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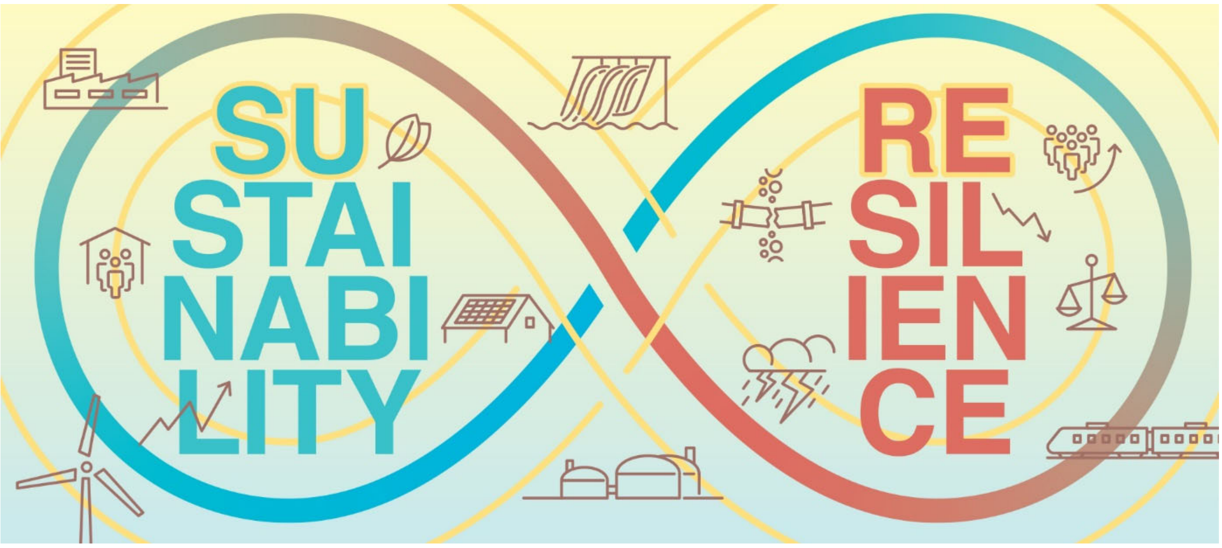
Federal Department of the Environment, Transport,
Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech

Report dated: 31.03.2024
Reporting period: 01.05.2023 – 29.02.2024

Highlights Report Year 3

SURE



sweet swiss energy research for the energy transition

Date: 31.03.2024

Location: Bern

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

SWEET Call: 1-2020

Subsidy recipient:
Host institution: PSI, Forschungsstr. 111, CH-5232 Villigen
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SFOE contract number: SI/502266-01

Highlights

The main highlights during the reporting period were the following:

- The modelling teams comprising the core of the SURE toolbox worked towards quantifying two SURE pathways (SPS1 – Team Sprint and SPS4 – Walk and Talk) and two shock scenarios (societal and weather shocks). The quantification is still ongoing, and the main achievements were: a) the verification of the feasibility of the quantification of all SURE pathways and shock scenarios, individually by each team; b) the revision of the storylines of the financial, nuclear and societal shock scenarios to make them more impactful to the economy and energy system of Switzerland; and c) the refinement and implementation of all model links and the model sequence to follow. This collective effort of almost all SURE partners resulted in a better alignment of assumptions considering the needs of the sectoral models and an improved understanding of results that can be expected, which is particularly important for the boundary conditions needed in the SURE case studies.
- During the reporting period, the SURE game was developed to its first playable version. In the game, players need to ensure that enough electricity for winter and summer is available in Switzerland by investing in renewable, fossil, and nuclear electricity production plants and implementing political measures. Besides electricity supply, players also receive information about how well they do with respect to biodiversity, land use, or public support. They are also faced with shocks they need to deal with. The game will be used for data collection, as "sophisticated information treatment" in the SURE survey, and for knowledge transfer. Distributing it to the broader public enhances the visibility of the SURE project and contributes to the population's sensitization to the sustainability and resilience of the future energy system.
- The Cantonal case study has achieved a significant milestone by translating complex qualitative hypotheses regarding the dynamic nature of the Ticino energy system structure into a computational simulation model. This was a collaborative effort with key stakeholders, ensuring the model reflects the insights gained through a participatory process. Moreover, the model development strengthened the connection between the case study and the SURE framework, as it laid the groundwork for identifying specific inputs and boundary conditions from the SURE modelling teams that are to be integrated into the cantonal model. This alignment will facilitate a harmonisation between national and cantonal energy transition strategies, enhance the credibility of the cantonal model outcomes, and pave the way for more effective energy policy interventions at both regional and national levels.
- Mrs. Lidia Stermieri completed her PhD thesis in the project's third year. The thesis focused on developing a new socioeconomic module for PSI's Swiss Energy System Model (STEM) to assess the impact of increased digital practices in society and energy production and end-use. The module, built from scratch, is an Agent-Based Model (ABM) based on social practice theory. It identifies several agents from the households, tertiary, and industry sectors of the energy system, capturing their heterogeneity in energy investment decisions and energy use. It also includes representations of societal networks, both physical and virtual ones, which influence the energy-related behaviors of these agents. Coupling it with STEM, the resulting energy system configurations account for consumer choices. Thus, the integrated framework SEED-STEM facilitates the integration of social aspects into the quantification of the SURE pathways and shock scenarios from STEM.

Faits marquants

Les principaux faits marquants au cours de la période couverte par le rapport sont les suivants :

