Empa
Materials Science and Technology

UNIGE Energy and Environment Seminar

Empa -Urban Energy Systems Lab and Flexibility aware Planning of Multi-Energy Districts

23. May 2024 – Dr. Binod Koirala

Agenda

- My academic journey
- Introduction
  - Empa
  - Urban energy systems lab
- Energy system Flexibility
- Flexibility aware energy system planning
  - E-mobility
  - Power to Hydrogen to Power (P2H2P)
  - Edge Data centers
- Take home messages

My academic journey

2001-03
Intermediate of Science,
Kathmandu University

2005 - 09
BTech Electrical Engineering, NIT Jaipur
Summer Internship, IIT Kanpur (2007)
Summer Internship, ISET, Kassel (2008)
DAAD WISE Fellowship, Fraunhofer IWES (2009)

2009 - 13
MSc Renewable Energy Management (2009-11)
Researcher, Fraunhofer ISE (2009-13)

2013 - 17
Erasmus Mundus Joint Doctorate
TU Delft, KTH, Comillas
Sustainable Energy Technologies
and Strategies / Electrical
Engineering

2017-19
Postdoc, Utwente
NNCI fellow – Arizona state University
Expert, IRENA-ADFD(2018)
International conference
2 special issues – community energy/storage

2019 - 21
Scientist, TNO Energy Transition
Acquisition/WP leader/project manager
(Hychain-4, NorthSea Energy,
H2020 BRIGHT, H2020 GRETA)
Lead I-ELGAS development
IEA liaison NL (Projected cost of
generating electricity 2025)
(permanent position)

2021 -
Empa, Urban Energy System Lab
Deputy, Multi-energy system group
Cluster leader, energy system design
Empa PI: SWEET PATHFNDR, DecarbCH
and CoSi, NCCR Sisslerfeld,
Net-Zero Rheitnal/Frauenfeld, HE HEATWISE
Leading EhubX development
Expert Energy & Environment, Innosuisse

2022 - 23
CAS Science Leadership
FHNW
Trust analysis @UESL

The ETH-Domain: Top-notch Research for Switzerland

Excellence times Six – the Institutions of the ETH Domain

ETH zürich

EPFL

PAUL SCHERRER INSTITUT
PSI

WSL

Empa

eawag

Empa locations – our Sites

Dübendorf

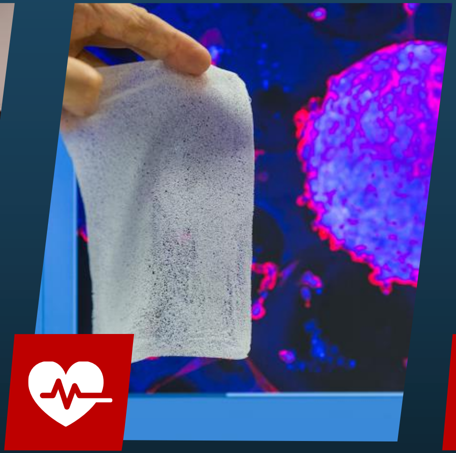
St. Gallen

Thun

Our Response – in four Research Focus Areas

Nanoscale Materials & Technologies

Built Environment



Health & Performance

Energy, Resources & Emissions

NEST – a Building for Innovation

In the NEST building of Empa and Eawag, new building technologies, construction and energy concepts are tested, optimized and demonstrated in practice under real-world conditions together with partners from research and industry.

“The energy landscape is shaped by cities”[1]

>55% of world’s population

75% of world’s primary energy

50-60% of total GHG emissions

→ **We need an urban future with net-zero emissions**

*“The **challenges of the 21st century** will be **solved in an urban context** for most of the world”* [2]

Research mission & vision: Urban Energy Systems Lab (UESL)

- Develop computational **energy models** and **analysis methods** to support the **practical realization** of **sustainable urban energy transitions**

[1] IEA, 2016. Energy Technology Perspectives 2016 - Towards Sustainable Urban Energy Systems.
[2] Fisk, D. (2009). “Renewables and the future of sustainable urban development.” In: CISBAT 2009, EPFL, Lausanne, Switzerland.

Urban energy systems lab's strategy

- Develop **innovative building energy systems** and technologies
- Design relevant **numerical models and analysis techniques** for assessing the optimal integration, design and operation of multi-energy systems from building to district and higher scales
- **Test and implement** the developed strategies through **demonstration** in close collaboration with research and industry partners

Some key details for our lab

- **35+ lab members** (research associates, PhD students, postdocs, scientists)
- Organized in two groups:
  - **Multi-energy systems (MES)** – led by G. Mavromatidis and Binod Koirala (deputy)
  - **ehub** – led by P. Heer
- Leading a wide range of projects from basic research to applied research and industry collaborations
  - Funding sources: BFE, SNSF, EU, etc.

