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Full-length article

Exploring possible futures or reinforcing the status-quo? The use of model-based scenarios in the Swiss energy industry

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ABSTRACT

Energy scenarios are often claimed to support decision-makers involved in the energy transition. However, an empirical understanding of how decision makers select, interpret, and use energy scenarios is largely missing. This study examined how high-level public utility executives in the energy sector, a key target audience of energy scenarios, perceive and interact with energy scenarios. Based on interviews with representatives of 20 Swiss utilities, we show that the use of scenarios is rarely part of a formalized process aimed at assisting decision-making processes. Instead, the selection of scenarios is often contingent on users' perceptions of their legitimacy, credibility, and salience. While utility executives could rely on a wide variety of scenarios published by academic, corporate, and non-governmental organizations, they often focus on a limited set. Given the complexity of contemporary energy scenarios, which are often based on sophisticated energy system models, familiarity with publishing organizations and reporting styles is an important selection heuristic for users. This stands in contrast to the purpose and of stated key motivation of considering a broad range of plausible futures and their associated trade-offs. Our results suggest that to evaluate the impact of energy scenarios, social-scientific research also needs to consider user groups that are neither involved in participative modeling activities, nor collaborating with scenario developers in any other form. The usefulness of energy scenarios in these contexts and particularly their capacity to contribute to integrative deliberations on plausible and desirable energy futures is highly relevant, yet largely unknown.

1. Introduction

The large-scale deployment of renewable energy technologies and their integration into the energy system requires a range of actors to make momentous decisions under conditions of considerable uncertainty [1]. In addition to renewable energy technologies bringing new dynamics, such as supply fluctuations [2] and geographically more decentralized production [3], into the current energy system, decision makers are often also required to consider the multiple and closely intertwined interactions between technology, economy, environment, policy, and society [4–6].

From an epistemological perspective, energy scenarios are ideal for supporting decision makers in the face of these uncertainties and interdependencies, as they offer the opportunity to explore multiple plausible decarbonization pathways and their trade-offs [7–9]. From a scenario user perspective, however, energy scenarios often resemble "black boxes" that are difficult to locate on a spectrum ranging from subjective beliefs to scientific assessments [10–12]. Particularly for actors who are not part of the scenario development process, it can be difficult to understand how insights are obtained, on what assumptions they are contingent, or what factors are considered out of scope [13,14].

When the fossil fuel company Shell pioneered the use of scenarios as a corporate foresight tool in the 1970s, integrating relevant decision-makers into the scenario development process and gradually training participants to embrace thinking about multiple plausible futures was a key part of Shell's scenario activities [15,16]. Scenario developers and users, who were expected to make decisions with the help of insights scenarios provide, collaborated closely. Over the past few decades, not only the popularity and diversity of energy scenarios, but also their level of technical and methodological sophistication, has increased [17,18]. Contemporary energy scenarios are typically based on highly specialized energy system models [19]. While actors from outside the modeling community are sometimes consulted to inform modeling activities—for example, to provide expert opinions on certain assumptions—Garb et al. [14] noted a gap between scenario producers (modelers) and users (decision-makers) in terms of expertise, needs, capabilities, and educational backgrounds.

To narrow the gap between scenario producers and users, recent research has often focused on participatory case studies to identify the best practices to streamline their interactions [20–23]. Most studies thus focus on energy scenario use contexts that involve some form of interaction between scenario developers and users [88–90]. In contrast, studies on how energy scenarios are used when there is no such interaction are rare [13,14]. However, these external types of scenario use (i.

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e., by users who are not part of the scenario development or modeling activities) constitute a widespread scenario use context. This study tries to answer the question how utility executives, a key actor group in energy transitions, perceive and use externally developed energy scenarios. These utility executives can choose from a variety of publicly available energy scenarios developed by organizations such as research institutions, governmental agencies, nongovernmental organizations, think tanks, public utilities, and fossil fuel companies, that often invest considerable resources in the development and dissemination of their energy scenarios [24–28].

Science and technology studies have shown that energy scenarios can function as socio-technical imaginaries that influence individuals' expectations and contribute to the formation of shared visions, thereby shaping technological change [29–31]. Energy scenarios can thus guide investment strategies, provide support for or contribute to the rejection of corporate decisions, and, through their influence across various political and geographical scales, influence the perceived desirability of energy transition trajectories more generally [32–35]. Customizable Energy scenario interfaces have also been used to elicit public preferences [36] or expectations of the energy future [37–40]. Therefore, understanding the mechanisms shaping the interdependency between the development of scenarios and their potential use is critical for evaluating their impact and usefulness for energy transitions. Given the wide diversity of (potential) users of energy scenarios, our empirical analysis focused on a single key target group—namely, electric utility companies—to study the perception and use of energy scenarios.

