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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

remap

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  - Prosumer conceptual idea
- Methodology
  - Cross-Border Electricity Market (BEM) Model
- Results and discussions
- Key messages

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

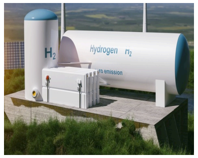
  - by the seasonal availability of hydro power

- Emission reduction targets

  - limit the global temperature increase to 1.5 degrees

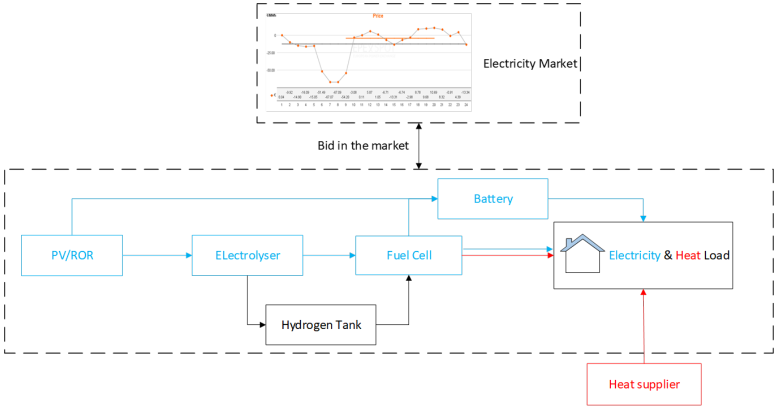
  - net-zero emissions by 2050

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

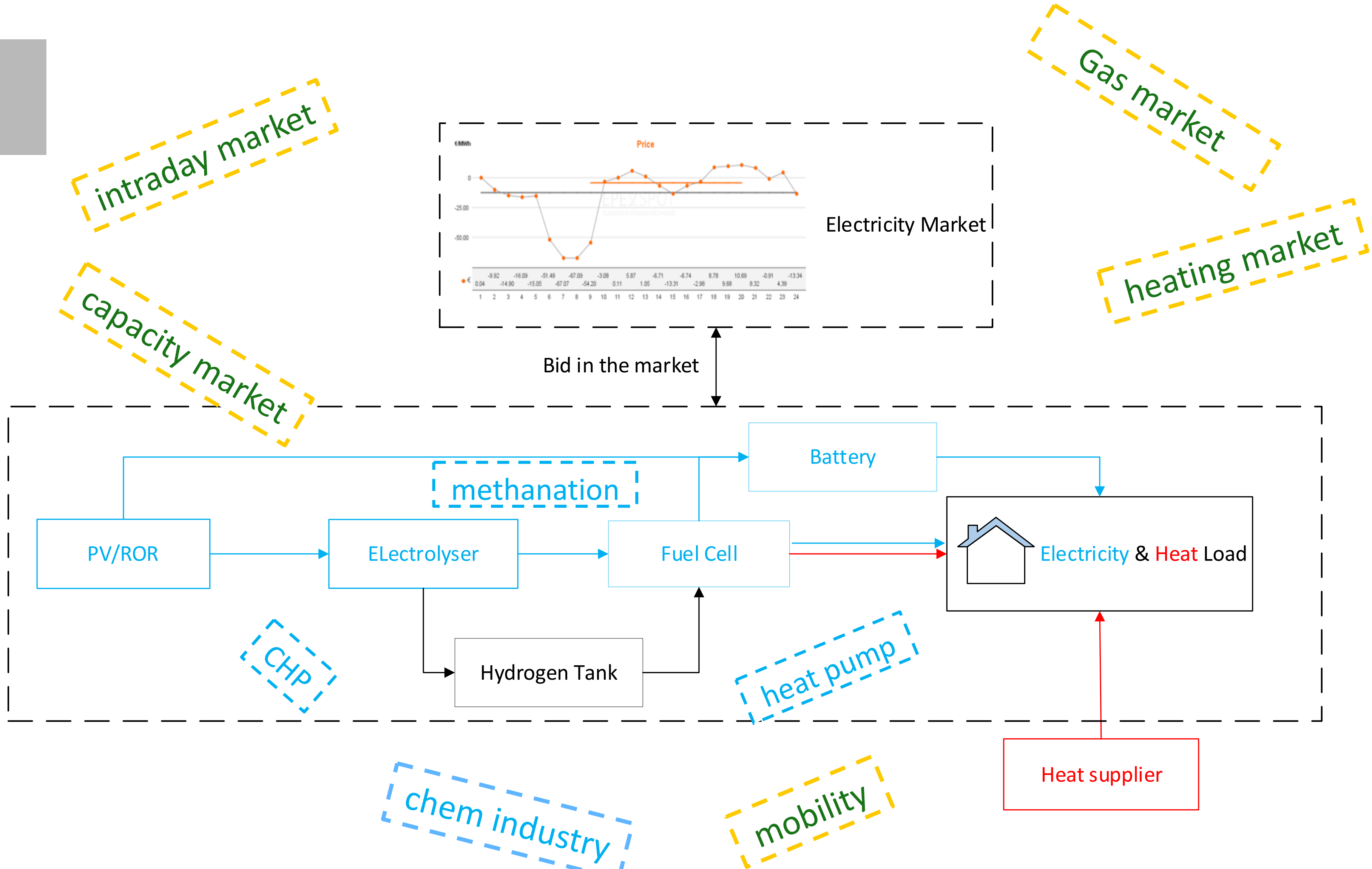


Research questions

- 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



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: $\max_{q\_i} P(q\_i) \cdot q\_i - Cost \cdot q\_i$

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)

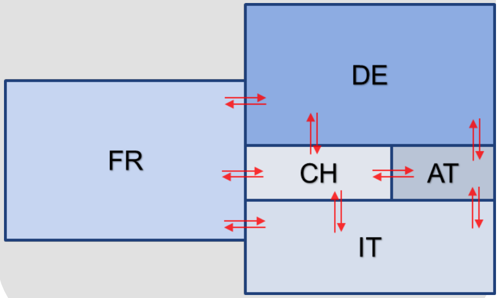
Generation Tech

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



Methodology
Prosumer settings and scenario assumptions

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.

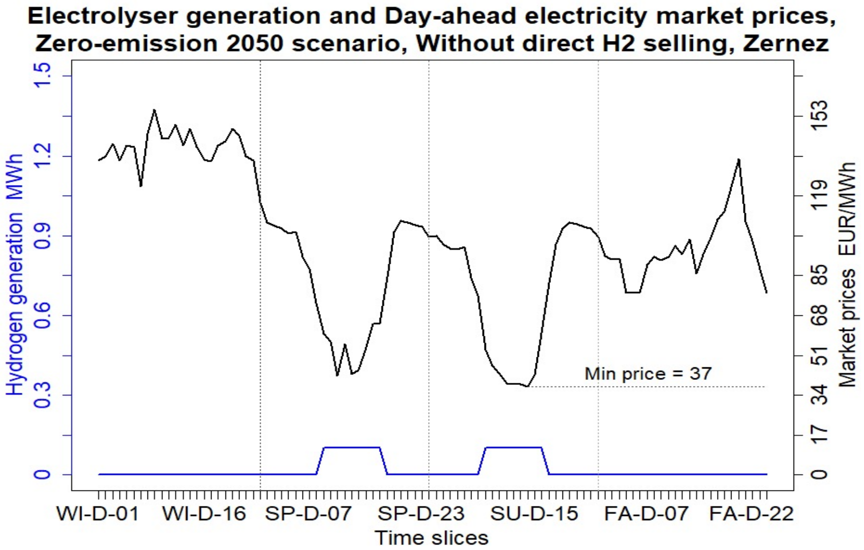
- **Large case: National level**
  Without distribution line capacity constraints and grid fees.
  - One player owns all plants including normal generation plants and P2G facilities;
  - Separate (S): separate players own normal generation plants and P2G facilities.