- Open-source modelling tools:
  - CESAR-P: Urban building energy simulations
  - ehubX: Multi-scale energy system optimization
- From research to practice:
  - Three spin-offs came out of our lab:
    - Sympheny
    - Viboo
    - Zurich Soft Robotics

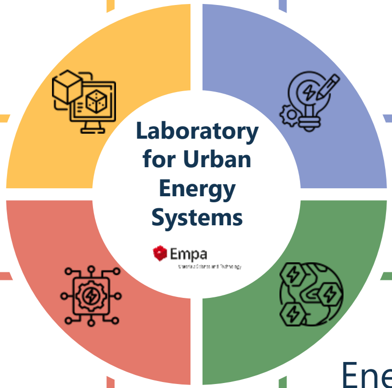
Four research clusters

Digital Twins

Digital Twins of buildings and building energy systems, semantic web technologies, knowledge graphs

Energy system design

Energy system optimization, sector coupling, building energy analysis and retrofit strategies at building and portfolio levels



Demand-side management

Energy system flexibility, market mechanisms, model-predictive control (MPC), machine learning

Large-scale energy systems

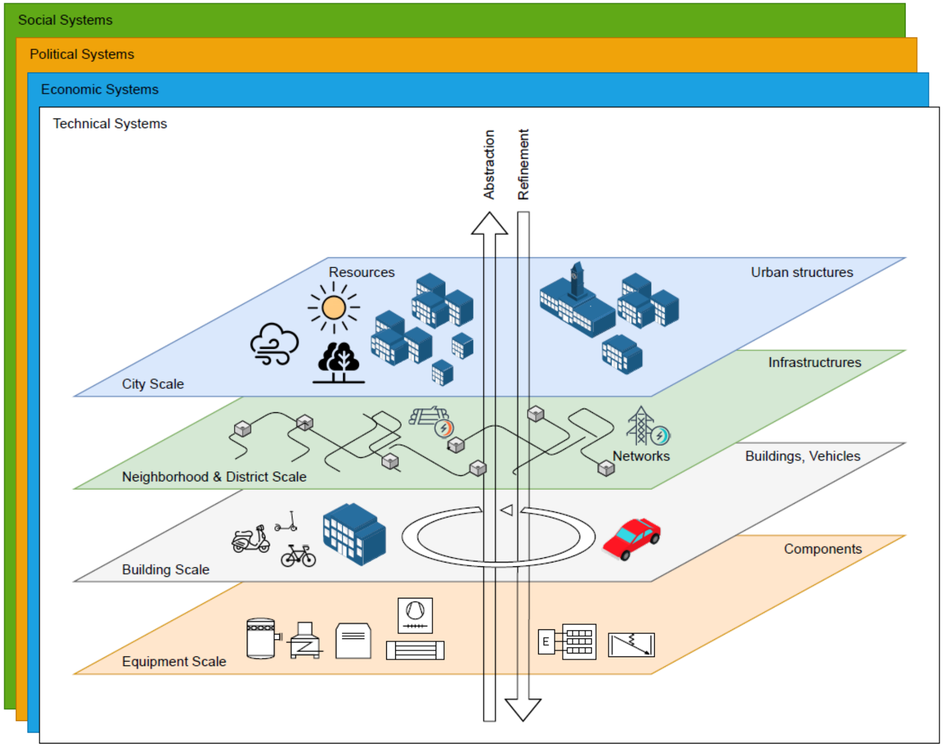
Energy system integration and sector coupling at different scales, impact analysis of socio-economic and policy factors, resilience & flexibility

Key research approaches & methods

<u>Methodologies</u>

- *Mathematical Optimization*
- *Machine Learning (ML)*
- *Applied Statistics*
- *Building Performance Simulation*
- *Geographical Information Systems (GIS)*

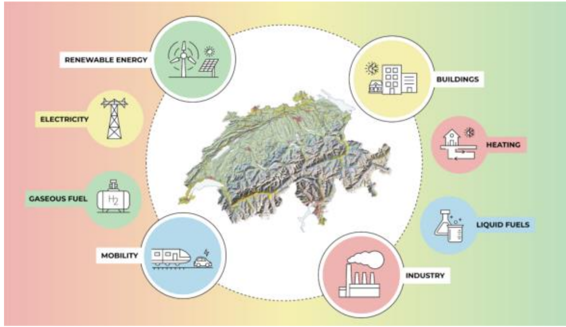
Research scales



Source: Sulzer, M., Wetter, M., Mutschler, R., & Sangiovanni-Vincentelli, A. (2023). Platform-based design for energy systems. *Applied Energy*, *352*, 121955.

