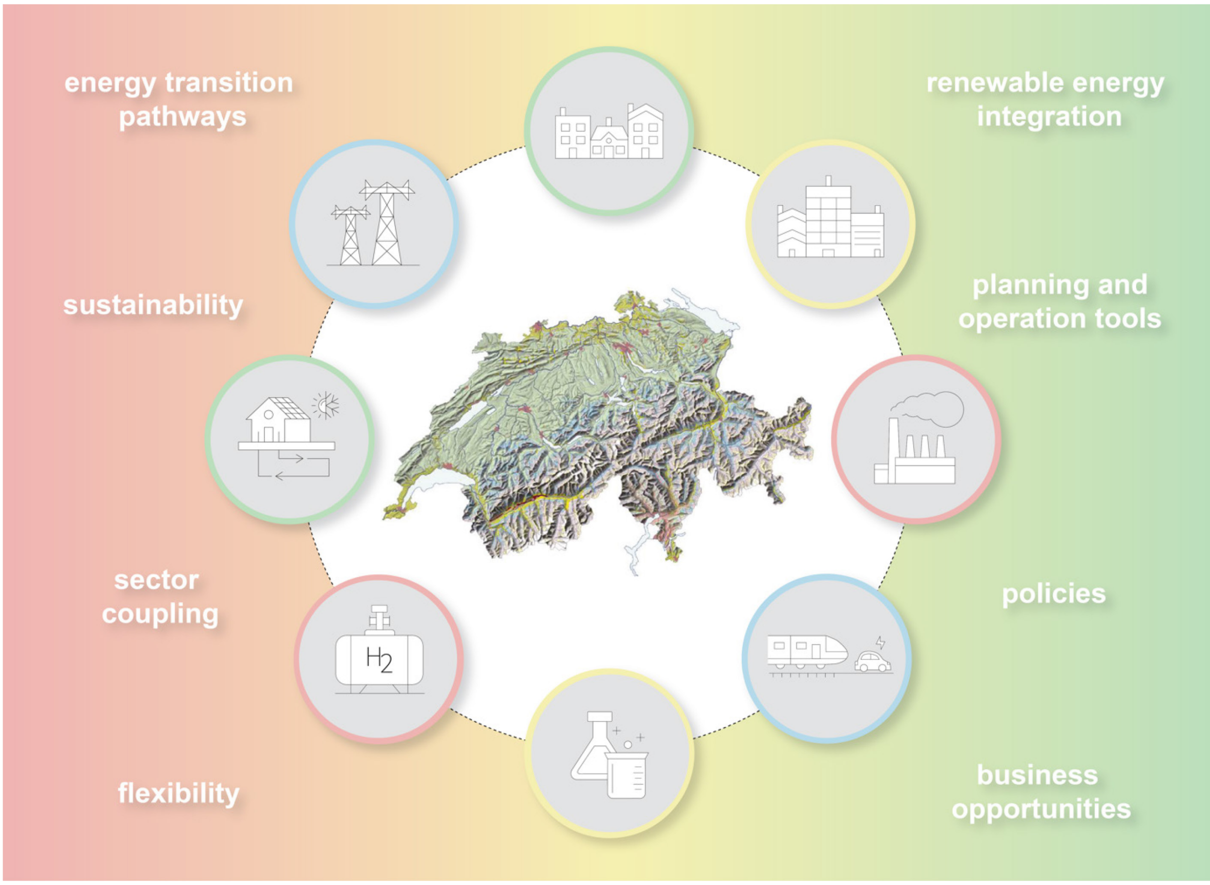
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech

Annual report dated 30 June 2022

SWEET Call 1-2020 – PATHFNDR



Source: © PATHFNDR 2022

sweet swiss energy research for the energy transition

Date: 30 June 2022

Location: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Bern
www.bfe.admin.ch

Year 1
Reporting period: 01.05.2021 **to** 30.04.2022

Subsidy recipient:
ETH Zurich
Rämistrasse 101
8092 Zurich
www.ethz.ch

Authors:
André Bardow, ETH Zurich, abardow@ethz.ch
Tobias Brosch, UNIGE, tobias.brosch@unige.ch
Felix Büchi, PSI, felix.buechi@psi.ch
Turhan Demiray, ETH Zurich, demirayt@fen.ethz.ch
Massimo Fiorentini, Empa, massimo.fiorentini@empa.ch
Philipp Heer, Empa, philipp.heer@empa.ch
Volker Hoffmann, ETH Zurich, vhoffmann@ethz.ch
Gabriela Hug, ETH Zurich, hug@eeh.ee.ethz.ch
Binod Koirala, Empa, binod.koirala@empa.ch
Christof Knoeri, ETH Zurich, cknoeri@ethz.ch
Adamantios Maranakis, ETH Zurich, marinakis@fen.ethz.ch
Jochen Markard, ZHAW, jmarkard@ethz.ch
Marco Mazzotti, ETH Zurich, marco.mazzotti@ipe.mavt.ethz.ch
Mario Paolone, EPFL, mario.paolone@epfl.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
Kristina Orehounig, Empa, kristina.Orehounig@empa.ch
Martin Rüdisüli, Empa, martin.Ruedisueli@empa.ch
Lea Rüfenacht, ETH Zurich, lea.ruefenacht@esc.ethz.ch
Giovanni Sansavini, ETH Zurich, sansavig@ethz.ch

Christian Schaffner, ETH Zurich, **schaffner@esc.ethz.ch**
Ingmar Schlecht, ZHAW, **ingmar.schlecht@zhaw.ch**
Philipp Schütz, HSLU, **philipp.schuetz@hslu.ch**
Evelina Trutnevyte, UNIGE, **evelina.trutnevyte@unige.ch**
Willy Villasmil, HSLU, **willy.villasmil@hslu.ch**
Christian Winzer, ZHAW, **christian.winzer@zhaw.ch**

Contributors:
Behnam Akbari, ETH Zurich, **bakbari@ethz.ch**
Viola Becattini, ETH Zurich, **viola.becattini@ipe.mavt.ethz.ch**
Gjorgiev Blazhe, ETH Zurich, **gblazhe@ethz.ch**
Alissa Ganter, ETH Zurich, **aganter@ethz.ch**
Jared Garrison, ETH Zurich, **garrison@fen.ethz.ch**
Mohammad Khosravi, **mohammad.khosravi@empa.ch**
Ludger Leenders, ETH Zurich, **leendersl@ethz.ch**
Gabrielli Paolo, ETH Zurich, **gapaolo@ethz.ch**

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

SFOE contract number: SI/502259-01

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

Table of Contents

Abbreviations

BECCS	Bioenergy with carbon capture and storage
BEV	Battery electric vehicles
CCU	Carbon capture and utilization
CDR	Carbon dioxide removal
CO2	Carbon dioxide
DSO	Distribution systems operator
ETH Zurich	Eidgenössische Technische Hochschule Zurich
Empa	Eidgenössische Materialprüfungs- und Forschungsanstalt
EMS	Energy management systems
EPFL	École Polytechnique Fédérale de Lausanne
ESC	Energy Science Center
ESI	Energy Systems Intregation
EV(s)	Electric vehicle(s)
EVSE	Electric vehicle supply equipment
HSLU	Hochschule Luzern
H2	Hydrogen
KPI	Key performance indicator
NTC(s)	Net transfer capacities
PATHFNDR	Pathways to an efficient future energy system through flexibility and sector coupling
PSI	Paul Scherrer Institute
P2X	Power-to-X
P&D	Pilot and demonstration
SFOE	Swiss Federal Office of Energy
SWEET	Swiss energy research for the energy transition
TU Delft	Delft University of Technology
UNIGE	Université de Genève
VSE	Verband Schweizerischer Elektrizitätsunternehmen
V2G	Vehicle-to-Grid
WP(s)	Work package(s)
ZEV	Zusammenschluss zum Eigenverbrauch
ZHAW	Zürcher Hochschulen für Angewandte Wissenschaften

Summary

The PATHFNDR consortium consists of nine academic partners and 25 cooperation partners, hosted by ETH Zurich. The project kick-off was held in May 2021. According to the schedule and budget, the project is on track (with only minor delays which are discussed in the report). During the reporting period, a major task was the coordination of the interfaces between the work packages (WP). In parallel, the individual WPs achieved the following results:

WP 1 assessed a first set of European-wide scenarios using the Euro-Calliope model, including many options with different technologies and spatial configurations. These results will serve as input for the evaluation of scenarios at the national level, for which the link between the Euro-Calliope and Nexus-e models was initiated. In addition, an analysis was performed of the potential of large-scale hydrogen storage in Switzerland and Europe.

WP 2 identified the main stakeholders and their goals or KPIs, which will be consolidated in a workshop with the cooperation partners. From a technological point of view, heating and cooling loads for residential and commercial buildings were estimated to validate the accuracy of the demand forecast and to integrate renewable energies. Also, a framework for optimizing electric vehicle charging and discharging at multiple sites was developed.

WP 3 connected the ESI demonstrator to ReMaP to demonstrate that remote control to achieve load shifting could be implemented using the experimental setup. Furthermore, the techno-economic modelling parameters and requirements were defined, and the fuel cell system model was validated.

WP 6 analysed the support of blue and green hydrogen by actors from a wide range of industries. Also, different projects were investigated ranging from mega, demonstrator, commercial and small international R&D projects. Finally, cyberphysical platforms were evaluated that combine digital platform technologies with physical technologies.

WP7 started in May 2022, so no deliverables have yet been completed.

WP 10 defined the main concepts (i.e., flexibility, sector coupling and sustainability) and key scenario dimensions and uncertainties to be used in PATHFNDR. These serve as the basis for assessing the energy pathways, and will be presented as technical and synthesis reports. Also, two P&D project ideas were developed: The first (WP 4) focuses on dynamic tariffs to enable efficient investment and dispatch flexibility for different sectors. The second (WP 5) focuses on planning and operation stage solutions to retrofit thermal grid connections to existing adjacent buildings.

As for the KTT, a website, a YouTube channel, and a newsletter were created. In addition, a series of lunch talks on tools, models and demonstrators were held. Periodic workshops on specific topics (based on the interest expressed in the stakeholder survey) were planned with the cooperation partners. Approximately 20 peer-reviewed articles were published, and several presentations were given at energy-related conferences and events. Finally, the data management plan was updated.

Résumé

Le consortium PATHFNDR est composé de neuf partenaires académiques et de 25 partenaires de coopération, hébergés par l'ETH Zurich. Le lancement du projet a eu lieu en mai 2021. Selon le calendrier et le budget, le projet est en bonne voie (avec quelques retards mineurs qui sont expliqués dans le rapport). Pendant la période du rapport, une tâche majeure a été la coordination des interfaces entre les work packages (WP). En parallèle, les WPs individuels ont réalisé les résultats suivants:

Le WP 1 a évalué une première série de scénarios à l'échelle européenne en utilisant le modèle Euro-Calliope, incluant de nombreuses options avec différentes technologies et configurations spatiales. Ces résultats seront la base pour l'évaluation des scénarios au niveau national, pour laquelle le lien entre les modèles Euro-Calliope et Nexus-e a été initié. En outre, une analyse sur le potentiel du stockage de l'hydrogène à grande échelle en Suisse et en Europe a été réalisée.

Le WP 2 a identifié les principales parties prenantes et leurs objectifs ou KPIs, qui seront consolidés dans un atelier avec les partenaires de coopération. D'un point de vue technologique, les charges de chauffage et de refroidissement des bâtiments résidentiels et commerciaux ont été approximées afin de valider la précision de la prévision de la demande et afin d'intégrer les énergies renouvelables. En plus, un framework pour optimiser la charge et la décharge des véhicules électriques à plusieurs sites a été développé.

Le WP 3 a connecté le démonstrateur ESI à ReMaP afin de montrer que la commande à distance pour réaliser le transfert de charge peut être mise en œuvre en utilisant l’installation expérimentale. En outre, les paramètres et les exigences de la modélisation technico-économique ont été définis, et le modèle du système de pile à combustible a été validé.