2. Methods

2.1. Case information: focusing on Swiss public utilities

This study relied on empirical observations of whether and how high-level decision makers of public utilities use energy scenarios. Utilities are an important actor group in the energy sector, as they have the resources and agency to influence nearly all aspects of the energy transition [41]. Due to their resource-intensive infrastructure, broad time horizons, and general need for evidence-based decision-making, utilities constitute a key target audience of energy scenarios. We focused on Switzerland because energy scenarios play an important role in the development of the Swiss energy system. The relevance of energy scenarios became evident in 2011, when the Federal Council decided to phase out all nuclear power stations, which still produce about a third of the country's electricity. The techno-economic feasibility of this phaseout had been assessed in a model-based scenario study called *Energy Perspectives,* which constituted the basis for the *Energy Strategy 2050* (ES2050) enacted after a referendum in 2017. In summary, the aim is to replace nuclear energy with renewables and achieve a significant reduction in energy demand [42]. The *Energy Perspectives* scenario study was updated in 2021, demonstrating the continuous relevance of energy scenarios to Swiss energy policy [43]. Various recent developments, while not directly related to ES2050, are difficult to predict and potentially disruptive to traditional business models of public utilities. This includes the volatile energy prices in the European market and the risk of losing access to this market faced by Swiss utilities due to a missing political agreement with the European Union, the incomplete liberalization of the Swiss electricity market, the increasing prevalence of local energy cooperatives, and the forthcoming relicensing of hydropower plants with a typical lifetime of 80 years. These drastically changing market conditions create a high demand for information about plausible energy futures, which makes the Swiss energy industry ideal for a case study. At the same time, the Swiss energy transition characteristics and challenges are comparable to energy transitions in many other contexts. This is best exemplified by the increasing urgency for utilities globally to both adapt to and mitigate climate change [44].

2.2. Sampling strategy

Switzerland has over 600 public utilities. The 15 biggest utilities cover around 50% of the household electricity demand, and the 200 biggest cover over 90%. The remaining 400 energy providers are very small, often serving only a few hundred customers. One key sampling goal was to represent the diversity of Swiss utilities. Adapted from a comparative study on the financial performance of Swiss utilities [45], we differentiated utilities according to their electricity production (TWh/a) and economic impact (average revenue over the past five years). Specifically, we grouped utilities into three clusters: large (>2 TWh/year), medium (<2 TWh/year, >150 mio CHF/year), and small (<2 TWh/year, <150 mio CHF/year). Accordingly, the sampled utilities ranged from small municipal companies supplying local communities to internationally operating and vertically integrated corporations. While the geographical scope of our sample is limited to Switzerland, it provides an interesting case for how utility executives operating in a highly decentralized market with increasing shares of renewable energy perceive and interact with energy scenarios. In each public utility, we intended to interview the person(s) most suitable for discussing energy scenarios and their relevance to the utility. To that end, we collaborated with the Association of Swiss Electricity Companies (VSE), which provided us with a long list of utility representatives with a demonstrated interest in energy scenarios. The list included energy scenario or modeling department leaders and utility representatives who had previously participated in the association's collaborative scenario processes. Additionally, we employed snowball sampling to identify further utility representatives working with energy scenarios.

In total, 22 representatives from 20 public utilities (five large, eight medium, and seven small) were interviewed (see Table 1 for an overview) from March to May 2019, covering all language parts of Switzerland (German, French, and Italian). In the case of two utilities, two interviewees were present, as they provided insights into scenario uses in different departments. We stopped conducting interviews when theoretical saturation was reached—that is, when no new scenario use types, selection criteria, or use purposes emerged.

2.3. Interview structure and content

Because understanding the finer mechanics of scenario use requires detailed exchanges using questions tailored to a specific scenario use context, we conducted semi-structured in-depth interviews. The interview guide consisted of four parts. Part 1 of the interviews was related to the interviewees' personal backgrounds, current positions, tasks and responsibilities, and experiences with scenarios. This allowed us to analyze whether a utility executives' personal competences, familiarity with energy scenarios or the energy system modeling competencies of their respective utility they work for influences their perception and use of energy scenarios. In Part 2, the interviewees were asked to assign national and international scenario studies previously identified *via* desk research into three categories: *unknown, known*, and *used*. Scenario *use* could encompass all kinds of *use* purposes, ranging from reading parts of a scenario study out of general interest to referring to information for specific planning or decision-making purposes. This provided a gateway to in-depth discussions of scenario selection and use practices that varied widely among interviewees. In particular, this allowed us to identify the purposes of scenario use, what type of scenario content is of interest to interviewees, whether they had interacted with modelers or discussed scenario studies with other users, and thus enabled us to gage the perceived relevance and value of scenarios for the respective utility executive. In Part 3, the interviewers presented six statements. The interviewees were asked to state whether they generally agreed or disagreed with each statement and then elaborate. The statements captured various aspects of scenario methodologies that have been critically discussed in the literature—for example, the role of probabilities, the perceived importance of scientific scenario development practices, and

