DeCarbCH Conference

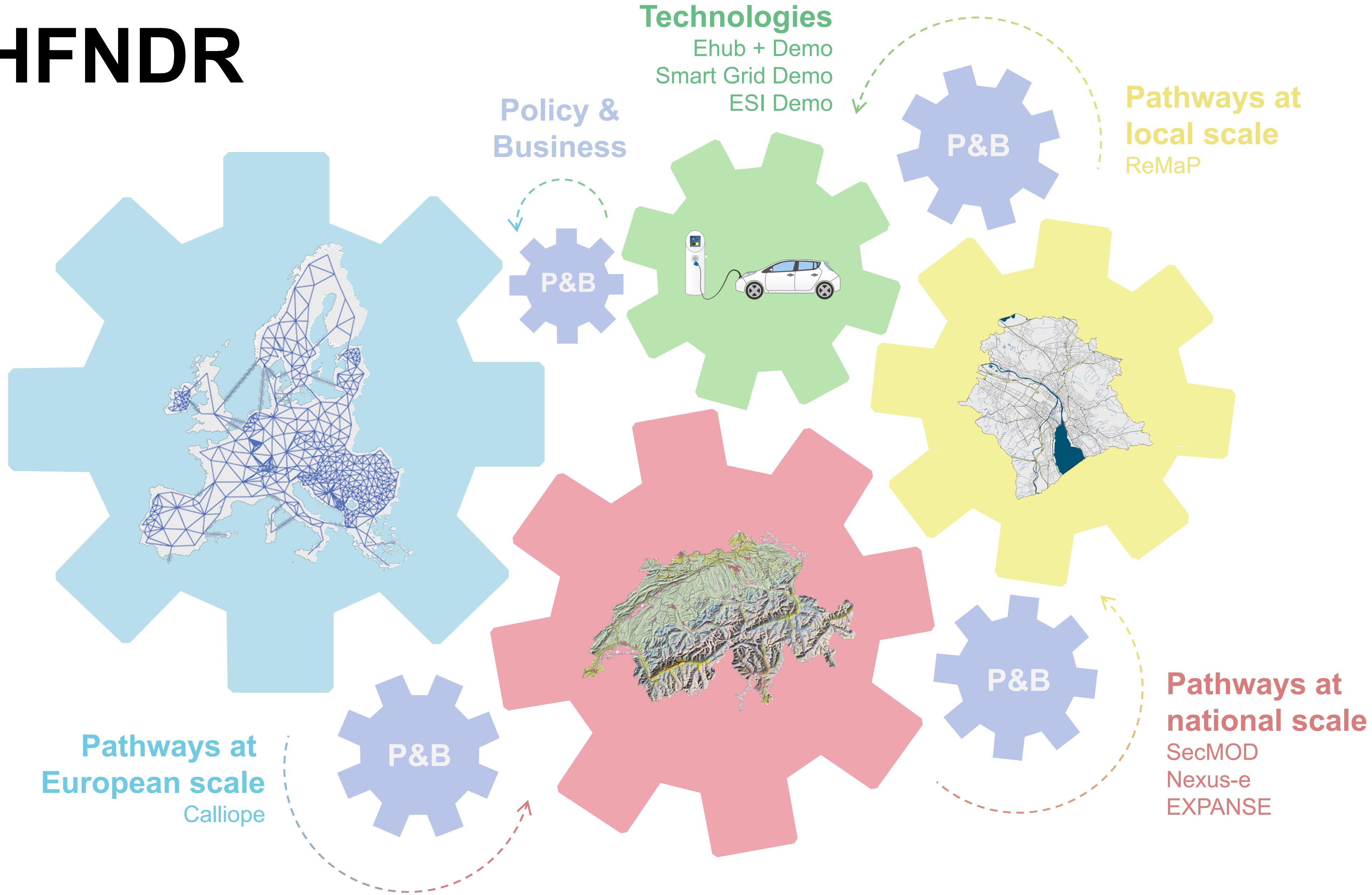
1 March 2023

Christian Schaffner

PATHFNDR

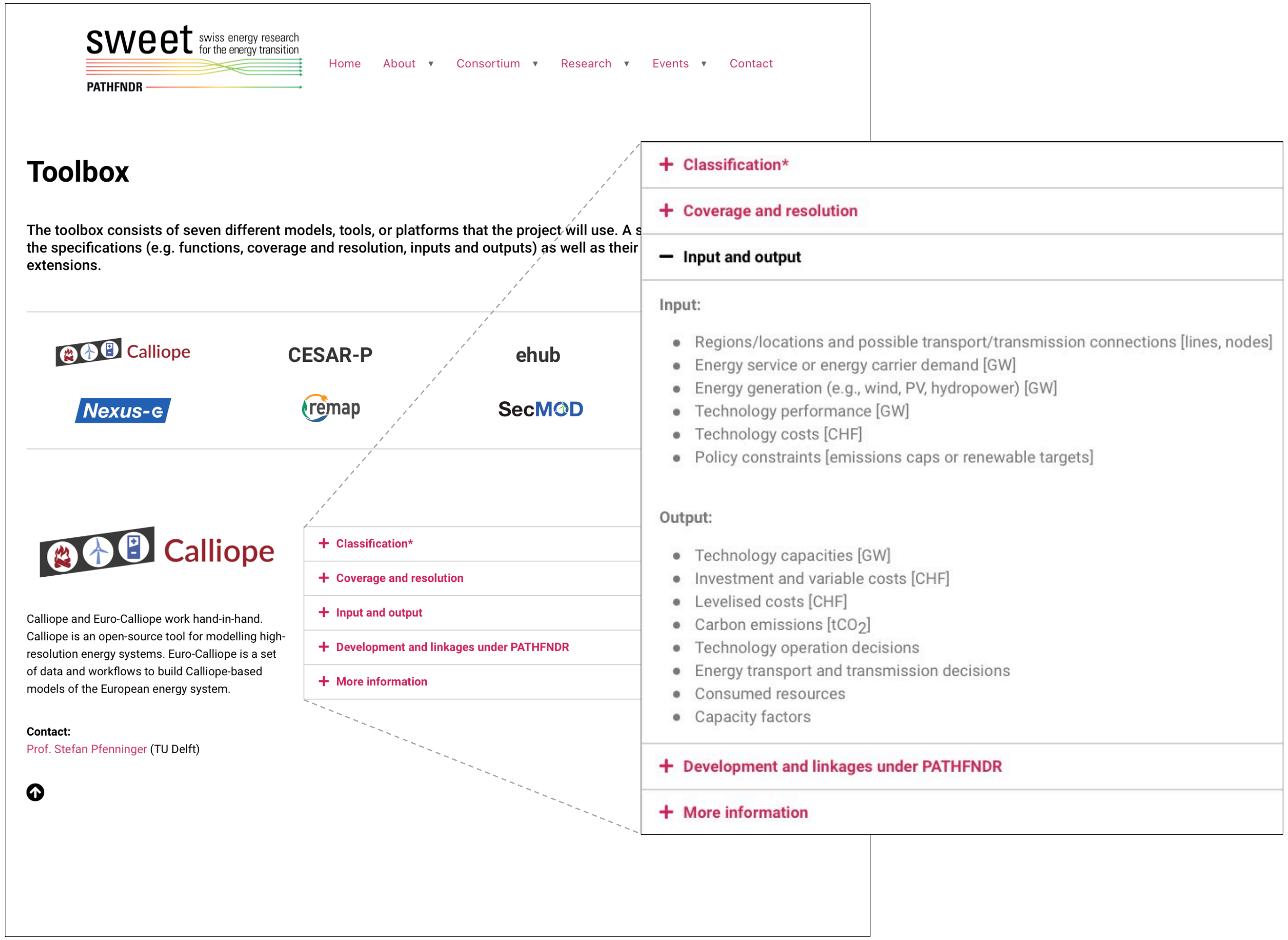
Pathways to an efficient future energy system through flexibility and sector coupling

The PATHFNDR Machine



Toolbox

https://sweet-pathfndr.ch/toolbox/



Tools / models

- Calliope
- Nexus-e
- SecMOD
- EXPANSE

National scale

- ReMaP
- Ehub
- CESAR-P

Local scale

Demonstrators

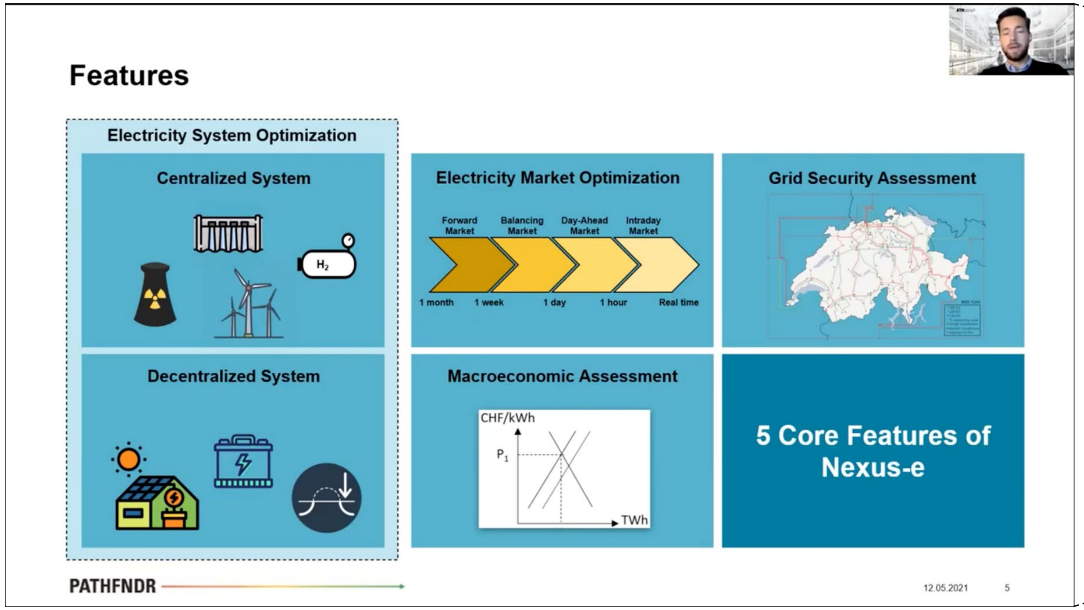
- Smart Grid
- Ehub, move and NEST
- Energy System Integration

Tech. scale

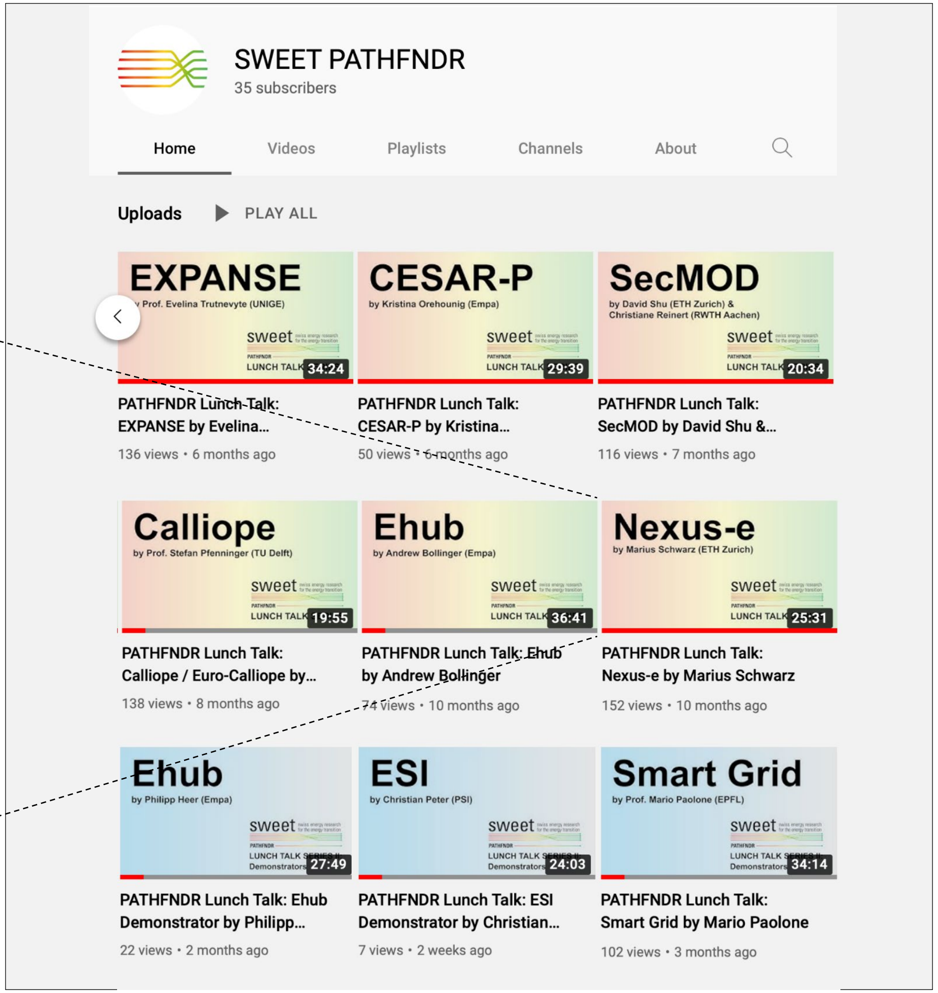
Lunch talks

https://sweet-pathfndr.ch/lunch-talks/

Series I: Tools / models (7 talks)
Series II: Demonstrators (3 talks)
Series III: Policy (4 talks)



