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Highlights Report Year 3

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ETH Zurich
Rämistrasse 101
8092 Zurich
www.ethz.ch

Consortium's website: www.sweet-pathfndr.ch

Authors:
Florian Baader, ETH Zurich, fbaader@ethz.ch
André Bardow, ETH Zurich, abardow@ethz.ch
Viola Becattini, ETH Zurich, viola.becattini@ipe.mavt.ethz.ch
Federica Bellizio, Empa, federica.bellizio@empa.ch
Tobias Brosch, UNIGE, tobias.brosch@unige.ch
Hanmin Cai, Empa, hanmin.cai@empa.ch
Yi-Chung Barton Chen, Empa, Yi-Chung.Chen@empa.ch
Turhan Demiray, ETH Zurich, demirayt@fen.ethz.ch
Philipp Heer, Empa, philipp.heer@empa.ch
Volker Hoffmann, ETH Zurich, vhoffmann@ethz.ch
Jared Garrison, ETH Zurich, garrison@fen.ethz.ch
Gabriela Hug, ETH Zurich, hug@eeh.ee.ethz.ch
Gabriele Humbert, Empa, gabriele.humbert@empa.ch
Binod Koirala, Empa, binod.koirala@empa.ch
Edward Lucas, HSLU, edward.lucas@hslu.ch
Adamantios Marinakis, ETH Zurich, marinakis@fen.ethz.ch
Jochen Markard, ZHAW, jmarkard@ethz.ch
Marco Mazzotti, ETH Zurich, marco.mazzotti@ipe.mavt.ethz.ch
Lucas Miehé, ETH Zurich, lmiehe@ethz.ch
Curtis Meister, HSLU, curtis.meister@hslu.ch
Christian Moretti, ETH Zurich, christian.moretti@usys.ethz.ch

Alejandro Nuñez-Jimenez, ETH Zurich, anunez-jimenez@ethz.ch
Mario Paolone, EPFL, mario.paolone@epfl.ch
María Parajeles Herrera, ETH Zurich, mparajele@ethz.ch
Anthony Patt, ETH Zurich, anthony.patt@usys.ethz.ch
Christian Peter, PSI, christian.peter@psi.ch
Stefan Pfenninger, TU Delft, s.pfenninger@tudelft.nl
Siobhan Powell, ETH Zurich, spowell@ethz.ch
Eyvonne Ranjan, ETH Zurich, eyvonne.ranjan@esc.ethz.ch
Lea Ruefenacht, ETH Zurich, lea.ruefenacht@esc.ethz.ch
Giovanni Sansavini, ETH Zurich, sansavinig@ethz.ch
Francesco Sanvito, TU Delft, f.sanvito@tudelft.nl
Christian Schaffner, ETH Zurich, schaffner@esc.ethz.ch
Ingmar Schlecht, ZHAW, ingmar.schlecht@zhaw.ch
Sarah Schneeberger, HSLU, sarah.schneeberger@hslu.ch
Philipp Schütz, HSLU, philipp.schuetz@hslu.ch
Malin Siegwart, HSLU, malin.siegward@hslu.ch
Malte Toetzke, ETH Zurich, mtoetzke@ethz.ch
Judit Tomás Verde, HSLU, judit.tomasverde@hslu.ch
Evelina Trutnevyte, UNIGE, evelina.trutnevyte@unige.ch
Thomas Hübner, ETH Zurich, thuebner@ethz.ch
Willy Villasmil, HSLU, willy.villasmil@hslu.ch
Natasa Vulic, Empa, natasa.vulic@empa.ch
Christian Winzer, ZHAW, christian.winzer@zhaw.ch

SFOE project coordinators:
Laura Ding, laura.ding@bfe.admin.ch
Head of the monitoring panel: Michael Moser, michael.moser@bfe.admin.ch

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The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.

Highlights

The main highlights during the reporting period were the following:

- Documentation of feasible pathways through
    - the submission of a synthesis report, which presents preliminary results on the configurations of the Swiss energy system in 2050 as a result of the analysis of four scenario storylines and two additional alternative scenarios aiming at investigating the impact of electric vehicles' flexibility on the energy system,

  supported and complemented by studies on

    - the potential of hydrogen and gas in the Swiss energy system to reduce the dependencies on fossil fuels, enable seasonal balancing, and utilize excess renewable energy;
    - waste heat recovery from hydrogen generation site and data centers in a multi-energy building (i.e., NEST building at Empa) as well as utilization in Power-to-X processes;
    - heat pump flexibility activation through direct load control and heat pump curtailments in buildings;
    - top-down economic and environmental analysis, including electricity winter deficit, import of synthetic fuels, and scaling of direct air capture.
- The following methods and tools:
    - A decision tree approach to simplify the description of complex energy system scenarios into concise storylines that are driven by policy decisions.
    - An estimation method for the electricity demand due to electromobility, and the benefits in terms of spatio-temporal flexibility within the Swiss energy system.
    - A method for flexibility-aware planning of distribution network reinforcements to identify trade-offs between networks reinforcement and end-user flexibility.
    - Databases of hydrogen/air fuel cell system characteristics, hydrogen storage potential in salt caverns, and measurements on CO_2 regeneration of polymer electrolyte membrane electrolysis.
- Business opportunities and potential policies:
    - Study on business case, policy interventions and new regulations to promote the deployment of vehicle-to-grid in Switzerland.
    - The concept for the first campaign to study Swiss citizens' public acceptance towards flexibility and sector coupling policies.
    - Proposals for the design of financial contracts for differences for renewables support which had significant impact on policy discussions in the European Union and in Switzerland.
    - Simulations suggesting that rebound peaks resulting from ex-ante dynamic volumetric tariffs (per kWh) could be solved by time-of-use capacity tariffs (per kW).
- Integration, synthesis and outreach:
    - Three pilot and demonstration projects were launched (NeDeLa, nanoverbund, H_2 districts).
    - Expansion of knowledge and technology transfer through internal monthly seminars, lunch talks, policy briefs, workshops, and collaborations with industry partners.

