Optimal Investment Decisions in Increasingly Variable Power and Energy Systems

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Rethinking our Energy Future: Collaboration and Integration

Agenda

- Background, motivation and research questions
- State of the art
- Model and data
- Selected results
- Conclusions and outlook

Background and Motivation

- Energy systems based on renewable energy sources (RES) have an increasing demand for flexibility

- Largely untapped source of flexibility: Energy Systems Integration (ESI)
  - **Increasing integration between energy pathways that were traditionally considered in isolation**
  - Increasing integration across scales
  - Making use of the arising synergies

- Power-to-Gas (PtG) as one example for ESI
  - Possibility to integrate the power and gas systems more strongly
  - Research objective: understand the role of PtG in a future energy system

Technology Background and Research Questions

Technology background

- Power-to-Gas: a form of electricity storage
- Use electricity for electrolysis (output: hydrogen + oxygen)
  - Inject hydrogen directly into gas grid
  - Convert hydrogen with CO_2 to methane
  - Efficiency: 80% vs. 50%

Research questions

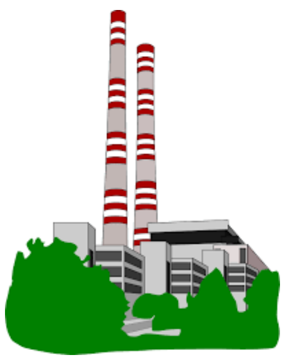
- What is the optimal investment in Power-to-Gas?
- How does it depend on increasing variable renewables?
- Are there portfolio effects?

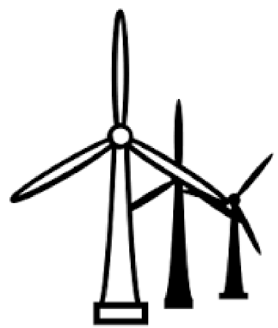
State of the Art

- Broad strands:
  - Power-to-Gas technology itself
  - Cost-benefit of Power-to-Gas
  - Power-to-Gas in electricity system (especially 100% RES-E)
- No real examination of endogenous investment decision
- No market or portfolio effects

Game Theory Model

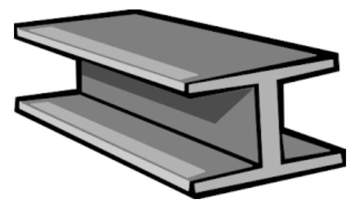
Generators:





- ❑ Maximise profit
- ❑ Decisions:
  - ❑ Generation
  - ❑ Investment/Decommission
- ❑ (May exert market power)

Consumers:

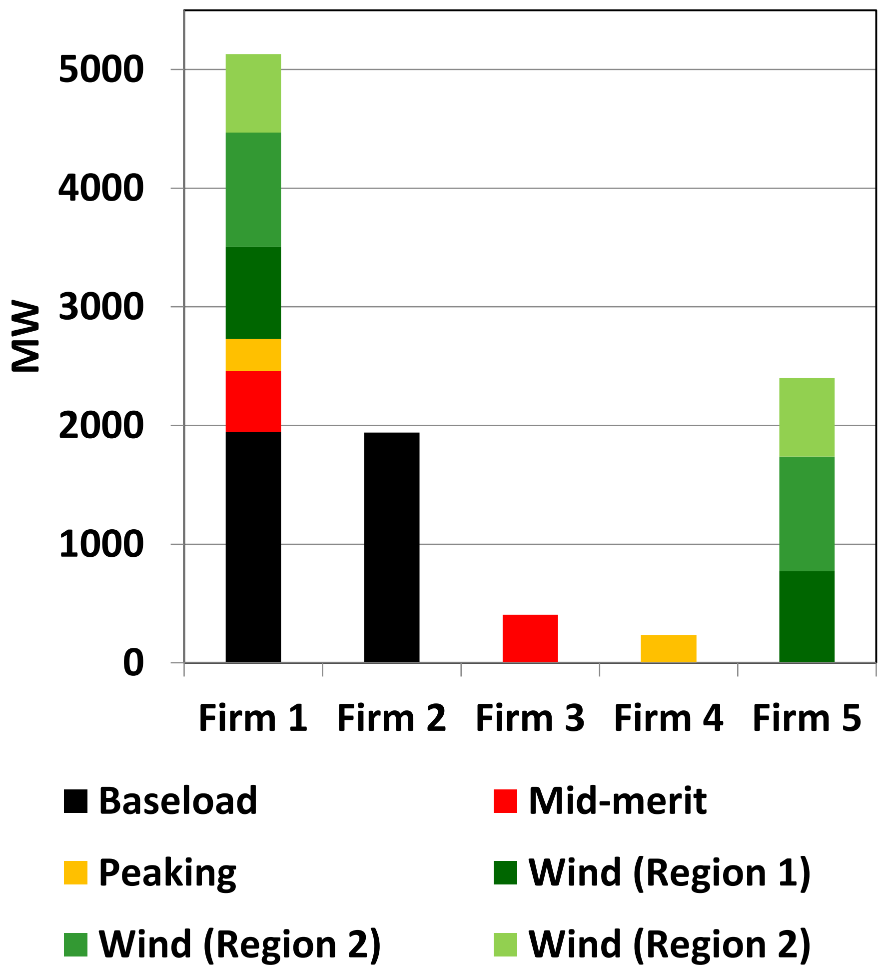


- ❑ Minimise costs
- ❑ Decisions:
  - ❑ PV or micro generation
  - ❑ (Load shifting)
  - ❑ (Load shedding)