Example: Nexus-e tool by Marius Schwarz



Main concepts & metrics

Sustainability

Focus on three measures from the **Sustainable Development Goals:**

- Share of **renewable energy**
- **Energy efficiency** for economies and technologies
- **Greenhouse gas emissions**

Flexibility

Ability of the energy system to respond to variability in electricity supply and demand at different time scales by adjusting its **supply, demand, storage and imports / exports** from/to neighboring systems

Sector coupling

Interconnection of **energy supply and demand sectors** (energy carriers and consumers):

- **Amount** of energy and power **exchanged**
- **Efficiency** of the energy conversion

Scenario dimensions & assumptions

Direct influence

Dimension	Variable	Quantification	CROSS
Climate policy	Net-zero	GHG target	x
	Carbon tax	Carbon tax	
	Technology incentives	Incentives for flexibility technologies	
Technological	Availability of technologies	Electricitity, nuclear life time, CCS, hydrogen	x
	Technology costs	Development of costs of keystone technologies	
Social	Public acceptance of new infrastructure	Solar, wind and hydropower potentials	x
	Willingness to change	Demand shift	
Geopolitical	Electricity trade	Transfer capacity	x
	Hydrogen	Hydrogen imports	x
	Carbon sequestration	Carbon sequestration abroad	x
	Biofuels and biomass	Biofuels and biomass imports	x

Key technologies

Technology

Local scale:

- **National scale**
- **Site Planning**
- **Utility Planning**
- **Site Control**
- **Network Control**

Thermal

- Solar thermal
- CHP
- Heat pumps
- Heat recovery
- Short-term and seasonal storage
- Thermal networks

Electricity

- Solar PV (rooftop, alpine, agri)
- Electro-chemical batteries (home- and district/grid-scale)
- Supercapacitor storage system
- EV chargers
- Grid expansion (distribution and transmission)
- New/expansion of hydroelectric (dams, pumps, reservoirs)

Gaseous fuels

- PEM electrolyzers
- Fuel cell (H_2/O_2)
- Fuel cell (H_2/air)
- Refinement and H_2/O_2 storage
- Methanation processes
- Gas grid
- H_2/CO_2 storage
- CO_2 capture/removal
- Gas-fired combined cycle

  New waste-fired
- New biomass or biogas
- New nuclear (small modular reactors or newest pressurized-water reactors)
- Direct air capture

Solid & liquid fuels

- Synthetic fuels and feedstocks for industry / transport

Synthesis topics

1

Measures for and lessons from the energy crisis for Switzerland

- High energy prices
- Reduction of energy import
- Fossil fuel phase-out,
- (Renewable) energy mix
- Season demand and supply
- EU energy policies

Energy challenge initiative
https://sweet-pathfndr.ch/energy-challenge/

2

Technologies and their potential for flexibility and sector coupling

- Different technologies
- Various scales (national to local)
- Technical, regulatory and market constrains / measures

Synergies with DeCarbCH?

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

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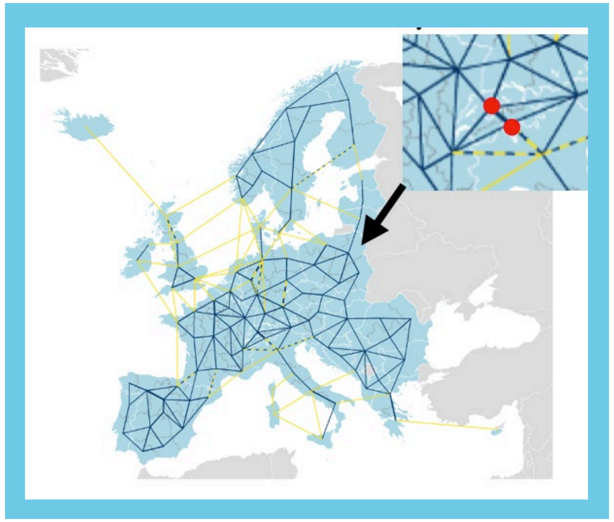
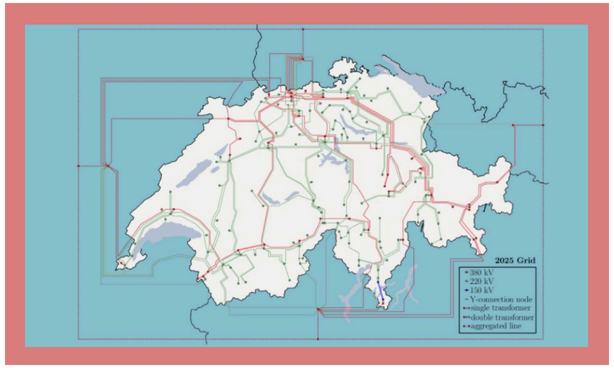
WP1

Overview of results / achievements





Task 1: Scenarios and objectives on an international scale

(1 group at TUD, 2 groups at ETHZ)

Task 2: Detailed pathways on a national scale

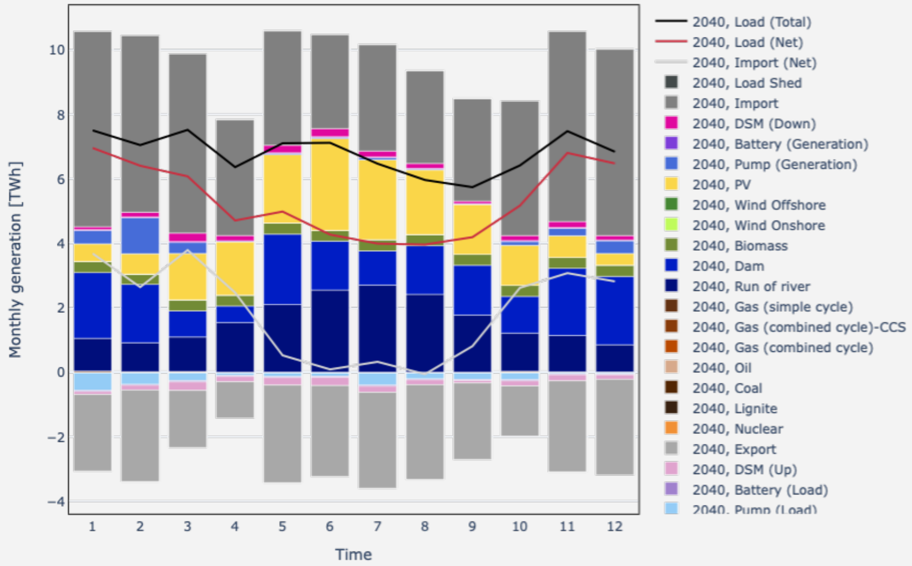
(3 groups at ETHZ, UniGe)

Task 3: Multi-level modelling methods

(ETHZ, ZHAW, TUD)

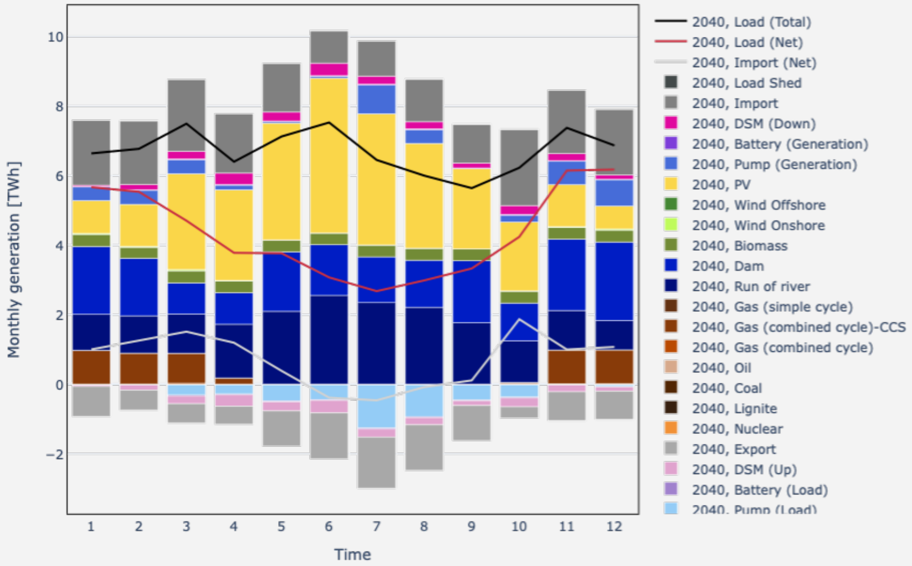
WP1
Switzerland within Europe if market transfer capacities are restricted

Base Scenario: Current NTCs



- PV: 20.4 GW / 17.6 TWh
- Gas: 0.07 GW / 0.13 TWh
- Import: 52.4 TWh
- Export: 29.6 TWh

Alternative Scenario 1: 30% NTCs



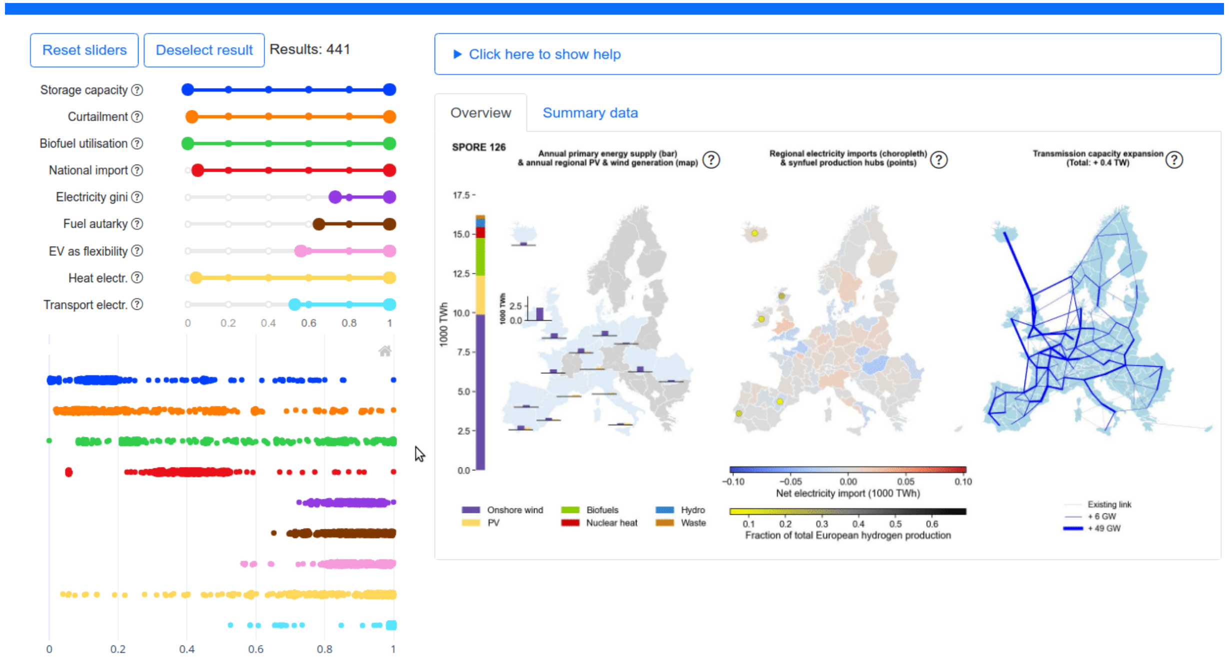
- PV: 36.2 GW / 28.3 TWh
- Gas: 0.18 GW / 4.96 TWh
- Import: 19.0 TWh
- Export: 10.6 TWh

Figure: ETH Zurich, ESC / Nexus-e team

WP1

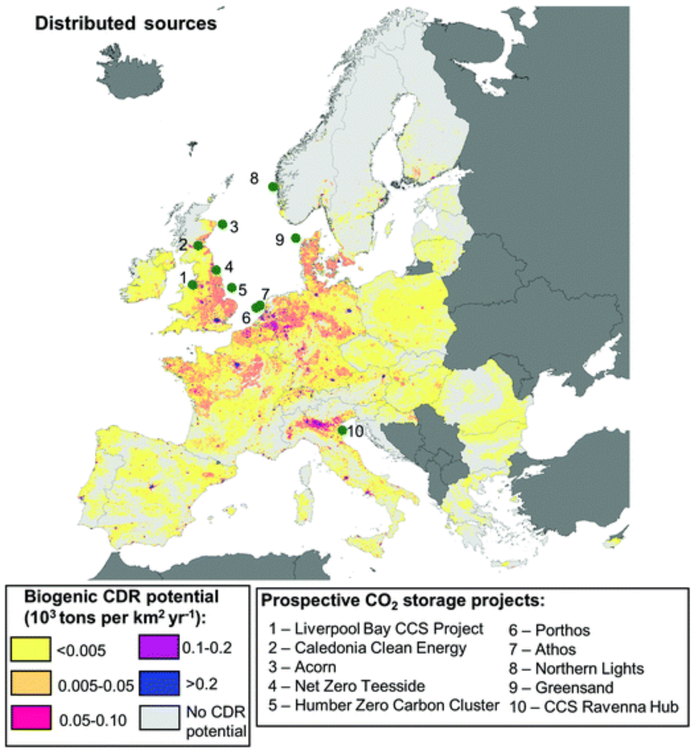
European context and technology data

Sector-coupled high-resolution model with ability to produce 100s of configurations



Explore results: https://explore.callio.pe/
Pickering et al, https://doi.org/10.1016/j.joule.2022.05.009

