sweet swiss energy research for the energy transition

PATHFNDR

PATHFNDR & the energy challenge

PATHFNDR Workshop
14 September 2022
13:00 – 18:30 (+ dinner)

Welcome

PATHFNDR

Pathways to an efficient future energy system through flexibility and sector coupling

8 research partners

25 cooperation partners

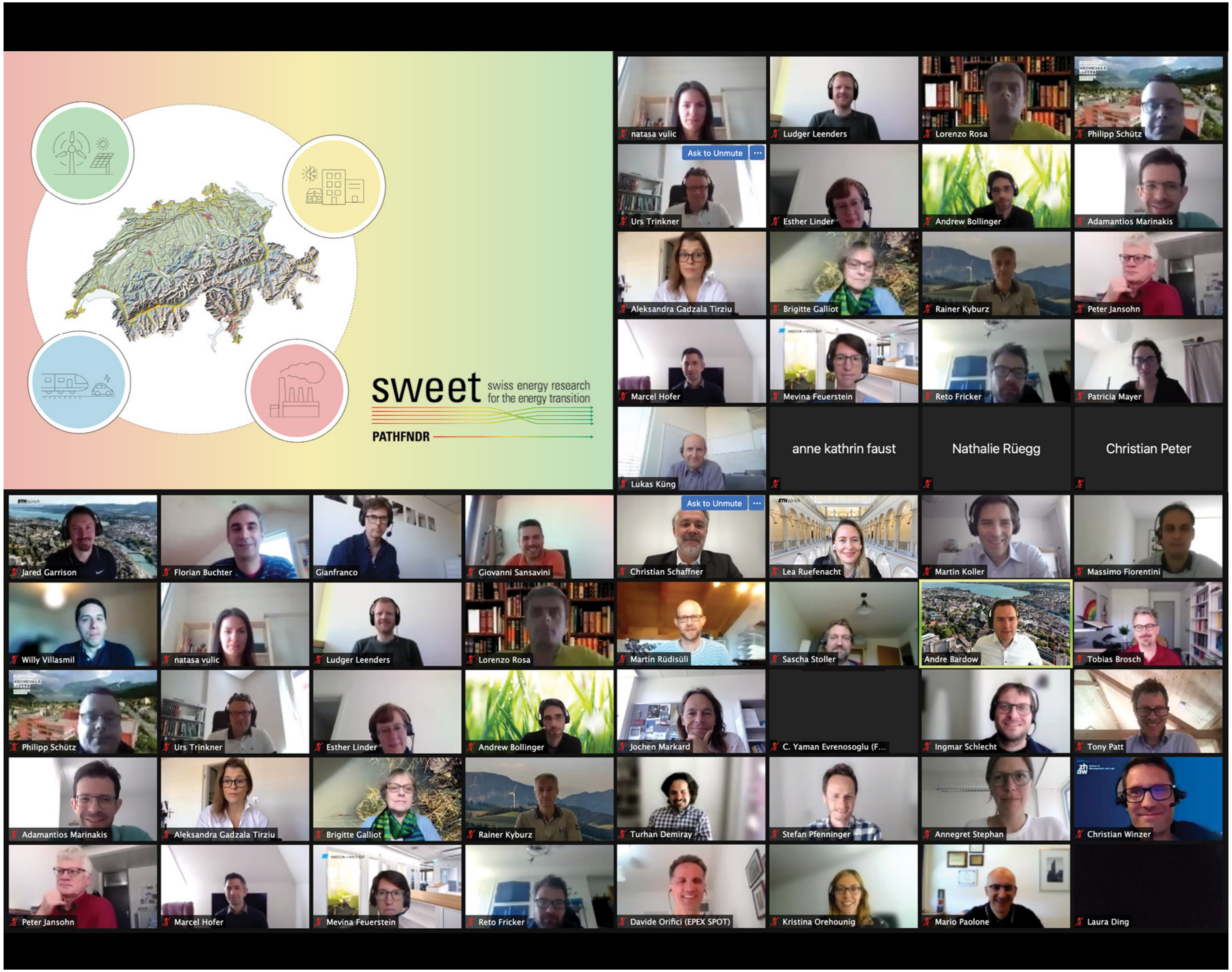
The team

69 researchers

25 cooperation partners

13 advisory board members

10 steering committee members



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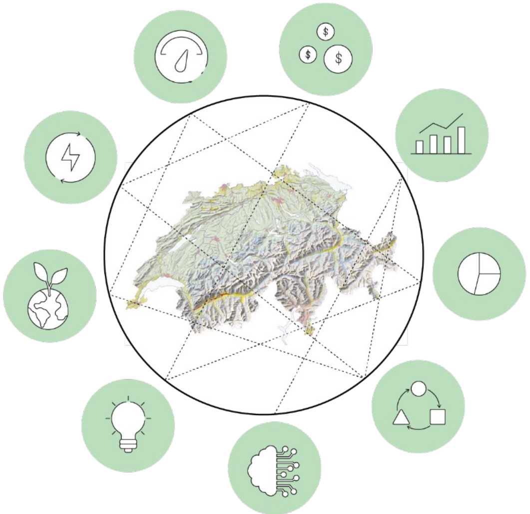
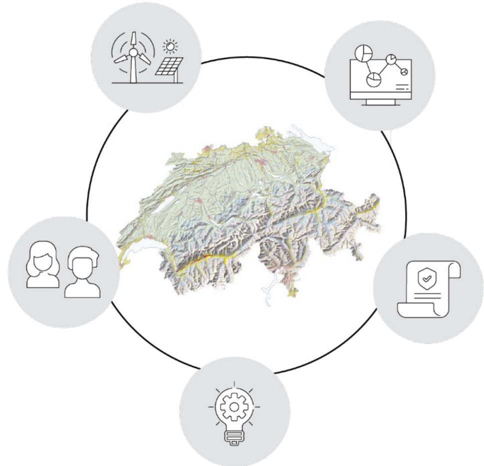
Project objectives



1. Improving performance

2. Enabling flexibility



3. Fostering sector coupling

Project outcomes

3. P&D projects

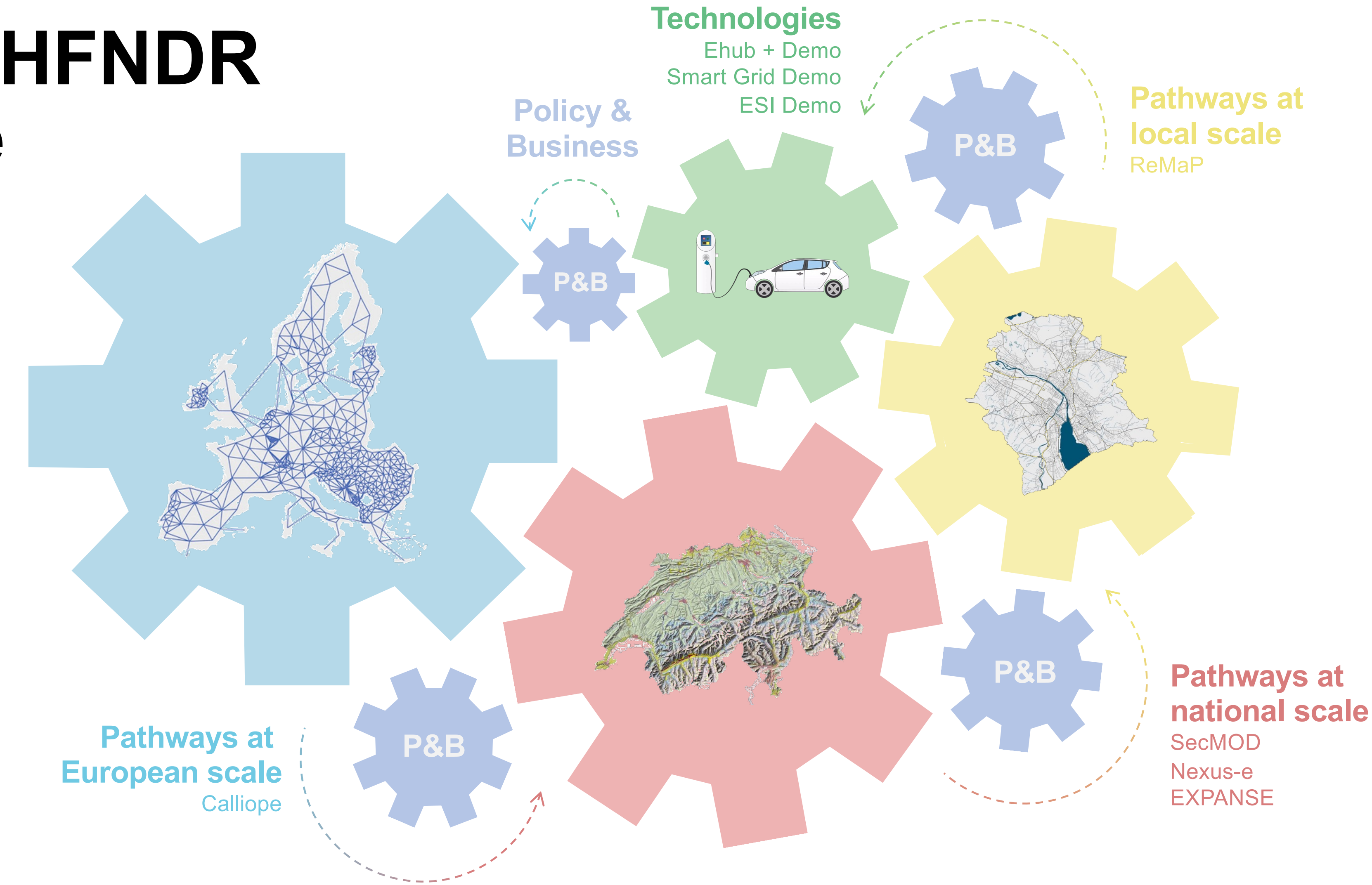
1. Feasible pathways

4. New business opportunities & innovation strategies

2. Planning & operation tools

5. Potential policies

The PATHFNDR Machine

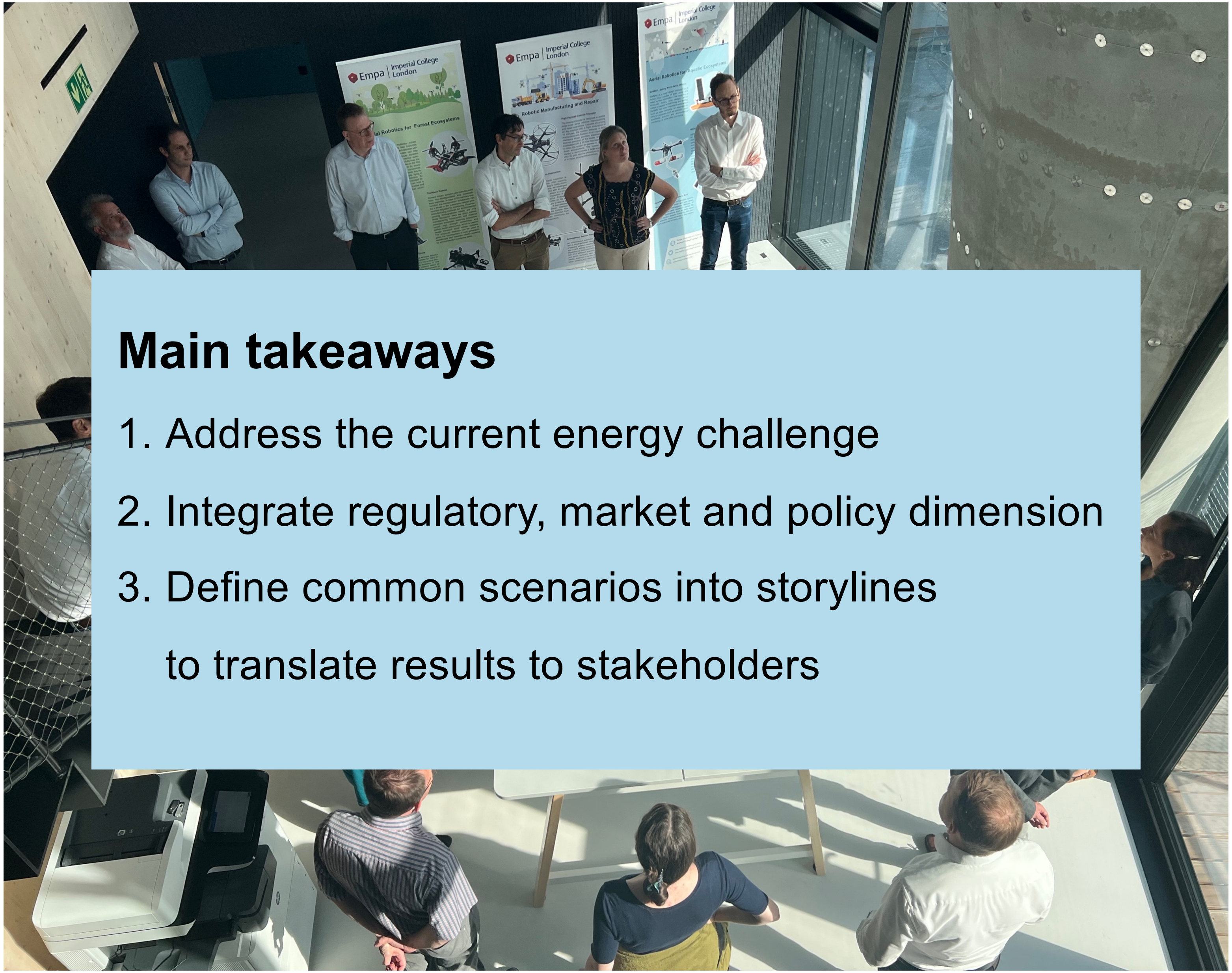


Progress review

1 September 2022

Review panel members:

- **Michael Moser**, SFOE
- Cedric Carnal, SFOE
- **Paul Dean**, Univ. College Cork
- **Viktoria Martin**, KTH Royal Institute of Technology
- **Felix Matthes**, Öko-Institut
  Aurelio Fetz, Alpiq SA
- **Anne-Kathrin Faust**, SFOE
- **Laura Ding**, SFOE
- **Andreas Haselbacher**, SFOE
- **Nathalie Rüegg**, SFOE



Main takeaways

1. Address the current energy challenge
2. Integrate regulatory, market and policy dimension
3. Define common scenarios into storylines
   to translate results to stakeholders

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The workshop goals

1. Get to know each other – in person
2. Present **preliminary results on the topics**
   of national scenarios, hydrogen, system flexibility, and sector coupling
3. Identify **synthesis topics that PATHFNDR will/should address**
   to align project objectives, preliminary results, and current challenges
4. Translate **input/feedback from academia and industry** into actions
   to shape the PATHFNDR energy pathways

Introduction to the workshop

Agenda
Day 1

N°	Topic	Time		Presenters
1	**Welcome**	10	13:00	André Bardow, ETH Zurich
2	**Introduction to the workshop**	10	13:10	Lea Ruefenacht, ETH Zurich
3	**Presentation 1:** A net-zero Switzerland and the impact of trade limitations	10	13:20	Jared Garrison, ETH Zurich
4	**Presentation 2:** The potential of hydrogen as energy storage medium for the electricity sector	10	13:30	Paolo Gabrielli, ETH Zurich
5	**Presentation 3:** Industry views and emerging conflicts around hydrogen	10	13:40	Jochen Markard, ZHAW
6	**Presentation 4:** Flexibility assessment of P2H2P and e-mobility in multi-energy districts	10	13:50	Binod Koirala, Empa
7	**Presentation 5:** Residential heating / cooling demand and flexibility potential	10	14:00	Phillip Schütz, HSLU
8	**Q&A**	10	14:10	All participants
-	Coffee break	20	14:20	All participants
9	**Poster pitches (2 minutes each)**	50	14:40	Researchers
10	**Poster exhibition**	70	15:30	All participants
	Poster exhibition + Coffee break	40	16:00	All participants
11	**World Café session (round 1)**	30	16:40	All participants divided into groups
12	**World Café session (round 2)**	30	17:10	All participants divided into groups
13	**Presentation of World Café dicussions**	40	17:40	Group representatives
14	**Closing remarks**	10	18:20	Christian Schaffner. ETH Zurich
-	Dinner	60-90	18:30	All participants

Presentations

Goal

Present **preliminary results**

(as input for the World Café session)

Approach

- 5 presentations, each 10 minutes (without Q&A)
- 10 minutes Q&A (3-4 questions) at the end presentations
- Further questions are answered during the break and World Café session

Presentation 1
A net-zero Switzerland and the impact of trade limitations
Presenter: Jared Garrison

Presentation 2
The potential of hydrogen as energy storage medium for the electricity sector
Presenter: Paolo Gabrielli

Presentation 3
Industry views and emerging conflicts around hydrogen
Presenter: Jochen Markard