Le WP 6 a analysé le soutien apporté à l'hydrogène bleu et vert par des acteurs issus des diverses industries. Différents projets ont été examinés, allant des méga-projets aux projets de démonstration, en passant par des projets commerciaux et des petits projets de R&D internationaux. Enfin, les plateformes cyberphysiques, qui combinent les technologies des plateformes numériques avec les technologies physiques, ont été évaluées.

Le WP7 a commencé en mai 2022, donc aucun livrable n'a encore été complété.

Le WP 10 a défini les principaux concepts (i.e., la flexibilité, le couplage sectoriel et la durabilité) et les dimensions et incertitudes clés des scénarios à utiliser dans PATHFNDR. Ceux-ci servent de base pour l'évaluation des trajectoires énergétiques, et seront présentés sous forme de rapports techniques et de synthèse. Aussi, deux idées de projets P&D ont été développées: Le premier (WP 4) se concentre sur les tarifs dynamiques pour permettre des investissements efficaces et une flexibilité de répartition pour des différents secteurs. Le deuxième (WP 5) se concentre sur les solutions de planification et d'exploitation pour rénover des connexions du réseau thermique avec des bâtiments adjacents existants.

Concernant le KTT, un site web, une chaîne YouTube et une newsletter ont été créés. En outre, une série de déjeuners parlants sur les outils, les modèles et les démonstrateurs ont été organisés. Des ateliers périodiques sur des sujets spécifiques (basés sur l'intérêt exprimé dans l'enquête auprès des parties prenantes) ont été planifiés avec les partenaires de coopération. Environ 20 articles évalués par des pairs ont été publiés, et plusieurs présentations ont été donnés aux conférences et événements liés à l'énergie. Enfin, le plan de gestion des données a été mis à jour.

Zusammenfassung

Das PATHFNDR-Konsortium besteht aus neun akademischen Partnern und 25 Kooperationspartnern, unter der Leitung ETH Zürich. Der Kick-off fand im Mai 2021 statt. Gemäss Zeitplan und Budget ist das Projekt auf Kurs (mit nur wenigen Verzögerungen, die im Bericht diskutiert werden). Eine wichtige Aufgabe im Berichtszeitraum war die Koordination der Schnittstellen zwischen den Arbeitspaketen. Parallel dazu wurden in den einzelnen Arbeitspaketen (AP) die folgenden Ergebnisse erzielt:

AP 1 bewertete eine erste Reihe von europaweiten Szenarien unter Verwendung des Euro-Calliope-Modells, die viele Optionen mit unterschiedlichen Technologien und räumlichen Konfigurationen umfassen. Diese Ergebnisse werden als Input für die Bewertung von Szenarien auf nationaler Ebene dienen, wofür die Verbindung zwischen den Modellen Euro-Calliope und Nexus-e initiiert wurde. Darüber hinaus wurde eine Analyse des Potenzials der grossmassstäblichen Wasserstoffspeicherung in der Schweiz und in Europa durchgeführt.

AP 2 identifizierte die wichtigsten Stakeholder und ihre Ziele bzw. KPIs, die in einem Workshop mit den Kooperationspartnern konsolidiert werden. Aus technologischer Sicht wurden die Heiz- und Kühllasten für Wohn- und Geschäftsgebäude geschätzt, um die Genauigkeit der Bedarfsprognose zu überprüfen und erneuerbare Energien zu integrieren. Ausserdem wurde ein Ansatz für die Optimierung des Ladens und Entladens von Elektrofahrzeugen an mehreren Standorten entwickelt.

AP 3 koppelte den ESI-Demonstrator mit ReMaP, um zu zeigen, dass die Fernsteuerung für die Lastverschiebung mit Hilfe eines Testaufbaus implementiert werden kann. Darüber hinaus wurden die technisch-ökonomischen Modellierungsparameter und -anforderungen definiert und das Brennstoffzellensystem-Modell validiert.

AP 6 analysierte die Unterstützung von blauem und grünem Wasserstoff durch Akteure aus einem breiten Spektrum von Branchen. Ausserdem wurden verschiedene Projekte untersucht, die von Mega- und Demonstrationsprojekten über kommerzielle Projekte bis hin zu kleinen internationalen F&E-Projekten reichen. Schliesslich wurden cyberphysische Plattformen bewertet, die digitale Plattformtechnologien mit physikalischen Technologien kombinieren.

AP7 begann im Mai 2022, daher wurden noch keine Ergebnisse erzielt.

AP 10 definierte die Hauptkonzepte (d.h. Flexibilität, Sektorkopplung und Nachhaltigkeit) und die wichtigsten Szenario-Dimensionen und -Unsicherheiten, die in PATHFNDR verwendet werden sollen. Diese dienen als Grundlage für die Bewertung der Energiepfade und werden als technische Berichte und Syntheseberichte veröffentlicht. Auch wurden zwei P&D-Projektideen entwickelt: Das Erste (AP 4) konzentriert sich auf dynamische Tarife, um effiziente Investitionen und Dispatch-Flexibilität für verschiedene Sektoren zu ermöglichen. Das Zweite (AP 5) konzentriert sich auf Lösungen für die Planungs- und Betriebsphase zur Nachrüstung von Wärmenetzanschlüssen an bestehende Gebäude.

Was das KTT betrifft, wurden eine Website, ein YouTube-Kanal und ein Newsletter eingerichtet. Darüber hinaus wurde eine Reihe von Lunch Talks über Werkzeuge, Modelle und Demonstratoren abgehalten. Gemeinsam mit den Kooperationspartnern wurden regelmässige Workshops zu bestimmten Themen (basierend auf dem in der Umfrage geäusserten Interesse der Stakeholder) geplant. Es wurden etwa 20 von Fachleuten begutachtete Artikel veröffentlicht und mehrere Präsentationen auf energiebezogenen Konferenzen und Veranstaltungen gehalten. Schliesslich wurde der Datenverwaltungsplan aktualisiert.

Riassunto

Il consorzio PATHFNDR è composto da nove partner accademici e 25 partner di cooperazione, guidato dal Politecnico di Zurigo. L'avvio del progetto si è svolto nel maggio 2021. Secondo il programma e il budget, il progetto è in linea con i tempi previsti (con solo piccoli ritardi che vengono discussi nel report). Durante il periodo di riferimento, un compito importante è stato il coordinamento delle interfacce tra i gruppi di lavoro (GL). Parallelamente, i singoli GL hanno raggiunto i seguenti risultati:

Il GL 1 ha valutato una prima serie di scenari a livello europeo utilizzando il modello Euro-Calliope, includendo molte opzioni con diverse tecnologie e configurazioni spaziali. Questi risultati serviranno come input per la valutazione degli scenari a livello nazionale, per i quali è stato avviato il collegamento tra i modelli Euro-Calliope e Nexus-e. Inoltre, è stata effettuata un'analisi del potenziale dello stoccaggio di idrogeno su larga scala in Svizzera e in Europa.

Il GL 2 ha identificato i stakeholder e i loro obiettivi o indicatori chiave di performance (KPI), che saranno consolidati in un workshop con i partner di cooperazione. Da un punto di vista tecnologico, sono stati stimati i carichi di riscaldamento e raffreddamento degli edifici residenziali e commerciali per convalidare l'accuratezza della previsione della domanda e per integrare le energie rinnovabili. Inoltre, è stato sviluppato un modello per l'ottimizzazione della ricarica e della scarica dei veicoli elettrici in diversi siti.

Il GL 3 ha collegato il dimostratore ESI a ReMaP per dimostrare che il controllo remoto per ottenere il trasferimento del carico può essere implementato utilizzando il setup sperimentale. Inoltre, sono stati definiti i parametri e i requisiti di modellazione tecno-economica ed è stato convalidato il modello del sistema a celle a combustibile.

Il GL 6 ha analizzato il supporto dell'idrogeno blu e verde da parte di attori provenienti da un'ampia gamma di industrie. Inoltre, sono stati analizzati diversi progetti che vanno dai mega, ai dimostratori, ai progetti commerciali e ai piccoli progetti internazionali di ricerca e sviluppo. Infine, sono state valutate le piattaforme ciberfisiche che combinano le tecnologie delle piattaforme digitali con quelle fisiche.

Il GL7 è iniziato nel maggio 2022, quindi non sono ancora stati completati i risultati.

Il GP 10 ha definito i concetti principali (flessibilità, sector coupling e sostenibilità) e le dimensioni chiave degli scenari e le incertezze da utilizzare nel PATHFNDR. Questi servono come base per la valutazione dei percorsi energetici e saranno presentati come rapporti tecnici e di sintesi. Inoltre, sono state sviluppate due idee di progetti pilota e dimostrativi (P&D): Il primo (GP 4) si concentra sulle tariffe dinamiche per consentire investimenti efficienti e flessibilità di dispacciamento per diversi settori. Il secondo (GP 5) si concentra sulle soluzioni per la pianificazione e la fase operativa per il retrofit delle connessioni alla rete termica degli edifici adiacenti esistenti.

Per quanto riguarda il trasferimento di sapere e tecnologia, sono stati creati un sito web, un canale YouTube e una newsletter. Inoltre, è stata organizzata una serie di conferenze a pranzo su strumenti, modelli e dimostratori. Con i partner della cooperazione sono stati programmati workshop periodici su argomenti specifici (in base all'interesse espresso nell'indagine sulle parti interessate). Sono stati pubblicati circa 20 articoli peer-reviewed e sono state fatte diverse presentazioni a conferenze ed eventi legati all'energia. Infine, è stato aggiornato il piano di gestione dei dati.

1 Consortium’s objectives

The main objectives are threefold:

1. **Improving performance:** Identify synergies and trade-offs between efficiency, resilience, cost-competitiveness, and sustainability of the Swiss energy system.

2. **Enabling flexibility:** Assess flexibility options across various sectors and along various spatiotemporal scales to integrate renewable energy.

3. **Fostering sector coupling:** Evaluate technologies, business models, innovation strategies, policies and end-user acceptance for sector coupling.

The expected outcomes are:

- **Feasible pathways:** Pathways for the energy transition at international, national to city and district scales that enhance flexibility and sector coupling.

- **Planning and operation tools:** Tools for planning and operation of distributed flexibility in multi-energy systems.

- **Pilot and demonstration projects:** Pilot and demonstration (P&D) projects of different flexibility market designs for existing and new technologies.

- **Identifying new business opportunities and innovation strategies:** New business opportunities and innovation strategies to exploit novel flexibility and sector coupling options.

- **Analysis of potential policies:** An analysis of potential policies for the energy transition and decarbonization of the Swiss energy system.

2 Status of the work packages

WP n°	WP title	Status *(X as appropriate)*					
		Previously completed: Final report published on ARAMIS	Completed during the reporting period (RP): Final report submitted to be reviewed	Ongoing: Progress & next steps to be reviewed	Starting during the next RP: First steps to be reviewed	New: Proposal and budget to be reviewed and approved; notes to be reviewed	Starting after the next RP: not yet reviewed
1	Pathways on national and international scale			X			
2	Pathways on district and city scale			X			
3	Technology and model development			X			
4	Test market designs for existing technologies (P&D project)					X	
5	Test new technologies for flexible use (P&D project)					X	
6	Business opportunities and innovation strategies			X			
7	Policies for sector coupling and enhanced flexibility						X
8	Management and coordination			X			
9	Knowledge and technology transfer			X			
10	Integration and synthesis			X			

3 Work performed and results of ongoing work packages

3.1 WP 1

Title	Pathways on national and international scale			
Actual start	05/2021		**End**	04/2026
TRL range	**Starting at**	3	**Ending at**	5
WP leader	Stefan Pfenninger, TU Delft, **s.pfenninger@tudelft.nl**			
Members and coop. partners	André Bardow, ETH Zurich Marco Mazzotti, ETH Zurich Martin Rüdisüli, Empa Giovanni Sansavini, ETH Zurich Christian Schaffner, ETH Zurich Ingmar Schlecht, ZHAW Evelina Trunevyte, UNIGE Christian Winzer, ZHAW			
Objectives				
1. Quantify large-scale energy scenarios for Switzerland embedded within its European context 2. Understand trade-offs between different Swiss pathways 3. Deliver methodological advances in multi-level modelling				

Work performed and results

Context:

The ongoing uncertainty about the participation of Switzerland in the European electricity market is being considered in the development of scenarios, and was considered in the initial efforts in linking Euro-Calliope and Nexus-e (T1.1 - T1.2).