Europe-wide CCS and BECCS: example of biogenic removal and geological storage



Rosa et al, https://doi.org/10.1039/D1EE00642H

WP1

Scenario definition through building blocks

“Direct” influence

Dimension	Variable
Climate policy	Net-zero
	Carbon tax
	Technology incentives
Technological	Availability of technologies
	Technology costs
Social	Public acceptance of new infrastructure
	Willingness to change lifestyle and consumption
Geopolitical	Electricity trade
	Hydrogen
	Carbon sequestration
	Biofuels and biomass

“No direct” influence

Parameter
Population
GDP
Energy demand
Resource potentials
Global climate change

Example scenario
Net-zero target
No technology incentives
With CCS in power sector
High public acceptance
Swiss self-sufficiency
RCP 4.5

WP1

Near-term outlook

1. scenario implementation
2. model + sector coupling

Task 1:
Europe

Task 2:
Switzerland

Scenarios:
Switzerland-specific and Europe-wide

Euro-Calliope model

Existing Nexus-e framework

- Electricity market optimization
- Power system optimization
- Macro-economic assessment
- Grid security assessment

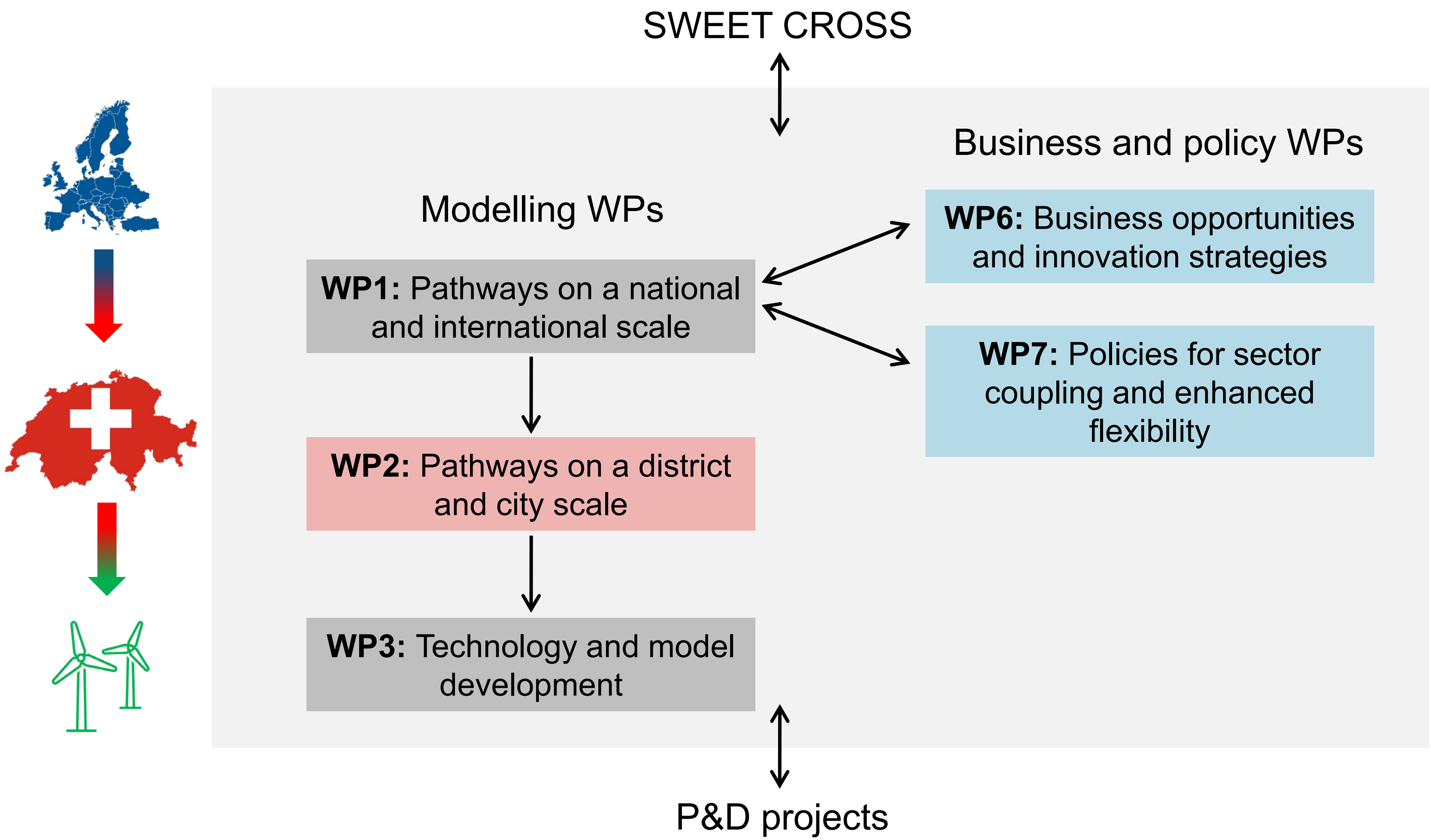
Nexus-e additions

- Mobility
- Gas
- Industry (via SecMOD model)

(Task 3: Modelling methods)

WP1

Contribution and impact



WP1

Expected deviations or delays

- The order of two milestones was reversed, to allow better synchronization of work within task 1
- M1.1.2.1 (Initial quantification of hourly end-energy demands and their shifting potentials across Europe)
  → originally month 12, now 24)
- M1.1.2.2 (Initial quantification of storage capacities across Europe)
  → originally month 24, now 12,

Work package 2

Title:	Pathways on local scale (city, village, district, site scale)
Leader:	Turhan Demiray (ETH Zurich) & Adamantios Marinakis (ETH Zurich)
Duration:	1 May 2021 – 30 April 2026 (60 months)

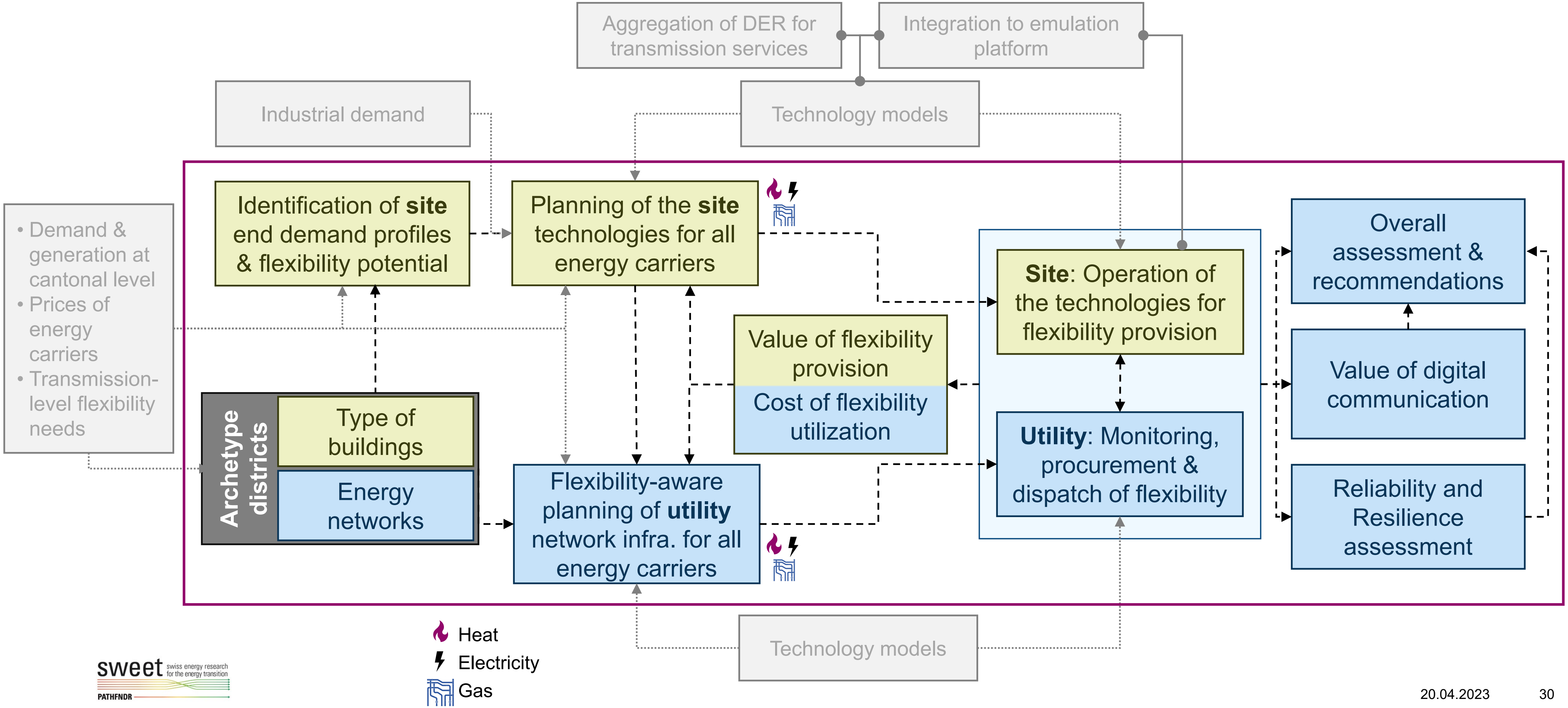
WP2
Contribution and impact

Objective: Identify the value of the various local distributed resources, as well as the specific role that they can play, as part of an optimal pathway to a flexible and low-carbon energy system.

Main research topics tackled in WP2:

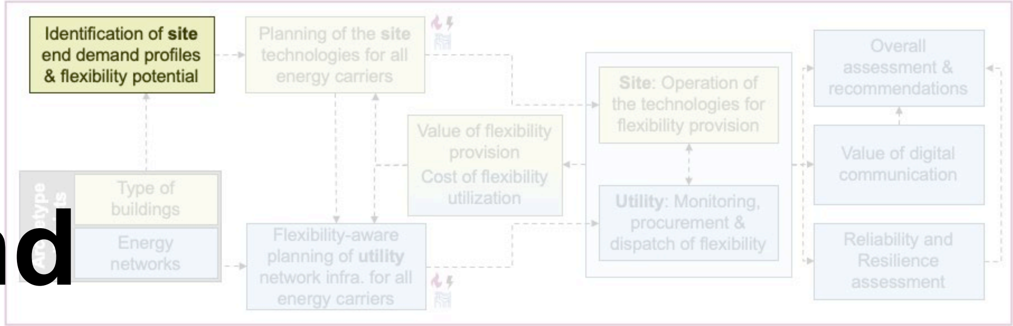
- Available flexibility by end-users
- Value of local flexibility for distribution utilities
- Operation of distribution networks
- Benefits (and risks) of sector coupling in distribution
- Infrastructure investments by distribution utilities

WP2
The big picture



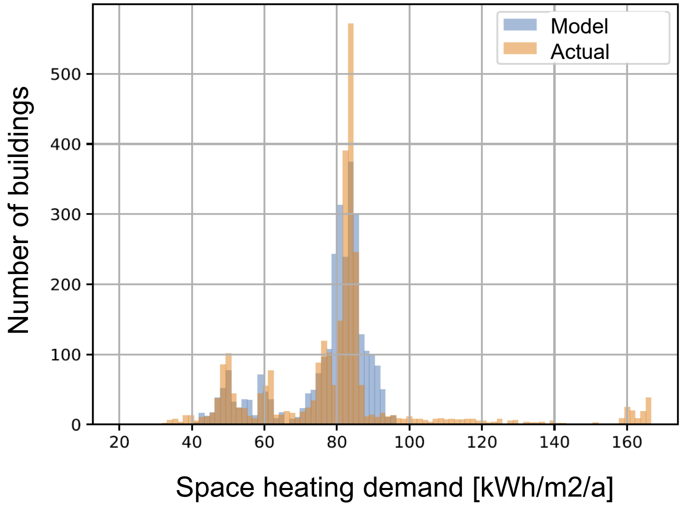
WP2

Heating and cooling demand

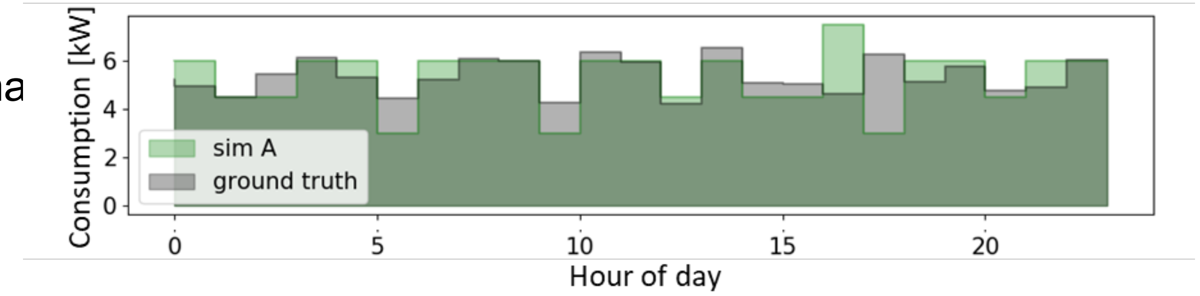


- 4 models in development for heating and cooling demand (currently residential, next step commercial):
  - Machine learning model based on RDB data only
  - Simplified physical model based on RDB data only
  - Building energy system dynamics model
  - Model based on actual measurement data
- Currently under validation with actual consumption data from Swiss cities and communities
- Achievement: Able to reproduce the heating energy dema with very little public RDB data