Table 1
Sampling overview.

Utility cluster	Interviewee #	Region	Electricity production (TWh/a)	Revenues (Ø Mio CHF 2014–2019)	Internal modeling resources
Small	1	Northeastern	<2	<150	No
Medium	2	Northeastern	<2	>150	Yes
Medium	3	Northeastern	<2	>150	No
Small	4	Central	<2	<150	No
Small	5	Central	<2	<150	No
Medium	6	Central	<2	>150	Yes
Small	7	Central	<2	<150	No
Medium	8	Northwestern	<2	>150	Yes
Small	9	Central	<2	<150	Yes
Medium	10	Central	<2	>150	Yes
Large	11	Northwestern	>2	>150	Yes
Large	12	National	>2	>150	Yes
Medium	13	Central	<2	<150	No
Large	14	Central	>2	>150	Yes
Medium	15	Northwestern	<2	<150	No
Large	16	Central	>2	>150	Yes
Large	17; 18	National	>2	>150	Yes
Medium	19	Southern	<2	<150	Yes
Large	20, 21	Southwestern	<2	<150	Yes
Medium	22	Central	>2	>150	Yes

Table 1. Overview of the interview sample. Utilities were grouped into three clusters (small, medium, large) according to their electricity production and average revenues in the period 2014–2019.

the contrast between forecasts and projections. This allowed us to contrast topics identified to be critical by academic research on energy scenarios with empirical insights on how these issues were perceived by practitioners interacting with energy scenarios. Part 4 was related to the interpretation, especially the comprehensibility, of scenario-based insights. The interviewees were asked to elaborate on the perceived efficiency of different communication methods and to state their ideas on how scenario developers could improve the comprehensibility and relevance of energy scenarios to the energy industry. An English version of the interview guide can be found in the Appendix.

2.4. Data analysis

The interviews lasted between one and two hours and were recorded, except for one interview for which permission to record was not granted. The entire audio files were transcribed verbatim [46]. Each interview was conducted in the interviewee's native language (German, Swiss German, French, or English). Original statements were translated into English. To examine how utility executives perceived the variety of available scenario studies, we evaluated the relevance of the knowledge system quality criteria developed by Cash et al. [47], according to whom scenarios, which produce information at the interface between science and practitioners, need to balance credibility, salience, and legitimacy. *Salience* refers to whether users perceive scenarios to be relevant to their needs. *Credibility* refers to whether users perceive the scientific or technical evidence of scenarios to be adequate. *Legitimacy* refers to whether users perceive scenarios to be fair and unbiased in their treatment of diverse views and interests. This framework has mainly been applied to climate scenarios. For the case of climate scenarios, it was determined that scenarios need to minimize conflicts between credibility, salience, and legitimacy while maintaining each at an adequate level to ensure effectiveness [48,49]. In a second step, thematic coding of the empirical material was performed to refine the coding structure with emerging subcodes. For each subcode, we provide corresponding examples identified in the interviews in Table 2. In line with Cash et al. [47] we find that examples covering all three knowledge system criteria influence the perception of energy scenarios. However, we also find that particularly the subcodes 'institutional bias' as well as 'institutional power' are often directed towards publishing institutions rather than scenario content. Whereas this conceptual framework adapted from Cash et al. [47] was used to analyze the perception of energy scenarios, the interaction of utility executives with energy scenarios was assessed more directly through the question blocks corresponding to which energy scenarios were used and for what purpose they were used. No formal intercoder reliability test was used. Instead, well-established practice in qualitative research was followed as the appropriateness of the interview guide and the coding structure were discussed after each of the first five interviews among the authors. Starting from interviewee 15, exchanges about the necessary level of theoretical saturation were held [50,51]. The transcripts were coded using the software package MAXQDA [52].

