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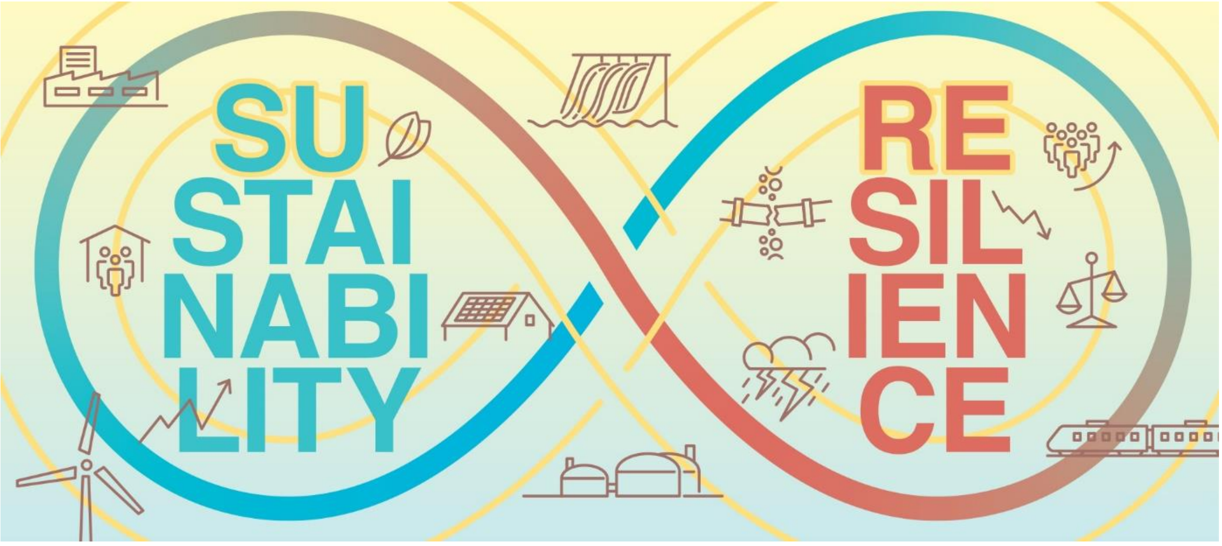
Highlights Report Year 2

SURE



sweet swiss energy research for the energy transition

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Highlights

The main five highlights (results, challenges, learnings, etc.) during the reporting period were the following:

- The SURE project analyses and identifies sustainable and resilient energy system transformation pathways for Switzerland until 2050. In-line with the aim to produce policy relevant output, the engagement of the SURE stakeholder forum facilitates the exchanges with experts in this research area. In 2022, SURE held two stakeholder workshops: 1) on future pathway and shock scenarios, which provided outcomes and learnings that supported the definition of scenarios analysed in the project; 2) on the identification of sustainability and resilience indicators, with the aim to set a solid basis for the evaluation of energy system transformation pathways under different shock scenarios. The findings of the workshop were published in a corresponding SURE deliverable (D2.1 and D17.2) and they also informed the scenarios definition activity in the joint research initiative SWEET-CROSS.
- In the second year of the SURE project, the analytical framework was further advanced, with the development of pathway and shock scenarios for the first modelling round of the project. This was a cross-cutting and interdisciplinary task involving almost all research partners, resulting in the publication of Deliverable 2.1 as a guideline and protocol for the model-based quantitative analyses in SURE.
- To better understand the impact of these shocks on different levels of governance and management, cantonal, urban, and sectorial case studies are conducted in SURE. In the cantonal case study of Ticino, for example, extreme weather events and societal changes due to immigration were identified as potential shocks that could disrupt the transition process to a sustainable and resilient energy system. In the case study of Zurich, stakeholders highlighted the need to strengthen the city's resilience against heat waves and cold spells. In the industry case study, financial shocks, heat waves, and cold spells were identified as major potential disruptors. In the SBB case study, stakeholders identified consequences from most SURE shocks, and resilience was assessed.
- Advanced Global Sensitivity Analysis (GSA) has been demonstrated for Life Cycle Assessment (LCA) in order to better understand uncertainties related to input parameters and outputs of LCA. The methodological advancements and results were subject to the dissertation of A. Kim, who successfully finished her Ph.D. thesis during the second year of SWEET-SURE.
- Technology detailed modelling of the industry sector in the context of the Swiss energy system was performed by M. Obrist who finished his Ph.D. thesis in the second year of SURE as well. His model developments represent a significant methodological advancement of representing industry technology in a TIMES modelling framework and allow for an in-depth analysis of decarbonisation measures and energy efficiency improvements for several industrial sectors.

Faits marquants

Les cinq principaux faits marquants (résultats, défis, apprentissages, etc.) pendant la période de référence ont été les suivants:

- Le projet SURE analyse et identifie les voies de transformation des systèmes énergétiques durables et résilients pour la Suisse jusqu'en 2050. Conformément à l'objectif de produire des résultats pertinents pour la politique, l'engagement du forum des parties prenantes de SURE facilite l'échange avec des experts dans le domaine. En 2022, SURE a organisé deux ateliers pour les parties prenantes : 1) sur les scénarios de trajectoires et de chocs, qui ont fourni des résultats et des apprentissages qui ont soutenu la définition des scénarios analysés dans le projet ; 2) sur l'identification des indicateurs de durabilité et de résilience, dans le but d'établir une base solide pour l'évaluation des voies de transformation du système énergétique dans le cadre de différents scénarios de choc. Les résultats de l'atelier ont été publiés dans les documents SURE correspondant (D2.1 et D17.2) et ont également servi à définir des scénarios dans le cadre de l'initiative de recherche conjointe SWEET-CROSS.
- Au cours de la deuxième année du projet SURE, le cadre analytique a été approfondi, avec le développement de scénarios de trajectoires et de chocs pour le premier cycle de modélisation du projet. Il s'agissait d'une tâche transversale et interdisciplinaire impliquant presque tous les partenaires de recherche, qui a abouti à la publication du livrable 2.1 en tant que ligne directrice et protocole pour les analyses quantitatives basées sur des modèles dans le cadre de SURE.
- Pour mieux comprendre l'impact de ces chocs sur les différents niveaux de gouvernance et de gestion, des études de cas cantonales, urbaines et sectorielles sont menées au sein de SURE. Dans l'étude de cas du canton du Tessin, par exemple, les phénomènes météorologiques extrêmes et les changements sociétaux dus à l'immigration ont été identifiés comme des chocs potentiels susceptibles de perturber le processus de transition vers un système énergétique durable et résilient. Dans l'étude de cas de Zurich, les parties prenantes ont souligné la nécessité de renforcer la résilience de la ville face aux vagues de chaleur et de froid. Dans l'étude de cas de l'industrie, les chocs financiers, les vagues de chaleur et les vagues de froid ont été identifiés comme des perturbateurs potentiels majeurs. Dans l'étude de cas des CFF, les parties prenantes ont identifié les conséquences de la plupart des chocs SURE, et la résilience a été évaluée.
- L'analyse de sensibilité globale avancée (GSA) a été démontrée pour l'analyse du cycle de vie (ACV) afin de mieux comprendre les incertitudes liées aux paramètres d'entrée et aux résultats de l'ACV. Les avancées méthodologiques et les résultats ont fait l'objet de la thèse d'A. Kim, qui a terminé avec succès sa thèse de doctorat au cours de la deuxième année de SWEET-SURE.
- La modélisation technologique détaillée du secteur industriel dans le contexte du système énergétique suisse a été réalisée par M. Obrist, qui a également terminé sa thèse de doctorat au cours de la deuxième année de SURE. Les développements de son modèle représentent une avancée méthodologique significative dans la représentation de la technologie industrielle dans un cadre de modélisation TIMES et permettent une analyse approfondie des mesures de décarbonisation et des améliorations de l'efficacité énergétique pour plusieurs secteurs industriels.

