ESRI ECONOMIC & SOCIAL RESEARCH INSTITUTE

Infrastructure investment in a future integrated energy system: an application to power-to-gas

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NREL, Golden, CO

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Agenda

- ❑ Background, motivation and research questions
- ❑ Literature
- ❑ Modelling approach
- ❑ Test system
- ❑ Results
- ❑ Conclusions and further work

Background and motivation

- Increased RES means increased variability
- Energy Systems Integration (ESI) as a means of managing variability

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- Power-to-Gas (PtG) as an ESI case study
- Privately determined infrastructure investment

Technology and research question(s)

- ❑ Power-to-Gas: a form of storage
- ❑ Use electricity for electrolysis
- ❑ Inject hydrogen to grid
- ❑ Convert hydrogen to methane

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What is the optimal investment in PtG?

- ❑ Impact of RES?
- ❑ Portfolio effects?

Literature review

Broad strands:

- ❑ PtG technology itself
- ❑ Cost-benefit of PtG
- ❑ PtG in electricity systems (especially 100% RES)

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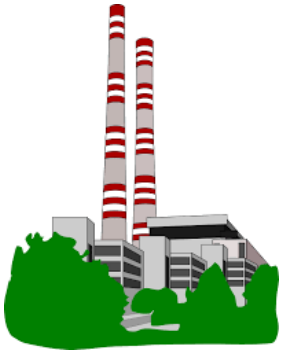
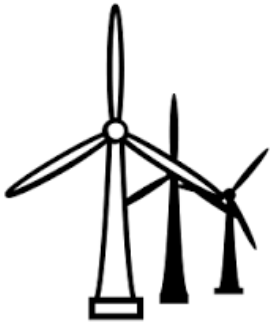
- ❑ PtG technology itself
- ❑ Cost-benefit of PtG
- ❑ PtG in electricity systems (especially 100% RES)

- ❑ No real examination of endogenous investment
- ❑ No market effects
- ❑ No portfolio effects

Methodology

Generators:



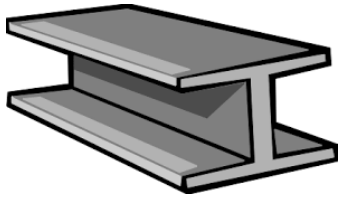


Maximise profit

Decision variables:

- ❑ Generation
- ❑ **Investment and exit**

Consumers:



Minimise costs

Decision variables:

- ❑ PV or microgeneration
- ❑ (Load shifting)
- ❑ (Load shedding)

Methodology

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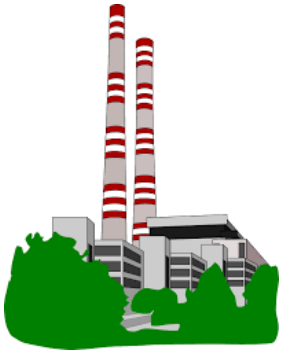

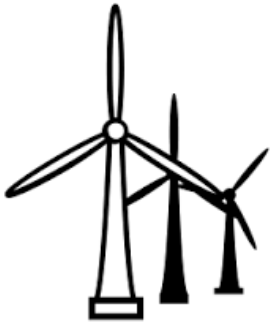

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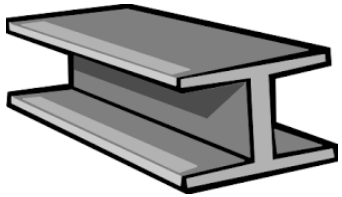

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Mixed Complementarity Problem (MCP) & Bender's Decomposition

Methodology

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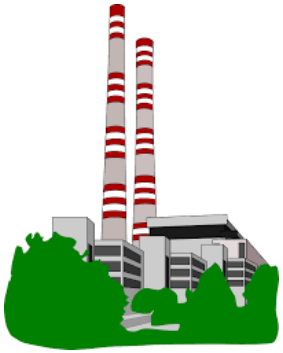

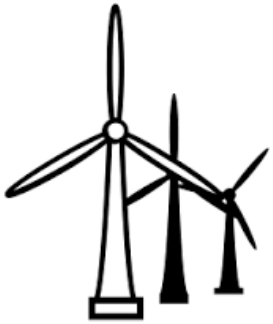

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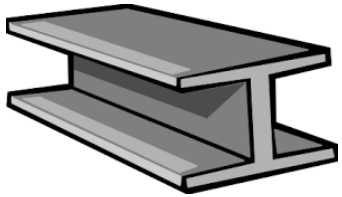

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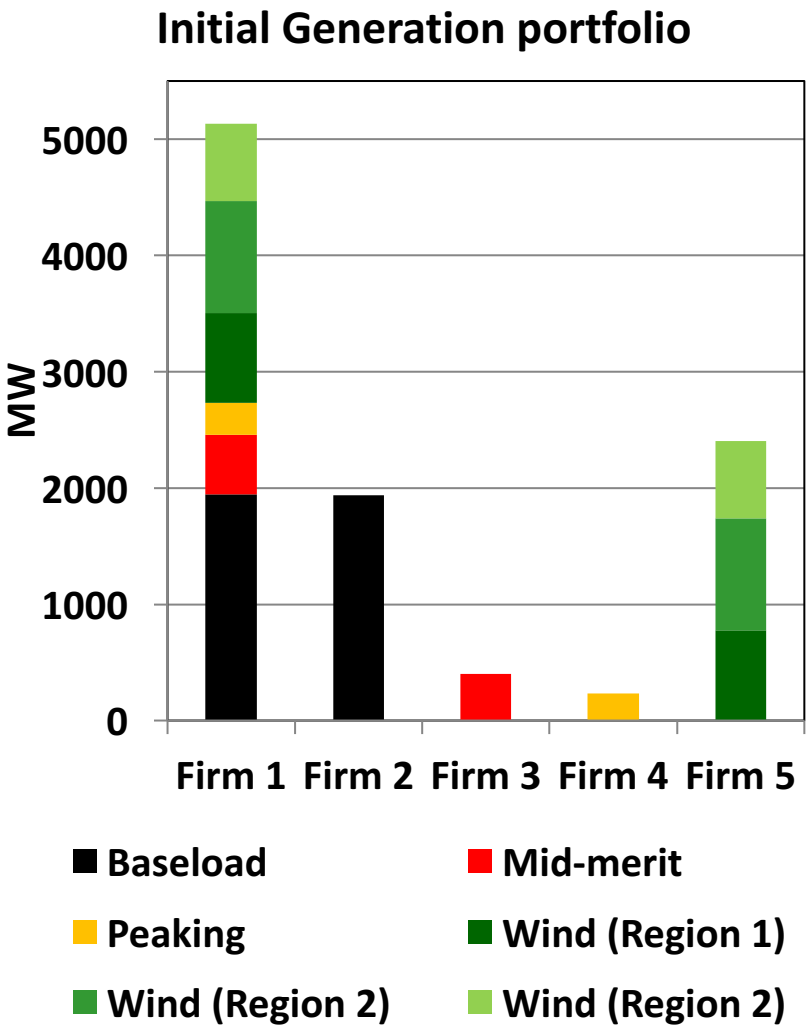
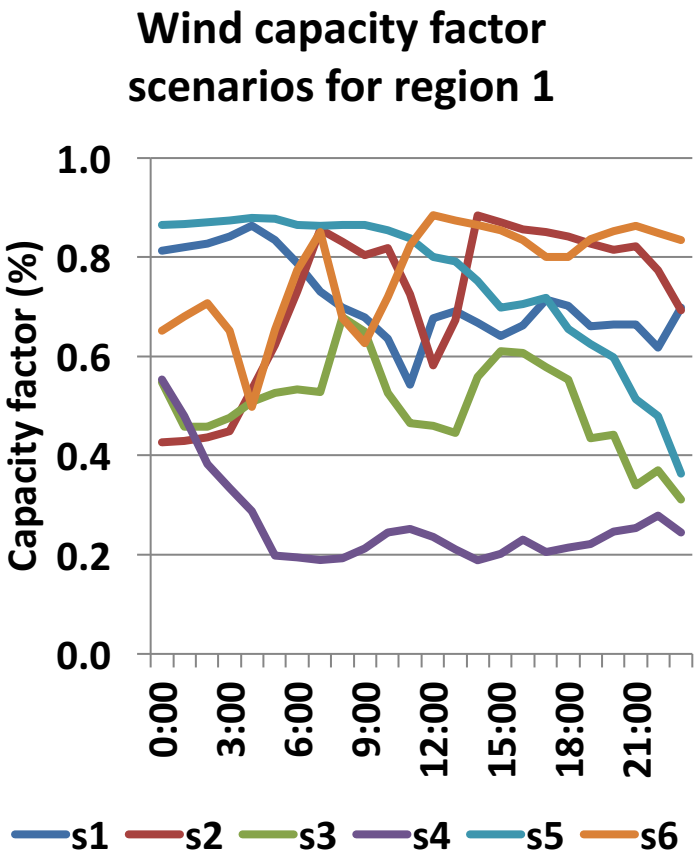
Mixed Complementarity Problem (MCP) & Bender's Decomposition
Generation firms determine the infrastructure portfolio