- Les équipes de modélisation qui constituent le noyau dur du projet SURE ont travaillé à la quantification de deux trajectoires pour la Suisse (SPS1 - Team Sprint et SPS4 - Walk and Talk) et de deux scénarios alternatifs introduisant un choc (i.e., chocs sociétaux et météorologiques). Ce processus de quantification n’est pas terminé. Cependant, les étapes clés suivantes ont déjà été achevées: a) la vérification (individuellement par chaque équipe) de la faisabilité de la quantification de toutes les trajectoires et scénarios de choc; b) la révision des scénarios introduisant un choc financier, nucléaire et sociétal pour les rendre plus impactant sur l'économie et le système énergétique de la Suisse ; et c) l'affinement et la mise en œuvre de toutes les interfaces entre les modèles impliqués et la séquence de modèles à suivre. Cet effort collectif de presque tous les partenaires de SURE a permis de mieux aligner les hypothèses sur les besoins des modèles sectoriels. Il permet aussi de mieux comprendre les résultats que l'on peut attendre. Ceci est particulièrement important pour définir les conditions limites nécessaires aux études de cas définis dans le projet.
- Au cours de la période considérée, le jeu SURE a été développé jusqu'à sa première version jouable. Dans ce jeu, les joueurs doivent veiller à ce que la Suisse dispose de suffisamment d'électricité pour l'hiver et l'été en investissant dans des centrales de production d'électricité renouvelable, fossile et nucléaire et en mettant en œuvre des mesures politiques. Outre l'approvisionnement en électricité, les joueurs reçoivent également des informations sur leur performance en matière de biodiversité, d'utilisation des sols ou de soutien public. Ils sont également confrontés à des chocs auxquels ils doivent faire face. Le jeu sera utilisé pour la collecte de données, nécessaire à l'enquête SURE, et pour le transfert de connaissances. Sa diffusion auprès du grand public renforce la visibilité du projet SURE et contribue à sensibiliser la population à la durabilité et résilience du futur système énergétique.
- L'étude de cas cantonale a franchi une étape importante : les hypothèses qualitatives complexes sur la dynamicité de la structure du système énergétique tessinois ont été traduites en un modèle de simulation informatique. Il s'agit d’une collaboration avec les principales parties prenantes, assurant que le modèle reflète les connaissances acquises dans le cadre d'un processus participatif. En outre, le développement du modèle a renforcé le lien entre l'étude de cas et le cadre du projet SURE. Il a en effet aidé à identifier les apports spécifiques et les conditions limites des équipes de modélisation SURE devant être intégrés dans le modèle cantonal. Cet alignement facilitera l'harmonisation entre les stratégies de transition énergétique nationales et cantonales. Cela renforcera la crédibilité des résultats du modèle cantonal et ouvrira la voie à des interventions plus efficaces en matière de politique énergétique aux niveaux régional et national.
- Mlle Lidia Stermieri a terminé sa thèse de doctorat au cours de la troisième année du projet. La thèse s'est concentrée sur le développement d'un nouveau module socio-économique pour le modèle suisse du système énergétique (STEM) du PSI afin d'évaluer l'impact de l'augmentation des pratiques numériques dans la société sur la production et l'utilisation finale de l'énergie. Le module, entièrement conçu par Mlle Stermieri, est un modèle basé sur les agents (Agent-Based Model ou ABM, en anglais) qui repose sur la théorie de la pratique sociale. Il identifie plusieurs agents issus des ménages, du secteur tertiaire et de l'industrie du système énergétique, en tenant compte de leur hétérogénéité en matière de décisions d'investissement et d'utilisation de l'énergie. Il comprend également une représentations des réseaux sociaux, tant physiques que virtuels, qui influence les comportements de ces agents en matière d'énergie. En l'associant à STEM, les configurations du système énergétique qui en résultent tiennent compte des choix des consommateurs. Ainsi, le cadre intégré SEED-STEM facilite l’intégration des aspects sociaux dans la quantification des trajectoires SURE et des scénarios de choc du modèle STEM.

Highlights

Die wichtigsten Highlights während des Berichtszeitraums waren die folgenden:

- Die Modellierungsteams, die den Kern der SURE-Toolbox bilden, arbeiteten an der Quantifizierung von zwei SURE-Entwicklungspfaden (SPS1 - Team Sprint und SPS4 - Walk and Talk) und zwei Schockszenarien (gesellschaftliche und wetterbedingte Schocks). Während die Quantifizierung noch im Gange ist, können die wichtigsten Ergebnisse wie folgt zusammengefasst werden: a) die Machbarkeit der Quantifizierung aller SURE-Pfade und Schockszenarien wurde individuell durch jedes Team geprüft; b) die Storylines der finanziellen, nuklearen und gesellschaftlichen Schockszenarien wurden überarbeitet, um sie für die Wirtschaft und das Energiesystem der Schweiz aussagekräftiger zu machen; und c) alle Modellverknüpfungen wurden verfeinert und implementiert. Dieser kollektive Effort fast aller SURE-Partner führte zu einer besseren Abstimmung der Annahmen unter Berücksichtigung der Bedürfnisse der sektoralen Modelle und zu einem besseren Verständnis der zu erwartenden Ergebnisse, was besonders wichtig für die in den SURE-Fallstudien benötigten Randbedingungen ist.
- Im Berichtszeitraum wurde die erste spielbare Version des SURE-Spiels entwickelt. Im Spiel müssen die Spielerinnen und Spieler dafür sorgen, dass in der Schweiz genügend Strom für den Winter und den Sommer zur Verfügung steht, indem sie in erneuerbare, fossile und nukleare Stromproduktion investieren und politische Massnahmen umsetzen. Neben der Stromversorgung erhalten die Spieler auch Informationen darüber, wie gut sie in Bezug auf Biodiversität, Landnutzung oder öffentliche Unterstützung abschneiden. Sie werden auch mit Schocks konfrontiert, mit denen sie umgehen müssen. Das Spiel wird für die Datenerhebung, als "anspruchsvolle Informationsbehandlung" in der SURE-Umfrage und für den Wissenstransfer eingesetzt. Die Verbreitung des Spiels in der breiten Öffentlichkeit erhöht die Sichtbarkeit des SURE-Projekts und trägt zur Sensibilisierung der Bevölkerung für die Nachhaltigkeit und Widerstandsfähigkeit des zukünftigen Energiesystems bei.
- Die kantonale Fallstudie hat einen wichtigen Meilenstein erreicht, indem sie komplexe qualitative Hypothesen zum Tessiner Energiesystem in ein robustes Computersimulationsmodell übersetzt hat. Dies geschah in Zusammenarbeit mit den wichtigsten Akteuren, um sicherzustellen, dass das Modell die in einem partizipativen Prozess gewonnenen Erkenntnisse widerspiegelt. Darüber hinaus stärkte die Modellentwicklung die Verbindung zwischen der Fallstudie und dem SURE-Rahmen, da sie die Grundlage für die Identifizierung spezifischer Inputs und Randbedingungen der SURE-Modellierungsteams bildete, die in das kantonale Modell integriert werden sollen. Sie stimmte die nationalen und kantonalen Energiewende-Strategien aufeinander ab, erhöhte die Glaubwürdigkeit der Modellergebnisse und ebnete den Weg für wirksamere energiepolitische Interventionen auf regionaler und nationaler Ebene.
- Frau Lidia Stermieri schloss ihre Doktorarbeit im dritten Jahr des Projekts ab. Die Arbeit konzentrierte sich auf die Entwicklung eines neuen sozioökonomischen Moduls für das Schweizer Energiesystemmodell (STEM) des PSI, um die Auswirkungen der zunehmenden digitalen Praktiken in der Gesellschaft, der Energieproduktion und der Endnutzung zu bewerten. Das Modul, das von Grund auf neu entwickelt wurde, ist ein agentenbasiertes Modell (ABM), das auf der «Social Practice» Theorie basiert. Es identifiziert Akteure aus den Sektoren Haushalte, Dienstleistungssektor und Industrie des Energiesystems und erfasst deren Heterogenität bei Energieinvestitionsentscheidungen und Energienutzung. Es umfasst auch Darstellungen gesellschaftlicher Netzwerke, sowohl physischer als auch virtueller Natur, die die energiebezogenen Verhaltensweisen dieser Akteure beeinflussen. Durch die Verknüpfung mit STEM berücksichtigen die resultierenden Energiesystemkonfigurationen die Entscheidungen der Verbraucher. Somit erleichtert der integrierte Rahmen SEED-STEM die Integration sozialer Aspekte in die Quantifizierung der SURE-Pfade und Schockszenarien von STEM.