Highlights

Die wichtigsten fünf Highlights (Ergebnisse, Herausforderungen, Lehren usw.) während des Berichtszeitraums waren die folgenden:

- SWEET-SURE zielt darauf ab, nachhaltige und widerstandsfähige Pfade für die Energiewende in der Schweiz bis 2050 zu analysieren und zu identifizieren. Im Einklang mit dem Ziel, politisch relevante Ergebnisse zu erzielen, ist das Engagement des SURE-Stakeholder-Forums ein wesentliches Mittel dazu, da es den Austausch mit anderen Experten auf diesem Gebiet fördert. Im Jahr 2022 veranstaltete SURE zwei Stakeholder-Workshops: 1) zu zukünftigen Pfaden und Schockszenarien, welche die Definition der im Projekt analysierten Szenarien unterstützen; 2) zur Identifizierung von Nachhaltigkeits- und Resilienzindikatoren, mit dem Ziel, eine solide Grundlage für die Bewertung der Pfade der Energiewende unter verschiedenen Schockszenarien zu schaffen. Die Ergebnisse des Workshops wurden in entsprechenden SURE-Projektberichten (D2.1 und D17.2.) veröffentlicht und flossen auch in die Definition von Szenarien im Rahmen der gemeinsamen Forschungsinitiative SWEET-CROSS ein.
- Im zweiten Jahr des SURE-Projekts wurde der analytische Rahmen mit der Entwicklung von Pfad- und Schockszenarien für die erste Modellierungsrunde des Projekts weiterentwickelt. Dies war eine bereichsübergreifende und interdisziplinäre Aufgabe, an der fast alle Forschungspartner beteiligt waren. Das Ergebnis war die Veröffentlichung von Deliverable 2.1 als Leitfaden und Protokoll für die modellbasierten quantitativen Analysen von SURE.
- Um die Auswirkungen der definierten Schocks auf verschiedenen Entscheidungsebenen besser zu verstehen, werden in SURE kantonale, städtische und sektorielle Fallstudien durchgeführt. In der kantonalen Fallstudie des Tessins wurden zum Beispiel extreme Wetterereignisse und gesellschaftliche Veränderungen aufgrund von Zuwanderung als potenzielle Schocks identifiziert, die den Übergangsprozess zu einem nachhaltigen und widerstandsfähigen Energiesystem beeinflussen könnten. In der Fallstudie von Zürich wurde die Notwendigkeit der Stärkung der Widerstandsfähigkeit der Stadt gegen Hitzewellen und Kälteeinbrüche betont. In der Fallstudie der Industrie wurden finanzielle Schocks, Hitzewellen und Kälteeinbrüche als wichtige potenzielle Störfaktoren identifiziert. In der Fallstudie der SBB wurden die Folgen der der im Projekt entwickelten Schocks bewertet.
- Für die Lebenszyklusanalysen (LCA) wurden ein innovativer Ansatz für Globale Sensitivitätsanalysen (GSA) entwickelt und angewandt, um die Unsicherheiten im Zusammenhang mit den Eingangsparametern und Ergebnissen der LCA besser zu verstehen. Die methodischen Weiterentwicklungen und Ergebnisse waren Gegenstand der Dissertation von A. Kim, die im zweiten Jahr von SWEET-SURE erfolgreich abgeschlossen wurde.
- Die technologisch detaillierte Modellierung des Industriesektors im Kontext des Schweizer Energiesystems wurde von M. Obrist durchgeführt, der seine Doktorarbeit ebenfalls im zweiten Jahr von SURE abschloss. Seine Modellentwicklungen stellen einen bedeutenden methodischen Fortschritt bei der Abbildung von Industrietechnologien im TIMES-Modellierungsrahmen dar und ermöglichen eine vertiefte Analyse von Dekarbonisierungsmassnahmen und Energieeffizienzverbesserungen für verschiedene Industriesektoren.

Punti salienti

I principali cinque punti salienti (risultati, sfide, lezioni apprese, ecc.) durante il periodo di riferimento sono stati:

