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ProdUse

Closing the gap between model-based energy scenarios and its potential users to support evidence-based decision-making for the transformation of the Swiss energy system

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sweet swiss energy research for the energy transition

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Summary

Model-based energy scenarios play an important role in many research projects. Energy scenarios promise to not only advance the scientific understanding of the energy future, but to support decision-makers in energy policy and industry. Evidence of this decision-support function is rare. This lack is often attributed to the complexity of energy scenarios and an insufficient consideration of user needs by the modelling communities developing energy scenarios. Based on interviews and surveys among both energy system modellers and potential scenarios users, ProdUse provides an empirical evaluation of the modeller-user interface in the Swiss context. The results confirm the general relevance and acceptance of energy scenarios as key tools for projecting and analyzing the energy future in academia and beyond. However, non-academic use-cases are much more rare than academic ones, as there are a range of barriers for them. Most importantly, the way in which energy scenarios are communicated primarily addresses scientific (academic papers) and modelling (technical reports) purposes. For users seeking a scientifically-derived information basis that is synthesized for their particular context of use, suitable energy scenario products are often missing. Additionally, there is a misalignment between what modellers offer, and what users want in terms of scenario content. For example, while modellers are stressing the values of techno-economic characteristics, most users would like to see more social and behavioral aspects represented in energy scenarios. Besides a need to align scenario communication efforts and scenario content between modellers and users in the future, the results also indicate that there are contrasting understandings of what energy scenarios represent and should provide. This is best exemplified by a strong user request for probabilities, while modellers point to the what-if logic as a fundamental aspect of scenario analyses. Similarly, while users expect more guidance on how to interpret energy scenarios, modellers tend to view themselves as neutral providers of scientific information. Participatory scenario development processes are often mentioned as potential ways to improve the modeller-user interface, but such exercises are highly resource-intensive for both modellers and users. This is why ProdUse included two case studies trying to communicate scenario-based information to audiences without a direct involvement between modellers and users. Such efforts are largely missing to date, hindering the embedding of energy scenarios in the societal discourse about the energy future. While energy scenarios and associated modelling approaches have become more detailed and complex in the last decades, our understanding of their usability is still in its early stages.

Zusammenfassung

Modellbasierte Energieszenarien spielen in vielen Forschungsprojekten eine wichtige Rolle. Energieszenarien wecken dabei die Erwartung, nicht nur das wissenschaftliche Verständnis der Energiezukunft zu verbessern, sondern auch Entscheidungstragende in der Energiepolitik und -industrie zu unterstützen. Belege für diese entscheidungsunterstützende Funktion sind rar. Dies wird häufig zurückgeführt auf die Komplexität von Energieszenarien und eine unzureichende Berücksichtigung der Nutzerbedürfnisse durch die Modellierungscommunity, welche die Energieszenarien entwickelt. Basierend auf Interviews und Umfragen unter Energiesystemmodellierenden und potenziellen Szenariennutzenden liefert ProdUse einen empirisch fundierten Überblick darüber, wie Energieszenarien im Schweizer Kontext produziert und genutzt werden. Die Ergebnisse bestätigen die Relevanz und Akzeptanz von Energieszenarien als Schlüsselinstrumente für die Projektion und Analyse der Energiezukunft in der Wissenschaft und Paxis. Für die meisten Anwendungsfälle sind jedoch nicht-

akademische Nutzergruppen die Ausnahme. Für diese nicht-akademischen Nutzenden gibt es eine Reihe von Hindernissen. Eine zentrale Hürde ist die bestehende Art und Weise, in der Energieszenarien kommuniziert werden. Bisher ist die Szenariodokumentaion und -Kommunikation in erster Linie auf wissenschaftliche (akademische Artikel) und Modellierungszwecke (technische Berichte) ausgerichtet. Für Nutzende, die eine wissenschaftlich gestützte Informationsbasis für einen konkreten Anwendungsfall suchen, fehlen geeignete Produkte. Darüber hinaus gibt es eine Diskrepanz zwischen dem, was die Modellierungscommunity anbietet, und dem, was sich die Nutzenden in Bezug auf den Inhalt der Szenarien wünschen. Während Modellierende sich beispielsweise auf techno-ökonomische Aspekte fokussieren, wünschen sich die meisten Nutzenden, dass in den Energieszenarien mehr soziale und verhaltensbezogene Aspekte integriert werden. Die Ergebnisse von ProdUse zeigen nicht nur, dass es wichtig ist bei der Entwicklung und der Kommunikation von Szenarien besser auf die Bedürfnisse der Nutzenden zu achten. Sie zeigen auch, dass es sehr unterschiedliche Auffassungen darüber gibt, was Energieszenarien repräsentieren und beinhalten sollen. Dies offenbart sich etwas beim starken Wunsch der Nutzenden nach Eintretenswahrscheinlichkeiten von einzelnen Szenarien, während Modellierende auf die was-wäre-wenn-Logik als grundlegenden methodischen Aspekt von Szenarioanalysen hinweisen. Während die Nutzenden darüber hinaus mehr Anleitung zur Interpretation von Energieszenarien erwarten, sehen sich die Modellierenden eher als neutrale Anbieter wissenschaftlich fundierter Informationen. Partizipative Szenarioentwicklungsprozesse werden oft als Möglichkeit zur Verbesserung der Schnittstelle zwischen Modellierenden und Nutzenden genannt, aber diese sind für beide Akteursgruppen sehr ressourcenintensiv. Aus diesem Grund hat ProdUse zwei Fallstudien einbezogen, in denen versucht wurde, szenariobasierte Informationen an ein Publikum zu vermitteln, ohne dass es zu einem direkten Austausch zwischen Modellierenden und Nutzenden kam. Solche Bemühungen fehlen bisher weitgehend, was die Einbettung von Energieszenarien in den gesellschaftlichen Diskurs über die Energiezukunft behindert. Während Energieszenarien und die damit verbundenen Modellierungsansätze in den letzten Jahrzehnten immer detaillierter und komplexer geworden sind, befindet sich unser Verständnis ihrer Nutzbarkeit noch immer in einem frühen Stadium.

Résumé

Les scénarios énergétiques basés sur des modèles jouent un rôle important dans de nombreux projets de recherche. Les scénarios énergétiques promettent non seulement de faire progresser la compréhension scientifique de l'avenir énergétique, mais aussi d'aider les décideurs dans les domaines de la politique énergétique et de l'industrie. Les preuves de cette fonction d'aide à la décision sont rares, ce qui est souvent attribué à la complexité des scénarios énergétiques et à une prise en compte insuffisante des besoins des utilisateurs par les communautés de modélisation qui élaborent les scénarios énergétiques. Sur la base d'entretiens et d'enquêtes auprès de modélisateurs de systèmes énergétiques et d'utilisateurs potentiels de scénarios, ProdUse fournit une évaluation empirique de l'interface modélisateur-utilisateur dans le contexte suisse. Les résultats confirment la pertinence et l'acceptation générales des scénarios énergétiques en tant qu'outils clés pour la projection et l'analyse de l'avenir énergétique dans le monde universitaire et au-delà. Toutefois, les cas d'utilisation non universitaires sont beaucoup plus rares que les cas d'utilisation universitaires, car ils se heurtent à toute une série d'obstacles. Plus important encore, la manière dont les scénarios énergétiques sont communiqués répond principalement à des objectifs scientifiques (articles universitaires) et de modélisation (rapports techniques). Pour les utilisateurs qui recherchent une base d'information scientifique synthétisée pour leur contexte d'utilisation particulier, les produits de scénarios énergétiques appropriés font souvent défaut. En outre, il existe un décalage entre ce que les modélisateurs offrent et

ce que les utilisateurs souhaitent en termes de contenu des scénarios. Par exemple, alors que les modélisateurs soulignent la valeur des caractéristiques technico-économiques, la plupart des utilisateurs souhaiteraient voir davantage d'aspects sociaux et comportementaux représentés dans les scénarios énergétiques. Outre la nécessité d'harmoniser à l'avenir les efforts de communication et le contenu des scénarios entre les modélisateurs et les utilisateurs, les résultats indiquent également qu'il existe des interprétations divergentes de ce que les scénarios énergétiques représentent et devraient fournir. Le meilleur exemple en est la forte demande des utilisateurs pour des probabilités, alors que les modélisateurs soulignent que la logique de simulation est un aspect fondamental de l'analyse des scénarios. De même, alors que les utilisateurs attendent davantage de conseils sur la manière d'interpréter les scénarios énergétiques, les modélisateurs ont tendance à se considérer comme des fournisseurs neutres d'informations scientifiques. Les processus participatifs d'élaboration de scénarios sont souvent mentionnés comme des moyens potentiels d'améliorer l'interface modélisateur-utilisateur, mais ces exercices sont très gourmands en ressources, tant pour les modélisateurs que pour les utilisateurs. C'est pourquoi ProdUse a inclus deux études de cas qui tentent de communiquer des informations basées sur des scénarios à des publics sans implication directe entre les modélisateurs et les utilisateurs. De tels efforts sont largement absents à ce jour, ce qui empêche l'intégration des scénarios énergétiques dans le discours sociétal sur l'avenir énergétique. Alors que les scénarios énergétiques et les approches de modélisation associées sont devenus plus détaillés et plus complexes au cours des dernières décennies, notre compréhension de leur facilité d'utilisation n'en est qu'à ses débuts.

Riassunto

Gli scenari energetici basati su modelli svolgono un ruolo importante in molti progetti di ricerca. Gli scenari energetici promettono non solo di far progredire la comprensione scientifica del futuro energetico, ma anche di sostenere i decisori della politica energetica e dell'industria. Questa funzione di supporto decisionale è raramente dimostrata, spesso attribuita alla complessità degli scenari energetici e all'insufficiente considerazione delle esigenze degli utenti da parte delle comunità di modellizzazione che sviluppano scenari energetici. Sulla base di interviste e sondaggi tra i modellisti di sistemi energetici e i potenziali utilizzatori di scenari, ProdUse fornisce una valutazione empirica dell'interfaccia modellista-utente nel contesto svizzero. I risultati confermano l'importanza generale e l'accettazione degli scenari energetici come strumenti chiave per progettare e analizzare il futuro energetico nel mondo accademico e non solo. Tuttavia, per la maggior parte dei casi di utilizzo, i gruppi di utilizzatori non accademici costituiscono l'eccezione. Per questi utilizzatori non accademici esiste una serie di barriere. L'aspetto più importante è che la gamma di prodotti esistente, in cui vengono comunicati scenari energetici, riguarda principalmente scopi scientifici (documenti accademici) e di modellizzazione (relazioni tecniche). Per gli utenti alla ricerca di una base di informazioni scientificamente dedotta e sintetizzata per il loro particolare contesto di utilizzo, spesso mancano prodotti adatti per lo scenario energetico. Inoltre, c'è un disallineamento tra ciò che i modelli offrono e ciò che gli utenti vogliono in termini di contenuto dello scenario. Ad esempio, mentre i modellisti sottolineano i valori delle caratteristiche tecno-economiche, la maggior parte degli utenti vorrebbe vedere più aspetti sociali e comportamentali rappresentati negli scenari energetici. Oltre alla necessità di allineare gli sforzi di comunicazione degli scenari e il loro contenuto tra i modelli e gli utilizzatori in futuro, i risultati indicano anche che esistono interpretazioni contrastanti di ciò che gli scenari energetici rappresentano e dovrebbero fornire. Ciò è

esemplificato al meglio da una forte richiesta di probabilità da parte degli utenti, mentre i modellizzatori indicano la logica del what-if come un aspetto fondamentale dell'analisi degli scenari. Allo stesso modo, mentre gli utenti si aspettano maggiori indicazioni su come interpretare gli scenari energetici, i modellizzatori tendono a considerarsi fornitori neutrali di informazioni scientifiche. I processi di elaborazione di scenari partecipativi vengono spesso citati come possibili modi per migliorare l'interfaccia modello-utente, ma tali esercizi richiedono un elevato dispendio di risorse sia per i modelli che per gli utenti. Questo è il motivo per cui ProdUse ha incluso due studi di casi che tentano di comunicare informazioni basate sugli scenari al pubblico senza un coinvolgimento diretto tra modellisti e utilizzatori. Tali sforzi sono in gran parte assenti fino ad oggi, ostacolando l'integrazione degli scenari energetici nel dibattito sociale sul futuro energetico. Mentre gli scenari energetici e i relativi approcci di modellizzazione sono diventati più dettagliati e complessi negli ultimi decenni, la nostra comprensione della loro utilizzabilità è ancora agli inizi.

1 Introduction

1.1 Context and state of the art of research

Reaching climate neutrality by 2050 entails decarbonization pathways across all sectors, of which many are dependent on the energy sector. The required large-scale deployment of renewable energy technologies and their integration into the energy system demands that a range of actors take momentous decisions under conditions of considerable uncertainty. In addition to renewable energy technologies introducing new dynamics to the current energy system, such as supply fluctuations and more decentralized production, decision-makers also need to consider the multiple and highly intertwined interactions between technology, economy, environment, policy and society.

From an epistemological perspective, model-based energy scenarios are an ideal tool to support decision-makers in the face of these uncertainties and interdependencies, as they offer the potential to explore multiple plausible decarbonization pathways and their respective trade-offs (Gilbert et al., 2018; Holtz et al., 2015; Pye et al., 2020; Strachan et al., 2009). Over the last decade, energy system models have advanced significantly, adding sectoral, geographical and temporal details. Despite the fact that scenarios have a long history in the energy sector and are well-researched, the empirical knowledge on their use in practice as well as their eventual impact on decision-making by different actors is limited (Braunreiter & Blumer, 2018; Pye et al., 2020; Süsser et al., 2021; Vögele et al., 2023).

Moreover, much of the empirical research on the use of energy system models and scenarios focuses on participatory case studies with high levels of interaction between scenario producers and users (e.g. Ernst et al., 2018; O'Brien & Meadows, 2013). These studies suggest that modelling results must be tailored to the needs of users to be useful. In contrast to that, examples of truly participatory modelling activities are rare. This may result in actors outside academia using and interpreting scenarios in unintended or even inadequate ways, leading to decisions not in line with scientific evidence (Braunreiter & Blumer, 2018; Pielke & Ritchie, 2021). In fact, a growing body of research over the last decade has identified a range of challenges related to the use of model-based energy scenarios as a decision support tool, including their difficulties to provide actionable answers to specific questions decision-makers encounter, a lack of transparency in model structures and assumptions as well as low levels of trust and missing capacities among decision-makers (DeCarolis et al., 2017; Fodstad et al., 2022; Gilbert et al., 2018; Paltsev, 2016; Pfenninger et al., 2014; Song et al., 2022).