T1.1 Scenarios and objectives on an international scale

a. Work performed and methods used:

The Euro-Calliope model was further developed to represent all energy-using sectors across all of Europe in preparation to model scenarios. Large scale energy storage technologies relevant for the European context were identified for implementation in Euro-Calliope. The potential of bioenergy with CO2 capture and storage (BECCS) was assessed for European countries with a 1 km resolution.

b. Intermediate results:

A first set of Europe-wide scenarios is published in Pickering et al. (2022). To expand potential design options, storage, and sector-coupling potential for Euro-Calliope is underway. High resolution and country-specific data on the potential of BECCS for European countries were generated and made available in Zenodo and as a spreadsheet.

c. **Contribution to WP, other WPs, and overall project objectives:**

The preliminary results contribute mainly to the first objective of WP 1. The results provide the European context within which Swiss decisions happen and quantify this context to the extent that the more detailed Swiss work can use it as input, in WPs 2 and 3.

d. **Contribution to the deliverables:**

The preliminary results conducted in this task contribute to D1.1.1, D1.1.2 and D1.1.3. The first deliverable (D1.1.1) deals with modelling scenarios for Switzerland embedded in Europe using Euro-Calliope. The second deliverable (D1.1.2) deals with the quantification of the demand shifting and storage potentials across Europe as input to Euro-Calliope, while the third deliverable (D1.1.3) aims to provide techno-economic assessment of value chains connecting Swiss and European bioenergy production, and direct air capture sites with CO2 permanent storage sites. However, no deliverables have yet been completed during the reporting period.

e. **Significance of results:**

The first significant policy conclusion is that from a geopolitical perspective, only a few European countries are able to reach or exceed their carbon dioxide removal (CDR) needs via BECCS. Thanks to large existing BECCS point sources, Switzerland could mitigate just above 5% of its emissions with domestic biogenic CDR. The second conclusion is that a wide range of climate-neutral energy systems are equally feasible Europe-wide, so Swiss decision-making should remain adaptive (Pickering et al., 2022).

T1.2 Detailed pathways on a national scale

a. **Work performed and methods used:**

Coordination among the existing Nexus-e modelling framework and the planned additions (i.e., industry, transportation, and gas) were ongoing to conceptualize and begin the integration of these new models within the Nexus-e platform. Regarding these new models themselves, each have made progress in their developments towards use as part of the Nexus-e platform. Related to gas infrastructure, the role of hydrogen as seasonal storage medium was investigated from Swiss and European perspectives using an optimization-based approach. Related to industry, the transition to net-zero chemicals via carbon capture and utilization (CCU) and the Swiss heating sector is partly integrated into the SecMOD framework, which will be also coupled with Nexus-e.

b. **Intermediate results:**

The Euro-Calliope and Nexus-e model connection was tested with an initial set of net-zero scenarios, including current, reduced, and expanded Swiss net transfer capacities (NTCs) as well as the option of maintaining a balanced annual trade flow. These preliminary results are still being evaluated. Regarding the potential of hydrogen in Switzerland and Europe, while several European countries install large hydrogen storage capacities, the role of hydrogen storage in the Swiss electricity system is minor. Related to industry, decarbonization of the industrial heat is challenging due to temperature requirements. The chemical industry might transition last relative to other sectors.

c. **Contribution to WP, other WPs, and overall project objectives:**

The preliminary results contribute mainly to the second objective of WP 1. Advances were made in Nexus-e and its connection with Euro-Calliope, which assess the European and Swiss decarbonization pathways of WP 1. The work in this task delves into the details of the Swiss system utilizing the context of the European developments from T1.1. Furthermore, the task contributes to the overall objectives of sector coupling and flexibility resolution.

d. **Contribution to the deliverables:**

The preliminary results conducted in this task contribute to D1.2.1, D1.2.2, D1.2.3, and D1.2.4. The first three deliverables (D1.2.1, D1.2.2, D1.2.3) deal with the planned additions to Nexus-e (i.e., industry, transport, and gas), while the latter two deliverables (D1.2.3, D1.2.4) deal with the connection to and simulation with Euro-Calliope. The incorporation of the heating sector and CCU into SecMOD contribute to D.1.2.1. The conceptualization and initial modelling of the Swiss transport sector contributes to D1.2.2, and D1.2.3 assesses the role of the Swiss gas network in flexibility provision. However, no deliverables have yet been completed during the reporting period.

e. **Significance of results:**

Initial simulation results of the combined Euro-Calliope and Nexus-e frameworks indicate the transition to a net-zero GHG emissions Switzerland could pose minimal additional costs under ideal policy conditions. However, the restriction of cross-border trading or the requirement for a balanced annual electricity trade could significantly increase the negative impacts of a net-zero GHG emissions Swiss electric power system. The use of hydrogen as an electricity storage medium within Switzerland was found to be economically attractive only when significant amounts of load shedding led to times of very high wholesale electricity prices in Switzerland. Related to gas infrastructure, power-to-gas could help address the heightened seasonality of Swiss generation and demand, and improve the economics and security of supply in the case of limited cross-border transfer. Power-to-gas might also be necessary for the decarbonization of high temperature heat, e.g., in the industry sector.

T1.3 Multi-level methods to link models and depict cross-scale interactions

a. **Work performed and methods used:**

A concept of locational price signals as price adders was developed to incentivize local flexibility. The frictionless energy data tool was developed to create and validate data packages in order to support conversion to/from the IAMC format. Furthermore, the bilevel optimization as multi-level modelling approach was implemented.

b. **Intermediate results:**

Strategic bidding incentives resulting from a zonal market with nodal redispatch, such as inc-dec gaming (Hirth & Schlecht, 2020), were modeled using the General Algebraic Modeling System (**GAMS**). Furthermore, the frictionless energy data tool is fully documented in **GitHub**. Also, a first application of the bilevel optimization is published in Leenders et al. (2022).

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results contribute mainly to the third objective of WP 1. The bilevel optimization is a potential method to connect scales (e.g., national and regional scale) and thus to link the WPs 2 and 3.

d. Contribution to the deliverables:

The preliminary results conducted in this task contribute to D.1.3.1, which deals with algorithms and methods for surrogate modelling to represent decisions at the finer scales, which will be implemented in multi-level (national to regional level) and multi-sector models used in the project. However, no deliverables have yet been completed during the reporting period.

e. Significance of results:

Inc-dec problems are one of the key barriers to unlocking local flexibility of prosumers. Bilevel optimization cannot be performed by out-of-the-box solvers and specialized solution algorithm need to be applied.

3.2 WP 2

Title	Pathways on district and city scale			
Actual start	05/2021		**End**	04/2026
TRL range	**Starting at**	3	**Ending at**	6
WP leader	Turhan Demiray, ETH Zurich, demirayt@fen.ethz.ch Adamantios Marinakis, ETH Zurich, marinakis@fen.ethz.ch			
Members and coop. partners	Yaman C. Evrenosoglu, ETH Zurich Gabriela Hug, ETH Zurich Giovanni Sansavini, ETH Zurich Binod Koirala, Empa Philipp Heer, Empa Kristina Orehounig, Empa Mohammad Khosravi, Empa Willy Villasmil, HSLU Philipp Schütz, HSLU			
Objectives				
1. Determine an optimal pathway to a renewable flexible energy system at local/regional level 2. Enable the holistic utilization of distributed and abundant flexibility, stemming from energy carriers 3. Propose optimal infrastructure expansion and operational strategies for Swiss local energy utilities				

Work performed and results

T2.1 Definition of scenarios and stakeholder objectives

a. Work performed and methods used:

A set of the most prominent stakeholders, and their objectives and/or KPIs (both listed below) were identified. This information will be consolidated in a workshop with the cooperation partners involved in the project on 7 July 2022. An additional objective of this workshop is to identify appropriate use-cases, and potential willingness of the various distribution utilities to share real or representative data of their systems.

b. Intermediate results:

The identified stakeholders are: gas & electricity utilities, district heating network owners, distribution grid owners & operators, (small-scale) energy producers and individual consumers, site or building management companies / systems, charging stations (e.g., parking lots, large-scale), traders, aggregators, policymakers (i.e., SFOE).

The identified stakeholder objectives and/or KPIs are: self-consumption for sites or districts, decrease in payback time of DER assets, grid / infrastructure utilization, system reliability, reduction in investment costs, overall energy system efficiency, CO_2 targets (emissions), low energy prices & tariffs, flexibility (type, resource, purpose), cross-vector utilization, renewable penetration level, electric vehicles (EVs) penetration level.

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results contribute mainly to the first objective of WP 2. This task aims at building the basis for the analysis, which is to be performed in WP 2. Precisely, a comprehensive list of entities (i.e., stakeholders) acting in the context of local (i.e., city- or district-scale) multi-energy systems will be identified. The objectives and/or KPIs based on which each of these entities take decisions (i.e., investment or operational) will be collected. Finally, a set of use cases will be identified that will form the reference (or archetype) “test systems” to which the various methods developed in WP 2 will be applied in order to derive recommendations.

d. Contribution to the deliverables:

The scheduled workshop will contribute to D2.1.1, which summarizes the stakeholder objectives, use cases, and future scenarios. However, no deliverables have yet been completed during the reporting period.

e. Significance of results:

Close collaboration with industry stakeholder aims to understand their objectives and KPIs, and also identify potential use cases. These insights are used to develop local scale (i.e., city, village, district, site) scenarios for achieving high energy system efficiency.

T2.2 Identification and quantification of local demand and the flexibility potentials at the end-user side

ST 2.2.1 Residential and commercial end-users

a. Work performed and methods used:

The modelling of the heating and cooling profiles (time series) was initiated. Based on simplified building models, three different procedures were developed. Firstly, a model estimating lumped building properties based on public building information was developed (mostly from the Swiss federal register for buildings and dwellings). Secondly, the building parameter estimation of the first approach was refined to provide the input required to run fast dynamic simulations with the Retrosim simulation framework (Schuetz et al., 2018). Thirdly, a method that determines the building modelling parameters based on (historic) measurements of the building was generated. The aim of all three models is to forecast a time series of the thermal demand of a building to maintain a quasi-constant room temperature. The advantage of the first two models is that they only require the address of a building to provide a first estimate, while the third model requires actual measured data. The third model typically provides more accurate forecasts because it does not rely on potentially faulty public data, but actual measurements of the system dynamics. The predictions for the annual space heating demand of the individual models are currently validated with measurements data from a Swiss city energy provider, and with the public heat consumption data from the canton of Geneva.

b. Intermediate results:

Three different methods were developed to estimate heating and cooling loads for residential and commercial buildings. These methods can be easily applied on data available to utilities and communal offices, enabling the modelling of forecasts with actual consumption data. The developed forecasting methods were applied on measurement data from a Swiss city and the canton of Geneva. The first results of this application validate the accuracy of the forecast of heating and cooling demand buildings.

c. **Contribution to WP, other WPs, and overall project objectives:**

The preliminary results contribute mainly to the second objective of WP 2, which will quantify the flexibility potentials of residential and commercial end-users. For WP 3, the derived demand profiles will elucidate the limitations for the (aggregated) load profiles when examining the impact of different storage and flexibility technologies. For the overall project, the results will help define the boundary conditions for flexibility potential, and provide models for estimating flexibility in different scenarios.

d. **Contribution to the deliverables:**

The heat and cooling demand profiles of residential and commercial buildings contribute to deliverable D2.2.2, which deals with the identification and quantification of flexibility resources. However, no deliverables have yet been completed during the reporting period.

e. **Significance of results:**

Space heat and cold provision are responsible for a large share of the energy consumption. Therefore, an accurate prediction of the heat and cold demand helps to operate energy efficiently and to increase the share of renewable energy.