- Il progetto SURE analizza e identifica percorsi di trasformazione del sistema energetico sostenibile e resiliente per la Svizzera fino al 2050. In linea con l'obiettivo di produrre risultati rilevanti per la politica, l'impegno del forum degli stakeholder di SURE facilita lo scambio con esperti del settore. Nel 2022, SURE ha organizzato due workshop per le parti interessate: 1) sui scenari di percorso e di shock, che ha fornito risultati e insegnamenti a sostegno della definizione degli scenari analizzati nel progetto; 2) sull'identificazione degli indicatori di sostenibilità e resilienza, con l'obiettivo di creare una solida base per la valutazione dei percorsi di trasformazione del sistema energetico in diversi scenari di shock. I risultati del workshop sono stati pubblicati in un corrispondente SURE rapporti (D2.1 e D17.2.) e hanno anche informato l'attività di definizione degli scenari nell'ambito dell'iniziativa di ricerca congiunta SWEET-CROSS.
- Nel secondo anno del progetto SURE, il quadro analitico è stato ulteriormente perfezionato, con lo sviluppo di scenari di percorso e di shock per il primo ciclo di modellizzazione del progetto. Si è trattato di un lavoro trasversale e interdisciplinare che ha coinvolto quasi tutti i partner di ricerca e che ha portato alla pubblicazione del Deliverable 2.1 come linea guida e protocollo per le analisi quantitative basate su modelli in SURE.
- Per comprendere meglio l'impatto di questi shock sui diversi livelli di governance e gestione, in SURE sono stati condotti studi di caso cantonali, urbani e settoriali. Nel caso di studio cantonale del Ticino, ad esempio, gli eventi meteorologici estremi e i cambiamenti sociali dovuti all'immigrazione sono stati identificati come potenziali shock che potrebbero interrompere il processo di transizione verso un sistema energetico sostenibile e resiliente. Nel caso di studio di Zurigo, gli stakeholder hanno evidenziato la necessità di rafforzare la resilienza della città contro le ondate di calore e di freddo. Nello studio di caso dell'industria, gli shock finanziari, le ondate di calore e i periodi di freddo sono stati identificati come i principali potenziali fattori di disturbo. Nel caso di studio delle FFS, gli stakeholder hanno identificato le conseguenze della maggior parte degli shock SURE ed è stata valutata la resilienza.
- È stata dimostrata l'analisi avanzata della sensibilità globale (GSA) per la valutazione del ciclo di vita (LCA), al fine di comprendere meglio le incertezze relative ai parametri di input e agli output della LCA. I progressi metodologici e i risultati sono stati oggetto della tesi di laurea di A. Kim, che ha concluso con successo il suo dottorato di ricerca durante il secondo anno di SWEET-SURE.
- La modellazione tecnologica dettagliata del settore industriale nel contesto del sistema energetico svizzero è stata eseguita da M. Obrist, che ha concluso la sua tesi di dottorato nel secondo anno di SURE. I suoi sviluppi del modello rappresentano un significativo progresso metodologico nella rappresentazione della tecnologia industriale in un quadro di modellazione TIMES e consentono un'analisi approfondita delle misure di decarbonizzazione e dei miglioramenti dell'efficienza energetica per diversi settori industriali.

1 Highlights of the reporting period

Highlight 1: SURE stakeholder forum facilitating the project's quantitative analytical approach

Towards the end of the first year of the project, the stakeholder workshop (Fig.1) on future pathway and shock scenarios was held. The outcomes and learnings from the workshop (see annual report of the first year) were further discussed and processed by the project team and supported the definition of the scenarios to be analysed in the project, which were published in the corresponding deliverable (D2.1). This activity also informed the scenarios definition process in the joint research initiative SWEET-CROSS. Results from the SWEET-CROSS scenarios, that were informed by the corresponding SURE scenarios, were presented at the CROSS final event on 18. January 2023 using the Swiss TIMES Energy system Model (STEM) of PSI-LEA – within the same event the SURE objectives and approach were also presented.

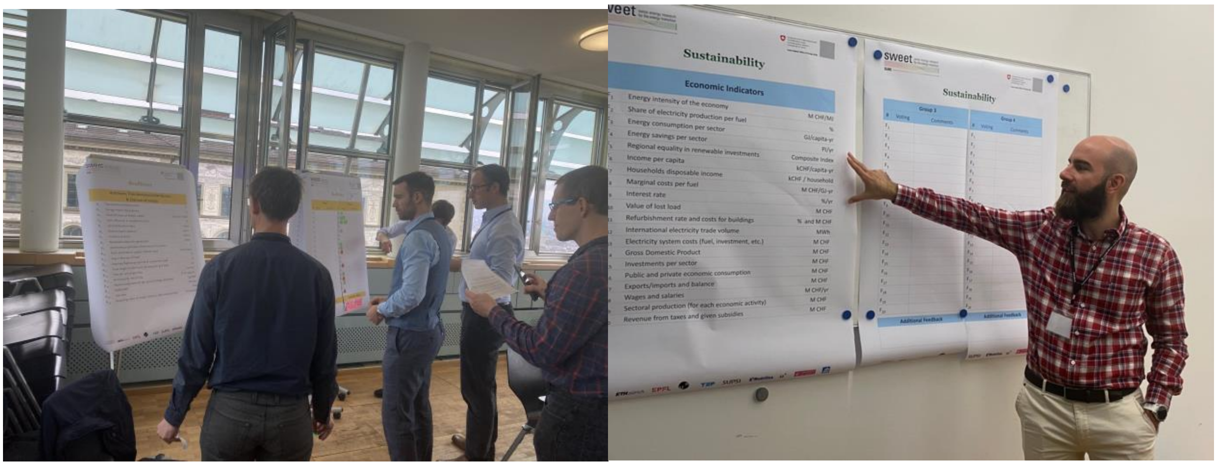


Fig. 1: Impressions from the SURE Stakeholder workshop on sustainability and resilience indicators

The SWEET-SURE stakeholder workshop on future pathway and shock scenarios was followed by a stakeholder workshop on sustainability and resilience indicators, which took place in October 2022. This workshop kicked off a series of three physical stakeholder meetings, which aim to evaluate the performance of different energy pathways for Switzerland until 2050. This first indicator workshop aimed at setting with the partners and stakeholders a solid and broadly accepted basis for a comprehensive multi-criteria evaluation of the long-term pathways of the Swiss energy system, including their performance under different shock scenarios. More specifically, the consortium presented to the stakeholders a set of resilience and sustainability indicators, which will serve as evaluation criteria for the pathways and shocks. The stakeholder forum provided critical feedback, requests for changes and additions, as well as new ideas that complement and enhance this set, rendering it as holistic as possible. Furthermore, the participants got acquainted with the philosophy and rationale of the Multi-Criteria Decision Aid (MCDA), exchanged viewpoints, and had their inquiries included in the discussion table and addressed. Specific MCDA tools were presented to the audience, before proceeding to an exemplary practical implementation. This was performed within four break-out groups, in which the stakeholders provided their preferences for a small-scale pilot example related to the future electricity supply configuration in Switzerland. This information helped to shape their personalized decision model in relation to the pilot example, and obtain individual evaluation results. This exercise resembled the challenge of the evaluation of the Swiss energy pathways, and thus provided valuable feedback about interdependencies among indicators and about the process for performing the MCDA in SWEET-SURE. In addition, guidelines were provided to the stakeholders for the two upcoming workshops, pertaining to the same series. Ultimately, the workshop was held in an interactive format and opened a dialogue between the SURE project team and a broad and diverse group of stakeholders. A detailed overview of this workshop is provided in deliverable D17.2.