Validation of building dynamics model

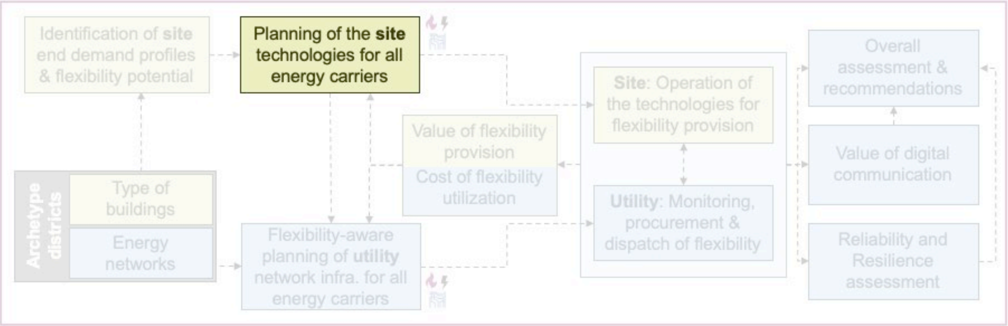


Validation of measurement data model

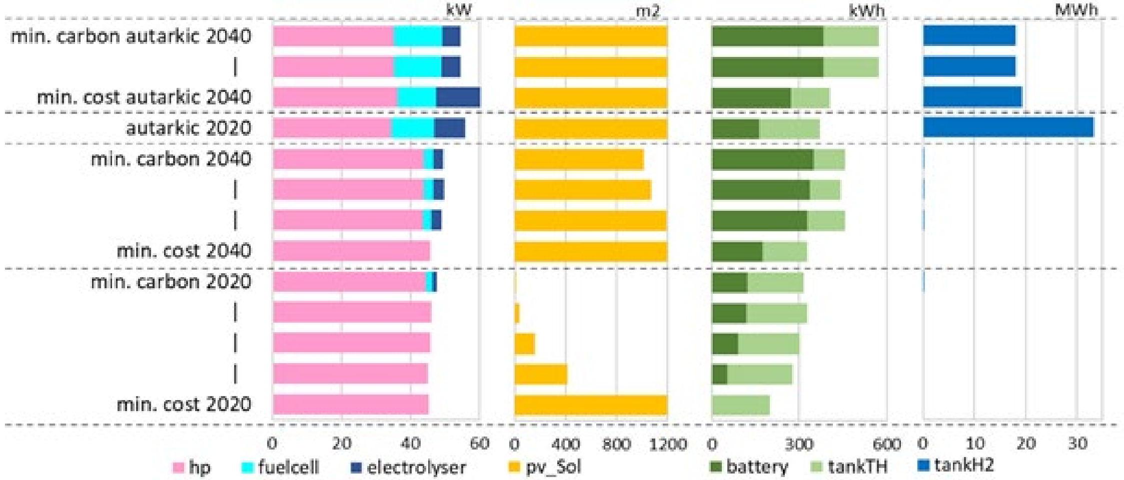


WP2

Ehub tool development

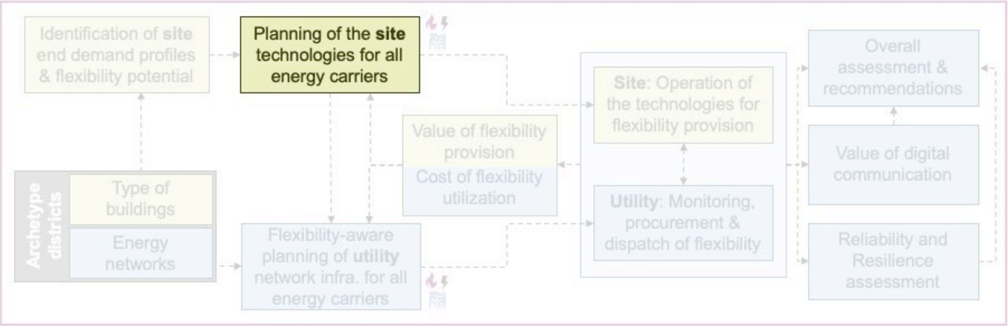


- Empa Ehub tool is used, a MILP model optimizing for cost, CO_2 emissions and level of autarchy
- E-mobility has been added to the Ehub tool*, considering fleet size, charger size, transport demand, vehicle avaialiblity, controllability and battery size
- Preliminary analysis has been performed on available (real evor simulated) examples using the Ehub tool
  - e-mobility flexiblity on Chur system (306 EVs, 100 MW power distribution grid, 161 GWh electricity demand)
  - power-to-H_2-to-power for autarkic building consisting of 40 apartments in Baden



WP2

Ehub tool development



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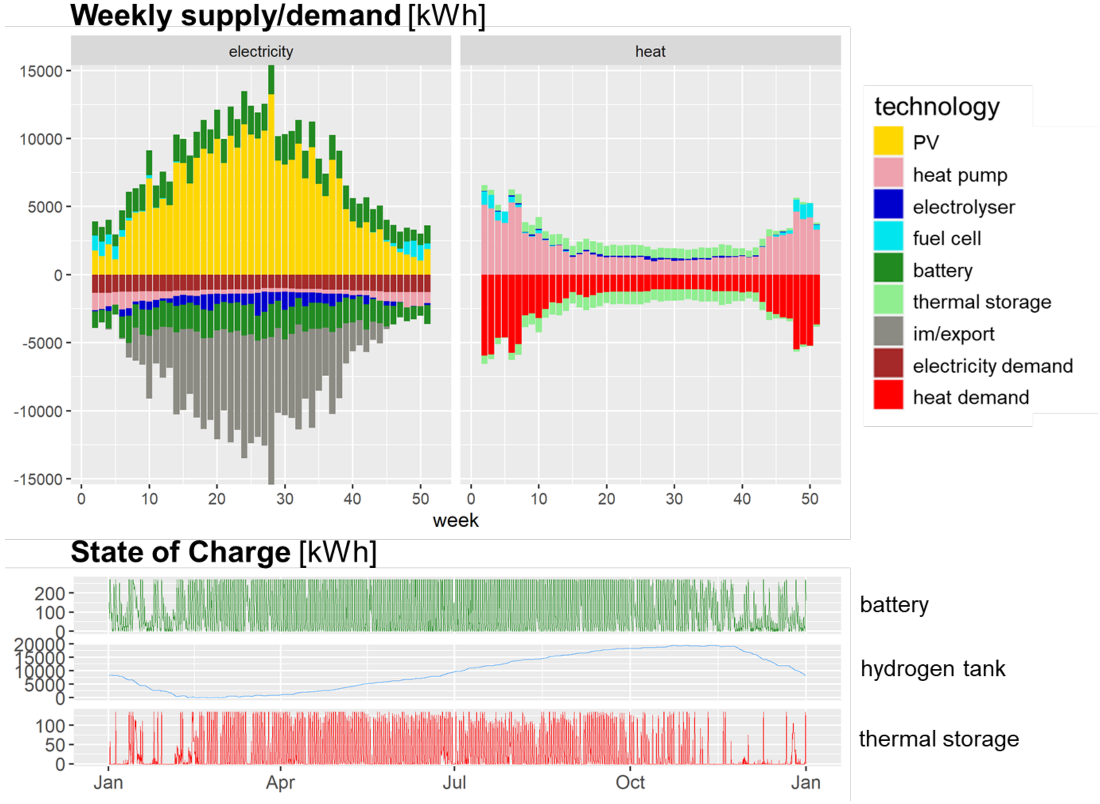
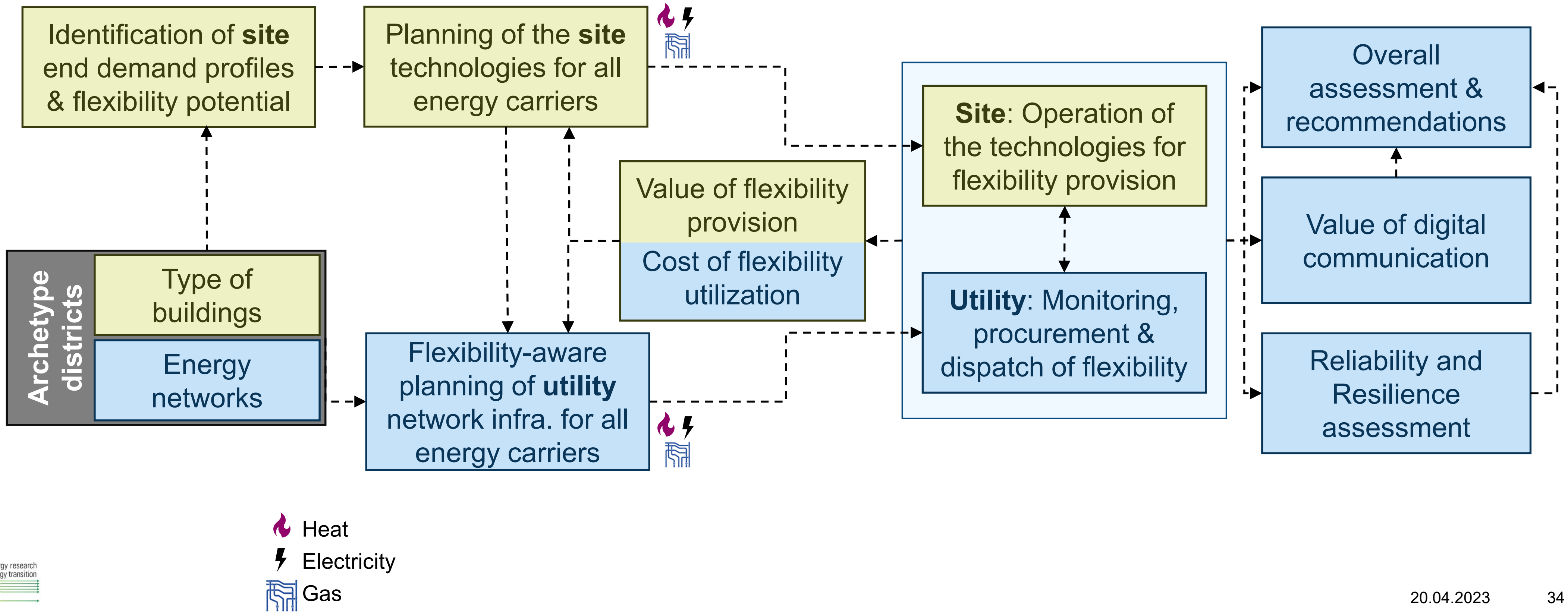


WP2

Cooperation partner workshop

Participants (*pitch): BKW*, Groupe-E*, WWZ*, A&W*, Swissgrid*, MAN, EWB, Siemens, ABB, SGVW

Pitched topics:
- Site planning & operation
- Flexilbity for elec. distribution grid
- Sector coupling in distribution
- Flexibility for elec. transmission grid



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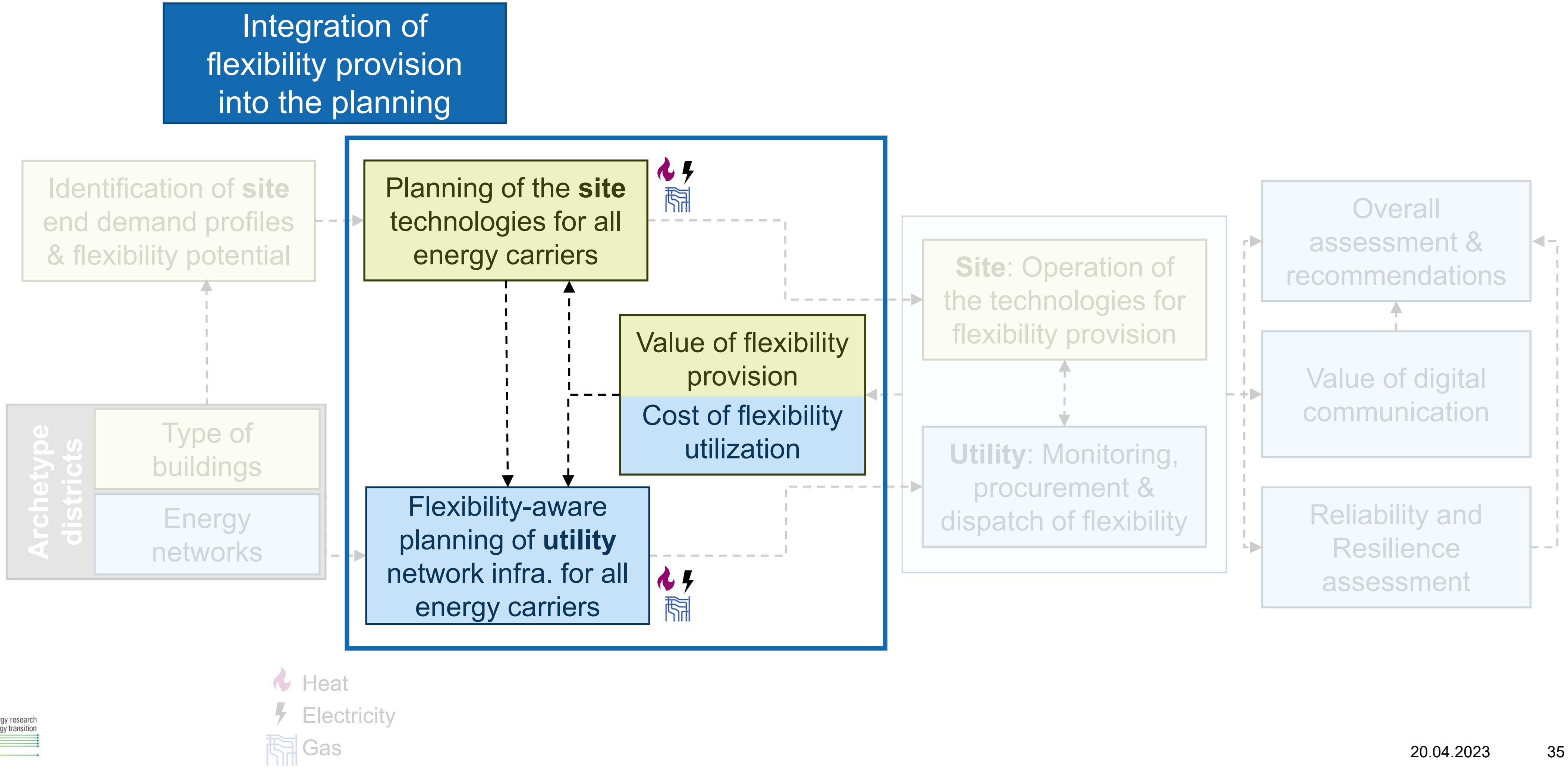