Punti salienti

I punti salienti (risultati, sfide, insegnamenti, ecc.) del periodo di riferimento sono stati i seguenti:

- I team di modellazione che costituiscono il nucleo di SURE hanno lavorato per quantificare gli scenari relativi a due percorsi (SPS1 - Team Sprint e SPS4 - Walk and Talk) e due shock (shock societari e meteorologici). La quantificazione è ancora in corso e i principali risultati sono stati: a) la verifica della fattibilità della quantificazione di tutti i percorsi e degli shock di SURE, individualmente da parte di ciascun team; b) la revisione delle narrative degli scenari di shock finanziario, nucleare e sociale per renderli più impattanti per l'economia e il sistema energetico della Svizzera; e c) il perfezionamento e l'implementazione di tutti i collegamenti fra modelli e la sequenza di modelli da seguire. Questo sforzo collettivo di quasi tutti i partner SURE ha portato a un miglior allineamento delle ipotesi rispetto alle esigenze dei modelli settoriali e ad una migliore comprensione dei risultati che ci si può attendere. Questo è particolarmente importante per le condizioni al contorno necessarie nei casi di studio SURE.
- Durante il periodo di riferimento, il gioco SURE è stato sviluppato fino alla sua prima versione. Nel gioco, i partecipanti devono garantire che in Svizzera sia disponibile elettricità sufficiente per l'inverno e l'estate, investendo in impianti di produzione di energia elettrica da fonti rinnovabili, fossili e nucleari e attuando misure politiche. Oltre alla fornitura di elettricità, i giocatori ricevono anche informazioni sul loro operato in termini di biodiversità, utilizzo del territorio e sostegno pubblico. Devono anche affrontare degli shock. Il gioco sarà utilizzato per la raccolta dei dati, come "trattamento informativo sofisticato" nell'indagine SURE e per il trasferimento delle conoscenze. La distribuzione al grande pubblico aumenta la visibilità del progetto SURE e contribuisce alla sensibilizzazione della popolazione sulla sostenibilità e la resilienza del futuro sistema energetico.
- Il caso di studio cantonale ha raggiunto un traguardo significativo, traducendo in un modello di simulazione computazionale le complesse ipotesi qualitative sulla natura dinamica della struttura del sistema energetico ticinese. Si è trattato di uno sforzo di collaborazione con i principali stakeholder, che ha garantito che il modello riflettesse le intuizioni acquisite attraverso un processo partecipativo. Inoltre, lo sviluppo del modello ha rafforzato la connessione tra il caso di studio e il quadro SURE, in quanto ha posto le basi per l'identificazione di input e condizioni al contorno specifici dei team di modellazione SURE che devono essere integrati nel modello cantonale. Questo allineamento faciliterà l'armonizzazione tra le strategie di transizione energetica nazionali e cantonali, aumenterà la credibilità dei risultati del modello cantonale e aprirà la strada ad interventi di politica energetica più efficaci sia a livello regionale che nazionale.
- Lidia Stermieri ha completato la sua tesi di dottorato nel terzo anno del progetto. La tesi si è concentrata sullo sviluppo di un nuovo modulo socioeconomico per il Modello del Sistema Energetico Svizzero (STEM) del PSI, al fine di valutare l'impatto dell'aumento delle pratiche digitali nella società e nella produzione e utilizzo finale dell'energia. Il modulo, costruito da zero, è un Agent-Based Model (ABM) basato sulla teoria delle pratiche sociali. Il modulo identifica diversi agenti dei settori domestico, terziario e industriale del sistema energetico, catturando la loro eterogeneità nelle decisioni di investimento e nell'uso dell'energia. Include anche rappresentazioni delle reti sociali, sia fisiche che virtuali, che influenzano i comportamenti energetici di questi agenti. Grazie al collegamento con STEM, le risultanti configurazioni del sistema energetico tengono conto delle scelte dei consumatori. Pertanto, il quadro integrato SEED-STEM facilita l'integrazione degli aspetti sociali nella quantificazione dei percorsi SURE e degli scenari di shock di STEM.

1 Highlights of the reporting period

The following three highlights showcase pivotal milestones and promising intermediate results within the SURE project’s dynamic framework, marking significant progress in ongoing efforts.

Highlight 1 – Model quantification

A major achievement in the current reporting period was the extensive collaboration between the modelling teams comprising the SURE toolbox to quantify two SURE pathways and two shock scenarios. The steps taken towards this achievement were a) to verify the feasibility of quantifying the SURE pathways and shock scenarios from all models in the SURE toolbox; b) to revise the storylines or assumptions for those shocks or intensities in which the first model results indicated minimal impacts to the Swiss economy or the energy system; c) to define, refine and ultimately implement the model links and the model run sequence for performing the quantification. This is a collective effort from all SURE partners, which enforced the exchanges between them.

What the quantification is about. Modelling quantification involves translating the assumptions of the overarching SURE scenarios (pathways and shocks) into concrete input for each of the models in the SURE toolbox, solving the models and producing a consistent set of results about the future configuration and transformation of the energy system, the macro-economic impacts of this transformation and the overall sustainability and resilience of the Swiss energy system and economy. A balance between consistency and complexity needs to be maintained throughout the quantification process because of the multitude of different modelling frameworks employed that exchange inputs and outputs with each other. At the same time, the modelling quantification could require deriving additional input assumptions or improving the definition of the SURE scenarios’ storylines by introducing additional elements into them. Ultimately, all obtained results coherently represent and reflect the storyline of the scenario that was quantified by the SURE toolbox and support the stakeholder-informed MCDA based on sustainability and resilience indicators of the Swiss energy system and economy. In the current reporting period, two pathways, SPS1 (Team Sprint) and SPS4 (Walk and Talk), are under quantification, together with the societal and cold spell shock scenarios that are applied to these two pathways. SPS1 aims to achieve net-zero emissions in 2050, assuming the world adopts a collective effort to mitigate climate change. On the other hand, SPS4 is a pathway that extrapolates current energy and climate policies and supply and consumption patterns and trends. These two pathways were quantified first because a) SPS2 and SPS3 are variants of SPS1, and b) SPS4 will serve as a benchmarking pathway for SPS1 - SPS3.

How we got there. Before starting the quantification process for the two pathways and shock scenarios, several intermediate but extremely important milestones needed to be completed. First, the feasibility of quantifying the SURE pathways and shock scenarios was verified for each model in the SURE toolbox. This was achieved by performing two test cases: one in November 2023 to prove the feasibility of the four pathway scenarios and one in January 2024 to ensure that the quantification of the five shock scenarios is also feasible. The latter case also served as a first benchmark for the models' responses to the shocks. This led to the complete redefinition of the financial shock, from exchange rates to interest rates, as the original version of the shock was not impactful enough due to the openness of the Swiss economy. The revised financial shock is global in scope, which was not the case in its original version. The nuclear shock needed to be refined to highlight its political dimension and to reflect the uncertainty in the energy markets and investors when new nuclear power plants are an option to invest in Switzerland, but financial support from the government is not guaranteed. Such a fluid situation can stagnate both the deployment of nuclear and renewable energy.