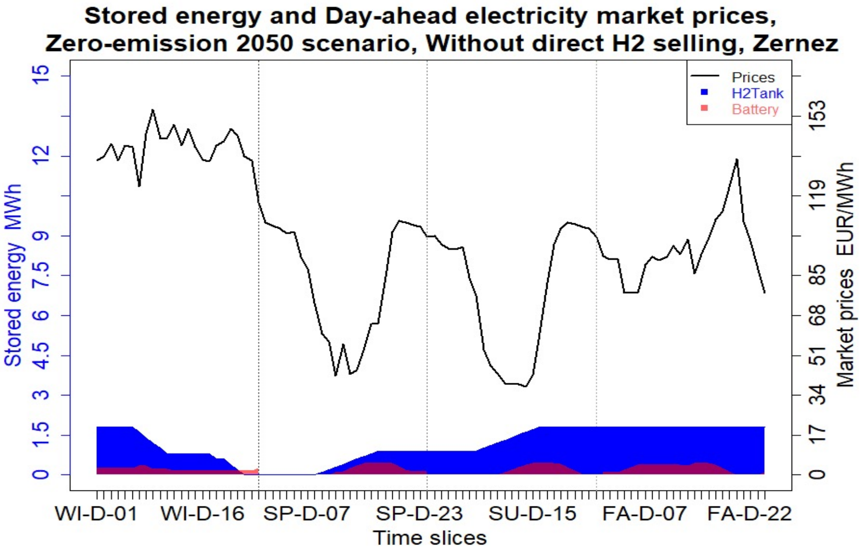
Renewable scenarios:

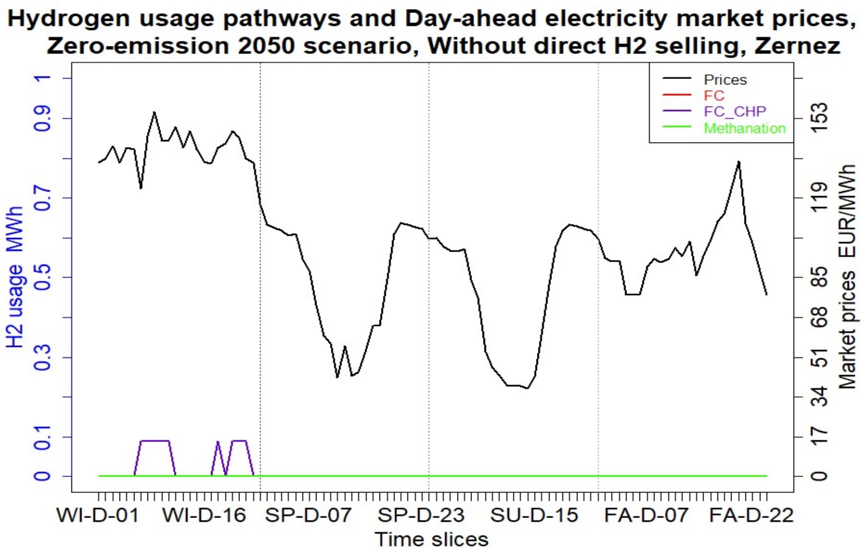
Today, Year 2030, Energy Strategy 2050, Zero-Emission 2050

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

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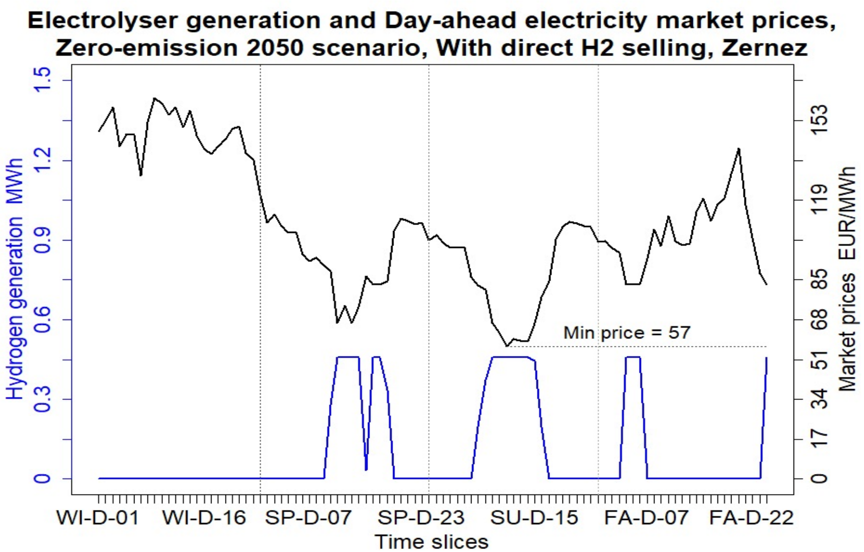
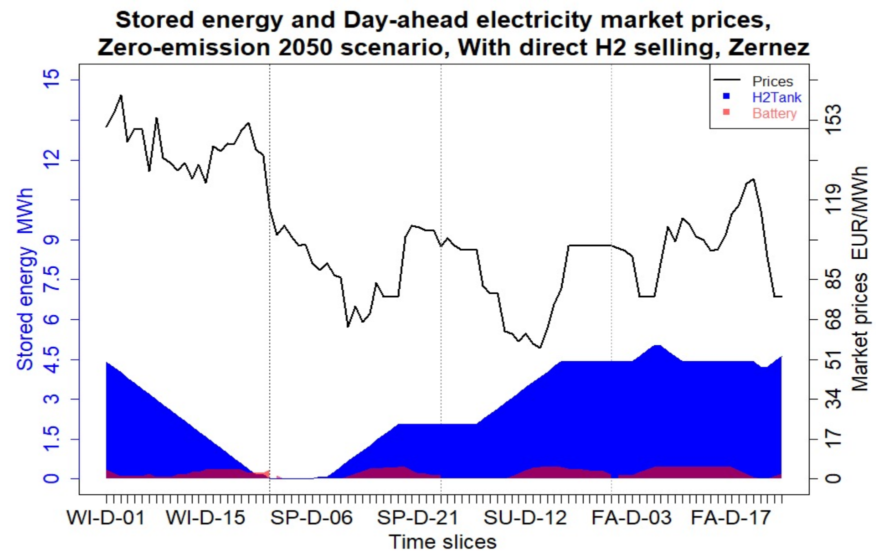
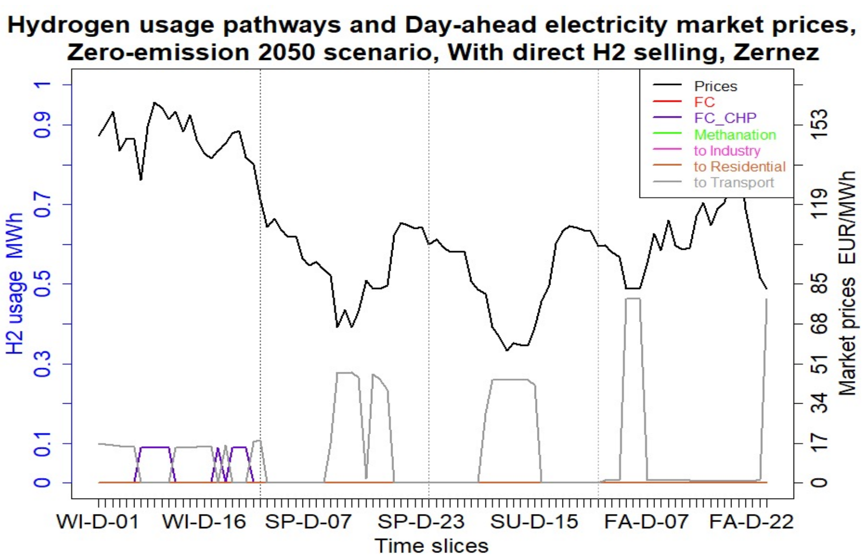
Results