Faits marquants

Les principaux faits marquants pendant la période de référence ont été les suivants:

- Voies réalisables grâce à
  - un rapport de synthèse présentant des résultats préliminaires sur les configurations du système énergétique suisse en 2050 suite à l'analyse de quatre scénarios et de deux scénarios alternatifs visant à étudier l'impact de la flexibilité de véhicules électriques,

  supportées et complétées par des études sur
  - le potentiel de l'hydrogène et du gaz en suisse pour réduire les dépendances aux énergies fossiles, permettre l'équilibrage saisonnier et utiliser l'excédent d'énergie renouvelable.
  - la récupération de la chaleur résiduelle de sites de production d'hydrogène et de centres de données dans un bâtiment multi-énergie (par exemple, le bâtiment NEST à l'Empa) ainsi que son utilisation dans les processus Power-to-X.
  - l'activation de la flexibilité des pompes à chaleur par le contrôle direct de la charge et la réduction des pompes à chaleur dans les bâtiments.
  - Analyse économique et environnementale, comprenant le déficit hivernal d'électricité, l'importation de combustibles synthétiques et la mise à l'échelle du captage direct de l'air.
- Méthodes et outils:
  - Une approche par arbre de décision pour simplifier les scénarios complexes du système énergétique en scénarios concis qui sont guidés par des décisions politiques.
  - Une méthode d'estimation de la demande d'électricité due à l'électromobilité et ses avantages en termes de flexibilité spatio-temporelle dans le système énergétique suisse.
  - Une méthode de planification de renforcement des réseaux de distribution permettant d'identifier les compromis entre le renforcement et la flexibilité de l'utilisateur final.
  - Bases de données sur le potentiel de stockage d'hydrogène dans les cavernes de sel, les caractéristiques de systèmes de piles à combustible hydrogène/air et des mesures de régénération du CO_2 lors de l'électrolyse à membrane électrolytique polymère.
- Opportunités commerciales et politiques potentielles:
  - Étude sur le potentiel commercial, les interventions politiques et les nouvelles réglementations visant à promouvoir le déploiement de la technologie vehicle-to-grid en Suisse.
  - Le concept de la première campagne visant à étudier l'acceptation publique des citoyens suisses à l'égard des politiques de flexibilité et de couplage sectoriel.
  - Propositions de conception de contrats pour la différence soutenant les énergies renouvelables impactant largement les discussions politiques dans l'UE et en Suisse.
  - Simulations suggérant des tarifs de capacité liés à l'heure d'utilisation (par kW) pour éviter les pics de rebond dus aux tarifs volumétriques dynamiques ex ante (par kWh).
- Intégration, synthèse et sensibilisation:
  - Trois projets pilotes et de démonstration lancés (NeDeLa, nanoverbund, districts H_2).
  - Séminaires mensuels, conférences, notes d'information, ateliers et collaborations avec l'industrie pour étendre le transfert de connaissances et de technologies.

Highlights

Die wichtigsten Highlights während des Berichtszeitraums waren die folgenden:

- Realisierbare Pfade
  - in einem Synthesebericht mit vorläufigen Ergebnissen, aus der Analyse von vier Szenarien, die die Auswirkungen der Flexibilität von Elektrofahrzeugen auf das Energiesystem untersuchen,

  unterstützt und ergänzt durch Studien

  - zum Potenzial von Wasserstoff und Gas im Schweizer Energiesystem, um die Abhängigkeiten von fossilen Brennstoffen zu reduzieren, einen saisonalen Ausgleich zu ermöglichen und überschüssige erneuerbare Energie zu nutzen.
  - zur Abwärmenutzung von Wasserstofferzeugungsanlagen und Rechenzentren in einem Multi-Energie-Gebäude (z.B. NEST-Gebäude an der Empa) sowie die Nutzung in Power-to-X-Prozessen.
  - zur Aktivierung der Wärmepumpenflexibilität durch direkte Laststeuerung und Wärmepumpen–abschaltungen in Gebäuden.
  - zur Top-Down-Analyse von Wirtschaft und Umwelt, einschliesslich Stromdefizit im Winter, Import von synthetischen Brennstoffen und Skalierung der direkten Lufterfassung.
- Methoden und Werkzeuge:
  - Ein Entscheidungsbaum-Ansatz zur Vereinfachung komplexer Energiesystem-Szenarien in prägnante Storylines, die durch politische Entscheidungen gesteuert werden.
  - Eine Abschätzungsmethode für die Stromnachfrage aufgrund von Elektromobilität und die Vorteile in Bezug auf die räumlich-zeitliche Flexibilität innerhalb des Schweizer Energiesystems.
  - Eine Methode zur flexibilitätsbewussten Planung von Verteilungsnetzen, um Kompromisse zwischen der Verstärkung der Netze und der Flexibilität der Endverbraucher zu ermitteln.
  - Datenbanken über die Eigenschaften von Wasserstoff/Luft-Brennstoffzellensystemen, das Wasserstoffspeicherpotenzial in Salzkavernen und Messungen zur CO_2-Regeneration bei der Polymerelektrolytmembran-Elektrolyse.
- Geschäftsmöglichkeiten und potenzielle politische Massnahmen:
  - Studie über Geschäftsmöglichkeiten, politische Massnahmen und neue Vorschriften zur Förderung der Einführung von Vehicle-to-Grid in der Schweiz.
  - Das Konzept für die erste Kampagne zur Untersuchung der öffentlichen Akzeptanz der Schweizer Bürger/innen gegenüber Flexibilitäts- und Sektorkopplungsmassnahmen.
  - Vorschläge für die Gestaltung von Finanzverträgen zur Differenzierung der Förderung von erneuerbaren Energien, die einen erheblichen Einfluss auf die politischen Diskussionen in der Europäischen Union und in der Schweiz hatten.
  - Simulationen, die darauf hindeuten, dass Rebound-Spitzen, die sich aus dynamischen Tarifen (pro kWh) ergeben, durch nutzungsabhängige Kapazitätstarife (pro kW) gelöst werden könnten.
- Integration, Synthese und Öffentlichkeitsarbeit:
  - Drei Pilot- und Demonstrationsprojekte wurden lanciert (NeDeLa, nanoverbund, H_2 districts).
  - Ausweitung des Wissens- und Technologietransfers durch interne monatliche Seminare, Lunch Talks, Policy Briefs, Workshops und Kooperationen mit Industriepartnern.

Punti salienti

I principali punti salienti durante il periodo di riferimento sono stati:

- Percorsi fattibili attraverso
  - la presentazione di un rapporto di sintesi che presenta i risultati preliminari sulle configurazioni del sistema energetico svizzero nel 2050 come risultato dell'analisi di quattro scenarii e di due ulteriori scenari alternativi volti a studiare l'impatto della flessibilità dei veicoli elettrici sul sistema energetico,