This second SURE stakeholder workshop was organised in addition to case-study-specific stakeholder interactions. Through active networking, the SURE stakeholder panel could be expanded by including further partners from industry.

Highlight 2: Specification of the analytical framework

The past few years have taught/reminded us that global and unexpected events can cause extreme strain on our society. Therefore, identifying potential shocks, systematically analysing their effects, and suggesting implementable contingency plans are essential to a sustainable and resilient energy system. Against this background, the SURE analytical framework has been specified more in detail in the second year of the project by developing pathway and shock scenarios to be analysed in the first modelling round of the project. The process to perform this achievement involved almost all research partners and was a cross-cutting and interdisciplinary task. The outcome of this process is deliverable D2.1 which serves as guideline and protocol for the model-based quantitative analyses of SWEET-SURE.

In SWEET-SURE four pathway scenarios and five shock scenarios have been defined. A *pathway* is the temporal evolution of the energy system towards a future state. Its concept ranges from sets of descriptions of potential futures to solution-oriented decision-making processes to achieve desirable energy and climate goals. A *shock* is an extreme and possibly disruptive event that occurs suddenly at a future point in time of a pathway. Similar to a pathway, a shock concept is based on a set of assumptions across multiple dimensions: environmental, societal, political, financial and technical. The main characteristics of the scenarios are summarised in the figure (Fig. 2) below, while comprehensive material and detailed information is provided in the deliverable D2.1.

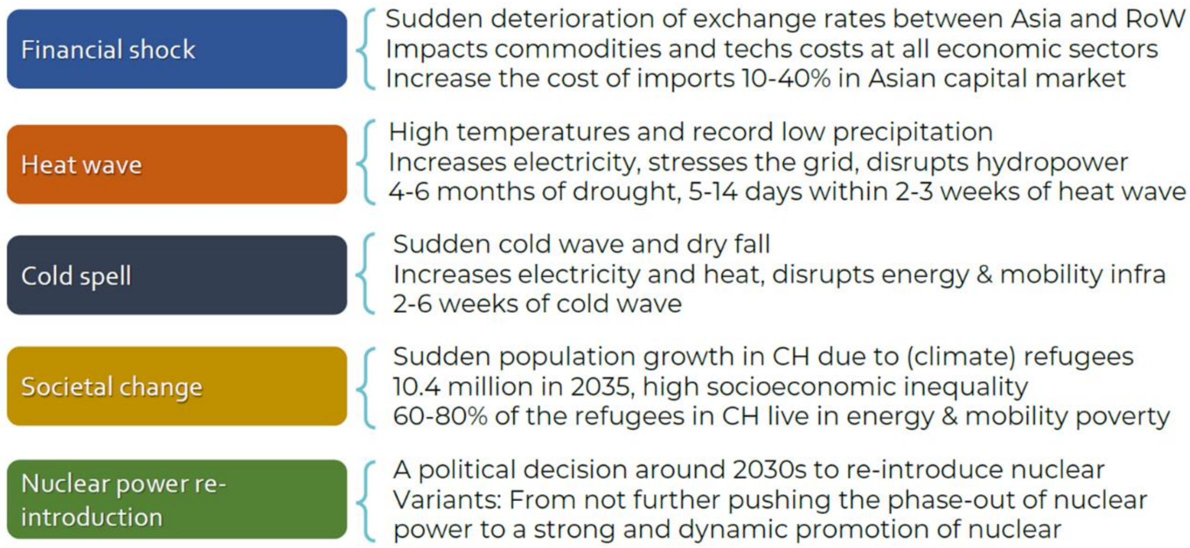


Fig. 2: Overview of the SURE scenario framework with short descriptions of the four pathways and five shocks

In view of incorporating legal aspects in the scenario framework, the specific legal status and liability of Swissgrid as transmission system operator was analysed as part of the analysis of the regulatory context of the electricity system of Switzerland. Since the federal state holds final responsibility, it was examined how appropriate it is to place the fulfilment of public tasks (esp. related to property and operation of the national electric transmission system) in the hands of a public limited company. The legal study thus contributes to the presentation of the existing legal basis for a resilient electricity supply.

Beyond the definition of the scenario framework, also the interfaces of the analytical tools were further specified and detailed. The SURE modelling framework consists of a large set of different mathematical models which are orchestrated to provide a comprehensive view of the transformation of the Swiss economy and energy system towards net GHG emissions in 2050. When quantifying the pathway scenarios, the modelling framework of SURE is involved at which the application of the models follows a specific sequence of interactions which is shown in Fig. 3. A comprehensive Input-Output matrix has been developed that sheds light on the major parameters and variables exchanged between the models. Thanks to the diversity of models involved, the SURE modelling framework does not require many exogenous variables. The most important ones are assumptions on demographic development, heating and cooling degree days, international fuel prices and import availability, and mobility demands which are not fully covered by the scope of the models in SURE. Macroeconomic developments and energy service demands (except mobility) are entirely generated within the framework. The related assumptions are documented in deliverable D2.1.

In addition to the specification of the model framework, also interfaces of the models to other analysis tools/methods, such as Life Cycle Analysis (LCA) were discussed. Along this line, a workflow between the energy models (STEM, BSM and GEM-E3) in quantifying the scenarios and providing input to the prospective LCA framework called *premise* has been designed. It is also important to note that a solution to translate financial flows between regions and sectors from the macro-economic model GEM-E3 to LCA has been identified (BACI database). The interfaces (input and output variables) of each model to modify the LCA database have been identified and described (deliverable D10.1).