The next important milestone was the definition, refinement, and development of the interfaces between all the models that exchange data with each other. The aim was to ensure consistency, acknowledge the different philosophies and scopes, and maintain their strengths. The approach followed is based on three main principles: a) integrating output from a more detailed model to a more aggregated model; b) introducing reduced forms of the constraints included in a more detailed model to a more aggregated model; and c) eliminating any overlaps when two models produce the same output. Examples of the first case are the direct substitution of the energy system configuration in the Computable General Equilibrium model GEM-E3-CH by the energy supply and consumption mixes and investments from the Partial Equilibrium Energy System model STEM or the substitution of the energy service demands and consumption mixes in the buildings sector of STEM by the ones calculated by the Building Stock Model BSM. Examples of the second case are the direct integration of the electricity transmission grid constraints from the electricity network model FlexECO into STEM and the spatially detailed EXPANSE electricity model. Suitable convergence criteria needed to be defined as well. These were established at the gross sectoral economic output (for the exchanges between GEM-E3-CH and STEM) and buildings' energy consumption (for the exchanges between STEM and BSM). No convergence criteria were required for the exchanges between STEM, EXPANSE and FlexECO, as practically no iterations occurred between these frameworks – in the unlikely case that FlexECO captures a violation of an electricity grid transmission constraint that is not present in STEM or EXPANSE, then an iteration by relaxing this constraint in these models will be required. An example of eliminating overlaps is the link between STEM and EXPANSE regarding the electricity sector, with the latter receiving the national electricity production mix from STEM as a boundary condition and performing a spatial allocation of it at the municipality level that FlexECO requires.

Regarding the model run sequence during the quantification, a top-down approach is followed for the SURE pathways and the disruptive financial, nuclear, and societal shocks: STEM runs first, followed by GEM-E3-CH, and then BSM, while EXPANSE and FlexECO are involved after STEM, GEM-E3-CH and BSM have converged. However, for the transient shocks of the cold spell and heat wave, a "bottom-up" approach was more suitable: FlexECO and EXPANSE run first by considering the extreme weather events, followed by BSM, STEM and GEM-E3-CH.

What the modelling will be used for. The output from the modelling quantification will be used to assess the sustainability and resilience of different configurations of the Swiss energy system, which is the outcome of national and international energy and climate policy developments. It will also form the basis for deriving policy recommendations for sustainable and resilient energy supply and consumption. It will also be used to calculate indicators for elicitation of stakeholder preferences regarding a sustainable and resilient transformation of the Swiss energy system. Figures 1-6 present some results from the different models of the SURE toolbox for the SPS1 and SPS4 scenarios, emphasising indicators for the MCDA analysis. What is shown is only a subset of the results produced by integrating several different frameworks in SURE.

Challenges identified: The model quantification also highlighted several challenges to be addressed in the next year of SURE. First, there is a need for more automation in the model exchanges. To this end, a prototype platform has been designed and tested but has not been fully exploited by the modelling teams because the priority for this year was on establishing robust interfaces. The second challenge is the need for continuous quality control of the results obtained at all stages of the model interactions to avoid delays during the quantification of the SURE scenarios. This also includes the need for a better versioning control system as a part of the prototype platform that has been developed. The third challenge is the development of suitable communication and dissemination strategies in SURE with close collaboration with the modelling teams. These strategies aim to communicate the results and provide the necessary context for correctly interpreting them, given the complexity of the analysis in SURE.

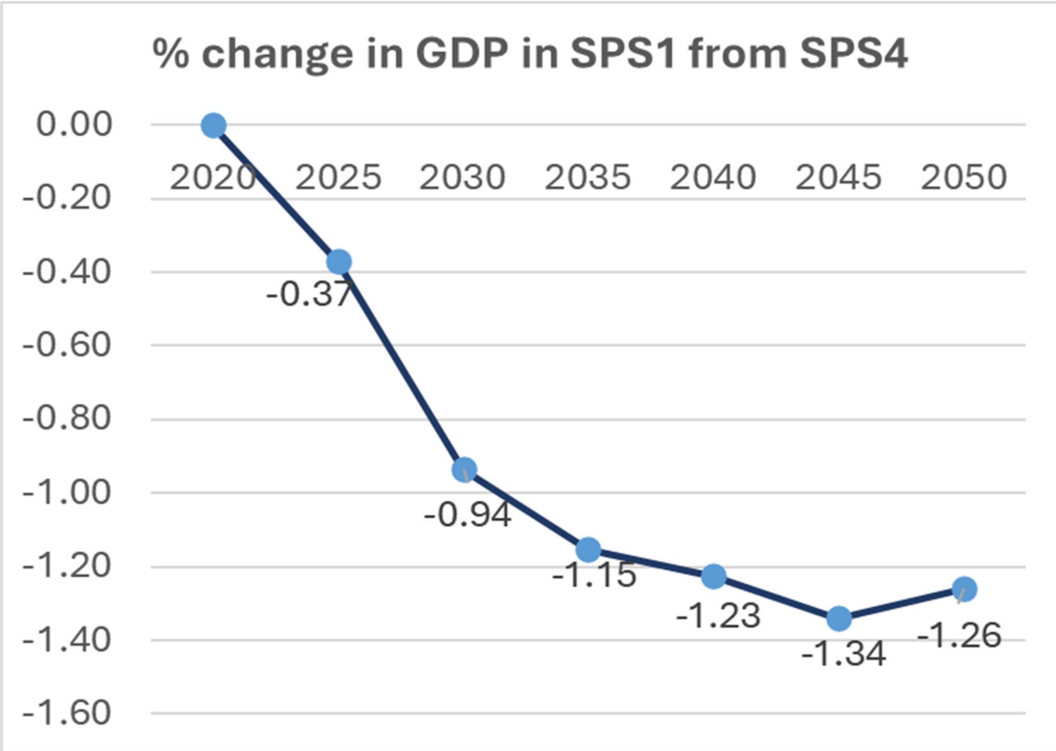

Figure 1: GEM-E3-CH – macroeconomic impacts.

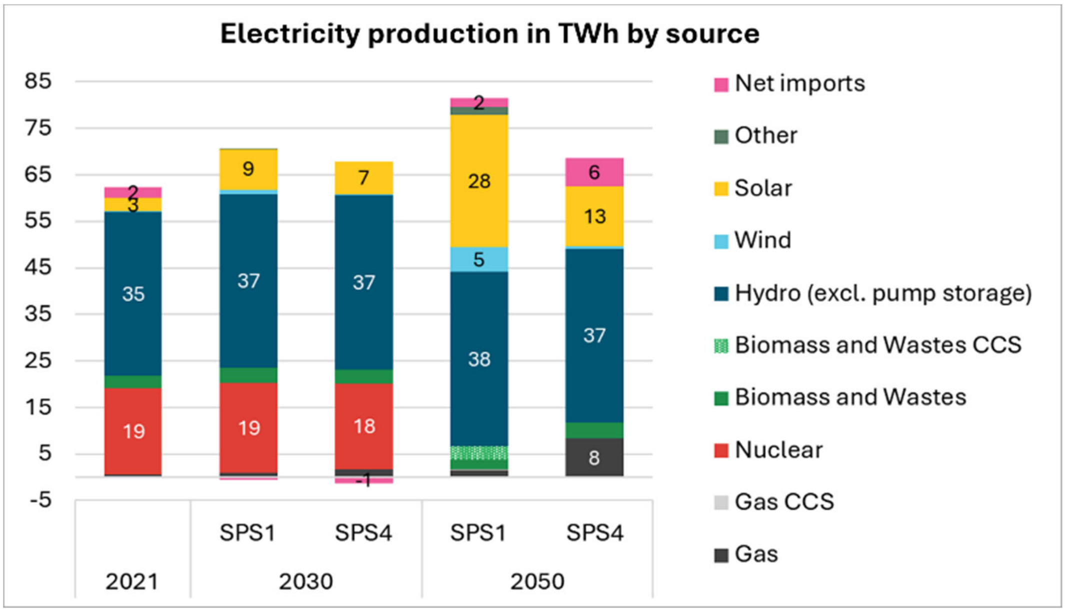

Figure 2: STEM – electricity supply mix.