ST 2.2.2 Transportation

a. **Work performed and methods used:**

The transportation sector is examined from two perspectives. Firstly, from the viewpoint of EV owners, and secondly, from the perspective of EV supply equipment (EVSE) and charging station owners. The primary focus is on the first perspective. To obtain a formulation suitable for real-world scenarios, the problem was tackled in three steps with an incremental generalization: (i) deterministic perfect information case, (ii) stochastic perfect information case, and (iii) stochastic imperfect information case. A deterministic receding horizon optimization problem for EV charging at multiple locations and sites was formulated in the first phase. The proposed decision-making framework was extended to the scenarios where information on electricity price, consumption, and other factors is provided in the form of probability distributions rather than accurate knowledge. In the next phase, learning theory and robust optimization techniques are used to obtain a flexible, resilient, and robust formulation of the problem. A similar line of arguments is proposed for formulating the problem from the perspective of EVSE owners.

b. **Intermediate results:**

A deterministic receding-horizon formulation was developed to optimize EV charging / discharging over multiple locations using learning theory and robust optimization approaches. The viewpoint of EVSE owners can be framed similarly, with analogous considerations.

c. **Contribution to WP, other WPs, and overall project objectives:**

The preliminary results contribute mainly to the second objective of WP 2. In connection with the Pilot and Demonstration (P&D) projects, the site in Zug (identified by WP 5) is the potential candidate for the design orientation and implementation testbed. However, the final site selection will be made once the P&D projects are accepted.

d. Contribution to the deliverables:

The preliminary results conducted in this task contribute to D2.2.2, which documents the developed algorithms. However, no deliverables have yet been completed during the reporting period.

e. Significance of results:

By providing EV owners with automated and near-optimal decision-making charging policies, EVs and their installed batteries will be utilized more efficiently and at a lower cost. As a result, a decrease in CO2 emissions can be achieved. Also, the potential of EVs as electricity storage is further utilized, which leads to more flexibility.

T2.3 Planning of multi-energy systems considering uncertainty and utilization of ubiquitous flexibility

ST 2.3.1 Site planning considering multi-energy systems

a. Work performed and methods used:

The Ehub tool was extended through new mathematical formulations for e-mobility. Short term and seasonal energy storage as well as Power-to-X (P2X) is parameterized and implemented. Techno-economic characteristics of conversion technologies and modelling requirements for optimization models are aligned with WP 3.

b. Intermediate results:

The effect of e-mobility, P2X and seasonal storage on supply and demand-side flexibility in the multi-energy system was demonstrated through multi-objective optimization. It was concluded that P2X with seasonal storage is economically feasible in multi-family houses only for autarkic scenarios.

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results contribute mainly to the second objective of WP 2, which aims to develop methods and tools to identify appropriate system design options considering flexibility stemming from multiple energy carriers.

d. Contribution to the deliverables:

The preliminary results conducted in this task contribute to D2.3.1. Flexibility from P2X and EVs is expected to be an important element of site planning of multi-energy systems from building to district scale. However, no deliverables have yet been completed during the reporting period.

e. Significance of results:

H2 storage in multi-family houses can manage seasonal imbalance in energy demand, leading to flexible / autarkic energy system. Currently, vehicle-to-grid (V2G) is an attractive solution in a cost optimization scenario over a CO2 optimization scenario, but may change with increasing share of renewables.

3.3 WP 3

Title	Technology and model development			
Actual start	05/2021		**End**	04/2025
TRL range	**Starting at**	3	**Ending at**	5
WP leader	Philipp Heer, Empa, philipp.heer@empa.ch Massimo Fiorentini, Empa, massimo.fiorentini@empa.ch			
Members and coop. partners	Christian Peter, PSI, Felix Büchi, PSI Mario Paolone, EPFL Kristina Orehounig, Empa Willy Villasmil, HSLU			
Objectives				
1. Develop and implement methodologies for the decentralized control of coupled energy networks and for online control of districts 2. Develop technologies such as high-capacity seasonal thermal storage technologies, advanced thermal management of Power-to-X, Carnot Batteries for the Swiss context 3. Model H2/O2 to H2/air hydrogen and thermal energy storage, sector coupling technologies, and borehole thermal energy storage 4. Experimental validation with EPFL Smart Grid campus infrastructure, PSI ESI demonstrator, Empa Ehub, NEST and move platforms				

<u>**Work performed and results**</u>

Context:

Energy flexibility is key in achieving a higher level of renewable energy generation penetration in modern energy systems. However, the quantification of this potential at technology level, ultimately providing the service, needs to be appropriately understood and modelled to be able to fully exploited.

T3.1 Extension of the technology portfolio

a. **Work performed and methods used:**

A shared workflow was established with WP 2 for the development of the parameters and metrics defining the flexibility of technological setups, and integration of technologies within the ReMaP platform. The Energy Systems Integration (ESI) demonstrator of PSI was connected to ReMaP, and the workflow for also connecting the Smart Grid demonstrator of EPFL was established. An optimization framework to aggregate power and energy flexibilities in an interconnected power distribution system was developed, and is used to compute the day-ahead dispatch plans of multiple and interconnected distribution grids operating at different voltage levels. The dispatching problem is formulated as a stochastic-optimization scheme considering uncertainty, and solved by a distributed optimization method. Novel concepts for high-capacity seasonal thermal energy storage for buildings were investigated both numerically with in-house simulation models, and experimentally with lab-prototypes built at HSLU.

b. **Intermediate results:**

The ESI demonstrator was successfully connected to ReMaP, demonstrating that remote control to achieve load shifting could be implemented on the experimental setup. An optimization framework was developed, showing the ability to enable a decentralized dispatch computation where the centralized aggregator is agnostic about the parameters / models of the participating resources and down-stream grids (Gupta et al., 2022). Short-term stability of materials for seasonal thermal energy storage was demonstrated at lab-scale at HSLU.

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results contribute mainly to the first and fourth objectives of WP 3. The development of technological setups, and integration of demonstrators in ReMaP is supporting directly the work of WP 2, which will demonstrate the exploitation of energy flexible resources at design stage and in real-time operation.

d. Contribution to the deliverables:

The preliminary results conducted in this task contribute to D3.1.1.1, D3.1.1.2, and D3.1.2. The development and optimization of thermal energy storage systems conducted by HSLU in close collaboration with the industry contributes to D3.1.1.1. Developments on the technology flexibility quantification and modelling, together the integration of the PSI and EPFL demonstrators with ReMaP contribute to D3.1.1.2. The experimental work conducted by PSI contributes to the modelling activities of T3.2, and deliverable D3.2.1. However, no deliverables have yet been completed during the reporting period.

e. Significance of results:

The work carried out in this task enables the use of energy flexibility at technological level, and through the implementation in the ReMaP platform. The aim is to demonstrate that these solutions are achievable not only in a design phase, but also in operation in a realistic setting. The technological implementation will be studied in a local scale (i.e., village, city, district) by WP 2, and upscaled to national scale by WP 1.

T3.2 Model development for integrated systems (power & heat)

a. Work performed and methods used:

The coordination with WP 2 was prioritized to determine the modelling parameters and requirements. Two categories of modelling approaches were identified: (i) high-fidelity models that closely emulate the real behaviour of technologies, and are implemented in the ReMaP platform, as well as (ii) optimization-oriented models that are included in either site- or national-scale design tools, or in control optimization methods. A work plan to implement case study setups in ReMaP from each research partner has also been developed. At PSI the system identification of a 100 kW H2/O2 PEM fuel cell system was carried out. The resulting system model was validated and can be used for optimal control or system design purposes.

b. Intermediate results:

Modelling parameters and requirements were defined, as well as the platform and methodology for implementation. Working documents were completed to exchange techno-economical model parameters with other WPs. The fuel cell system model of PSI (Peter et al., 2022) was validated. The component and systems models of HSLU were developed, and experimentally validated to allow assessing the techno-economic feasibility of sensible and latent seasonal thermal energy storage systems in WP 2.

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results contribute mainly to the second and thirds objectives of WP 3. The models developed contribute to WP 2 to achieve an accurate estimation of optimal system, and inform the national-scale modelling in WP 1.

d. Contribution to the deliverables:

The modelling of technologies undertaken in this task contribute to D3.1.1.1, and D3.1.1.2, which include techno-economic simulation models of thermal energy storages, as well as the integration of model libraries in ReMaP. The modelling activities conducted by PSI contribute to D3.2.1, which deals with experimental data for parametrization of electrolyser and fuel cell systems. However, no deliverables have yet been completed during the reporting period.

e. Significance of results:

Peter et al. (2022) reported fundamental data on the efficiency, and dynamics of the Power-to-Gas-to-Power technologies, crucial to assess the flexibility potential of such technologies.

3.4 WP 6

Title	Business opportunities and innovation strategies			
Actual start	05/2021		**End**	04/2026
TRL range	**Starting at**	-	**Ending at**	-
WP leader	Christof Knoeri, ETH Zurich, **cknoeri@ethz.ch** Jochen Markard, ZHAW, **jmarkard@ethz.ch**			
Members and coop. partners	Volker Hoffmann, ETH Zurich			
Objectives				
1. Systematically map potential disruptions and business interests 2. Identify coordination challenges and strategies to address them 3. Develop new insights and tools to support strategic decision-making at the firm level				

<u>**Work performed and results**</u>

Context:

There are two important developments in the broader context relevant for work in WP 6. The first is about an increasing number of net-zero commitments at the level of countries, cities (e.g., the recent decision in Zurich to become carbon neutral in 2040), and companies. These targets are a game changer for decarbonization efforts because it will not be sufficient to focus on the "usual" sectors, such as energy and transport, but to also include sectors such as aviation, cement or chemicals that are very difficult to decarbonize. The second is the war on Ukraine, which has brought geopolitical issues and energy security back on the policy agenda. This brings major repercussions on the future use of natural gas and increasing efforts to ramp up the deployment of renewable energy technologies.

T6.1 Transition pathways, disruption and business interests

a. **Work performed and methods used:**

The analysis and coding of position papers, newspaper articles, and policy documents, as well as expert interviews mapped the position of industry actors regarding the production, import and use of hydrogen in electricity, transport, heating and industry. A similar analysis was conducted for phase-out policies, and a theoretic concept was developed.

b. **Intermediate results:**

A first result is the analysis of support for hydrogen in Germany (i.e., one of the European leaders for an ambitious hydrogen strategy) by actors from a broad range of industries. Emerging conflicts about whether to produce H2 from renewables only or also to include natural gas was evaluated.

c. **Contribution to WP, other WPs, and overall project objectives:**

The preliminary result contributes mainly to the first objective of WP 6. It provides first insights into industry / firm interests and positions. It also includes conceptual foundations from transition theory: net-zero as a multi-sector, multi-technology, and multi-transition endeavour with increasing complexity for policymaking. The insights are used as input in all WPs, mainly in WP 7.

d. Contribution to the deliverables:

The preliminary result conducted in this task contributes to D6.1.1, where one concept paper, and three journal papers (a **published paper**, a **viewpoint**, and a **policy brief**) were produced. In addition, one paper was submitted, two papers and two book chapters are in preparation.

e. Significance of results:

In terms of policy, low-carbon electrification is a dominant strategy for the current phase (phase 3: transformation across systems) of the net-zero transition. There is increasing complexity for policy making due to X-departmental coordination. H2 is a key strategy for phase 4 (difficult-to-decarb. industries). Regarding science, first concepts / ideas to capture multi-transition dynamics are needed.