- ❑ Mixed Complementarity Model & Bender's Decomposition

Power generation firms and technologies

Initial Generation portfolio



- Firms can invest in Power-to-Gas technology
- Costs: Investment and electricity price
- Revenues: Gas price
- Fix wind capacity and allow investment and exit in all other technologies

Renewables uncertainty in the model *

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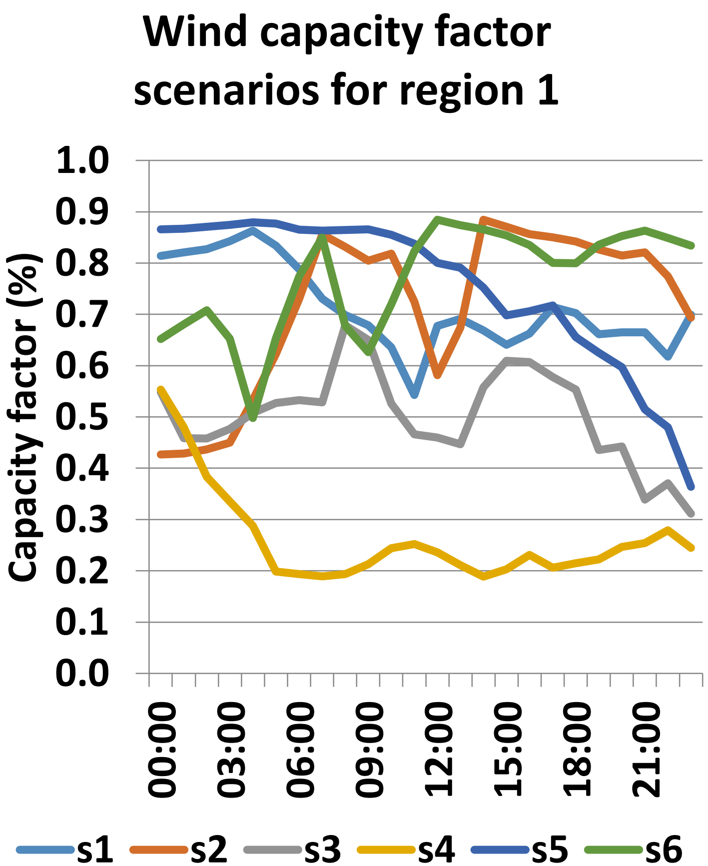
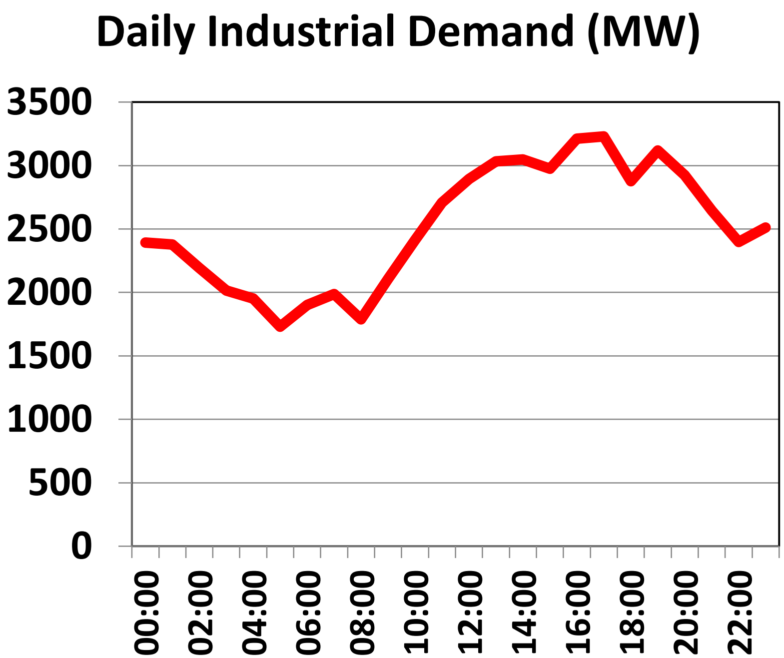


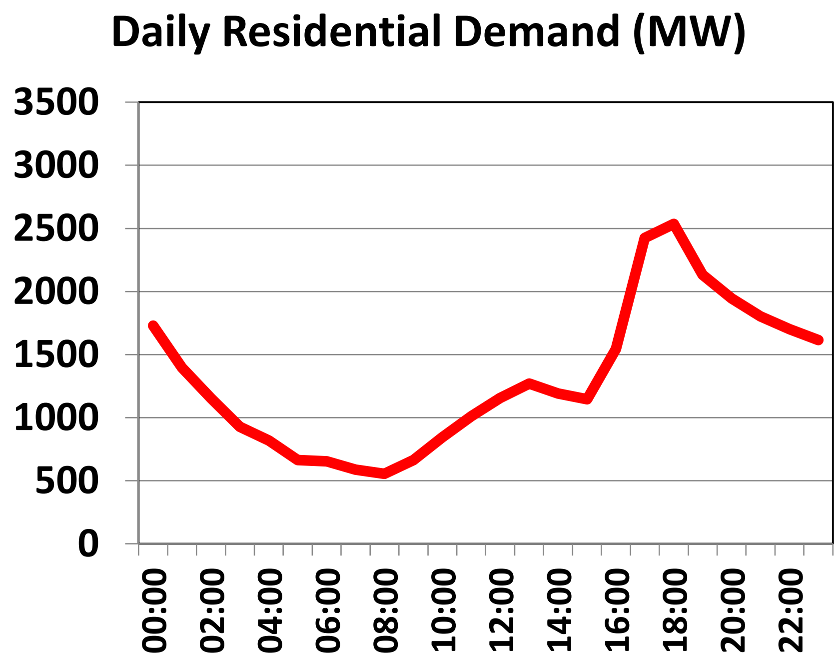
- ❑ Similar capacity factor scenarios for uncertain PV generation
- ❑ Consideration of spatial and temporal correlation between wind and PV

