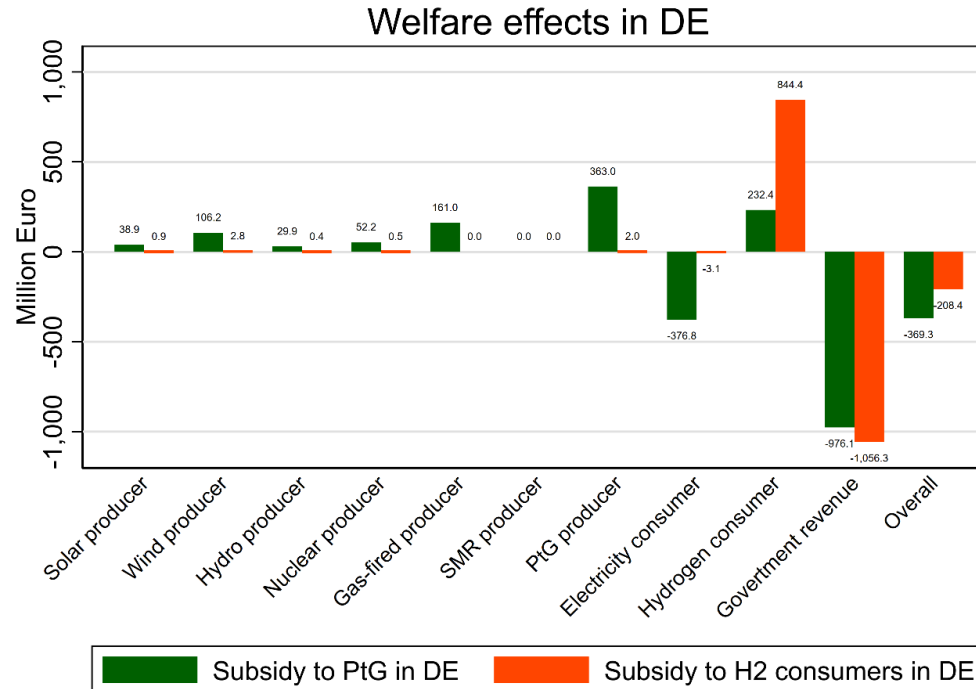
- Subsidy to hydrogen consumers does not raise the hydrogen price in case of abundant SMR capacity
- Subsidy to PtG producers may reduce hydrogen price if PtG gets lower marginal costs than SMR

Impact on electricity price duration curve in Germany



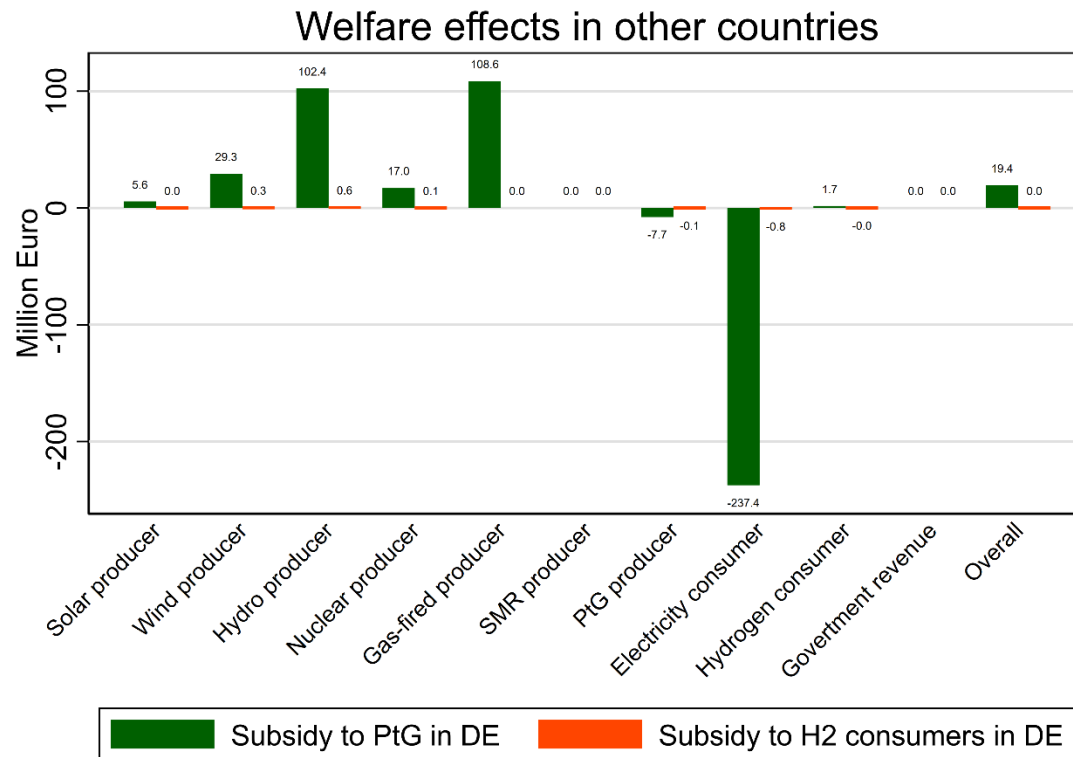
- Subsidy to PtG increases electricity prices
- Subsidy to hydrogen consumers hardly has any effect

.. But how does this policy impact welfare?