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

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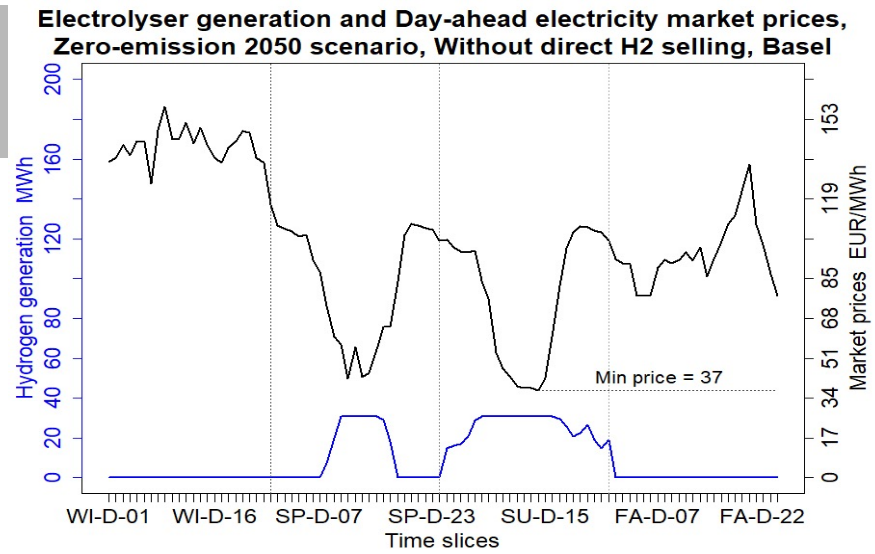
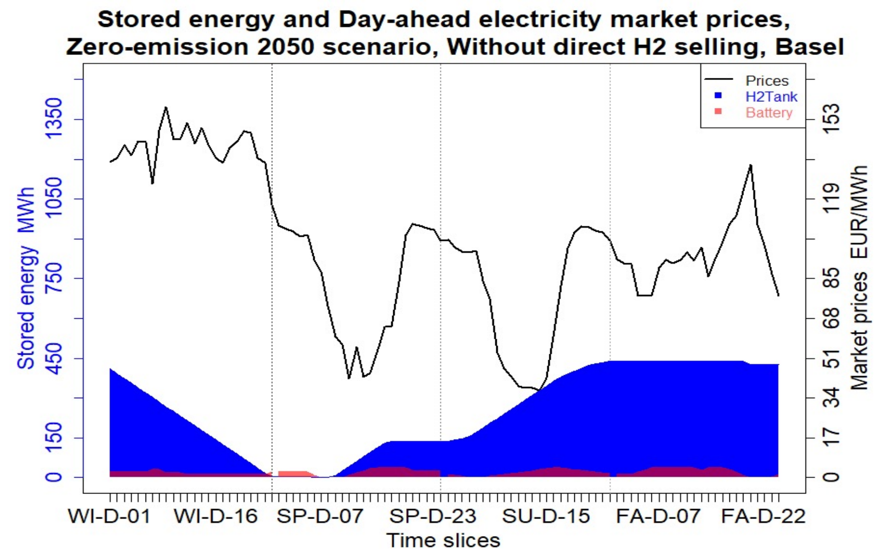
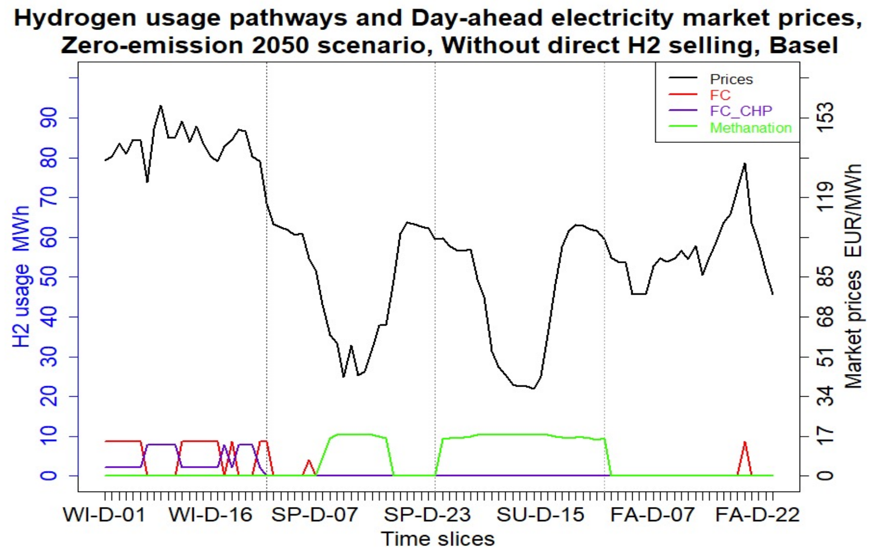
Results

Medium scale (Basel, 17.8 MW electrolyser), Zero-emission 2050 Without direct H2 selling



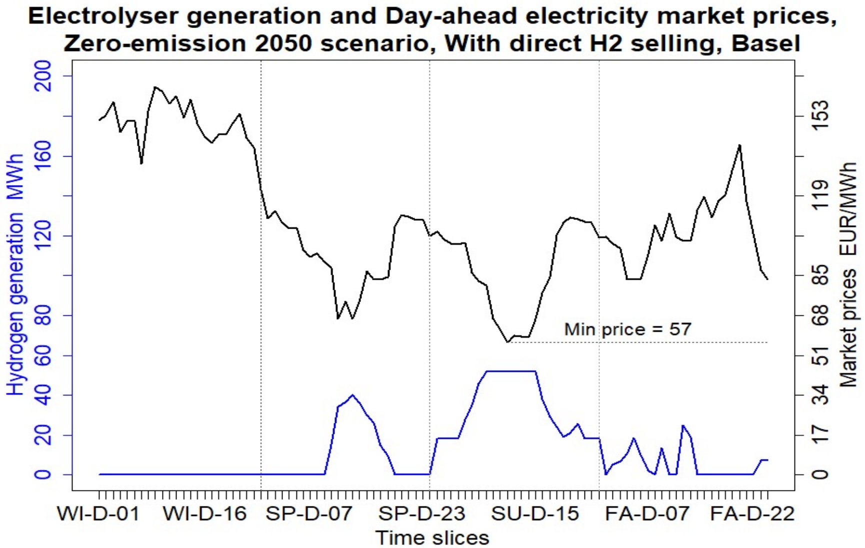


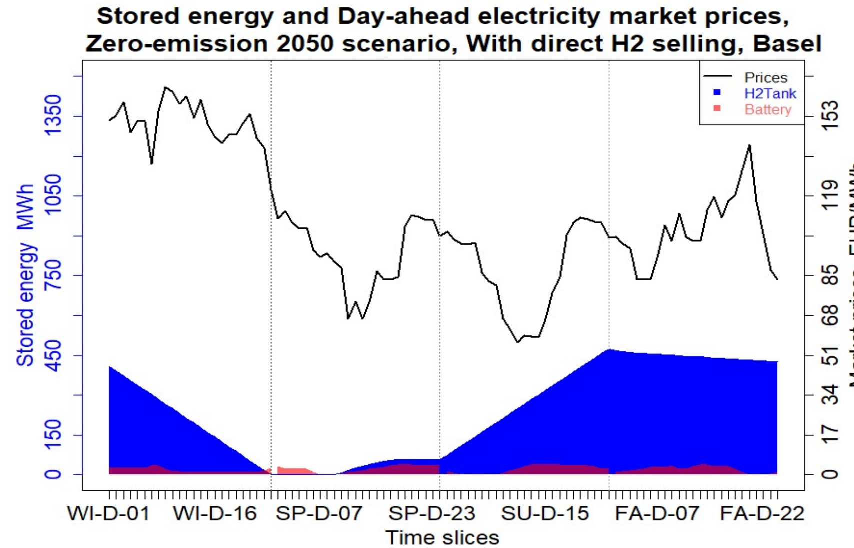


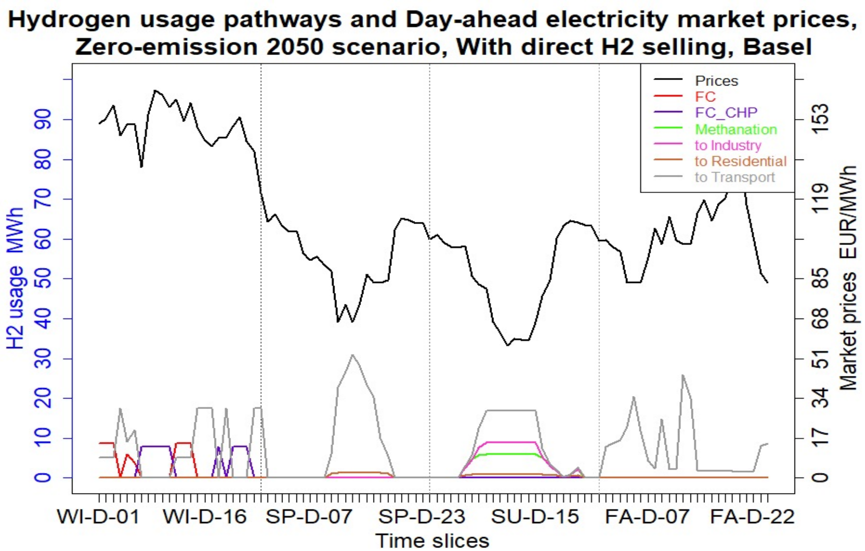
- H2 tank capacity (decided endogenously in the model): 440 MWh (about 25 times of installed electrolyser)
- 440*90=40000MWh=9500 ESI