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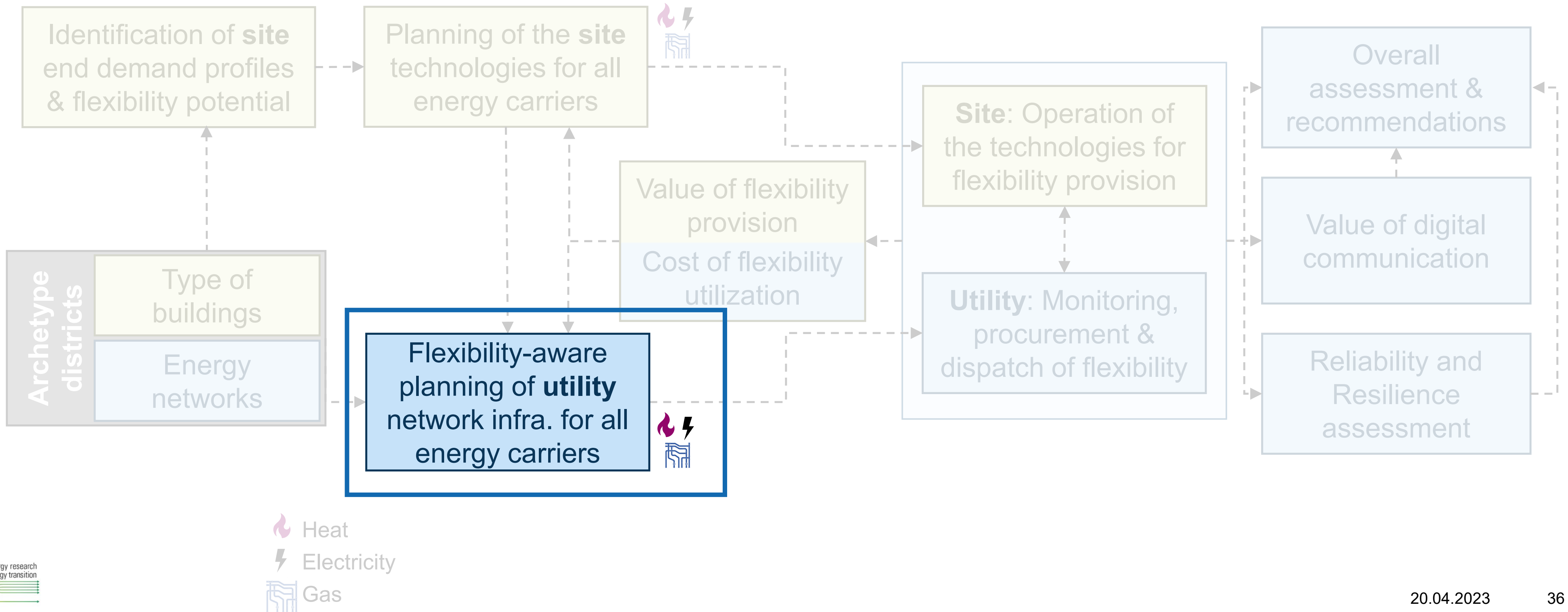
Integration of flexibility provision into the planning

Co-optimization of electricity & heating at district level



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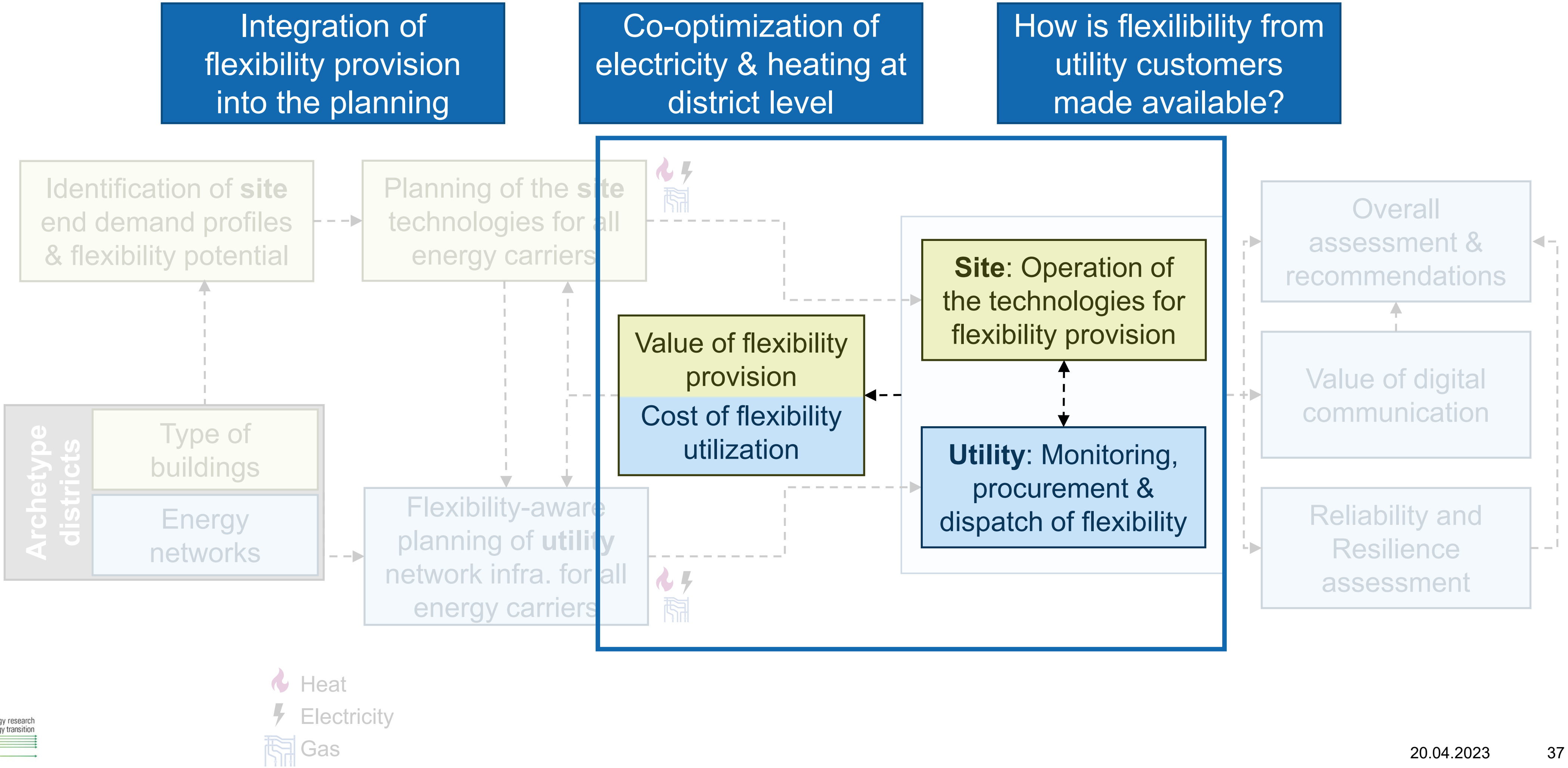


sweet swiss energy research for the energy transition
PATHFNDR

WP2

Cooperation partner workshop

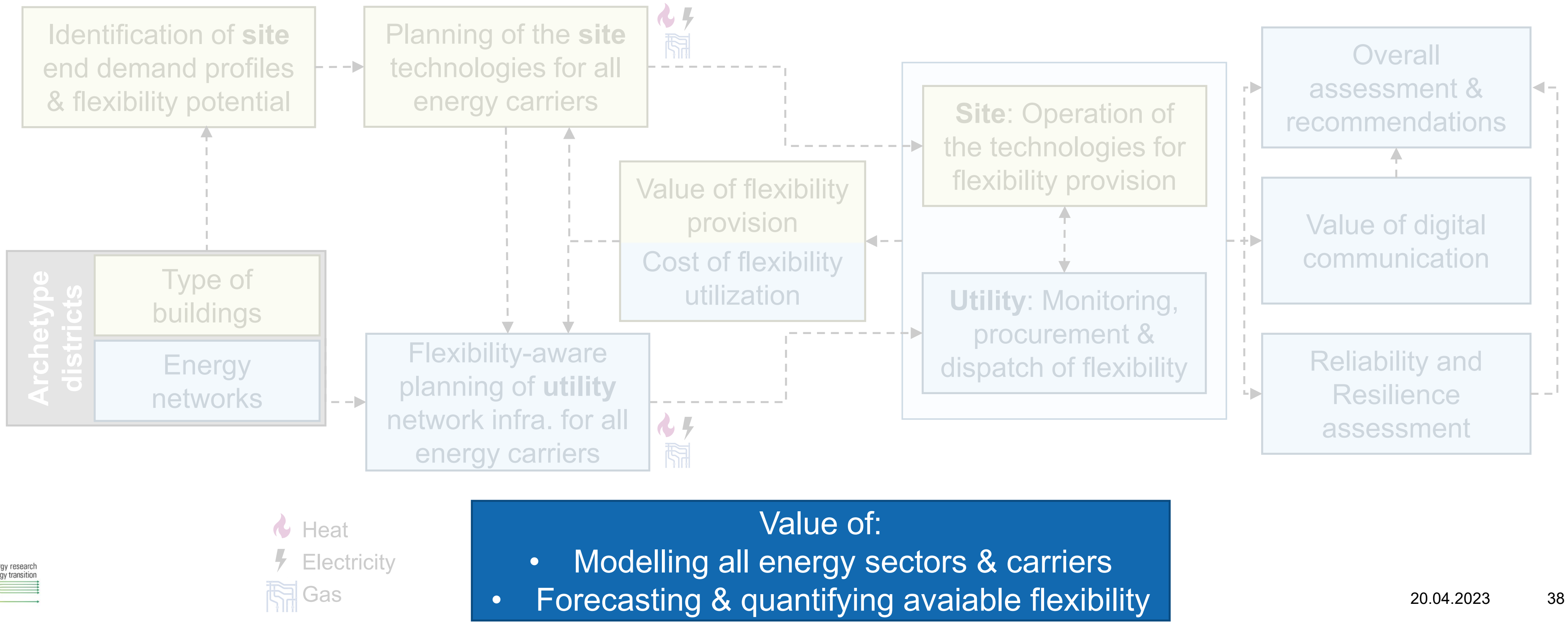
Pitched topics:
- Site planning & operation
- Flexilbity for elec. distribution grid
- Sector coupling in distribution
- Flexibility for elec. transmission grid

Participants (*pitch): BKW*, Groupe-E*, WWZ*, A&W*, Swissgrid*, MAN, EWB, Siemens, ABB, SGVW

Integration of flexibility provision into the planning

Co-optimization of electricity & heating at district level

How is flexibility from utility customers made available?