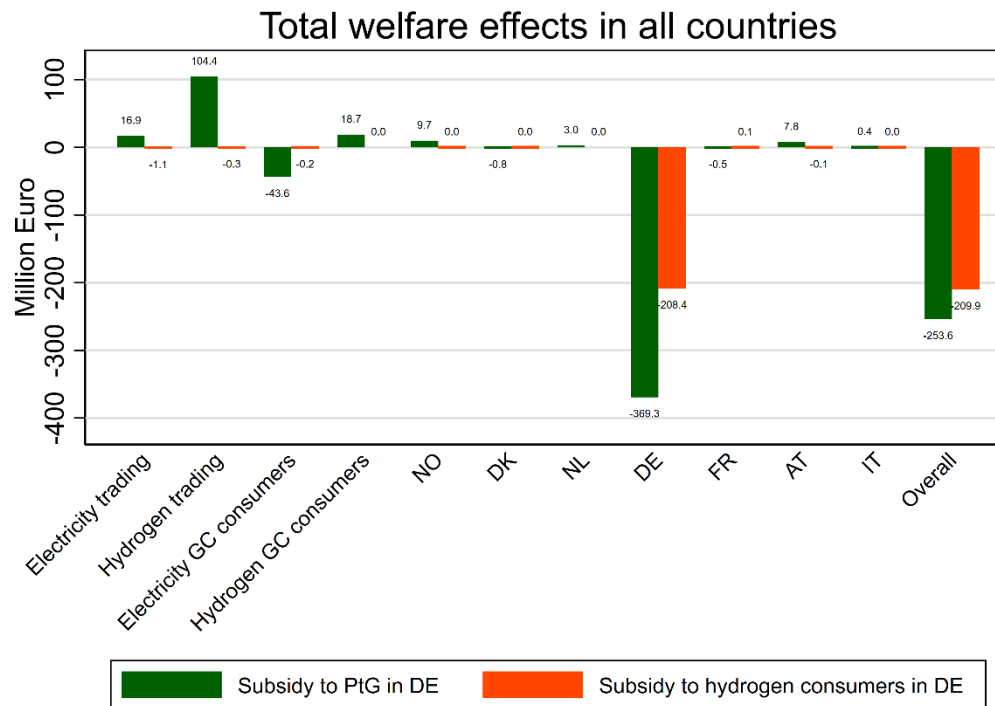
- Subsidy to PtG producers harm electricity consumers, but benefit hydrogen producers and consumers, and electricity producers
- Subsidies to hydrogen consumers benefit those consumers at expense of taxation (government)
- In both cases, overall welfare effect is negative
- Note that we already included a carbon price of about 25 euros/ton

.. But what are welfare effects in other countries?



- Subsidy to PtG producers harm electricity consumers and PtG producers, but benefit electricity producers and hydrogen consumers
- Subsidy to hydrogen consumers have almost the same direct effect but at lower degrees
- Overall welfare in other countries is positive, so they benefit from subsidies in a country

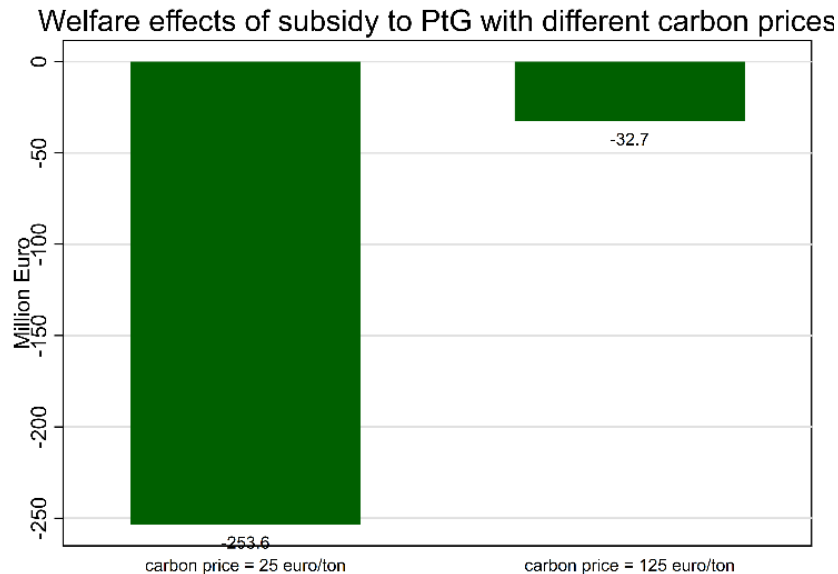
Overall welfare impact is negative



The spillover welfare effects are small because

- the current hydrogen production and consumption levels are so low that a support policy hardly changes the electricity prices
- in addition, limited cross-borders capacities for trading electricity and hydrogen also reduces the spillover

Finally: what is overall welfare impact when CO₂ price is higher (125 euro/ton)



- In case of subsidy for PtG, they will produce more hydrogen which will partly replace SMR
- If the carbon price is higher, the value of this replacement is higher because there will be less carbon emissions
- therefore lower loss of welfare
- The lower break-even value for carbon than previously comes from lower level of installed PtG capacity



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