* ESRI-UCD-ESIPP Collaboration: Bertsch, V., Devine, M. T., Sweeney, C., & Parnell, A.. Analysing interactions between demand response and investment decisions using a stochastic market equilibrium model (work in progress).

Considered consumer groups

	Industrial/Commercial	Residential
No micro or PV	Group 1	Group 4
With thermal micro	Group 2	Group 5
With PV	Group 3	Group 6





Results: Power-to-Gas itself is loss-making

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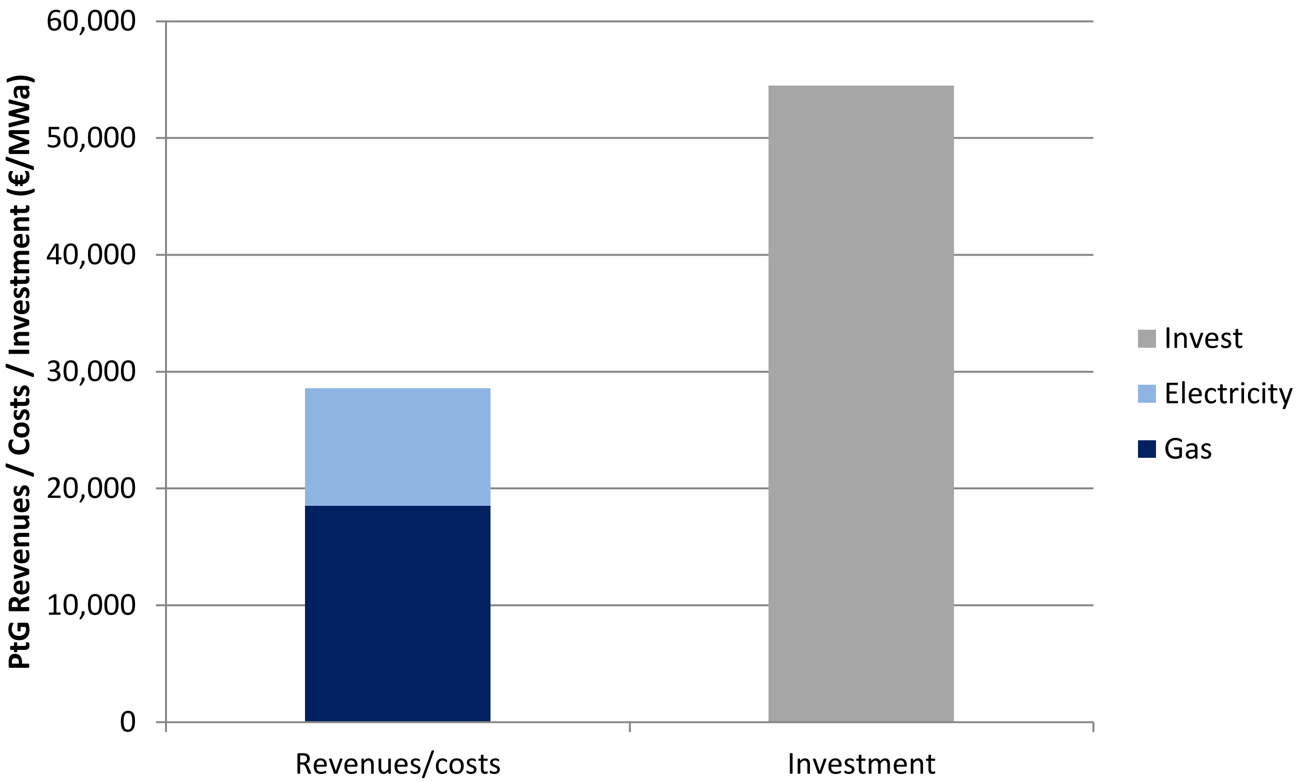
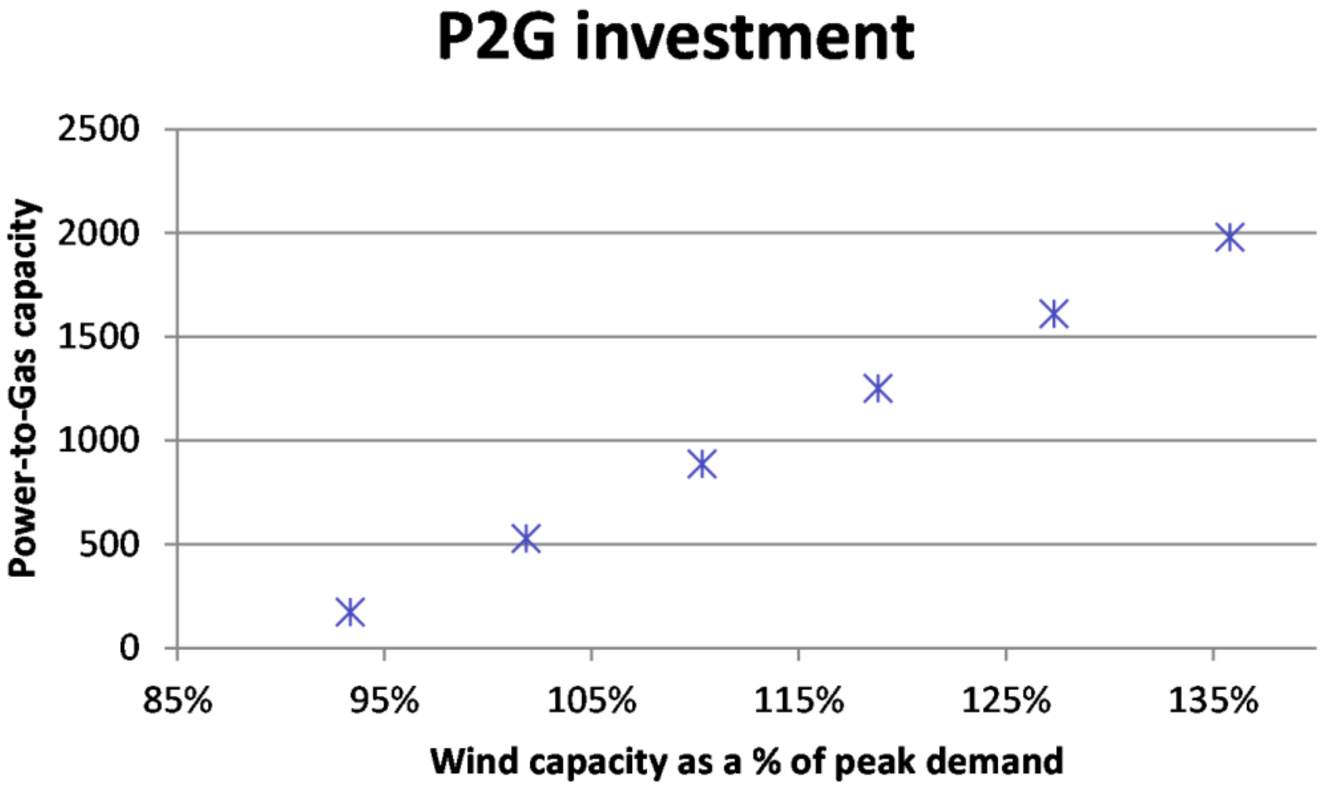