Some example projects

sweet swiss energy research for the energy transition
PATHFNDR



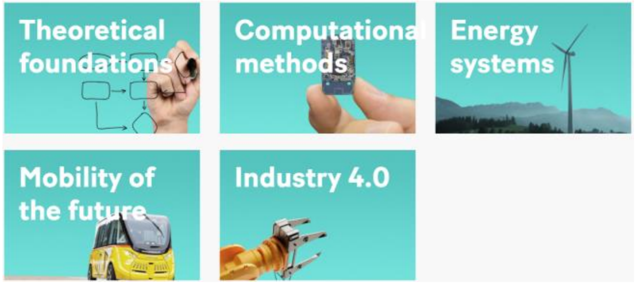
sweet swiss energy research for the energy transition
DeCarbCH

sweet swiss energy research for the energy transition
CoSi

Funded by: Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

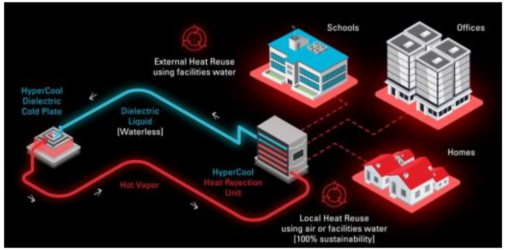
Swiss Federal Office of Energy SFOE

NCCR Automation



Funded by: FNSNF SWISS NATIONAL SCIENCE FOUNDATION

HEATWISE

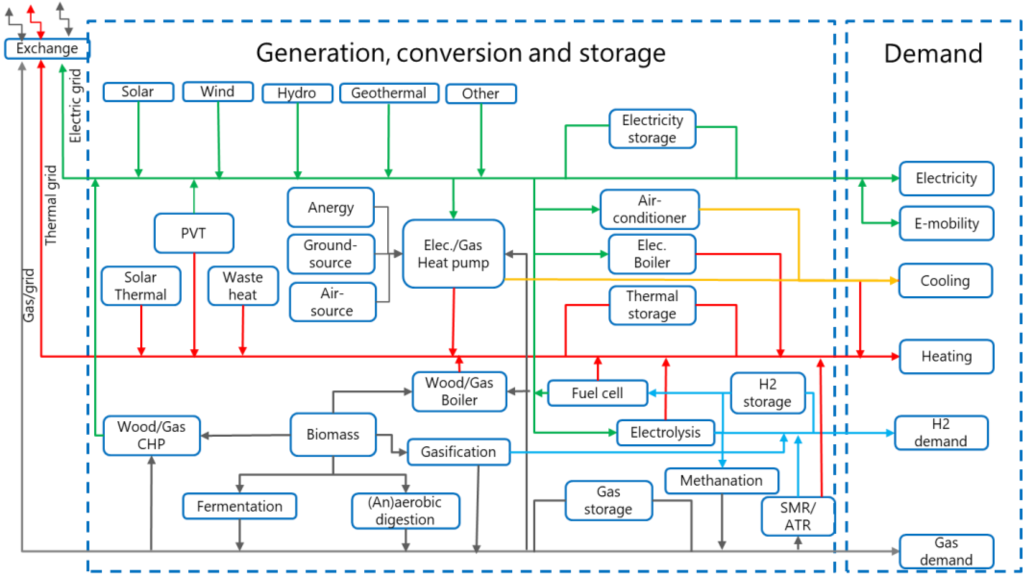


Funded by: HORIZON EUROPE

Flexibility aware planning of multi-energy districts

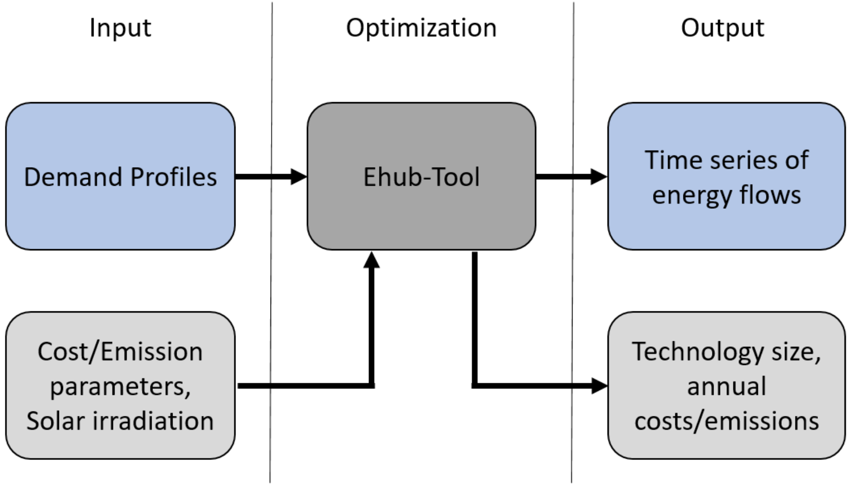
Multi-energy districts planning

- The energy landscape is changing quickly to meet decarbonization objectives.
- Increased level of integration between energy carriers in future energy districts through conversion and storage technologies.
- The design of multi-energy districts is a function of the overall multi-energy boundary conditions given by the energy supply and demand as well as objectives to minimize costs and emissions.