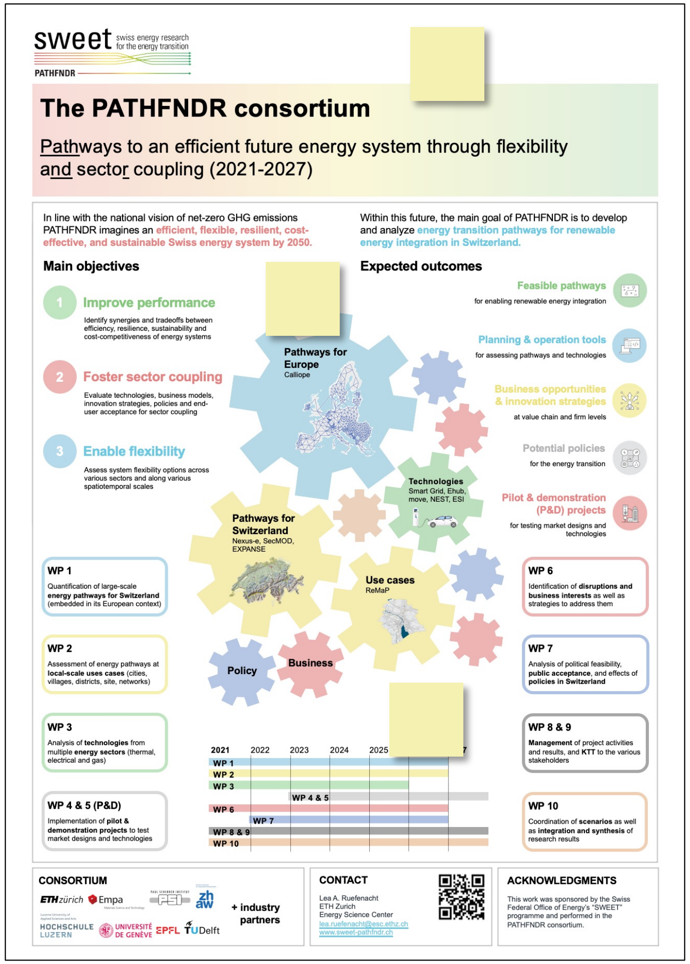
Presentation 4
Flexibility assessment of P2H2P and e-mobility in multi-energy districts
Presenter: Binod Koirala

Presentation 5
Residential heating / cooling demand and flexibility potential
Presenter: Philipp Schütz

Presentations + Q&A
13:20 – 14:20 (60 min)

Poster pitches

e.g.,
20



Goal

Present preliminary results (as further input for the World Café session)

Approach

- 22 poster pitches, each 2 minutes (without Q&A)
- Questions are answered during the poster exhibition (70 minutes, with coffee break)
- Feedback/inputs/comments are written on post-its and sticked on the poster

Poster pitches + exhibition
14:40 – 16:40 (120 min)

World Café session

Goal

Identify **synthesis topics that PATHFNDR will/should address**

Approach

- Participants gather around a table (8 tables)
- Participants are already pre-assigned to a table (see list)
- Each facilitator explains the question

World Café table 1 & 2
Can Switzerland reach its net-zero goal with import/export limitations?
Facilitiator(s): Jared Garrison & Stefan Pfenninger

World Café table 3 & 4
Is hydrogen a hype and is it not needed for the energy transition in Switzerland?
Facilitiator(s): Paolo Gabrielli & Binod Koirala

World Café table 5 & 6
Are current regulations or institutional interests preventing efficient use of flexibility?
Facilitiator(s): Adamantios Marinakis & Philipp Schütz

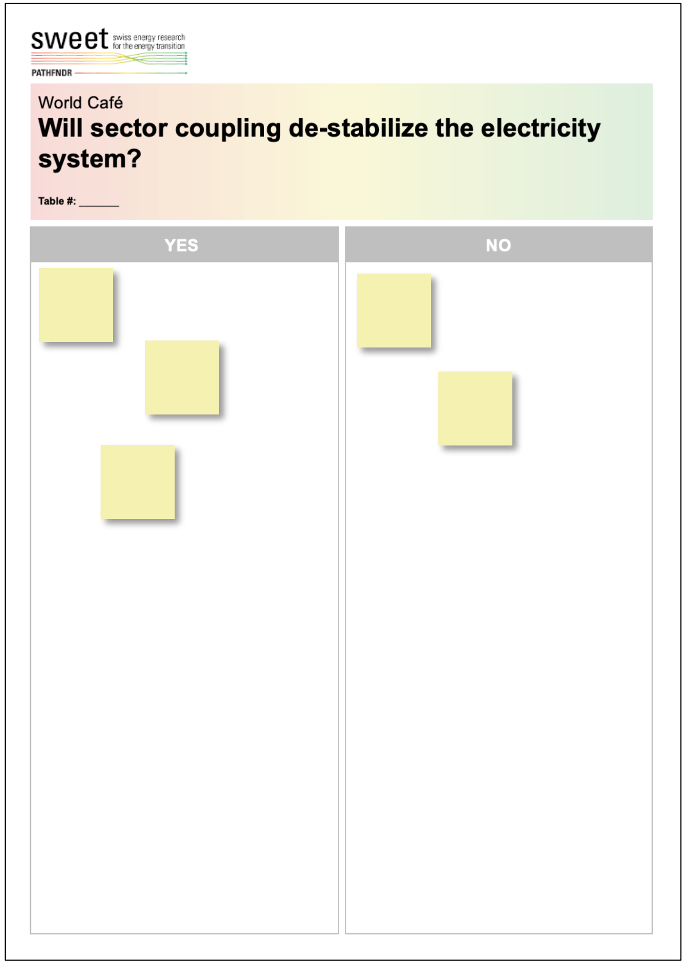
World Café table 7 & 8
Will sector coupling de-stabilize the electricity system?
Facilitiator(s): Massimo Fiorentini & Florian Baader

World Café session
16:40 – 18:20 (100 min)

World Café session

…

- Participants answer "Yes" or "No" and "Why?" to the question
- After 30 minutes (1 round), participants move to another table for another 30 minutes (2 rounds)
- Answers/inputs/comments are written on post-its and sticked on the board
- A group representative is selected to present the results (in 5 minutes)



Poster pitches + exhibition
14:40 – 16:40 (120 min)

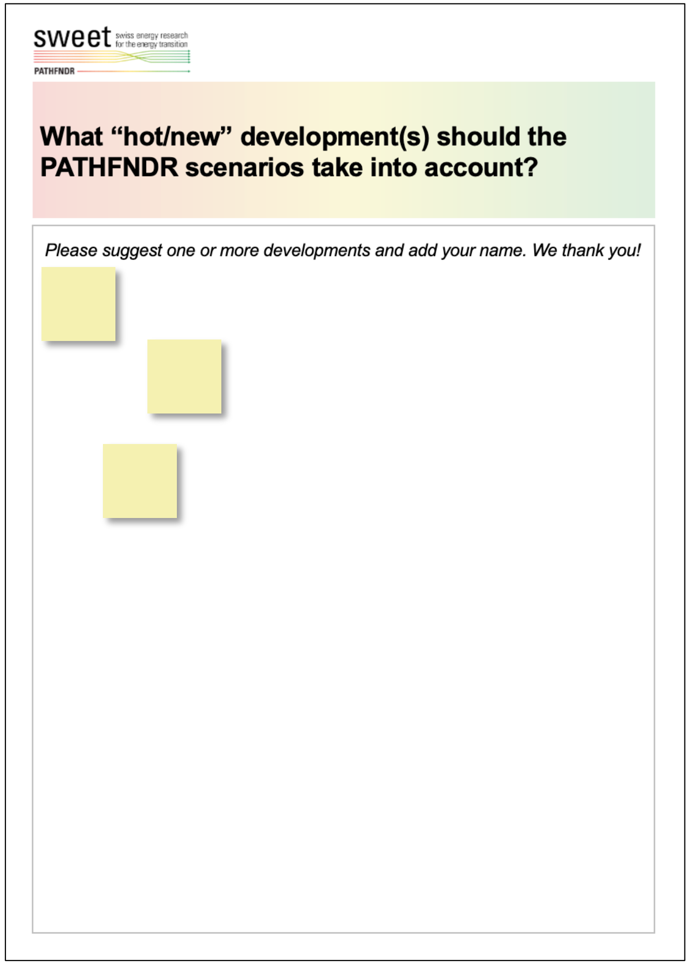
Additional board #1

Goal

Collect ideas/suggestions on “hot/new” development that PATHFNDR should take into account.

Approach

- Participants suggest one or more development(s) during the break(s)
- Suggestions (+ their names) can be written on post-its and sticked on the board



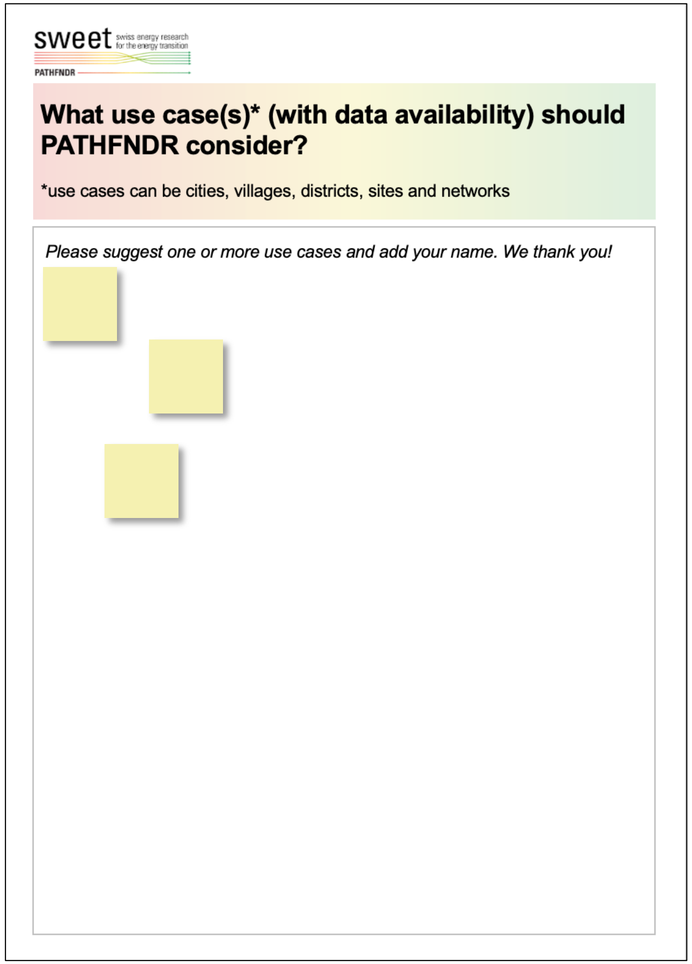
Additional board #2

Goal

Collect use cases (with data availability) that PATHFNDR should consider.

Approach

- Participants suggest one or more use case(s) during the break(s)
- Use cases (+ their names) can be written on post-its and sticked on the board



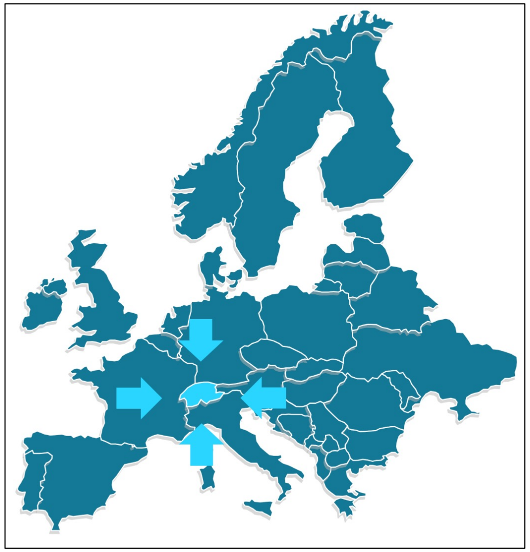
Presentations

1

A net-zero Switzerland and the impact of trade limitations

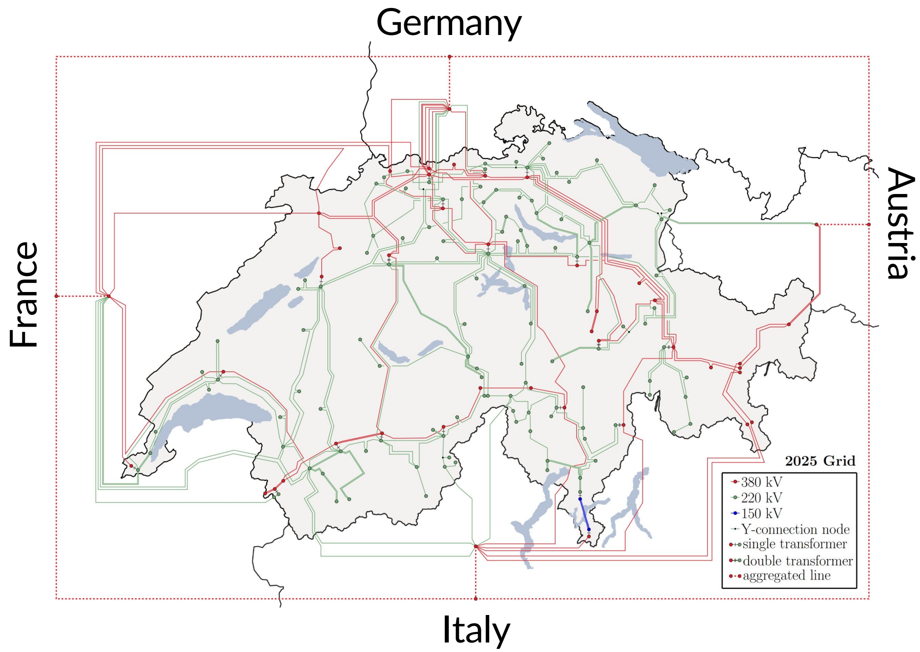
Presenter: Jared Garrison, ETH Zurich

Connecting models: European scope with Swiss details



Euro-Calliope provides the development of the EU toward net-zero

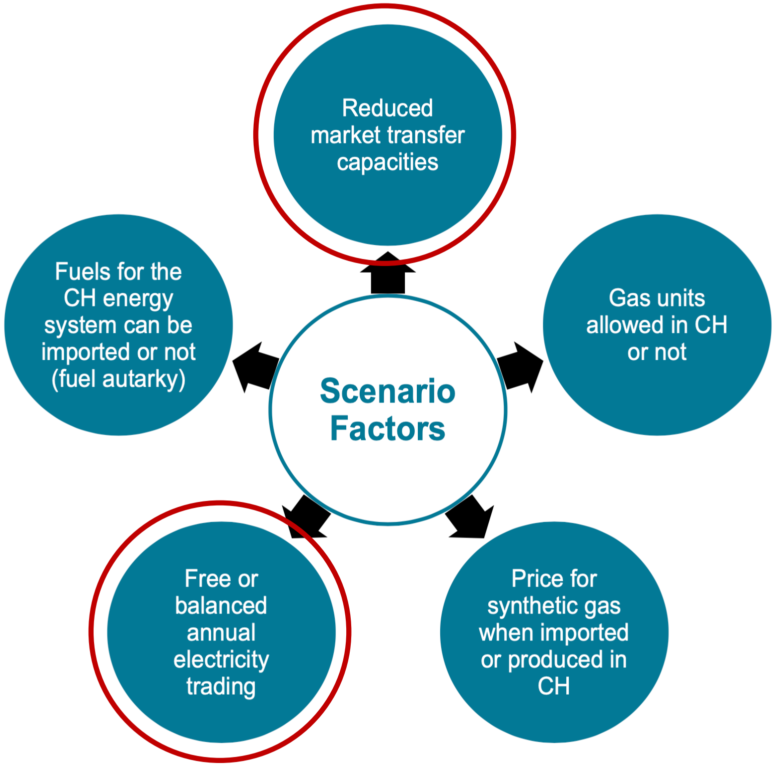
Tröndle et al., *Joule*, 2020, 4(9)



Nexus-e provides a more detailed assessment of the Swiss electricity system

Gjorgiev et al., *Applied Energy*, 2022, 307

Explore impacts of decarbonization by 2040 under relevant policy scenarios



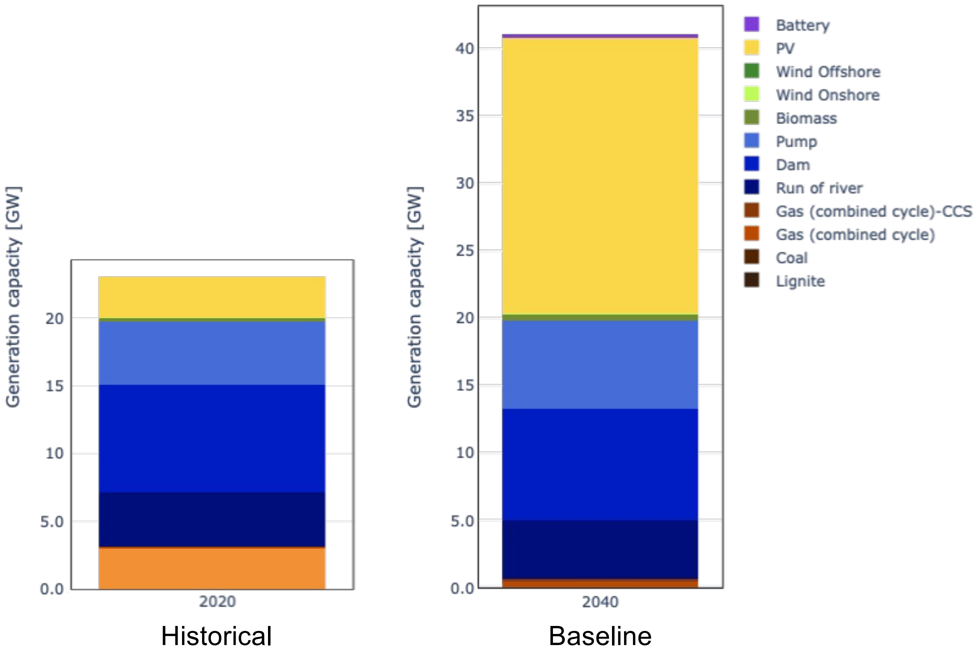
*All results shown:

- For Switzerland electricity system only
- Given Euro-Calliope's EU & CH transition toward net-zero (dominated by: PV, Wind, Hydro)