Data



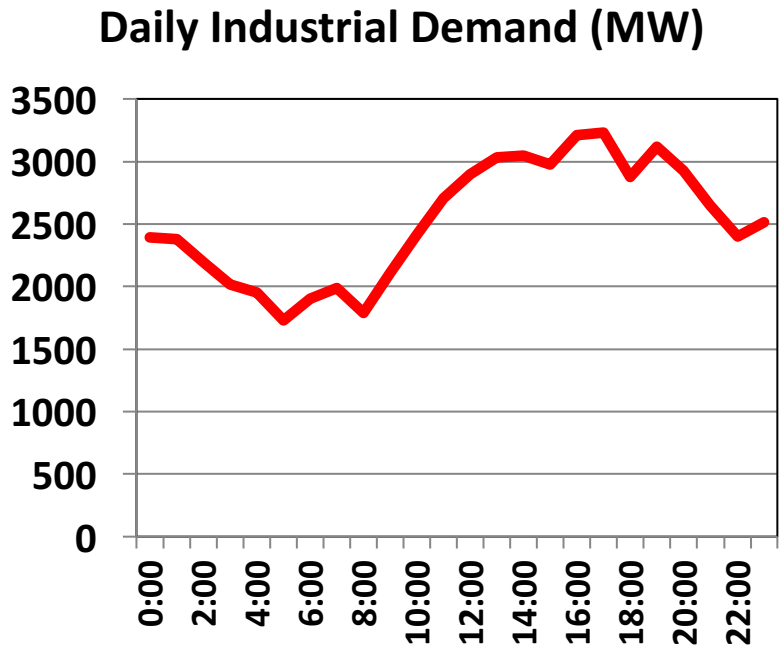
- ❑ Firms invest and retire conventional units
- ❑ Firms can invest in Power-to-Gas
- ❑ Cost: Investment and electricity price
- ❑ Revenues: Gas prices
- ❑ Wind investment is exogenous