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

a. Work performed and methods used:

Data of 125 green hydrogen valley projects were collected from the "The Fuel Cells and Hydrogen Joint Undertaking" (FCHJU) database. A systematic analysis was performed using a set-analytic / configurational method (fsQCA) to identify specific phenotypes of collaboration in green hydrogen projects. Also, 20 semi-structured interviews were conducted with industry experts, and project partners to validate the typology, and understand how specific types work.

b. Intermediate results:

A typology with five specific types of collaboration was developed, distinguishing between mega projects, demonstrator projects, commercial projects, localized projects, and small international R&D projects. Each type builds on specific pre-existing relationships (i.e., trust, skills) and requires different governance structures. The collaborative types have different functions in the industrial transformation towards a more sustainable industry.

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results contribute mainly to the second objective of WP 6. The insights are relevant to T6.1 in understanding cross-sectoral collaboration as an underlying mechanism in the transition. Insights from the firm perspective in implementing hydrogen projects along the entire value chain (i.e., generation, transmission, application, storage) contribute to WP 3 for technology and model development.

d. Contribution to the deliverables:

The preliminary results conducted in this task contribute to D6.2.1., where one Master thesis was completed, and will be presented at an academic conference (in June 2022). Furthermore, one paper will be published, and one paper will be submitted to a peer-reviewed journal (planned for July 2022).

e. Significance of results:

First insights into cross-sectoral collaboration, and the conditions under which they allow for successful innovation between firms across the (green hydrogen) value chain was provided. Also, changes in existing value chains (industries) with the emergence of new value chains (hydrogen) are being analysed.

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

a. Work performed and methods used:

An in-depth case study of Enel X, a business division of Enel responsible for innovative solutions in the energy industry, was evaluated. The case study focuses on the implementation of a smart city approach. 29 interviews with Enel X experts and customers (i.e., municipalities) were conducted. Inductive coding of interviews was performed, and a framework with features in the emergence of cyber-physical platforms was developed.

b. Intermediate results:

First results show that cyberphysical platforms combine digital platform technologies with physical technologies, starting in the energy field, and moving beyond energy into other fields (e.g., mobility, and health). As a new integrative technology, cyberphysical platforms are subject to specific R&D and competitive factors. They span across industries and sectors, and offer new business opportunities that not only accelerate the energy transition but also require particular skills to recognize these opportunities.

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results contribute mainly to the third objective of WP 6. The insights are relevant to WP 2 (i.e., pathways at district and city scale) by focusing on the realization of a smart city emerging from energy. Also, relevant to T6.2 by offering insights into the increasing interconnectivity among sectors and technologies.

d. Contribution to the deliverables:

The preliminary results conducted in this task contribute to D6.3.1., where one Master thesis was completed, and presented at various academic and industry conferences (i.e., ETH Energy Week, Enel X Symposium, Academy of Management). Furthermore, one paper will be submitted to a peer-reviewed journal (planned for July 2022).

e. Significance of results:

So far, only limited attention was given to cyberphysical platforms despite their importance for the energy transition. Success factors for developing and using platforms commercially need to be identified. Challenges in cross-sectoral collaboration are predictable.

3.5 WP 10

Title	Integration and synthesis			
Actual start	05/2021		**End**	04/2027
TRL range	**Starting at**	-	**Ending at**	-
WP leader	André Bardow, ETH Zurich, **abardow@ethz.ch** Christian Schaffner, ETH Zurich, **schaffner@esc.ethz.ch**			
Members and coop. partners	Philipp Heer, Empa Ingmar Schlecht, ZHAW Christian Winzer, ZHAW			
Objectives				
1. Integrated scenarios 2. Synthesis view of the consortium 3. Two P&D proposals				

Work performed and results

T10.1: Integrated scenarios

a. Work performed and methods used:

Two main activities were conducted: The first activity was to define the concepts of flexibility, sector coupling, and sustainability to be used throughout the PATHFNDR consortium. The definitions are summarized in a report providing a brief description for each concept, quantitative metrics, and its relationship to WPs 1, 2, 3, 6, and 7. The content is based on a review of the existing literature.

The second activity was to define the scenario dimensions (variables that directly influence energy demand or supply and on which policy makers or citizens can exert influence) and the scenario uncertainties (variables on which policy makers or citizens have less influence). In the scenario dimensions, a total of five dimensions were identified (i.e., policy, social, technological, geopolitical, and environmental), each consisting of a set of variables and their quantification. The dimensions form the building blocks for constructing the scenarios to be assessed in PATHFNDR.

Regarding the scenario uncertainties, uncertainty ranges were defined for the following parameters: population, GDP, energy demand, climate change, and its influence on space heating demand and hydropower, and resource potentials. The definition of the scenarios was closely coordinated with SWEET-CROSS to ensure that the analysis in PATHFNDR is comparable and complements the work of the other SWEET consortia.

b. Intermediate results:

A technical report on the consortium-wide definitions and metrics for flexibility, sector coupling, and sustainability is in preparation and will be published in an open access archive. The content will also be synthesized, and form the basis for T10.2. In addition, a technical report on the consortium-wide scenarios, including the description of the dimensions and variables, is in preparation and will also be published in an open access archive. The scenarios form the basis for work to be conducted in WPs 1, 2, and 3.

c. **Contribution to WP, other WPs, and overall project objectives:**

The preliminary results mainly contribute to the first objective of WP 10. However, the results will be used in all work packages, and serve as a basis for the assessment of scenarios / pathways at national to local scale.

d. **Contribution to the deliverables:**

The preliminary results conducted in this task contribute to D10.1.1, and D10.1.2. Both deliverables are technical reports and currently in preparation.

e. **Significance of results:**

The technical reports serve both as a basis for evaluating scenarios / pathways, and as documentation of PATHFNDR's position on the concepts of flexibility, sector coupling, and sustainability. Establishing a common understanding of the key concepts is important for the consistency of the future work in PATHFNDR.

T10.2: Synthesis view of the consortium on the research challenge

a. **Work performed and methods used:**

A synthesis view was established among the research institutions for the concepts of flexibility, sector coupling, and sustainability as used in PATHFNDR. For this purpose, two project-wide workshops have been conducted and cross-work package working groups have been established for each topic.

The synthesis view will be exchanged with stakeholders. For this purpose, the preparation of stakeholder interviews / surveys was initiated to collect stakeholder opinions and views. Both the results from T10.1, and the results of the stakeholder interviews and surveys will be summarized in an easy-to-read synthesis report, and published on the PATHFNDR website.

b. **Intermediate results:**

Four groups of stakeholders have been identified for the interviews and surveys: DSO and TSO, regulators and policymakers, consulting firms, and end-users.

c. **Contribution to WP, other WPs, and overall project objectives:**

The preliminary results mainly contribute to the second objective of WP 10, the synthesis view of the consortium. The results will be used to disseminate the knowledge generated by the consortium to the general public.

d. **Contribution to the deliverables:**

The preliminary results conducted in this task contribute to D10.2.1. However, no deliverables have yet been completed during the reporting period.

e. **Significance of results:**

The synthesis of the results will serve as internal document to align the work, and externally to inform the general public of the position / views of the PATHFNDR consortium.

T10.3: P&D proposal for WP 4

a. Work performed and methods used:

The preparation of the WP 4 P&D project outline was initiated. The outline was presented to and discussed with the research team, the project Advisory Board, the Verband Schweizerischer Elektrizitätsunternehmen (VSE) working group, and interested Distribution Systems Operators (DSOs).

b. Intermediate results:

Together with the research team, it was decided to focus on the P&D project on dynamic tariffs, which aims to investigate dynamic tariffs that could enable efficient investment in, and dispatch of flexibility from different sectors. In addition, the project outline was developed based on feedback and interest from potential project partners in the private and public sectors.

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results mainly contribute to the third objective of WP 10. The P&D project proposal could contribute to WP 1, 2, 6 and 7. For WP 1, the tariffs tested in WP4 could help to overcome the inc-dec problem of market-based approaches. For WP 2, the tariffs we test in WP4 could avoid the need for explicit procurement of flexibility, and dispatch and scheduling. For WP 6, a widespread use of dynamic tariffs could open new business models/revenues for flexible loads. For WP 7, a mandatory use of dynamic tariffs could be a possible policy option.

d. Contribution to the deliverables:

The preliminary results conducted in this task contribute to D10.3.1. However, no deliverables have yet been completed during the reporting period.

e. Significance of results:

Dynamic grid tariffs could reduce need for and cost of grid expansion and increase the security of supply.

T10.4: P&D proposal for WP 5

a. Work performed and methods used:

The preparation of the WP 5 P&D project outline was initiated. The outline was presented to and discussed with the research team, the project Advisory Board, and potential academic and industry partners.

b. Intermediate results:

Two project ideas were developed, for which potential collaboration partners, and pilot sites were identified: One project idea is "nanoverbund", and the second project idea is "MEHs Zug", both address shortcomings while simultaneously covering the core aspects of the original tasks. These tasks are:

- The task multi-site BEV (Battery Electric Vehicle) enabled flexibility matured, as described in chapter 3.2 (ST 2.2.2) to better integrate the idea into a P&D format.

- Topics are only loosely tied to the SFOE Project "KiG – Konnektivität im Gebäude". However, the SFOE Project "KiG – Konnektivität im Gebäude" was dropped to focus more on identifying PATHFNDR developments considered in P&D projects.

- Funding for hardware was clarified to allow project ideas to build up on already existing infrastructure or infrastructure to be built outside of the P&D budget. Thus, only minor positions for hardware are expected.

- The less developed topic "Coordinated prosumer side flexibilities for multi-use-case applications" was transformed into the "Nanoverbund", which is discussd in more detail in section 9.1.

c. Contribution to WP, other WPs, and overall project objectives:

The preliminary results mainly contribute to the third objective of WP 10. The P&D project proposal could use the insights generated in WP 2 and 3, as well as contribute to WP 1, 6 and 7. For WP 2, it could provide specific use cases on the utilization of identified sector coupled flexibility, verification data for developed models, and scenarios of the WP. For WP 3, it could deliver questions for case studies on development pathways of the implementation sites. For WP 6 and 7, the specific settings, needs and pains of the involved partners and implementation sites could inform possible policy structures, stakeholder interactions, and market designs to facilitate flexibility use cases that go beyond the scope of WP 5.

d. Contribution to the deliverables:

The preliminary results conducted in this task contribute to D10.4.1. However, no deliverables have yet been completed during the reporting period.

e. Significance of results:

The current mind-set and policy context make operational improvements spanning over more than one stakeholder very difficult to achieve. However, the potential contribution of such cross-stakeholder interaction is large. Cooperation partners show interest in both: (i) how operational improvements should look like, and (ii) how the topic of stakeholder engagement (or bypassing) could be manifested.

3.6 Knowledge and technology transfer

WP leader	Christian Schaffner, ETH Zurich, **schaffner@esc.ethz.ch** André Bardow, ETH Zurich, **abardow@ethz.ch**
Members and coop. partners	Lea Rüfenacht, ETH Zurich, **lea.ruefenacht@esc.ethz.ch**

Work performed and results

The PATHFNDR project kick-off event was held in May 2021 with the research team and participating cooperation partners. Since then, PATHFNDR established communication and dissemination channels to inform about the main objectives of the project, ongoing activities and events, and to transfer data and results generated by the consortium.

A series of recurring lunch talks was launched in May 2021, a public virtual event to present project results and findings. In the first series seven tools / models / software (e.g., Euro-Calliope, ReMaP, SecMOD) were presented. In the second series three demonstrators (e.g., ESI, Smart Grid, Ehub) were introduced. The 30-minutes presentations are recorded and posted on the PATHFNDR website and YouTube channel, and a detailed overview of the tools is provided on the website.