- Considered as a stand-alone technology, PtG makes a loss of 25,950 €/MWa
- Corresponds to price gap of ~25€/MWh of gas (hydrogen) on top of the gas price of 18€/MWh

Results: Optimal investment into Power-to-Gas increases with installed wind capacity



- Power-to-Gas investment once wind generation exceeds 50% of annual demand

Results: Changing profits of conventional generators for increasing levels of wind penetration

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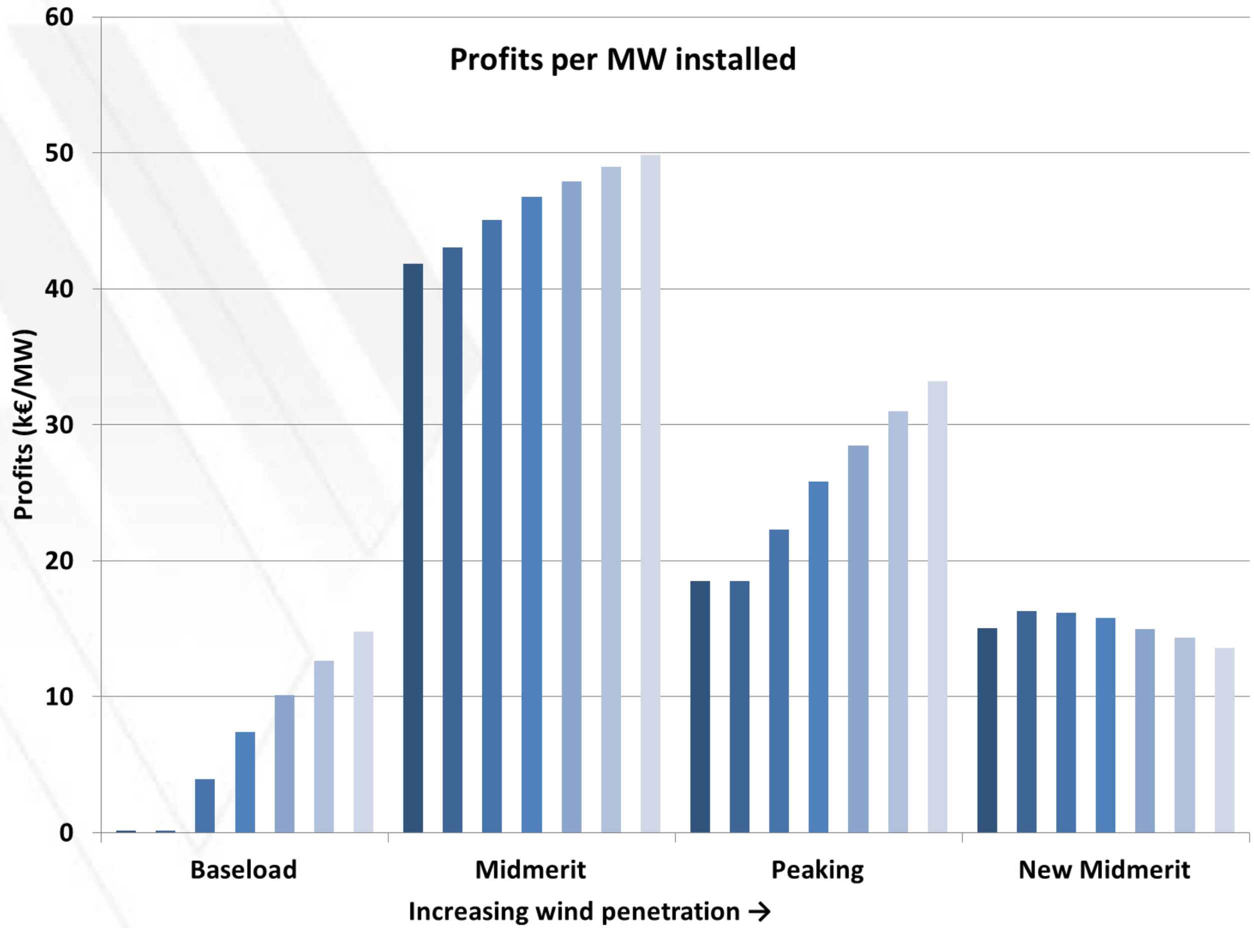
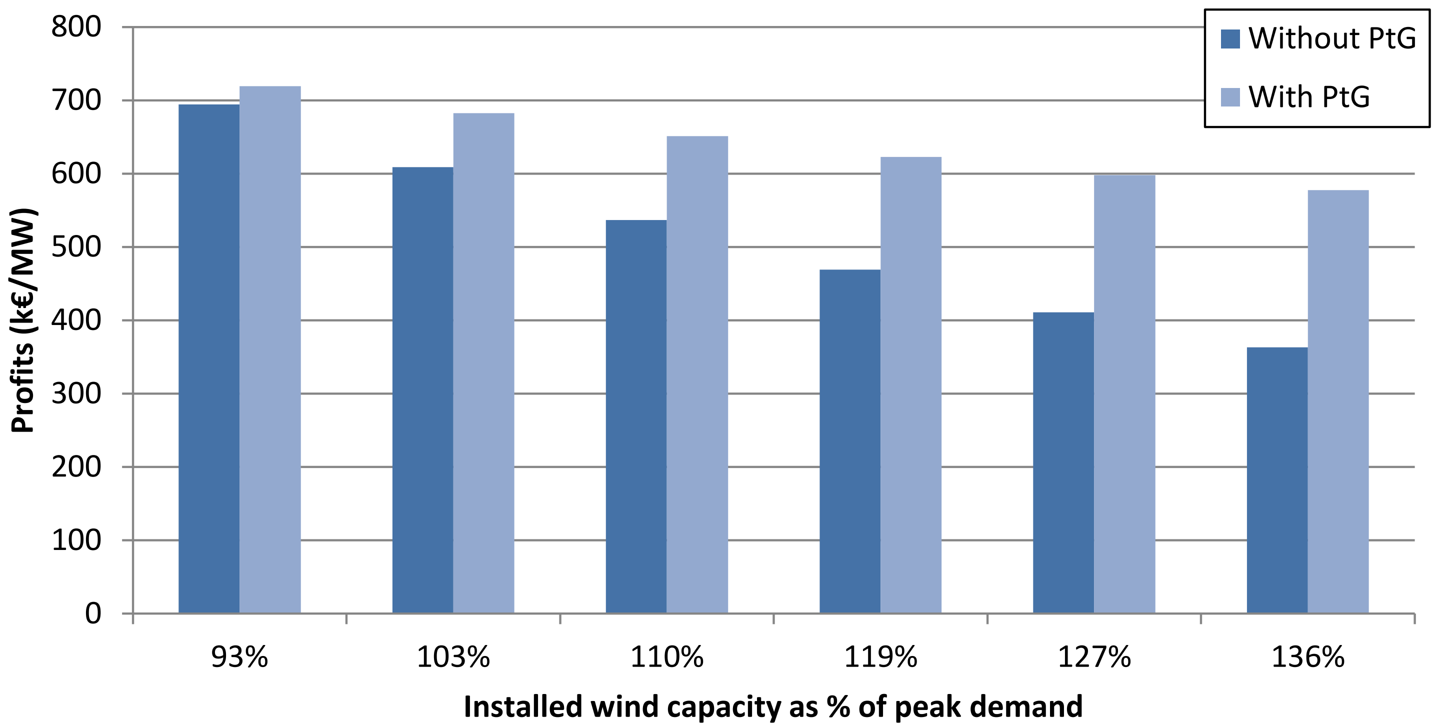
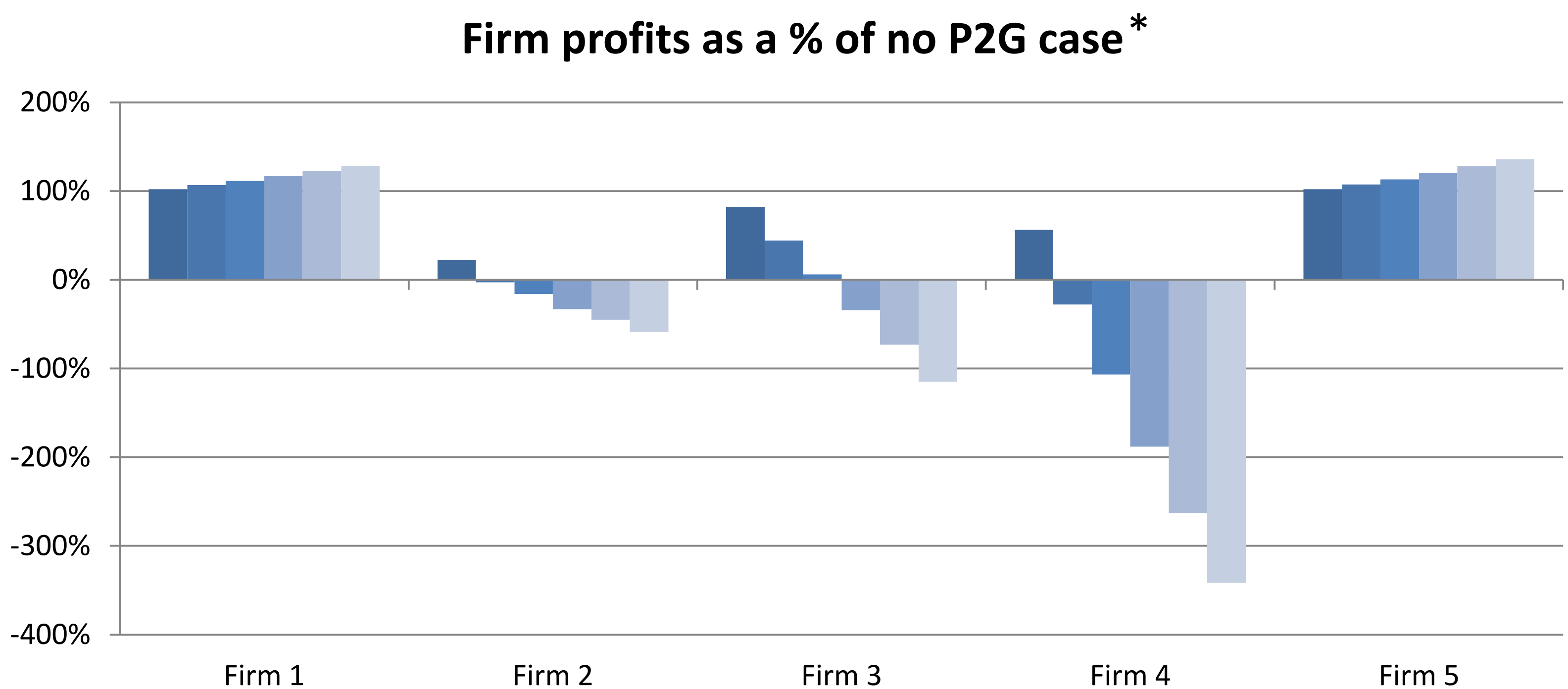