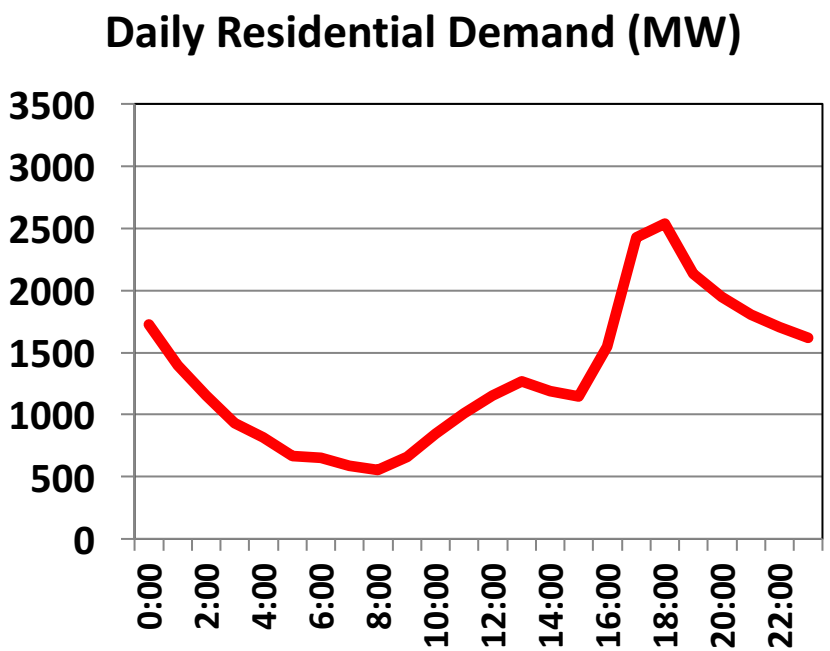
Data



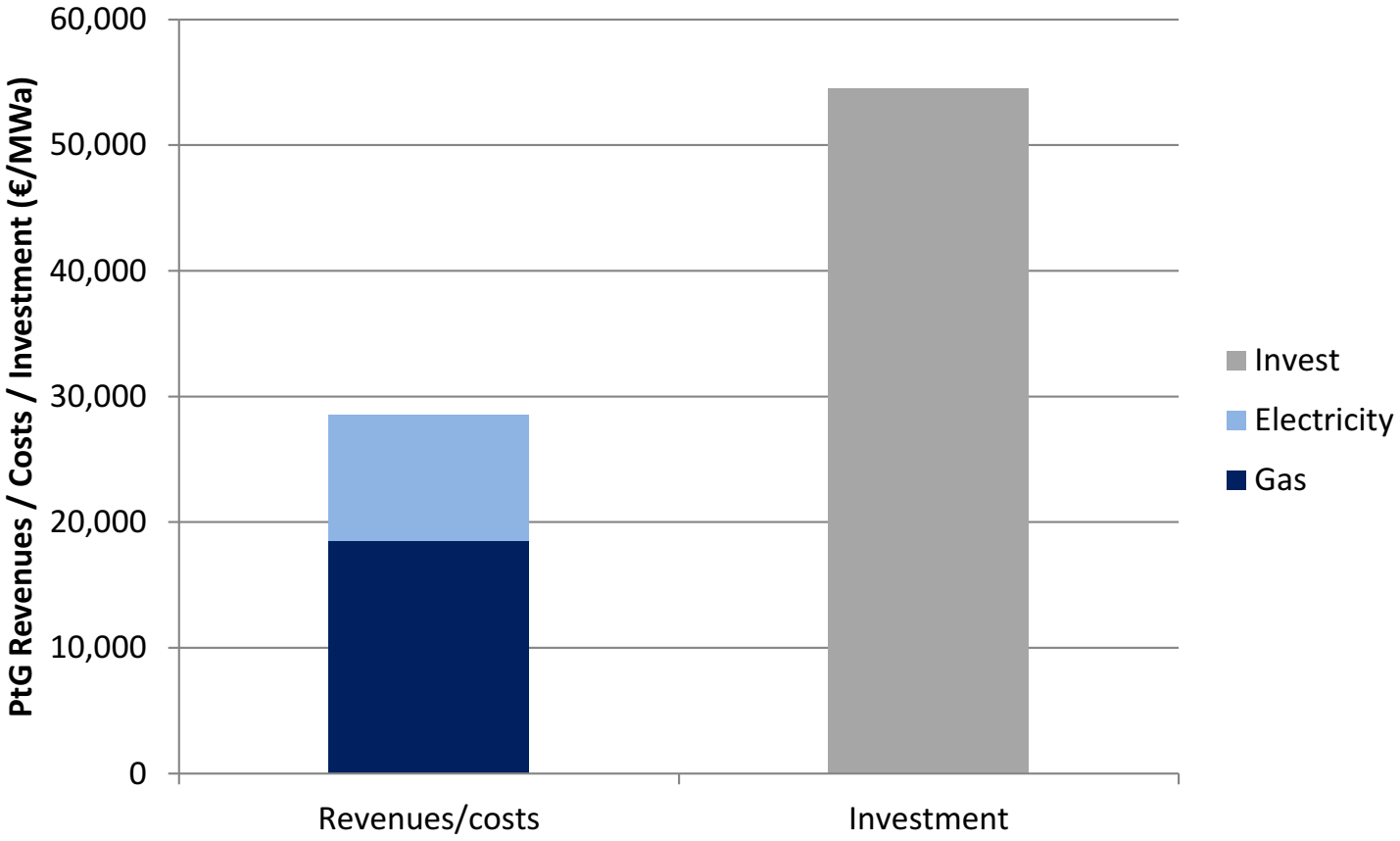
Wind receives a Feed-in Premium of €23/MWh

Data


Daily Industrial Demand (MW)
3500
3000
2500
2000
1500
1000
500
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00

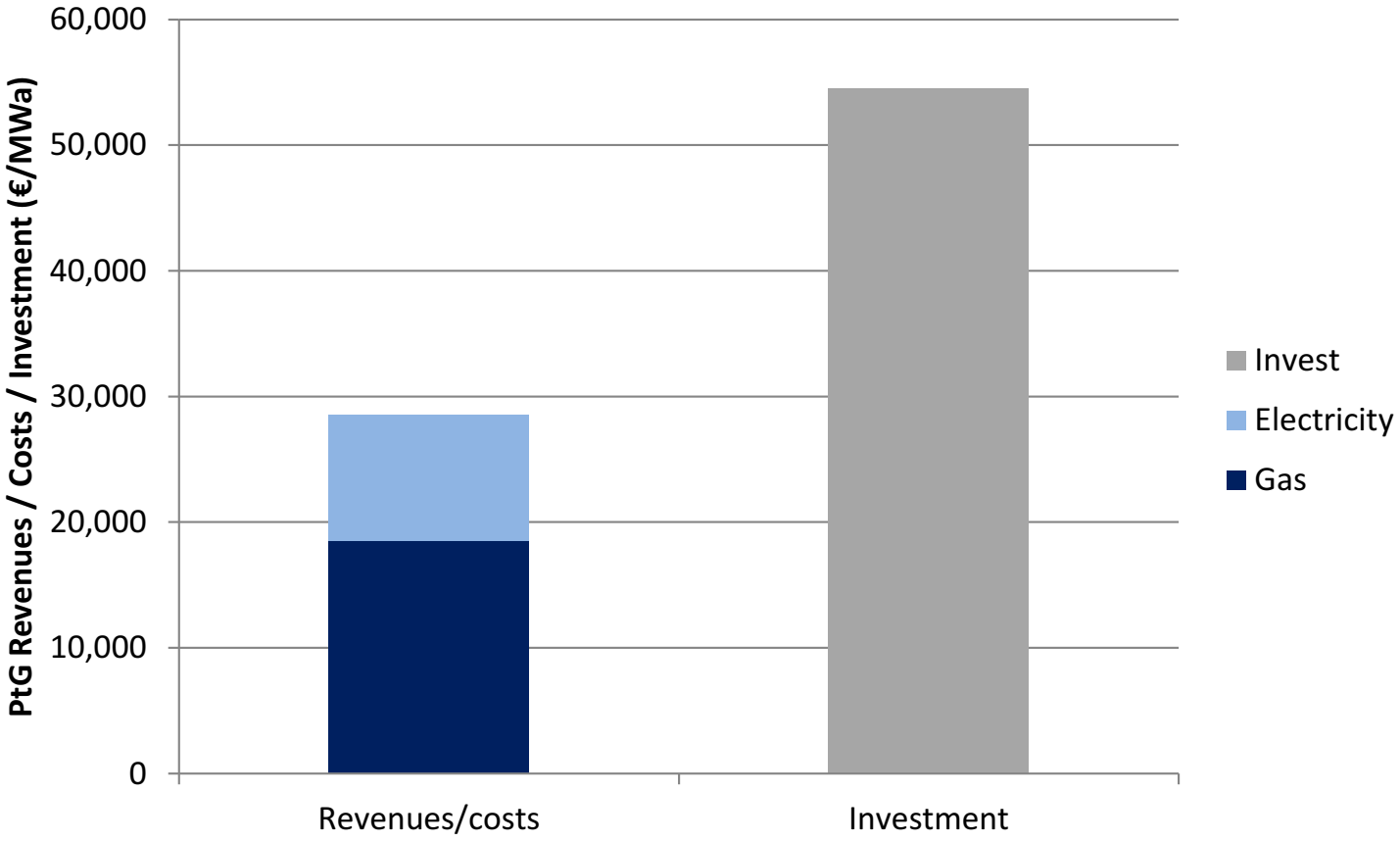

Daily Residential Demand (MW)
3500
3000
2500
2000
1500
1000
500
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00