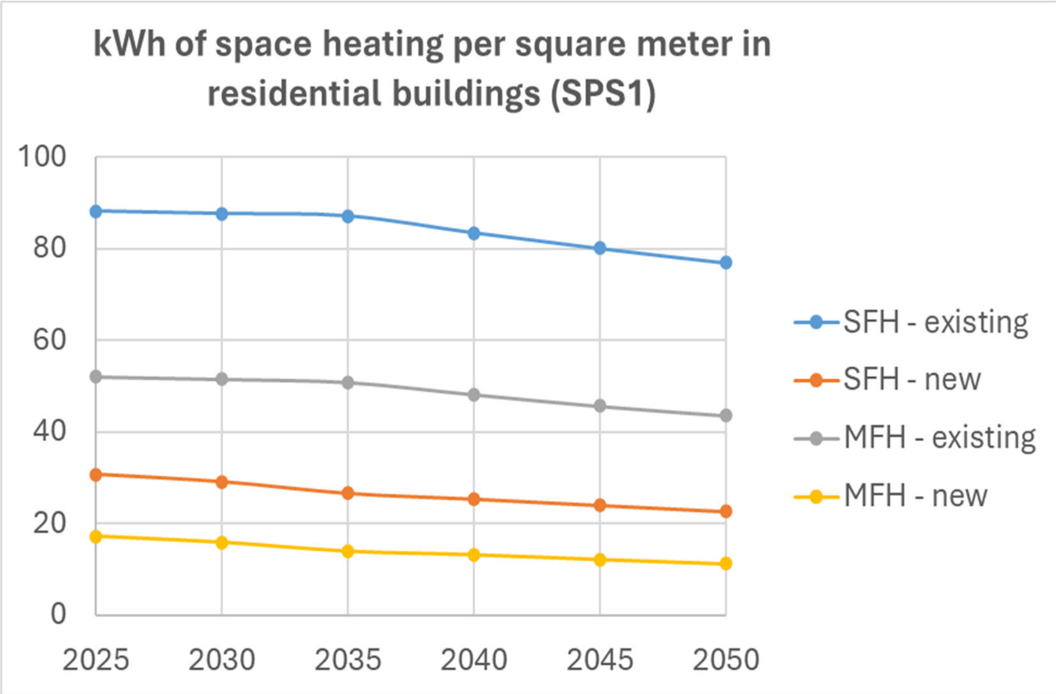

Figure 3: BSM – heating demand per type of building

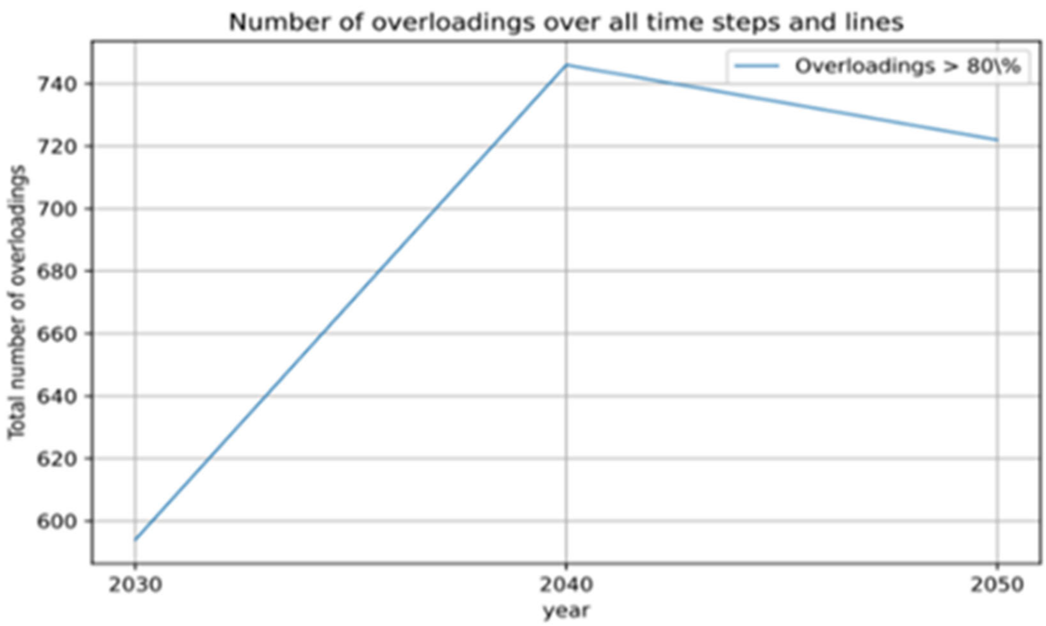

Figure 4: FlexECO – number of electricity lines overloaded in SPS1. Reduction of the number of overloaded lines due to increased decentralized electricity.

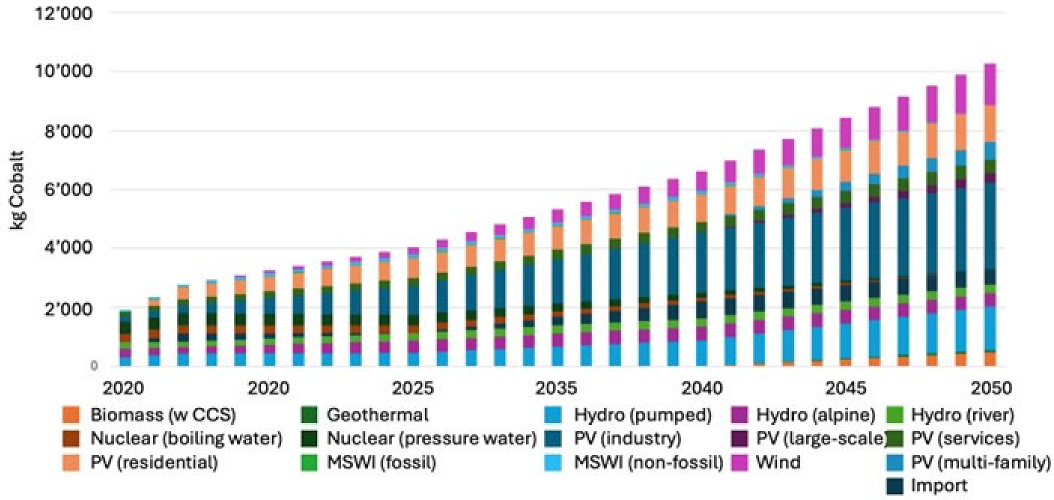

Figure 5: Life cycle-based cobalt demand (in kg) for the Swiss electricity supply, by power technology, for SPS1.