Results

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



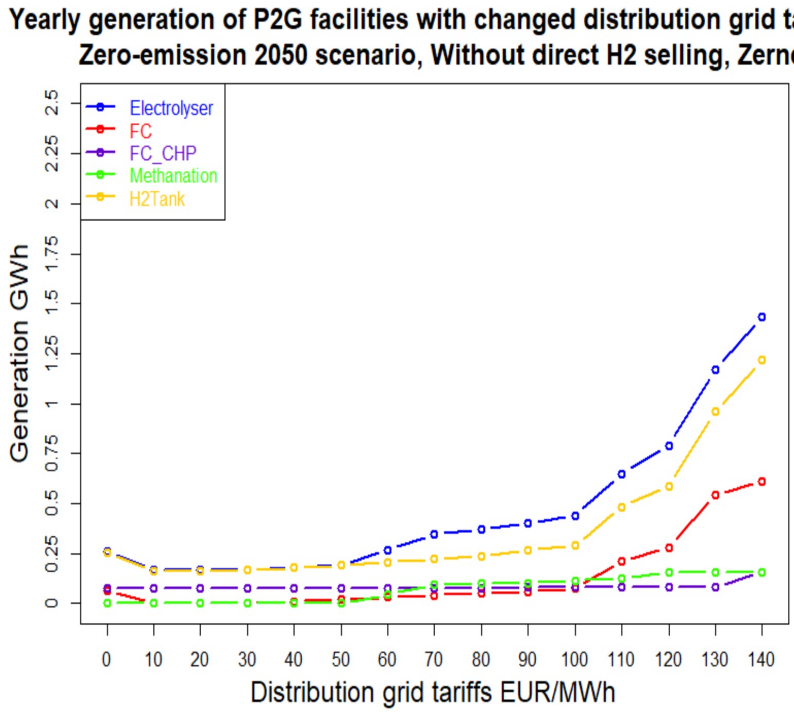


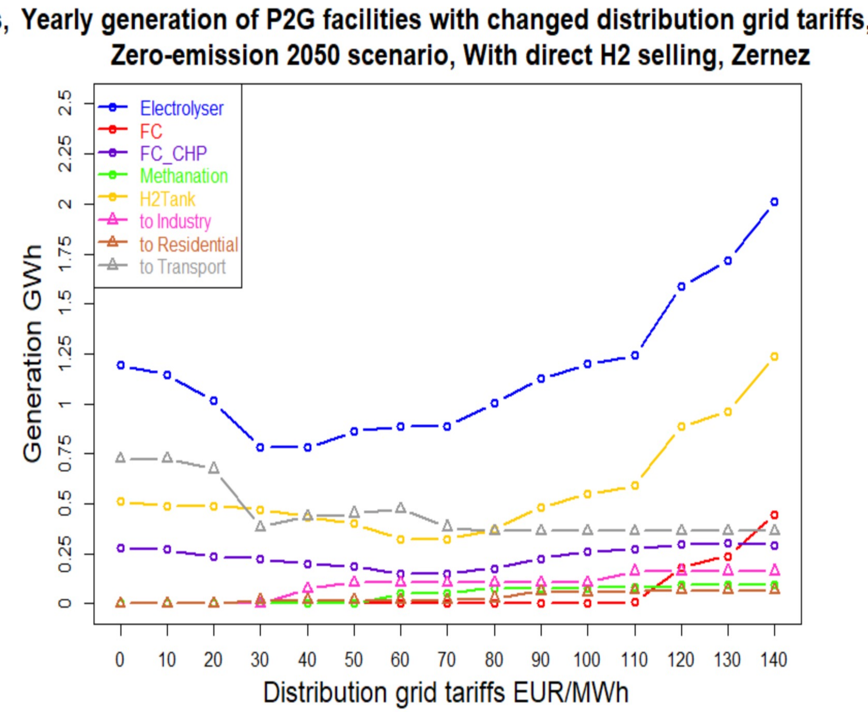


- H2 tank capacity (decided endogenously in the model): 475 MWh
- New electrolyser investment: 34 MW

Results

Impacts of distribution grid fees
Small scale (Zernez), Zero-emission 2050



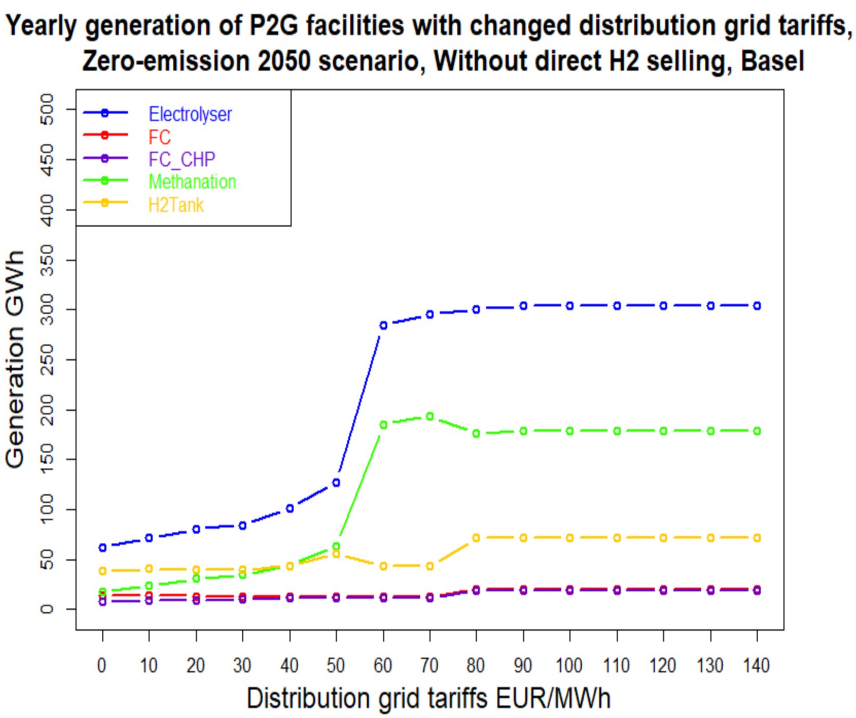


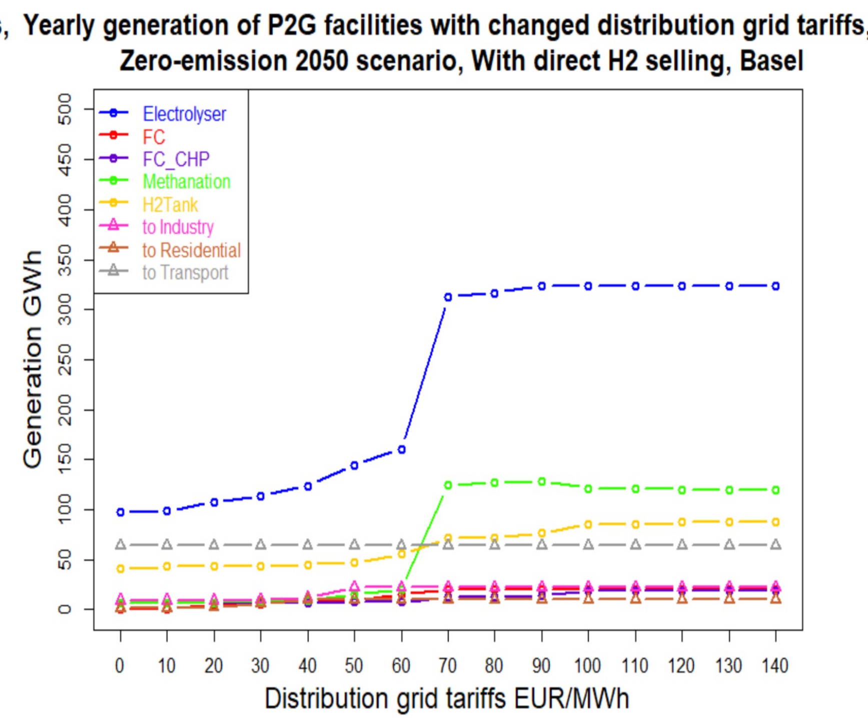
- With the increasing distribution grid tariffs, the generation of P2G facilities increases.