Results



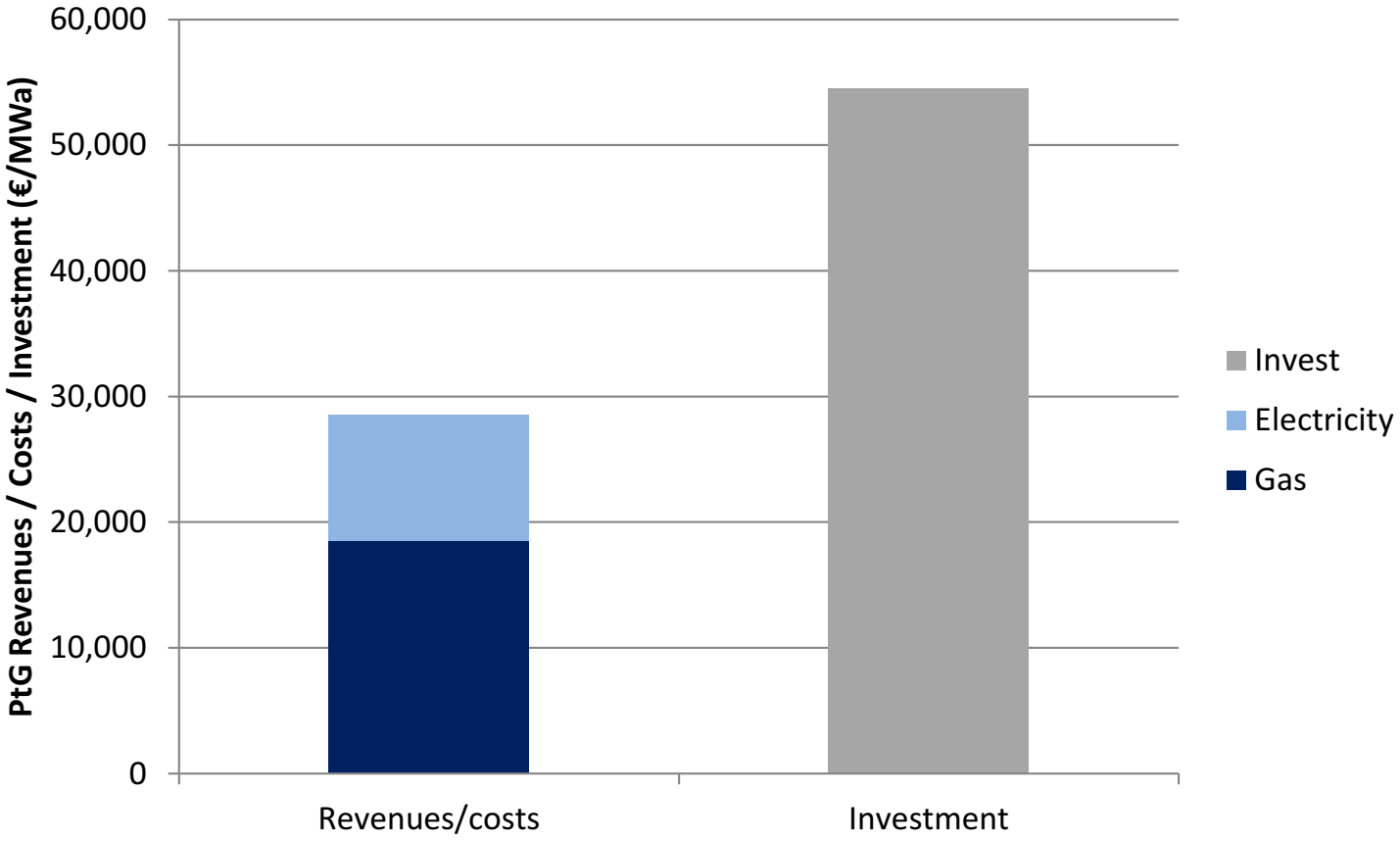
- PtG is loss-making as a standalone technology

Results



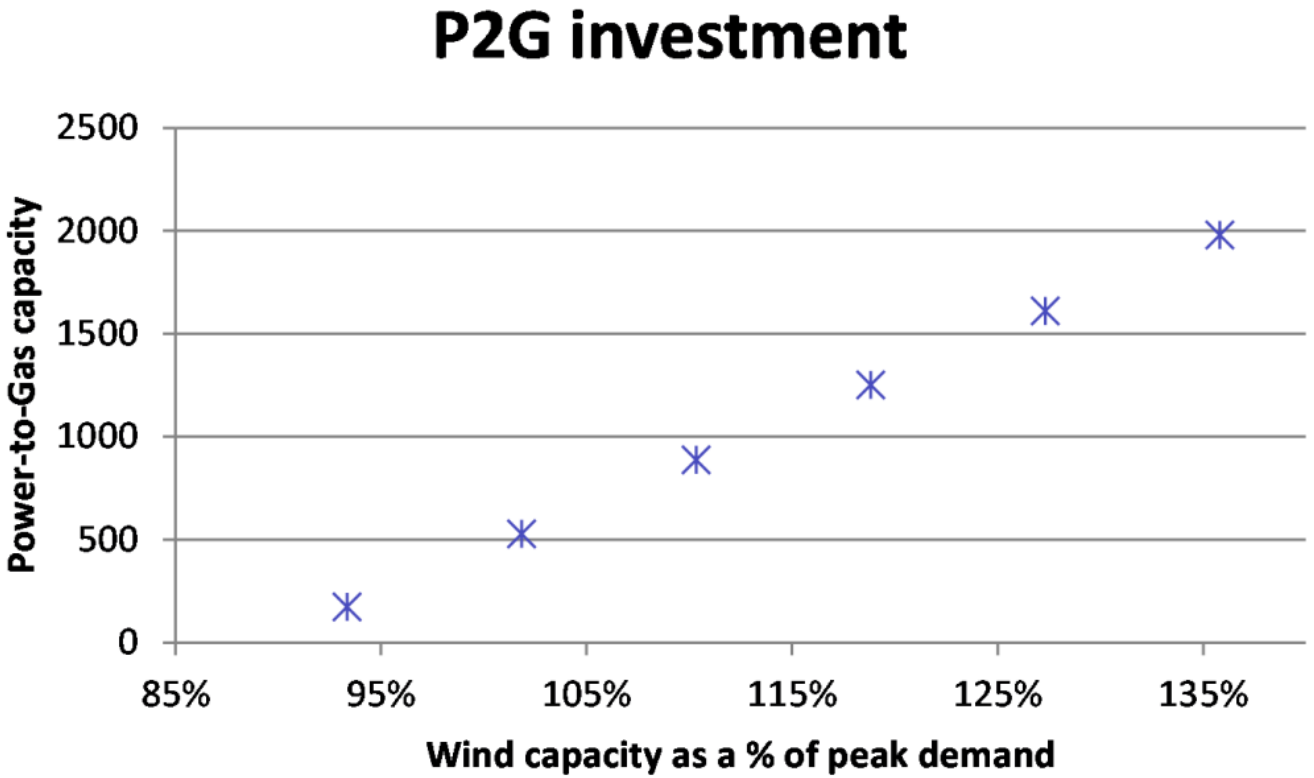
- PtG is loss-making as a standalone technology – duh