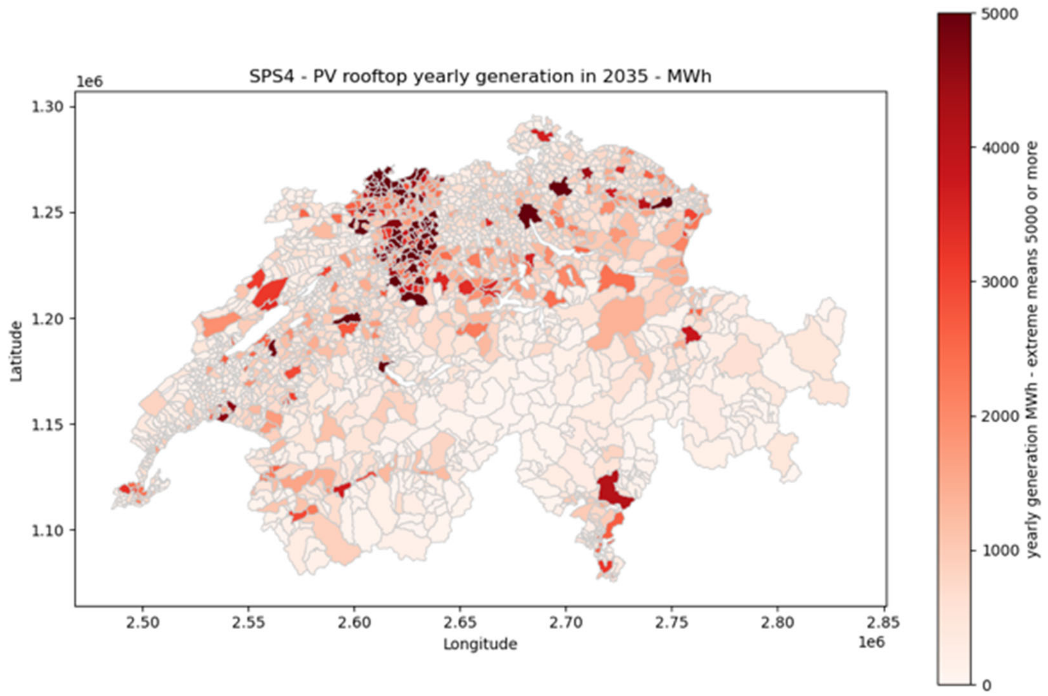

Figure 6: EXPANSE – Regional-based analysis and annual electricity generation of solar PV on rooftops in SPS4.

Highlight 2 – The SURE game *Ensured*

During the reporting period, the SURE game has been developed to the point where the first playable version is now available (Figure 7). It can be accessed at **https://astonedf.itch.io/ensured-energy**. As a first test, we presented the game – which we provisionally named *Ensured* – at the “Nachhaltigkeitstag der Berner Hochschulen” in November 2023, during which the public could play the game. On the one hand, the feedback was positive, with many players enjoying the game and showing interest in the topic and the game as such. On the other hand, this event provided us with valuable insights and feedback about where to improve. In year 4, the game will be finalized.

Figure 7: Screenshot of the game frontend (still in development).

What the game is about. In the game, players are responsible for providing electricity in Switzerland. The game begins by presenting the player with a representation of the energy system of Switzerland in the present day based on the official SFOE statistics. As an experimental element, the framing of the game introduction varies between a control and a treatment group: Whereas the control group is introduced to the game mainly from an energy supply perspective, the treatment group is more framed explicitly towards the sustainability of the system, namely the net zero target. Subsequently, over several periods from 2024 to 2050, players need to ensure enough electricity for winter and summer is available. To do so, they have a budget to invest in varying electricity production plants (renewable, fossil, and nuclear), which involve varying costs, construction periods, electricity production, and electricity import (for winter). For example, while solar plants mainly produce electricity in summer, wind plants provide electricity in winter. Besides electricity supply, players also receive information about how well they do (per period) with respect to biodiversity, land use, or public support. They can also implement political measures, e.g., to reduce electricity consumption or sensitize the public. Additionally, in every period, players are randomly assigned a shock (one of the SURE shocks), which typically requires an immediate decision by the player. In sum, players in the game face several challenges, options, and trade-offs in which they need to make decisions. In the end, they are shown the result of their decisions by 2050 with respect to CO_2 emissions, costs, biodiversity, land use and popular support.

How we got there. The game's development has been a showcase example of interdisciplinary collaboration and related challenges. It combines relevant inputs from computer scientists, energy modellers, game designers, and political scientists based on intense and repeated interaction and relies on many rounds of iterations and cross-checks. The main challenge has been to find a compromise between what the political scientists suggested to have in the game to have a “world” as realistic as possible, what the computer scientists and modellers could implement technically, and what the game designers thought would make the game an attractive game. The latter, for example, led to the important decision that players in the game shall not act as individual citizens (e.g., deciding on their personal situation only) but as a “minister” responsible for Switzerland’s electricity supply. This means we will not observe “individual behaviour” in the game, but it makes it more interesting because it enables us to investigate how players deal with decisions that affect the collective good and their situation (in the game, they can lose public support if they make a “bad decision”).

What the game will be used for. The game will fulfil three main purposes. First, it will be used for *data collection*. When playing the game, players are repeatedly faced with decisions that are registered in the background and can be analysed. Second, the SURE game can also be seen as a “*sophisticated information treatment*”. Hence, by playing the game, players learn about the challenges related to the energy transition, the trade-offs, and potential solutions. We want to analyse how far this learning affects individual preferences and the acceptance of future energy systems. Third, the SURE game will also be used for *knowledge transfer*. It is based on the SURE models and, thus, presents different pathways for the Swiss energy system until 2050 in an accessible and illustrative way. Distributing it to the broader public can contribute not only to the visibility of the SURE project but also to the population’s sensitization to the sustainability and resilience of the future energy system.

Highlight 3 – The Cantonal case study of Ticino

Over the past year, the Cantonal case study of Ticino has achieved significant milestones, marking notable progress in two key areas; 1) establishing and strengthening connections between the case study and the overarching SURE framework and 2) converting the qualitative dynamic hypotheses, crafted with the Ticino Core Stakeholder Group, into a System Dynamics simulation model.

What the model is about. The simulation model aims to replicate the dynamic shifts within Canton Ticino's energy landscape up to 2050. By design, the methodical development of the simulation model builds upon regular structured exchanges with a Ticino Core Stakeholder Group, comprising 7-10 participants with high interest and influence on the cantonal energy system and its decarbonization pathways (**https://sweet-sure.ch/publications/**).