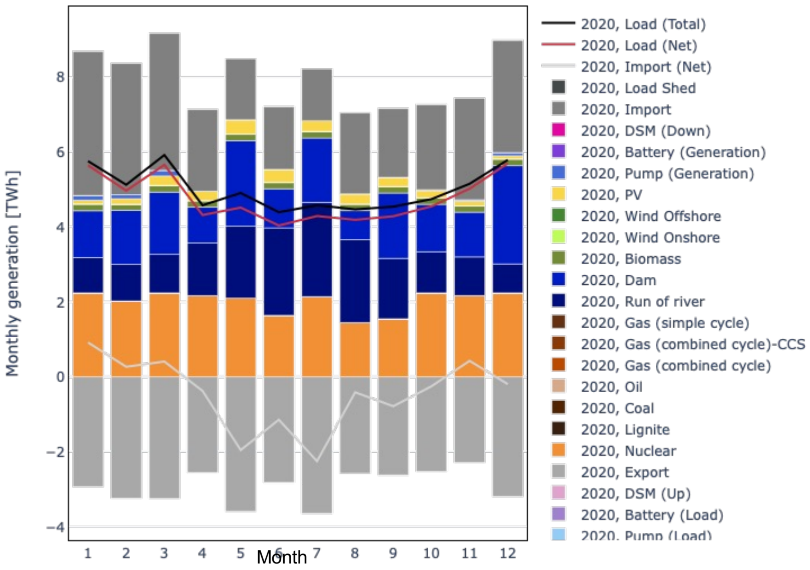
Under baseline conditions, net-zero transition:
Swiss consumer investments in rooftop PV

Context: Net-Zero transition in CH
- *2020 Swiss demand = 60 TWh*
- *Euro-Calliope Electrification → 81 TWh*
- *EP2050+ ZERO-Basis in 2040 = 71.5 TWh*
- *EP2050+ ZERO-A in 2040 = 80.1 TWh*

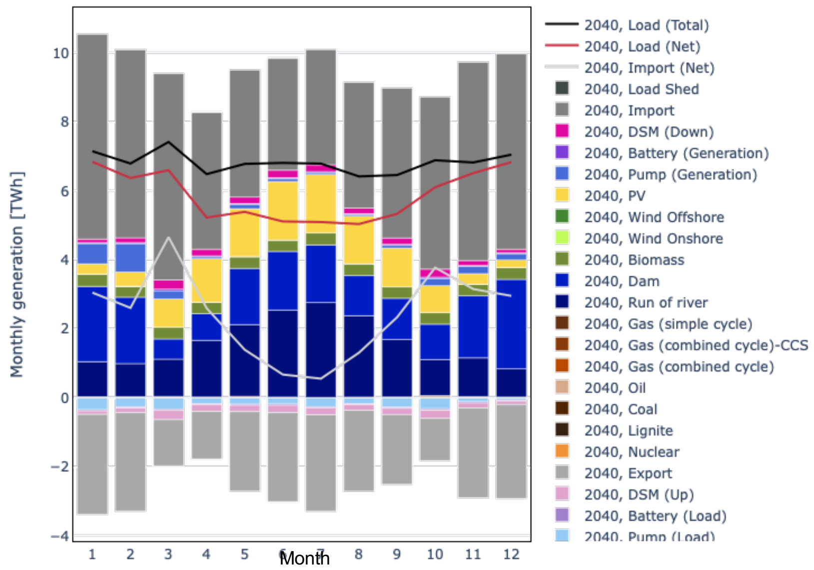
Capacity transition in CH
- Nuclear phased out: 3 → 0.0 GW
- Rooftop PV: 3 → 20.4 GW
- Little more GasCC: 0.1 → 0.7 GW
- Little new Battery: → 0.2 GW



Under baseline conditions, net-zero transition: production shifts to PV, imports



2020 Historical



2040 Baseline

- Removal of 24 TWh of Nucl → 17.5 TWh of PV (+15), 4 TWh of KVA (+2)
- Shift from net Exporter in 2020 (30 – 35 = -5) → to net Importer in 2040 (52 – 30 = +22)
- Generally lower wholesale prices in all countries because high RES

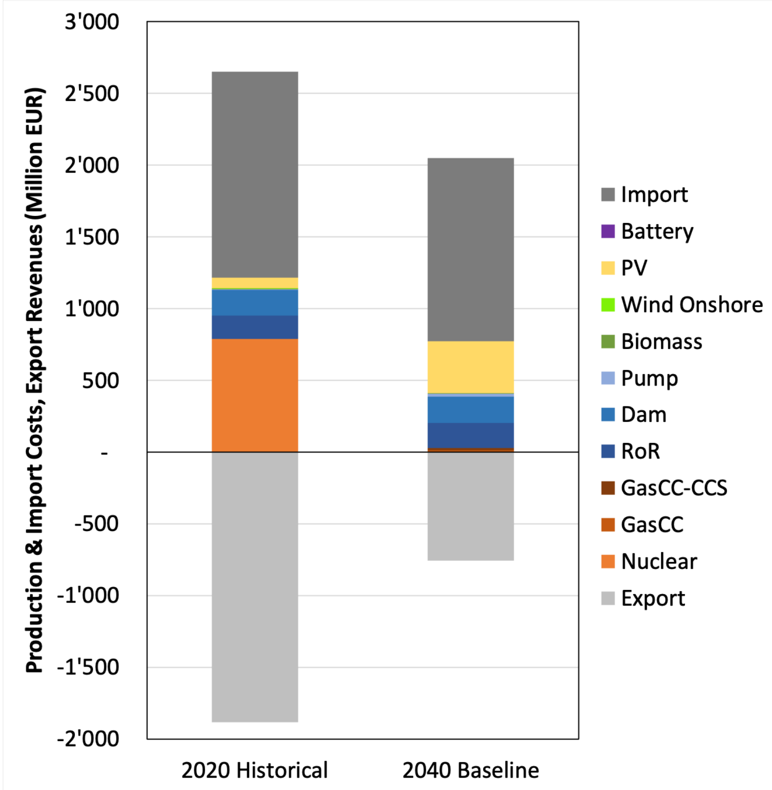
Under baseline conditions, net-zero transition: impact on operating costs are modest

Operating Costs
- Phase out of Nuclear
- Similar Hydro
- Increase from rooftop PV

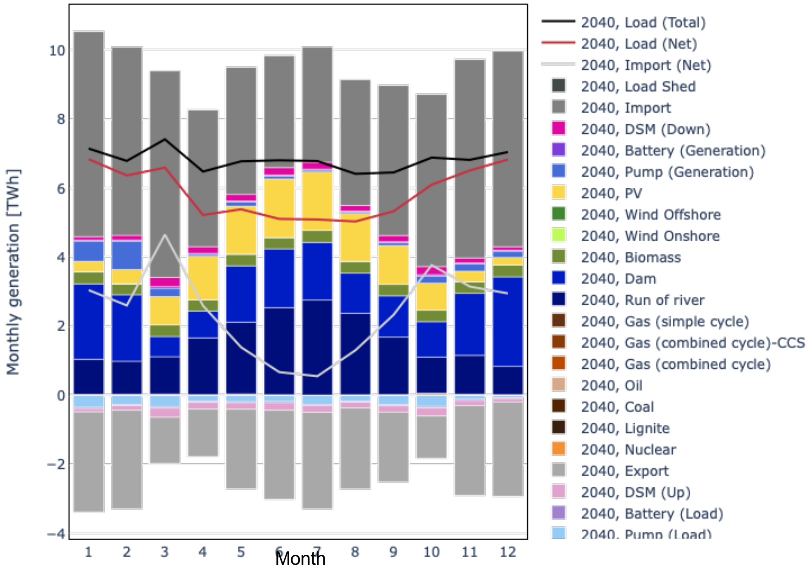
➢ Lower operating costs are also reflected in lower wholesale prices across all countries

Import costs / Export revenues
- Higher quantity of import but similar cost
- Similar quantity of export but less revenue

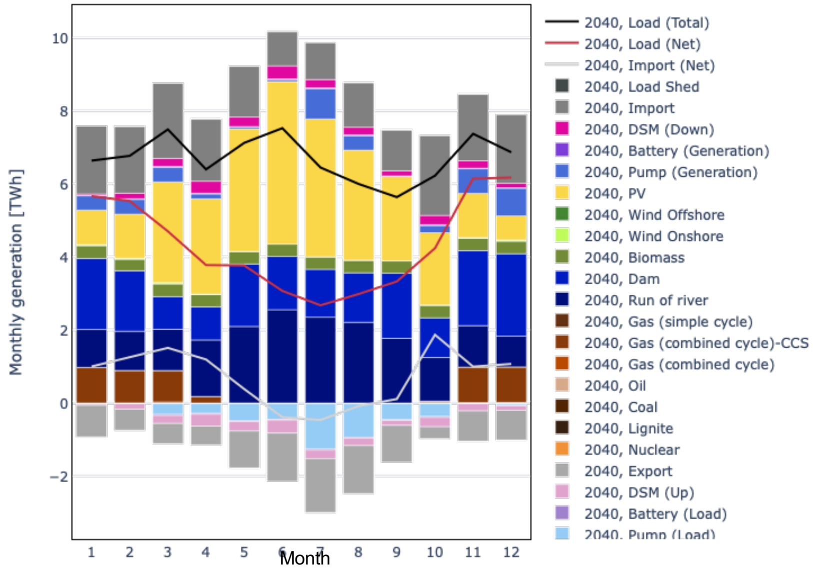
➢ Lower prices



Restricting transfer capacities:
shift to focus on domestic electricity capacities



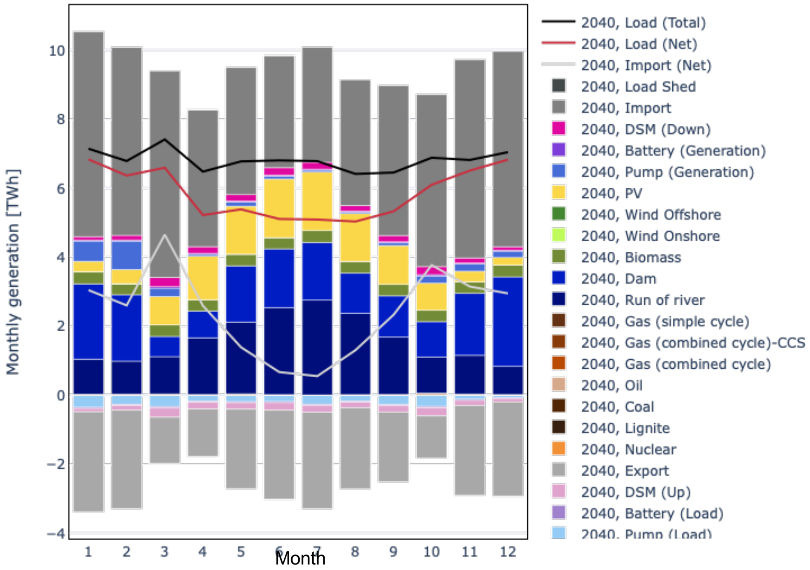
2040 Baseline



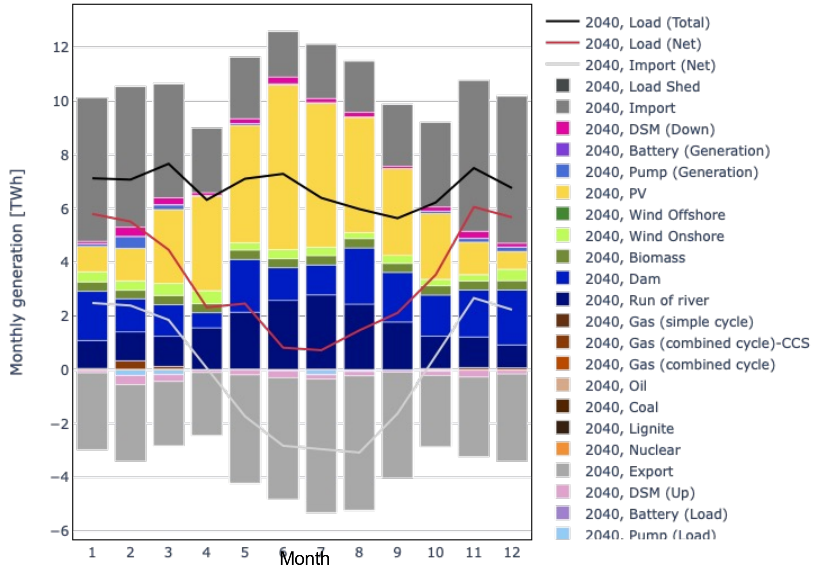
2040 Reduced NTCs to 30%

- Large increase in domestic PV (36 GW / 29 TWh) and Gas (0.2 GW / 5 TWh)
- Imports (52 → 19 TWh) and Exports (30 → 11 TWh) strong concentration into the seasons of greater need
- Impacts extend into surrounding countries

Requiring a balanced electricity trade: similar but less pronounced impacts



2040 Baseline



2040 Balanced Annual Imports/Exports

- Large increase in domestic PV (36 GW / 36 TWh) and less Swiss PV curtailment
- Imports (52 → 42 TWh) and Exports (30 → 42 TWh) moderate concentration into the seasons of greater need
- Only price impacts in surrounding countries

Conclusions recap

Swiss net-zero transition

- High level of electrification
- Consumer investments in rooftop PV leads to greater imports and moderate operating cost impacts

Restricting Swiss NTCs to 30%

- Huge reduction in the annual imports and exports of electricity from Switzerland
- Concentration of imports/exports into seasons of greatest need
- Leads to an increased need for domestic Swiss capacities (PV, Gas)
- Noticeable impact on neighboring countries since the transit of power through Switzerland is much more limited

Requiring balanced annual trade

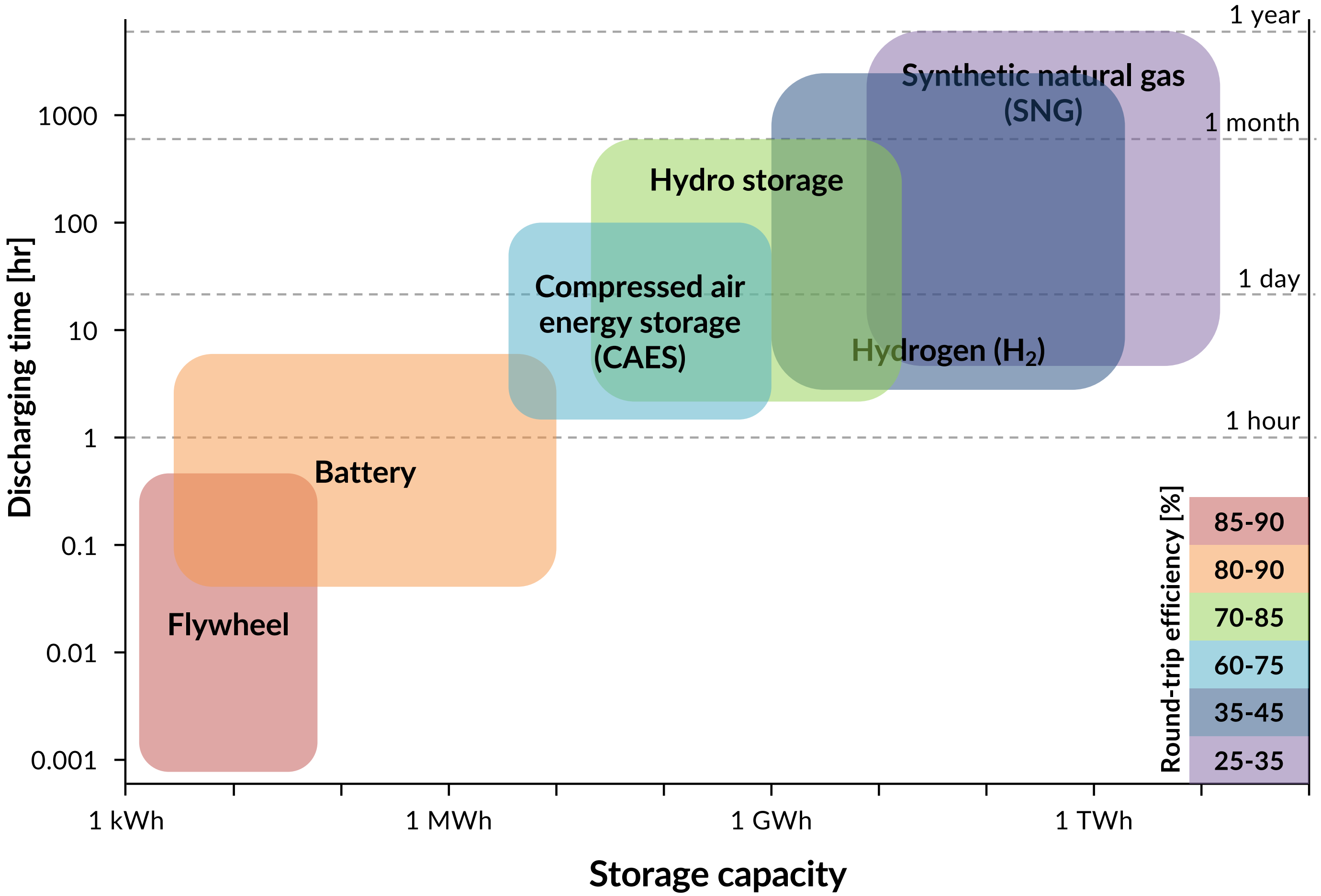
- Similar overall trends as 30% NTCs but less pronounced
- Imports reduce (especially in summer) while exports increase (especially in summer)
- Most seasonally pronounced import/export behavior
- Still impact neighboring country wholesale prices