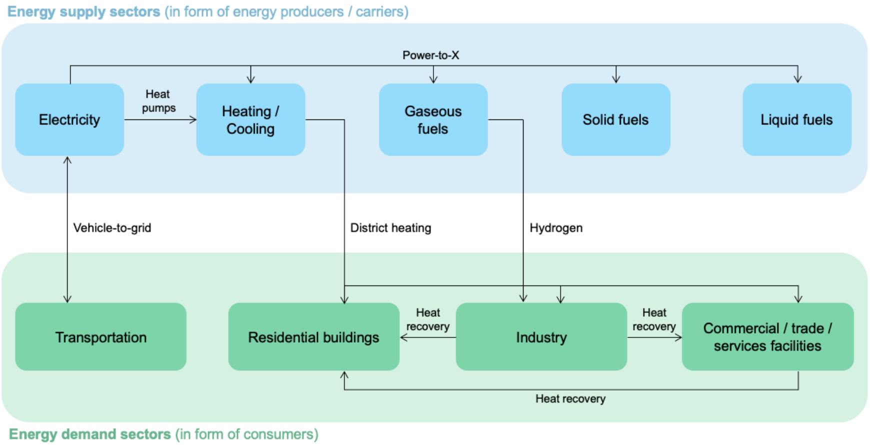
EhubX tool

- Design optimization of multi-energy system
- Objective: cost/CO2 minimization, multi-objective
- Scope: Buildings/neighbourhoods/ district/cities/countries
- Granularity: Hourly/sub-hourly dispatch of power, gas (CH4/H2)& heating/cooling system, Annual/multi-stage/multi-hub
- Will be open sourced in Q4 2024



Energy System Flexibility

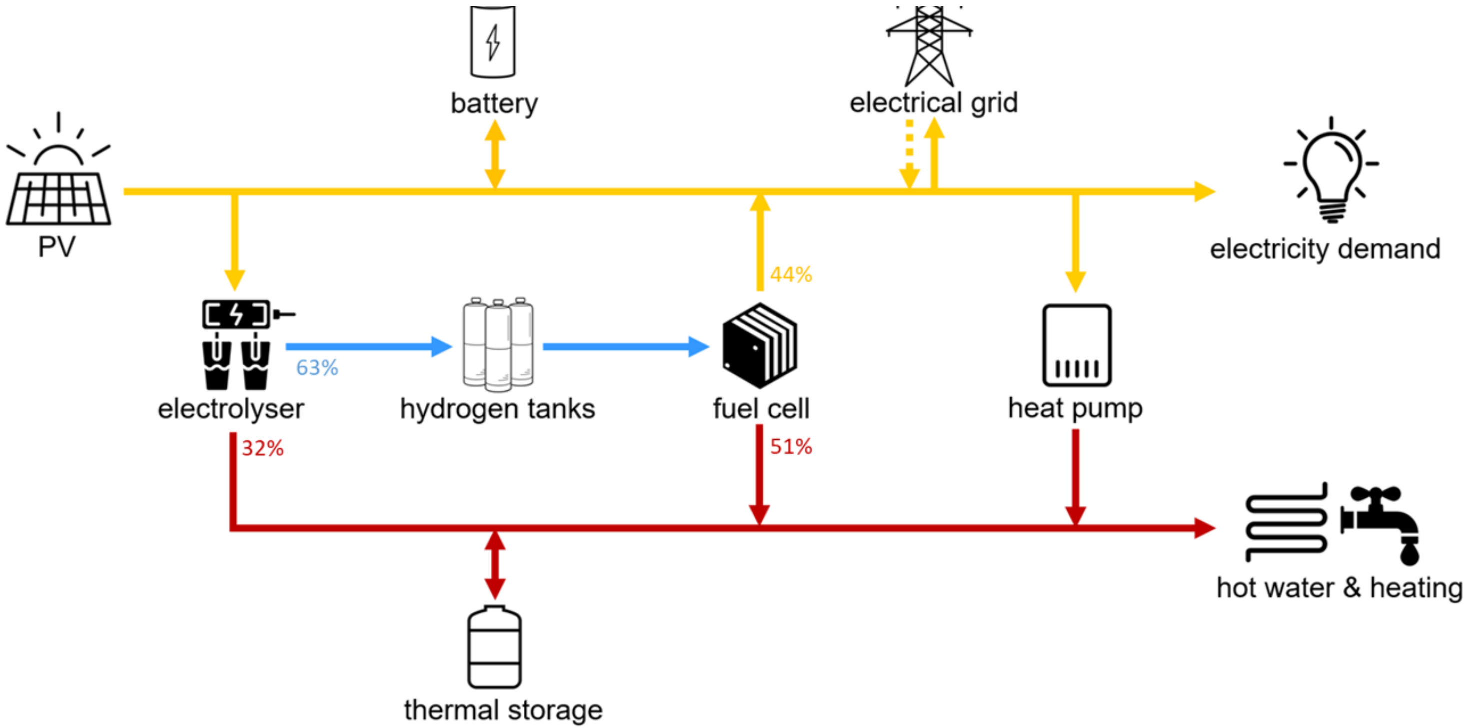
- Ability of the energy system to react to the fluctuating needs (supply shortage, increasing renewables, electrification of transport/heating sectors)
- Key means:
  - Supply side flexibility (e.g. curtailment, ramp up/down),
  - Demand side flexibility (e.g. DSM (heat pumps, **EVs**, **data centers**, curtailment)
  - Energy storage
  - Conversion/sector coupling **(e.g. P2H2P)**
  - Interconnection/grid reinforcement