buyer

Results

Impacts of distribution grid fees
Medium scale (Basel), Zero-emission 2050



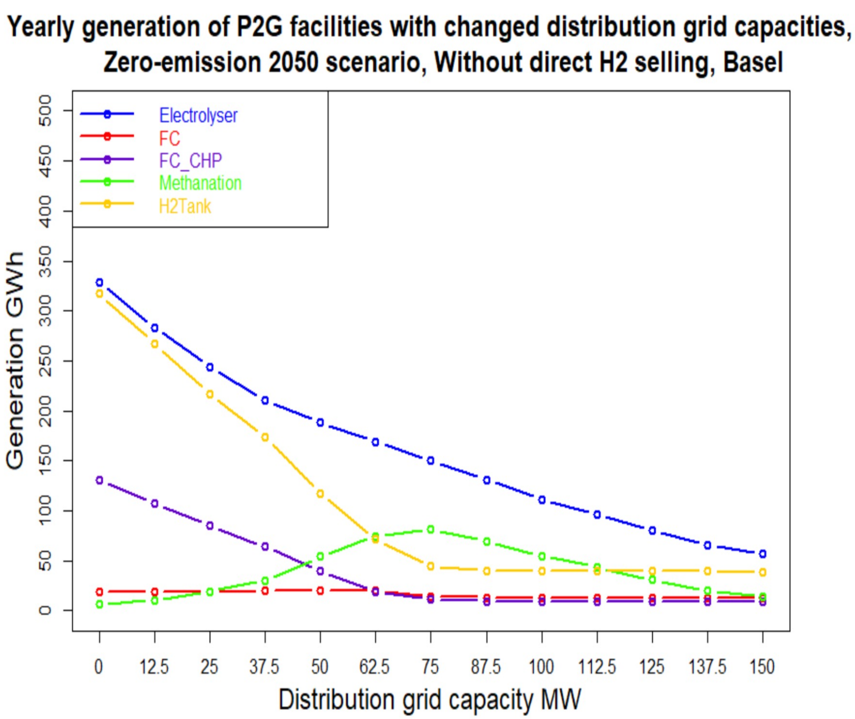


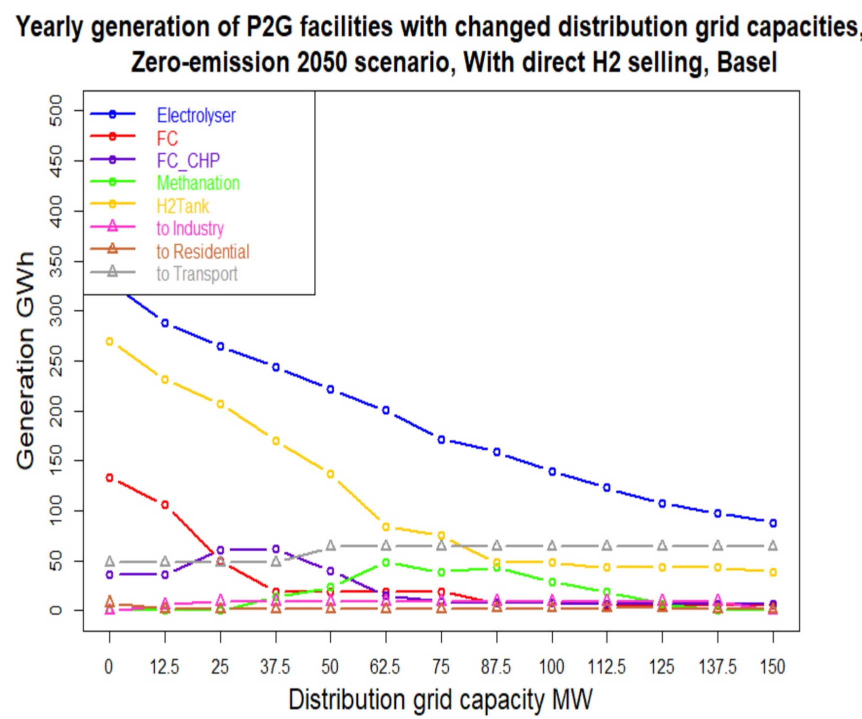
- With the increasing distribution grid tariffs, the generation of P2G facilities increases.

seller

Results

Impacts of distribution grid capacities
Medium scale (Basel), Zero-emission 2050



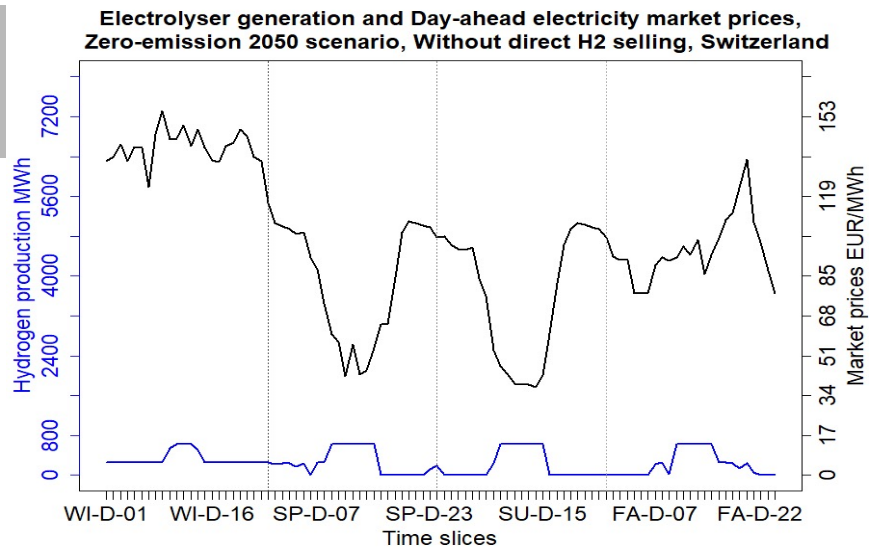


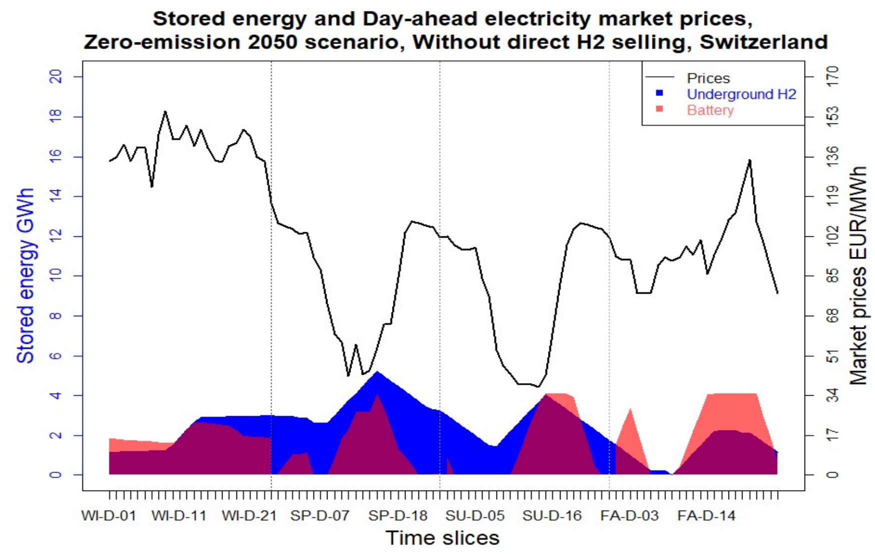
- With the increasing distribution grid capacities, the generation of P2G facilities decreases.