The needs and interests of the Cooperation Partners were collected through a survey. The survey results helped to identify topic-specific workshops, and classify the 25 partners into smaller target / working groups. Specific topics (e.g., planning and operation, scenarios, technologies, policies) will be discussed in each workshop, and exchange activities will be identified.

In terms of internal communication, we established regular exchanges with the Executive Board (i.e., WP leaders), Steering Committee, Advisory Board, and the research team. One project-wide team workshop was held in January 2022, and two further workshops will be conducted in June and September 2022.

a. **Channels and stakeholders:**

The project website publishes information about the project, its main activities and results. Recorded presentations are published on the YouTube channel. Both channels are aimed at the scientific community, industry partners, policymakers, and the general public. Newsletters are sent regularly to subscribers of the PATHFNDR mailing list to provide updates on the project. These updates are also posted on social media managed by the Energy Science Center (ESC), which has approximately 3,000 subscribers.

The project results are published in scientific journals and conference papers, as well as technical reports, most of which are openly accessible. Results will also be summarized in synthesis reports posted on the website, and targeted to the general public. In addition, results are presented at lunch talks, and energy-related events aimed at the scientific community and industry partners. At the Energy Week 2021, an annual event of the Energy Science Center (ESC) with more than 400 participants, three PIs (André Bardow, Gabriela Hug, and Christian Schaffner) presented the objectives and initial resutls of PATHFNDR.

Two types of workshops are being hold: The first workshop is targeted at the research team, and aims to discuss the research results. The second workshop is targeted at Cooperation Partners, and aims to identify the implementation potential implementation potential of the research results.

b. Impact to stakeholders:

Of the 22 (non-academic and industry) Cooperation Partners, 20 participated in the survey, which is a very high participation. Partners expressed interest in specific project objectives, expected outcomes, technologies (for energy conversion, storage, use, and transport), and communication formats (e.g., technical reports, data hub, workshops), as well as their capacity to contribute to the project (e.g., data sharing, test models, review of results, participation in P&D projects). The first workshop on multi-energy systems at local level will be held in June 2022 with 13 partners (i.e., ABB, Amstein Walthert, BKW, Energie 360, EWB, Groupe-E, MAN Energy Solutions, Primeo Energie, Siemens, SVGW, Swiss Grid, VSE, WWZ).

c. Contribution to achieve visibility and impact:

To increase the visibility of the project, the website and YouTube channel are updated monthly, and newsletters and social media posts are shared regularly to keep subscribers informed. In addition, PATHFNDR members present project goals and results at energy-related industry and academic events (e.g., Energy Week @ ETH, EnelX Symposium). To foster exchange between PATHFNDR researchers, international academic partners, and industry partners, workshops are held approximately two to three times per year. Furthermore, technical and synthesis reports are published in open access repositories, and on the website.

d. Contribution to deliverables:

The results obtained for KTT contribute to D9.2.1, D9.2.2, D9.3.1, D9.3.6, and D9.3.7. In deliverable D9.2.1, a project **website** was established, and is online. In deliverable D9.2.2, a **toolbox** was published on the website describing a total of seven tools / models (i.e., Calliope, CESAR-P, Ehub, EXPANSE, Nexus-e, ReMaP, SecMOD) used in PATHFNDR. In deliverable D9.3.1, project members participated in various energy-related events to present PATHFNDR objectives. In addition, several workshops are planned with industry partners to link research and practice challenges and opportunities. In deliverable D9.3.6, the ESC **LinkedIn**, and **Twitter** accounts are used to post news about PATHFNDR. Furthermore, a **YouTube** channel has been established to post presentations / lectures given by project members. In deliverable D9.3.7, a **newsletter**, and mailing list were created to inform currently approximately 200 subscribers of new PATHFNDR activities.

e. Updates in KTT plan and data management plan:

There are no significant updates in the KTT plan. The data management plan (DMP) was updated with regard to data documentation (including metadata standards), and data sharing (including storage resources, and access rights). In addition, data management from PATHFNDR and CROSS was aligned. The updated DMP is still a draft that has to be approved by the Executive Board and PIs (see **appendix 1**).

4 Outreach & outputs during the reporting period

The work published in the following publications was partially funded by PATHFNDR and initiated before the project start.

Peer-reviewed publications

Members and coop. partners	**Description:** author(s), title, journal or type of publication, year of publication	**doi**
Empa	Eggimann, S., Vulic, N., Rüdisüli, M., Mutschler, R., Orehounig, K., & Sulzer, M., **Spatiotemporal upscaling errors of building stock clustering for energy demand simulation,** Energy and Buildings, 2022.	**10.1016/J.ENBUILD.2022.111844**
ETH Zurich	Gjorgiev, B., Garrison, J.B., Han, X., Landis, F., van Nieuwkoop, R., Raycheva, E., Schwarz, M., Yan, X., Demiray, T., Hug, G., Sansavini, G., & Schaffner, C., **Nexus-e: A platform of interfaced high-resolution models for energy-economic assessments of future electricity systems,** Applied Energy, 2022.	**10.1016/j.apenergy.2021.118193**
ETH Zurich	Gjorgiev, B., David, A.E., & Sansavini, G., **Cascade-risk-informed transmission expansion planning of AC electric power systems**, Electric Power Systems Research, 2021.	**10.1016/j.epsr.2021.107685**
ETH Zurich	Leenders, L., Hagedorn, D. F., Djelassi, H., Bardow, A., & Mitsos, A., **Bilevel optimization for joint scheduling of production and energy systems,** Optimization and Engineering, 2022.	**10.1007/s11081-021-09694-0**
ETH Zurich, TU Delft	Pickering, B., Lombardi, F., & Pfenninger, S., **Diversity of options to eliminate fossil fuels and reach carbon-neutrality across the entire European energy system**, Joule, 2022	**10.1016/j.joule.2022.05.009**
ETH Zurich	Rosa, L., & Mazzotti, M., **Potential for hydrogen production from sustainable biomass with carbon capture and storage,** Renewable and Sustainable Energy Reviews, 2022.	**10.1016/j.rser.2022.112123**
ETH Zurich	Gjorgiev, B., Sansavini, G., **Identifying and assessing power system vulnerabilities to transmission asset outages via cascading failure analysis**, Reliability Engineering & System Safety, 2021.	**10.1016/j.ress.2021.108085**
ETH Zurich	Han, X., Garrison, J.B., Hug, G., **Techno-economic analysis of PV-battery systems in Switzerland**, Renewable and Sustainable Energy Reviews, 2022.	**10.1016/j.rser.2021.112028**

ETH Zurich	Meys, R., Kätelhön, A., Bachmann, M., Winter, B., Zibunas, C., Suh, S., & Bardow, A.. **Achieving net-zero greenhouse gas emission plastics by a circular carbon economy,** Science, 2021.	**10.1126/science.abg9853**
ETH Zurich	Rosa, L., Sanchez, D. L., & Mazzotti, M., **Assessment of carbon dioxide removal potential via BECCS in a carbon-neutral Europe,** Energy & Environmental Science, 2021.	**10.1039/D1EE00642H**
Empa	De Koning, J., & Koirala, B.P., **Analysis of a residential power to hydrogen to power system using MILP optimization and the energy hub concept**, International Energy Workshop, May 25-27, 2022.	-
Empa	Koirala, B.P., Mutschler, R., Bartolini A., Bollinger A., & Orehounig K., **Flexibility assessment of E-mobility in multi-energy systems**, CIRED workshop on E-mobility and power distribution systems, June 2-3, 2022.	-
HSLU	Barahona, B., Buck, R., Okaya, O., & Schuetz, P., **Detection of thermal anomalies on building façades using infrared thermography and supervised learning,** Journal of Physics: Conference Series, 2021.	**10.1088/1742-6596/2042/1/012013**
HSLU	Melillo, A., Linder, E., Barahona, B., & Schuetz, P., **Statistical analysis of 200 digital twins for thermal load of Swiss buildings created from smart grid monitoring data.** Journal of Physics: Conference Series, 2021.	**10.1088/1742-6596/2042/1/012009**
HSLU	Villasmil, W., Troxler, M., Hendry, R., Schuetz, P., & Worlitschek, J., **Control strategies of solar heating systems coupled with seasonal thermal energy storage in self-sufficient buildings,** Journal of Energy Storage, 2021.	**10.1016/j.est.2021.103069**
HSLU	Villasmil, W., Troxler, M., Hendry, R., Schuetz, P., & Worlitschek, J., **Parametric Cost Optimization of Solar Systems with Seasonal Thermal Energy Storage for Buildings,** E3S Web of Conferences, 2021.	**10.1051/e3sconf/202124603003**
EPFL	Gupta, R., Fahmy, S., & Paolone, M., **Coordinated Day-ahead Dispatch of Multiple Power Distribution Grids hosting Stochastic Resources: An ADMM-based Framework,** Proceedings of the 22nd Power Systems Computation Conference, June 27 - July 1, 2022.	-
PSI	Peter, C., Vrettos, E., & Büchi, F. N., **Polymer electrolyte membrane electrolyzer and fuel cell system characterization for power system frequency control,** International Journal of Electrical Power & Energy Systems, 2022.	**10.1016/J.IJEPES.2022.108121**

ZHAW, ETH Zurich	Markard, J., Rinscheid, A., & Widdel, L., **Analyzing transitions through the lens of discourse networks: Coal phase-out in Germany**, Environmental Innovation and Societal Transitions, 2021.	**10.1016/j.eist.2021.08.001**
ZHAW, ETH Zurich	Rinscheid, A., Rosenbloom, D., Markard, J., & Turnheim, B., **From terminating to transforming: The role of phase-out in sustainability transitions**, Environmental Innovation and Societal Transitions, 2021.	**10.1016/j.eist.2021.10.019**

Policy briefs, white papers

Members and coop. partners	**Description:** author(s), title, channel or type of publication, year of publication
ZHAW, ETH Zurich	Markard, J., **Beyond Carbon Pricing: Six sustainability transition policy principles for net zero**, Heinrich Böll Stiftung, Brussels.

Other non-peer-reviewed publications (working papers, press articles, etc.)

Members and coop. partners	**Description:** author(s), title, channel or type of publication, year of publication
ETH Zurich, (Enel X)	Meuer, J., Melegati, G., & Coiro, S., **Moving Beyond Digital Platforms: Exploring the Design and Competitive Dynamics of Cyber-Physical Platforms**, June 2022
ETH Zurich, KIT Karlsruhe, ISI Fraunhofer	Stephan, A., Wildgruber, K., Meuer, J., & Wietschel, M., **Collaborative patterns in the industrial transformation: a study on cross-sectoral technology alliances for a green hydrogen value chain,** June 2022

Public oral and visual presentations (scientific or broad audience)

Members and coop. partners	**Description:** author(s), title, name of the event and location, year of presentation
ZHAW	Winzer, C., Ludwig, P., Schlecht, I., **Approach using locational price signals as price adders**, Verband Schweizerischer Elektrizitätsunternehmen (VSE), December 2021
HSLU	Schuetz, P., **Buildings in the overall system and contribution to net-zero**, Zukunftsregion Argovia Forum, Turgi, April 2022
HSLU	Schuetz, P., **Data-based assessment of retrofitting measures,** Tech outlook 2022, Online, March 2022