Results



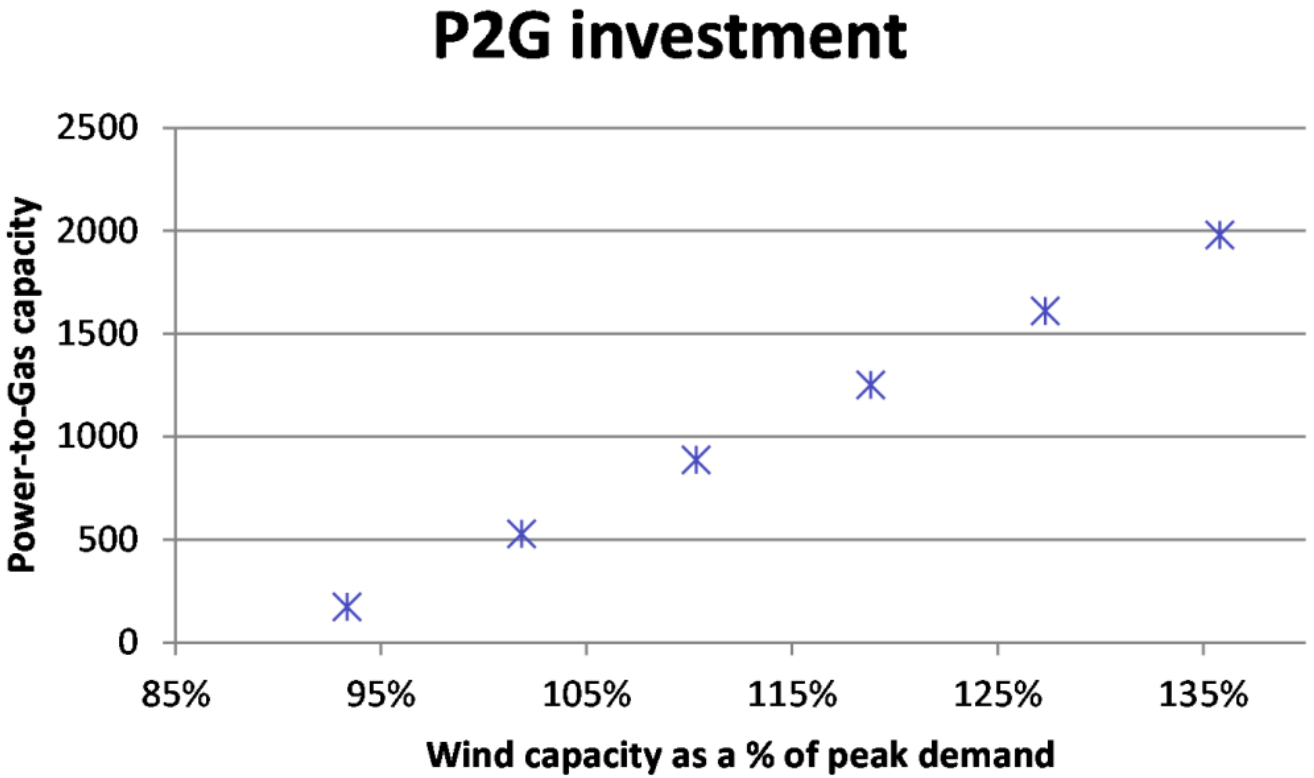
- PtG is loss-making as a standalone technology – duh
- Price gap is ~€25/MWh of gas

Results



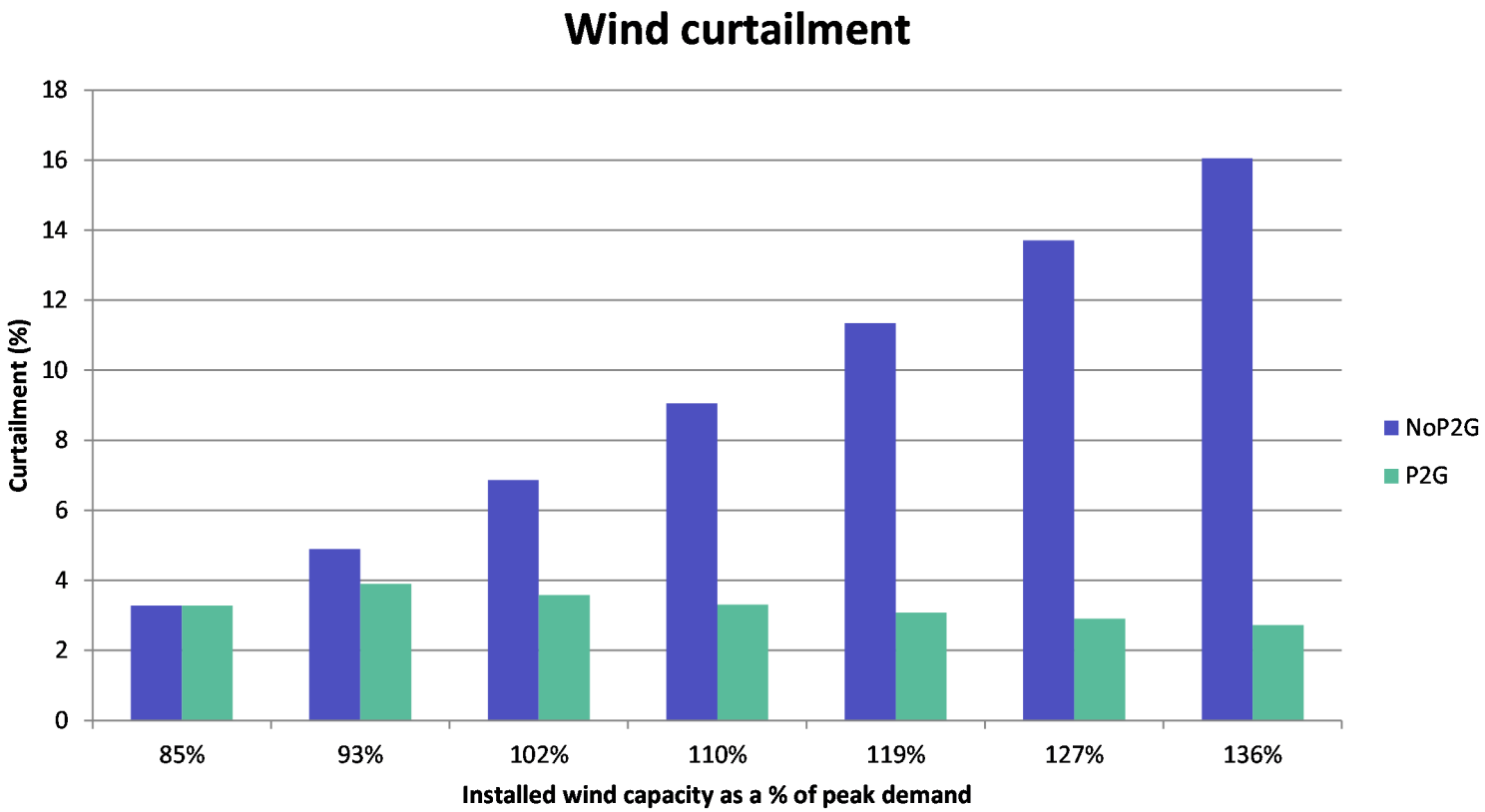
- PtG investment is positive with wind above 50% of demand