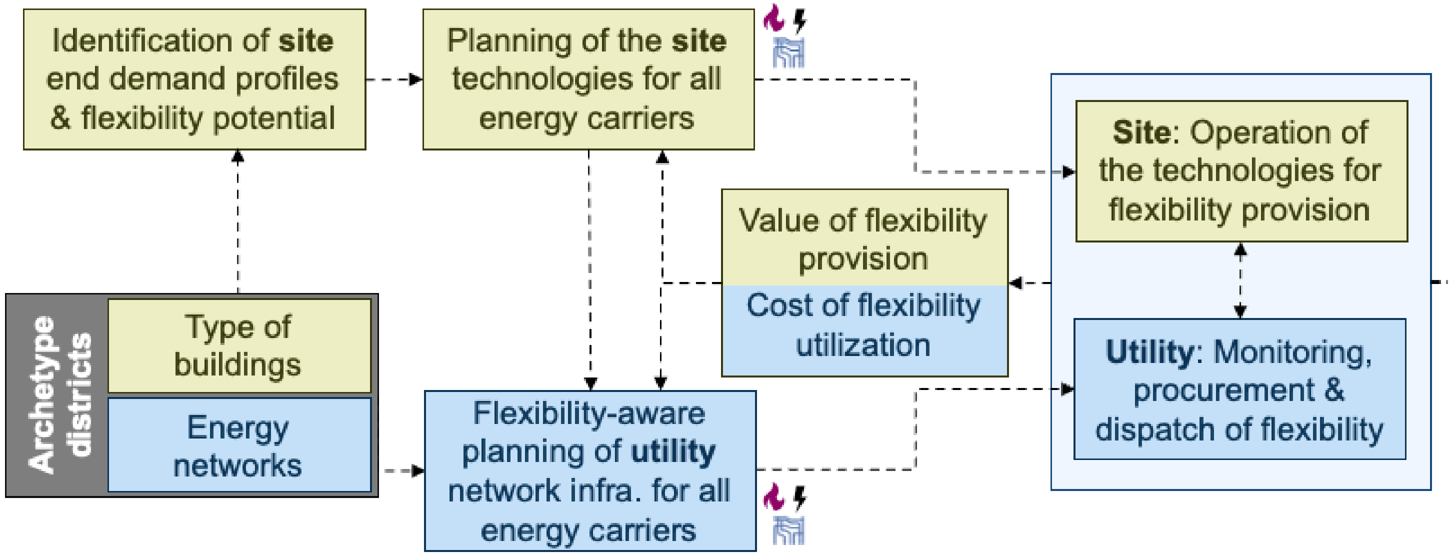


Value of:
- Modelling all energy sectors & carriers
- Forecasting & quantifying avaiable flexibility

WP2

Near-term outlook

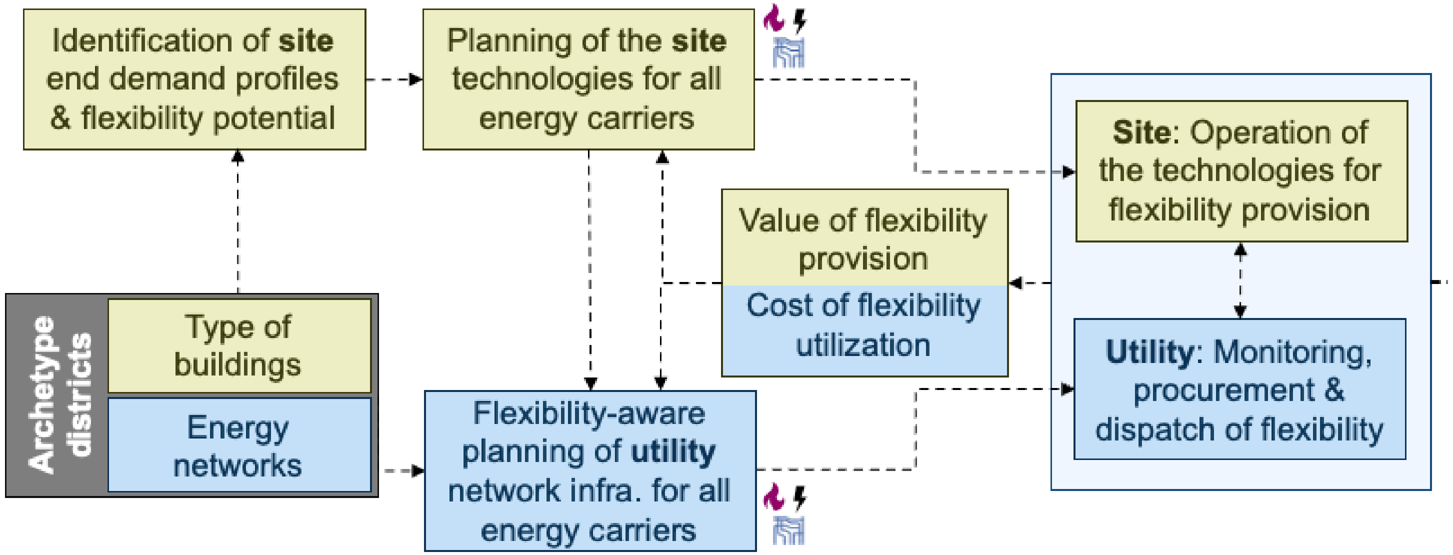
- Set up small working groups with cooperation partners
- Development of archetype "use-cases"
- Finalization of work on end demand
  - Tool used in EDGE and DecarbCH
  - High interest from multiple utilities
  - Potential link with P&D in EDGE
- Progress in site planning
  - Implement load shifting
  - Consolidate use-cases
  - Perform sensitivity analysis



WP2

Near-term outlook

- Exchange on models/data with WP3 on considered technologies
- Progress in multi-site EV charging case
  - Example simulations
  - Reflect settings of collaboration partner (MEH Zug) in the controller
  - Potential link with P&D project
- Start of utility planning
  - Optimization framework
  - Archetype use-cases
- Start of utility-level flexibility monitoring



Work package 3

Title: Technology and model development

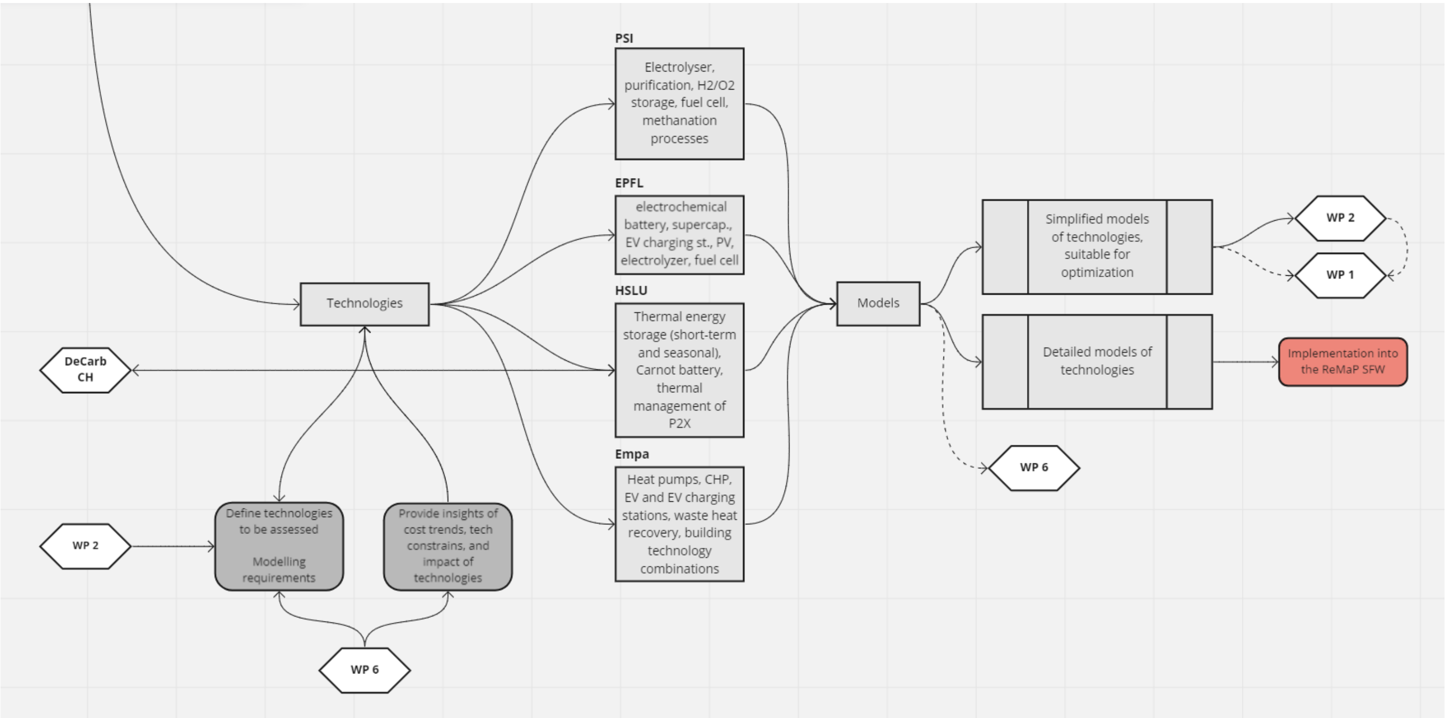
Leader: Philipp Heer (Empa) & Massimo Fiorentini (Empa)

Duration: 1 May 2021 – 30 April 2025 (48 months)

WP3

Contribution and impact

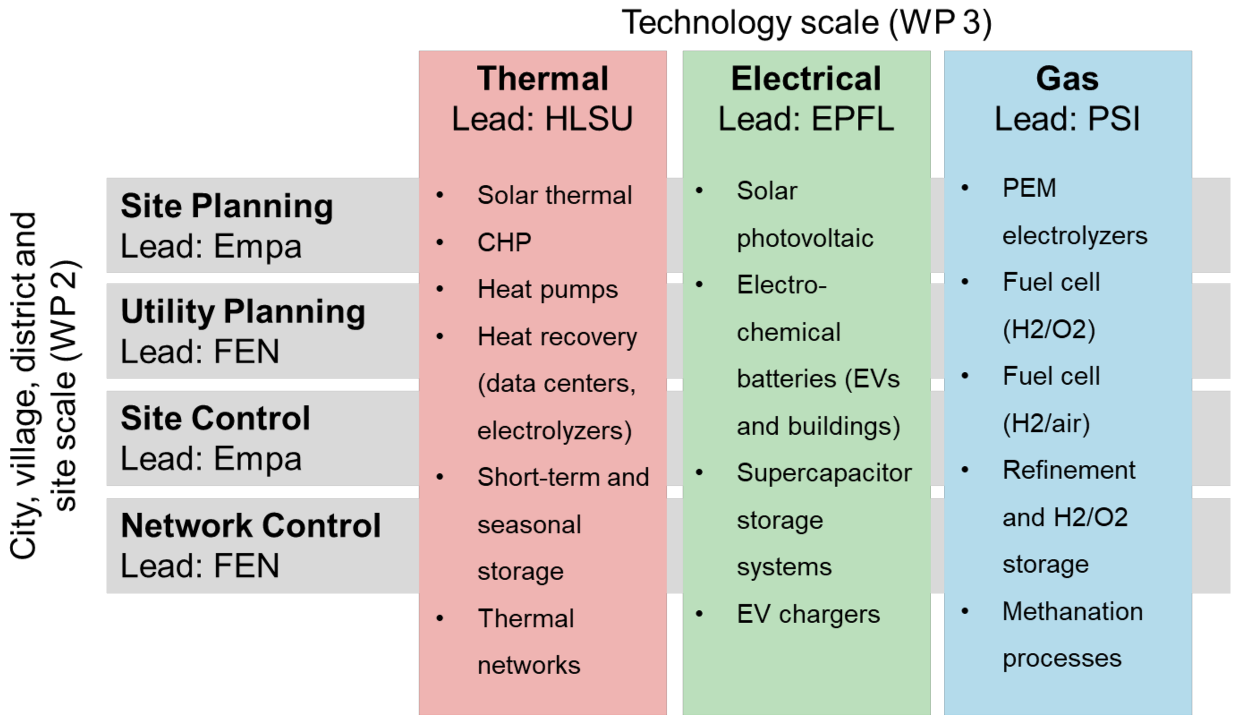
- **Support WP2 / WP1** with high-detail modelling and techno-economical parameters for site-scale to national-scale analyses
- **Coordinate with other SWEET** and compare inputs/outputs (e.g., assumptions in EDGE and DeCarbCH)
- **Support future P&D projects** on modelling of case studies



WP3
Coordination activities

Shared workflow with WP2 for parameters of technological setups and their models

- Simplified (techno-economical parameters tables)
- Detailed (models to be integrated in high-fidelity simulation platform)

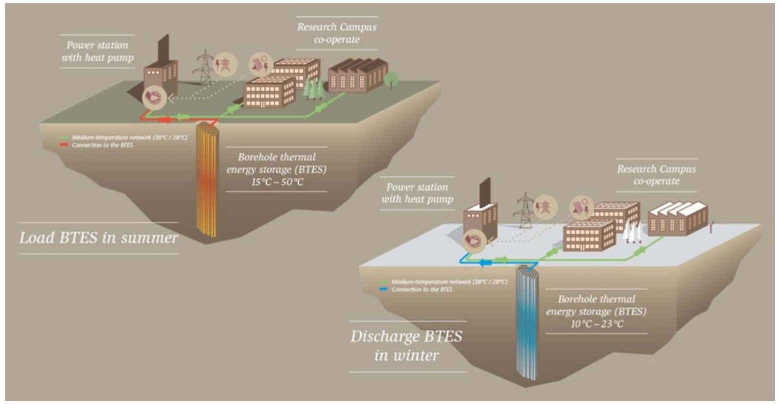


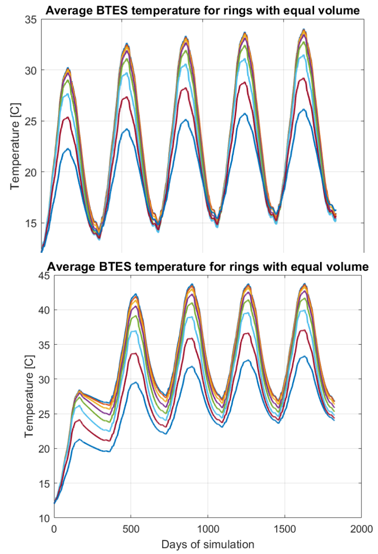
Source: M. Fiorentini (Empa)