  supportato e integrato da studi su

  - il potenziale dell'idrogeno e del gas nel sistema energetico svizzero per ridurre la dipendenza dai combustibili fossili, consentire il bilanciamento stagionale e utilizzare l'energia rinnovabile in eccesso.
  - il recupero del calore di scarto dal sito di generazione dell'idrogeno e dai datacenter in un edificio multi-energia (ad esempio, l'edificio NEST dell'Empa) e l'utilizzo nei processi Power-to-X.
  - attivazione della flessibilità delle pompe di calore attraverso il controllo diretto del carico e la disconnessione controllata delle pompe di calore negli edifici.
  - analisi economica e ambientale top-down, che include il deficit invernale di elettricità, l'importazione di combustibili sintetici e l'aumento di scala di direct air capture.
- Metodi e strumenti:
  - Un approccio ad albero decisionale per semplificare i complessi scenari del sistema energetico in trame concise guidate da decisioni politiche.
  - Un metodo di stima della domanda di elettricità dovuta alla mobilità elettrica e dei benefici in termini di flessibilità spazio-temporale nel sistema energetico svizzero.
  - Un metodo per la pianificazione consapevole della flessibilità dei rinforzi della rete di distribuzione per identificare i compromessi tra il rinforzo della rete e la flessibilità dell'utente finale.
  - Banche dati sulle caratteristiche dei sistemi di celle a combustibile idrogeno/aria, sul potenziale di stoccaggio dell'idrogeno in caverne saline e sulle misure di rigenerazione della CO_2 nell'elettrolisi a membrana di elettrolita polimerico.
- Opportunità commerciali e politiche potenziali:
  - Studio sul business case, sugli interventi politici e sulle nuove normative per promuovere la diffusione del vehicle-to-grid in Svizzera.
  - Il concetto della prima campagna per studiare l'accettazione pubblica dei cittadini svizzeri per le politiche di flessibilità e di accoppiamento settoriale.
  - Proposte per la progettazione di contratti di differenza per il sostegno alle energie rinnovabili che hanno avuto un impatto significativo sulle discussioni politiche nell'Unione Europea e in Svizzera.
  - Simulazioni che suggeriscono che i picchi di rimbalzo derivanti da tariffe volumetriche dinamiche ex-ante (per kWh) potrebbero essere risolti da tariffe di capacità in funzione del tempo di utilizzo (per kW).
  - Il lancio di policy briefs per fornire raccomandazioni rilevanti dal punto di vista politico sulla base dei risultati della ricerca pubblicati in rapporti di sintesi e nelle pubblicazioni scientifiche.
- Integrazione, sintesi e divulgazione:
  - Sono stati avviati tre progetti pilota e di dimostrazione (NeDeLa, nanoverbund, H_2 districts).
  - Ampliamento del trasferimento di conoscenze e tecnologia attraverso seminari interni mensili, lunch talks, policy briefs, workshops e collaborazioni con partner industriali.

1 Highlights of the reporting period

The primary objective of PATHFNDR is to analyse energy transition pathways for renewable energy integration in Switzerland, while considering flexibility and sector coupling options across national to local scale. To tackle the complexity of this challenge, the PATHFDNR consortium explores the energy system through various scales, disciplines, and sectors (Figure 1). More information can be found on the **PATHFNDR website**.

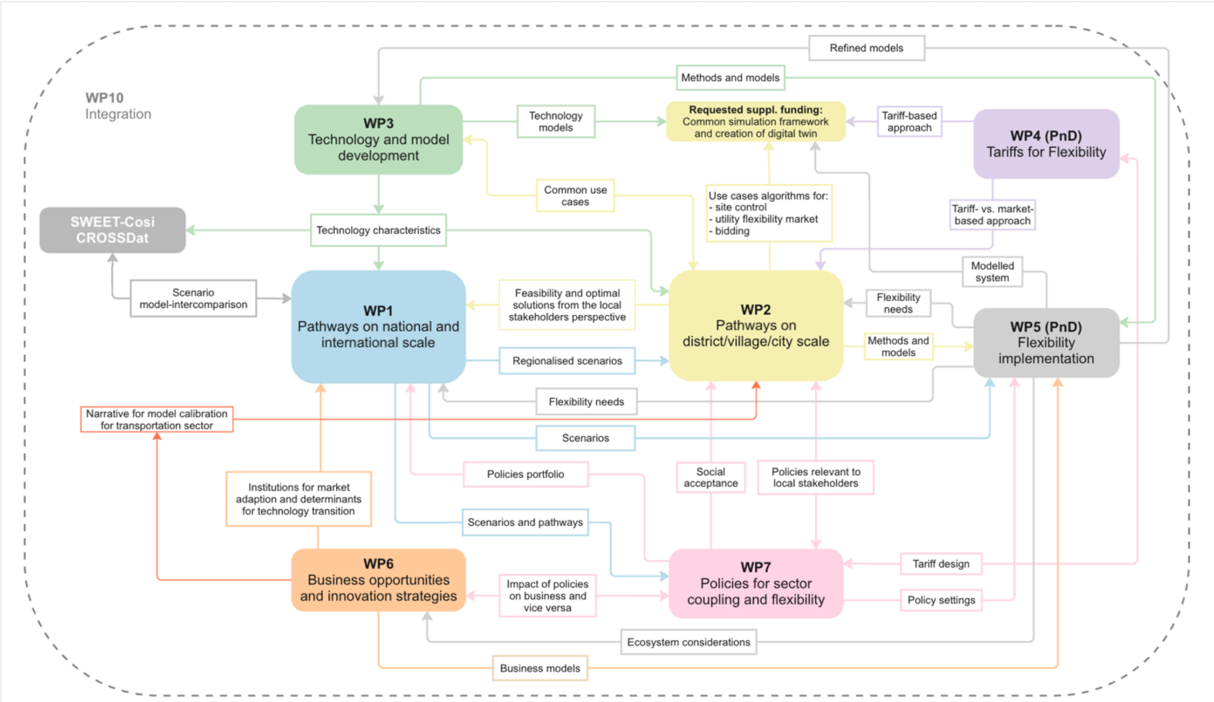

Figure 1: Relationship between work packages © PATHFNDR 2023

During the reporting period, a major task was the development of the synthesis report process, which consolidates the technical and socio-economic interfaces of the different studies conducted in PATHFNDR. After the first synthesis report (Bardow et al., 2023) defined the concepts and metrics for sector coupling and flexibility, the second synthesis report presents the results from the assessment of energy system scenarios by 2050 for Switzerland. The third synthesis report will focus on the system needs, technological capabilities, market rules, and policy and business strategies.

The first work package (WP1) dealing with pathways at national and European scale, developed a decision-tree approach to simplify complex and large number of energy system scenarios into concise storylines that are driven by policy decisions (Baader et al., 2023). Furthermore, WP1 studied different energy scenarios for Switzerland looking at three primary factors: (1) Carbon compensation, (2) energy system integration, and (3) level of flexibility and resource availability (Figure 2). These scenarios are derived from the CROSS scenarios but are expanded to include flexibility options, changes in resource potential, and the adoption of specific technologies. The results were published in a technical report describing the energy system scenarios and a synthesis report presenting the preliminary results of the assessment of four scenarios modelled with the Euro-Calliope and Nexus-e models. The key messages are:

1. **Sector coupling through electrification:** Achieving net-zero emissions will require the electrification of the transport and heating sectors as the preferred path to decarbonization.

2. **Demand flexibility from electric vehicles and heat pumps:** By 2050, the energy system, which will be primarily based on electricity, will demand more short-term and seasonal flexibility. Electric vehicles and heat pumps can provide significant demand-side flexibility, optimizing the use of resources such as photovoltaics and hydropower.

3. **Impact of carbon compensation and system integration:** When carbon capture is mandated within Switzerland and interconnection capacities are reduced, there is an increase in domestic renewable energy generation as well as curtailments.

Given the local and distributed nature of photovoltaics, electric vehicles, and heat pumps, a more detailed analysis at the local level is required. This will be explored in the upcoming third synthesis report, which will focus on the provision of flexibility from electromobility and buildings from national to local scale.