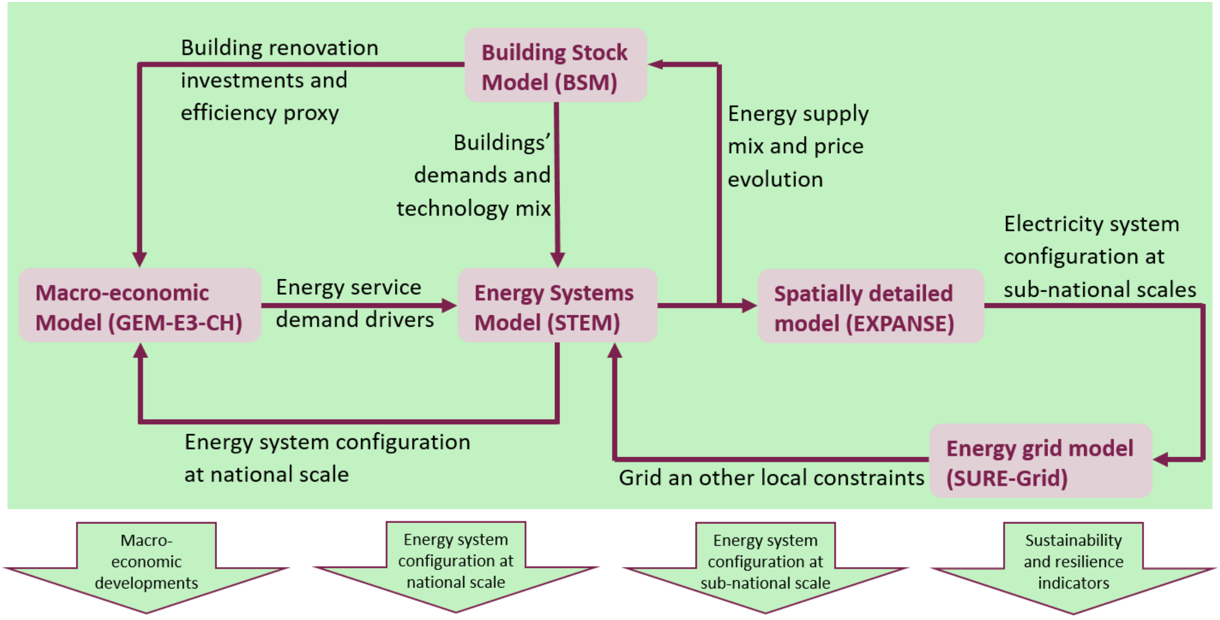


Fig. 3: Major energy model interactions in SURE to inform the Swiss national analysis

Highlight 3: National, regional, urban, and sectorial spotlights on disruptive events to the energy system transition

In SURE, a significant transdisciplinary effort that involved academics, industrial experts, and public authorities (highlights 1 & 2) culminated in the definition of the five shock scenarios. The cantonal, urban, and sectorial case studies partially build on the SURE shock scenarios. The case studies stimulate interdisciplinary exchange within a specific context, identifying various gaps and potential anticipative measures to be taken locally. Through the interpellation of key public authorities and subject matter experts, the case studies trace the relevance of the SURE pathways and shocks in important sub-levels of governance and management. Additionally, through the case studies, certain case specific shocks are revealed that might put in peril the sustainability and resilience of a Swiss region, city, or sector.

In the context of the cantonal case study of Ticino (WP13), a stakeholder group was formed comprising key local public authorities and experts in the energy field. This group was consulted at a very early stage of the project regarding global and national events that could impact the transition process of the canton to a sustainable and resilient energy system. During this initial deliberation it was perceptible that the effects of climate change resonated strongly amongst the participants. The subject was considered relevant at the regional level due to the stresses and disruptions they could impose on the local citizens and energy system. Extreme weather events that could intensify with climate change (such as the heat wave and a cold spell shock of SURE) are of high interest as the cantonal authorities themselves would be responsible for preparing infrastructure and procedures that increase the region's resilience. The subject of societal changes due to immigration (related to the SURE societal shock) raised interest as well, considering that it would most probably necessitate changes in the incumbent energy system regimes and possibly alter the current urban and rural population balance. From a regional perspective, certain shock themes, such as nuclear power, seemed to sway less the cantonal stakeholder group as these are presumed to be dealt with by the Federal authorities.

In the context of the case study of Zurich (WP14), the relevance of SURE shock scenarios was assessed for the urban context. Together with stakeholders from the city administration of Zurich, an assessment of shocks illustrates differences between the relevance of national and urban resilience. The stakeholders particularly highlighted their possibilities for strengthening the city's resilience against heat waves and cold spells. Measures include a toolbox to combat the heat island effect, existing planning criteria from norms and the diversification of heat provision and fuels, among others. Challenges remain, for instance the expansion of the district heating network and the cooling distribution in building. The other SURE shocks are of less direct relevance for Zurich, in other words, no major strategies are being developed. This is either because the shocks affect Switzerland as a whole or because the capabilities to increase resilience on the urban level (alone) are limited (e.g., storage). In addition to the shocks identified in the SURE workshops, the stakeholders in Zurich have identified additional shocks which are of particular interest on the urban level, e.g., related to the usage rights of certain infrastructure buildings.

In the context of the SBB and industrial case study (WP15), the relevance of SURE shock scenarios was assessed for the sectorial context. Together with stakeholders, an assessment of shocks illustrates some differences between the relevance of national and sectorial resilience. In the industry case study, a high relevance was attributed to financial shocks, heat waves and cold spells. In the SBB case, stakeholders identified major consequences from most SURE shocks. In addition, resilience was assessed in different dimensions that are very specific to the industry and SBB, for instance energy price and supply resilience, operational or seasonal resilience. Aside from the identified SURE shocks, these dimensions provide another angle for considering the resilience of these systems.

Highlight 4: Global Sensitivity Analysis of Life Cycle Assessment

In order to reduce anthropogenic environmental impacts, it is important to properly measure them. Life Cycle Assessment (LCA) is a well-established tool for the quantification of the potential environmental impacts of a product or service throughout its complete life cycle. It can be used to compare various alternatives, assess environmental benefits and negative impacts in a systematic manner, integrate environmental sustainability aspects already at the product design and development stages, and support environmental communication and effective decision-making. LCA models are based on the analysis of complex supply chains and environmental processes. Naturally, there exists variation in the performance of technical systems, differences in efficiencies or output quantities, and changes in equipment efficacy due to varying internal and external factors. A slightly different combination of parameters compared to their default values in simultaneously many processes can significantly affect LCA results. Depending on the objective of LCA, interpretation of the results might change in the presence of selected uncertainties. Global Sensitivity Analysis (GSA) is a mean to better understand which inputs are responsible for most of the LCA output uncertainty.

A. Kim successfully completed her PhD on “Global Sensitivity Analysis of Life Cycle Assessment” (https://doi.org/10.3929/ethz-b-000588835) during the second reporting period of the SWEET SURE project. This work – published in the two journal articles Kim et al. 2022a and Kim et al. 2022b - provides the methodological starting point for the analytical framework to be developed and employed in Task 10.2. Fig. 4 shows the interplay of new methodologies for validated GSA of Life Cycle Assessment (LCA), and in particular the following achievements were accomplished: 1) provision of computationally and methodologically feasible methods and tools for complex uncertainty and global sensitivity analysis for high-dimensional LCA models; 2) application of GSA to support more robust decision-making and to gradually improve data and modelling quality in LCA; 3) open source software practices can facilitate integration of novel data sources, better inventory and uncertainty modeling, etc.