From a user perspective, understanding how scenario-based insights materialize, on what assumptions they are contingent on, or what factors were considered to be out of scope, is challenging (Ernst et al., 2018; Garb et al., 2008). Energy scenarios are thus often perceived as 'black-boxes' that are difficult to locate on a spectrum between subjective beliefs and scientific assessments. One root cause of these challenges identified in most of these studies (Chatterjee et al., 2022; Garb et al., 2008; O'Brien & Meadows, 2013; Süsser et al., 2022) is the widening gap between producers (highly specialized modellers at research institutions or consulting agencies) and users (heterogeneous groups of decision-makers) of energy scenarios in terms of their respective expertise, needs and capabilities.

Bridging this gap between scenario developers and users is highly challenging – both from a practical and a scientific perspective. To date, improving models is thus often practiced as a purely scientific exercise based on what modellers think are the most relevant areas to improve. In contrast, user needs are rarely considered when models are developed or adapted. In particular, what is needed is a better understanding of (i) what constitutes the modeller-user interface shaping the interactions between various actor groups (ii) the perspectives, needs and incentive structures of both modellers and potential scenario users, and (iii) empirical analyses investigating how model-based insights are communicated and whether the goals associated with their dissemination are achieved.

1.2 Unconventionality and originality of the project

The key novelty of this research project in contrast to other ones in this field is its clear empirical focus. While best-practice guidelines and scenario use typologies do exist, they tend to describe how scenarios should be used from a methodological standpoint and thus neglect the empirical realities affecting the usability of energy scenarios (Börjeson et al., 2006). However, to enable and accelerate the urgently required evidence-based decisions related to the energy transition, viable strategies how insights derived from energy scenarios can be communicated, adapted and disseminated to match the needs and competencies of the relevant decision-makers are needed. Furthermore, ProdUse is original in the following ways:

First, it is characterized by a deliberately transdisciplinary research approach in the sense of Lang et al. (2012), in that that intends to bridge the perspectives of scenario producers and users. Being reflective of the specific contexts in which scenario producers and decision-makers are embedded is of fundamental importance because they are both associated with different disciplinary backgrounds, competencies, and resource constraints. ProdUse attempts to show that these aspects influence the legitimacy, credibility and salience – three key characteristics relevant to the perception of scenarios identified by Cash et al., (2003) – attributed to particular modelling approaches or scenario studies by their users.

Second, ProdUse strives to provide a holistic assessment of the functions that energy scenarios can provide and the actors for which these might be relevant. This is important because scenarios can support decision-making processes at different stages of decision-making processes and policy-making cycle. This may be directly through the identification of solutions that are optimal from a techno-economic perspective, or indirectly by providing an information basis to stimulate deliberations about plausible pathways towards a renewable energy future among actors with diverging values and interests. Accordingly, in addition to utility representatives (see Braunreiter et al., 2023), we include a diverse set of potential users of energy scenarios, such as energy start-ups or governmental representatives, in our analysis. This is critical because the energy transition creates challenges and opportunities for a broad range of actors, and their decisions in turn shape the energy future. ProdUse is holistic in its analysis of the modeller-user interface. While there are studies examining this interface, they often focus on particular aspects, such as the model design, modelling processes, scenario content or associated communication strategies (Beek et al., 2020; Heink et al., 2015; Lacey et al., 2018; Pahl-Wostl et al., 2000; Süsser et al., 2021; Turnheim et al., 2020; van der Sluijs, 2005). Thereby, research often takes the perspective of either modellers or scenario users, without considering how the ecosystem in which they interact shapes the exchange of information (Garb et al., 2008; Süsser et al. 2022).

Third, ProdUse recognizes the variety of modelling approaches existing across the Swiss research institutions (ranging from MARKAL-type bottom-up to macro-economic top-down and agent-based models) as an asset which is not yet used to its full potential. Instead of focusing on particular modelling approaches, we intend to convey that their suitability to answer specific questions is highly context dependent, which is exemplified by the fact that scenarios can generate contradictory insights (Thimet &

Mavromatidis 2022; Vögele et al. 2023). ProdUse tries to investigate whether this diversity of modelling approaches is recognized and valued by potential users.

While energy system models are advancing rapidly, it is not clear whether models and corresponding scenarios are becoming better in the sense that they address the questions that users want to have answered to make well-informed decisions. In Switzerland, energy system models and scenarios are a key pillar of energy research. Switzerland has a particularly relevant, active, and diverse community of energy system modellers (Thimet & Mavromatidis, 2022). This is also reflected in the type of research conducted in the consortia supported by the programme SWEET of the Swiss Federal Office of Energy (SFOE), which often either focuses on improving existing energy system models or on developing new ones. Despite this importance, and research generally claiming that energy scenarios can act as boundary objects for deliberations about the energy future between science, policy, and society, the usefulness of model-based insights for decision-makers involved in the energy transition is largely unknown.

2 Objectives

Increasing the usability of energy scenarios is key to enable and accelerate the urgently required evidence-based decisions related to the energy transition, particularly among non-academic actor groups. ProdUse investigates the space between where developers of energy scenarios see the potential impact of their work and the perspective of potential users of these model results, who want to make better decisions. Ultimately, ProdUse attempts to provide an energy scenario usability analysis for the Swiss context. The analysis hence deliberately includes both the perspective of modellers, who are developing scenarios, as well as users, who are expected to apply its insights.

While we focus on modellers working for Swiss research institutions, we intentionally define *users* broadly as individuals who are using modelling results for their work, including commissioning modelling studies and referring to findings from modelling studies. This is consistent with the overarching goal of providing an overarching analysis of the modeller-user interface. As modellers and users often have different educational backgrounds, capabilities, needs, and are incentivized by different goals, eliciting the purpose, usefulness and broader role of energy scenarios as perceived by both modellers and users is key.

3 Methodology

3.1 Overview of methodology

ProdUse employs a mixed methods approach and is structured along three work packages.

- WP1 **aims to characterize the scope of the modeller-user interface**. Using a literature review and a set of exploratory interviews with modellers and users, it attempts to identify best-practices and existing gaps in evaluating the usability of scenario-based information, as well as to identify the type of information modellers and users respectively consider to be relevant. Apart from informing the design of the survey in WP2, making sure that the modeller-user interface can be captured holistically, a key output of WP1 consists of a working document, containing a collection of key questions for users, designed to improve the credibility and understanding of model-based information (see Appendix A).

- WP2 provides a **holistic and empirical analysis of the modeller-user interface.** Using a parallel survey distributed among Swiss energy modellers and potential users (see Appendix B), it attempts to capture the respective perspectives of these two groups on the modeller-user interface and identifies potential areas and measures on how insights derived from energy scenarios can be communicated, adapted, and disseminated to match the needs and competencies of users. The results of this survey not only informed the selection and design of two case studies in WP3, but also were the basis of various outreach activities (see chapter 7).
- WP3 studies the **usability of energy scenarios in practice.** To that end, two case studies with contrasting empirical settings have been conducted with partners from the modelling community. Specifically, our goal was to document, evaluate and learn from the two case studies' approaches in communicating scenario-based information. The results of these case studies highlight the strengths, weaknesses, and trade-offs associated with different ways of communicating model-based insights.

3.2 Literature review and explorative interviews with modellers and users (WP1)

To define the scope of the modeller-user interface from both perspectives, we conducted a literature review synthesizing scenario use in the energy sector (particularly focusing on modelling communities embedded in different institutional settings, such as the U.K., Germany and the U.S.) as well as experiences from related research fields (particularly integrated assessment modelling). On that basis, a set of explorative interviews with energy system modellers as well as potential users was conducted to assess how usability criteria could be refined to account for the diversity of the Swiss energy system modelling community as well as the most important issues relevant from an energy policy perspective.

Insights provided by the SWEET CROSS activity[1] were used to get an overview of the various modelling approaches across Swiss research institutions. The interviewees representing modellers (N=10) were chosen to cover these institutions and modelling initiatives, and all had a track-record and established role in the Swiss modelling community. For the interviews with potential scenario users (N=15), we focused on non-academic actor groups, as these are currently under-represented in research (as an exception, see Scheer (2017), who concluded that energy scenarios seem to be vulnerable for strategic and tactical use in press reporting). Also, it can be assumed that a potential gap between what modelling provides and what users need is most pronounced in non-academic actor groups. SWEET EDGE[2] supported the sampling procedure by providing access to some of their stakeholders as interview candidates. Finally, the characterization of potential scenario users was complemented by an additional analysis of interview insights gained for a study on energy scenario use in the Swiss energy industry (Braunreiter et al., 2023) by ProdUse project team members.

For energy modelling practices to be useful in their role as a decision-support tool, modellers are required to provide a sufficient level of transparency (Baard, 2021; Cash et al., 2003; Murphy et al., 2023; Strachan et al., 2009). Users should be aware of the strengths and limitations of particular energy scenarios in order to be able to interpret scenario results accordingly (Binsted et al., 2020; Junne et al., 2019; Lahn et al., 2020; Nadaï et al., 2023; Niet et al., 2022). During the interviews, however, it became apparent that modellers and users have often quite opposite perspectives on the relative importance of particular

[1] See: https://sweet-cross.ch

[2] See: https://www.sweet-edge.ch/de/home

energy system modelling aspects. For modellers, how the results come about (modelling design and processes) are as important as the results (scenarios). Scenarios' strengths lie therefore not necessarily in providing a precise projection but in highlighting the underlying and often systemic relationship between energy system characteristics. For users, aspects concerning model design and process are typically not in the focus. They tend to be much more interested in what type of information about the energy future scenarios can provide. In addition, modellers stress that energy scenarios should be interpreted within their defined purpose and scope, because when the context changes, the assumptions shaping the scenario may not be applicable. Most users, however, perceive energy scenarios as a source of information without considering underlying modelling designs and processes.

Based on the literature review and the interviews, four main issues shaping the usability of model-based energy scenarios were identified. These are (i) model design (defining the underlying structure and data basis of scenarios), (ii) modelling processes (referring to the procedures of how scenarios are developed), (iii) scenario content (what kind of information about energy futures is provided) and (iv) interaction and communication efforts (how model-based information is presented and explained). These four issues were characterized by a set of guiding questions (see Appendix A) and served as a general framework when designing the survey for both modellers and users (WP2).

3.3 Complementary surveys of modellers and potential scenario users (WP2)

Two complementary online surveys were developed (see Appendix B). One that targets modellers and one that targets potential users. They are designed in a way that allows for a direct comparison of the answers provided by members of the two groups concerning the four main issues at the interface between energy scenarios and their potential users.

The number of potential users is huge, ranging from energy companies, political parties to homeowners. Each of these groups likely has their unique perspective on energy scenarios. In an attempt to address this diversity, this study focused on stakeholders of the SWEET consortia, as they are most likely to refer to energy scenarios due to their interest in and association with Swiss energy research. The consortia DeCarbCH[3], EDGE and PATHFNDR[4], financed by the programme SWEET of the Swiss Federal Office of Energy (SFOE), supported the dissemination of the survey via newsletters or the provision of mailing lists. This makes the sample as diverse as the corresponding consortia stakeholders, and most participants tend to be interested in energy research, the energy transition or energy scenarios. Participants were also encouraged to share the survey invitation link in their professional networks. As they are often considered a key target group of model-based information, we specifically tried to reach energy startups (via the innovation monitor[5]) and governmental representatives (via the association of Swiss cities[6]). Overall, the user sample includes N=246 individuals, who have provided useful answers. The sample consists of representatives from energy startups (N=55) cantons (N=62), municipalities (N=43), research innovation and consultancy companies (N=22), energy industry (N=7), investors (N=6), NGOs (N=3) and others (e.g. journalists, architects, etc., N=48). The surveys have been conducted between 17th May 2022 and July 17th 2022 and took on average 7 minutes and 47 seconds to complete.

[3] See: https://www.sweet-decarb.ch

[4] See: https://sweet-pathfndr.ch

[5] See: https://www.innovation-monitor.ch/

[6] https://staedteverband.ch/

Only complete questionnaires were included in the analysis. 36 participants requiring less than 3 minutes to fill out the survey were excluded.

The modellers, in contrast, are the individuals developing, running and adapting the models to produce scenario studies. Here, the goal was to capture as many modellers and modelling approaches as possible to represent the diversity of energy system modelling activities in Switzerland. They were contacted via a PATHFNDR newsletter as well as by the ProdUse project team using mailing lists provided by DeCarbCH and EDGE. The large number of modellers (N=105) participating indicates that this goal was achieved. In the survey development, trying to achieve a holistic view on the usability of energy scenarios while maintaining a satisfactory level of user-friendliness for participants was key. The surveys have been conducted between 17th May 2022 and July 12th 2022 and took on average 8 minutes and 31 seconds to complete. Only finished questionnaires were included in the analysis. Six participants requiring less than 3 minutes to fill out the survey were excluded.

3.4 Case studies on usability of energy scenarios (WP3)

As WP2 identified a relative lack of non-academic users, two case studies focusing on such user groups were selected to analyze the modeller-user interface in practice. Additionally, the case studies were selected as they represent complementary approaches for communicating scenario-based information. While the Energy Week @ETH case study offered a variety of scenario-based exhibition formats for users to experience on their own, the HSLU VisEnergy Project involved a direct exchange between researchers and users. See below for a short description of how the case studies were analyzed.

Energy Week @ ETH case study: This exhibition is unique in its multi-layered approach to communicate scenario-based insights. The main goal was to evaluate how well the exhibition was able to communicate issues related to the Swiss energy transition to participants. For that purpose, the popularity, user-friendliness and perceived credibility of the different exhibition formats was assessed along with some demographic data (age, gender, course of studies or profession). The respective questionnaire (see Appendix C) was available in two formats: Attendees could either take part in an online survey (N=103) via QR code or manually through an equivalent printed A4-version (N=67) of the questionnaire that was placed at the exhibition.

HSLU VisEnergy Project: For the second case study, exchanges with the organization team at HSLU and two separate participant observation settings were conducted. Due to the relatively low number of users and their already high commitment through the case study setting, the decision was taken to refrain from formally assessing their user experience. Instead, participant observation was conducted on two occasions. Once at a workshop for homeowners of the Kuonimatt neighborhood (municipality of Kriens) and once at the "Experience Energy!" exhibition at the Swiss Museum of Transport in Lucerne, where the data tables used to visualize energy-related data were available to all attendees. Additionally, ProdUse tracked the development and adaptation of these data tables, as well as the general discussions about their key purpose and target-audience among modellers and project leaders (see Appendix D for the VisEnergy project report).

4 Results and discussion

4.1 Key findings and discussion of work packages 1 and 2

Following is a presentation and discussion of the key findings of WP1 (literature review and interviews) and WP2 (survey of modellers and users), which are closely interlinked. The results of the case studies will be discussed below.