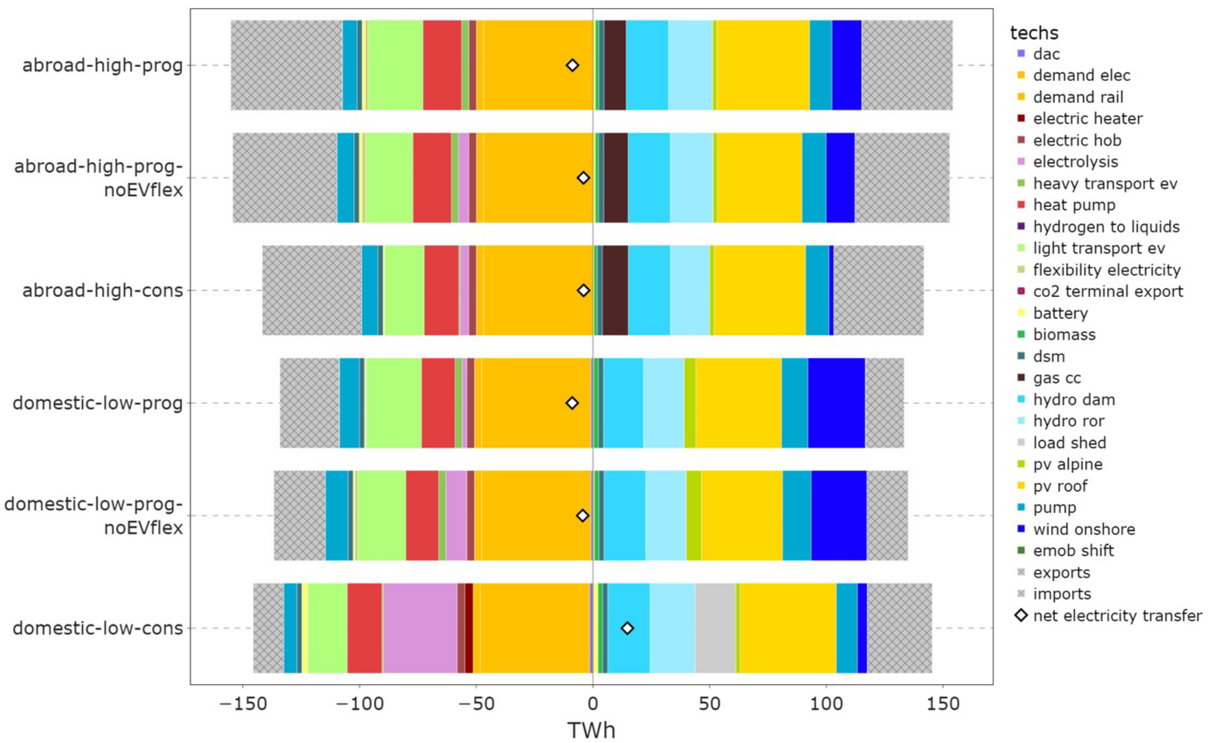

Figure 2: The four main scenario storylines investigated, where three primary dimensions have been considered: Compensation abroad, energy market integration, technology acceptance and flexibility. Two additional sensitivity scenarios were analyzed on the impact of electric vehicle charging flexibility on the Swiss energy system. © PATHFNDR 2024

The second work package (WP2), addressing pathways at local scale, developed methods to investigate the role of buildings and electromobility in enhancing demand-side flexibility (Figure 3). One study found that enabling flexibility service provision from electric vehicles can result in revenues for end-users higher than energy costs under certain market conditions and these revenues can increase by up to 14% with

V2G technology and by up to 5% with EV users flexible with their parking times (Bellizio, 2023). Additionally, a case study in the canton Basel-Landschaft estimated a total heat energy demand from residential buildings in 2020 at 1,291,000 MWh, with older buildings consuming an average of 23 MWh (per building) – 38% more than newer buildings at 15.6 MWh (Lucas 2023, Schneeberger 2024). Another study on direct load control for heat pump flexibility highlighted the importance of effective compensation, information sharing, and price forecasts for user participation. WP2 also assessed a power-to-hydrogen-to-power system in a multi-family building (Koirala et al., 2023), showing that increasing deployment of conversion and storage technologies are leading to more integrated electricity, hydrogen, and heat systems, with battery and thermal storage providing short-term flexibility, while hydrogen storage offers both short- and long-term flexibility. Furthermore, a method for flexibility-aware planning of distribution network was developed and applied to medium- and low-voltage networks (Lustenberger, 2024). The analysis showed that current medium-voltage and low-voltage networks cannot support the photovoltaics capacity outlined in the Swiss Energy Strategy due to over-voltages, necessitating upgrades. Integrating solar photovoltaics with battery energy storage systems can help manage injections. In some cases, demand-side flexibility mechanisms, aligning heat pump and electric vehicle charging demand with peak solar generation, can alleviate grid violations and thus help utilities to defer network expansion investments. Finally, market designs to incorporate flexible resources were analysed, concluding that incorporating flexibility aggregators into wholesale day-ahead and intraday auctions requires revising bid formats to ensure accurate renewable energy shifting (Hübner & Hug, 2024).

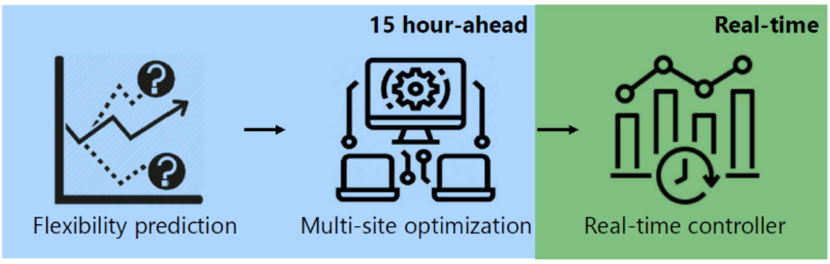

Figure 3: The developed operational tool for demand-side flexibility provision © PATHFNDR 2023

The third work package (WP3), focusing on technology and model development, has generated databases of hydrogen/air fuel cell system characteristics, seasonal hydrogen storage potential in salt caverns, and measurements on CO_2 regeneration of a polymer electrolyte membrane electrolysis stack in a sub-MW electrolyser system. Furthermore, simplified techno-economic models for thermal energy storage were integrated in an energy balance model to study the impact of actual control strategies on flexibilization as well as to elucidate roles of waste heat recover in Power-to-X plants (Figure 4). The databases are available on the CROSSDat platform (Humbert et al., 2024). Studies on waste heat recovery from hydrogen generation site and data centres in a multi-energy building (i.e., NEST building at Empa), as well as utilization in Power-to-X processes were carried out. Several preliminary findings have been identified. For instance, the flexibility of IT workloads through edge data centres are projected to increase local heat consumption, although the benefits of thermal energy storage in the analysed building are expected to be modest. Additionally, sector coupling solutions, such as waste heat recovery, could reduce the levelized cost of hydrogen by up to 5.3%, supporting the wider adoption of hydrogen systems.