2

The potential of hydrogen as energy storage medium for the electricity sector

Presenter: Paolo Gabrielli, Reliability and Risk Engineering, ETH Zurich

Hydrogen could have a role as long-term storage



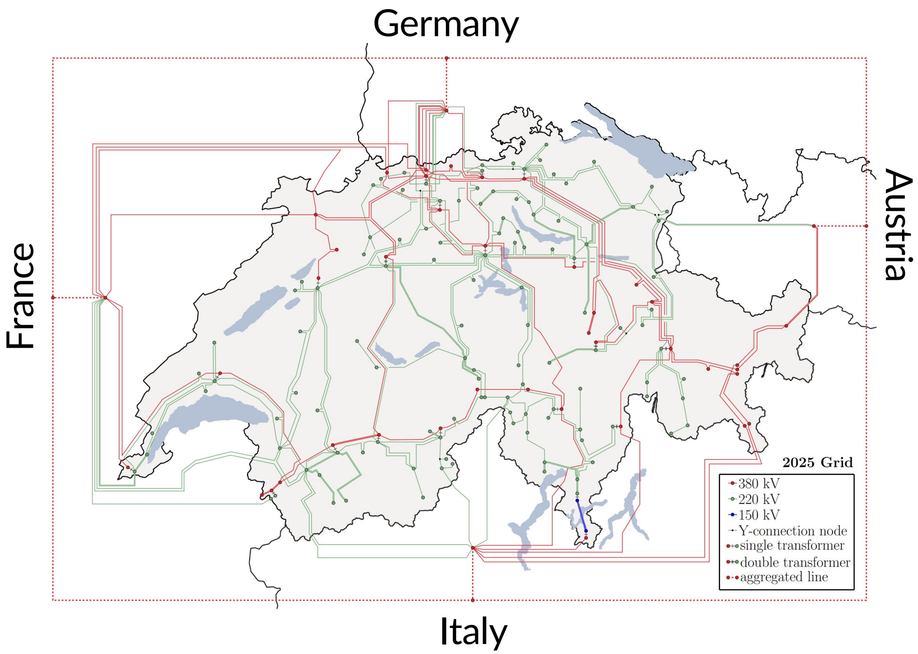
Adapted from: Yao et al., *Sustainable Energy and Fuels*, 2019, 3

- Competition among different energy storage technologies, each with different techno-economic characteristics
- Hydrogen is characterized by a low round-trip efficiency, but energy capacity costs and low losses over long time horizons
- Thus, hydrogen might play a role when large sizes are installed or energy is stored for a long time

Scenarios for the Swiss electricity sector

National analysis via **Nexus-e** model:

- Scenario-based analysis to investigate role of hydrogen for electricity storage
- Minimum-cost optimization complying with zero-emissions targets



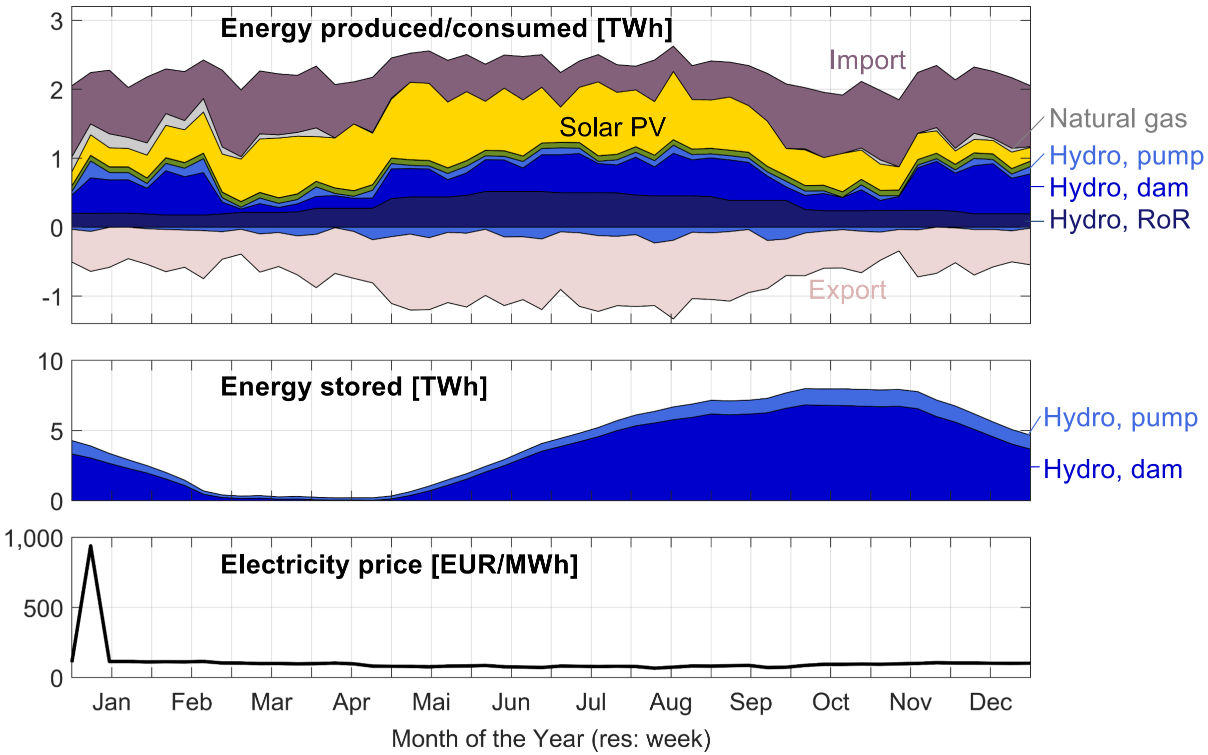
Quantity	Range of variation
Target year	2020, 2030, 2040, 2050
Learning rates of hydrogen-based technologies	5%, 12%, 20%
Net Transfer Capacity (NTC)	0 – 100%
Load-shedding cost	1,000 – 10,000 EUR/MWh
Meteorological year (Switzerland)	Dry, Average, Wet
European scenarios (TYNDP)	National Trends, Distributed Energy, Global Ambitions

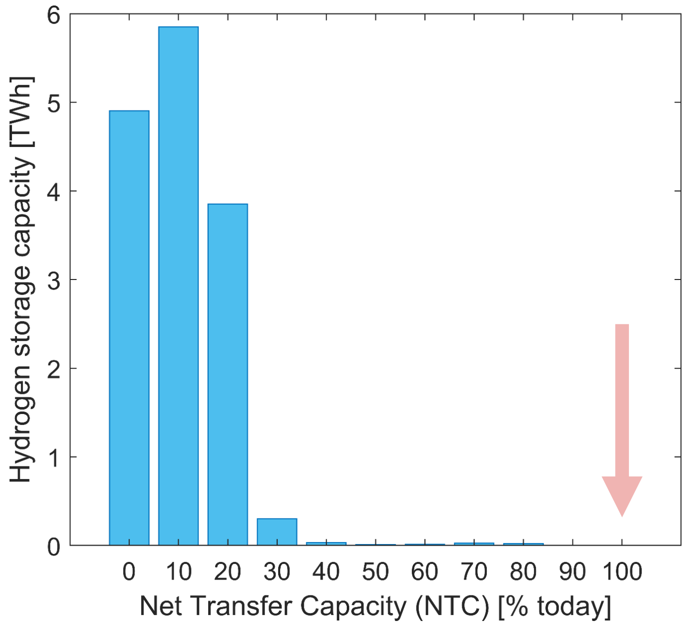
Reference scenario

Gjorgiev et al., *Applied Energy*, 2022, **307**

Hässig, *Master Thesis*, 2022

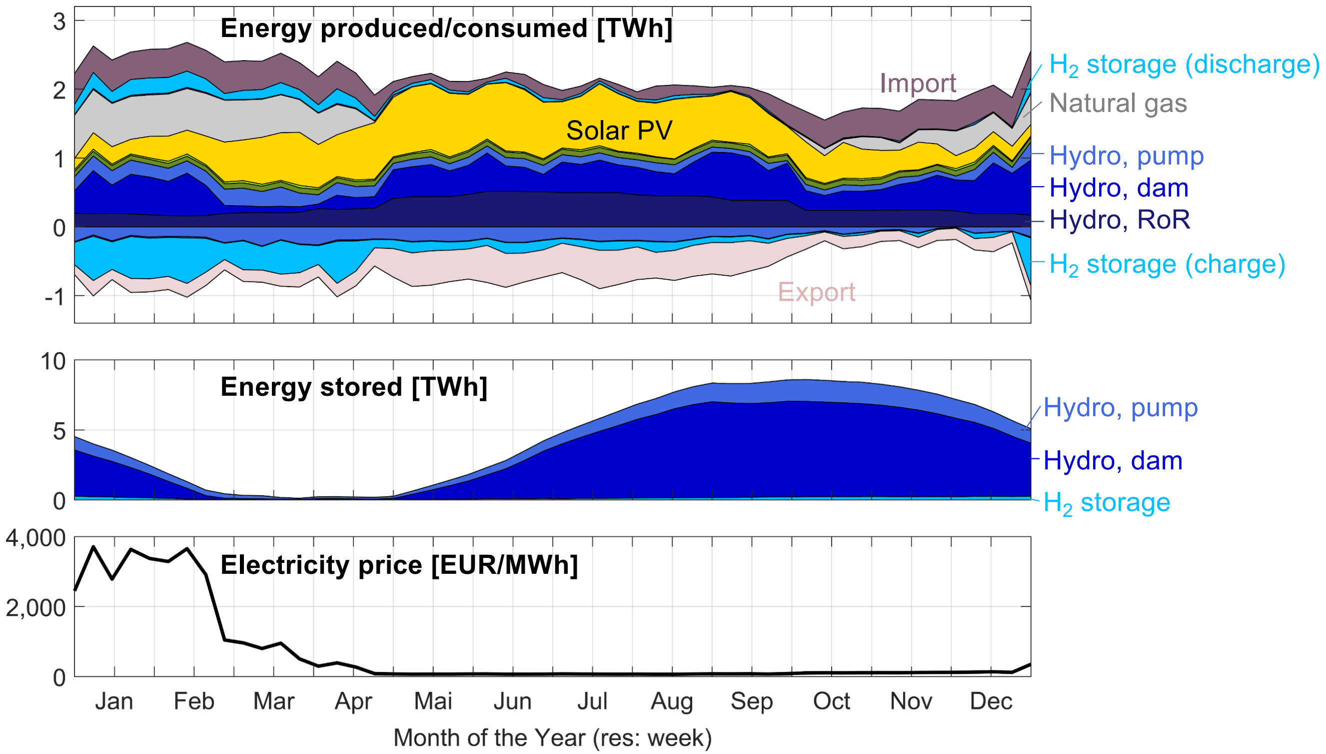
The role of hydrogen: Reference scenario 2050

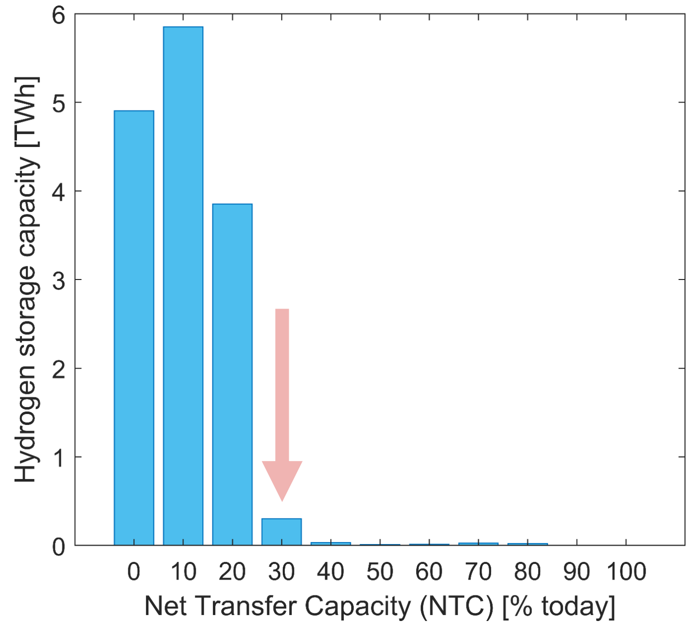




- No hydrogen storage is installed
- Existing hydro storage is sufficient to balance energy generation and demand: Dam (6.9 TWh) and pump (1.9 TWh)
- No significant differences are observed for different meteorological years and European development scenarios (TYNDP)

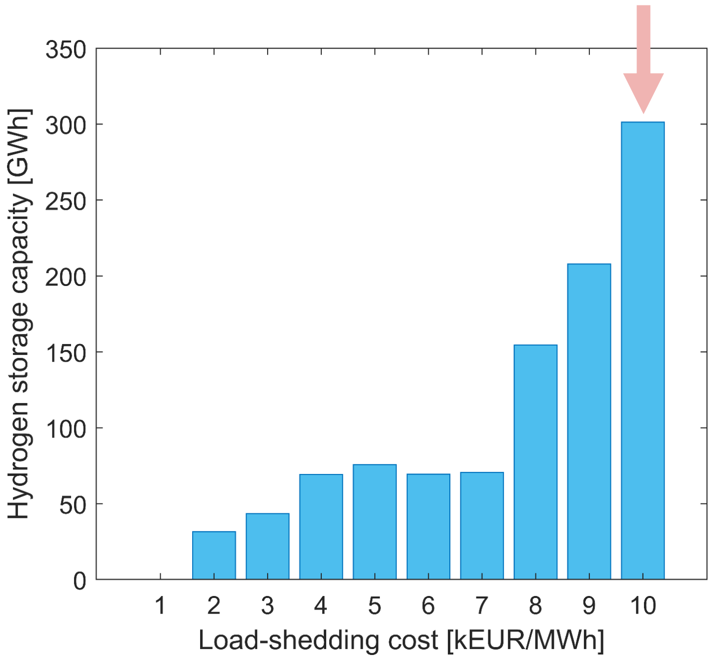
The role of hydrogen: Cross-border power flow



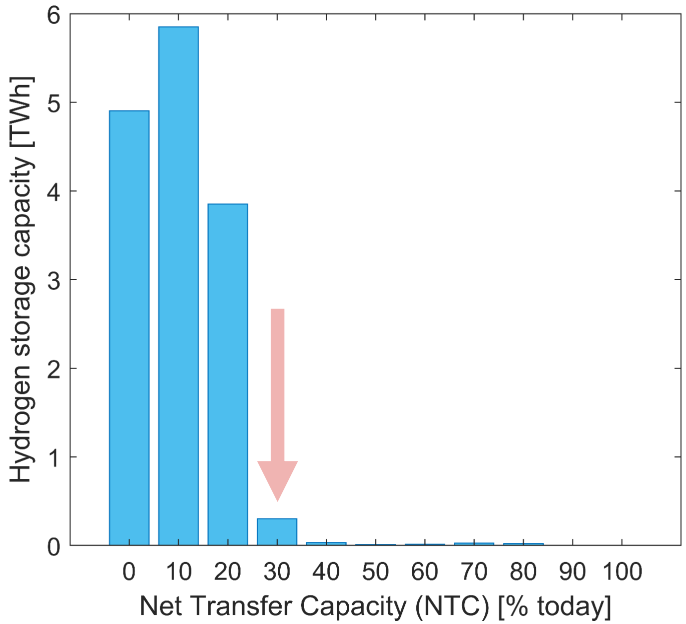


- Hydrogen storage starts being installed when NTC is limited below 30% of current value
- Hydrogen storage operated not only seasonally, but also used for short-term balancing
- Reduced NTCs cause load shedding: Hydrogen storage installed for load-shedding costs of 10,000 EUR/MWh

The role of hydrogen: Impact of load-shedding



The more we are willing to shed load, the smaller hydrogen capacities are installed



- For NTC of 30%, hydrogen storage disappears for load-shedding costs of 1,000 EUR/MWh

From national to European electricity sector

European analysis via **Euro-Calliope** model:

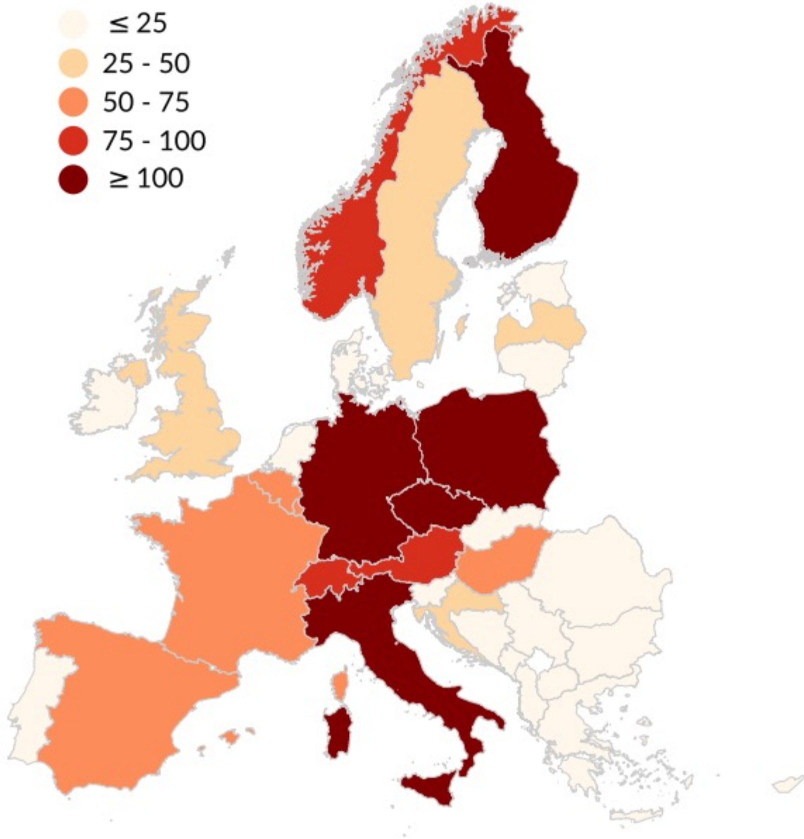
- Scenario-based analysis to investigate role of hydrogen as electricity storage medium and flexibility provider
- Minimum-cost optimization subject to zero-emissions targets (cap on CO_2 emissions)
- NTC 100% and average meteorological year
- Regional resolution (502 European regions as locations)
- Greenfield approach: analysis of optimal system in 2050, not bound to current installed capacities