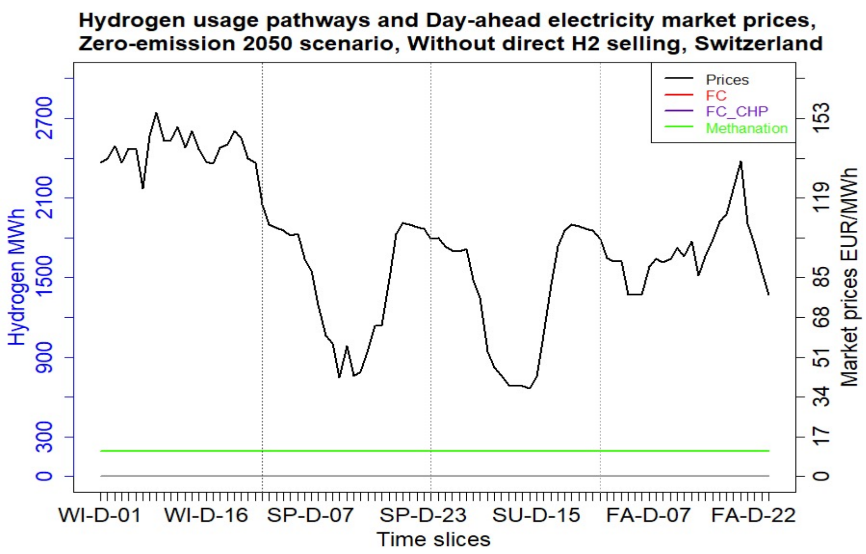
seller

Results

National scale (Switzerland), Zero-emission 2050
Without direct H2 selling



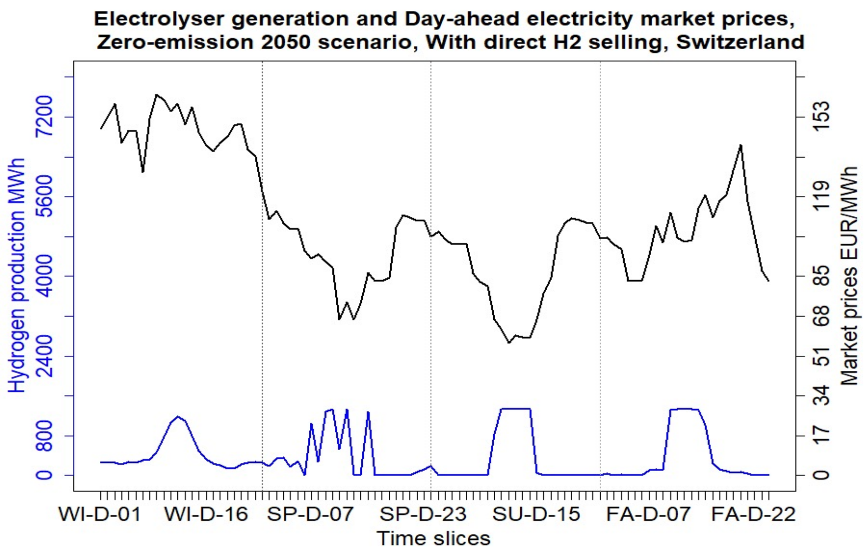


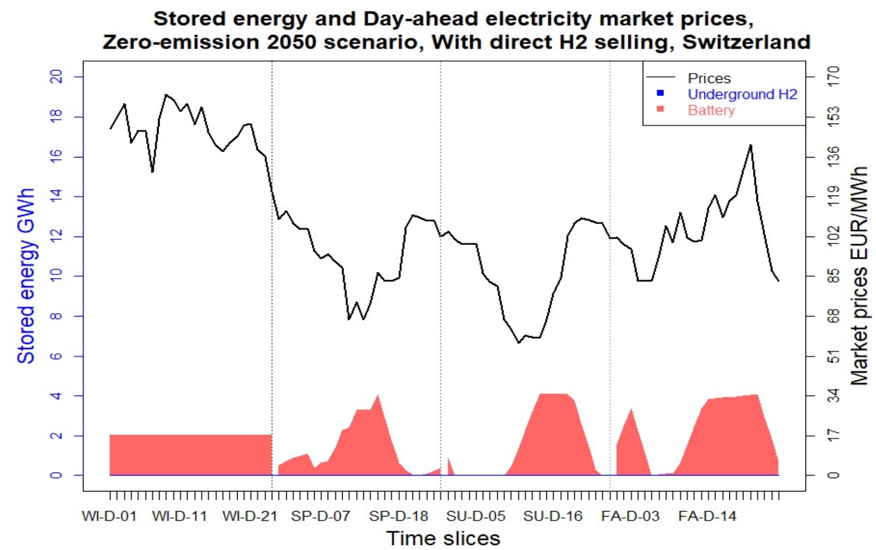


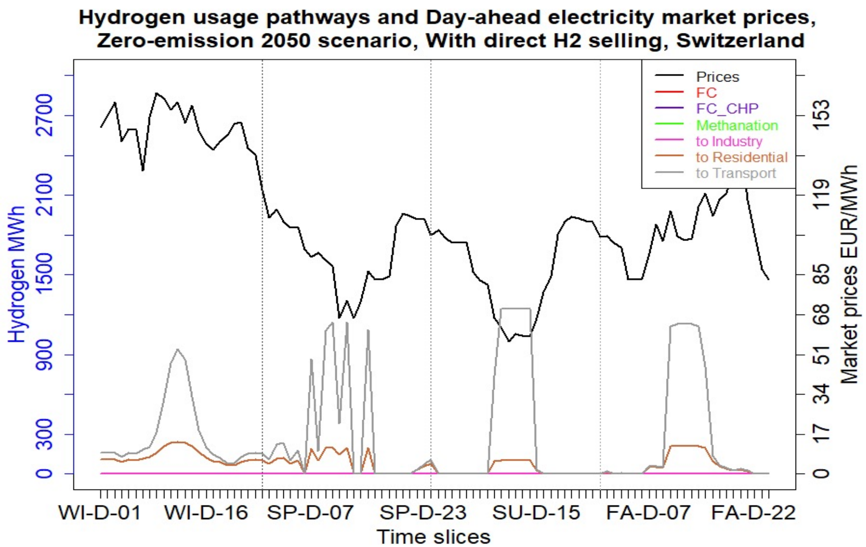
- Electrolyser investment: 622 MW
- Underground H2 storage investment: 5222 MWh
- Methanation investment: 194 MW
- For National player, no fixed local demand has to be satisfied. The demand is elastic with prices.
- As a result, the seasonal shift is not profitable using FC/FC CHP.