4.1.1 Modellers and users agree: energy scenarios are a key decision-support tool

The findings of this study demonstrate the widespread recognition and acceptance of energy scenarios as a valuable tool for analyzing potential energy futures. Both modellers and users acknowledge the pivotal role played by energy scenarios within the context of energy transitions (see figure 1). Both groups perceive energy scenarios as a crucial foundation for decision-makers in energy policy and the energy industry. Similarly, there is a consensus among these actor groups that the general public should not be the main target group for energy scenarios. The shared perspective is that energy scenarios are designed for experts, a viewpoint reflected in the perceptions of both modellers and users regarding the primary purpose of energy scenarios. Specifically, assessing the feasibility of existing energy policy goals, such as the Paris Agreement or CO2 laws, emerges as the most relevant objective for both modellers and users. While modellers place greater importance on considering a wide range of plausible energy futures compared to users, both groups perceive stimulating societal debates about key energy transition issues as the least significant purpose associated with energy scenarios. Notably, neither modellers nor users agree with the often stated criticism in the scientific literature (Dieckhoff, 2015; Grunwald, 2011; Pulver & VanDeveer, 2009; Sgouridis et al., 2022) that energy scenarios are 'black boxes' and thus incomprehensible to individuals not involved in their development.

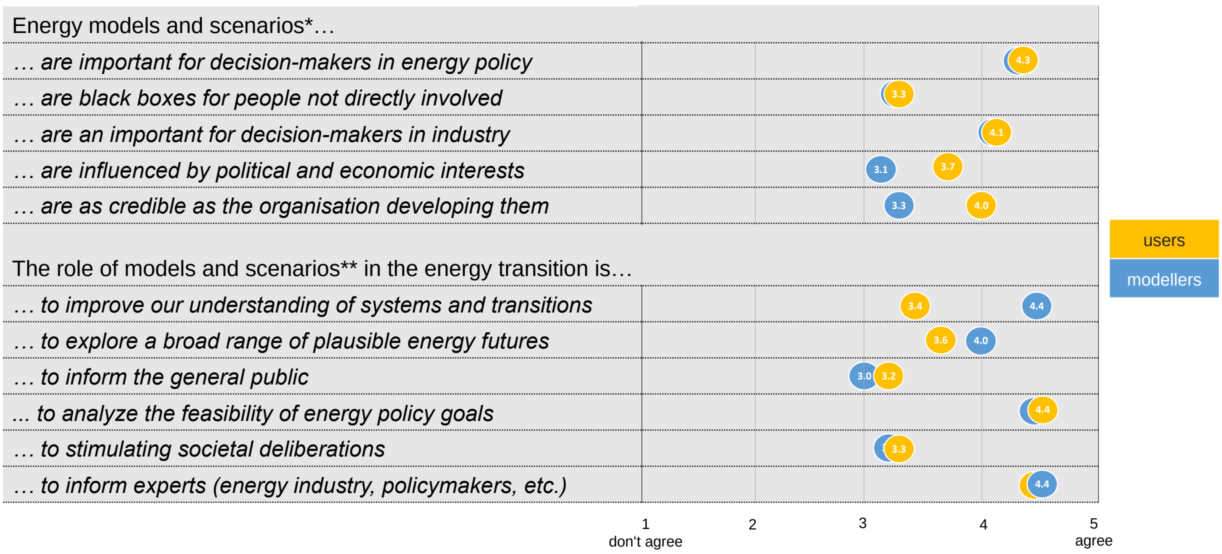

figure 1: Assessments of users (n=246) and modellers (n=105) concerning a set of beliefs related to (*"*Do you agree with the following statements about energy models and scenarios?* ", *5-point scale*) and societal functions of (** *"What should be the role of energy models and scenarios in the energy transition?", 5-point scale*) energy model and scenarios.

4.1.2 More explicit, more radical, more guidance – users want energy scenarios to go beyond contemporary practices and conventions

The survey questions aimed at capturing where modellers and users see potential to enhance the usefulness of energy scenarios for decision-making reveal a variety of concerns that go beyond the typical scope of state-of-the-art energy scenarios (see figure 2). In particular, they demonstrate a desire among users for the inclusion of probabilities associated with energy scenarios. For modellers, however, probabilities represent a fundamental discrepancy with key methodological aspects of energy system modeling. Modellers tend to view each scenario as a unique "what-if" projection. As such, scenarios represent an intentional deviation from probabilistic analyses that are often perceived to be inadequate to capture developments and timescales associated with high levels of complexity and uncertainty. Nevertheless, to make scenarios more tangible and useful for their specific context, users often attribute a higher or lower likelihood to particular scenarios, sometimes based on their subjective beliefs on the energy future (Braunreiter et al., 2023). In the survey, users furthermore express the need for more practical guidelines on how to utilize the findings derived from energy scenarios. While some modellers argue that the interpretation of results for decision-making falls outside their role as scientists, as they consider the deduction of insights to be the users' responsibility, users still seek greater clarity in the explicitness of key assumptions made within energy scenarios. In contrast, modellers tend to emphasize the systemic and often intricate interconnections between modeling approaches, data inputs, and assumptions, which cannot easily be reduced to a limited number of key assumptions (Niet et al., 2022). What is striking is that potential users are having higher expectations for future improvements of energy system models and scenarios than modellers. Overall, the results suggest that users need more support in interpreting the validity and robustness of scenario-based information. Additionally, modelling communities need to define target-audiences in order to think about specific guidelines how the methodological underpinnings of what-if projections can be reconciled with the probability-based decision-making processes representing the reality in which most user groups operate. A recent study conducted in Norway employed a probabilistic modeling approach based on expert assessments, suggesting the feasibility of establishing such methodological connections (Nagel et al., 2023).

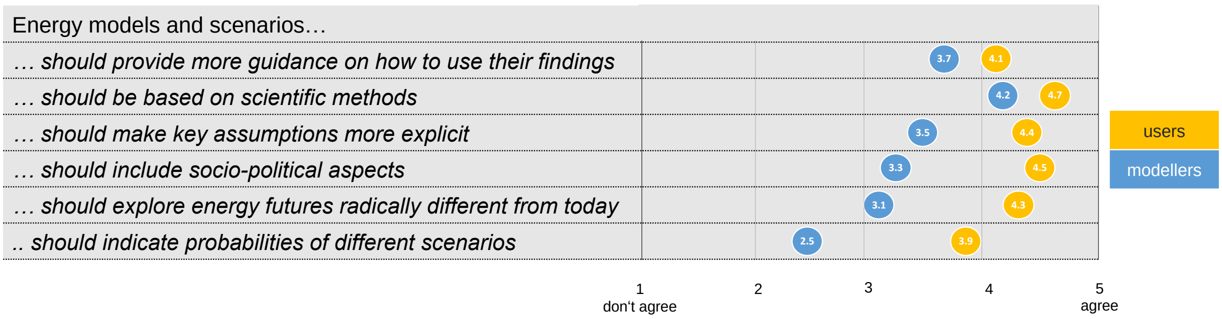

figure 2: Assessments of users (n=246) and modellers (n=105) concerning a set of beliefs ("*Do you agree with the following statements about energy models and scenarios?* ", *5-point scale*) related to energy models and scenarios.

4.1.3 Users want more social aspects in energy scenarios

Users express a stronger desire toward incorporating social aspects into energy scenarios than modellers. This observation remains consistent regardless of the specific social aspect under consideration (see figure 3 and 4). This is also evident in the finding that users perceive the identification of socially desirable pathways as equally important, if not more so, than identifying technically or economically feasible pathways. In contrast, modellers prioritize techno-economic aspects and pathways, which are much more established in the modelling community as associated methodological standards exist. For many social factors, instead, it is often still unknown how they can be represented and sometimes suitable and reliable data sources are missing. In that sense, the survey results mirror an ongoing debate within the broader energy system modelling community: Recent studies have highlighted behavioral aspects as a critical determinant shaping the future energy system (Krumm et al., 2022; Stermieri et al., 2023). In fact, Grubler et al. (2018) contend that lifestyle changes represent the sole viable option for achieving the 1.5°C climate target without extensive deployment of negative emission technologies. However, to date, the modelling community has primarily operationalized social aspects as energy demand factors (as exemplified in works such as Chatterjee et al., 2022). In contrast, integrated assessment models have made significant progress in integrating behavioral aspects and encompassing social phenomena more comprehensively within their scenarios (Beckage et al., 2020; Saujot et al., 2021; van Sluisveld et al., 2016, 2020). Promising approaches that blend participatory scenario development activities with the integration of relevant social aspects, including public preferences, attitudes, and acceptability, are emerging from transdisciplinary research (Demski et al., 2017; Kattirtzi & Winskel, 2020; McGookin et al., 2021, 2022). Research conducted by Swiss researchers suggests that diverse societal groups hold varying normative expectations regarding the energy future (Holzer et al., 2023; Volken et al., 2018; Xexakis et al., 2020; Xexakis & Trutnevyte, 2022). Consequently, incorporating social aspects in energy scenarios not only enhances their realism (Keen, 2021; Trutnevyte, 2014) but also facilitates including non-expert groups who both shape and are impacted by the energy transition (in line with Braunreiter et al., 2021).

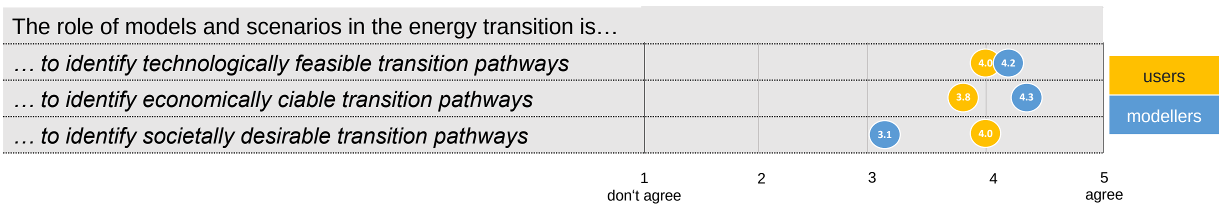

figure 3: Assessments of users (n=246) and modellers (n=105) concerning societal functions of energy models and scenarios (*"What should be the role of energy models and scenarios in the energy transition?", 5-point scale*).

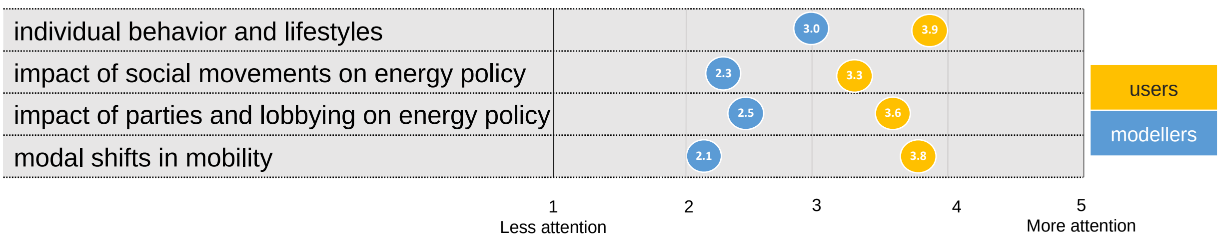

figure 4: Preferences of users (n=246) and modellers (n=105) concerning inclusion of socio-political factors in energy models and scenarios (*"The inclusion of socio-political factors in energy models is often considered a promising focus. Which factors do you consider most important? ", 5-point scale*).

4.1.4 Communication and interaction formats: modellers provide what users rarely need

For modellers, enhancing the scientific understanding of the energy transition holds significant importance, which is evident in their output. Typically, modellers provide scientific outputs, such as journal papers, as well as technical resources like data repositories and model documentation reports. However, these outputs cater to only a minority of potential users. Instead, users express a preference for engaging with energy scenarios through qualitative formats, such as podcasts or videos, and interactive formats like workshops and web-interfaces. Such formats are seldom offered by modellers as they often diverge from the scientific allure and technical nature associated with energy scenarios and rigorous scientific work. Consequently, the presentation of energy scenarios by modellers frequently fails to align with the interactive experiences desired by users (figure 5). In contrast, other disciplines that rely on model-based scenarios, such as climate sciences and environmental sciences, have made greater strides in integrating qualitative narratives with computational modelling compared to the energy system modelling community (as observed by Garnett et al., 2023; Lübker et al., 2023; Mathy et al., 2015; Moezzi et al., 2017). While the technical and numerical focus of energy scenarios is a valuable asset and regarded as a prerequisite by many modellers and users (Braunreiter et al., 2023), research also shows that subjective expectations and values of modellers shape energy scenarios (Ellenbeck & Lilliestam, 2019; Göke et al., 2023; Haikola et al., 2019).

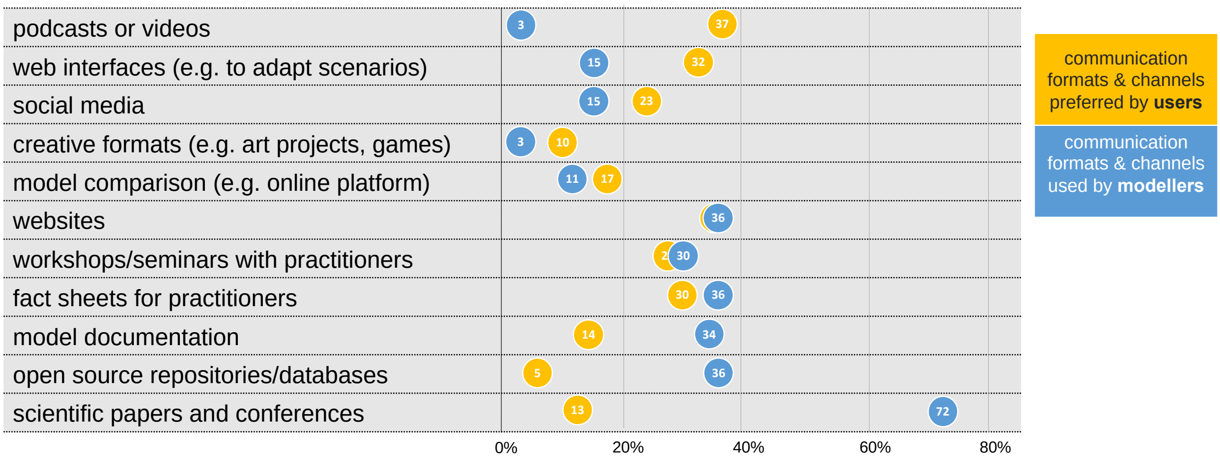

figure 5: Comparison of formats and channels for communicating scenario insights preferred by (i) users (*"What formats and communication channels would you like to have as an option to interact with energy models and scenarios?",* n= 246) and (ii) provided by modellers (*"What formats and communication channels do you use to communicate your findings?"*, n=105).