Results: Changing profits of renewable generators for increasing levels of wind penetration



- ❑ Adding more wind generation to the system is more profitable in the presence of PtG

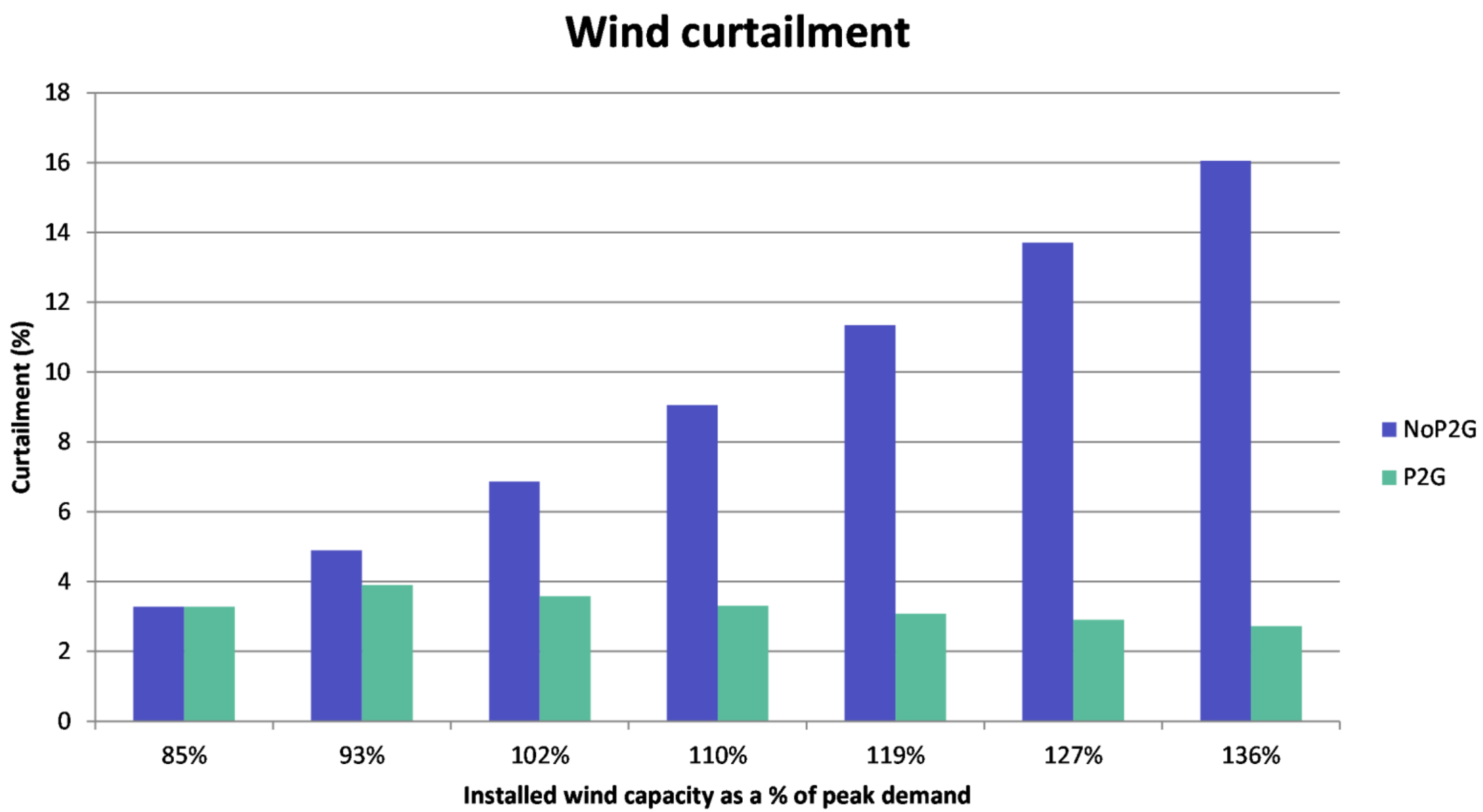
Results: Generator profits by firm



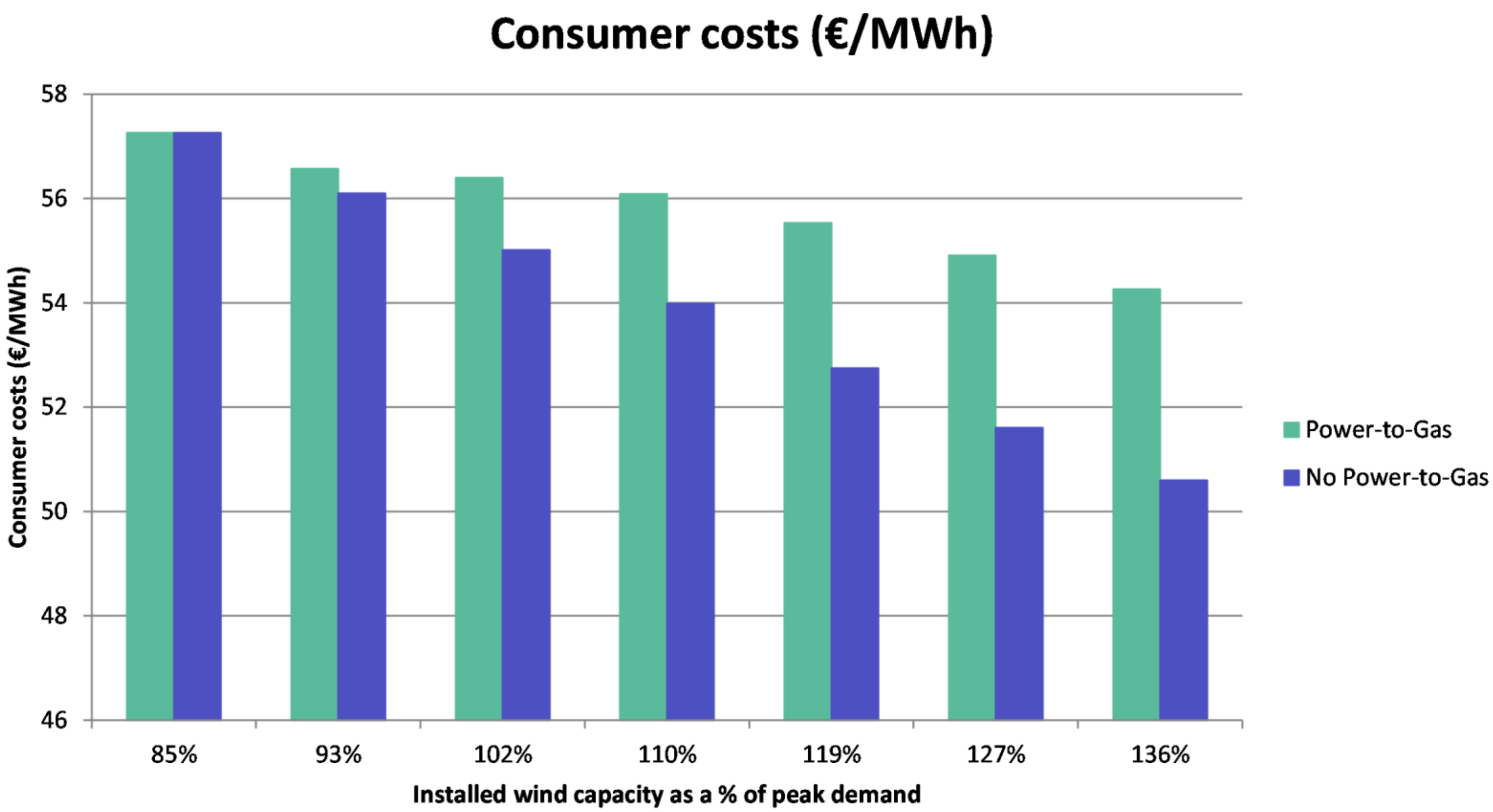
- Firms with wind generation have an incentive to invest in PtG