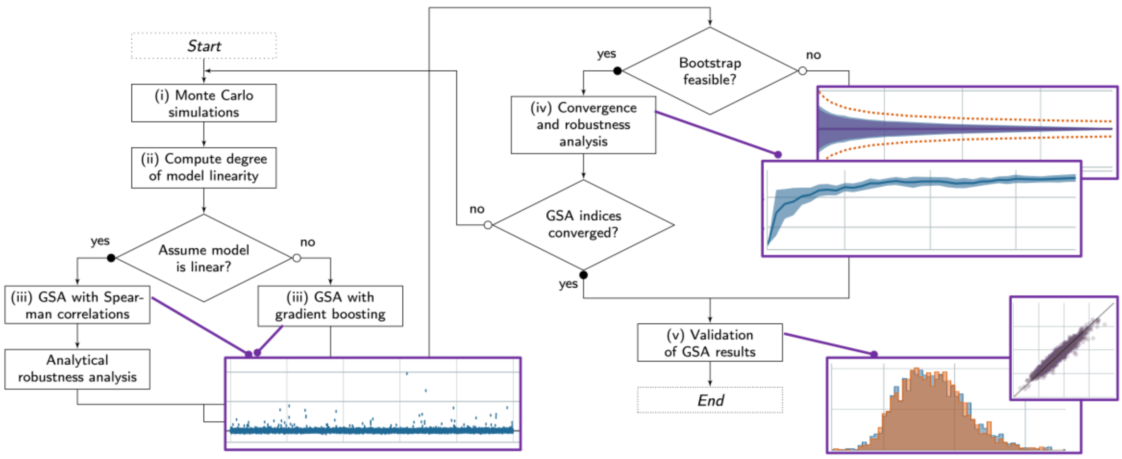
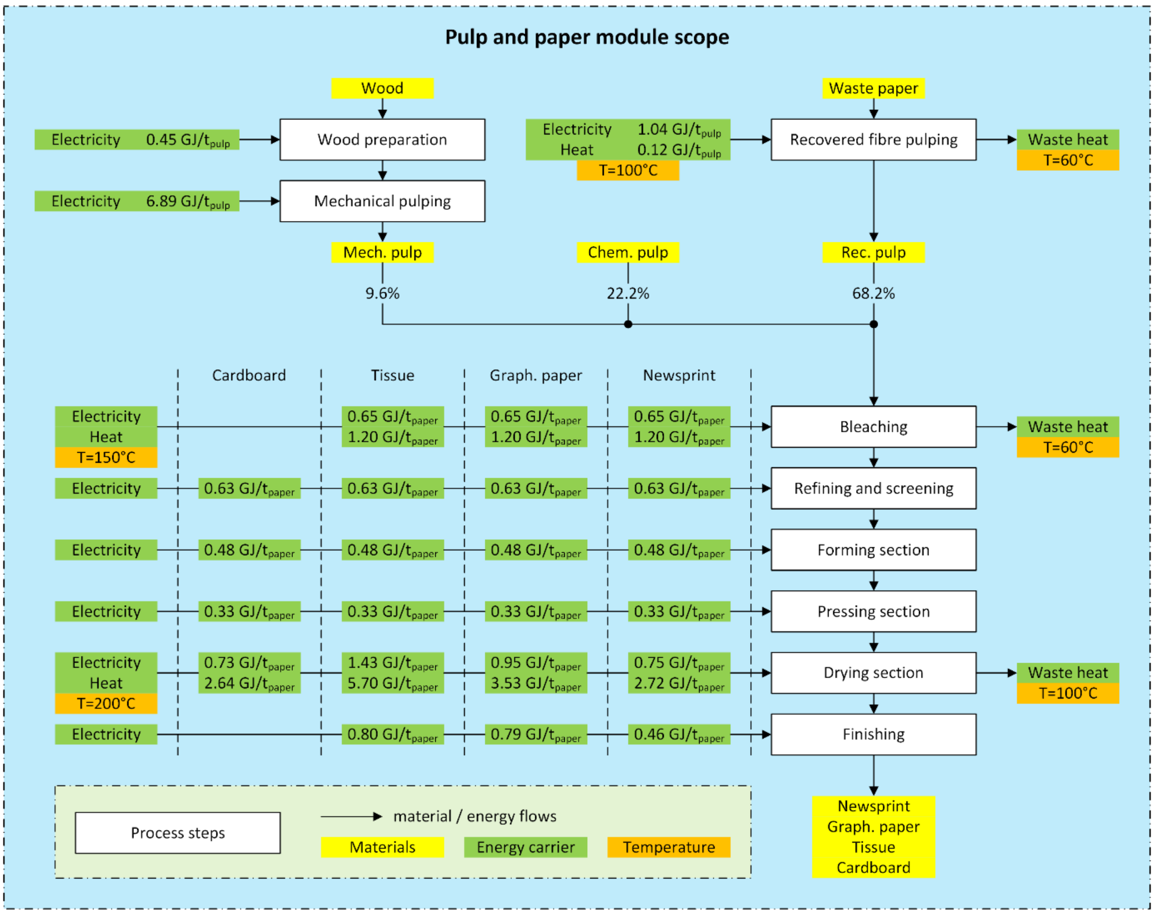


Fig. 4: Overview of the Global Sensitivity Analysis for LCA

Highlight 5: Advanced modelling of the industry sector in an energy system context

Within the second year of the project, Mr. Michel Obrist completed his PhD thesis (Obrist, 2022). The focus of the thesis was the development of a set of detailed industrial energy models (or modules) for the Swiss industrial sub-sectors, *viz.* cement, pulp and paper, and food. These sub-sectoral models, which represent an extension of the Swiss TIMES Energy system Model (STEM), entail modelling of production processes with material flows, besides energy and emission flows. The inclusion of production processes and material flows enables tracking of production process-related emissions and their mitigation. These model advancements enabled accounting for efficiency improvements of specific technologies and identification of alternative production process while considering distinct temperature levels for process heat supply. For example, the cement sector has significant process related CO_2 emissions and therefore this methodological development is more relevant to explore mitigation options. This is the first time that energy and material flows are combined in a TIMES modelling framework with a very high technology representation of specific industrial sectors at a national scale.

Fig. 5 illustrates the complexity of the detailed model for the example of the pulp and paper sector. In addition to the energy and emission flows associated with pulp and paper production processes, the model distinguishes heat demands and waste heat by temperature levels. The modelling of temperature-specific heat demand and supply offers new opportunities to account for appropriate technology combinations depending on the applicable temperature levels (e.g. heat pumps and solar heat or use of waste heat recovery options).