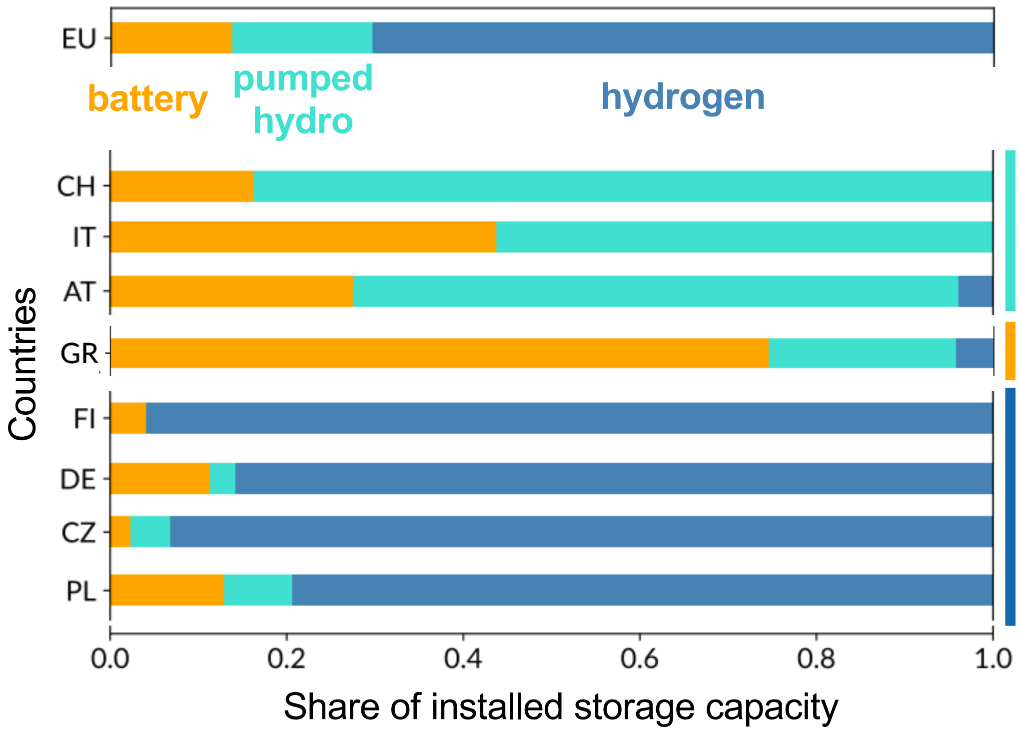
Tröndle et al., *Joule*, 2020, **4**(9)

Upadhyay, *Master Thesis*, 2022

European perspective: Types of countries

Total installed storage capacity [GWh]





Total installed storage capacity in Europe in 2050: 3.1 TWh

- Battery: 0.4 TWh
- Pumped hydro: 0.5 TWh
- Hydrogen: 2.2 TWh

Upadhyay, *Master Thesis*, 2022

Conclusions and recommendations

- Hydrogen plays **no major role** as an electricity storage medium and flexibility provider **under most conditions**, for the **Swiss electricity sector**:
  - Hydrogen plays a role for **limited NTCs**, below 30% of current values
  - Limited NTCs impact the possibility of meeting electricity demands, and results in hydrogen storage for **high load-shedding costs** (> 2,000 EUR/MWh)

- Overall, hydrogen storage is not required in a reasonably-interconnected Switzerland to transition to a zero-emissions electricity system.

- When considering **European electricity sectors**, **hydrogen does play a role**; different types of countries are observed:
  1. Large hydro resources and no hydrogen is installed (e.g. Switzerland)
  2. Some hydrogen is installed, but battery dominates the storage mix (e.g. Greece)
  3. Hydrogen dominates the storage mix and large amounts are installed (e.g. Germany)

3

Industry views and emerging conflicts around hydrogen

Presenter: Jochen Markard, ZHAW

Net-zero energy transition

Particularities

- Multiple sectors

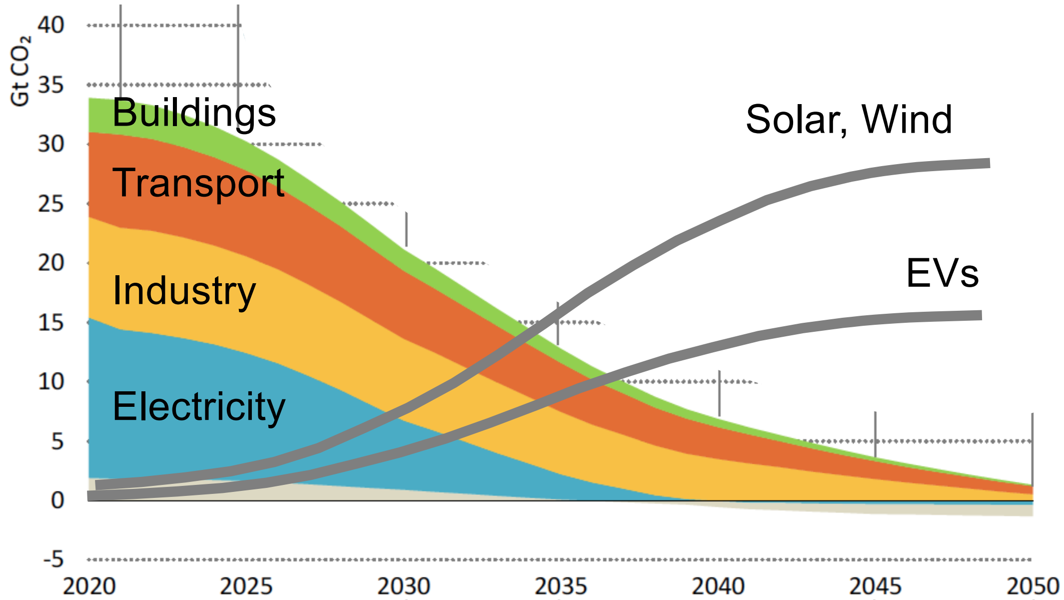
  Some: Difficult-to-decarbonize, e.g. chemicals, cement, aviation H_2

- Multiple actors & interests H_2
- Multiple technologies / solution strategies

  Some sector specific, e.g. EVs

  Some for multiple applications: clean electricity, hydrogen, saving H_2

- Dominant strategy "electrify everything" H_2



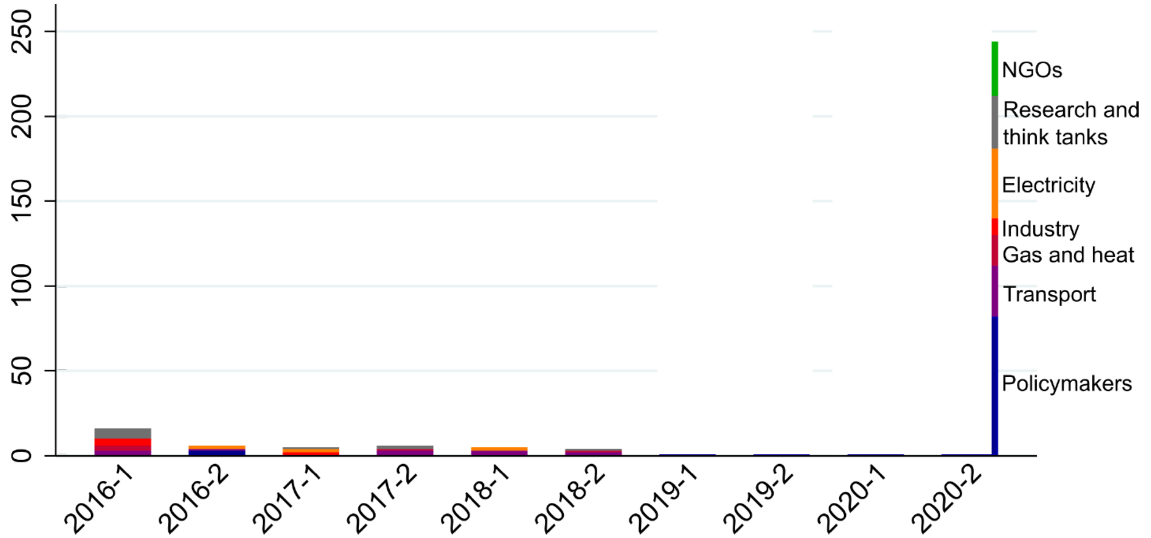
IEA 2021

Firm perspective: Who supports H_2 and why?

Case & approach

- H_2: Many diff. actors from diff. sectors
- Germany: National hydrogen strategy (2020)
- Exploration of public debate
  with discourse analysis
- Source: Newspapers
- Time: 2016-2020
- Analysis of storylines:
  Dense arguments around novel technology
- Idenfification of conflicts & discourse network

Figure A.1: Attention actors



Ohlendorf et al., under review

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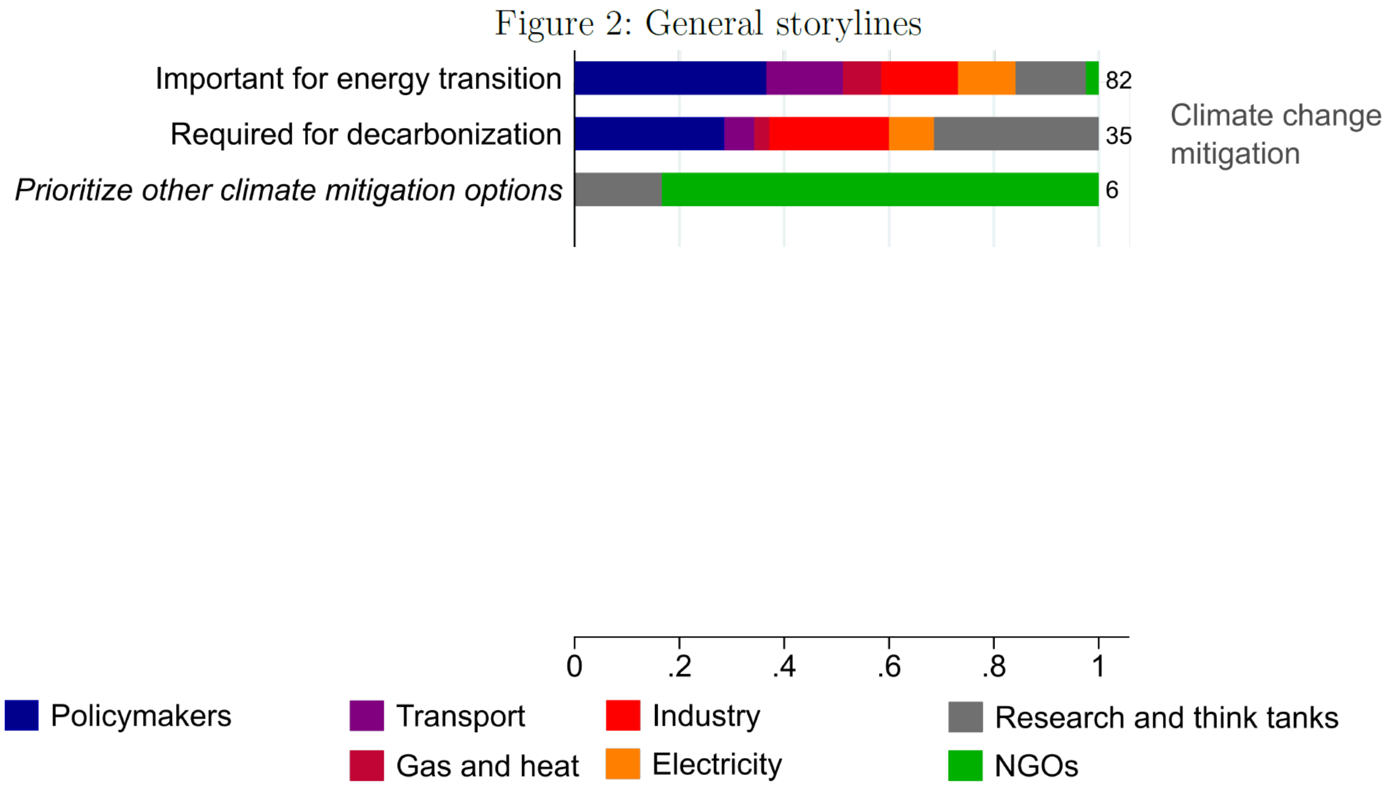
General discourse



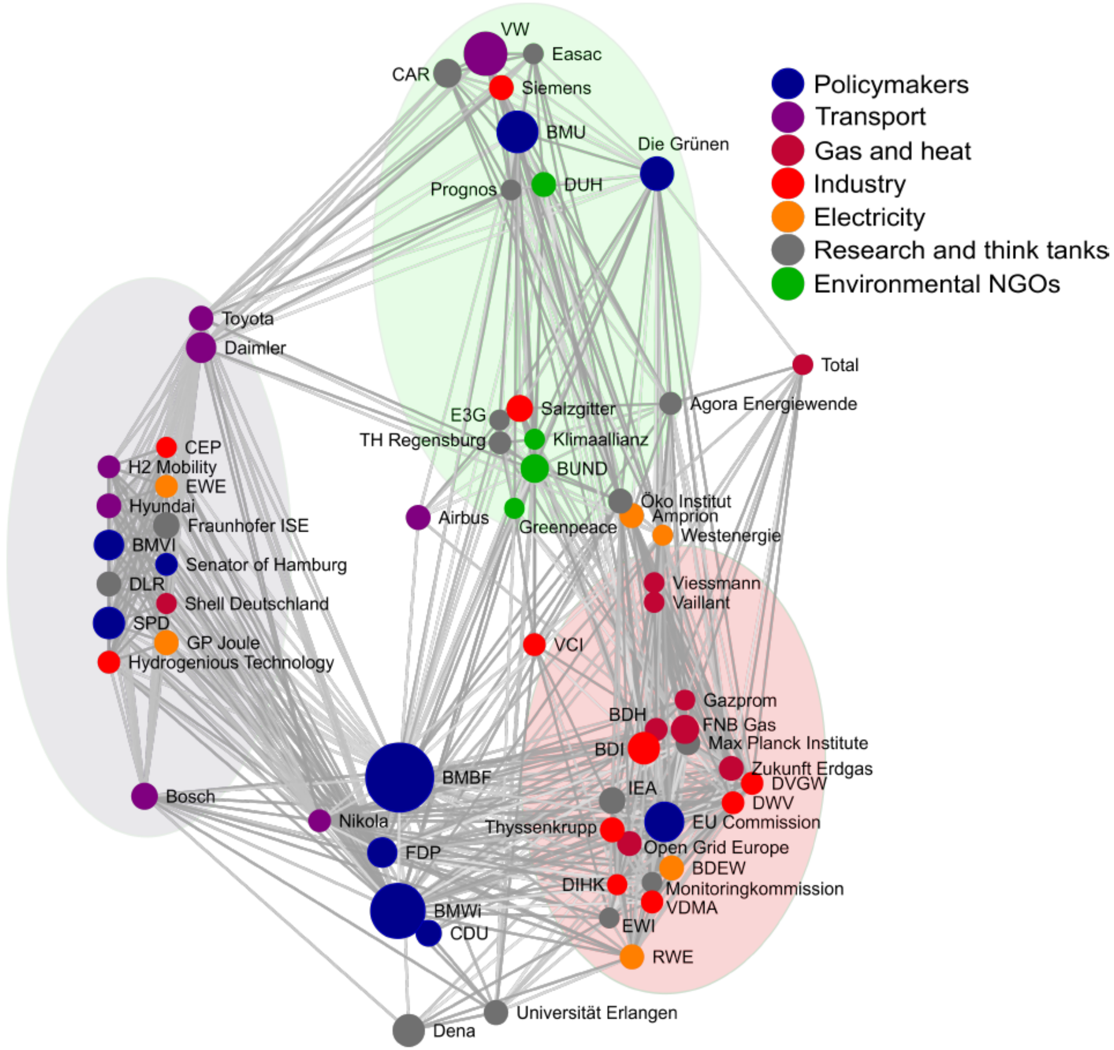
Discourse network

Dominance of policy actors

Three groups with similar positions

- Car industry (grey)
- Energy industry (red)
- NGOs / think tanks (green)

Figure 3: Discourse network of key conflicts in the German hydrogen debate



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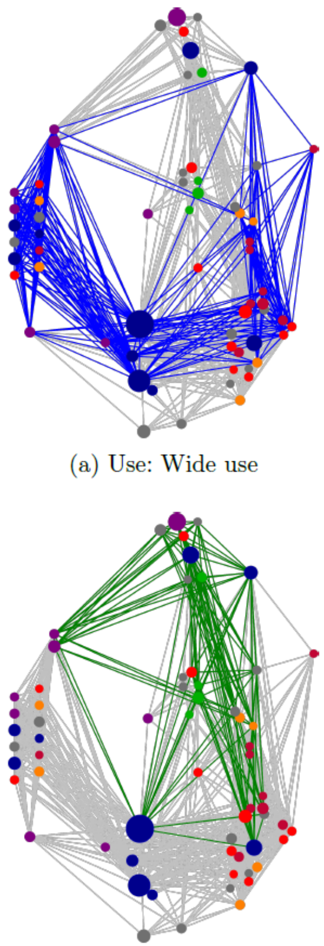
Three emerging conflicts

Where to use hydrogen

How to produce hydrogen

How to deal with imports

Figure 4: Specific lines of conflict



(a) Use: Wide use

(d) Use: Restricted use

Main insights

Much support for H_2 across all industries,

only a few critical voices

No ‘classic’ resistance by incumbent actors

→ everybody sees a benefit

- Industry: little alternatives
- Gas & heat: use of existing assets
- Transport: some car producers with H_2 strategies
- Electricity: balancing (?)