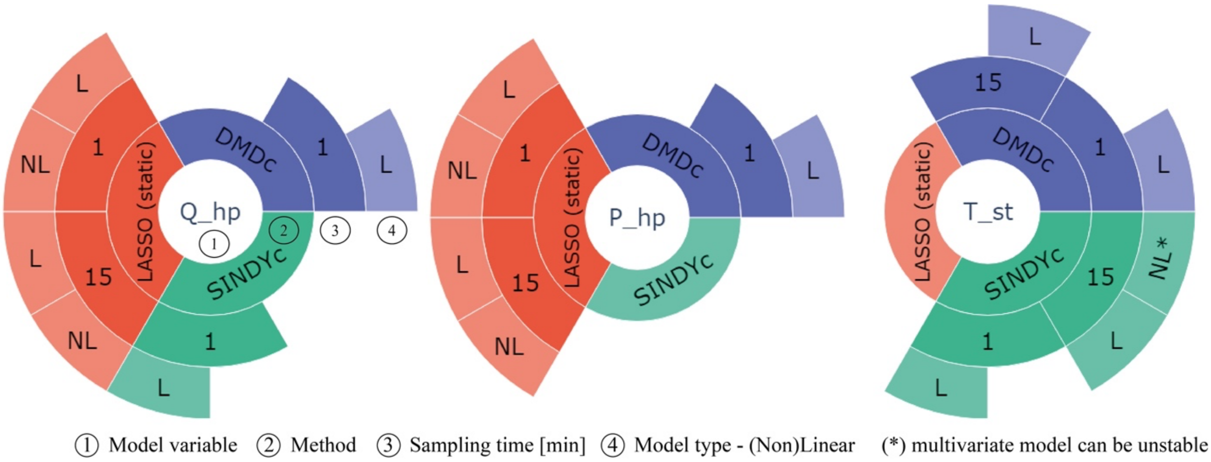

Figure 4: All feasible combinations of model variables, methods, sampling time, and model types that result in stable models of heat pumps with buffer tanks. This representation forms the systematic screening of the best-suited model © PATHFNDR 2023

The sixth work package (WP6), assessing business opportunities and innovation strategies, investigated market adaption strategies in the electromobility sector to induce favourable consumer evaluations for sector coupling technology innovations (Palmié et al., 2024). A key finding is that by linking complementary products (such as a private system for electric vehicles) and anticipating future technological advances, companies create added value to products that, coupled with future policy measures, encourages customers to adopt sustainable innovations. Furthermore, a study was conducted on business case, policy interventions and new regulations to promote the deployment of vehicle-to-grid in Switzerland (Andersen & Powell, 2024). It showed that Switzerland's current regulations may unintentionally disincentivize small-scale aggregators from deploying vehicle-to-grid. To make vehicle-to-grid profitable, lower station costs and new regulations to end double taxation on vehicle-to-grid discharged energy are needed (Figure 5). Also, empirical studies tested how car manufacturers adjust their innovation activities in response to policies for supporting innovation and diffusion of electric vehicles. Results show that technology-push policies (e.g., R&D funding) have unclear effects on incumbents' innovation in old technologies, while demand-pull policies (e.g., tax credits for electric vehicles) can reduce innovation (e.g., fewer efforts to innovate in diesel and gasoline cars). These findings suggest that combining both types of policies may be the best strategy for guiding firms away from outdated technologies.

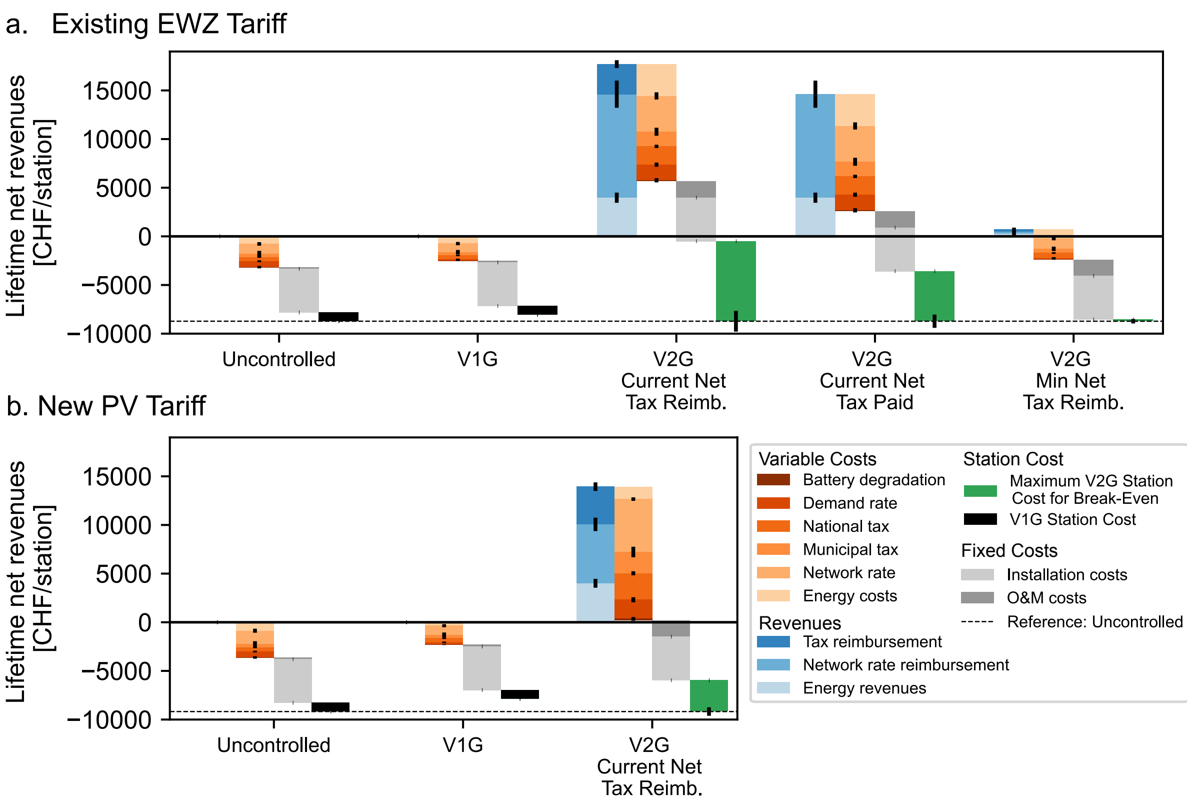

Figure 5: Breakdown of costs and revenues for a workplace aggregator doing vehicle-to-grid control under different tariff and network rate reimbursement cases © PATHFNDR 2023