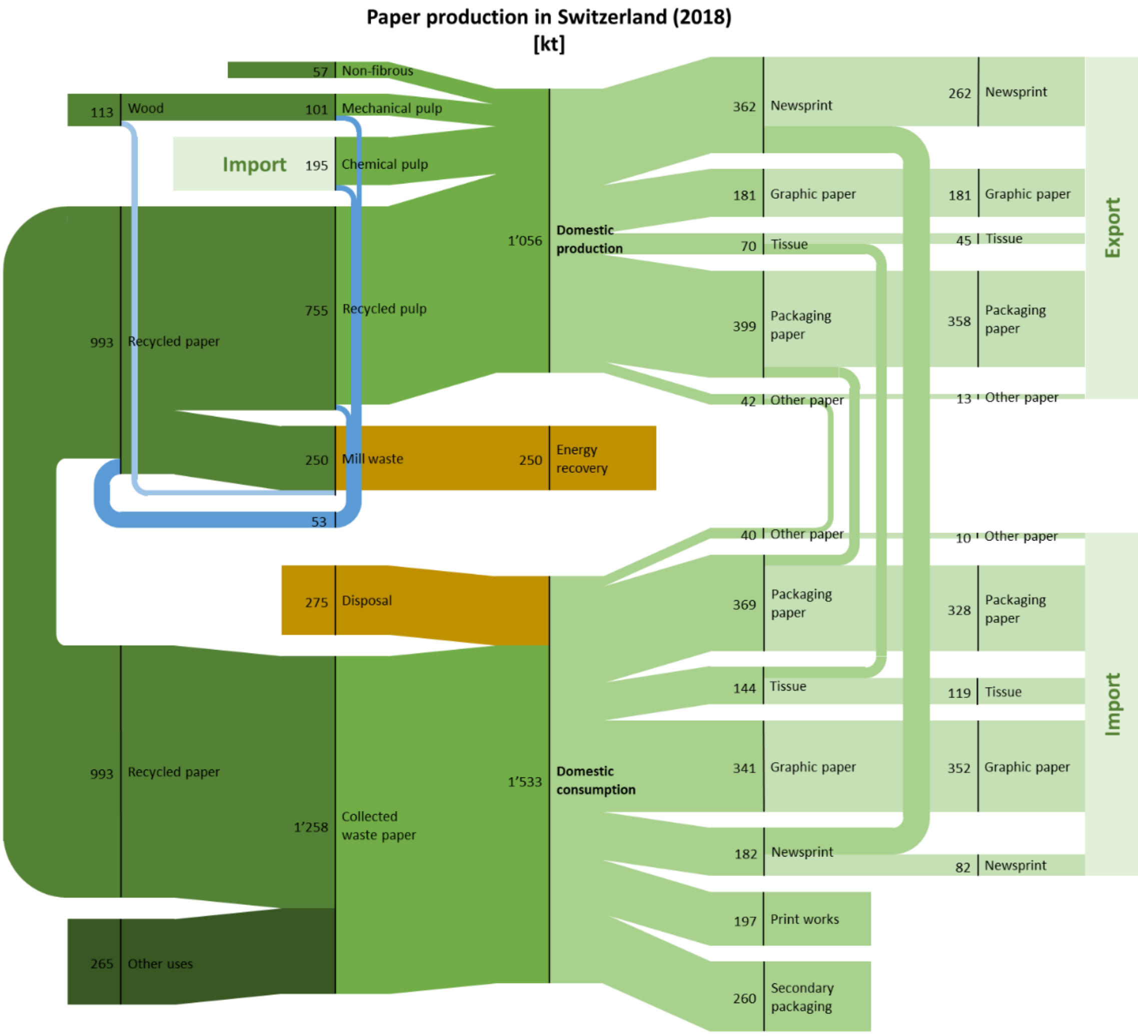


Fig. 5: Illustration of the pulp and paper sector with material and energy flows (Obrist et al. 2022)

The advanced industrial sub-sectoral model was applied for several scenario analyses, published in three peer-reviewed papers: 1) with focus on decarbonisation of Swiss cement industry (Obrist et al., 2021)[1], pulp and paper industry (Obrist et al., 2022)[2], and potential for application of high temperature heat pumps in industries (Obrist et al., 2023).

The aforementioned detailed sub-sectoral modelling was implemented for selected industry branches and did not cover the entire Swiss industrial sector on account of many factors such as the complexity of the industrial production processes, heterogeneity in industrial products, and data obtainability. An alternate, less detailed, approach was applied for some industrial sub sectors (e.g., chemical, machinery)

[1] https://www.sciencedirect.com/science/article/pii/S0959652620354597

[2] https://doi.org/10.1016/j.seta.2021.101937

where a proxy of general process applications was assumed considering numerous heat production technologies of different fuels. Ultimately, this allows to account for the energy use and emissions of the whole Swiss industry sector. Most importantly, all the aforesaid detailed industrial sub-modules are integrated into the whole energy system model of Switzerland, i.e., the Swiss Times Energy System Model (STEM). STEM originally had an aggregated industrial sector only with process heat demands. This model development not only has resulted in novel model advancements and new analytical insights for the Swiss policymakers but has also attempted the application of multiple models in an orchestrated fashion.

2 Outputs of the reporting period

Peer-reviewed publications

Author(s), title, journal name, year	**doi**
Eder, Ch., Stadelmann-Steffen I. **“Bringing the political system (back) into social tipping relevant to sustainability**” *Energy Policy*. 2023; Volume 177	https://doi.org/10.1016/j.enpol.2023.113529
Obrist MD, Kannan R, McKenna R, Schmidt TJ, Kober T **High-temperature heat pumps in climate pathways for selected industry sectors in Switzerland** *Energy Policy*. 2023; 173: 113383 (20 pp.)	https://doi.org/10.1016/j.enpol.2022.113383
Stermieri L, Kober T, Schmidt TJ, McKenna R, Panos E **"Quantifying the implications of behavioral changes induced by digitalization on energy transition: a systematic review of methodological approaches"** *Energy Research and Social Science*. 2023; 97: 102961 (19 pp.).	https://doi.org/10.1016/j.erss.2023.102961
Trutnevyte E., Zielonka N., Wen X. **“Crystal ball to foresee energy technology progress?”** *Joule* 2022, 6(9), 1969-1970 (2 pp).	https://archive-ouverte.unige.ch/unige:163602
Robert Baumann **Die nationale Netzgesellschaft Swissgrid: Wer haftet für die sichere Stromversorgung der Schweiz? Eine Aufgabe von nationalem Interesse in privatrechtlichem Gewand.** Schriften zum Energierecht (SzE), Vol. 26 (115 p.); open access	https://doi.org/10.3256/978-3-03929-025-3
H. Harbrecht, M. Multerer **Samplets: Construction and scattered data compression.** Journal of Computational Physics Volume 471, 2022, 111616	https://doi.org/10.1016/j.jcp.2022.111616