* Assuming for each firm that this firm is also facing the investment costs

Results: Curtailment with vs. without PtG

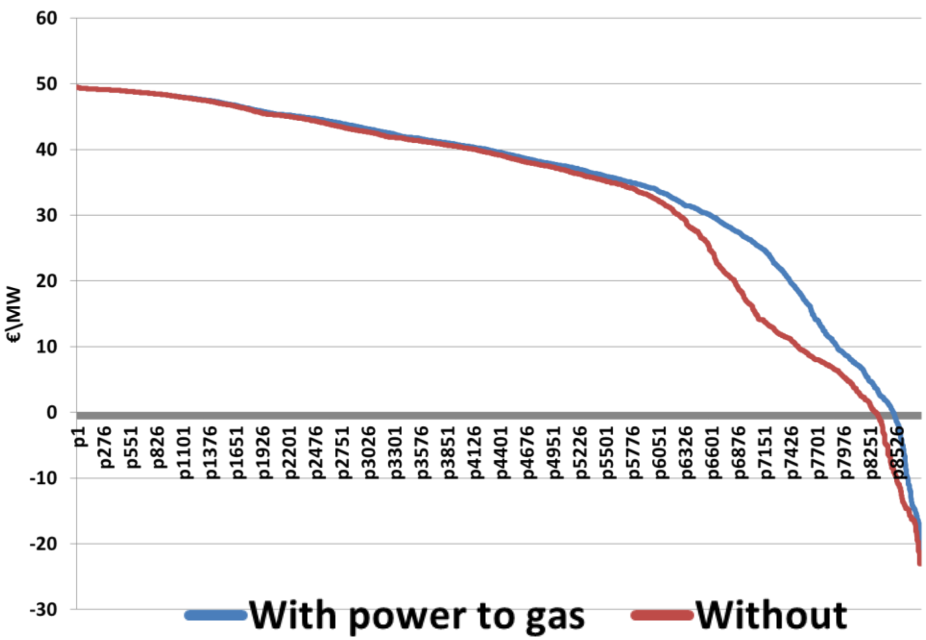


Results: Consumer costs with vs. without PtG

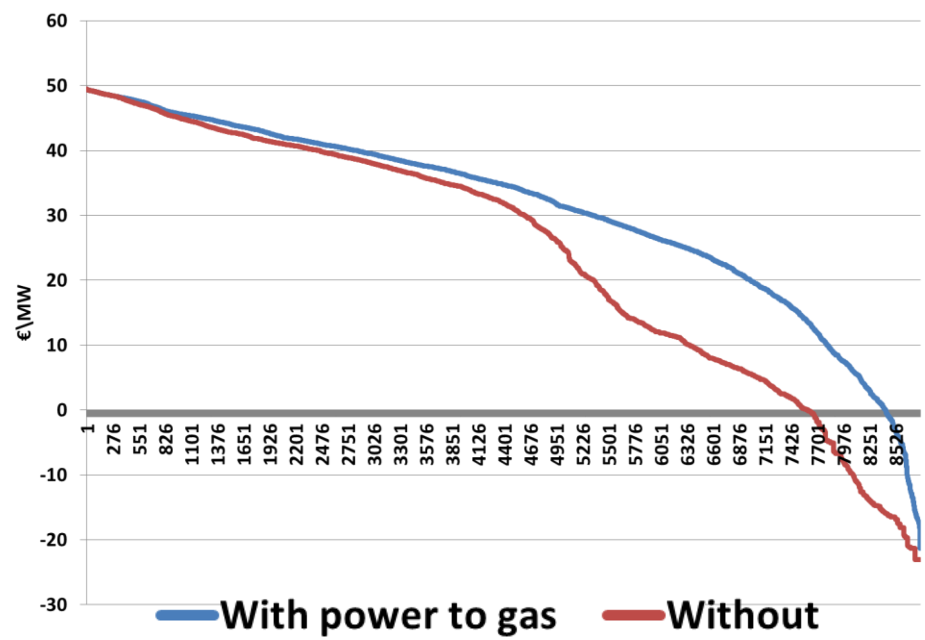


Results: Changes in market price structure

Price Duration Curve (Wind 85% of peak demand)



Price Duration Curve (Wind 135% of peak demand)



Summary

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- ❑ Investment into Power-to-Gas creates a new demand on the electricity system, particularly during low-price hours (low load and/or high RES)
- ❑ As opposed to pumped storage or battery storage, Power-to-Gas does not directly provide supply during peak hours

⇒ Offpeak prices increase while peak prices remain unchanged

⇒ Profits, particularly of renewable generation, increase

- ❑ While Power-to-Gas on its own is loss-making, it increases the profits of the entire generation portfolio of firms with renewable generation
- ❑ This effect is particularly strong in a small island system, such as the Irish power system

Outlook

- ❑ Impact of market power on findings
- ❑ Competition of large-scale PtG with consumer investments in small-scale (battery) storage technologies
- ❑ Understand potential benefits of using “green gas” from PtG outside the electricity sector
- ❑ “Optimal mix” of different PtG technologies
  - ❑ Electrolysis vs. methanation
  - ❑ Investment costs vs. efficiency
  - ❑ Ramping and other constraints
- ❑ Analyse potential synergies from using oxygen of electrolysis in wastewater treatment

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ESB

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An Coimisiún um Rialáil Fóntais
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Assumptions (selection)

- Gas price: 18.00 €/MWh_th
- Coal price: 9.36 €/MWh_th
- CO_2 price (ETS): 10 €/t CO_2

- Power-to-Gas
  - Specific investment (electrolysis): 750 €/kW, corresponding to an annualised specific investment of 54,487 €/MWa
  - Efficiency (electrolysis): 70%