Source: SWEET PATHFNDR

Power to hydrogen to power system (P2H2P)

Power to hydrogen to power (P2H2P) system



P2H2P system@Brütten (2016)

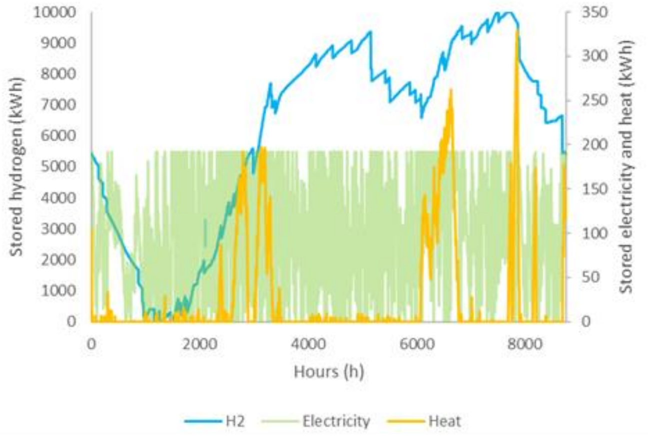
P2H2P system at MFH Brütten

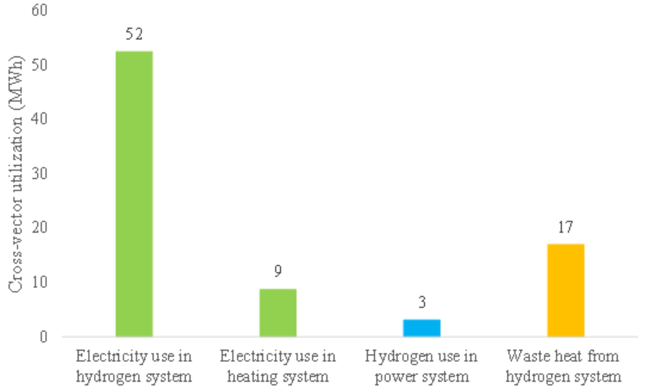
- Fully autarkic MFH at Brütten (ZH) with 9 apartments, fully operational since 2016
- Energy reference area – 1328 m2
- Imports: Solar electricity and geothermal heat
- Conversion and storage technologies:
  - Solar PV roof: 512 m^2 (79 kWp)
  - Solar PV facade: 485 m2 (47 kWp)
  - Electrolyser: 14.5 kW (waste heat 30°C)
  - Fuel cell: 6.2 kW (waste heat at 60°C)
  - Heat pump: 28 kWth
  - Borehole: 338m, 40W/m, 14 kW
  - Battery: 192 kWh
  - Heat storage: 250 m3
  - Hydrogen tank storage: 120 m3