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

Author(s), title, channel or type of publication, year
PSI News – Scientific Highlights – Preparing for energy shortages and blackouts. (13.12.2022). **https://www.psi.ch/en/media/our-research/preparing-for-energy-shortages-and-blackouts**
PSI News – Scientific Highlights – Evaluation of European electricity supply resilience. (09.12.2022). **https://www.psi.ch/en/nes/scientific-highlights/blue-hydrogen-can-help-protect-the-climate-copy-0**
MDR Aktuell – Anschläge auf kritische Infrastrukturen (30.10.2022).
SRF 4 – So gefährdet ist die kritische Infrastruktur in der Schweiz (11.10.2022). **https://www.srf.ch/audio/srf-4-news/so-gefaehrdet-ist-die-kritische-infrastruktur-in-der-schweiz?uuid=1573b767-1b31-4db4-a48a-67d59e1a484f**
Die Zeit – Anschläge auf kritische Infrastruktur. Wie verwundbar sind wir? (06.10.2022).
Der Spiegel – Monster aus der Tiefe (01.10.2022). Print Ausgabe
Spiegel.de - Nord-Stream-Anschlag: Wie verwundbar ist unsere Energie-Infrastruktur? (Interview) (29.092022). **https://www.spiegel.de/wirtschaft/anschlag-auf-nord-stream-pipelines-interview-mit-risikoforscher-peter-burgherr-a-307f263f-1ff3-4f3d-942a-4e9b4c3bc56e**
Bulletin.ch - Mit Akzeptanz zur Energiesicherheit (13.12.2022 online, Print 1/2023) (Interview) **https://www.bulletin.ch/de/news-detail/mit-akzeptanz-zur-energiesicherheit.html**
PSI-Magazin 5232: "Sichere Energie für die Zukunft" Schwerpunktartikel in PSIs 5232 Magazin 03/2022
Panos E, Kober T, Fragkiadakis K, Paroussos L, Cellina F, Maayan J, Stadelmann I, Fuchs A, Demiray T, Zielonka N, Trutnevyte E (2022). **1st scenario protocol capturing the definition of pathway and shock scenarios**. SWEET-SURE deliverable report D2.1
Trutnevyte E., Zielonka N., Heinisch, Müller J. Sasse J.P, Wen Xin, Zhang H. (2023). **Publication on modeling spatial scenarios of disruptive growth in PV and heat pumps.** SWEET-SURE deliverable report D5.1
Fuchs A. & Demiray T. (2022.) **Report on energy grid modeling**. SWEET-SURE deliverable report D6.1
Sacchi R (2023).**Consistency across Swiss and Global Scenarios.** SWEET-SURE deliverable report D10.1
Celina F., Tardif J., Palucci M. Rudel R. (2022). Report **on local stakeholder analysis and system mapping.** SWEET-SURE deliverable report D13.1
Jakob M., Melliger M., Bagemihl J., Talary Z. (2023). **Techno-economic cost-effectiveness analysis of process heat decarbonization options**. SWEET-SURE deliverable report D15.1
Kober T., Ramachandran K., Panos E. Tsianou E.**, Project Flyer**. SWEET-SURE deliverable report D17.3
Melliger M., Jakob M., Talary Z. (2023)**. Develop a resilience and sustainability concept for the urban context**. SWEET-SURE deliverable report D14.0
Melliger M., Fuchs A., Jakob M., Talary Z. (2023). **Report on resilience and sustainability concept for the industry and the mobility sector**. SWEET-SURE deliverable report D15.4

Invited talks (scientific or broad audience)

Presenter(s), title, name of the event and location, year
Burgherr, P. (2022) Invited Presentation: **Integrated Sustainability Assessment of Energy Systems and Decision Support for the Energy Transition**. Sustainable Futures Lunch Talk, 8 April 2022, Basel, Switzerland, Hybrid Event.
Stadelmann-Steffen I. (2022) Invited Presentation: **Warum wir uns so schwer tun mit der Energietransition, presentation at the Rotary Club meeting**, 17 November 2022, Konolfingen.\\
Stadelmann-Steffen, I. (2023) **Invited Presentation and Roundtable participation: Insights aus der Akzeptanzforschung, Schweizerischer Stromkongress**, 19 January 2023, Bern.
Kober, T.: **Understanding the transformation of the energy and industry sectors towards decarbonisation,** ETH - Industry Dialogue on the Future, Nestlé Research, 2 December 2022
Kober, T. **Decarbonisation Pathways for Switzerland: Costs and the role of industry and sector coupling**, Orgalim annual meeting, Villigen PSI, 16. November 2022
Kober, T. **Netto-Null CO2 Emissionen: mögliche Transformationspfade und deren Kosten**, Sommertagung der FDP Aargau, Villigen, 7. 6. 2022
Kober, T., Michel D. Obrist, R. McKenna **Decarbonising Industry long-term transformation pathways of Swiss industry in view of a zero-carbon energy system** ETH Zürich Industry Day, Zürich, 5 Sep. 2022
Kober, T., **Long-term developments in the energy system – focus gas** Group E annual board meeting, Villigen-PSI, 14 Sep. 2022
Kober, T **Energieversorgungssicherheit im «Netto-Null-Kontext»** VSG webtalk, online, 16 March 2022

Completed PhD theses

Author, title, year
Michel D. Obrist (2022) **Long-Term Energy and Emission Pathways for the Swiss Industry.** Dissertation PSI/ETH Zürich No. 28890
Aleksandra Kim (2022) **Global Sensitivity Analysis of Life Cycle Assessment**. Dissertation PSI/ETH Zürich No. 28687

Completed master theses

Author, title, year
Zhang Haodong, Spatial diffusion of residential heat pumps in Switzerland, 2022
Antoine Desbordes, Heuristics for the robust implementation of the Choquet integral in multicriteria ranking problems, PSI LEA-TAG, 2022.
Hugo Hous: Prospective techno-economic analysis of future nuclear power in Switzerland, ETH Zürich, MAVT