4.1.5 The energy scenario usability gap: non-academic user groups are an exception

This mismatch between communication and interaction formats is likely a key contributor to the usability gap that was identified in the survey. While modellers think that their work can be relevant for a range of stakeholders (see figure 6), they are only aware of a few representatives of these user groups that are actually using them. At the moment, the primary user groups predominantly consist of other model developers and the scientific community at large. In contrast, non-academic users groups are very rarely using energy scenarios to date (for an exception, studying how young people imagine the energy future, see Holzer et al., 2023).

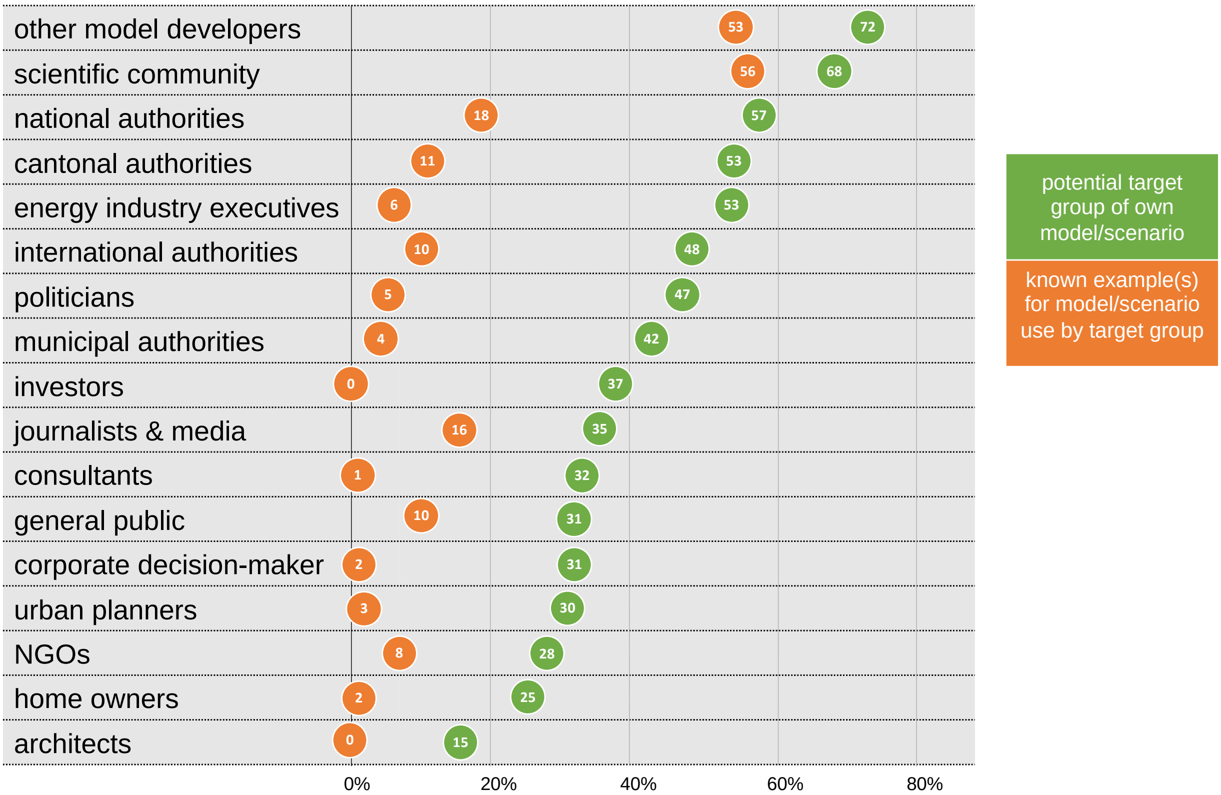

figure 6: Share of energy modellers who stated that their models or scenarios could be useful for different actor groups (green) and which actors are currently using their models or scenarios (red) (n= 105).

4.2 Key findings and discussion of work package 3

4.2.1 Case study selection

The identified usability gap, particularly concerning non-academic user groups, coupled with the scarcity of communication efforts targeting these groups, prompted a focus on case studies addressing these challenges. Furthermore, the selected case studies represent complementary approaches for communicating scenario-based information to non-academic audiences. This was achieved by examining the usability of energy scenarios at the Energy Week at ETH exhibition, as well as the VisEnergy project of HSLU.

4.2.2 Case study Energy Week @ ETH: Exhibition 2022

The ETH Energy Science Center (ESC), the ETH Zurich's centre for energy research and education, held its sixth annual energy conference from 5-11 December 2022. It consisted of a range of events such as symposiums, the energy sprint, focus dialogues and the science policy panel. For the first time, Energy Week @ ETH was accompanied by a public energy exhibition. During the whole week, visitors had the opportunity to visit the exhibition in the main hall of ETH Zurich (see figure 7).

figure 7 Visualization of the energy transition at the Energy Week @ ETH exhibition in December 2022[7].

The goal of the exhibition was for participants to find out about Switzerland's current and future energy system, understand the diverse challenges and opportunities and, above all, learn what a possible energy scenario could look like in 2050. The exhibition was conceptualized by the ESC with many researchers collaborating to develop the exhibition formats. It included the following formats related to the energy future: **1)** A **ground floor graphic** covering the ETH main hall floor illustrated energy flows and the relative importance of energy carriers in the Swiss energy system. **2)** To illustrate the scale of the energy transition, **energy columns** relative to the size of the respective energy sources in 2020 vs. 2050 were placed at the edge of the ground floor graphic. **3)** Participants could visualize the energy future in different geographical regions using **augmented reality** using a headset. **4)** Participants could interact with a **customizable scenario tool**[8] to adapt existing energy scenarios presented by research, utilities, or politicians or to create their own energy future.

The results suggest that overall, the exhibition was successful in raising awareness about the energy transition, particularly in creating a more concrete idea of potential pathways. Participants also reported to be more optimistic and knowledgeable about the energy transition, more likely to engage with it, and to be generally more interested in energy topics (see figure 8). Given the diverse characteristics of the audience regarding age and educational background, the diversity of formats with varying levels of detail turned out to be an asset.

[7] See **https://energyweek.ethz.ch/de/** for more pictures and information about the exhibition.

[8] Based on the Axpo Powerswitcher tool which also exists as an **online** version.

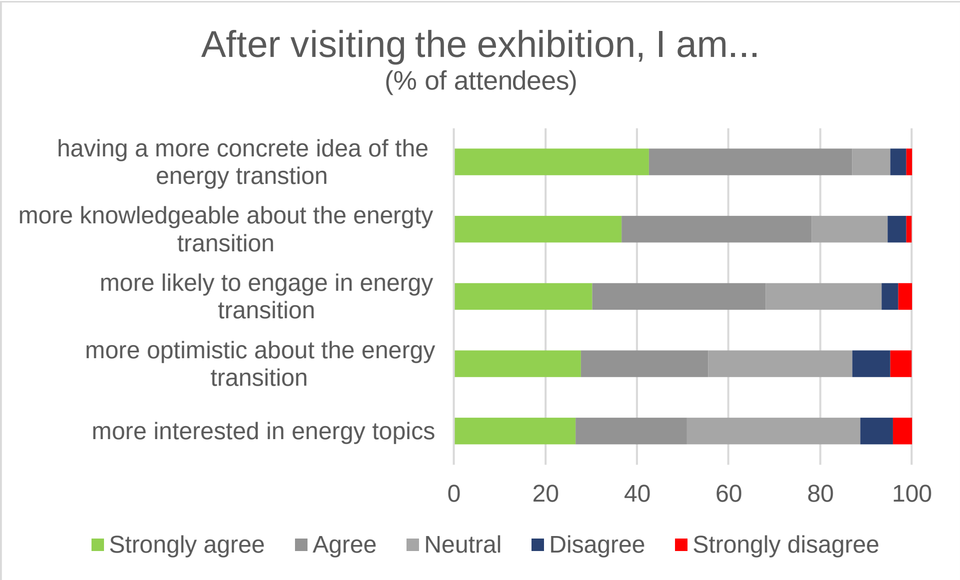

figure 8 How Energy Week @ ETH exhibition attendees (n=170) evaluated the overall impact of the exhibition on their knowledge and interest in the energy transition.

In particular, the exhibition achieved to show a nuanced picture of the energy transition and its relationship to environmental challenges. Similar to the survey among scenario users, attendees would like to have more information about social aspects, most prominently acceptability (see figure 9). The open concept of the exhibition allowed participants to freely choose among the different formats, which were offering various informational foci.

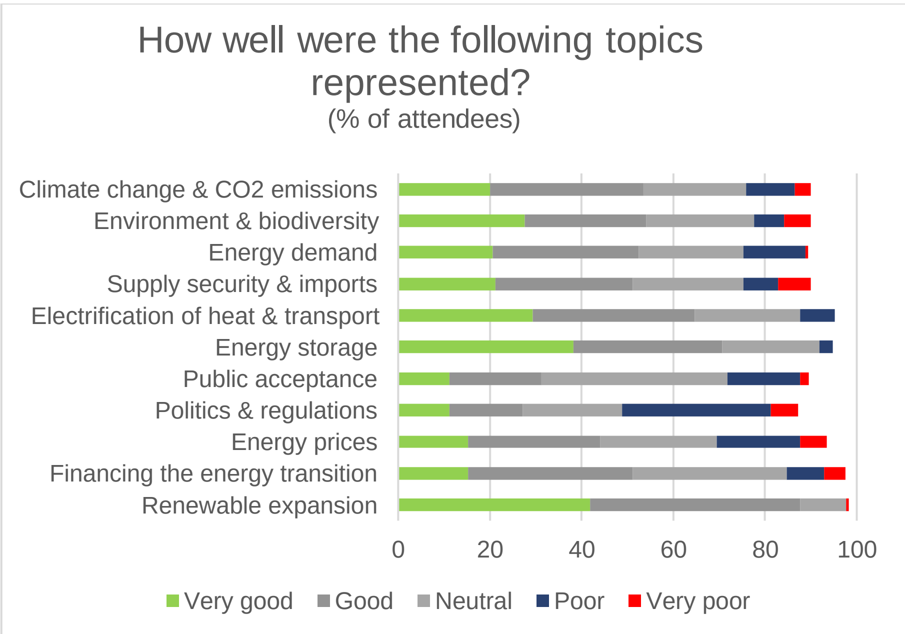

figure 9 How well Energy Week @ ETH exhibition attendees (n=170) perceived key energy transition topics, ranging from technological to social areas, to be covered by the exhibition.

While most exhibition formats seemed to achieve a good balance between simplicity and complexity (see figure 10), the customizable online scenario tool stands out, as most users perceived it to be too complicated. Overall, however, participants found all exhibition formats to provide meaningful (and not meaningless), innovative (and not unimaginative) as well as fact based (and not speculative) information.

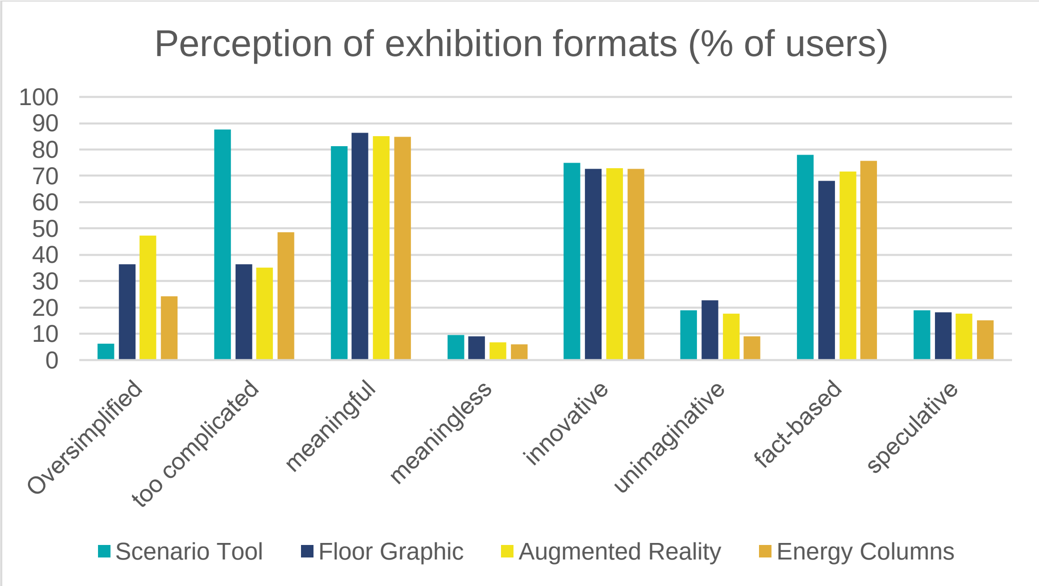

figure 10 How Energy Week @ ETH exhibition attendees (n=170) rated the five individual exhibition formats in terms of their complexity, meaningfulness, innovativeness, and fact-based appearance.

What needs to be taken into consideration in the interpretation of these results is the embedding of the energy scenario formats in the exhibition context (e.g. corresponding lectures, workshops and guided tours) as well as the overall impression provided by ETH (e.g. credibility associated with ETHs leading role in climate & energy research).

4.2.3 Case study HSLU: Visualizing the energy future

The project "Visualisation of the energy transition in Lucerne South" aims to explore the potential of data visualization, primarily by means of interactive data tables, for supporting the energy transition in municipalities and cantons. The aim is to realize an interactive, easily understandable visualization of the energy system of Lucerne South that can be used for various questions (see Appendix D for details on the project).

The project exemplifies the intricate and resource-intensive inter- and transdisciplinary collaboration necessary to convey model-based information. In the preparatory phase, the project idea was discussed with various representatives of municipalities, cantons and civil society in a workshop with around 20 participants. From the beginning, the visualization tool was to be developed in cooperation with partners, which were found with the Association of Municipalities of Lucerne South and the municipalities of Kriens and Lucerne to test and further develop the visualization of energy transition data on the interactive data tables. The involved HSLU Smart Region Lab works in an interdisciplinary way, combining IT competencies required for the technological development and programming of the data table with the data procurement and input gathered in collaboration with researchers from EDGE, PATHFNDR and DeCarbCH.