Complementary decarbonization strategies

Challenges

- Complex interactions & interdependencies

  Between entire sectors,
  e.g. clean electricity for transport

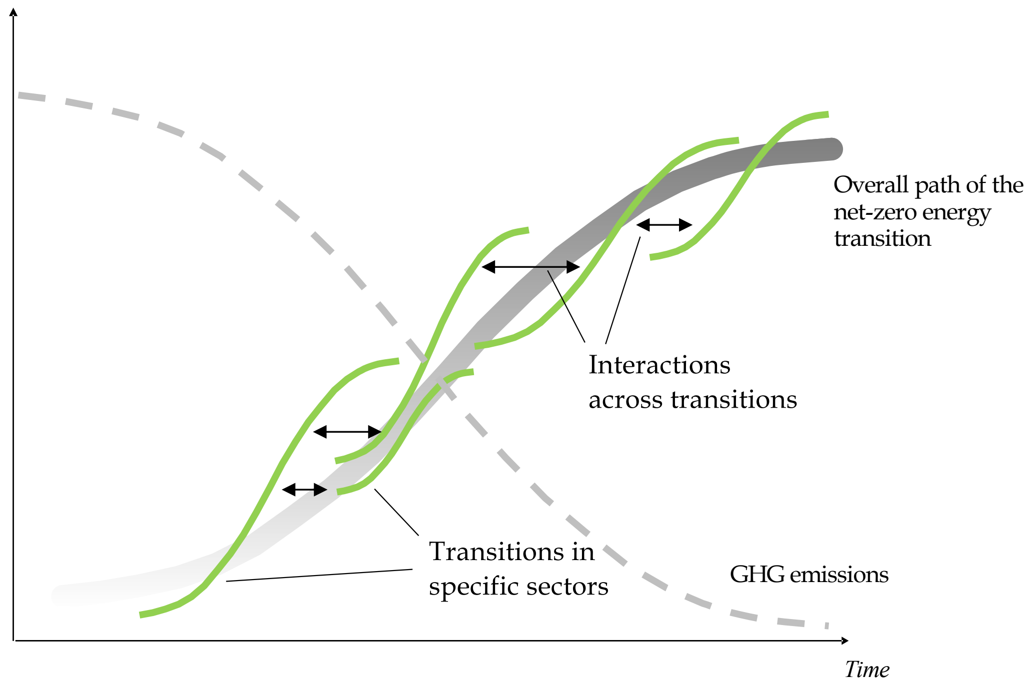
  Between specific technologies,
  e.g. EVs, load curves, grid balancing

- Competition for scarce resources,

  e.g. hydrogen

- Coordination across sectors

  → seek to exploit complementarities



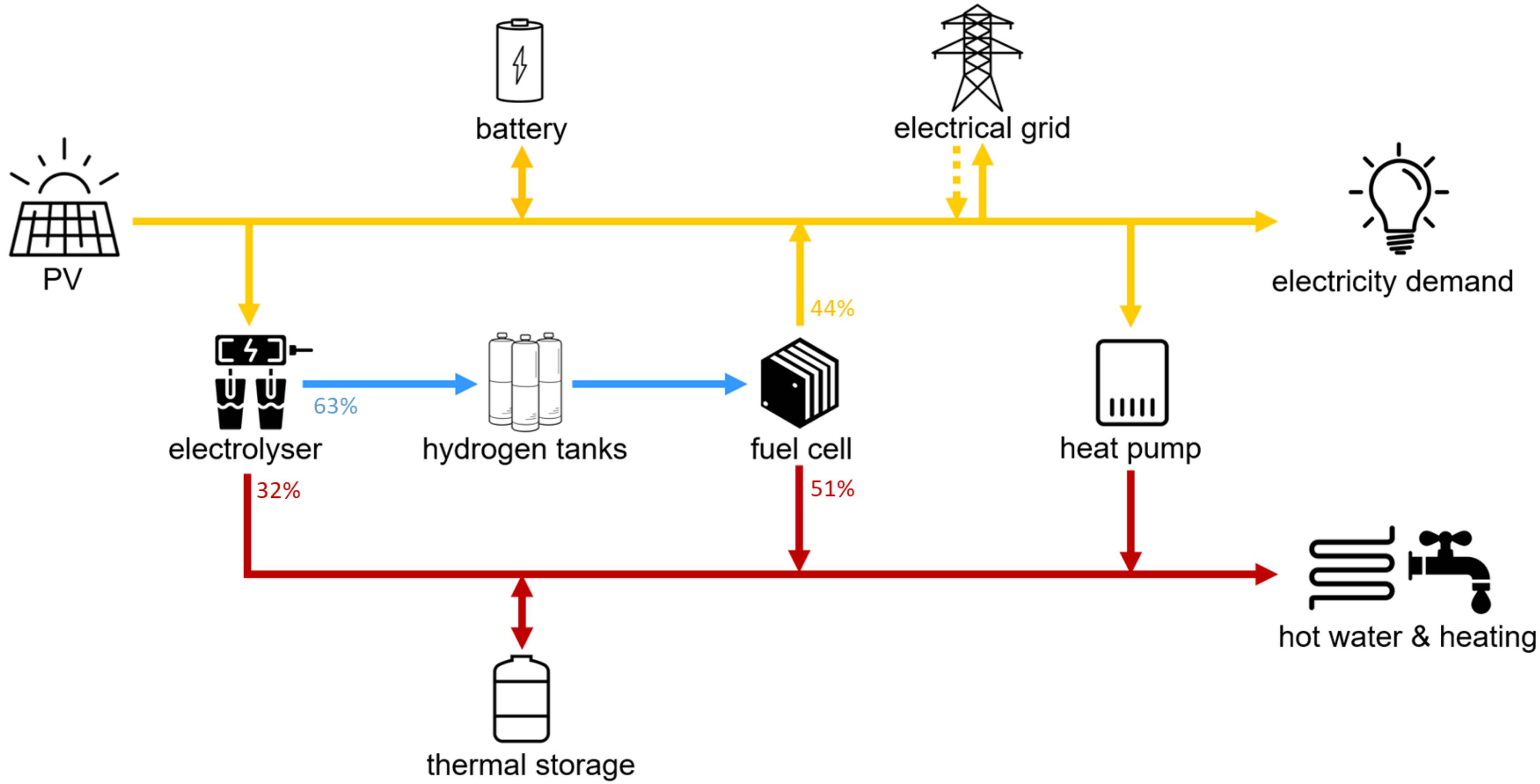
Markard & Rosenbloom, forthcoming

4

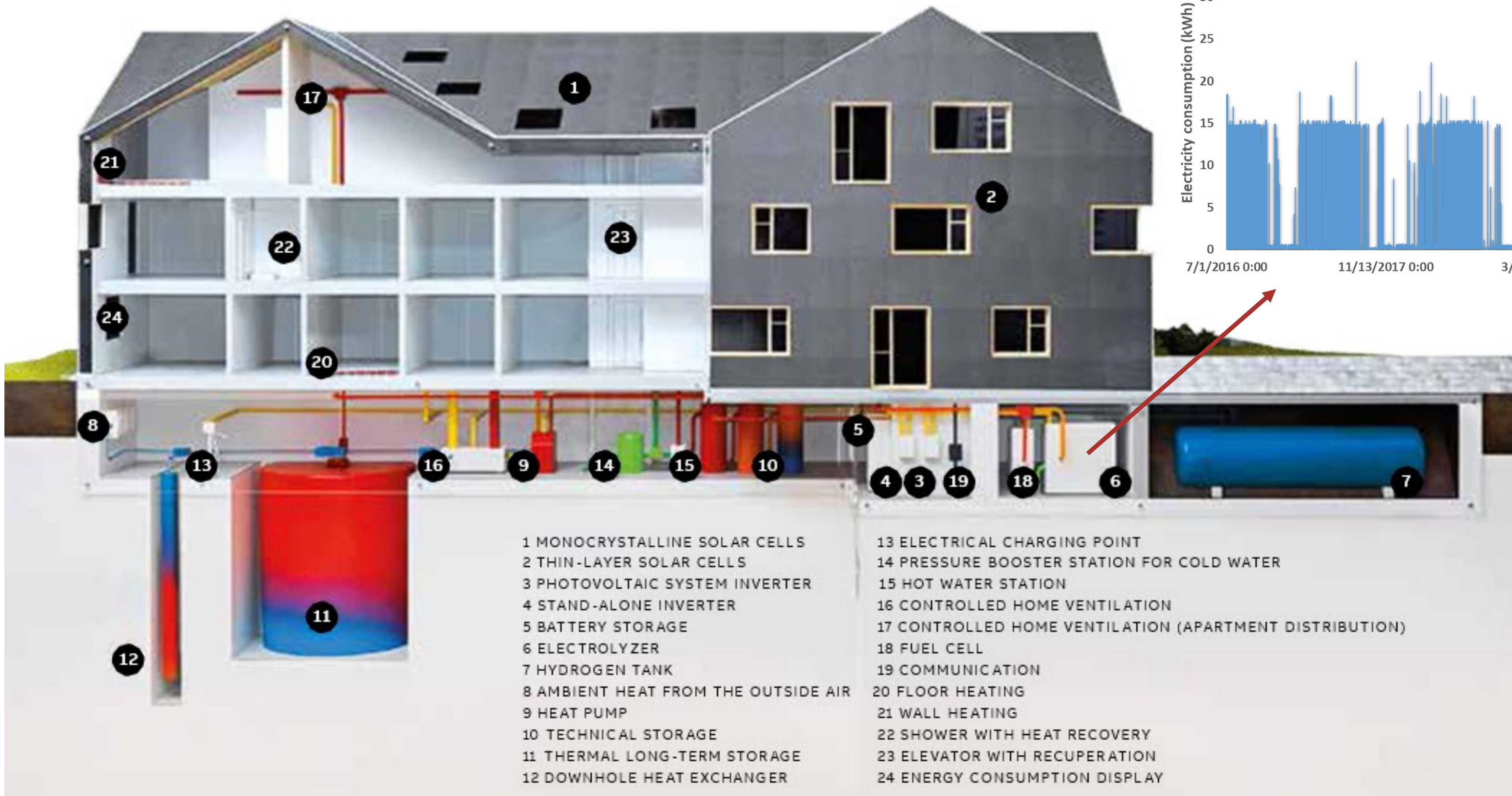
Flexibility assessment of P2H2P and e-mobility in multi-energy districts

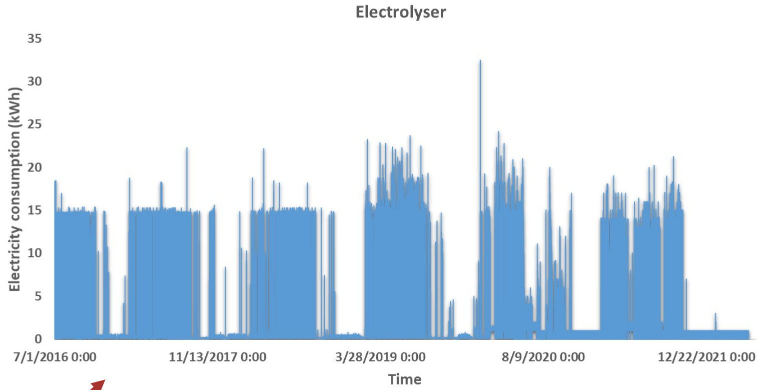
Presenter: Binod Koirala, Empa

Power-hydrogen-power (P2H2P) system



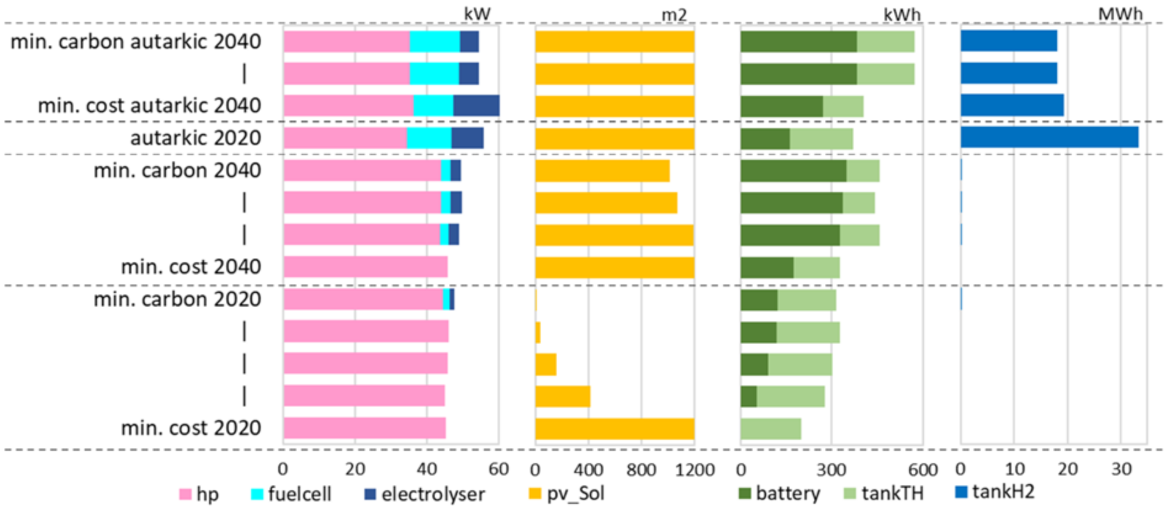
Power-hydrogen-power (P2H2P) system – Brütten (2016)

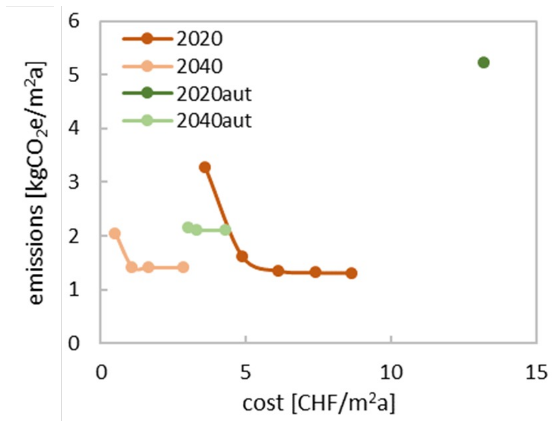




Power-hydrogen-power (P2H2P) system

- A residental P2H2P system is modelled in Ehub tool for a building consisting of 40 apartments in Baden.
- All autarkic as well as low carbon solutions use P2H2P system.
- P2H2P systems will be more attractive in 2040 due to higher efficiencies and lower costs.
- Pressurized hydrogen storage presents large cost and embodied emissions due to huge size.

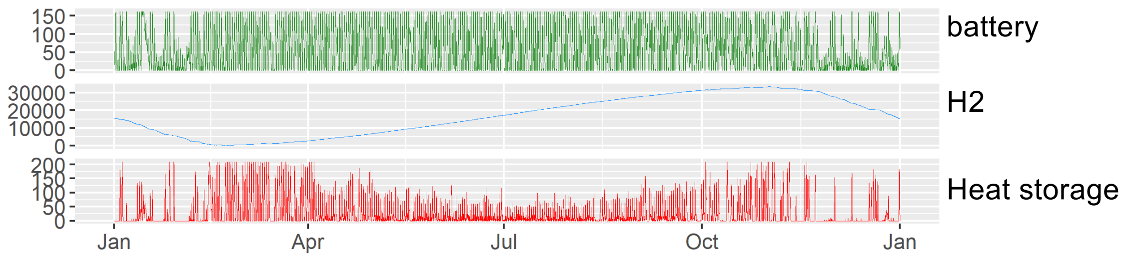


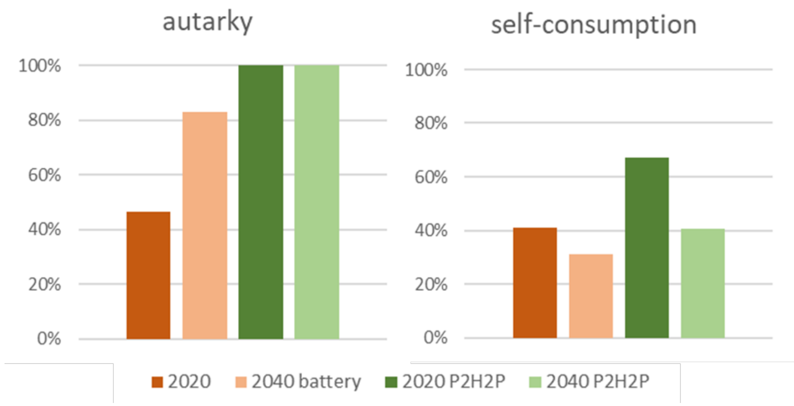


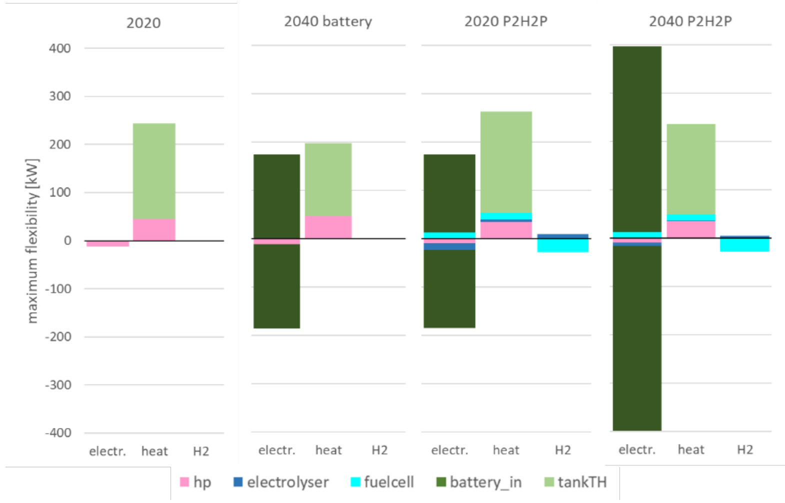
De Koning, Josien and Koirala, Binod; Analysis of a Residential Power-to-Hydrogen-to-Power System using MILP Optimization and the Energy Hub Concept, International Energy Workshop, 25-27 May, 2022, Freiburg, Germany

Power-hydrogen-power (P2H2P) system

- >80% autarky can already be achieved with a battery, without P2H2P
- P2H2P systems will have higher self-consumption/autarky.
- P2H2P system will be more flexible.
- P2H2P system can also provide seasonal flexibility.