Results

National scale (Switzerland), Zero-emission 2050
With direct H2 selling



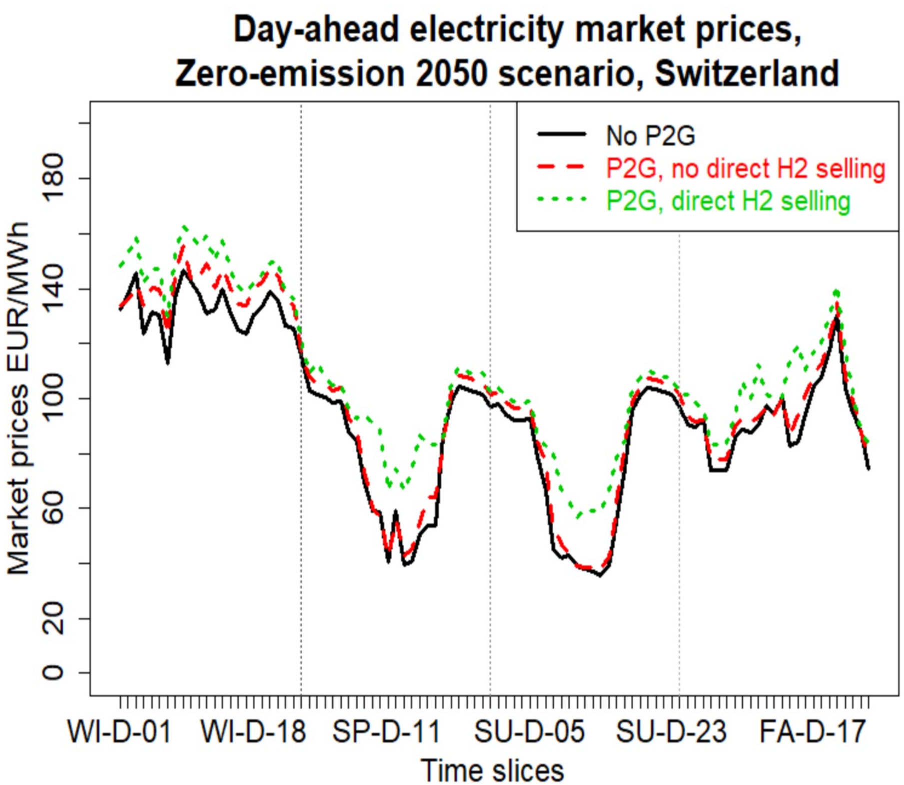


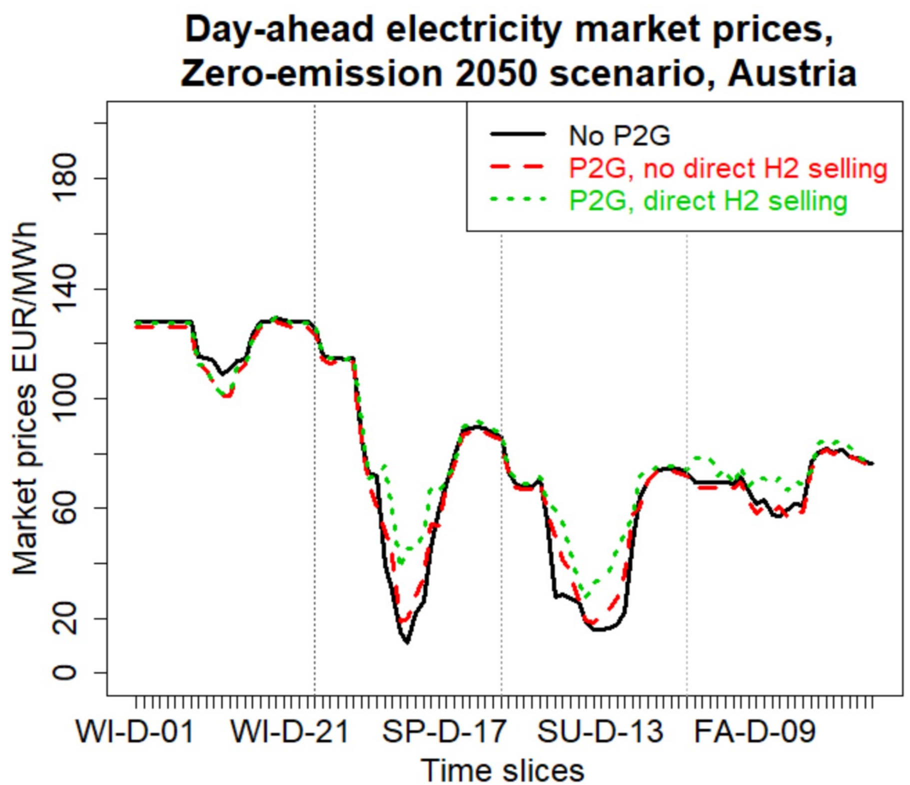


- Electrolyser investment: 1343 MW
  (two times larger)
- No requirement for H2 storage.

Results and discussions

Impacts of P2G on electricity market prices
Zero-emission 2050





Standard deviation EUR/MWh	No P2G	P2G, no direct H2 selling	P2G + direct H2 selling
Switzerland	30.0	31.3	27.6
Austria	34.5	31.6	27.7

Results

Impacts of P2G on electricity market
Zero-emission 2050

Summary of P2G impacts on Switzerland compared with no P2G situation

Cases		Renewable generation (PV + Wind)	Battery Discharging	Operational profit
National, P2G	no direct H2 selling	13.2%	-12.6%	4.2%
	direct H2 selling	17.9%	-19.5%	26.6%
National, P2G, Separate	no direct H2 selling	Separate player does not invest any P2G facilities.		
	direct H2 selling	10.3%	5.5%	22.3%[1]

1. Sum of normal and P2G player

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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.

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- Dr. Evangelos Panos
- Prof. Dr. Thomas Schmidt