The interactive data tables can present georeferenced data in a visually appealing way. The multitouch control and additional physical magnifying glasses, so-called tangibles, make it possible to work with the data directly at the table and to call up evaluations or scenarios immediately. To find out what type of information users want to see, a workshop for the Kuonimatt neighborhood in Lucerne south was organized. 15 residents, all of them home-owners in the respective neighborhood, participated together with representatives from the municipality and the cantonal energy department. A main goal was to find out how the integration of additional layers - such as an orthophoto or zoning plans – could enable data-based collaboration among homeowners in the same neighborhood. Prior talks with the municipality had shown that for them, communication with residents of areas or neighborhoods with a great need for action in terms of energy transition is often a challenge. The knowledge, attitudes and engagement of workshops participants with the energy transition was quite diverse, which represented an additional challenge for the project. Some participants had already taken measures towards renewable energies, such as the installation of PV, heat pumps, building insulation or smart home elements, or had sensitized co-owners. Others were focused on potential barriers, such as investment costs, access to subsidies or problems with the timing of heating replacement and amortization. They also saw legal hurdles or a need for clarification of legal issues. Participants worked in groups to develop ideas for a visual, digital tool to support the energy transition in the neighborhood, which was to be realized on the "data table" shown on site. They developed answers as to what information neighborhood residents would expect from a discussion event and how this could be presented. They concerned (1) information on the current state of the neighborhood, (2) ways of presenting scope and potential in the neighborhood, (3) the use of successful examples as inspiration and (4) the presentation of legal and financial information. The inputs and ideas offered hints on what is important from the perspective of potential users and what is not in the focus. At the same time, the requests concerned a rather broad range of topics, which would further complicate the use of the data tables. In addition, much of the legal and regulatory information requested by participants is difficult to display on the data tables, indicating that the visualization can be a first step to engaging with people that needs to be followed-up by more in-depth supporting activities with thematic experts.

The data tables were also used at the “Experience Energy!” exhibition at the Swiss transport museum. Also this exhibition was open to the general public. In general, visitors to the exhibition showed great interest in the data tables. The close supervision by the research team of the HSLU provided opportunities for dialogue and opened up space for questions. Most of the questions were again about financing and the political framework, which confirms a fundamental need for knowledge in this area. However, only 1 or 2 attendees could interact with the table at any given time and each user had to be accompanied by a HSLU member at all times as the functionality (zooming in, enabling and disabling information layers) was not self-explanatory. Some participants mentioned that some data was missing or not up to date, which contrasts the key goal of the data table, which is to form a personal relationship of the participants with the energy transition. Following the opening week, the Swiss Museum of Transport showed interest in continuing the presence of the data tables in the exhibition "Experience Energy!”. The aim is now to develop a long-term exhibition tool together with the Swiss Museum of Transport. The Smart Region Lab is currently working with the City Science Lab in Hamburg to design a corresponding tool so that the university can make a contribution to visually communicating the energy transition to the population. The VisEnergy project has not been completed at the time of writing[9]. The data tables will be further developed based on the results of the Kuonimatt workshop and the experiences at the Swiss Museum of Transport. Cooperation with the municipalities and with Lucerne South will continue, with the aim of implementing local energy transition projects on a participatory basis in dialogue

[9] For a summative VisEnergy project report until 07/2023 see Appendix D.

with citizens. Specifically, it is planned to use the revised visualization tool in a future neighborhood event in the municipality of Kriens as part of participatory energy planning. While the data tables succeeded in sensitizing participants about key issues and emphasizing their personal opportunities and challenges related to the energy transition in workshop settings, their value in highlighting the trade-offs between different energy scenarios to a non-expert audience remains to be evaluated in detail in future empirical studies.

4.3 Discussion

ProdUse offers the most comprehensive analysis of energy scenario usability in the Swiss context to date. It provides valuable insights by capturing the perspectives of more than 100 energy system modellers and comparing them to those of 250 potential scenario users. This mixed-method social science approach, in a field traditionally dominated by technocratic perspectives, presents an empirically grounded investigation of the modeller-user interface, crucial for enhancing energy scenarios as decision-support tools. What is more, ProdUse takes a holistic approach, which stands in contrast to mechanistic scenario typologies (e.g. Börjeson et al., 2006) and idealized best-practice guidelines (e.g. DeCarolis et al., 2017; Schoemaker, 1991) that often focus on specific aspects of the modeller-user interface, such as participatory scenario development (Ernst et al., 2018) or narrative construction (Houet et al., 2016).

The results show that energy scenarios are a widely recognized and accepted tool for projecting energy futures in academia and beyond. However, for the time being, typical use-cases mainly involve academic purposes. For non-academic users, a range of barriers exist. Most importantly, the existing products and channels, in which energy scenarios are communicated, primarily address scientific (academic papers) and modelling (technical reports) purposes. For users seeking a scientifically derived information-basis that is synthesized for their particular context of use, suitable energy scenario products are missing. While participatory scenario development processes can be a solution in some cases, such exercises are highly resource-intensive for both modellers and users (McGookin et al., 2021). Accordingly, ProdUse analyses alternative ways in which energy scenarios can be communicated to audiences without demonstrated expertise in energy system modelling. In this context, the Energy Week @ ETH exhibition can be considered a first step towards increasing the ‘Futures Literacy’ (Mangnus et al., 2021), thereby sensitizing the general population about the opportunities and challenges related to the energy transition. The data tables developed by the HSLU VisEnergy project highlighted how a meaningful and innovative dissemination of energy scenarios requires researchers to collaborate in inter- and transdisciplinary settings that are still not the norm, and that the integration of user feedback is often challenging.

Examples from other energy and climate modelling contexts suggest that communicating scenario-based information to target-audiences is not a task that can be achieved by modelling communities by themselves, as they are often focused on improving the scientific quality of their work. Instead, intermediaries dedicating their efforts towards improving the modeller-user interface are needed to bridge the increasingly complex modelling landscape. Successful pilot projects from the Netherlands show that so-called ‘techniques of futuring’ can both expand the range of products in which energy scenarios are presented (Bendor et al., 2021; Light, 2021; Oomen et al., 2022), for example by combining energy system modelling with inputs from arts, humanities and science fiction (Bina et al., 2016; Candy & Dunagan, 2017; Candy & Kornet, 2019; Nikoleris et al., 2017; Raven, 2017) as well as contribute to communities of practice on the side of energy system modellers (Niet et al., 2021). This is an area that should be given a lot more attention by actors comissioning model-based energy scenarios, for example by specifying target groups and potential use cases already in the call for tenders or very early in the process together with the modellers.

In the current Swiss energy research context, embedding energy system modelling in wider public and societal discourses is particularly important. Although energy scenarios already play a central role in many research projects and funding opportunities, there is a lack of corresponding links to effectively translate scenario-based insights in alignment with underlying modelling approaches as well as specified use-cases. Currently, the most notable cases of energy scenario use outside academic circles tend to involve misuse, such as using single scenario projections to de(legitimize) the technological or economic feasibility of energy transitions contrary to modelling communities' consensus[10]. As a result, the potential of energy scenarios to facilitate deliberation and societal-level discussions about the trade-offs of the energy transition remains unrealized. A main contributor to this is that while energy scenarios and associated modelling approaches have become more detailed and complex in the last decades, our understanding of their usability is still in its early stages.

5 Cooperation and coordination with SWEET consortia and SOUR projects

ProdUse builds on a close cooperation with different SWEET consortia: The initial interview phase included exchanges with representatives from the DeCarbCH, EDGE and PATHFNDR consortia on the respective role of energy system models and scenarios in these projects. EGDE additionally supported ProdUse by proposing potential scenario users from their stakeholder group for the initial interview phase. Furthermore, the activities and insights of the CROSS activity were taken into account for the design of the surveys. The subsequent survey dissemination was also supported and coordinated with the DeCarbCH, EDGE and PATHFNDR consortia. They either included the survey in their newsletter to stakeholders (EDGE, PATHFNDR) or provided a mailing list (DeCarbCH). Case study 1 evolved around the Energy Week exhibition, in which representatives from SWEET consortia had a leading role. The scenario visualization tables in case study 2 were inter alia based on input data generated by the EDGE consortia.

Without the support of all these partners, ProdUse would not have been possible. We are very grateful for their support. Additonally, we would like to thank all our interviewees, survey participants and attendees of the case studies. Special thanks goes to Marius Schwarz and Annina von Mentlen for enabling the evaluation of case study 1, as well as Jonas Mühletaler, Francesca Paoletti and Christopher Young for being equally supportive during the different phases of case study 2.

6 Outlook and next steps

The work conducted in ProdUse will be used for various subsequent activities:

- It will inform a book chapter initiated and funded by the international **SSH Centre** to develop policy recommendations for the EU Green New Deal. In this forthcoming book chapter, we argue

[10] See for example the discussion around the use of energy scenarios prior to the vote on the climate protection act in June 2023. **https://www.nzz.ch/schweiz/klimaschutzgesetz-exorbitant-teuer-wird-die-energiewende-nur-wenn-sich-die-schweiz-isoliert-ld.1737725?reduced=true**

that an integrated and complementary energy modelling and social science and humanities research approach is crucial to enable fair and equitable climate neutrality pathways. Political decisions would benefit from insights not only based on modelled techno-economic pathways and scenarios of the energy transition, but also on the findings of discussions and debates with the many stakeholders involved or impacted. This is particularly important as there will be geographically dispersed winners and losers in the energy transition, and the transition process can offer different socio-economic benefits for broader regional transitions.

- The insights and established networks with project partners (i.e. the ETH Science Center, members of SWEET CROSS and the HSLU VisEnergy project) will be an important basis for WP3 of SWEET CoSi, which is placed at the interface between energy system modelling (WP1 and WP2) and social sciences and humanities (WP4-6) and is led by ProdUse team member Yann Blumer.

7 Outputs and outreach

Peer-reviewed publications

Project team member	**Description:** author(s), title, journal or type of publication, year of publication	**Doi**
Lukas Braunreiter, Yann Blumer	Braunreiter, L., Marchand, C., & Blumer, Y. (2023). Exploring possible futures or reinforcing the status-quo? The use of model-based scenarios in the Swiss energy industry. *Renewable and Sustainable Energy Transition*, *3*, 100046.	https://doi.org/10.1016/j.rset.2023.100046

Policy briefs, white papers

Project team member	**Description:** author(s), title, channel or type of publication, year of publication
Lukas Braunreiter	Diana Süsser, Will McDowall, Connor McGookin, Francesco Lombardi, Stefan Bouzarovski, Lukas Braunreiter: *Rethinking energy system models: Inclusive pathways to climate neutrality*, SSH book chapter focusing on policy recommendations for the EU Green New Deal, 2024 (forthcoming).

Public oral and visual presentations (scientific or broad audience)

Team members and coop. partners	**Description:** author(s), title, name of the event and location, year of presentation
Lukas Braunreiter	*Lukas Braunreiter, oral presentation "Controllable vs. Contested Futures: A Comparative Study among Swiss Energy and Food Incumbents" at the STS Conference 2022, Graz, Austria.*

Lukas Braunreiter	*Lukas Braunreiter, ProdUse poster presentation at the SWEET Conference 2022, Bern, Switzerland.*
Lukas Braunreiter	*Lukas Braunreiter, oral presentation "Why we need to diversify energy futures" at the SSH Conference 2022, Martigny, Switzerlland.*
Lukas Braunreiter	*Lukas Braunreiter, oral presentation "Beyond the numbers: Why energy Scenarios Often Fail to Connect With Decision-Makers" at the SSH Conference 2023, Sion, Switzerland.*
Lukas Braunreiter	*Lukas Braunreiter, oral presentation "Beyond the numbers: Why energy Scenarios Often Fail to Connect With Decision-Makers" at the DeCarbCH Lunch Seminar Series 2023, online.*
Yann Blumer, Lukas Braunreiter	*Yann Blumer, Lukas Braunreiter, oral presentation "Who are we doing this for? Analysis of recommendations by Swiss energy researchers" at the SSH Conference 2023, Murten, Switzerland.*

8 Related projects

Project name	Co-Evolution and Coordinated Simulation of the Swiss Energy System and Swiss Society (CoSi)		
Funding instrument	*SFOE SWEET*	**Project n°**	
Start	*08/2023*	**End**	*07/2032*
Leader	*Prof. Dr. Hannes Weigt, University of Basel*		
Objectives and relation to the SOUR project			
CoSi will tackle three key issues raised by *ProdUse*. First, it will try to enhance energy system models and scenarios by integrating social scientific insights. Second, it will co-create transition pathways through a participative and interdisciplinary development process. Third, it will analyse the usability of these enhanced energy system models and scenarios for different user groups. As such, CoSi will take a leading role in advancing the usability and impact of model-based insights beyond academic purposes. Insights on potential user groups, the perception of energy scenarios and challenges in minimizing trade-offs between relevance and credibility that *ProdUse* provided will provide an informed starting ground for these activities.			

Project name	Delivering the next generation of open Integrated Assessment MOdels for Net-zero, sustainable Development (DIAMOND)		
Funding instrument	EU RIA - Research and Innovation action	**Project n°**	Grant agreement ID: 101081179
Start	*12/2022*	**End**	*11/2026*
Leader	Dr. Alexandros Nikas (National Technological University of Athens)		
Objectives and relation to the SOUR project			
DIAMOND will update, upgrade, and fully open six IAMs that are emblematic in scientific and policy processes, particularly focusing on demand-side transformations such as the ones included in ProdUse. For this DIAMOND will integrate insights from psychology, finance research, behavioural and labour economics, operational research, and physical science. This transdisciplinary scientific approach will try to legitimise the implementation of social scientific insights by way of co-creation with (non-academic) stakeholder groups such as the ones included in ProdUse.			

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10 Appendices

Following is an overview of all appendices

Appendix A is a factsheet developed in wock package 1, which provides a framework of the scenario modeller-user interface as well as a set of guiding questions to develop a specific scenario use case.

Appendix B consists of the two questionnaires that were used in work package 2 to survey modellers as well as users of energy scenarios, respectively.

Appendix C consists of the questionnaire used to survey visitors of the Energy Week @ ETH in 2022 and participants of the VisEnergy workshop (work package 3).

Appendix D consists of a short report of the VisEnergy project by HSLU (work package 3).

A: Framework to conceptualize the interface between energy scenarios and potential users

Zürcher Hochschule
für Angewandte Wissenschaften

School of
Management and Law

Institute of Innovation and
Entrepreneurship

Framework to conceptualize the interface between energy scenarios and potential users

Working document of SFOE-SOUR Project ProdUse[1], August 2023

Contact: Lukas Braunreiter (lukibraunreiter@gmail.com), Yann Blumer (yann.blumer@zhaw.ch)

Background

Model-based energy scenarios are considered to have the potential to guide decision-making under considerable uncertainty by conceptualizing multiple pathways and assessing associated trade-offs. However, in order to realize this potential, decision-makers in policy and industry, which have often not been involved in the scenario development process, must be able to access, navigate, interpret and utilize relevant information and insights coming out of the scenario process. Given the scope and complexity of scenario development processes, designing such an interface between model-based energy scenarios and its users is very challenging and requires answering a wide range of questions.