Photo: Beat Bühler

P2H2P system

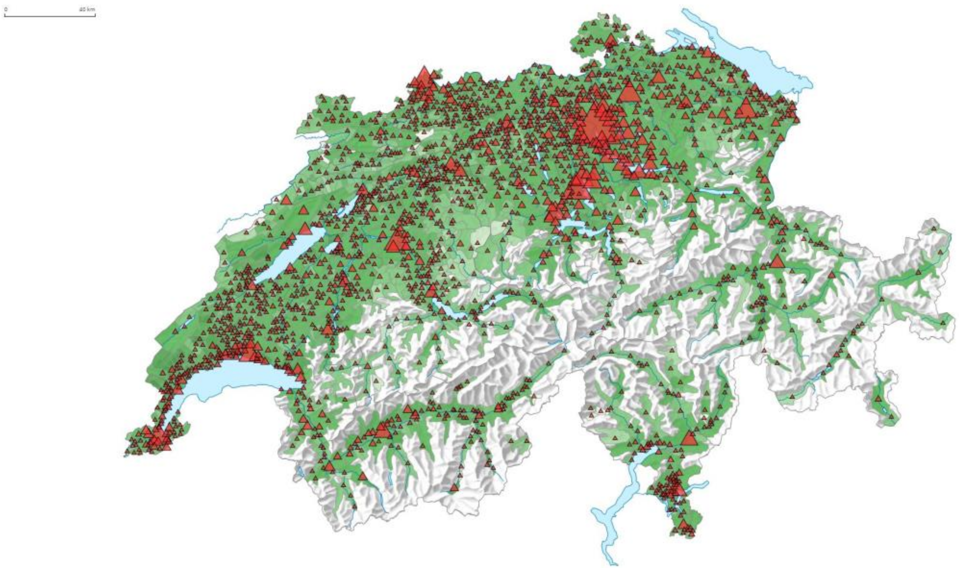
- An autarkic residential P2H2P system@Brütten is modeled in the ehubX tool.
- Battery and thermal storage cover short-term imbalances, while hydrogen storage covers short-term and long-term seasonal imbalances.
- The case study will be further extended with scaling up to district scale, different combination of conversion and storage technologies as well as sensitivity analysis on input parameters





E-mobility Flexibility

E-mobility in Switzerland (2023)



Anteil der rein elektrischen Fahrzeuge am Personenwagenbestand, in %*

	≥ 4,8
	2,4 – 4,7
	1,2 – 2,3
	0,6 – 1,1
	0,3 – 0,5
	< 0,3
	keine rein elektrischen Fahrzeuge [–]

Schweiz: 3,3

Anzahl der rein elektrischen Personenwagen*

6 521
2 500
750
≤ 50

Schweiz: 155 498

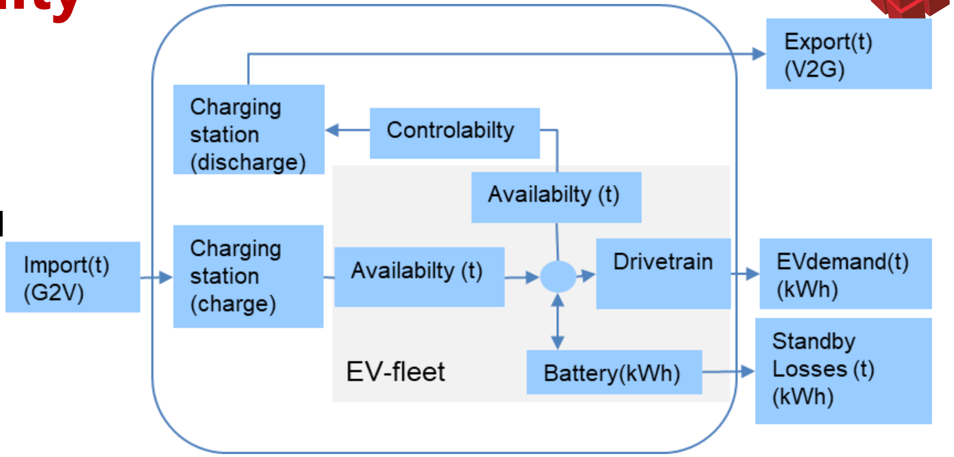
Symbole mit einem Wert unter ±50 wurden zur besseren Lesbarkeit visuell vergrössert dargestellt.