The seventh work package (WP7), dealing with policies, reviewed policies supporting flexibility and sector coupling from electric vehicles, buildings, hydrogen and direct air capture in Switzerland, its neighbours, and the European Union. The review revealed key differences among the countries in (1) policy instruments for renovations, non-fossil heating systems, and smart meter rollouts, (2) incentives for battery electric vehicles and charging infrastructure, (3) hydrogen targets, (4) international policies for direct air capture, and (5) time-of-use and dynamic tariffs for electric vehicles and heat pumps (Figure 6). Furthermore, three studies were conducted in the top-down economic and environmental analysis. The first study assessed policy strategies to mitigate Switzerland's electricity winter deficit. It found that reducing net winter imports under the Energy Perspectives 2050+ roadmap will raise energy costs, but options like gas-fired power plants, alpine photovoltaics, and wind turbines can effectively mitigate the winter deficit and lower costs by enabling greater electrification of heating systems. The second study investigated the costs of importing synthetic fuels and concluded that CO_2-based fuels from cost-effective regions could compete with fossil fuels in the long term, with estimated minimum selling prices for synthetic fuels are 2.2 - 3.0 times higher than those of fossil fuels. The third study examines policy pathways for scaling direct air capture (DAC) technologies and identifies the major challenges for both carbon removal and storage as well as CO_2 utilization. These challenges include the need for compliance markets, regulatory frameworks, short-term market gaps, polarized debates, and dependence on technical factors influenced by policy support and market conditions. Furthermore, the first campaign to study Swiss citizens' public acceptance towards flexibility and sector coupling policies was designed. The campaign is an online informed citizen panel that will assess policies related to electricity import, direct carbon capture and storage, electric vehicle charging, and heating systems. The aim is to understand which of these policies are likely to receive public support, and how information shapes public acceptance. Finally, a proposal was also developed for the design of financial contracts for differences in the support of renewable energy to solve issues with existing support contracts (Schlecht et al., 2024). The proposed contracts for differences use asset independence to avoid distortions found in conventional contracts for differences by linking payments to an objective benchmark correlated with electricity generation. This approach hedges both volume and price risks, stabilizing revenues and preventing liquidity squeezes by allowing physical assets as collateral. Combining features of conventional contracts for differences and forward contracts, it reduces revenue risk while remaining tailored to specific technologies.

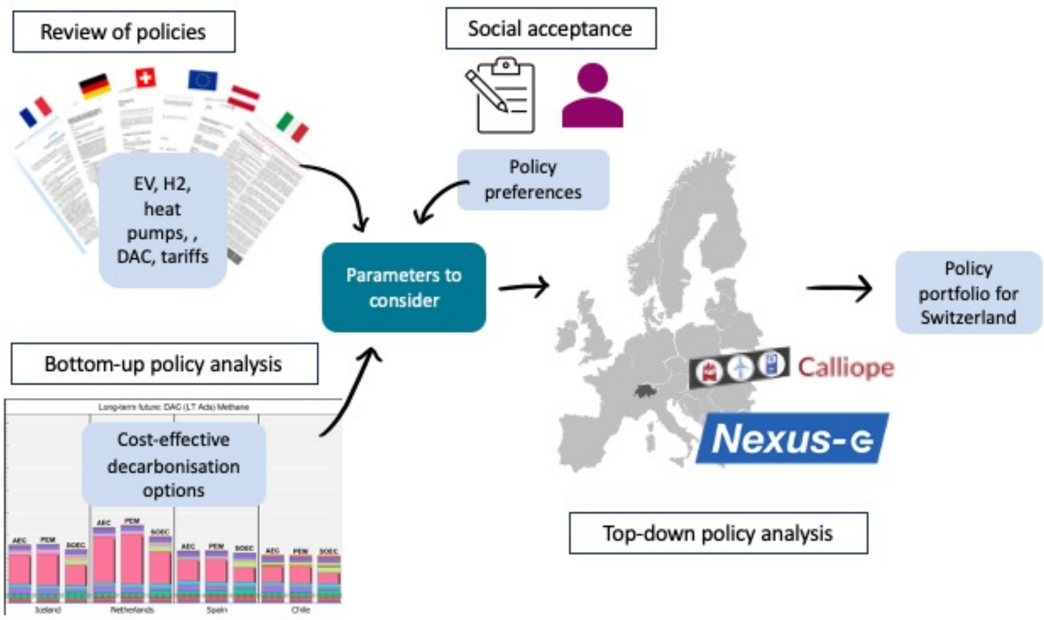

Figure 6: The PATHFNDR WP7 activities from policy, social acceptance and bottom-up and top-down analysis © PATHFNDR 2023

The tenth work package (WP10), responsible for the integration and synthesis of the overall project results, published the second synthesis report on energy system scenarios and is coordinating the third on electromobility and buildings. Furthermore, a total of three pilot and demonstration projects were submitted and approved:

- **NeDeLa – Grid tariffs for decentralized load control**
- **nanoverbund**
- **H_2-districts**

In terms of knowledge and technology transfer, internal and external communication and dissemination channels were established (such as monthly seminars, lunch talks, policy briefs, workshops, and meetings with industry partners). The annual two-day PATHDNDR workshop with academic and industry partners was held at Siemens to present and discuss the preliminary results of the energy system scenarios (Figure 7). Furthermore, meetings with cooperation partners were conducted to (1) get feedback on the scenario assumptions and boundary conditions, (2) identify the use cases and the corresponding partner. Finally, the framework of evidence-based policy briefs was kicked-off. The briefs aim to provide policy-relevant recommendations based on research results published in synthesis reports and journal articles.

Figure 7: Participants at the annual PATHFNDR Workshop © PATHFNDR 2023

2 Outputs of the reporting period

Peer-reviewed publications

Author(s), title, journal name, year	doi / link
Akbari, B., & Sansavini, G. (2023). **Adaptive robust AC optimal power flow considering intrahour uncertainties**. Electric Power Systems Research, 216, 109082.	https://doi.org/10.1016/j.epsr.2022.109082
Andersen, D. & Powell, S. (2024). **Policy and Pricing Tools to Incentivize Distributed Electric Vehicle-to-Grid Charging Control**. *Energy Policy preprint.*	https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4918051
Baader, F. J., Moret, S., Wiesemann, W., Staffell, I., & Bardow, A. (2023). **Streamlining Energy Transition Scenarios to Key Policy Decisions**. *arXiv preprint arXiv:2311.06625.*	https://arxiv.org/pdf/2311.06625.pdf
Bellizio, F., Guo, Y., & Heer, P. (2023). **Optimal V2X operation of EV fleets with PV-battery charging station for demand-side flexibility provision**. TechRxiv.	10.36227/techrxiv.24590955.v1
Ehrhart, K. M., Schlecht, I., Schmitz, J., Wang, R. (2023). **Comparison of price caps and tariffs to counter a foreign monopoly**. Economics Letters, 227, 111128.	Journal: https://doi.org/10.1016/j.econlet.2023.111128 Open access: http://ingmarschlecht.de/Ehrhart_et_al_2023.pdf
Gabrielli, P., Garrison, J., Hässig, S., Raycheva, E., & Sansavini, G. (2024). **The role of hydrogen storage in an electricity system with large hydropower resources**. Energy Conversion and Management, 302, 118130.	https://doi.org/10.1016/j.enconman.2024.118130
Ganter, A., Gabrielli, P., & Sansavini, G. (2024). **Near-term infrastructure rollout and investment strategies for net-zero hydrogen supply chains**. Renewable and Sustainable Energy Reviews, 194, 114314.	https://doi.org/10.1016/j.rser.2024.114314
Koirala, B.P., Cai, H., De Koning, J., Heer, P., Orehounig K. **Flexibility assessment of power-hydrogen-power (P2H2P) system in multi-energy districts**. J Phys: Conf Ser 2023;2600:072007.	https://doi.org/10.1088/1742-6596/2600/7/072007
Le Dréau, J., Lopes, R. A., O'Connell, S., Finn, D., Hu, M., Queiroz, H., ... & Saeed, M. H. (2023). **Developing energy flexibility in clusters of buildings: A critical analysis of barriers from planning to operation**. Energy and Buildings, 113608.	https://doi.org/10.1016/j.enbuild.2023.113608
Leenders, L., Sollich, M., Reinert, C., & Bardow, A. (2023). **Integrating quantum and classical computing for multi-energy system optimization using Benders decomposition**. *arXiv preprint arXiv:2309.16363.*	https://arxiv.org/ftp/arxiv/papers/2309/2309.16363.pdf
Lustenberger, M., Bellizio, F., Cai, H., Heer, P., & Ziras, C. (2024). **Introducing price feedback of local flexibility markets into distribution network planning**. *Electric Power Systems Research, 236,* 110686.	https://www.sciencedirect.com/science/article/pii/S0378779624005728
Mannhardt, J., Gabrielli, P., & Sansavini, G. (2023). **Collaborative and selfish mitigation strategies to tackle**	https://doi.org/10.1016/j.isci.2023.106750