Purpose of this document

Based on a literature review as well as a series of interviews with modellers as well as potential users, ProdUse has identified four different issues at the interface of scenarios and their users, which shape the scenarios' usability: Model design, modeling processes, scenario content and scenario communication. While not of equal relevance for each use case,
these four issues provide a general conceptualization of a typical model-user interface. Following is a series of guiding question in the form of a checklist-style working paper for each issue. The document is supposed to provide scenario users with a basis for developing their specific use case. In case of a direct exchange with energy system modelers, the document can also be used to facilitate the knowledge transfer between modelers and users in the sense of the emancipatory boundary critique[2].

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[1] SFOE contract number: SI/502273. Full project title: "*Closing the gap between model-based energy scenarios and its potential users to support evi-dence-based decision-making for the transformation of the Swiss energy system"*

[2] For more information about the method, see https://naturalsciences.ch/co-producing-knowledge-explained/methods/td-net_toolbox/emancipatory_boundary_critique_final_

1. Model design: The underlying structure and data basis of scenarios

Model design is a critical step in the development of energy scenarios, as it determines the scope, boundaries, and key variables of the model. When designing the model, modelers strive to design an abstraction of the intricate interplay between energy sources, technologies, policies, and economic factors that is appropriate for a particular research question or thematic focus.

Guiding questions:

- What do we know about the model type?
- Why was a simulation/optimization model chosen?
- What temporal and spatial resolution is applied?
- What do we know about the model data?
- What are the sources?
- What is the history and quality of the data?
- What are the associated unknowns (uncertainties)?
- Is the model transparent?

2. Modelling processes: How scenarios are developed

The modelling process involves a range of decisions about the level of detail, spatial and temporal resolution, and the inclusion of feedback loops that mirror real-world cause-and-effect relationships. Typically, data collection and validation are conducted to ensure accurate representation of historical trends and current energy dynamics. Furthermore, sensitivity analyses are conducted in many cases in order to encompass variations in technology adoption, policy frameworks, demand patterns, and external factors.

Guiding questions:

- What do we know about the modelling assumptions?
- Are they well-founded?
- Have external stakeholder been involved in the creation of assumptions?
- Which assumptions are similar/different from other models?
- How accurate is it (model sensitivity)?
- Are model inputs and outputs publicly available?
- Is the model code accessible and clearly described?
- Is model development and performance documentation available?
- What do we know about model quality?

- Has the model been discussed in the scientific community and reviewed by independent experts?
- Has the model been compared to other models?
- Are there linkages to other models?

3. Scenario content: What information the scenarios provide

This concerns the results provided by energy scenarios. Depending on the study, a number of scenario projections (usually three to five) are provided. Here, it is important to understand what range these scenarios represent and how they differ from each other.

Guiding questions:

- Do model results refer to a specific context?
- Is the model being used in a new context?
- Does this introduce new limitations?
- Is the model fit to answer the policy question it was created for?
- What has not been considered?
- What biases or limits exist and are their implications for the results explained?
- Is there a statement on the unknowns (uncertainties) and is it explained?
- Why were not more/less scenarios presented?

4. Scenario communication: How the information is presented, visualized and explained.

This concerns the dissemination and communication of energy scenarios. Depending on the target-audience and intended use-cases, appropriate levels of detail on model design, modelling process and scenario content should be provided.

Guiding questions:

- Is there a specified use-purpose or target audience mentioned?
- Are model results communicated clearly and accurately?
- Are the questions asked to the model clear and relevant for the problem at stake?
- Are there graphical or qualitative elements to support the understanding of the scenarios?
- Are there guidelines for the interpretation of the results?
- Can the modelers be contacted or are there accompanying presentations or workshops mentioned?

B: Questionnaires used to survey modellers (B1) as well as users of energy scenarios (B2)

Welcome to the *ProdUse* survey for energy modellers!

This survey is intended for people working with energy models or scenarios. Your answers will help us to **increase the relevance and usability of energy models and scenarios**. Completing the survey will take about **10 minutes**. Your data will be evaluated anonymously and will only be used for research purposes. All data protection regulations will be observed.

If you want to know more about the *ProdUse* project or have any questions, please get in touch. We hope you enjoy the survey and thank you for supporting our research.

Lukas Braunreiter, ZHAW Innovation Systems Group

lukas.braunreiter@zhaw.ch / Tel: +41 58 934 64 75

If you agree with the privacy policy, you can start your participation in the survey at the bottom.

☐ I consent to the processing of my data in accordance with the information provided

Survey Questionnaires for modellers and users

1. Modeller Survey

Number	Question
1.1	**Gender** • Woman • Man • Transgender • Non-binary/non-conforming • Prefer not to respond **Age** • 25 or younger • 26-35 • 36-45 • 46-55 • 56-65 • 66 or older • Prefer not to respond
1.1	**Please indicate your current academic status.** [Dropdown] • PhD Student • Post-Doc Researcher • Senior Scientist/Lecturer • Professor • Other:____ **Please indicate your educational background. You can choose multiple options.** • Arts & humanities • Social Sciences • Natural Sciences • Engineering

	• Economics • Mathematics • Other:____
1.2	This first part of the survey covers your view on energy models and scenarios in general. **What should be the role of energy models and scenarios in the energy transition?** [5-point Likert: Not important → Very important] • Improving the scientific understanding of energy systems or transitions • Exploring a broad range of plausible energy futures • Analysing the feasibility of existing energy and policy goals (e.g. Paris agreement, CO_2-law) • Informing experts (energy industry, policymakers, etc.) • Informing lay people (general public, home owners, etc.) • Stimulating societal deliberations about key energy transition issues • Identifying *technologically* feasible pathways towards a renewable energy future • Identifying *economically* viable pathways towards a renewable energy future • Identifying *socially desirable* pathways towards a renewable energy future • Other:____
1.3a	**What factors do you consider to be important in energy models?** [5-point Likert: importance] • Impact of energy infrastructure on natural environment and resources • Total costs and investment costs of energy transition • Degrowth or low growth • Electricity market liberalisation • Energy import availability and dependency • Energy supply security • Energy strategies of neighbouring countries • Seasonal energy storage • Heating technologies and networks • Energy systems with high shares of renewables • Net zero society • Role of nuclear energy • Role of hydrogen • Carbon capture and storage • Electric vehicles • Modal shifts (role of walking and cycling)

	• Shock events (e.g., natural hazards, blackouts, wars) • Other: __
1.3b	The inclusion of **socio-political factors** in energy models is often considered a promising focus. **Which factors do you consider tob e important?** [5-point Likert: Less attention → More attention] • Social impacts of the energy transition (e. g., gain and losses of jobs, energy poverty & justice) • Behavior & lifestyles of citizens • Consumer preferences • Impact of political parties or lobbies on energy politics and policies • Impact of social movements on energy politics and policies • Public acceptance and attitudes towards energy technologies • Demand elasticity or rebound effects • Prosumerism and community energy • Geopolitical developments • Other:
1.4	**Do you agree with the following statements about energy models and scenarios?** [5-point Likert: Don't agree → Agree] • They are an important basis for decision-makers in energy *policy* • They are an important basis for decision-makers in energy *industry* • They are only as credible as the organisation developing them • They are black boxes for people who are not involved in their development • They are most useful when a diverse set of scenarios is considered • They are influenced by contemporary political and economic interests [visual break] • They should be based on scientific methods • They should make key assumptions more explicit • They should indicate the probabilities associated with different scenarios • They should explore energy futures that are radically different from the status quo • They should not only consider techno-economic factors, but also socio-political factors • They should provide more guidance on how their findings can be used

1.5	**Almost done! The following questions are about the specific models and scenarios you are using. What is the name of the energy model you are working with? Please list one or more.**
1.6	**What formats and communication channels do you use to communicate your findings?** [Multiple choice] • Scientific papers or conferences • Fact sheets or reports for practitioners • Podcasts or videos • Workshops or seminars with practitioners • Website • Web-interfaces (e.g. for users to adapt scenarios) • Open-source repositories & databases (e.g. GitHub) • Model documentation (technical reports on model purpose and capabilities) • Model comparison or overview platforms • Social media • Creative formats (art installations, serious games, etc.) • Other: ____
1.7	**Who could potentially use the findings of your work?** [Multiple choice] very unlikely→very likely • Other model developers • Scientific community • International authorities • National authorities • Cantonal authorities • Municipal authorities • Energy industry executives • Transmission or distribution system operators (TSOs/DSOs) • Urban planners • Architects • Corporate decision-makers • NGO’s • Politicians • Investors • Consultancies

	• Media • Home owners • General Public • Others:______
1.7b	**You marked the following actors as potential recipients of model-based findings. To your knowledge, which actors are already using your findings?** [Multiple choice based on 1.4 selections] …
1.8	**Do you have suggestions to increase the usability or relevance of energy models and scenarios that you want to share?** [Optional free text field]
1.9	In this research project, a small set of scenario developer-user exchanges will be organised to improve the usability of specific energy models. **Are you interested in participating in this process?** Please leave your contact details and we will get in touch to discuss the most suitable options and target-audience for your model. **Name** **Email address:** ______________________ [open field; optional]
1.10	We would like to inform you about our results. If you agree to hearing from us again, please enter your contact email address below. Your personal data will not be linked to the questionnaire. Email address: ______________________ [open field; optional]

Welcome to the *ProdUse* survey!

This survey is designed for people and organisations interested in the Swiss energy future and its representation in energy research. You don't need prior experience with energy models and scenarios to take part. Your answers will help us to identify ways to make energy models and scenarios more user friendly and relevant. Completing the survey will take about **10 minutes**. Your data will be evaluated anonymously and will only be used for research purposes. All data protection regulations will be observed.

If you want to know more about the *ProdUse* project or have any questions, please get in touch. We hope you enjoy the survey and thank you for supporting our research.

Lukas Braunreiter, ZHAW Innovation Systems Group

lukas.braunreiter@zhaw.ch / Tel: +41 58 934 64 75

If you agree with the privacy policy, you can start your participation in the survey at the bottom.

☐ I consent to the processing of my data in accordance with the information provided

2. User survey

Number	Question
1.1	**Which actor group do you count yourself among?** [Drop-down list] • Association • Energy industry • Federal government • Cantonal government • Municipal government • Insurance • Investor • Journalism & Media • Non-governmental organisation • Politics • Research, Innovation & Consultancy • Transmission or distribution system operator • Other:
	Gender • Woman • Man • Transgender • Non-binary/non-conforming • Prefer not to respond **Age** • 25 or younger • 26-35 • 36-45 • 46-55 • 56-65

	• 66 or older
1.2	**Have you ever used or referred to energy models or scenarios in your work?** • Yes, frequently • Yes, but not often • No, never
1.2.1a	**For what purpose have you used or referred to energy models or scenarios?** • General interest in energy topics • Interest in a specific topic-→Please specifiy • Understanding the impact of technologies or policies • Identifying new business opportunities • Strategy development • Internal decision-making (Please specify) • Informing external stakeholders or partners • Other:___
1.2.2	**Optional: Please describe your user experience shortly. If you remember which energy models or scenarios you used, please list them.**
1.2.1b	If no on 1.1: …**What are the reasons why you have not used energy models and scenarios so far?** • I don't consider them relevant • I don't know how to find or access them • I am not sure how to interpret their results • I am critical of their assumptions • I don't trust energy models • Other information sources are more appropriate →Please specify: _____ • Other: ___
1.3	This part of the survey covers your personal preferences with regards to energy models and scenarios. **What geographical area would you like to see represented in energy models and scenarios?** You can select multiple options. [Multiple choice] • Global • EU • Switzerland • Regional (e.g. cantonal) • Local (e.g., municipal)

	• District or village • Buildings • Other:
1.4	**What time horizon would you like to see represented in energy models and scenarios?** You can select multiple options. [Multiple choice] • Progression until 2035 • Progression until 2050 • Progression until 2100 • Other_____________
1.8	**What formats and communication channels would you like to have as an option to interact with energy models and scenarios?** [Multiple choice] • Scientific papers or conferences • Fact sheets or reports for practitioners • Podcasts or videos • Workshops or seminars with practitioners • Website • Web-interfaces (e.g. to adapt scenarios) • Open-source repositories & databases (e.g. GitHub) • Model documentation (technical reports on model purpose and capabilities) • Model or scenario comparison or overview platforms • Social media • Creative formats (art installations, serious games, etc.) • Other: _____
1.5	**What should be the role of energy models and scenarios in the energy transition?** [5-point Likert: Not important → Very important] • Improving the scientific understanding of energy systems or transitions • Exploring a broad range of plausible energy futures • Analysing the feasibility of existing energy policy goals • Informing experts (energy industry, policymakers, etc.) • Informing lay people (general public, home owners, etc.) • Stimulating societal deliberations about key energy transition issues

	• Identifying *technologically* feasible pathways towards a renewable energy future • Identifying *economically* viable pathways towards a renewable energy future • Identifying *socially desirable* pathways towards a renewable energy future • Other:____
1.6a	**Which of the following factors should receive more attention in energy models?** [5-point Likert: Less attention → More attention] • Impact of energy infrastructure on natural environment and natural resources • Total costs and investment costs of energy transitions • Electricity market liberalisation • Energy import availability and dependency • Energy supply security • Seasonal energy storage • Energy systems with high shares of renewables • Net zero society • Role of nuclear energy • Role of hydrogen • Degrowth or low growth scenarios • Shock events (e.g., natural hazards, blackouts, wars) • Other: __
1.6b	The inclusion of **socio-political factors** in energy models is often considered a promising focus. **Which factors do you consider most important?** [5-point Likert: Less attention → More attention] • Social impacts of the energy transition (e. g., gain and losses of jobs, energy poverty) • Behavior & lifestyles of citizens • Consumer preferences • Impact of political parties or lobbies on energy politics and policies • Impact of social movements on energy politics and policies • Public acceptance and attitudes towards energy technologies • Demand elasticity or rebound effects • Prosumerism and community energy • Modal shifts (e.g. role of EVs, E-bikes, bicycles) • Geopolitical developments • Other:

