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Prosumers with power to gas (P2G) in cross-country electricity markets based on a game-theoretic equilibrium model

07.06.2021
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Introduction

• Demand profiles typically exhibit a mismatch to energy supply options
  - by intermittent generation of solar PV (38 times increase from 2009 to 2019 in Switzerland) and wind power
  - by the seasonal availability of hydro power
• Emission reduction targets
  - limit the global temperature increase to 1.5 degrees
  - net-zero emissions by 2050

• need to increase flexibility and reliability of electricity system
• require the deployment of new low-carbon energy transition solutions
Research questions

• How electricity markets drive the operation of P2G technologies of different players, e.g. big national players and small prosumers?

• What factors will affect the deployment and operation of P2G technologies of prosumers and how these factors influence?
  - Likely factors include distribution capacity, grid tariffs, CO2 prices.

• What is the impacts on the electricity market if many prosumers (with P2G facilities) join the markets?
Introduction
Prosumer conceptual idea

![Diagram of energy system components]

- PV/ROR
- Electrolyser
- Fuel Cell
- Battery
- Hydrogen Tank
- Electricity & Heat Load
- Heat supplier

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- Intraday market
- Gas market
- Heating market
- Capacity market
- Chem industry
- Mobility
Methodology
Cross-Border Electricity Market (BEM) Model

A numerical model to maximize the profit for each player subject to physical constraints.
Objective function for player $i$: $\max_{q_i} P(q_i) \cdot q_i - \text{Cost} \cdot q_i$

**Inputs**
- technology capacity and availability
- marginal generation cost
- transmission capacity
- regional demand

**BEM**
- technology-detailed
- game-theoretic
- Nash-Cournot
- equilibrium model
- market power

**Outputs**
- market clearing prices and volumes
- production
- net imports
- new technology investments
Methodology
Cross-Border Electricity Market (BEM) Model

Main settings

**Players**
Five country players (Austria, France, Germany, Italy, Switzerland) + prosumer (with P2G) player

**Time slices**
Four seasons with 24 typical hours for each season (4*24 hours)

**Generation Tech**
Multiple supply technologies (coal, lignite, oil (steam, turbine, CC), gas (steam, turbine, CC), nuclear, biomass-waste, run of river, hydro-storage, wind, PV, battery) + P2G technology (electrolyser, fuel cell (CHP), H2 tank, underground H2 storage, methanation)

**Nodes**
Five country-scale nodes (Austria, France, Germany, Italy, Switzerland) so far

**Import/export**

![Diagram showing import/export flows between countries: FR, DE, CH, AT, IT]
Prosumer scales:

• **Small case: Zernez-based**
  Technologies: PV, Battery, Eheatpump,
  P2X technologies (Electrolyser, Fuelcell, Fuelcell_CHP, Methanation, H2 Tank)

• **Medium case: Basel-based**
  Technologies: **Run of river**, PV, Battery, Eheatpump,
  P2X technologies (Electrolyser, Fuelcell, Fuelcell_CHP, Methanation, H2 Tank)

In the small and medium cases, prosumer players have to pay for the distribution grid fee and are subject to distribution line capacity constraints.

• **Large case: National level**
  Without distribution line capacity constraints and grid fees.
  - One player owns all plants including normal generation plants and P2G facilities;
  - Separate (S): separate players own normal generation plants and P2G facilities.

**Renewable scenarios:**
**Today, Year 2030, Energy Strategy 2050, Zero-Emission 2050**
Results
Small scale (Zernez, 0.1 MW electrolyser), Zero-emission 2050, Without direct H2 selling

- H2 tank capacity (decided endogenously in the model): 1.8 MWh
Results

Small scale (Zernez, 0.1 MW electrolyser), Zero-emission 2050, With direct H2 selling

- H2 tank capacity (decided endogenously in the model): 3.4 MWh
- New electrolyser investment: 0.36 MW
Results
Medium scale (Basel, 17.8 MW electrolyser), Zero-emission 2050
Without direct H2 selling