Results

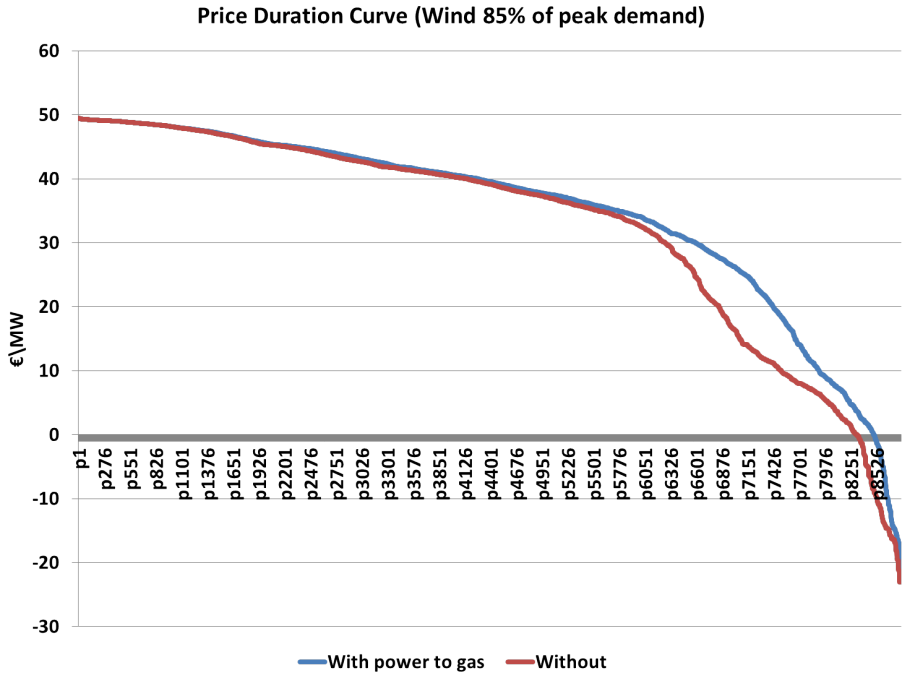


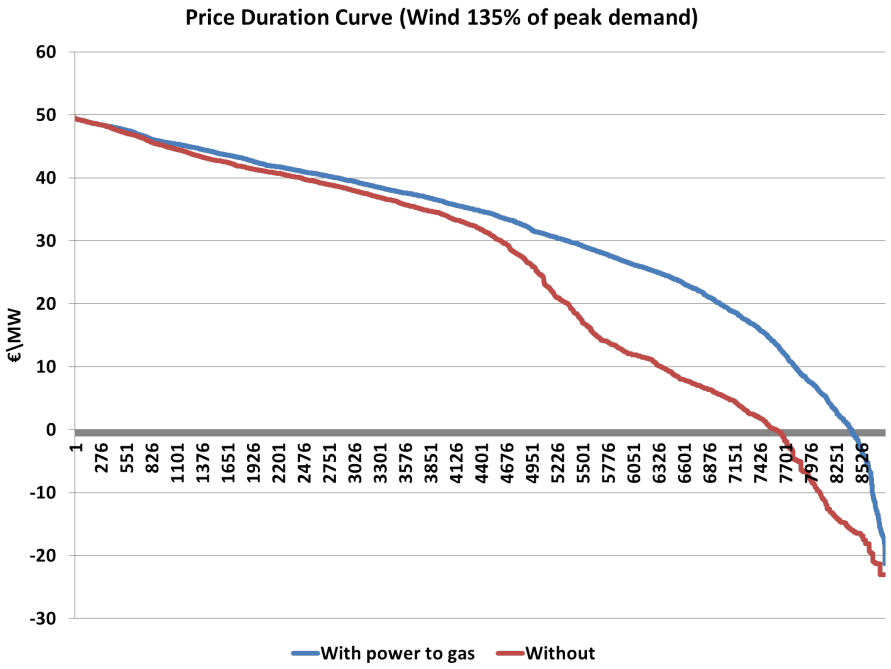
- PtG investment is positive with wind above 50% of demand
- Portfolio effect?

Results

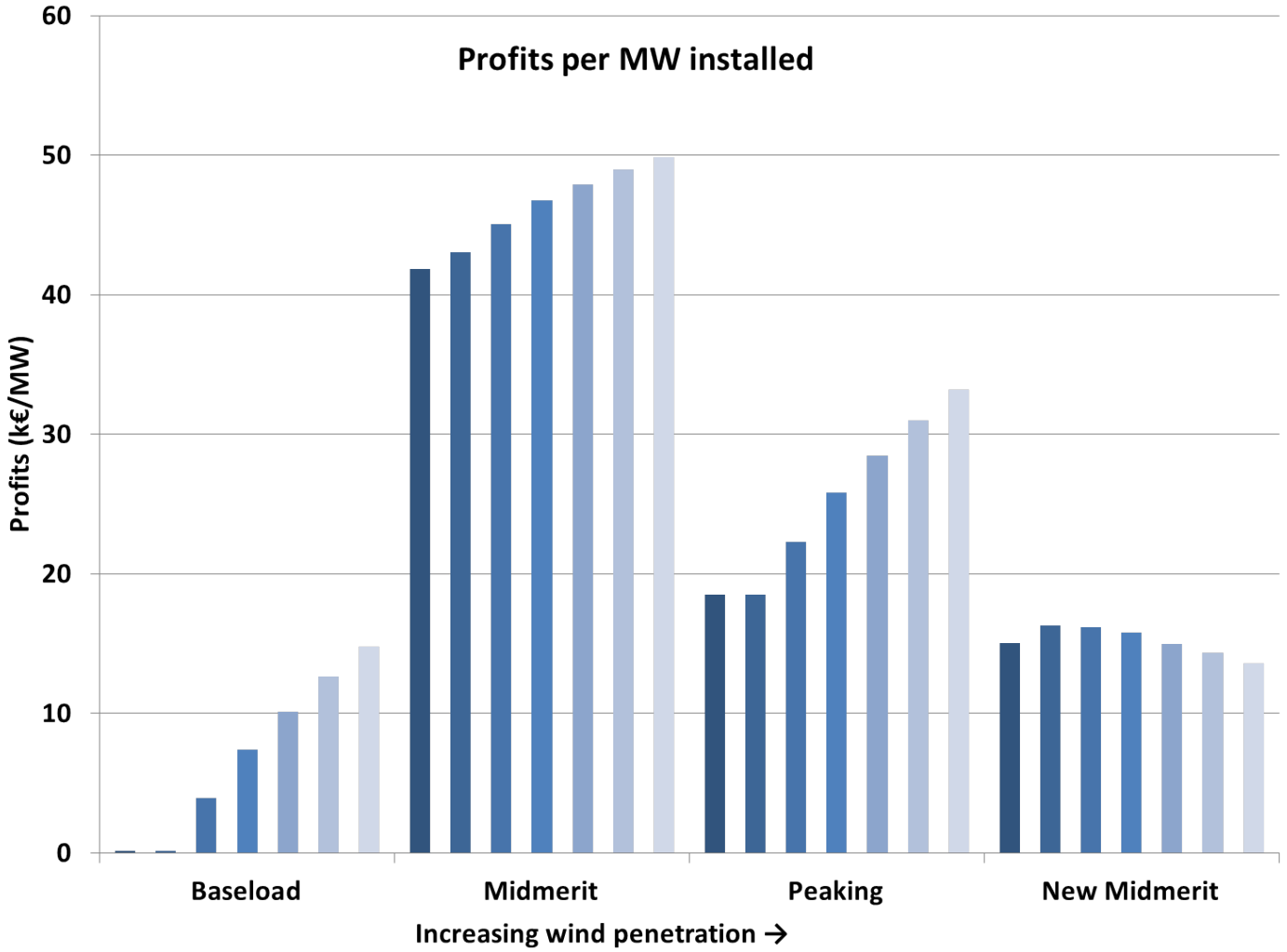

Wind curtailment
Curtailment (%)
18
16
14
12
10
8
6
4
2
0
85%
93%
102%
110%
119%
127%
136%
Installed wind capacity as a % of peak demand
NoP2G
P2G