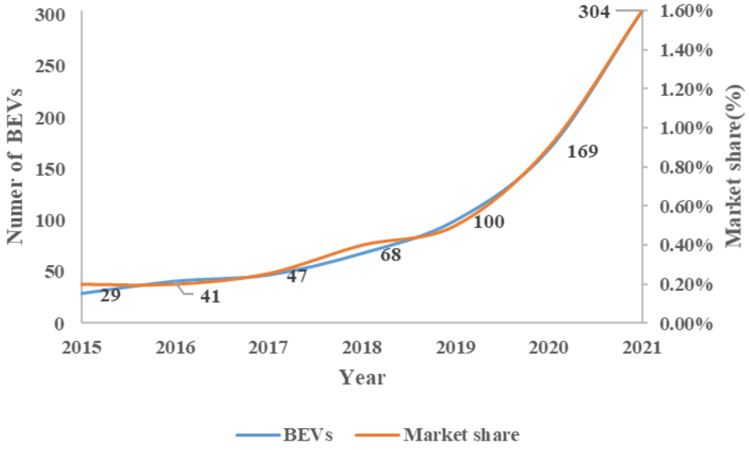
– = keine rein elektrischen Fahrzeuge

* Bestand am 30.09.2023

Modelling E-mobility Flexibility

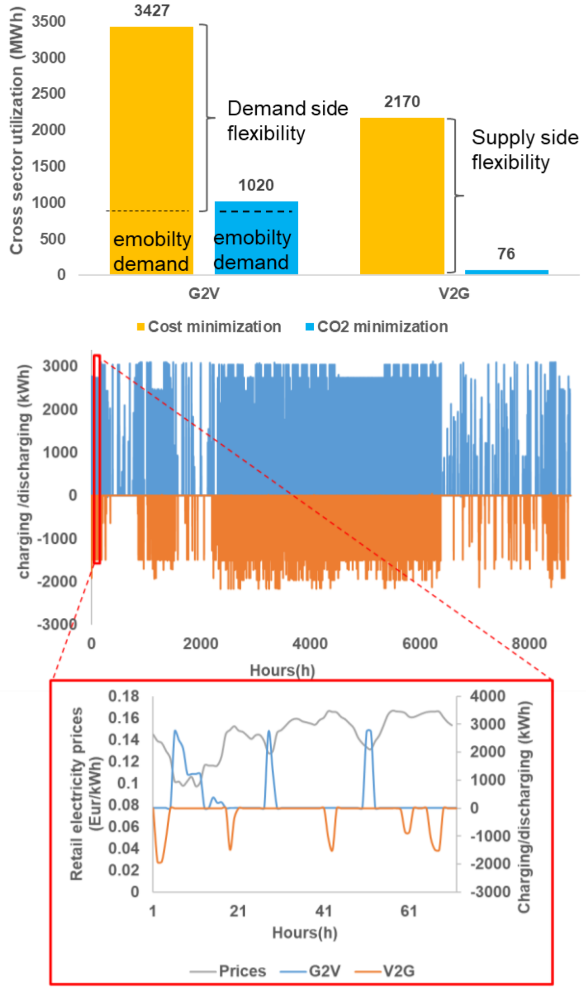
- An e-mobility module is developed and integrated into the ehubX Tool.
- Captures the **fleet size, charger size, transport demand, vehicle availability, controllability** and **battery size**.
- The module is tested using the multi-energy system in Chur
  - 304 EVs (1.6% market share, 2021)
  - Avg. annual mobility demand – 12440 km
  - Battery – 60 kWh, controlability – 0.7
  - Charger capacity – 10 kW, min SOC- 0.2
  - Energy demand (E-161 GWh, H-330 GWh)
  - Network (E-104 MW, G-216 MW, H- 9 MW)
  - Electricity mix (renewables (88.7%), nuclear (10.8%) and gas (0.5%)





E-mobility Flexibility

- Currently, V2G is an attractive solution in a cost optimization over a CO_2 optimization scenario, this may change with higher share of renewables.
- E-mobility and V2G services will add 2.14 and 1.36 % of electricity demand in cost and CO2 minimization scenarios respectively.
- In future – sensitivity analysis will be conducted for different share of EVs/renewables, controlability, battery size, charger capacity, etc.



B. Koirala, Mutschler, R, 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

Edge Data Centers

Data Centers

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

The Federal Council
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Press releases

Press releases by the Federal Council

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Launch of the Horizon Europe project HEATWISE: Computers heat buildings

Der Landbote

Abo Heizen mit Computern

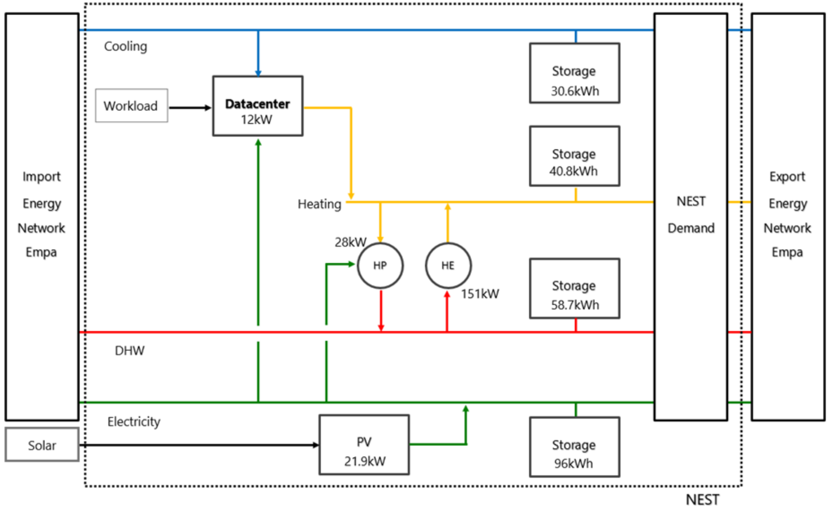
Nur Winterthur nutzt die Abwärme aus dem Datacenter noch nicht