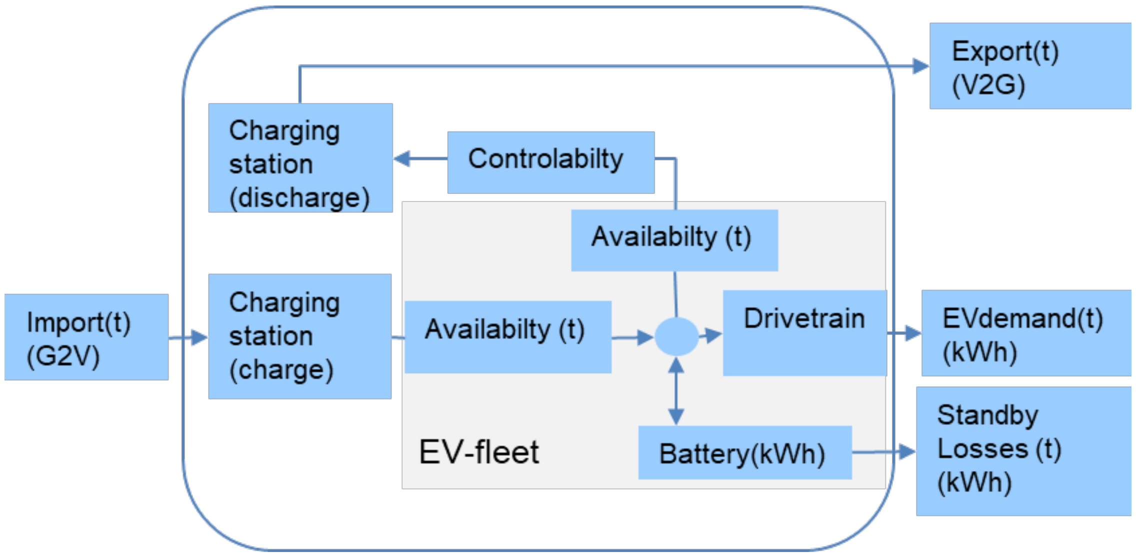


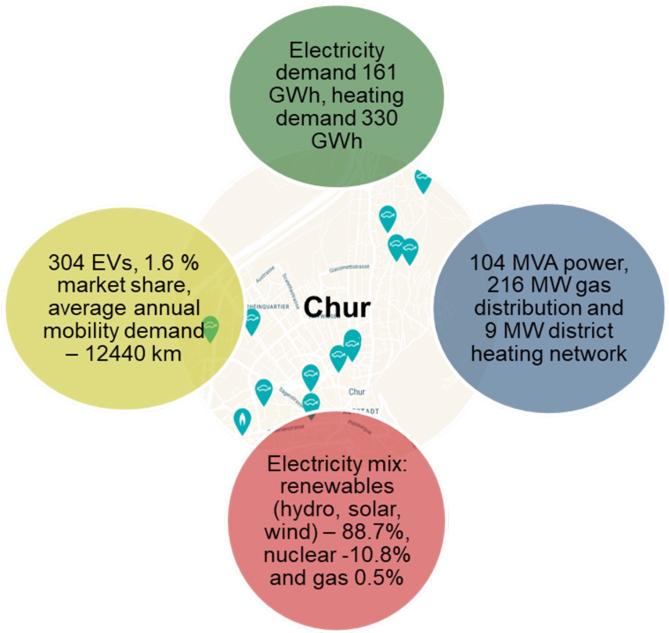


De Koning, Josien and Koirala, Binod; Analysis of a Residential Power-to-Hydrogen-to-Power System using MILP Optimization and the Energy Hub Concept, International Energy Workshop, 25-27 May, 2022, Freiburg, Germany

E-mobility flexibility

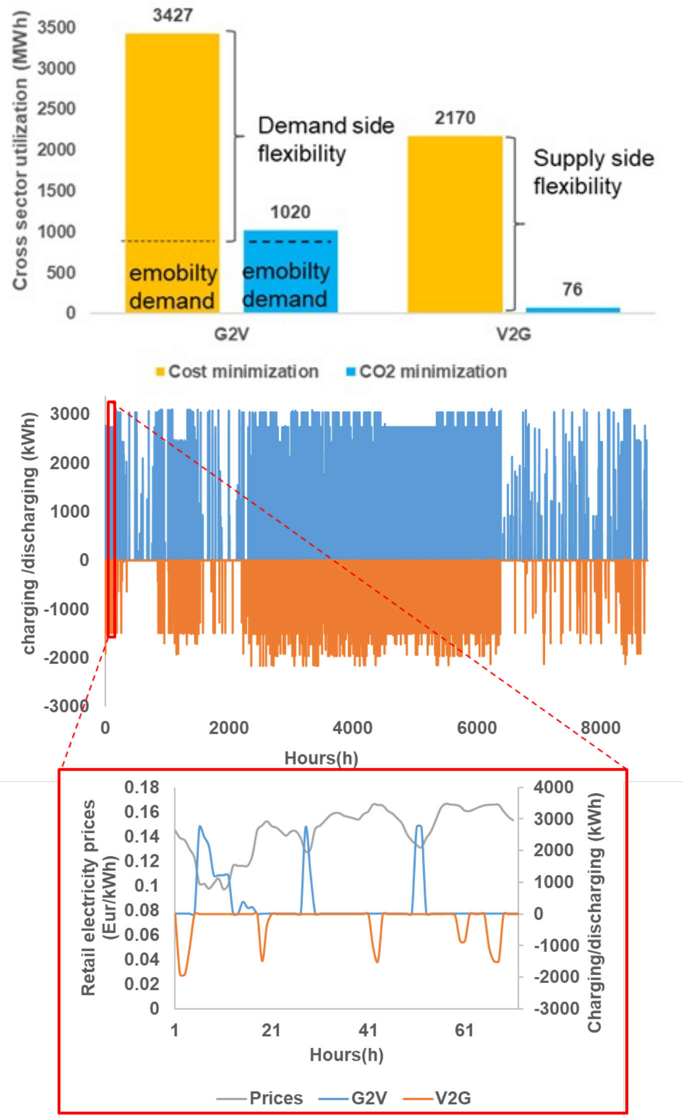
- An e-mobility module is developed and integrated into the E-hub Tool.
- It captures the fleet size, charger size, transport demand, vehicle availability, controllability and battery size.
- The module is tested using the multi-energy system in Chur.





E-mobility flexibility

- Under the current boundary conditions and energy-mix, V2G is an attractive solution in a cost optimization over a CO_2 optimization scenario, this may change with higher share of renewables.
- In future – sensitivity analysis will be conducted for different share of EVs, renewables etc.



B. Koirala, Mutschler, A. Bartolini, A. Bollinger, and K. Orehouning, "Flexibility assessment of e-mobility in multi-energy districts ," CIRED e-mobility workshop, 2-3 June 2022, Porto, doi: [10.1049/icp.2022.0827](https://doi.org/10.1049/icp.2022.0827)

Conclusions and recommendations

P2H2P:

- Multi-energy system with P2H2P has potential to be more flexible and autarkic.
- Both technological and costs improvements are needed for P2H2P systems to be more attractive option.

E-mobility

- E-mobility can provide both supply and demand side flexibility.
- Institutional arrangements are needed to harness flexibility potential of V2G (controlabilty, incentives, etc.)

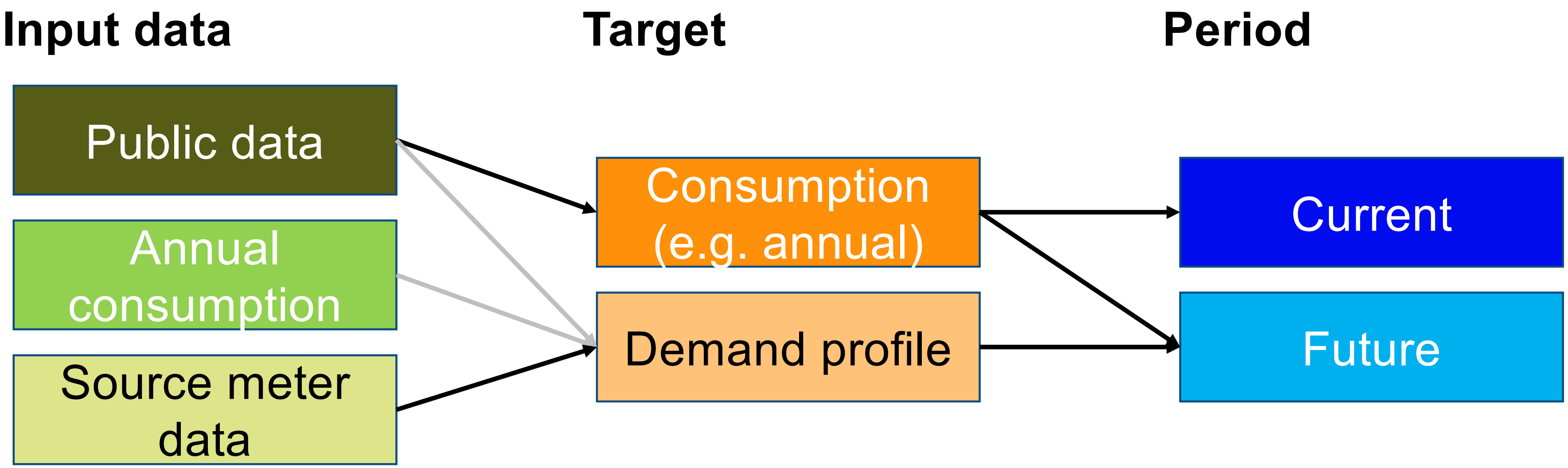
5

Residential heating / cooling demand and flexibility potential

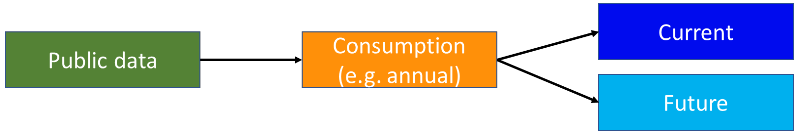
Presenter: Philipp Schütz, HSLU
In collaboration with: Marcel Troxler, Esther Linder, Edward Lucas

What are we considering?

Task: Estimate heating/cooling demand for (residential) buildings in Switzerland



Heating/cooling loads from public data



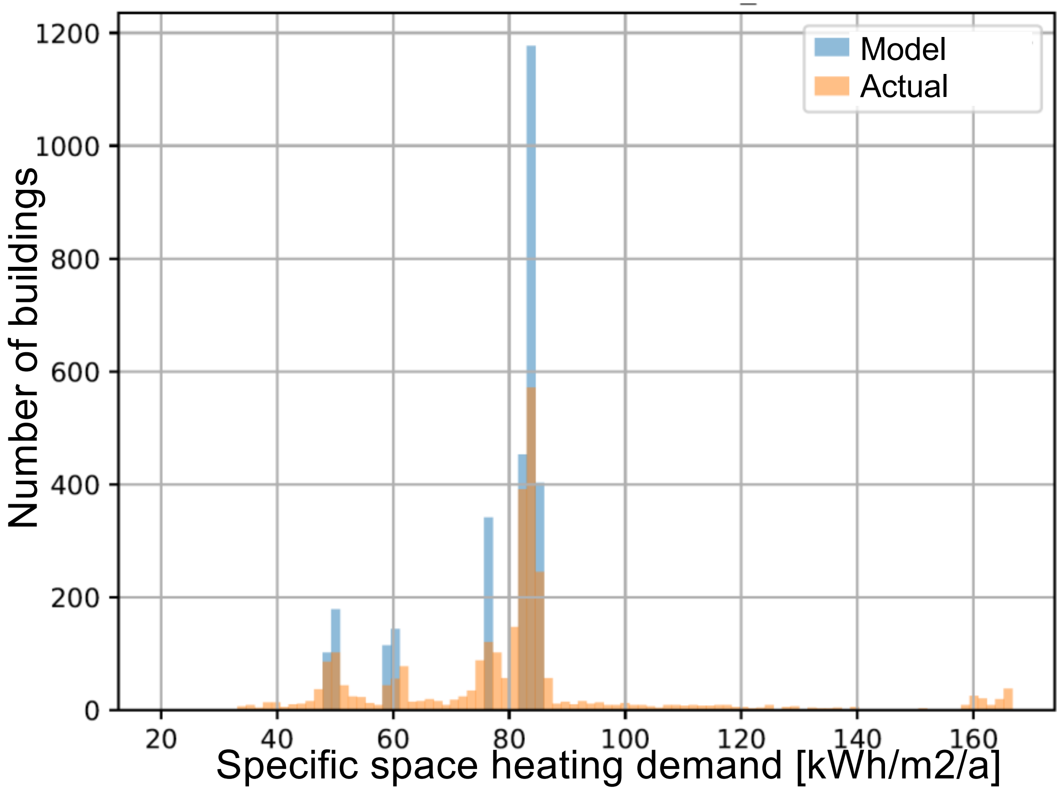
Approach:
Estimate heating loss from register of buildings and dwelling data (RDB):

$$Demand = Heat\ loss\ factor \cdot ERA \cdot (T_{room} - \bar{T}_{ambient})$$

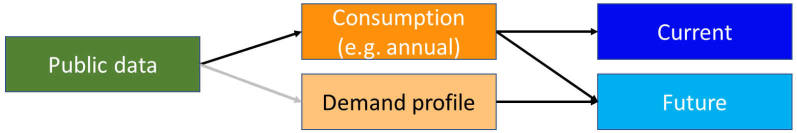
$Heat\ loss\ factor$:	Estimated based on RDB data
ERA:	Energy reference area (estimated as 85 % of building area * #floors)
T_{room}:	Target room temperature (here 20 °C)
$\bar{T}_{ambient}$:	Average ambient during heating season ($T_{ambient} < 15°C$)

Heating/cooling loads from public data

Validation: Annual consumption data of Swiss city



Heating/cooling loads from public data

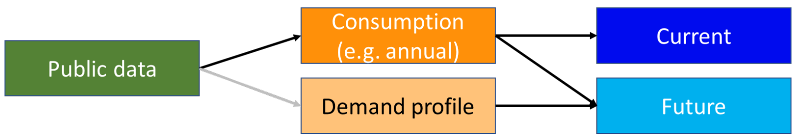


Approach:
Estimate parameters of simple building dynamics model and run model

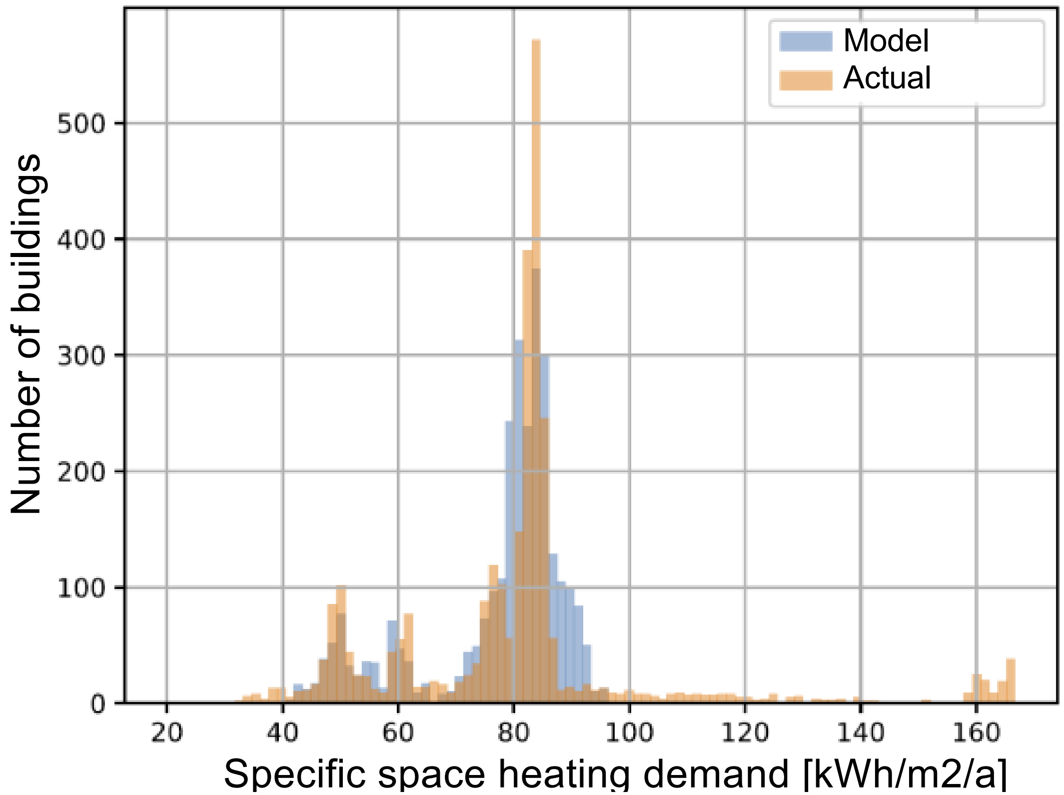
$$C\frac{\partial T_{room}}{\partial t} = -H\left(T_{room} - T_{ambient}\right) + gI + \dot{Q}_{Es} + \dot{Q}_{internal}$$