Results

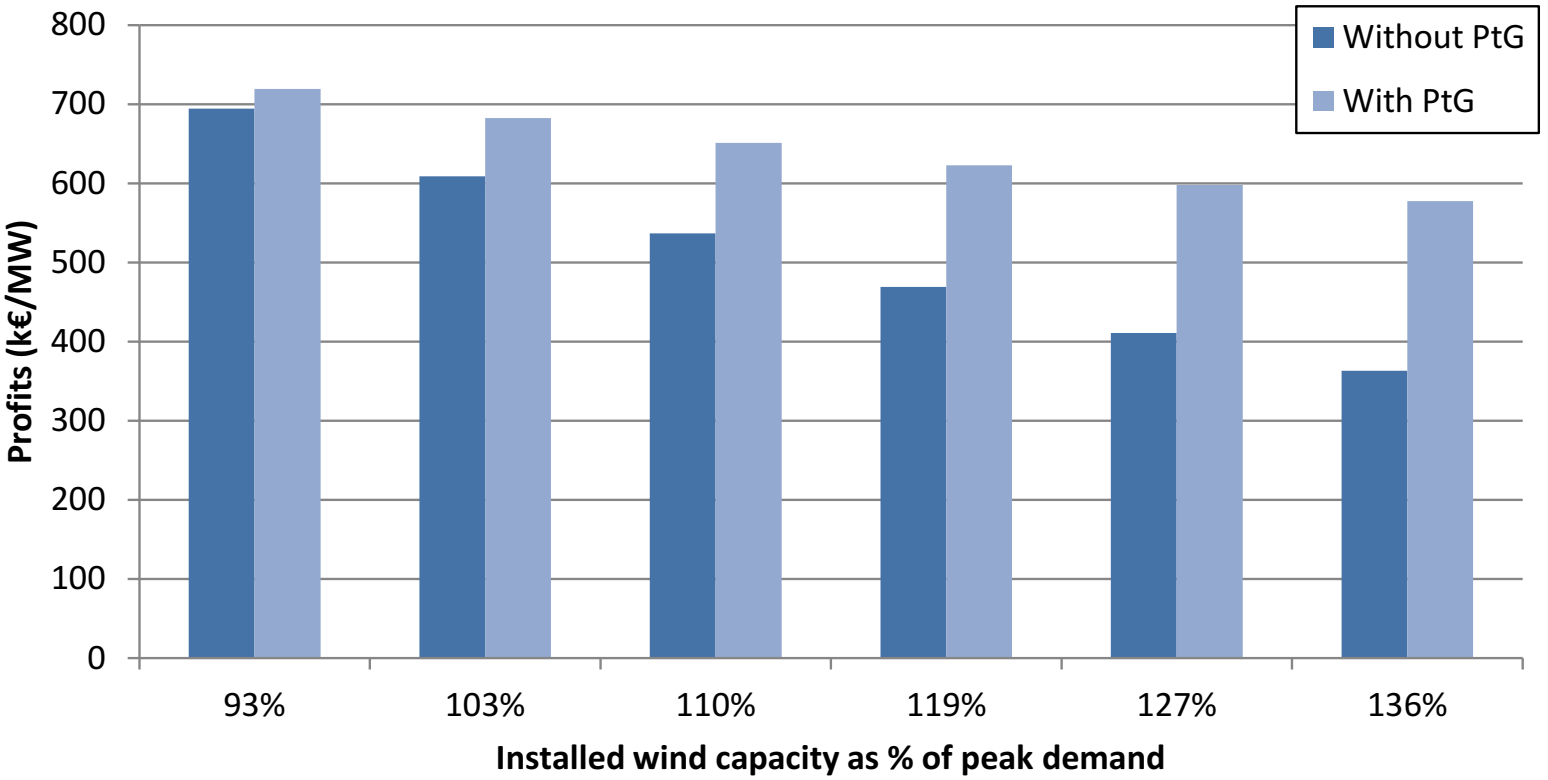

Price Duration Curve (Wind 85% of peak demand)
€\MW
60
50
40
30
20
10
0
-10
-20
-30
p1
p276
p551
p826
p1101
p1376
p1651
p1926
p2201
p2476
p2751
p3026
p3301
p3576
p3851
p4126
p4401
p4676
p4951
p5226
p5501
p5776
p6051
p6326
p6601
p6876
p7151
p7426
p7701
p7976
p8251
p8526
With power to gas
Without


Price Duration Curve (Wind 135% of peak demand)
€\MW
60
50
40
30
20
10
0
-10
-20
-30
1
276
551
826
1101
1376
1651
1926
2201
2476
2751
3026
3301
3576
3851
4126
4401
4676
4951
5226
5501
5776
6051
6326
6601
6876
7151
7426
7701
7976
8251
8526
With power to gas
Without