	Which questions or topics should be addressed in energy models and scenarios so that they become more useful for your specific context? [Optional free text field]
1.7	**Almost done! Do you agree with the following statements about energy models and scenarios?** [5-point Likert: Don't agree → Agree] • They are an important basis for decision-makers in energy *policy* • They are an important basis for decision-makers in energy *industry* • They are only as credible as the organisation developing them • They are black boxes for people who are not involved in their development • They are most useful when a diverse set of scenarios is considered • They are influenced by contemporary political and economic interests [visual break] • They should be based on scientific methods • They should make key assumptions more explicit • They should indicate the probabilities associated with different scenarios • They should explore energy futures that are radically different from the status quo • They should not only consider techno-economic factors, but also socio-political factors • They should provide more guidance on how their findings can be used
1.10	**What can researchers do to increase the relevance or usability of energy models and scenarios for you?** [Optional free text field]
1.11	In this research project, a small set of scenario developer-user exchanges will be organised. Would you be interested in participating in a scenario development process with energy modelers? If yes, please shortly describe in what kind of topics or scenario you would be interested in. We will get in touch to discuss the most suitable options with you. **Topic:** **Name:** **Email address:**
1.12	We would like to inform you about our results. If you agree to hearing from us again, please enter your email address below. Your personal data will not be linked to the questionnaire. **Email address:**______________________

C: Short survey of Energy Week @ ETH 2022 visitors and VisEnergy workshop participants

Energy Week @ ETH 2022

Feedback Energy Week @ ETH exhibition 2022

Gender: ☐ Female ☐ Male ☐ Diverse
Age: ☐ 18 and younger ☐ 19-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ 66 and older
Profession or course of study: _____________

How much do you agree with the following statements? After visiting this exhibition...	++	+	o	-	--
...I have a more concrete idea of the Swiss energy future	o	o	o	o	o
...I know more about the current Swiss energy system	o	o	o	o	o
...I am more optimistic that we can achieve a sustainable energy transition	o	o	o	o	o
...I am motivated to get involved in the energy transition	o	o	o	o	o
...I am more interested in the topic of energy than before	o	o	o	o	o

How well are the following topics represented in the exhibition?	**Don't know**	++	+	o	-	--
Expansion of renewable energies (e.g. water, solar, wind)	o	o	o	o	o	o
Financing the energy transition	o	o	o	o	o	o
Energy prices	o	o	o	o	o	o
Political and regulatory framework (e.g. laws)	o	o	o	o	o	o
Public acceptance of energy technologies	o	o	o	o	o	o
Energy storage (e.g. batteries, pumped storage, hydrogen)	o	o	o	o	o	o
Electrification of transport and heat (e.g. heat pumps)	o	o	o	o	o	o
Security of supply & energy imports	o	o	o	o	o	o
Energy demand & sufficiency (e.g., energy conservation)	o	o	o	o	o	o
Environment and biodiversity	o	o	o	o	o	o
Climate change and greenhouse gas emissions	o	o	o	o	o	o
Did you miss anything? ________________________________						

How do you evaluate the different exhibition formats?	**Did not use**	++	+	o	-	--
A) Axpo Powerswitcher (tablets to create your own scenarios)	o	o	o	o	o	o
B) Ground graphic (change of the energy system from today to 2050)	o	o	o	o	o	o
C) AR-Landscape Switzerland (visualization of the energy future)	o	o	o	o	o	o
D) Energy transition video (tablets with explanatory video)	o	o	o	o	o	o
E) Energy source columns (change in relevance from today to 2050)	o	o	o	o	o	o

Which of these exhibition formats (A-E) was most successful in making the energy future imaginable?
☐ **A** ☐ **B** ☐ **C** ☐ **D** ☐ **E**

How do you evaluate the selected exhibition format? Choose which description applies more.

	<<	<	o	>	>>	
oversimplified	○	○	○	○	○	too complicated
meaningful	○	○	○	○	○	meaningless
innovative	○	○	○	○	○	unimaginative
fact-based	○	○	○	○	○	speculative
How do you feel about the energy future shown in it? Choose which description applies more.						
credible	○	○	○	○	○	implausible
surprising	○	○	○	○	○	expectable
too extreme	○	○	○	○	○	too close to status quo
desirable	○	○	○	○	○	daunting

If you wish, you can rate other exhibition formats on the reverse side ⤸

Anything else you would like to tell us? We are happy to receive any feedback. Thank you!

ENERGY WEEK
@ ETH 2022

If you would like to evaluate additional exhibition formats, you can do so on this page.

Which exhibition format (A-E) would you like to provide feedback on? ☐ A ☐ B ☐ C ☐ D ☐ E						
How do you evaluate the selected exhibition format? Choose which description applies more.						
	<<	<	o	>	>>	
oversimplified	○	○	○	○	○	too complicated
meaningful	○	○	○	○	○	meaningless
innovative	○	○	○	○	○	unimaginative
fact-based	○	○	○	○	○	speculative
How do you feel about the energy future shown in it? Choose which description applies more.						
credible	○	○	○	○	○	implausible
surprising	○	○	○	○	○	expectable
too extreme	○	○	○	○	○	too close to status quo
desirable	○	○	○	○	○	daunting

Which exhibition format (A-E) would you like to provide feedback on? ☐ A ☐ B ☐ C ☐ D ☐ E						
How do you evaluate the selected exhibition format? Choose which description applies more.						
	<<	<	o	>	>>	
oversimplified	○	○	○	○	○	too complicated
meaningful	○	○	○	○	○	meaningless
innovative	○	○	○	○	○	unimaginative
fact-based	○	○	○	○	○	speculative
How do you feel about the energy future shown in it? Choose which description applies more.						
credible	○	○	○	○	○	implausible
surprising	○	○	○	○	○	expectable
too extreme	○	○	○	○	○	too close to status quo
desirable	○	○	○	○	○	daunting

Information about the survey
This survey is conducted by the Zurich University of Applied Sciences (ZHAW) in collaboration with the Energy Science Center (ESC) of ETH Zurich. Your data will be analysed anonymously and used only for research purposes and the improvement of future exhibitions.

Thank you for visiting us and for your feedback on Energy Week @ ETH 2022.

Contact
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Energy Science Center

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Feedback Fragebogen HSLU Workshops House of Energy

Geschlecht: ☐ Weiblich ☐ Männlich ☐ Divers
Alter: ☐ 18 und jünger ☐ 19-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ 66 und älter
Beruf oder Studiengang: ____________

Wie sehr stimmen Sie den folgenden Aussagen zu? Durch den House of Energy Workshop…	++	+	o	-	--
…habe ich eine konkretere Vorstellung der Schweizer Energiezukunft	o	o	o	o	o
…weiss ich mehr über das aktuelle Schweizer Energiesystem	o	o	o	o	o
…bin ich optimistischer, dass wir die Energiewende schaffen	o	o	o	o	o
…bin ich motiviert, mich für die Energiewende zu engagieren	o	o	o	o	o
…interessiere ich mich stärker für das Thema Energie als zuvor	o	o	o	o	o

Über welche Themen der Energiezukunft hätten Sie im House of Energy Workshop gerne mehr erfahren?	++	+	o	-	--
Ausbau erneuerbarer Energien	o	o	o	o	o
Energiepreise	o	o	o	o	o
Politische und regulatorische Rahmenbedingungen (z.B. Gesetze)	o	o	o	o	o
Öffentliche Akzeptanz von Energietechnologien	o	o	o	o	o
Energiespeicherung (z.B. Batterien, Pumpspeicher, Wasserstoff)	o	o	o	o	o
Elektrifizierung von Transport und Wärme (z.B. Wärmepumpen)	o	o	o	o	o
Versorgungssicherheit & Energieimporte	o	o	o	o	o
Energienachfrage & Suffizienz (z.B. sparsamer Umgang mit Energie)	o	o	o	o	o
Umwelt und Biodiversität	o	o	o	o	o
Klimawandel und Treibhausgas-Emissionen	o	o	o	o	o
Anderes:					

Wie bewerten Sie den House of Energy Workshop? Kreuzen Sie an, welche Beschreibung eher zutrifft.

	<<	<	o	>	>>	
zu stark vereinfacht	○	○	○	○	○	zu kompliziert
aussagekräftig	○	○	○	○	○	nichtssagend
innovativ	○	○	○	○	○	einfallslos
faktenbasiert	○	○	○	○	○	spekulativ

Wollen Sie uns noch etwas mitteilen? Wir freuen uns über jedes Feedback. Herzlichen Dank!

D: Short report of VisEnergy project

Projektbericht[1] «Visualisierung der Energiewende»

Eckpunkte des Projekts

Mit dem Projekt «Visualisierung der Energiewende in Luzern Süd» soll das Potenzial der Visualisierung von Daten, in erster Linie mittels «interaktiver Datentische», für die Unterstützung der Energiewende in Gemeinden und Kantonen ausgelotet werden. Der Gemeindeverband Luzern Süd soll bei der Ausarbeitung von Massnahmen für die Energiewende und der Definition eines CO2-Absenkpfads begleitet und unterstützt werden.

Ziel ist es, eine interaktive, für verschiedene Fragestellungen nutzbare, leicht verständliche Visualisierung des Energiesystems von Luzern Süd zu realisieren. Diese Visualisierung wird in erster Linie auf Datentischen (*RegionScope* des Smart Region Lab der Hochschule Luzern) umgesetzt, welche die Möglichkeit taktiler, interaktiver Bedienung und der Verwendung in der Gruppe bieten.

Der aus den interaktiven Datentischen der Hochschule Luzern resultierende Mehrwert geht aus der Zusammenarbeit zwischen dem Smart Region Lab sowie den Departementen Technik & Architektur, Informatik, Soziale Arbeit und Design & Kunst hervor. Das interdisziplinäre Projektteam verknüpft auf einer soliden wissenschaftlichen Grundlage deren Expertise rund um Energiesysteme, Strom- und Wärmenetze, Informatik, Datenvisualisierung, partizipative Prozesse sowie die Entwicklung von Regionen, Kantonen, Städten, Gemeinden und Unternehmen.

Entstehung des Projekts

Das Projekt Visualisierung der Energiewende wurde als interdisziplinäres Projekt konzipiert und unter anderem vom Förderprogramm der HSLU für interdisziplinäre Zusammenarbeit (ITC) finanziert. Dem Projektteam gehörten Mitarbeitende mit Hintergrund in Sozialwissenschaften und soziokultureller Entwicklung, in Informatik und in Energietechnik an.

In der Vorbereitungsphase wurde die Projektidee mit verschiedenen Vertreter*innen von Gemeinden, Kanton und Zivilgesellschaft diskutiert. Das Visualisierungstool sollte von Anfang an in Zusammenarbeit mit Partnern, die es selber verwenden wollten, entwickelt werden. Bei der Suche nach geeigneten Partnern stiess die Projektidee auf Interesse und wurde in folgenden Kontexten präsentiert:

- Treffen mit Vertretern und Energiebeauftragten der Gemeinde Hergiswil
- Präsentation am Jahrestreffen der Energiebeauftragten der Nidwaldner Gemeinden
- Treffen mit Vertretern einer Energieinitiative in Buttisholz
- Treffen mit Mitarbeitenden des Kantons Luzern zum Thema GIS
- Präsentation an Sitzung von Vertreter*innen von Gemeinden im Entlebuch
- Präsentation am Jahresanlass des Gemeindeverbands Luzern Plus

Mit dem Gemeindeverband Luzern Süd und den Gemeinden Kriens und Luzern konnten dann Partner gefunden werden, um die Visualisierung der Energiewendedaten auf den interaktiven Datentischen zu testen und weiterzuentwickeln.

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[1] Dieser Projektbericht wurde Ende Juni 2023 für die Zwecke des SOUR ProdUse erstellt. Beitragende: Francesca Paoletti, Christopher Young, Lucas Caluori, Philipp Schütz (alle HSLU).

Zwei Anwendungsbereiche wurden in der Zusammenarbeit mit Luzern Süd in Erwägung gezogen.
(1) Workshop- und Präsentationsformate, bei denen es um die Kommunikation oder Diskussion von energiepolitischen Fragen und Massnahmen bzw. die Sensibilisierung für diese geht. Zielgruppe sind dabei die Bevölkerung von Luzern Süd oder bestimmte Akteursgruppen (z.B. Liegenschaftseigentümer*innen, Arealentwickler*innen).
(2) Workshop- und Präsentationsformate, mit denen Akteure auf der Ebene von Politik und Verwaltung bei Planungs- und Entscheidungsprozessen unterstützt werden. Hier könnte ein Mehrwert durch die Verknüpfung von Daten über verschiedene Themen und Verwaltungseinheiten hinweg generiert werden.

Im Verlauf des Projekts wurde entschieden auf den ersten Anwendungsbereich zu fokussieren. Für Gemeinden ist die Kommunikation mit Bewohnenden von Arealen oder Quartieren mit einem grossen Handlungsbedarf in Sachen Energiewende oft eine Herausforderung. Das sind beispielsweise Quartiere, die hauptsächlich fossil beheizt werden, wo ein Potenzial für einen Wärmeverbund oder Photovoltaik vorhanden ist. Bei Wohnquartieren sind zentrale Energiethemen das CO2-freie Heizen von Gebäuden, die Verbesserung der Wärmedämmung oder die Nutzung von Dach- und Fassadenflächen für die Produktion von Strom mit Photovoltaik. Aus anderen Energieprojekten der HSLU ist bekannt, dass es fruchtbar sein kann, wenn Bewohnende eines Quartiers an einem Workshop zusammenkommen. Hier können Ideen im Austausch zwischen Eigentümer*innen und Fachleuten entstehen, für einzelne Eigentümer*innen kann der Austausch mit anderen motivierend und informativ sein und schliesslich können an einem solchen Anlass auch die Grundlagen für kooperative Lösungen gelegt werden.
Die Vermittlung der Probleme und der Potenziale an die Bewohnenden zu erleichtern wurde als zentrales Ziel des Projekts gesetzt. Das Informieren, das Erkennen von Möglichkeiten, das Ausarbeiten von Szenarien sollte durch die Bereitstellung der richtigen Informationen in verständlicher Form verbessert werden. Das wird durch eine Kombination des Datentisches mit geeigneten Workshopformaten angestrebt.

Das Smart Region Lab und die interaktiven Datentische

Das Smart Region Lab ist das Herzstück der strategischen Initiative «Smart Region Zentralschweiz» der Hochschule Luzern. Smart Region Zentralschweiz arbeitet mit interaktiven Datentischen, um komplexe Daten auf intuitive Art zu visualisieren und dadurch nutzbar zu machen. Die Initiative entstand 2021 als Kooperation mit dem CityScienceLab der HafenCity Universität Hamburg und hat zum Ziel, durch datenbasierte Kooperation regionale Transformationsprozesse inklusiv und nachhaltig zu gestalten.

Die interaktiven Datentische dienen dazu, georeferenzierte Daten visuell ansprechend aufzubereiten und dank der Integration von zusätzlichen Layern – etwa einem Orthofoto oder Zonenplänen – Fragestellungen datenbasiert und kollaborativ zu bearbeiten. Die Multi-Touch-Steuerung sowie zusätzliche physische Lupen, sogenannte Tangibles, ermöglichen es dabei, direkt am Tisch mit den Daten zu arbeiten und unmittelbar Auswertungen oder Szenarien abzurufen.