Edge Data Centers Integration

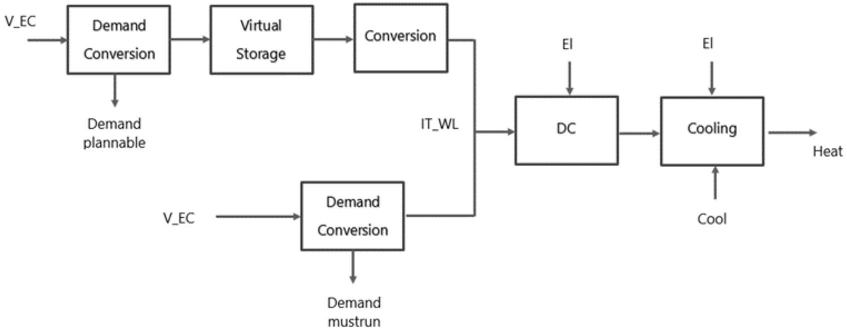
- Increasing electricity prices
- Mismatch between IT workload and building heating energy demand
- Multi-vector interdependencies
- Quality and usability of the waste heat
- Different cooling options: air-cooling, liquid-cooling, oil-immersed – different quality of heat

Edge data center modelling

- 12 kW EcoQube edge data centers @NEST building: 60 kWth peak, 114 MWhth annual
- Conversion of IT workload into Heat
- Cooling unit converts waste heat into usable heat, expending electricity and cooling energy
- Virtual Storage modeling the time independence of the plannable workload
- Two types of workload: must-run and plannable

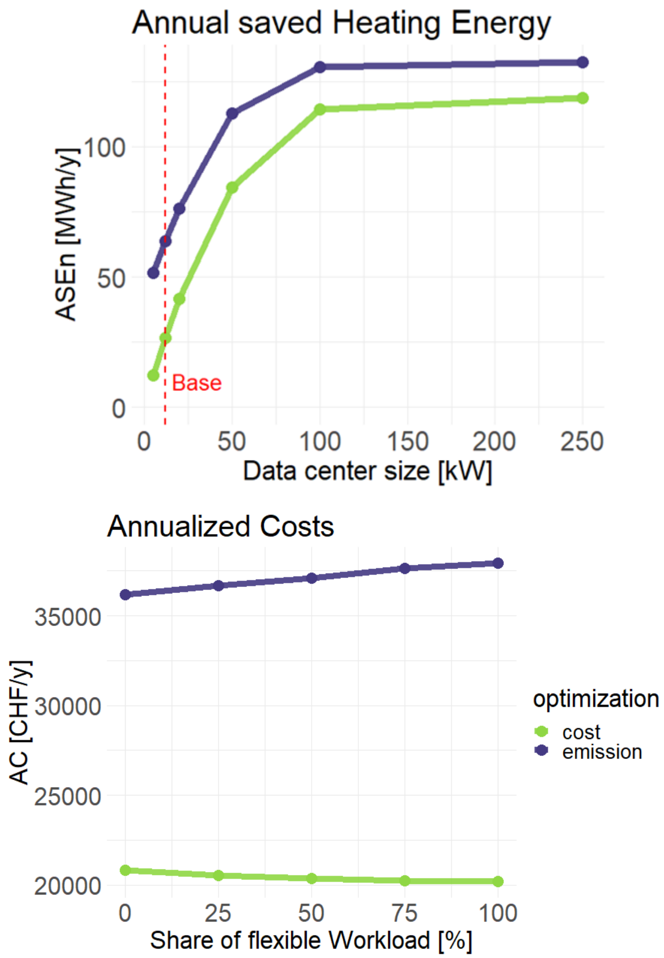


HP = Heat pump HE = Heat exchanger PV = Photovoltaics



Edge data centers modelling

- Higher heating demand → more heat reused → more cost efficient but saturates above building demand
- Flexibility of IT workload – slight improvement due to presence of thermal storage
- Optimal sizing depends on building demand and available conversion and storage techs
- Benefits from waste heat recovery alone not viable but improve the business case



Take home messages

- Flexibility-aware multi-energy planning will be increasingly important in the future.

P2H2P

- P2H2P will lead to higher self-consumption/autarky in multi-energy systems.
- P2H2P will be more attractive in the future (higher efficiencies, lower costs).
- Cost-effective seasonal storage remains a challenge.

E-mobility

- V2G/G2V (V1G) will be an important source of flexibility in the future.
- V2G must overcome regulatory and operational challenges (e.g., only selected vehicle types of Nissan, Mitsubishi, and Volkswagen are V2G capable).

Data Centers

- No heat waste principle – waste heat utilization
- Optimal sizing depends on building demand and available conversion and storage techs

Thank you for your attention!
Merci pour votre attention!
Vielen Dank für Ihre Aufmerksamkeit!