energy scarcity: The case of the European gas crisis. iScience, 26(5).	
Markard, J., Wells, P., Yap, X. S., & van Lente, H. (2023). **Unsustainabilities: A study on SUVs and Space Tourism and a research agenda for transition studies**. Energy Research & Social Science, *106*, 103302.	**https://doi.org/10.1016/j.erss.2023.103302**
Palmié, M., Miehé, L., Mair, J., Wincent, J. (2024). Valuation entrepreneurship through product-design and blame-avoidance strategies: **How Tesla managed to change the public perception of sustainable innovations**. Journal of Product Innovation Managment, 41 (3), 644-676.	**https://doi.org/10.1111/jpim.12732**
Raycheva, E., Gjorgiev, B., Hug, G., Sansavini, G., & Schaffner, C. (2023). **Risk-informed coordinated generation and transmission system expansion planning: A net-zero scenario of Switzerland in the European context**. Energy, 280, 128090.	**https://doi.org/10.1016/j.energy.2023.128090**
Reinert, C., Nolzen, N., Frohmann, J., Tillmanns, D., & Bardow, A. (2023). **Design of low-carbon multi-energy systems in the SecMOD framework by combining MILP optimization and life-cycle assessment**. *Computers & Chemical Engineering*, *172*, 108176.	**https://www.sciencedirect.com/science/article/pii/S0098135423000455**
Ruefenacht, L.A., Marcucci, A., Leenders, L. (eds.), Bardow, A., Fiorentini, M., Heer, P., Kaemper, A., Koirala, B., Knoeri, C., Marinakis, A., Markard, J., Mayer, P., Oswald, K., Peter, C., Pfenninger, S., Sansavini, G., Schaffner, C., Schlecht, I., Schuetz, P., Schwarz, M., Villasmil, W. (2023). **Flexibility and sector coupling in energy systems: definitions and metrics**. SWEET PATHFNDR consortium.	**https://www.research-collection.ethz.ch/handle/20.500.11850/641177**
Schlecht, I., Maurer, C., & Hirth, L. (2024). **Financial contracts for differences: The problems with conventional CfDs in electricity markets and how forward contracts can help solve them**. Energy Policy, 186, 113981.	**https://doi.org/10.1016/j.enpol.2024.113981**
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Stankovski, A., Gjorgiev, B., Locher, L., & Sansavini, G. (2023). **Power blackouts in Europe: Analyses, key insights, and recommendations from empirical evidence**. Joule, 7(11), 2468–2484.	**https://www.cell.com/joule/pdfExtended/S2542-4351(23)00366-5**
Thimet, P., Mavromatidis, G. (2023). **What-where-when: Investigating the role of storage for the German electricity system transition**. *Applied Energy*, *351*, 121764.	**https://doi.org/10.1016/j.apenergy.2023.121764**
Toetzke, M., Probst, B., & Feuerriegel, S. (2023). **Leveraging large language models to monitor climate technology innovation**. *Environmental Research Letters*, *18*(9), 091004.	**https://doi.org/10.1088/1748-9326/acf233**

Vivian, J., Heer, P., & Fiorentini, M. (2023). **Optimal sizing and operation of seasonal ice thermal storage systems**. Energy and Buildings, 300, 113633.	**https://doi.org/10.1016/j.enbuild.2023.113633**
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Other non-peer-reviewed publications (working papers, press articles, etc.)

Author(s), title, channel or type of publication, year
Beaud, M., Cai, H., Perera, A. T. D., & Heer, P. (2023). **Performance gaps between energy system planning and operation: a study exploring the impacts of model fidelity and dispatch strategy**. In Journal of Physics: Conference Series (Vol. 2600, No. 3, p. 032016). IOP Publishing.
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Cuony, P., Bellizio, F., Chanez, C., Heer, P., Winzer, C. (2023, July 19). **Dynamische Tarife für ein effizientes Stromsystem | VSE. https://www.strom.ch/de/nachrichten/dynamische-tarife-fuer-ein-effizientes-stromsystem**
Cuony, P. (2023, December 14). **Dynamische Stromtarife kommen in die Schweiz: So funktioniert das Modell – Technikblog. https://technikblog.ch/2023/12/dynamische-stromtarife-kommen-in-die-schweiz-so-funktioniert-das-modell/**
Humbert, G., Cai, H., Peter, C., Jacobs, M., Lucas, E., Heer, P. (2024). **Database for Techno-Economic Parameters of Energy Technologies**. CROSS. **https://sweet-cross.ch/data/energy-tech-parameters/2024-02-27/**
Schneeberger, S., Lucas, E., Meister C., & Schuetz P. (2024), **Wärmebedarfsschätzungen für Wohngebäude**, 18. Symposium Energieinnovation, 14.-16.2.2024, Graz/Austria, **https://www.tugraz.at/fileadmin/user_upload/tugrazExternal/f560810f-089d-42d8-ae6d-8e82a8454ca9/files/lf/Session_F3/631_LF_Schneeberger.pdf**

Invited talks (scientific or broad audience)