HSLU	Schuetz, P., **Examples of energy research**, General Assembly of NELU, HSLU, March 2022
HSLU	Linder, L., **Statistical analysis of 200 digital twins for thermal load of Swiss buildings created from smart grid monitoring data**, CisBAT, September 2021
Empa	De Koning, J., & Koirala, B.P., **Analysis of a residential power to hydrogen to power system using MILP optimization and the energy hub concept**, International Energy Workshop, May 2022
Empa	Koirala, B.P., Mutschler, R., Bartolini A., Bollinger A., & Orehounig K., **Flexibility assessment of E-mobility in multi-energy systems**, CIRED workshop on E-mobility and power distribution systems, June 2-3, 2022
ZHAW, ETH Zurich	Markard, J., **Net-zero as a multi-transition challenge,** IED Seminar, ETH Zurich, April 2022
ZHAW, ETH Zurich	Markard, J., **Sustainability transitions and net-zero,** Invited talk, University of Tokyo, January 2022
ZHAW, ETH Zurich	Ohlendorf, N., Löhr, M., Markard, J., **(Un)usual actor coalitions in a nascent policy subsystem: the case of hydrogen in Germany**, 12th IST Conference, Karlsruhe, October 2021
ZHAW, ETH Zurich	Markard, J., & Rosenbloom, D., **Four phases of the low-carbon energy transition**, 12th IST Conference, Karlsruhe, October 2021
ETH Zurich, (Enel X)	Meuer, J., Melegati, G., & Coiro, S., **Moving Beyond Digital Platforms: Exploring the Design and Competitive Dynamics of Cyber-Physical Platforms**, Academy of Management Meeting, 2021
ETH Zurich, KIT Karlsruhe, ISI Fraunhofer	Stephan, A., Wildgruber, K., Meuer, J., & Wietschel, M., **Collaborative patterns in the industrial transformation: a study on cross-sectoral technology alliances for a green hydrogen value chain**, EGOS, 2022
ETH Zurich, (Enel X)	Coiro, S., **Smart cities at the center of the Energy (R) evolution**, ETH Energy Week, 2020

Completed theses

Members and coop. partners	**Description:** author(s), title, type (master, PhD), year
ETH Zurich	Upadhyay, A.A., Gabrielli, P., Petkov, I., Ganter, A., & Sansavini, G., **Assessment of the role of hydrogen as a long-term storage medium and as a flexibility provider for the European electricity system,** Master thesis, 2022
ETH Zurich	Hässig, S.J., Gabrielli, P., Garrison, J.B., Sansavini, G., **Assessment of the role of hydrogen as a long-term storage medium and as a flexibility provider for the Swiss electricity system,** Master thesis, 2022

ETH Zurich	Andreotti, A., **Assessment of source-to-sink BECCUS value chains in a climate-neutral Switzerland by 2050**, Master Thesis, 2021 (Supervised by Mazzotti, M., Becattini, V., Gabrielli, P., Rosa, L.)
Empa, ETH Zurich	Lienhard, N., **Modelling and Analysis of the Future Energy Supply in Switzerland within the European Electricity System**, Master Thesis, 2021 (Supervised by Mutschler, R., Rüdisüli, M., Leenders, L., Bardow, A.)
ETH Zurich	Wildgruber, K., **Cross-sectoral collaboration for a green hydrogen value chain,** Master Thesis, 2022

5 Updated list of consortium members and cooperation partners

Table 5-1: List of consortium members

Additional members					6 (Massimo Fiorentini, Christof Knoeri, Binod Koirala, Adamantios Marinakis, Christian Peter, Philipp Schütz)		
Previous members (no longer part of the consortium)					3 (Andrew Bollinger, Peter Jansohn, Annegret Stephan)		
N°	**Members**	**Short name**	**Type of organisation**	**Canton or country**	**Language CH region**	**Expertise and contribution**	**Member in other SWEET consortia**
1	Eidgenössische Technische Hochschule Zurich, Energy and Process Systems Engineering, **André Bardow**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: Professor; Consortium Director and PI; WP leader Expertise: energy systems optimization, life cycle assessment, power-to-x Contribution: sector-coupled energy systems modelling, heating sector, industrial sector, national energy system scenarios WP involvement: WP 1 + 10	SWEET CROSS
2	Université de Genève, Psychology of Sustainable Development, **Tobias Brosch**	UNIGE	Institute for higher education	Geneva, Switzerland	French	Role: Associate Professor; Consortium PI Expertise: energy systems modelling,	Call1-2020 EDGE, Call1-2020 SURE

						renewable energy, socio-technical transitions <u>Contribution</u>: energy systems modelling, municipal energy systems scenarios, citizen engagement <u>WP involvement:</u> WP 1 + 7	
3	Paul Scherrer Institute, Electrochemistry Laboratory, **Felix Büchi**	PSI	Research Institute	Aargau, Switzerland	German	<u>Role</u>: Head of Laboratory; Consortium PI <u>Expertise</u>: electrochemical conversion technologies, energy storage on different scales <u>Contribution</u>: hydrogen for energy storage, electrochemical conversion technologies evaluation, storage options assessment <u>WP involvement:</u> WP 3	-
4	Eidgenössische Technische Hochschule Zurich, Research Center for Energy Networks,	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	<u>Role</u>: Director of Center; Consortium PI; WP co-leader	Call1-2020 SURE

	Turhan Demiray					Expertise: multi-energy distribution networks planning, electricity distribution systems operation, electricity markets Contribution: local energy system scenarios, infrastructure planning of multi-energy systems, coordinated utilisation of distributed flexibility resources at the network level WP involvement: WP 2	
5	Eidgenössische Materialprüfungs- und Forschungsanstalt, Laboratory of Urban Energy Systems, **Massimo Fiorentini**	Empa	Research Institute	Zurich, Switzerland	German	Role: WP co-leader Expertise: energy technology modelling, energy system design and operation optimization Contribution: energy technology modelling, energy flexibility quantification, sector coupling, flexibility exploitation WP involvement: WP 3	Call1-2020 DeCarbCH

6	Eidgenössische Materialprüfungs- und Forschungsanstalt, Laboratory of Urban Energy Systems, **Philipp Heer**	Empa	Research Institute	Zurich, Switzerland	German	Role: Deputy Head of Laboratory; Consortium PI; WP co-leader; P&D project leader Expertise: learning based control of energy systems, P&D projects Contribution: ideation of P&D projects WP involvement: WP 3; WP 5 (P&D project)	Call1-2021 LANTERN
7	Eidgenössische Technische Hochschule Zurich, Sustainability and Technology, **Volker Hoffmann**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: Professor; Consortium PI Expertise: innovation, policy making Contribution: policy impact of innovation WP involvement: WP 6 + 7	-
8	Eidgenössische Technische Hochschule Zurich, Power Systems Laboratory, **Gabriela Hug**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: Professor; Consortium PI Expertise: power systems, renewable generation integration	Call1-2020 EDGE

						Contribution: identification of flexibility in demands, monitoring tool for distribution grids WP involvement: WP 2	
9	Eidgenössische Materialprüfungs- und Forschungsanstalt, Laboratory of Urban Energy Systems, **Binod Koirala**	Empa	Research Institute	Zurich, Switzerland	German	Role: Consortium PI Expertise: multi-energy systems, optimization, flexibility, sector coupling Contribution: flexibility assessment, site planning, multi-energy system modelling WP involvement: WP 2	Call1-2020 DeCarbCH
10	Eidgenössische Technische Hochschule Zurich, Sustainability and Technology, **Christof Knoeri**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: Consortium PI; WP co-leader Expertise: socio-technical system modelling, innovation research, policy analysis Contribution: business model innovation, policy mix analysis, innovation strategies WP involvement: WP 6	-

11	Zürcher Hochschule für Angewandte Wissenschaften, Center for Energy and Environment, **Jochen Markard**	ZHAW	Institute for higher education	Zurich, Switzerland	German	Role: Consortium PI; WP co-leader *(moved from ETH Zurich to ZHAW)* Expertise: sustainability transition studies, innovation theory, political sciences Contribution: empirical analyses on hydrogen and preferences of industry actors, concept / theory development WP involvement: WP 6 + 7	-
12	Eidgenössische Technische Hochschule Zurich, Research Center for Energy Networks, **Adamantios Marinakis**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: WP co-leader Expertise: multi-energy distribution networks planning, electricity distribution systems operation, electricity markets Contribution: local energy system scenarios, infrastructure planning of multi-energy systems, coordinated utilisation of distributed	Call1-2020 SURE

						flexibility resources at the network level WP involvement: WP 2	
13	Eidgenössische Technische Hochschule Zurich, Process Engineering, **Marco Mazzotti**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: Professor; Consortium PI Expertise: CO2 capture, transport and storage, bioenergy with CO2 capture and storage, system-level analysis Contribution: potential of DACCS and BECCS, system analysis WP involvement: WP 1	-
14	Eidgenössische Materialprüfungs- und Forschungsanstalt, Laboratory of Urban Energy Systems, **Kristina Orehounig**	Empa	Research Institute	Zurich, Switzerland	German	Role: Head of Laboratory; Consortium PI; P&D project leader Expertise: urban energy system, simulation and optimization of energy systems, whole building energy simulation Contribution: energy flexibility potentials of building stock, flexibilities in district energy	Call1-2020 DeCarbCH, Call1-2021 SWICE

						systems, building system modelling WP involvement: WP 10; WP 5 (P&D project)	
15	École Polytechnique Fédérale de Lausanne, Distributed Electrical Systems Laboratory, **Mario Paolone**	EPFL	Institute for higher education	Vaud, Switzerland	French	Role: Professor; Consortium PI Expertise: power systems, optimal control, uncertainties Contribution: dispatch, microgrids, stochastic generation WP involvement: WP3	-
16	Eidgenössische Technische Hochschule Zurich, Climate Policy, **Anthony Patt**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: Professor; Consortium PI; WP leader Expertise: climate policy, energy policy, politics Contribution: policy recommendations WP involvement: WP 7	-
17	Paul Scherrer Institute, Energy System Integration, **Christian Peter**	PSI	Research Institute	Aargau, Switzerland	German	Role: Consortium PI Expertise: fuel cells, electrolyser, hydrogen	-

						Contribution: efficiency, dynamics, model data WP involvement: WP 3	
18	Delft University of Technology, Energy and Industry Group, **Stefan Pfenninger**	TU Delft	Institute for higher education	Netherlands	-	Role: Assistant Professor; Consortium PI; WP leader *(moved from ETH Zurich to TU Delft)* Expertise: energy system modelling, renewable energy variability, sector coupling Contribution: European energy system scenarios WP involvement: WP 1 + 7	-
19	Eidgenössische Materialprüfungs- und Forschungsanstalt, Urban Energy Systems, **Martin Rüdisüli**	Empa	Research Institute	Zurich, Switzerland	German	Role: Consortium PI Expertise: energy system modelling, sector coupling, demand quantification Contribution: EU flexibility modelling	-

						WP involvement: WP 1	
20	Eidgenössische Technische Hochschule Zurich, Reliability and Risk Engineering, **Giovanni Sansavini**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: Associate Professor; Consortium PI Expertise: energy system modelling, interdependent gas/power infrastructure, resilience Contribution: natural gas network for flexibility provision to the Swiss energy system, system security assessment WP involvement: WP 1 + 2	Call1-2020 EDGE
21	Eidgenössische Technische Hochschule Zurich, Energy Science Center, **Christian Schaffner**	ETH Zurich	Institute for higher education	Zurich, Switzerland	German	Role: Director of Center; Consortium Deputy Director and PI; WP leader Expertise: energy system modelling, energy policy Contribution: energy system modelling,	Call1-2020 EDGE, SWEET CROSS

						national energy system scenarios WP involvement: WP 8, 9 + 10	
22	Zürcher Hochschule für Angewandte Wissenschaften, Center for Energy and Environment, **Ingmar Schlecht**	ZHAW	Institute for higher education	Zurich, Switzerland	German	Role: Consortium PI; WP co-leader; P&D project leader Expertise: demand-side flexibility, electricity markets, market design Contribution: coupling zonal to local markets, integrating congestion management in incentives for flexibility on distribution grid level WP involvement: WP 1 + 10; WP 4 (P&D project)	-
23	Hochschule Luzern Competence Center, Thermal Energy Storage, **Philipp Schütz**	HSLU	Institute for higher education	Lucerne, Switzerland	German	Role: Consortium PI Expertise: residential and commercial buildings modelling, optimised control schemes design and operation, data science and machine learning	Call1-2020 EDGE, Call1-2020 DecarbCH, Call1-2021 Lantern