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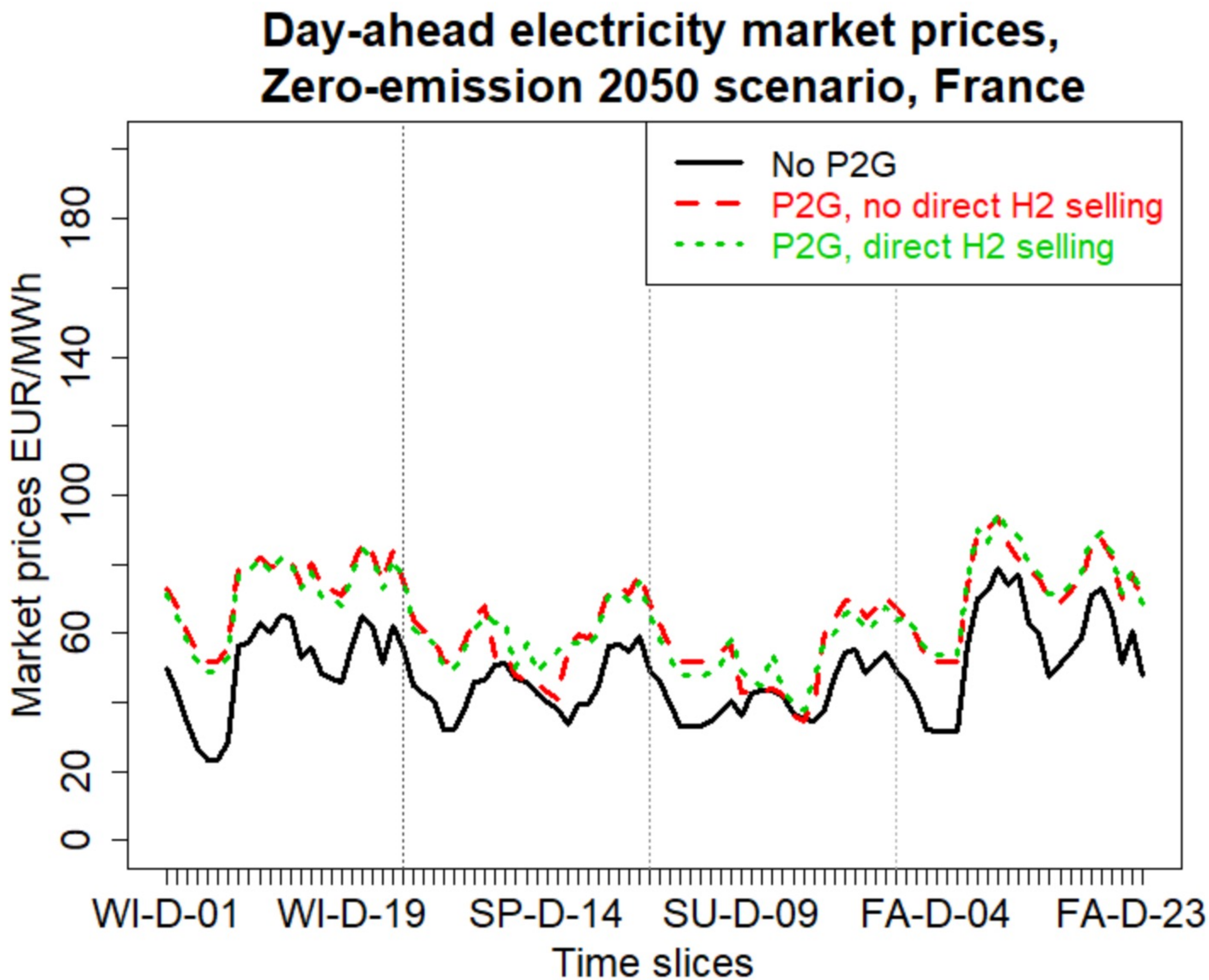
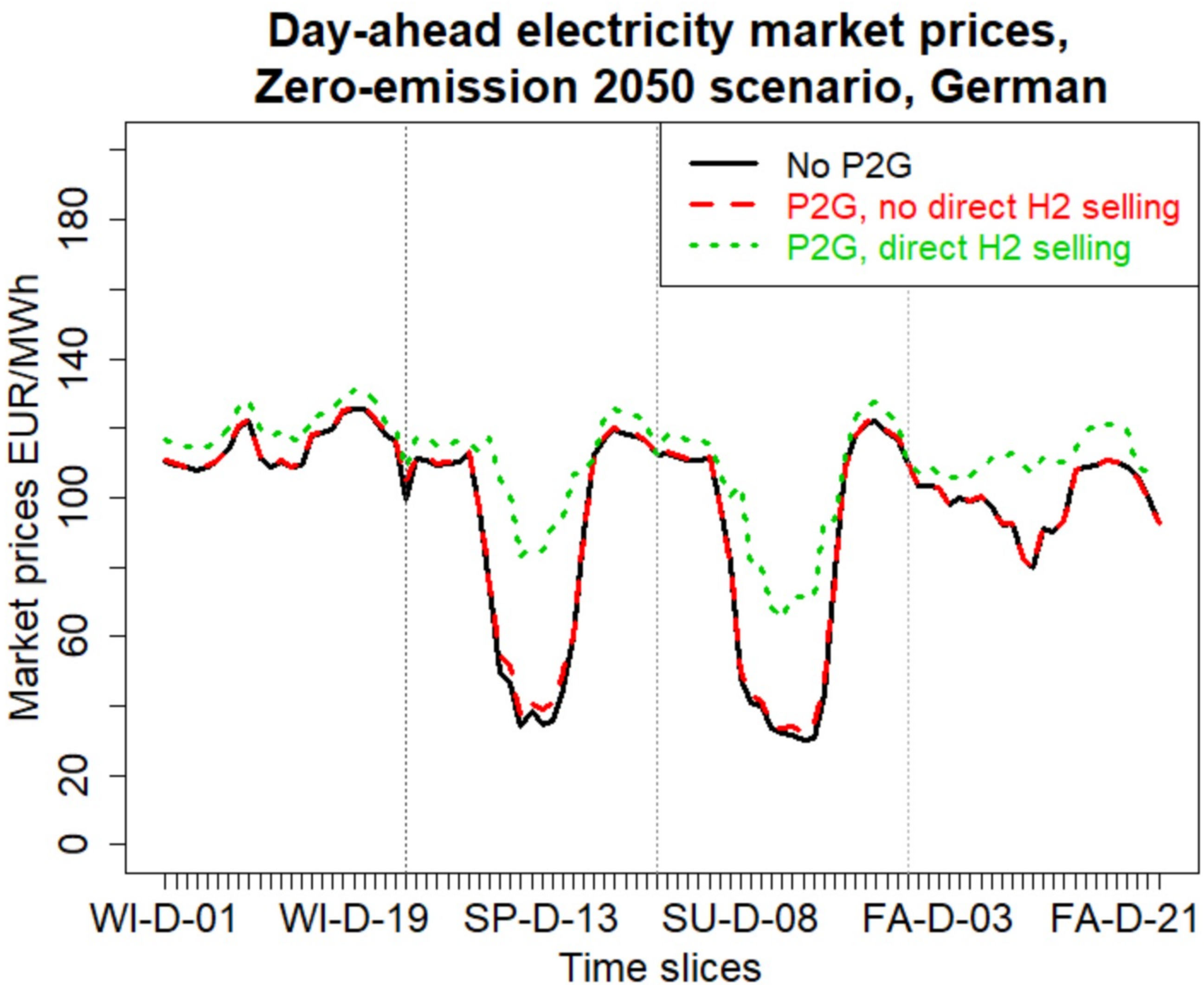
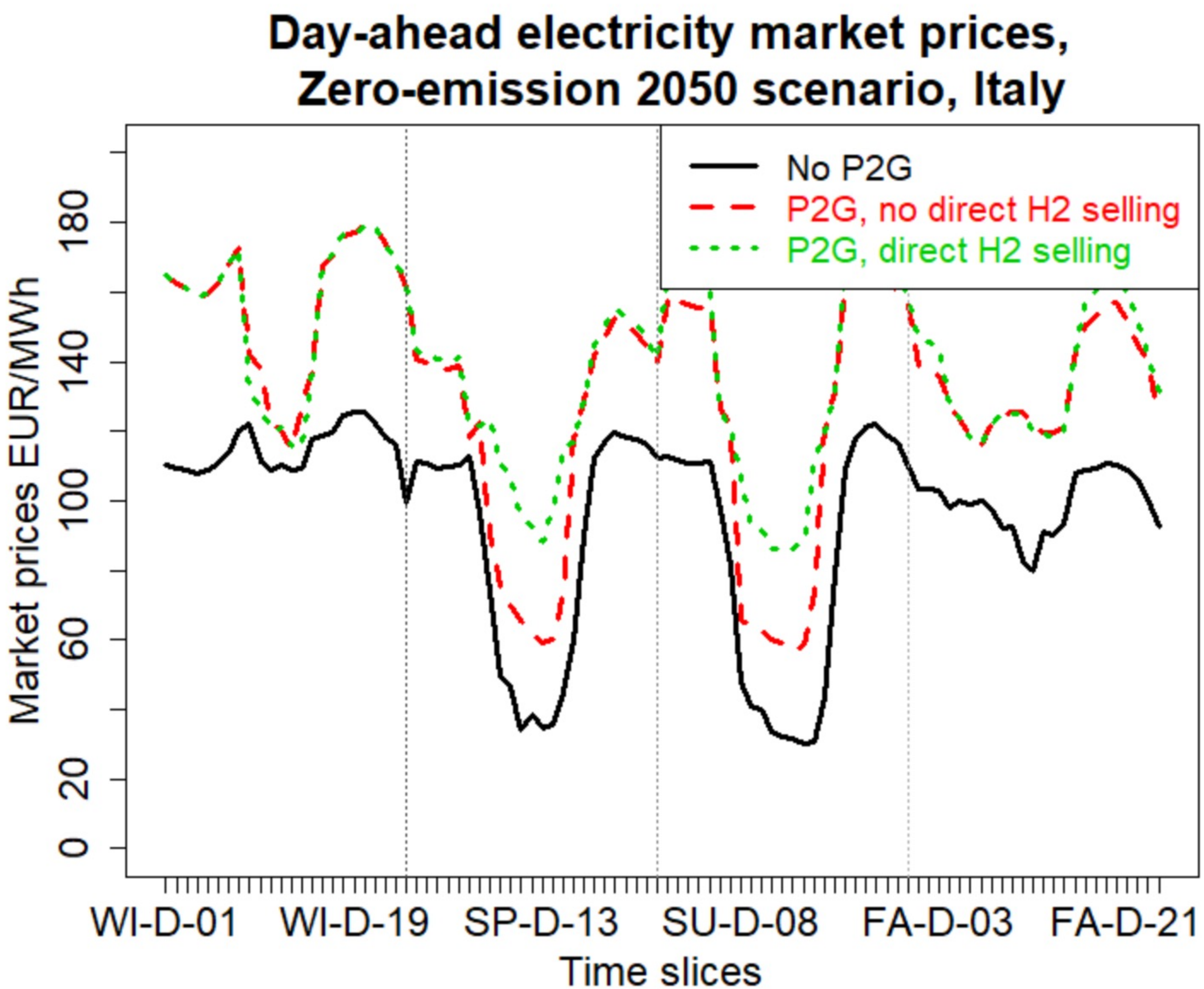



Day-ahead electricity market prices,
Zero-emission 2050 scenario, German
No P2G
P2G, no direct H2 selling
P2G, direct H2 selling
Market prices EUR/MWh
0
20
60
100
140
180
WI-D-01
WI-D-19
SP-D-13
SU-D-08
FA-D-03
FA-D-21
Time slices



Day-ahead electricity market prices,
Zero-emission 2050 scenario, Italy
No P2G
P2G, no direct H2 selling
P2G, direct H2 selling
Market prices EUR/MWh
0
20
60
100
140
180
WI-D-01
WI-D-19
SP-D-13
SU-D-08
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Time slices