Presenter(s), title, name of the event and location, year
Aliana A. (2023, June). **MANGOpol: MANGOpol: A modelling framework for the optimal co-design of policy mixes and energy systems**. 36th Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS), Gran Canaria.
Born, D. (2024, March 6). **Nanoverbund - Wärme smart und flexibel teilen**, Info- und Diskussionsveranstaltung "Heizdialog Mausacker", Rainach BL, Switzerland. **https://www.reinach-bl.ch/de/aktuell/news/meldungen-projekte/stadtentwicklung/Mausacker.php**
Brazzola N., Moretti C., Sievert K., Patt A., Lilliestam J. (2023, April). **Policy Pathways to Reduce DAC Costs**. 11th Conference on CO2 as Feedstock for Fuels and Chemicals, Cologne.
Cuony, P. (2024, March 8). **A DSO strategy for EV integration**. Presented at PVInMOtion conference, in Neuchâtel, Switzerland. **https://www.pvinmotion-conference.com/fileadmin/data/PVinMotion/2024/Documents/PVinMotion_2024_Program_Ultimate_Updated.pdf**
Cuony, P., Winzer, C. (2023). **Dynamische Tarife bei Groupe-E und NEDELA Projekt**. Presented at VSE Tarif Workshop, Aarau, Switzerland.
Cuony, P. (2024, January 31). **E-Autos, Wärmepumpen und Heimspeicher in Aktion: Mit dynamischen Strompreisen und dynamischen Netzentgelten schlummernde Potentiale heben**. Presented at Agora Energiewende, Bern, Switzerland. **https://www.agora-energiewende.de/aktuelles/e-autos-waermepumpen-und-heimspeicher-in-aktion-mit-dynamischen-strompreisen-und-dynamischen-netzentgelten-schlummernde-potentiale-heben**

Cuony, P. (2024, March 22). **Neue Netztarife für die Energiewende**. Presented at Swissolar, Lausanne, Switzerland. **https://www.swissolar.ch/de/pv-tagung/programm**	
Lötscher, R., Miehé, L., Philippi, M., Tollin, F., (2023). **Focus Dialog Mobility**. Invited Talk, *ETH Energy Science Week*. Zurich/Online, Switzerland.	
Markard, J., (2023). **Multi-level perspective**. Guest Lecture, *MAK'IT Seminar Université de Montpellier*. Online.	
Markard, J., (2023). **Sustainability Transitions: New challenges**. Invited Talk, *STRN / NEST PhD school on methods*. Winterthur, Switzerland.	
Markard, J., (2023). **Sustainability Transitions: Systems perspective & new challenges**. Invited Talk, *EGOS Conference*. Cagliari, Italy.	
Markard, J., (2023). **Multi-system transition dynamics: The role of meta-rules**. Invited Talk, *SPRU Seminar University of Sussex*. Brighton, England.	
Markard, J. (2023, September) **Multi-system transition dynamics: The role of meta-rules**. SPRU Seminar, University of Sussex, Brighton.	
Markard, J., (2023). **Destined for decline? Examining nuclear from an innovation systems perspective**. Invited Talk, *Finnish Institute for International Affairs (FIIA) Spotlight Webinar*. Online.	
Markard, J., (2024). **Reflections on sustainability, new technologies and transitions**. Guest Lecture Sustainable Management and Operations, *Kühne Logistics University*, Hamburg, Germany.	
Miehé, L., (2023). **Ökosystem Wohnen: Ein Blick in die Zukunft, Öffentlicher Informationsanlass «Energiebewusstes Wohnen: Mein Beitrag»**. Invited Talk, *FDP Meggen*. Meggen, Switzerland.	
Moretti C. (2024, March). **Embedding Switzerland in the European electricity system**. ElCom Workshop, Bern, Switzerland.	
Nuñez-Jimenez, A. (2023). **Breaking the ICE?** Invited talk, *International Sustainability Transitions conference.* Utrecht, Netherlands.	
Powell, S. (2023). **Charging Toward a Cleaner Future: The Transition to Electric Vehicles**. Invited Talk, *ETH Energy Week*. Zurich, Switzerland.	
Thimet, P., Powell, S., Knöri, C. (2023). **How electric vehicle charging behaviours impact long-term electricity system capacity investment planning in Germany**. Conference, *36th International Conference on Efficiency, Cost, Optimization, Simulation, and Environmental Impact of Energy Systems (ECOS)*. Las Palmas, Spain.	
Toetzke, M. (2023). **Potential of Natural Language Processing Tools to Monitor Technology Innovation**. Invited Expert Presentation, *62nd Meeting of the Working Party on Innovation and Technology Policy of the OECD*. Paris, France.	
Toetzke, M. (2024). **Mapping global innovation networks around climate technologies**. Invited Talk, *SWEET PATHNFDR*. Online.	

Completed PhD theses

Author, title, year
Thimet, P. (2023). **A model-based exploration of energy storage in decarbonizing electricity systems**. **https://doi.org/10.3929/ethz-b-000636187**

Completed master theses

Author, title, year
Andersen, D. (2023). **Which policies make vehicle-to-grid profitable while integrating renewables in Switzerland until 2050?**.
Bernadino, B. (2024). **Economic and Environmental Assessment of Heat Prosumer Communities**.
Bürgler, F. (2023). **Integration of small-scale data centers in multi-energy building systems**.
De Koning, J. (2023). **Long and short term flexible control of power-to-hydrogen system with terminal cost function and flexibility envelope**.
Vandenberghe, R. (2023). **Optimal sizing and operation of hydrogen generation site with waste heat recovery.**
Linder, J. (2024). **Buildings' Flexibility in the Future Swiss Electricity System: An Analysis of Direct Load Control Policies for Heat Pumps**.
Mellot, A. (2023). **Economic and Environmental Assessment of Energy Strategies Designed to Mitigate the Swiss Electricity Winter Problem**.

Other outputs

Brief description
Bürgler, F., Humbert, G., Heer, P., Koirala, B. P. (2023, December 5-7). **Optimizing Waste Heat Utilization from Small-scale Data Centers in Multi-Energy Building Systems**, International Conference on Applied Energy, Doha, Qatar.
Cuony, P. (2024). **Groupe E führt einen variablen Stromtarif ein.** Smartgridready. **https://smartgridready.ch/news/groupe-e-f%C3%BChrt-einen-variablen-stromtarif-ein-2**
Cuony, P. (2024). **In der Schweiz haben wir Tarifstrukturen aus dem letzten Jahrhundert**. Smartgridready. **https://smartgridready.ch/news/in-der-schweiz-haben-wir-tarifstrukturen-aus-dem-letzten-jahrhundert**
Humbert, G., Cai, H., Koirala, B. P., Heer, P., (2023, December 5-7). **Cost-Effective Hydrogen Generation: Concurrent Optimization of Component Sizes and System Operation**, International Conference on Applied Energy, Doha, Qatar.
Humbert, G., Cai, H., Peter, C., Jacobs, M., Lucas, E., Heer, P.(2024). Database for Techno-Economic Parameters of Energy Technologies. CROSS. **https://sweet-cross.ch/data/energy-tech-parameters/2024-02-27/**
IWB, Product & Service web page (2024). **IWB Nanoverbund**. **https://www.iwb.ch/angebote/produkte/nanoverbund**
Nappi, G. **Formulating an Approach for Estimating National Heating Demand Flexibility Using Building Archetypes: towards the development of a predictive model using Machine Learning**. Semester project, ETHZ.
SRF Audio, radio broadcast, (2024, March 11). **IWB-Lösung: Verbünde statt Fernwärme**, **https://www.srf.ch/audio/regionaljournal-basel-baselland/iwb-loesung-verbuende-statt-fernwaerme?id=12553085**