						Contribution: residential and commercial buildings heat / cooling / electricity load modelling, heating / cooling system rooted flexibility analysis, operation of residential and commercial sites optimisation WP involvement: WP 2	
24	Université de Genève, Renewable Energy Systems, **Evelina Trunevyte**	UNIGE	Institute for higher education	Geneva, Switzerland	French	Role: Associate Professor; Consortium PI Expertise: energy system modelling, renewable energy, socio-technical transitions Contribution: energy systems modelling, municipal energy systems scenarios, citizen engagement WP involvement: WP 1 + 7	Call1-2020 EDGE, Call1-2020 SURE
25	Hochschule Luzern Competence Center, Thermal Energy Storage, **Willy Villasmil**	HSLU	Institute for higher education	Lucerne, Switzerland	German	Role: Head of Center; Consortium PI Expertise: thermal energy storage, thermal	Call1-2020 DeCarbCH

						networks, simulation models <u>Contribution</u>: techno-economic models and KPIs of thermal energy storage systems, innovative thermal energy storage technologies, technology solutions for heat recovery of P2X processes <u>WP involvement:</u> WP 2 + 3	
26	Zürcher Hochschule für Angewandte Wissenschaften, Center for Energy and Environment, **Christian Winzer**	ZHAW	Institute for higher education	Zurich, Switzerland	German	<u>Role</u>: Consortium PI; WP co-leader; P&D project leader <u>Expertise</u>: demand-side flexibility, electricity markets, market design <u>Contribution</u>: coupling zonal to local markets, integrating congestion management in incentives for flexibility on distribution grid level <u>WP involvement:</u> WP 1 + 10; WP 4 (P&D project)	-

Table 5-2: List of cooperation partners

Additional cooperation partners				0		
Previous cooperation partners (no longer cooperating)				-		
N°	**Cooperation partner**	**Short name**	**Type of organisation**	**Canton or country**	**Language CH region**	**Expertise and contribution**
1	ABB Schweiz AG, Energy Industries Division, **Matthias Bolliger**	ABB	Private sector	Aargau, Switzerland	German	Expertise: multi energy systems operation (for owners, operators, and energy providers) Contribution: test models and software, provide know-how WP involvement: WP 3, 4, 5 + 6
2	Aliunid AG, **David Thiel**	Aliunid	Private sector	Aargau, Switzerland	German	Expertise: energy flows measurement, analysis, and management (from households to pump storage power plant) Contribution: TBD WP involvement: WP 2, 3 + 5
3	Amstein + Walthert AG, **Mevina Feuerstein**	A+W	Private sector	Zurich, Switzerland	German	Expertise: communal energy strategies, energy supply networks and multi-energy hubs (for districts and buildings) Contribution: provide site / case study, provide know-how, participate in interviews / workshops, give lectures WP involvement: WP 1, 2, 3, 5 + 6
4	AXPO Holding AG, Energy Economics Division,	AXPO	Private sector	Aargau, Switzerland	German	Expertise: electricity market modelling and analysis

	Martin Koller					Contribution: review project results, co-develop scenarios / pathways, provide know-how, give lectures WP involvement: WP 1, 2, 3, 4, 5, 6 + 7
5	BKW Energie AG, **Andreas Jöckel**	BKW	Private sector	Bern, Switzerland	German / French	Expertise: technologies and business models, investment incentives and regulations, trading, market analysis Contribution: provide data, review project results, provide know-how WP involvement: WP 1, 3, 4, 5, 6 + 7
6	EBP Schweiz AG, Resources, Energy and Climate Division, **Peter De Haan**	EBP	Private sector	Zurich, Switzerland	German	Expertise: distribution grids for mobility and residential sectors, charging infrastructure and heat pumps, policy and regulations, business opportunities, innovation strategies, technology choices Contribution: provide data, test models and software, review project results, co-develop scenarios / pathways, participate in interviews / workshops, give lectures WP involvement: WP 1, 2, 3, 5, 6 + 7
7	ECO-Qube, H2020 Project, **Cagatay Yilmaz**	ECO-Qube	Private sector	Bern, Switzerland	German	Expertise: sector coupling demonstration, flexibility integration in distribution grids Contribution: TBD WP involvement: WP 3 + 5

8	Energie 360° AG, **Verena Lübken**	E360°	Private sector	Zurich, Switzerland	German	<u>Expertise:</u> renewable energy access, mobility solutions <u>Contribution:</u> provide site / case study, provide know-how, participate in interviews / workshops <u>WP involvement:</u> WP 1, 2, 3, 4, 5, 6 + 7
9	Energie Wasser Bern, Network Infrastructure Management Division, **Simon Summermatter**	EWB	Private sector	Bern, Switzerland	German	<u>Expertise:</u> renewable energy access, mobility solutions <u>Contribution:</u> provide data, review project results <u>WP involvement:</u> WP 2, 3, 4, 5 + 7
10	Energie Zukunft Schweiz AG, New Energy Division, **Stefan Liechti**	EZS	Private sector	Basel-Stadt, Switzerland	German / French / Italian	<u>Expertise:</u> renewable energy integration, new business models <u>Contribution:</u> test market algorithms, provide know-how, participate in interviews / workshops <u>WP involvement:</u> WP 4, 5 + 6
11	EPEX Spot Schweiz AG, **Davide Orifici**	EPEX	Research Institute	Bern, Switzerland	German / French / Italian	<u>Expertise:</u> renewable energy integration, consumer and producer engagement in the power market, local flexibility markets <u>Contribution:</u> test models and software, test market algorithms, participate in interviews / workshops <u>WP involvement:</u> WP 1, 4, 5 + 6

12	Groupe E AG, **Florian Buchter**	Groupe E	Private sector	France	French	Expertise: energy systems analysis, storage technologies implementation at regional scale, hydropower plants, electrical and gas network, H2-mobility fuel networks Contribution: provide data, review project results, provide site / case study, co-develop scenarios / pathways, provide know-how, participate in interviews / workshops WP involvement: WP 1, 2, 3, 4, 5, 6 + 7
13	Helmholtz-Gemeinschaft Deutscher Forschungszentren, Energy Systems Design Research Program, **Veit Hagenmeyer**	Helmholtz-Gemeinschaft	Research Institute	Germany	German	Expertise: energy system modelling, optimisation and control Contribution: test models and software, review project results, give lectures WP involvement: WP 1, 2, 3 + 10
14	Imperial College London, Centre for Process Systems Engineering, **Nilay Shah**	Imperial	Institute for higher education	United Kingdom	English	Expertise: energy system modelling and optimisation, new technologies, sector coupling Contribution: review project results, give lectures WP involvement: WP 1, 2, 3 + 10
15	Kopernikus Projekte, Power-to-X, **Walter Leitner**	Kopernikus	Research Institute	Germany	German	Expertise: energy system modelling, sector coupling demonstration, Power-to-X Contribution: review project results, give lectures

						WP involvement: WP 1, 2, 3 + 10
16	MAN Energy Solutions AG, **Emmanuel Jacquemoud & Philipp Jenny**	MAN ES	Private sector	Zurich, Switzerland	German	Expertise: technologies for sector coupling (electro-thermal energy storage), heat pump (pumped heat storage technologies), district heating networks Contribution: test models and software, review project results, test technology, co-develop scenarios / pathways, provide know-how, participate in interviews / workshops, give lectures WP involvement: WP 1, 2, 3, 4, 5 + 6
17	Primeo Netz AG, **Lukas Küng**	Primeo	Private sector	Baselland, Switzerland	German	Expertise: distribution network, renewable energy production Contribution: provide data, provide site / case study, test technology, provide know-how, participate in interviews / workshops WP involvement: WP 4 + 7
18	Schweizerischer Verein des Gas- und Wasserfaches, Gas- and District Heating Section, **Bettina Bordenet**	SVGW	Non-profit organisation	Zurich, Switzerland	German	Expertise: renewable gases, district heating, gas infrastructure, standards Contribution: provide data, review project results, test technology, provide know-how, give lectures WP involvement: WP 1, 2, 4, 5 + 6
19	Sentinel Project, **Anthony Patt**	Sentinel	Research Institute	Zurich, Switzerland	German	Expertise: energy system modelling

						Contribution: provide know-how WP involvement: WP 1 + 7
20	Siemens Schweiz AG, Research Group ESM, **Ingo Herbst**	Siemens	Private sector	Zug, Switzerland	German	Expertise: smart infrastructure, smart buildings, smart grid, distribution networks, electro mobility, charging infrastructure, optimization and automation software, business models, forecasting, real time control systems Contribution: provide data, test models and software, review project results, provide site / case study, test technology, provide know-how, participate in interviews / workshops WP involvement: WP 1, 2, 3, 5 + 6
21	Swiss Economics SE AG, **Urs Trinkner**	SEAG	Private sector	Zurich, Switzerland	German	Expertise: efficiency and security of energy system supply, electricity, gas and district heating, market design, policy and regulations Contribution: review project results, co-develop scenarios / pathways WP involvement: WP 1, 4, + 7
22	The Singularity Group AG, **Evelyne Pflugi**	Singularity Group	Non-profit organisation	Zurich, Switzerland	German	Expertise: innovation strategies and technologies, policy, business opportunities Contribution: provide know-how, participate in interviews / workshops WP involvement: WP 1, 6 + 7

23	Urban Sympheny AG, **Andrew Bollinger**	Sympheny	Private sector	Zurich, Switzerland	German	Expertise: energy system modelling, optimisation-based planning of local energy systems Contribution: provide know-how WP involvement: WP 1, 2 + 5
24	Verband Schweizerischer Elektrizitätsunternehmen, Grids Division, **Michael Paulus**	VSE	Non-profit organisation	Aargau, Switzerland	German	Expertise: electricity network, supply security, energy storage, standards, sector coupling Contribution: review project results, co-develop scenarios / pathways, provide know-how, participate in interviews / workshops, give lectures WP involvement: WP 1, 2, 3, 4, 5 + 7
25	Wasserwerke Zug AG, **Roman Tschanz**	WWZ	Private sector	Zug, Switzerland	German	Expertise: district energy system, flexibility quantification and utilization, thermal and electrical systems operation (with a coupling to electric vehicle charging) Contribution: provide data, provide know-how WP involvement: WP 1, 2, 3, 5, 6 + 7

6 References

Gupta, R., Fahmy, S., & Paolone, M. (2022). **Coordinated Day-ahead Dispatch of Multiple Power Distribution Grids hosting Stochastic Resources: An ADMM-based Framework**, *Proceedings of the 22nd Power Systems Computation Conference (PSCC 2022),* Porto, Portugal.

Hirth, L., & Schlecht, I. (2020). **Market-Based Redispatch in Zonal Electricity Markets: The Preconditions for and Consequence of Inc-Dec Gaming**. **10419/222925**

Leenders, L., Hagedorn, D. F., Djelassi, H., Bardow, A., & Mitsos, A. (2022). **Bilevel optimization for joint scheduling of production and energy systems**, *Optimization and Engineering*, 1-39. **10.1007/s11081-021-09694-0**

Peter, C., Vrettos, E., & Büchi, F. N. (2022). **Polymer electrolyte membrane electrolyzer and fuel cell system characterization for power system frequency control**, *International Journal of Electrical Power & Energy Systems*, 141, 108121. **10.1016/J.IJEPES.2022.108121**

Pickering, B., Lombardi, F., & Pfenninger, S. (2022). **Diversity of Options to Reach Carbon-Neutrality Across the Entire European Energy System**, *Joule.* **10.1016/j.joule.2022.05.009**

Schuetz, P., Scoccia, R., Gwerder, D., Waser, R., Sturzenegger, D., Elguezabal, P., Arregi, B., Sivieri, A., Aprile, M., & Worlitschek, J. (2018). **Fast simulation platform for retrofitting measures in residential heating**, *Cold Climate HVAC Conference* (pp. 713-723), Springer, Cham. **10.1007/978-3-030-00662-4_60**