Das Smart Region Lab arbeitet dabei immer interdisziplinär: Für die technologische Entwicklung und Programmierung der Datentische besteht ein eigenes IT-Team, für die Datenbeschaffung sowie die konzeptuell/inhaltliche Ausarbeitung der Tools werden projektspezifisch Expert:innen aus anderen Departementen (oder auch aus der Industrie und Wirtschaft) beigezogen. Diese Zusammenarbeiten fördern transdisziplinäre Denkweisen, bilden aber auch kommunikative Herausforderungen.

Die visualisierten Daten

Die auf den Datentischen[2] visualisierten Datensätze ermöglichen es, für jedes Gebäude der Schweiz den CO2-Fussabdruck zu visualisieren und mit anderen Gebäuden in der Umgebung bzw. in der Gemeinde zu vergleichen (Benchmark-Funktion). Weiterhin werden einfache Szenarien berechnet, z.B. die Veränderung im CO2-Fussabdruck, falls der Primärenergieträger gewechselt wird (z.B. von Gas oder Heizöl zu PV) oder der Einfluss auf die Gesamtenergiebilanz einer Gemeinde (oder eines Areals/Quartiers), wenn eine bestimmte Anzahl an Gebäuden den Energieträger wechselt.
Die Gebäudedaten, welche auf den interaktiven Datentischen erlebbar sind, stammen aus dem eidgenössischen Gebäude- und Wohnungsregister (GWR) und die Daten zu Potenzialen von Photovoltaikanlagen (PV) aus dem öffentlichen Solarkataster des Bundes. Das GWR wurde aus Daten der Volkszählung erstellt und wird laufend vom Bundesamt für Statistik in Zusammenarbeit mit den Kantonen und Gemeinden – etwa anhand von Baugesuchen – nachgeführt. Die zur Visualisierung der Energiewende genutzten Grunddaten sind allesamt öffentlich zugänglich und werden vom Bund als datenschutztechnisch unproblematisch eingestuft.

Forschungsarbeiten, welche ins Projekt eingeflossen sind

- **SWEET-EDGE:** Integration hoher Anteile dezentraler erneuerbarer Energien in das Schweizer Energiesystem: Das EDGE-Programm zielt darauf ab, den Einsatz von erneuerbaren Energien, lokal und dezentral in der Schweiz, zu beschleunigen. Das Projekt soll sicherstellen, dass bis 2035 und 2050, wenn erneuerbare Energien einen ambitionierten Anteil erreicht haben, das Schweizer Energiesystem optimal ausgelegt und betrieben, sowie technisch und wirtschaftlich sicher und auf den europäischen Märkten positioniert ist. Link zum Projekt: https://www.hslu.ch/de-ch/hochschule-luzern/forschung/projekte/detail/?pid=6178
- **SWEET-PATHFNDR:** Pathways to an efficient future energy system through flexibility and sector coupling: Das Projekt zielt auf die Entwicklung und Analyse von Transitionspfaden für die Integration erneuerbarer Energien im Schweizer Energiesystem ab. Das Projekt wird realisierbare Wege aufzeigen, Planungs- und Betriebsinstrumente bereitstellen, Pilot- und Demonstrationsprojekte entwickeln, neue Geschäftsmöglichkeiten und Innovationsstrategien identifizieren und mögliche politische Maßnahmen analysieren. Mehr zum Projekt: https://sweet-pathfndr.ch
- **SWEET-DeCarbCH:** DeCarbonisation of Cooling and Heating: Das Projekt DeCarbCH befasst sich mit der gewaltigen Herausforderung der Dekarbonisierung der Wärme- und Kälteerzeugung in der Schweiz innerhalb von drei Jahrzehnten und bereitet die Grundlagen für negative CO2-Emissionen vor. Das Gesamtziel des Projekts (mit dem letztendlichen Ziel von Netto-Null-Emissionen) besteht darin, die Einführung von erneuerbaren Energien für Heizung und Kühlung im Wohnbereich sowie im Dienstleistungs- und Industriesektor zu erleichtern, zu beschleunigen und Risiken zu verringern. Mehr zum Projekt: https://www.sweet-decarb.ch/

Der Workshop «Kuonimatt» (Januar 2023)

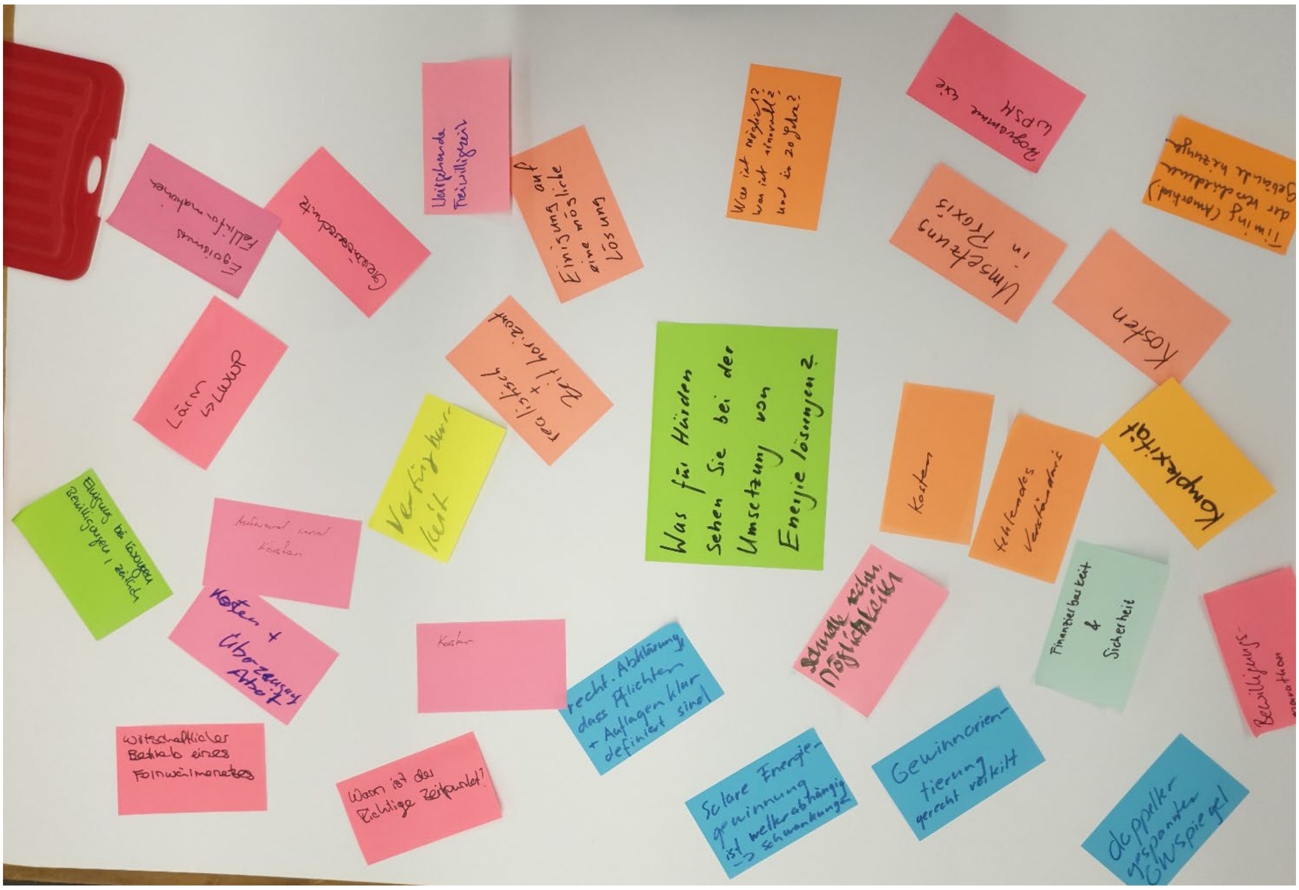
Am 31.01.2023 fand ein Workshop zur Energiesituation des Quartiers Kuonimatt (Gemeinde Kriens) statt.Teilgenommen haben neun Hauseigentümer aus dem Quartier Kuonimatt, fünf Vertreter*innen der Gemeinden Kriens und Luzern und eine Vertreterin des Kantons Luzern.

Für den Workshop wurde eine erste Version einer Energie-Visualisierung auf dem Datentisch realisiert. Auf dieser waren CO2 Ausstoss und Solarpotenzial jedes Gebäudes im Kanton Luzern visualisiert.

[2] Dieser Abschnitt beschreibt die Daten und Funktionen der aktuellen Version des Energie-Datentisches Juni 2023. Frühere Versionen wichen in einzelnen Punkten davon ab.

Ablauf des Workshops

- Begrüssung, Kennenlernen
- Einstieg ins Thema mit Energie-Fragen
- Zwei 40-minütige «Ideen-Runden», in denen die Teilnehmenden in Gruppen Ideen entwickelten
- Abschluss mit Apéro



Visuelles Protokoll aus dem Workshop

Einstieg in den Workshop: Einander «energetisch» besser kennenlernen

Um die Ausgangslage besser zu verstehen, haben zu Beginn alle Teilnehmenden folgende Fragen rund um Energie im Quartier beantworten und konnten die Antworten gegenseitig studieren.

- Was haben Sie schon an Massnahmen für den Umstieg auf erneuerbare Energien an Ihrem Gebäude umgesetzt?
- Was sind wichtige Hürden für Umsetzung von erneuerbaren Energien in der Kuonimatt?
- Welche Lösungen sehen Sie für eine Versorgung der Kuonimatt mit erneuerbaren Energien?

In den Antworten erschienen eine Reihe von Themen. Einige hatten schon Massnahmen hin zu erneuerbaren Energien getroffen, wie die Installation von PV, Wärmepumpen, Gebäudedämmung oder Smarthome-Elementen oder hatten Miteigentümer sensibilisiert. Als potenzielle Hürden nannten sie erstens finanzielle, Investitionskosten, Zugang zu Fördergeldern oder Probleme des Zeitpunkts des Heizungsersatzes und der Amortisierung. Weiter sahen sie rechtliche Hürden bzw. Aufklärungsbedarf bei rechtlichen Fragen. Ein spezifisches Thema war der Lärm bei Luft-Wasser-Wärmepumpen genannt (der Einsprachen auslösen kann). Auf der Ebene der Hausbesitzer*innen wurden fehlendes Wissen und Verständnis, die notwendige Einigung bei gemeinsamen Lösungen und die Überzeugungsarbeit, die bei manchen geleistet werden müsste, ins Feld geführt. Sie sahen auch viele Potenziale und Chance für eine Energiewende im Quartier, z.B. eine «Quartierstrom» IG oder Genossenschaft, der gemeinsame Einkauf von Energie, oder einen Wärmeverbund im Quartier.

Der Kern des Workshops: Ideen für ein visuelles Werkzeug
Im zweiten Teil des Workshops haben die Teilnehmenden in Gruppen Ideen für ein visuelles, digitales Werkzeug zur Unterstützung der Energiewende im Quartier entwickelt. Dieser sollte auf dem vor Ort gezeigten «Datentisch» realisiert werden. Sie haben Antworten entwickelt, welche Informationen Quartierbewohnende von einem Diskussionsanlass erwarten würden und wie diese dargestellt werden könnten. In den zwei Runden sind viele spannende Ideen zusammengekommen. In der Auswertung nach dem Workshop wurden diese Ideen geordnet. Die betrafen (1) Informationen zum Ist-Zustand des Quartiers, (2) Möglichkeiten zur Darstellung von Spielräumen und Potenzialen im Quartier, (3) die Verwendung von gelungenen Beispielen als Inspiration und (4) die Darstellung von rechtlichen und finanziellen Informationen. Die Inputs und Ideen boten Hinweise, was aus Sicht von potenziellen Nutzer*innen wichtig ist, und was nicht im Zentrum steht.

Beteiligung an der Ausstellung «Experience Energy!» im Verkehrshaus der Schweiz

Anlässlich der Eröffnung der Ausstellung «Experience Energy!» im Verkehrshaus der Schweiz Anfangs April 2023 wurden die interaktiven Datentische der Hochschule Luzern eine Woche lang (03.-07.04.2023) zum ersten Mal einer breiten Öffentlichkeit vorgestellt. Die Erkenntnisse aus dem Workshop wie auch aus der Ausstellungswoche wurden dabei laufend für die Weiterentwicklung des Tools genutzt. Besucherinnen und Besucher des Verkehrshauses (geladene Gäste aus Politik und Wirtschaft an der Vernissage wie auch Familien und Schulklassen in den folgenden Tagen) hatten die Möglichkeit, die Datentische interaktiv zu erleben und mit einem Team von Forschenden in Dialog zu treten.

Die Besucher*innen der Ausstellung zeigten grosses Interesse an den Datentischen. Die enge Betreuung durch das Forschungsteam der Hochschule Luzern hat Möglichkeiten für Dialog geboten und Raum geöffnet für Fragen. Dabei gingen die meisten Fragen in Richtung der Finanzierung und der politischen Rahmenbedingungen, was einen grundsätzlichen Wissensbedarf in diesem Bereich aufzeigt.

Im Anschluss zur Eröffnungswoche zeigte das Verkehrshaus der Schweiz grosses Interesse daran, die Präsenz der Datentische in der Ausstellung «Experience Energy!» zu verstetigen. Ziel ist es nun, gemeinsam mit dem Verkehrshaus ein langfristiges Ausstellungstool zu entwickeln. Das Smart Region Lab ist derzeit daran, in Zusammenarbeit mit dem City Science Lab in Hamburg eine entsprechendes Tool zu konzeptionieren, sodass die Hochschule einen Beitrag dazu leisten kann, die Energiewende visuell an die Bevölkerung zu vermitteln.

Ausblick

Das Projekt VisEnergy ist zum Zeitpunkt des Verfassens dieses Berichts nicht abgeschlossen. Die Datentische werden anhand der Ergebnisse des Workshops «Kuonimatt» und den Erfahrungen im Verkehrshaus der Schweiz weiterentwickelt. Die Zusammenarbeit mit den Gemeinden und mit Luzern Süd wird weitergeführt, mit der Zielsetzung, lokale Energiewende-Projekte auf einer partizipativen Basis im Dialog mit den Bürgerinnen und Bürgern umzusetzen. Konkret ist geplant, das überarbeitete Visualisierungstool in einer Veranstaltung Ende 2023/Anfang 2024 in einem Quartieranlass der Gemeinde Kriens im Rahmen der partizipativen Energieplanung anzuwenden.