C:	Lumped heat capacity
T_{room}:	Room temperature
H:	Heat loss factor
$T_{ambient}$:	Ambient temperate
$g\ I(t)$:	Solar irradiation contribution
$\dot{Q}_{Es}$:	Contribution of emitter / heating system
$\dot{Q}_{internal}$:	Internal loads (e.g. appliances and persons)

Heating/cooling loads from public data



Validation: Annual consumption data of Swiss city



Heating profiles from metered source data

Approach:
Parameter identification for dynamic building model

Approach:
Parameter identification for dynamic building model
based on measured source profiles.
(Parameter fitting for C, H, g based on minimisation of RMS deviation of simulated and actual cumulative heat demand)

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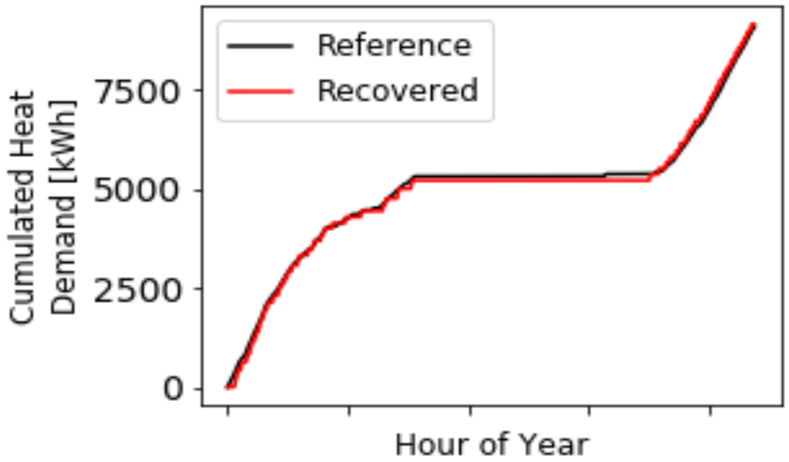
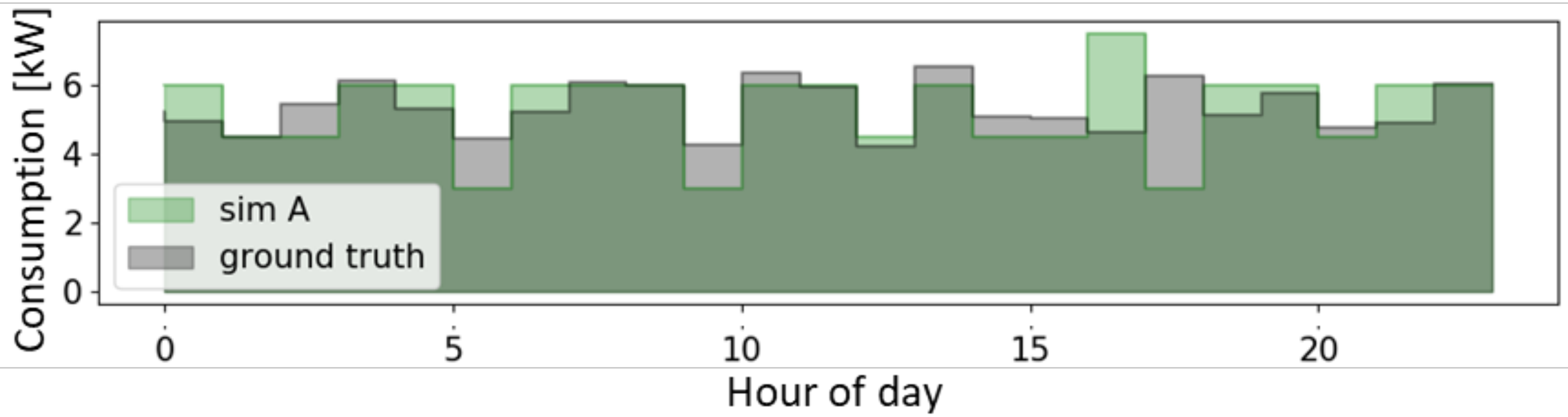


Heating profiles from metered source data

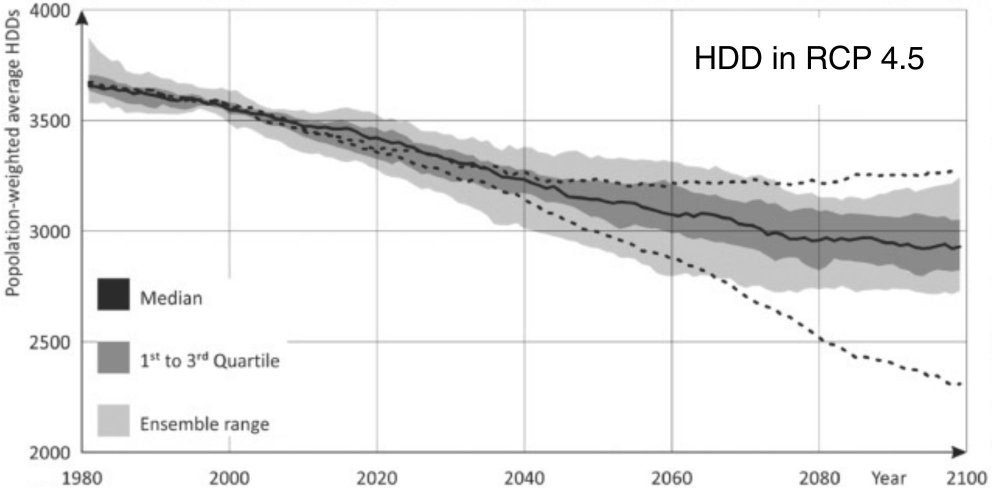
Validation: Test procedure on actual measurement data

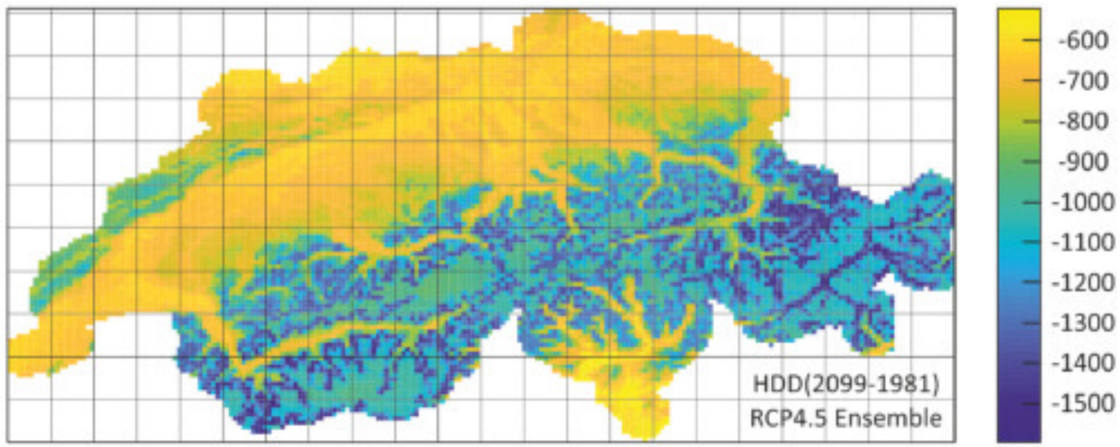


Observation: Good overall description of system behaviour, but controller not synchronised.

Investigating the evolution of heating / cooling demand

Estimating heating/cooling demands based on heating/cooling degree days (HDD/CDD) evolution:





M. Berger, J. Worlitschek, The link between climate and thermal energy demand on national level: A case study on Switzerland, https://doi.org/10.1016/j.enbuild.2019.109372

What happens if we cut the heating system?

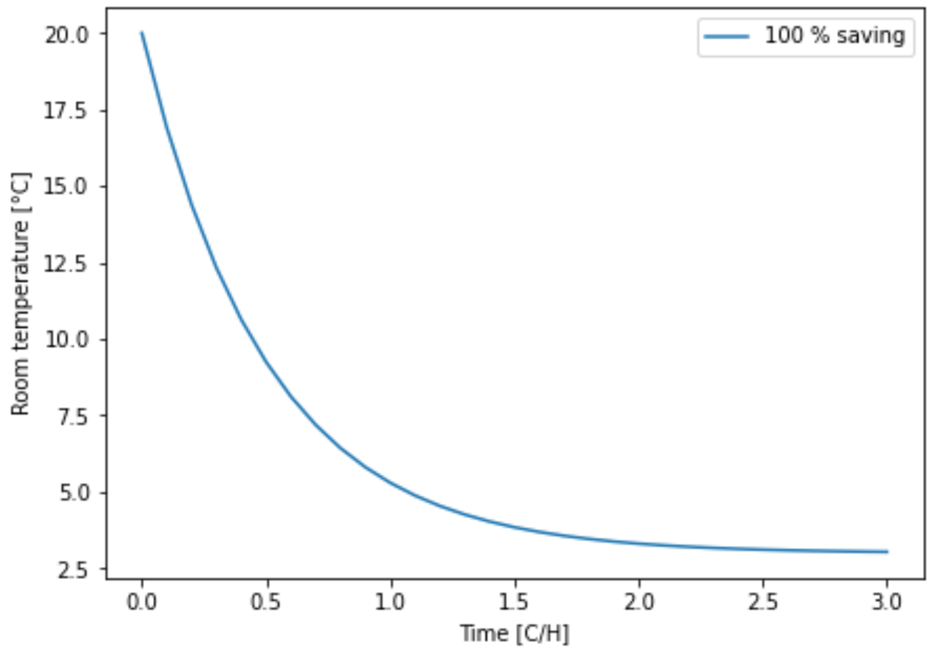
Assumptions:

- Governing equation for room temperature T:
  $$C\,\dot{T} = -H(T - T_{amb}) + \dot{Q}_{ES}$$
  Uniform building with linear heat loss rate

- Constant, but variable ambient temperature T_{amb} and heating power $\dot{Q}_{ES}$

➔ Normal exponential cooling down behaviour

➔ Target temperature is offset by the heating power's contribution



Flexibility without comfort loss

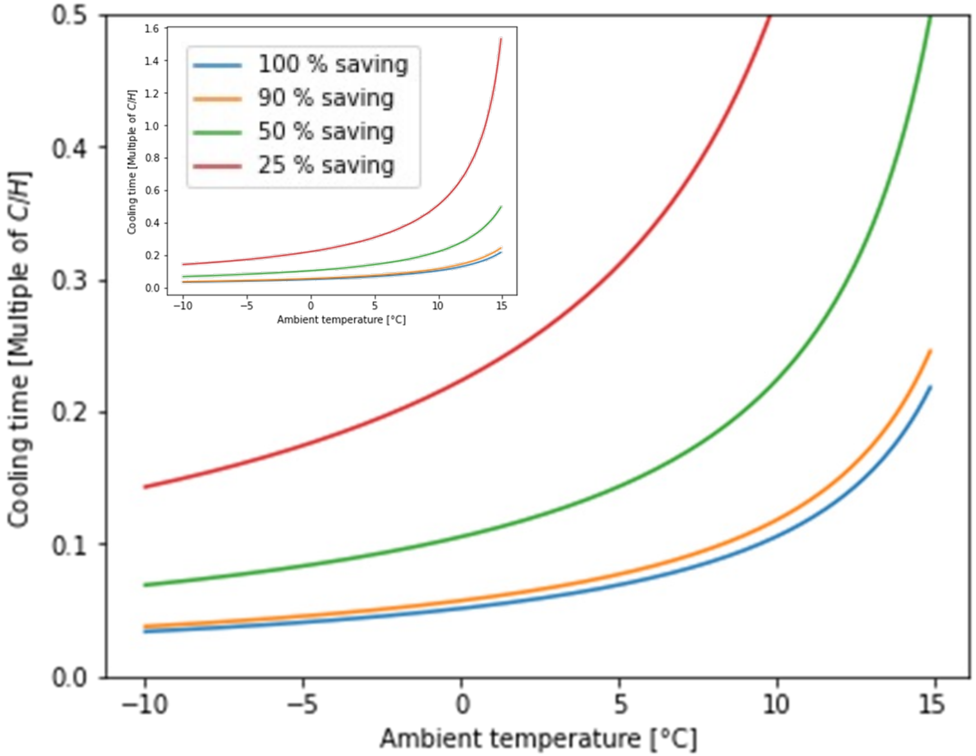
Guiding questions:

- How long does it take until the room cooled down by 1 K?
- By how much can we prolong this time if we maintain a bit of heating?

→ Easily accessible potential of 5 – 20 % characteristic time *C/H* of building with 100 % saving (full shut down)

→ Typical values of C/H:
- old building 6 h
- modern building 12 – 24 h
- Minergie building 24 h +

Analytical solution



Take home messages

- Public data enable the estimation of residential heating/cooling loads
- Three different procedures to estimate the heat / cooling load are validated
- Already public data are sufficient for decent reproduction of cumulative heating / cooling demand
- Accuracy depends on available data

Call for support:
If you have access to large-scale heat consumption data, please get in contact with us.

Poster pitches

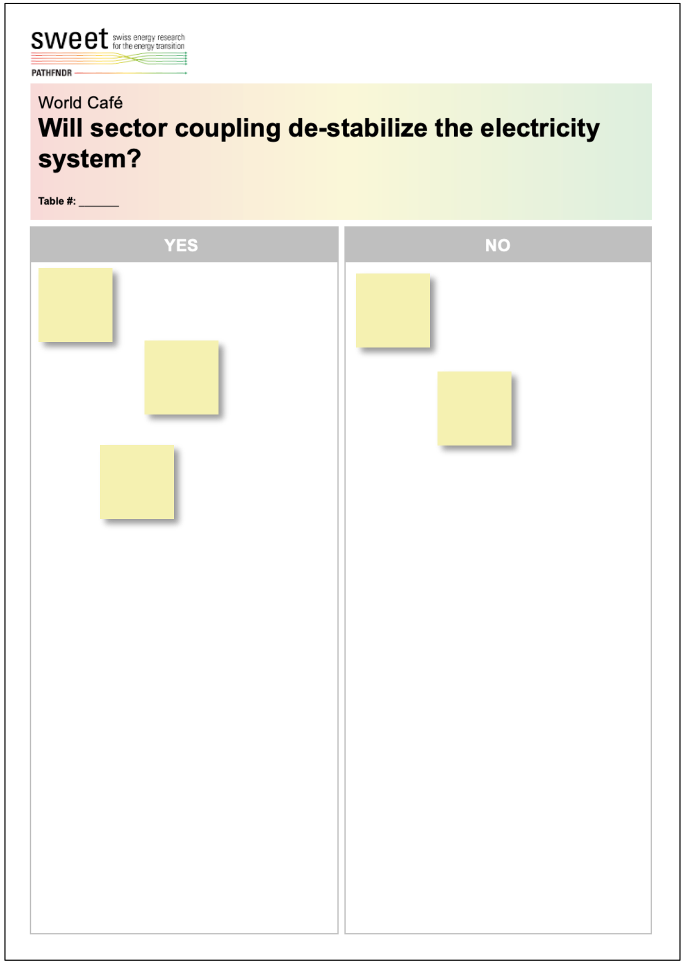
World Café session

World Café table 1 & 2
Can Switzerland reach its net-zero goal with import/export limitations?
Facilitiator(s): Jared Garrison & Stefan Pfenninger

World Café table 3 & 4
Is hydrogen a hype and is it not needed for the energy transition in Switzerland?
Facilitiator(s): Paolo Gabrielli & Binod Koirala

World Café table 5 & 6
Are current regulations or institutional interests preventing efficient use of flexibility?
Facilitiator(s): Adamantios Marinakis & Philipp Schütz

World Café table 7 & 8
Will sector coupling de-stabilize the electricity system?
Facilitiator(s): Massimo Fiorentini & Florian Baader



Closing remarks

Thank you!

Dinner

18:30

Drinks at The Bristol Hotel bar

21:30 (for participants staying in Bern)

Workshop day 2

9:00 (please arrive 10-15 minutes earlier)

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PATHFNDR

PATHFNDR was sponsored by the Swiss Federal Office of Energy (SFOE)

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