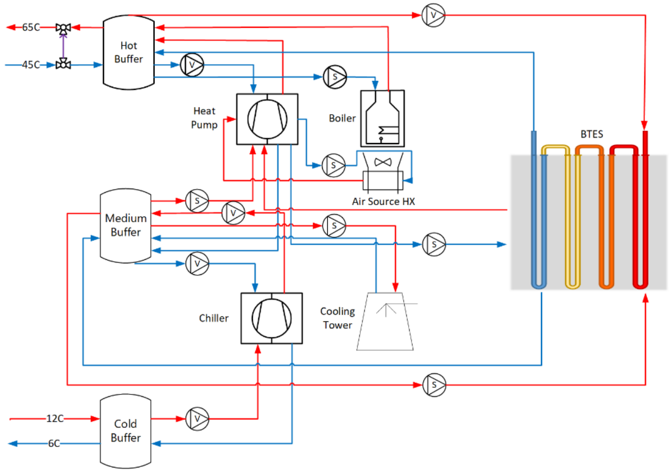
WP3

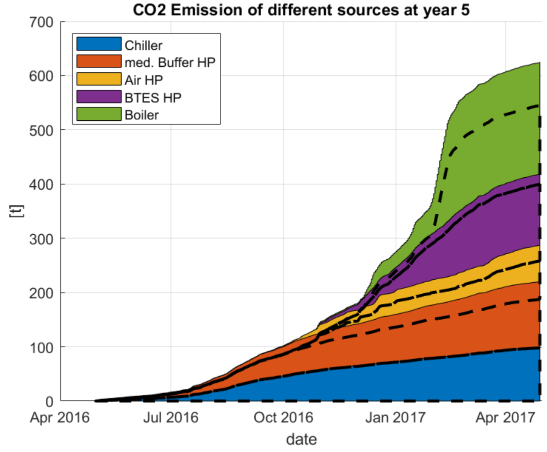
Extension of technology portfolio

- ESI (PSI) demonstrator connected to ReMaP
- Path for EPFL’s Smart Grid defined.
- A stochastic-optimization for aggregate power and energy flexibility dispatch in grids was developed (EPFL)
- Novel concepts of high-capacity seasonal thermal storage were investigated (HSLU) and impact of modelling abstraction in optimization methods (EMPA)







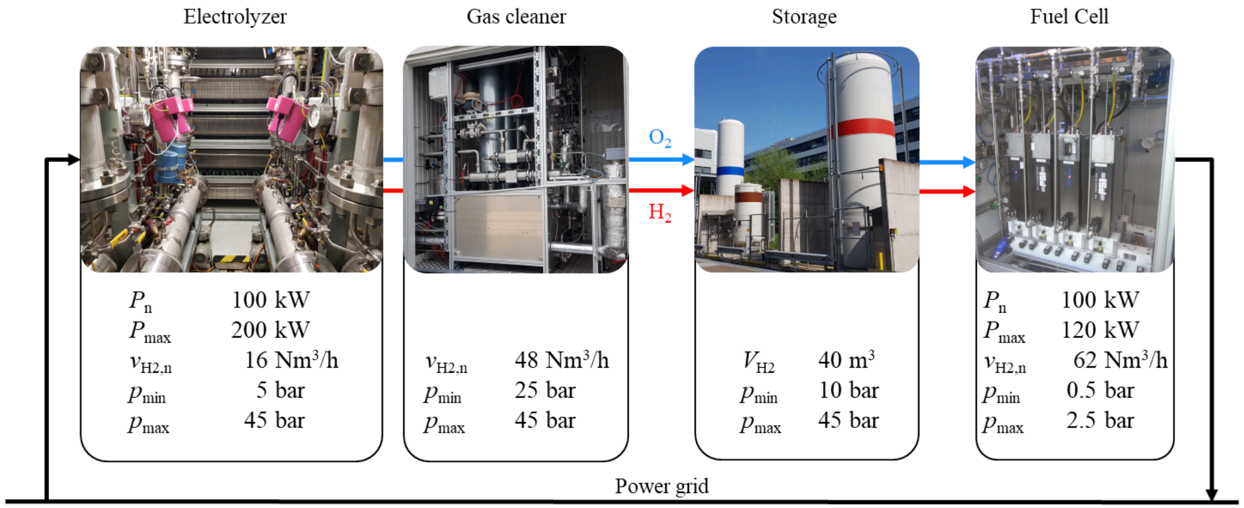


Source: M. Fiorentini (Empa)

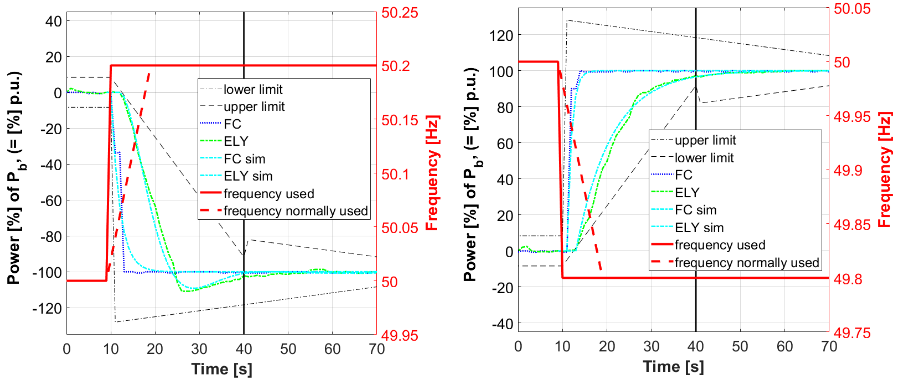
WP3

Model development for integrated systems (power & heat)

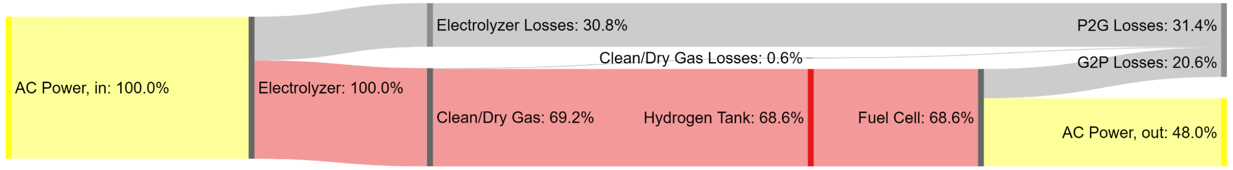
- System identification of a 100 kW H2/O2 PEM fuel cell system was carried out (PSI) - can be used for optimal control or system design purposes
- Preliminary use for MPC application



Dynamics PtH_2 & H_2tP :



Efficiency PtH_2tP in 2040, estimated:



- PEM based
- O_2 based
- Automated
- Intermittent operation
- ReMaP access

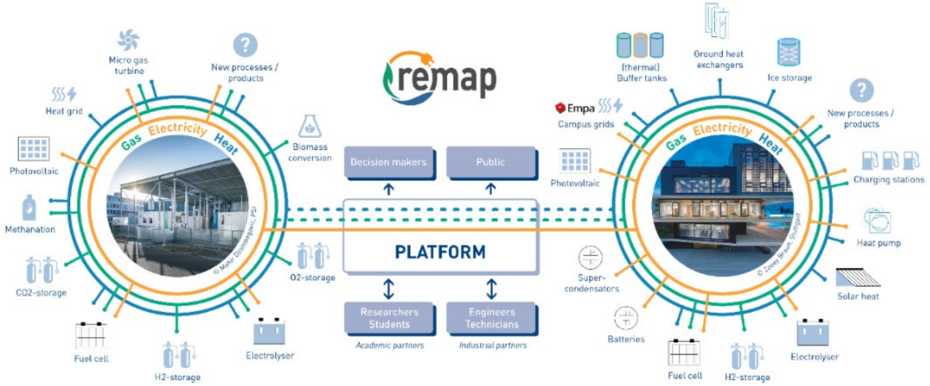
Source: C. Peter (PSI)

WP3

Near-term outlook

- **Technologies selection and techno-economical parameters** defined and tables completed, optimization-oriented modelling reviewed with WP2
- **Development of case-study systems for each “silo”, implemented in high-fidelity simulation platform** to test the technologies models integration and interaction
- **EPFL platform connected** to ReMaP through Empa’s Ehub
- **Opportunities: Exchange with other SWEETS**, particularly Edge and DeCarbCH, Build on **consortium partners**’ case studies

A	B	C	D	E	F	G	H	I	J	K	L	M
	Parameters/Technologies	Electrolysers						Fuel cells				
		who	importance	form	units	source	remark	who	importance	form	units	source
Size	min-max unit size range (archetypes)				MW						kW MW	
Cost	Fixed installation costs (licensing / fee - size independent / per system)				kCHF						kCHF	
	Investment cost (CAPEX / per kW)				kCHF/kW						kCHF	
	OPEX (fixed, ie yearly returning, and variable (only when being used, eg fuel cost), including maintenance)				kCHF/kW						kCHF	
	Cost of providing flexiblity (OPEX wise, e.g. using more fuel during startup, nonlinear aspects, not degradation wise) (e.g. ramping up/down, starting up, etc.)				kCHF						kCHF	
Ageing / degradation	Maximum amount of cycles - Lifetime vs. loading (i.e., how loading impacts the lifetime of the technology)				[-]						[-]	
	Degradation rate				[uV/h]							
	Maintenance frequency and durations				[-],[-]						[-],[-]	
	Minimum time to failure				[kh]						[kh]	
	Failure rate (probability of failure)				[%]						[%]	
	Standby losses (storage losses over time)				n. a.						n. a.	
Efficiency	Can be step-wise				[0 .. 1]						[0 .. 1]	
	Standby losses				n. a.						n. a.	
Energy density	Volumetric				n. a.						n. a.	
	Gravimetric				n. a.						n. a.	
Power density	Volumetric				kW/m3						kW/m3	
	Gravimetric				kW/kg						kW/kg	
Flebility characteristics	Ramping: rate of increase / decrease of input and output (demand / generation, charging / discharging)				kW/s (p.u.) / s						kW/s (p.u.) / s	
	Minimum up and down times (more detailed is prefered) Ts > 10min				sec						sec	
	Response time (from receipt of signal until activation)				sec						sec	
	Minimum operational level				kW p.u.						kW p.u.	
	Availability to provide flexibility (how often, how much) (e.g. restrictions because of cooling down, heating up, when not...)											
	Controllability (e.g. what share of EV fleet or demand is controllable)											
other technical constraints	e.g.1: heat pumps as of today cannot be continuously ramped up/down											
	e.g.2: blending of H2 in gas devices (or networks) parallel vectors vs mixing vectors											
	e.g.3: thermal network constraints											
	e.g. Multi-vector interaction such as waste heat recovery etc.											
Emissions	Embodied emissions											



Work package 6

Title:	Business opportunities and innovation strategies
Leader:	Christof Knoeri (ETH Zurich) & Jochen Markard (ZHAW)
Duration:	1 May 2021 – 30 April 2026 (60 months)

WP6

Overview of results / achievements

T6.1 Transition pathways and business interests

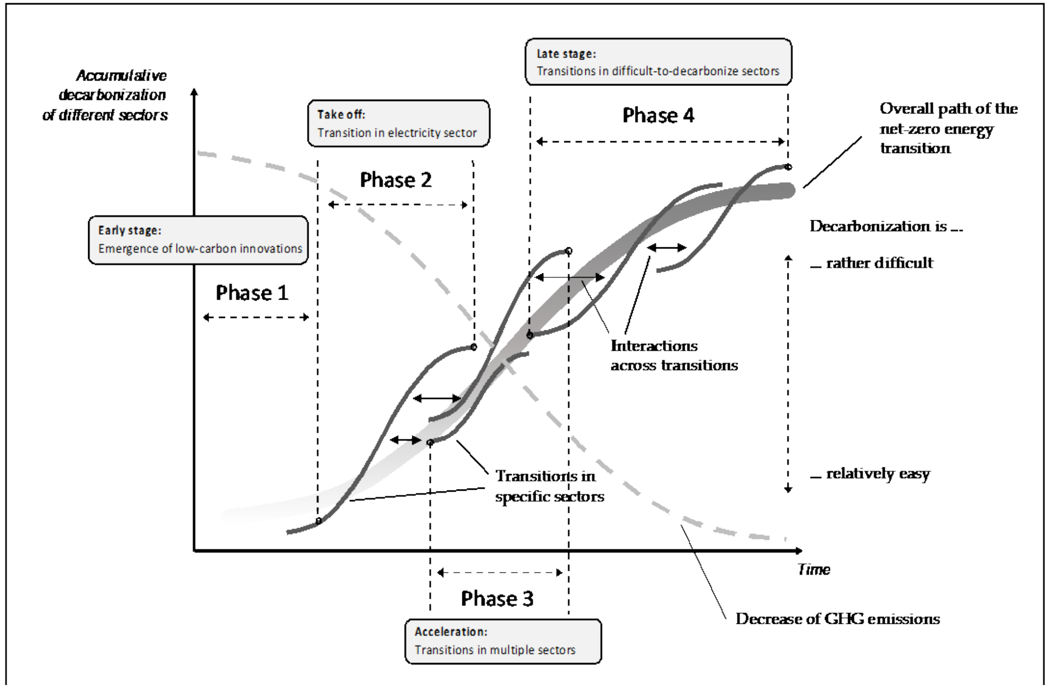
- Phases to net-zero, multi-sector interaction, phase-out policies, hydrogen discourse
  (3 articles published/accepted, 2 under review, 2 in prep)

T6.2 Technological innovation and the interplay between firms at value chain level

- On cross-sectoral collaboration for a green hydrogen
  (1 article to be submitted)

T6.3 Business opportunities and innovation strategies at the firm level

- Cyber-physical platforms (enel x) and sustainable innovations (TESLA) (1 article submitted & 1 to be submitted)



Phases to net-zero; Markard & Rosenbloom (forthcoming)

WP6

Emerging conflicts around hydrogen?