How we got there. Beginning with a meticulous system mapping exercise involving the Ticino Core Stakeholder Group, a qualitative hypothesis on the cantonal energy system dynamics emerged. Subsequently, emphasis was placed on translating this understanding into a computational simulation model, starting from the residential sector, as it is the largest energy consumer in Ticino. The residential sector module achieves granularity by categorizing Ticino's residential building stock into 10'800 representative archetypes, considering diverse attributes such as physical building properties, sub-cantonal geographical locations, presence of photovoltaic systems, and type of heating solution. Each archetype exercises agency in adopting heating technologies and photovoltaics during simulation runs, subject to the perceived utility of the technology. The residential sector simulation model holds profound significance in assessing the specific impacts of policies, as it can provide insight into the reach of each policy instrument for different types of dwellings, as well as an aggregated picture of the overall progress towards achieving regional decarbonisation goals. Moreover, its feedback loop structure allows for the evaluation of co-adoption patterns. An example is illustrated in Figure 8, where the application of the regulatory framework outlined by the Model Cantonal Regulations in the Energy Sector (MoPEC/MuKEN), mandating a certain percentage of renewable energy usage for heating, not only influences the adoption rate of heat pumps but also triggers ripple effects, resulting in an 11% increase in photovoltaic system adoption compared to scenarios where MoPEC is not enforced.

Throughout the Ticino model development, careful consideration was given to the interconnections between the cantonal case study and the SURE modelling work packages, recognizing their crucial role in providing quantitative inputs and boundary conditions to the TI model for each pathway and shock. This strategic collaboration between the case study and other work packages facilitates the alignment and coherence of national and cantonal energy transition strategies.

What the model will be used for. The System Dynamics-based model is a versatile platform for simulating policy interventions and projecting potential outcomes through scenario analysis. It enables explicit simulation of various policy instruments (e.g., subsidies, taxes, regulations), facilitating estimation of their effectiveness in achieving desired targets. Incorporating global sensitivity and uncertainty analysis techniques enhances decision-making support for the Ticino Core Stakeholder Group. This ensures better navigation through uncertainties related to model inputs, structure, and outcomes, thereby increasing the stakeholders' trust in the model results. Thus, the Cantonal case study of Ticino continues to spearhead a participatory planning approach towards sustainable energy transition. The current residential model will be expanded to encompass all the other energy sectors identified with the Ticino Core Stakeholder Group, fostering informed decision-making and strategic policy formulation.

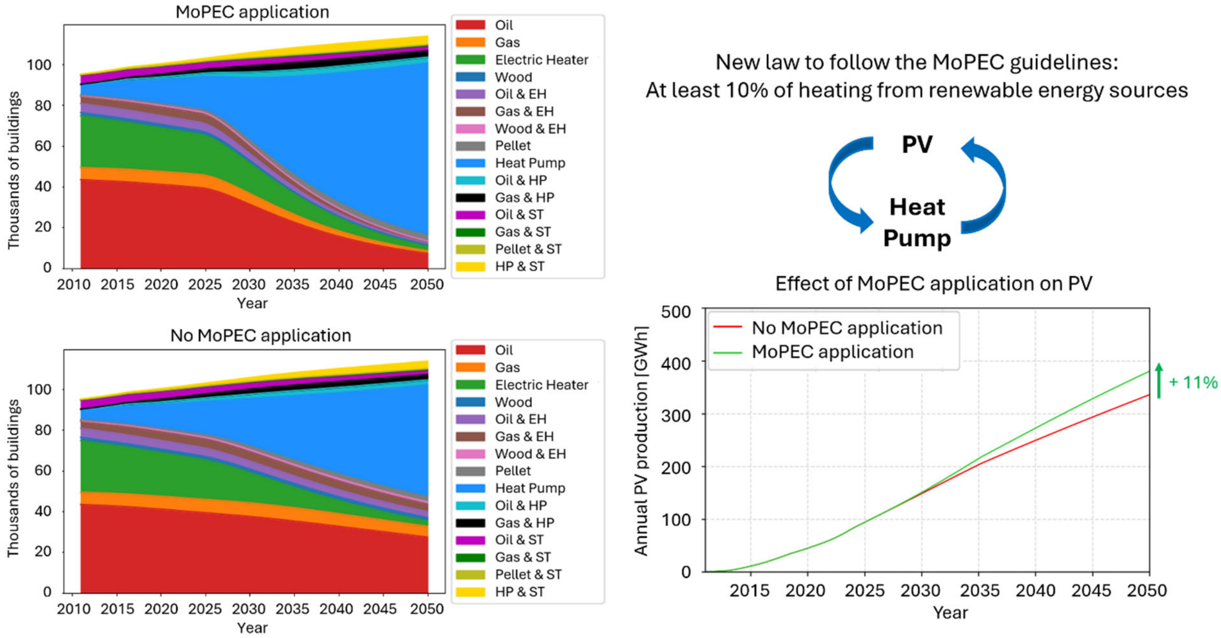

Figure 8: Example of testing policies with the model - evolution of the residential heating solutions with (top left) and without (bottom left) the application of MoPEC, and the influence of the application of the MoPEC on the adoption of PV (bottom right).

Highlight 4 – SEED: A socioeconomic energy model for digitalisation

Within the third year of the project, Mrs Lidia Stermieri completed her PhD thesis[1]. The focus of the thesis was the development of a new socioeconomic module for the Swiss Energy System Model (STEM) of PSI to assess the impact of increased digital practices in society (e.g., home-office, e-learning, e-banking) and increased digitalisation in the production and end-use of energy (e.g., smart homes and smart meters) on the Swiss energy transition. The module was built from scratch, belongs to the class Agent-Based Models (ABM), and is based on social practice theory.

What the model is about. The Socio-Economic Energy Model for Digitalization (SEED) quantifies digitalisation's impacts on technology investment choices, energy consumption, and emissions in different energy sectors. SEED represents the heterogeneity of decision processes of the various actors in the energy sectors (households, sub-sectors of the services sector, and industries) to analyse synergies and interactions in adopting low energy-consuming digital services and practices induced by digitalisation (the so-called spillover effects). The new digital practices in households can accelerate the diffusion of e-services in the services sector (and vice versa). In addition, the adoption of digital technologies by households and services sub-sectors can also trigger further diffusion of digital technologies for process optimisation in industry. When households embrace new digital practices, their mobility needs, and residential end energy use change, too, altering their investment decisions in transport and residential technologies. Figure 9 shows an overview of SEED:

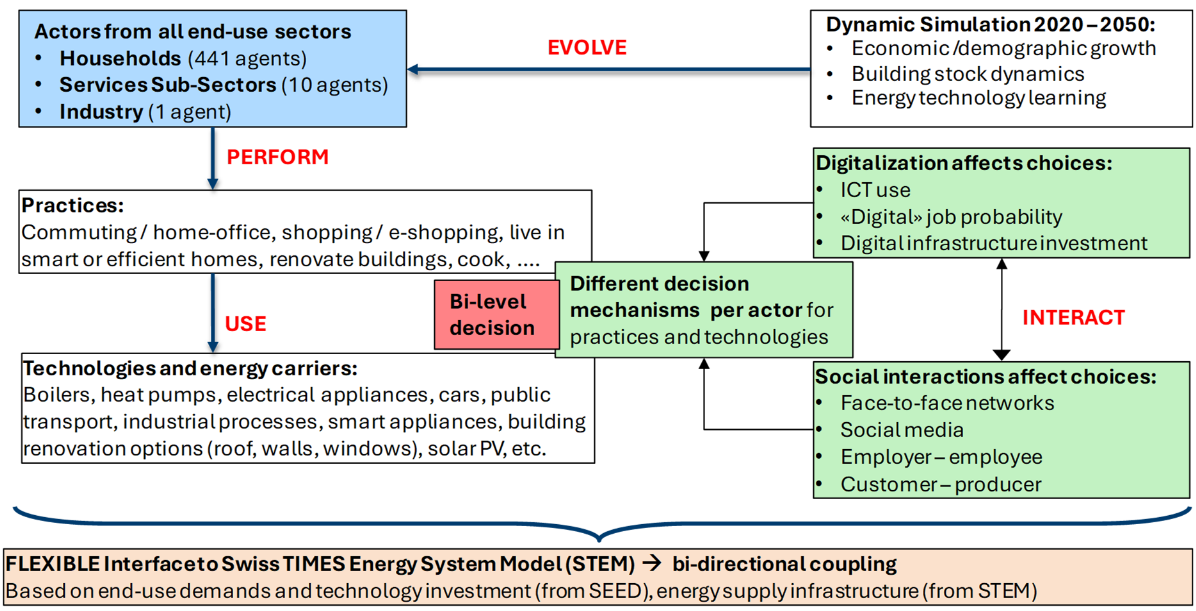

Figure 9: Schematic overview of SEED.

SEED comprises several agents: Households, tertiary Sub-sectors, and Industry – the agents in this text are identified by a capital first letter. Households perform social practices to fulfil essential needs by utilising technologies that consume energy. They base their decisions by comparing costs, preferences, and availability of practices and technologies. However, preferences can be changed by interactions among Households in their social networks ("social media" and "face-to-face" networks). Households interact with the tertiary Sub-sectors by working for them (employees – employer relationship) or when adopting their services (consumer – Sub-sector relationship). Each Sub-sector agent represents one of the main service sectors: Education, Health, Commerce, IT, Real Estate, Hospitality, Insurance, Research, and Bank(ing). The objective of the Sub-sector agents is to minimise costs by considering the

[1] Stermieri, L. (2023), Digitalization's Role on Decarbonized Swiss Energy and Social Systems: A New Agent-Based and Energy System Framework. Dissertation PSI/ETH Zürich No 29480. https://doi.org/10.3929/ethz-b-000647171.

needs of employees and customers. When sub-sector agents select the most cost-efficient way to provide their products and services, they can enable or hinder Household agents from performing digital practices. For example, by adopting the e-commerce service, they would allow Households to perform the practice of e-shopping. The digitalisation level of the services Sub-sector agents serves as a proxy for the digitalization level of the industry sector agent, and, in this context, the two agents exchange information on digitalization. It should be noted that while the model has several Household and service Sub-sector agents, there is only one (aggregated/representative) agent for the industry in the current version of the model. This is to be improved in a future version. SEED proceeds in annual time steps covering the period from 2020 to 2050 for Switzerland.

How we got there. The potential for energy demand reduction enabled by the digitalisation of social practices and services is of great relevance for the decarbonisation of Switzerland, given the limited domestic and national resources. At the same time, SURE provides additional insights regarding social acceptance and transformation of society to support the energy transition, which cannot be included in STEM without a suitable module that has a representation of the societal systems (both physical, i.e., peer-to-peer networks, and virtual, i.e., the various online social media). Hence, by performing a systematic literature review on the new societal and energy behaviours resulting from the increased use of Information and Communication Technology, it became apparent that a new framework is needed for STEM that not only captures these changes in consumer behaviour but also accounts for cross-sectoral interdependencies as energy saving gains in one sector could result in undesirable rebound effects in another industry. SEED was developed with its soft coupling with STEM in mind to translate these changes into broader impacts for the energy system, including the energy transformation and upstream sectors. In this regard, the co-evolution of society and the energy system could be assessed to achieve Switzerland's long-term energy and climate change mitigation goals.

What will the model be used for. The advanced SEED-STEM model was applied to scenario analyses in the context of the thesis, which were published in a peer-reviewed paper[2]. These scenarios compare different evolutions of digitalisation in Switzerland. The insights gained from this analysis show that digitalisation can support the co-evolution of society and the energy system towards net-zero targets and enable emissions cuts. In particular, the application shows that an accelerated diffusion in the society of digital practices, digital technologies, and digital services results in overall energy consumption reductions and cumulative savings in the total energy system costs compared to a scenario with digitalisation frozen at the 2020 level. The analysis also showed that adopting digital practices results in financial savings for the population that can be used for investing in low-carbon and more efficient technologies in the transport and residential sectors. Still, the heterogeneity in the population's decisions to invest in new technologies requires targeted policies for households with different socioeconomic characteristics.

The integrated framework SEED-STEM will be used in the next quantification round of the SURE pathways and shock scenarios to quantify the interdependencies between different actors in the energy transition (citizens, companies, and industry). Hence, the long-term SURE pathway scenarios will be assessed by accounting for consumer preferences, energy supply, resources, technology constraints, and different energy and climate change mitigation policies. In addition, input regarding legal, political and behavioural aspects will be integrated into STEM.

[2] Stermieri, L., Kober, T., McKenna, R., Schmidt, T., Panos, E. (2023). Impacts of digitalization and societal changes on energy transition: a novel socio-techno-economic energy system model. Energy Strategy Reviews, Volume 50, 101224. https://doi.org/10.1016/j.esr.2023.101224.

2 Outputs of the reporting period

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Invited talks
Siskos, E. **A participatory group decision making framework to evaluate the Swiss energy transition,** 95th meeting of the EWG on MCDA, Jaen, Spain, 13-15 April 2023.
Tsianou, E. **Musical Chairs as Commons: The Resource Challenge,** Berufswahlschule District of Horgen, 30 June 2023.
Burgherr, P. **Geopolitics of the Global Energy Transition** (Invited Expert Lecture), Nordic Pine 23 – Tabletop Exercise on Hybrid Threats to Renewable Energy Systems: Cyber and Malign Influence, fully distributed (physical & online), 19-21 Sep 2023.
Burgherr, P., **Hybrid Threats and Critical Energy Infrastructure in the Context of the Energy Transition** (Invited Plenary Lecture), CRITIS 2023 – 18th International Conference on Critical Information Infrastructures Security, Helsinki, Finland 13-15 Sep 2023.
Müller, R. P. **Legal bases for electricity supply: Regulations, markets and shocks SWEET SURE**, General Assembly, 17 March 2023.
Müller, R. P. **The changing role of energy companies in Switzerland Swiss Energy Law Association** (SELA), General Assembly 21 September 2023.
Kober, T. **Forschung für die Energiewende**, 2 September 2023

Completed PhD theses
Stermieri, L. (2023**), Digitalization's Role on Decarbonized Swiss Energy and Social Systems: A New Agent-Based and Energy System Framework.** Dissertation PSI/ETH Zürich No 29480. https://doi.org/10.3929/ethz-b-000647171.

Completed master theses
Metzger, D. **Identification and evaluation of policy measures for the Swiss energy transition.** Paul Scherrer Institut (PSI) & ETH Zurich, Jul 2023 – Feb 2024.
Zhang, H. **Spatial diffusion of residential heat pumps in Switzerland.** University of Geneva, 2023.

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Open-access datasets:
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