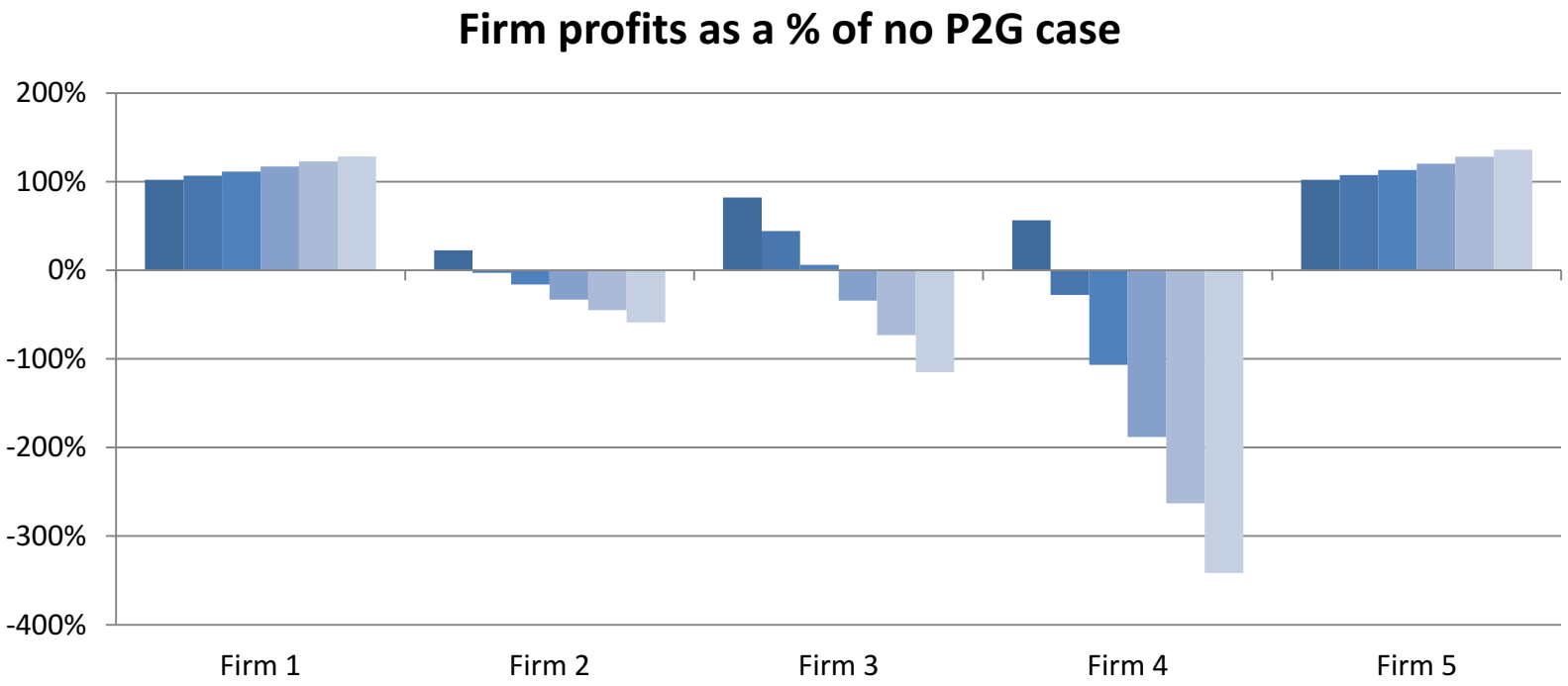
Results


Profits per MW installed
Profits (k€/MW)
60
50
40
30
20
10
0
Baseload
Midmerit
Peaking
New Midmerit
Increasing wind penetration →

Results

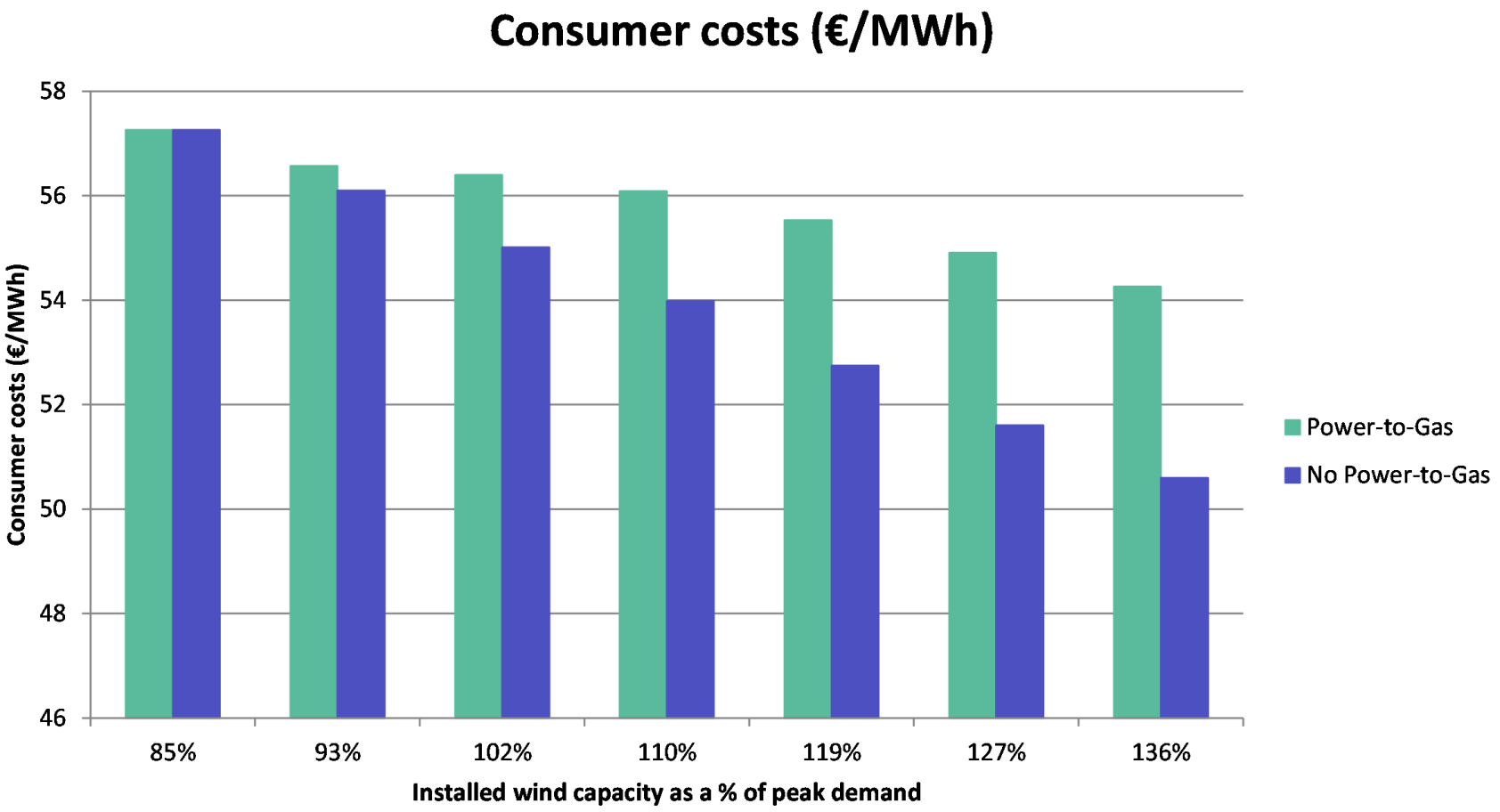

800
700
600
500
400
300
200
100
0
Profits (k€/MW)
Without PtG
With PtG
93%
103%
110%
119%
127%
136%
Installed wind capacity as % of peak demand

Results



Increasing wind penetration →

Results


Consumer costs (€/MWh)
58
56
54
52
50
48
46
Consumer costs (€/MWh)
85%
93%
102%
110%
119%
127%
136%
Installed wind capacity as a % of peak demand
Power-to-Gas
No Power-to-Gas

Conclusions

- Profit-maximising firms have an incentive to invest in loss-making Power-to-Gas
- Portfolio effects drive this result
  - Power-to-Gas increases off-peak demand
  - Renewable profits increase

Future work

- Market power – difficult to model
- Competition from alternative technologies
  - Small scale battery storage
  - Consumer investments
- Potential for “green gas” in other sectors
- Optimal mix of PtG technologies
- Potential synergies with wastewater treatment

Acknowledgements

The authors acknowledge funding from the ESRI's Energy Policy Research Centre. All omissions and errors are our own.