- H2 tank capacity (decided endogenously in the model): 440 MWh (about 25 times of installed electrolyser)
- $440 \times 90 = 40000 \text{MWh} = 9500 \text{ESI}$
Results

Medium scale (Basel, 17.8 MW electrolyser), Zero-emission 2050
With direct H2 selling

- H2 tank capacity (decided endogenously in the model): 475 MWh
- New electrolyser investment: 34 MW
Results
Impacts of distribution grid fees
Small scale (Zernez), Zero-emission 2050

With the increasing distribution grid tariffs, the generation of P2G facilities increases.
Results
Impacts of distribution grid fees
Medium scale (Basel), Zero-emission 2050

- With the increasing distribution grid tariffs, the generation of P2G facilities increases.
Results
Impacts of distribution grid capacities
Medium scale (Basel), Zero-emission 2050

- With the increasing distribution grid capacities, the generation of P2G facilities decreases.
Results
National scale (Switzerland), Zero-emission 2050
Without direct H2 selling

- Electrolyser investment: 622 MW
- Underground H2 storage investment: 5222 MWh
- Methanation investment: 194 MW
- For National player, no fixed local demand has to be satisfied. The demand is elastic with prices.
- As a result, the seasonal shift is not profitable using FC/FC CHP.
Results
National scale (Switzerland), Zero-emission 2050
With direct H2 selling

- Electrolyser investment: 1343 MW (two times larger)
- No requirement for H2 storage.
Results and discussions
Impacts of P2G on electricity market prices
Zero-emission 2050

<table>
<thead>
<tr>
<th></th>
<th>Standard deviation EUR/MWh</th>
<th>No P2G</th>
<th>P2G, no direct H2 selling</th>
<th>P2G + direct H2 selling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switzerland</td>
<td>30.0</td>
<td>31.3</td>
<td>27.6</td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>34.5</td>
<td>31.6</td>
<td>27.7</td>
<td></td>
</tr>
</tbody>
</table>
## Results

Impacts of P2G on electricity market

Zero-emission 2050

### Summary of P2G impacts on Switzerland compared with no P2G situation

<table>
<thead>
<tr>
<th>Cases</th>
<th>Renewable generation (PV + Wind)</th>
<th>Battery Discharging</th>
<th>Operational profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>National, P2G</td>
<td>no direct H2 selling</td>
<td>13.2%</td>
<td>-12.6%</td>
</tr>
<tr>
<td></td>
<td>direct H2 selling</td>
<td>17.9%</td>
<td>-19.5%</td>
</tr>
<tr>
<td>National, P2G, Separate</td>
<td>no direct H2 selling</td>
<td>Separate player does not invest any P2G facilities.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>direct H2 selling</td>
<td>10.3%</td>
<td>5.5%</td>
</tr>
</tbody>
</table>

1. Sum of normal and P2G player
Key messages

• For a small prosumer connected to the distribution grid,
  • more P2G technologies are used with reduced grid capacities or increased grid tariffs, but the mechanism behind varies.
  • the reaction of prosumers to the increasing “islanding” effect depends on its local energy surplus/shortage.

• From the national case, it is shown that P2G technologies can help reduce market variance, increase renewable generation, and increase operational profit if multiple/large plants are invested (more likely when direct H2 selling is introduced).

• Introducing direct selling as a pathway for green H2 can promote electrolyser investment and H2 production.
My thanks go to

• Dr. Martin Densing
• Dr. Tom Kober
• Dr. Evangelos Panos
• Prof. Dr. Thomas Schmidt

and all support from team members.
Thank you very much for your attention.

Thanks a lot for the support from the Renewable Management and Real-Time Control Platform (ReMaP).

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Day-ahead electricity market prices,
Zero-emission 2050 scenario, France

- No P2G
- P2G, no direct H2 selling
- P2G, direct H2 selling
Day-ahead electricity market prices,
Zero-emission 2050 scenario, German

Market prices EUR/MWh

Time slices

WI-D-01  WI-D-19  SP-D-13  SU-D-08  FA-D-03  FA-D-21