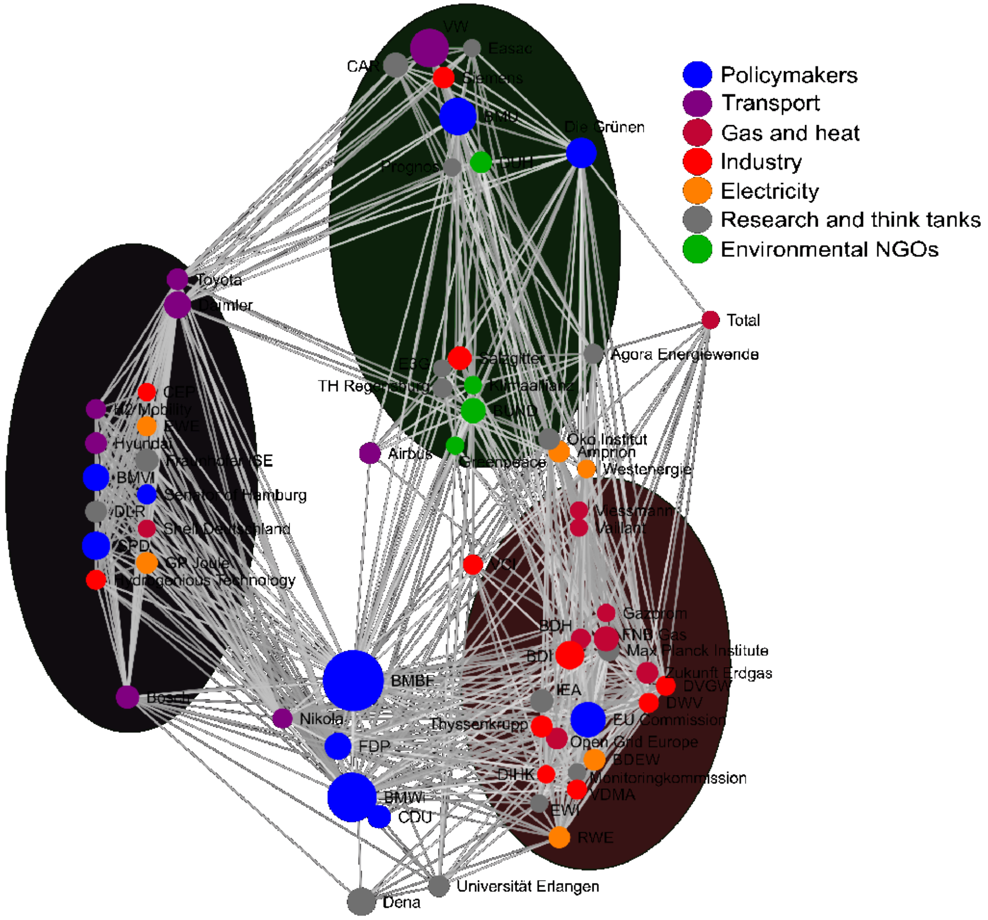
A discourse network analysis of the debate in Germany

Nils Ohlendorf, Meike Löhr, Jochen Markard

Production: Green vs. blue hydrogen

Use: Wide vs. restricted

Import: Risks vs. benefits



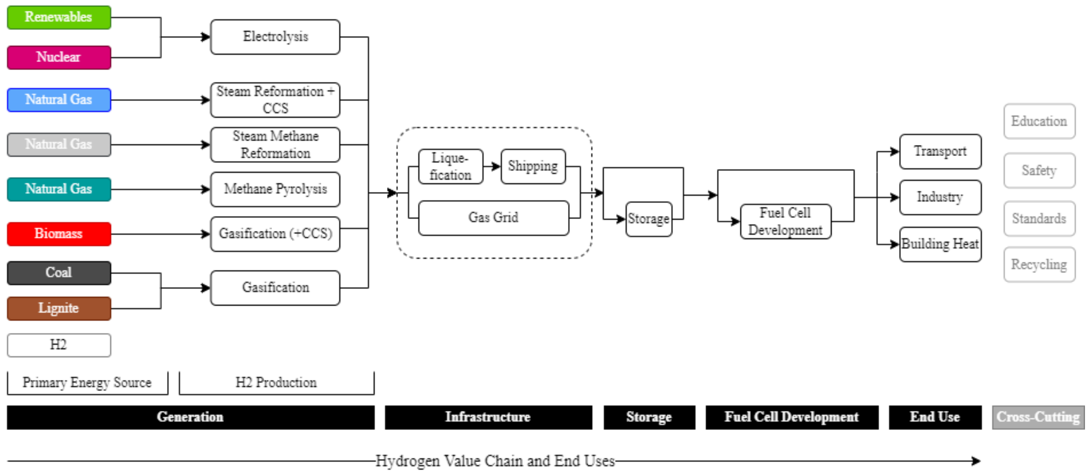
WP6

Cross-sectoral collaboration for a green hydrogen value chain

Katharina Wildgruber, Annegret Stephan, Johannes Meuer

4 archetypes of green hydrogen projects identified:

1. **The Mega Project** (Hight project cost, many project partners.)
2. **The Big Local Project** (Many project partners, very local project consortium. Not long project duration.)
3. **The Few Nationalities Project** (Not very international consortium, local or big and short term.)
4. **The commercial project** (High share of commercial partners.)



WP6

Near-term outlook

- Analysis of value chains:

  Sector analysis of truck-based cargo transportation

- Advancing paper projects presented before

Samstag, 18. September 2021 — Neue Zürcher Zeitung — MOBILITÄT 57

Die Zukunft liegt in der Vielfalt

Der Bierbrauer Feldschlösschen ist neu mit 20 Elektro-Trucks unterwegs. Doch in der Branche ist man sich einig, dass Lastwagen künftig über eine breite Palette von Antrieben verfügen werden. VON MARTIN SALZMANN

Volvo Trucks setzt bei seinen Baustellenlastwagen auf Elektroantrieb.

Mit Wasserstoff als Antrieb sieht DAF eine Zukunft für den Verbrennungsmotor.

Während beim Personenwagen die Serienproduktion von Elektromobilen schon rundläuft, rollen erst wenige Elektro-Lastwagen aus den Werken. Etwas weiter ist Renault Trucks, wo man sich sehr früh auf Elektro-Lastwagen ausgerichtet hatte und in der Normandie die Serienproduktion von mittelschweren E-Lastwagen (bis 26 Tonnen Gesamtgewicht)* gestartet hat. Die erste Grossbestellung bei Renault tätigte die Carlsberg-Gruppe 2019 für ihre Schweizer Tochter Feldschlösschen.

Im Herbst 2020 begannen die ersten Lkw bei der Brauerei in Rheinfel-

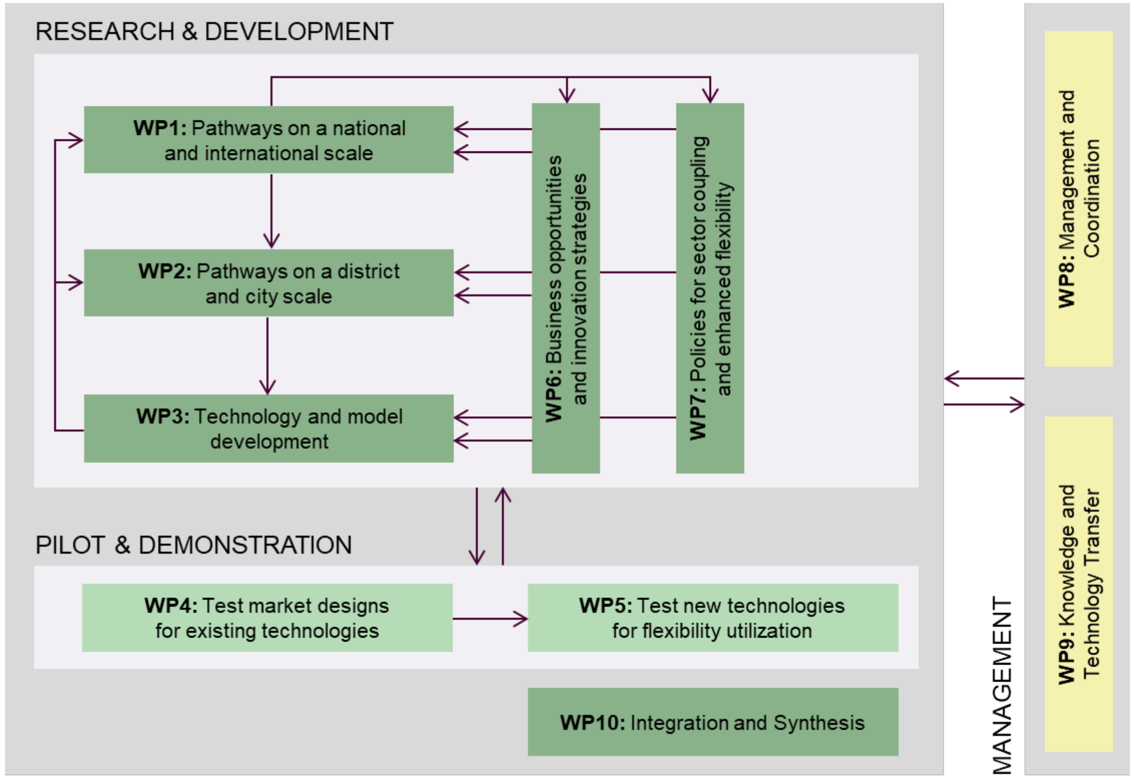
mittel- bis langfristig die Elektrizität im E-Lastwagen auch aus der Brennstoffzelle (Wasserstoff) zu beziehen. Im EU-Raum erklingt aus der Lkw-Branche deshalb der laute Ruf, dass Regierungen nicht nur die CO_2-Reduktion forderten, sondern auch dafür sorgten, dass die nötige Lade- und Tankinfrastruktur für die alternativen Antriebe zeitnah aufgebaut würde.

In der Schweiz ist die Wasserstoffinfrastruktur bereits weit gediehen, denn dank der Initiative von H2 Energy aus Zürich und der sektorenübergreifenden Zusammenarbeit von Hyundai Hydrogen Mobility, Hydrospi-

WP6

Contribution and impact

- Through the internal PATHFNDR channels we feed our findings back WP 1,2 and 3.
- We are discussing collaborations with the P&D projects (WP 4 and 5)



Work package 7

Title: Policies for sector coupling and enhanced flexibility

Leader: Prof. Anthony Patt (ETH Zurich)

Duration: 1 May 2022 – 30 April 2026 (48 months)

WP7
Overview of activities

T7.1 Policy mixes for transition to net zero

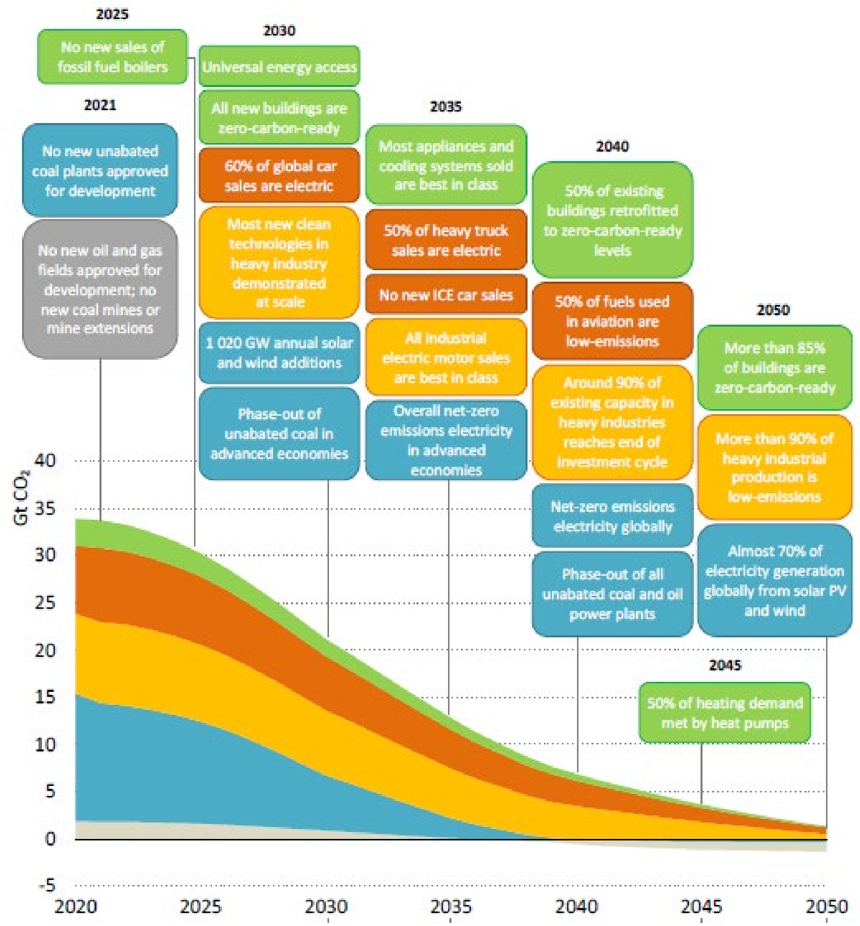
- International Net-zero policies for deep decarbonization: Analysis of net-zero strategies (CH, UK, NO, EU Green Deal)

T7.2 Public acceptance

- Identification of factors leading to greater or lesser public acceptance of alternative policy approaches

T7.3 Top-down economic and social analysis of policy portfolios

- Appraisal of economic, social, and environmental consequences policies for decarbonizing the Swiss energy system



(IEA, 2021)

WP7
Near-term outlook

- Official WP7 kick-off (October 2022)
- Concept development for comparative policy mix analysis