3. Results: assessing the usability of energy scenarios

3.1. The diversity of publicly available energy scenarios was recognized by utility representatives

Public utility representatives were aware of the diversity of publicly available energy scenario studies. Asked about which energy scenario studies they knew, a total 40 different energy scenario studies were mentioned by interviewees. This awareness also translates to the individual level. Every interviewee had interacted (e.g. partially read or attended a corresponding presentation or workshop) with energy scenarios published by at least four different organizations. On average, each interviewee was even aware of nine energy scenario studies. However, their levels of knowledge of or interaction with these studies varied widely. In most cases, interviewees did little more than go over key results, assumptions, or modeling paradigms. Hence, utility representatives only studied a very limited set of studies that they were aware of in detail. Consequently, also in terms of energy scenario *use*, defined as the application of scenario-based information, most utility representatives considered only a small subset of the scenario studies of which they knew. Specifically, 13 of the 22 interviewees reported having used no more than three scenario studies, and only two reported having used more than 10 studies. The most widely used scenarios were from studies conducted in the Swiss context. Among international energy scenarios, the most popular was the International Energy Agency's (IEA) World Energy Outlook series [53], followed by the scenario studies developed by Shell [54] and BP [55]. Energy scenarios developed or commissioned by both national and international research institutions belonged to the least known and used scenario studies. The World Energy Council's scenarios [56] were among the few international research–based energy

Table 2
Coding structure.

Main codes and subcodes	Description	Examples identified in the interviews
Legitimacy	Whether users perceive scenarios to represent unbiased values and beliefs that are impartial to diverse views and interests.	
Diversity of opinions	Whether users perceive scenario development to be inclusive of different opinions, leading to a scenario that encompasses different values and opinions.	Balance of stakeholder involvement; unbiased integration of normative values and perspectives
Institutional bias	What kinds of policy goals and interests scenario users associate with the institutions that publish scenarios.	Overarching vision or agenda; promotion of specific business models; interests linked to scenario content
Institutional power	Whether users perceive scenario developers and commissioning institutions to be influential in the energy system and related policy processes.	Role in and perceived influence on energy system and policymaking; recognition as a longstanding scenario developer
Credibility	Whether users perceive the scientific and technical evidence of scenarios to be adequate.	
Validity	Whether users perceive the data sources and methods used to develop scenarios to be adequate.	Data; assumptions; modeling framework; scientific development standards; scenario results; and their broader implications
Presentation	Whether users perceive the presentation style to be adequate for conveying scenario-based information.	Report structure and language; visualizations; communication tools and events
Transparency	Whether users consider that all information necessary to retrace scenario results is available.	Documentation; open access; interaction with scenario developers
Salience	Whether users perceive scenarios to be relevant to their needs.	
Scope	Whether users perceive the type of information provided to be relevant to them.	Suitability of the time horizon; geographical scale; topics covered; technologies; sectoral links
Comprehensibility	Whether users consider the information provided to be comprehensible and aligned with their competencies and capabilities.	Comprehensibility, complexity, interpretation of probabilities or lack thereof
Purpose	For what purposes users consider energy scenarios and how they interact with them.	General information basis; integration of numerical data into own modeling or planning tools; formation of qualitative storylines; direct and indirect links to decision-making processes

scenarios used by Swiss utility representatives.

3.2. Between biases and agency - why utility executives used particular energy scenarios

Most interviewees stated that they did not actively search for new energy scenarios. Instead, they were informed about scenarios either directly by publishing organizations, in which case they often subscribed to previous iterations of the respective scenario studies, or through recommendations from colleagues and industry associations. Only two interviewees mentioned institutionalized and regular screening of energy scenarios. For the selection of energy scenarios, the publishing organization was a key factor. Organizations with a long history of energy scenario development, such as the IEA, Shell, or BP, tended to be seen as more legitimate scenario producers than less established or known organizations. Very few interviewees differentiated between an organization that commissioned or published a scenario study and the scenario developers—that is, the modeling teams. Similarly, only one interviewee reported examining the list of individual organizations or experts involved in the development of a scenario. Thus, the interviewed utility representatives used the overall reputation of a publishing institution as a proxy for its perceived legitimacy. Interestingly, most interviewees considered energy scenarios to be biased in the sense that they reproduced the perspectives of the respective publishing institutions. However, this was generally not perceived to be problematic by the utility representatives who stated that this could be considered when interpreting the scenario content.

Of course, I know that Shell scenarios are biased, but at least I know where they come from and what I get. (Interviewee #4)

In response to the perceived bias of many energy scenarios, some users tried to integrate varying perspectives by comparing scenarios.

Of course, none of them are completely independent; they are all affected by the interests of the [publishing] organizations. . . . But [when multiple scenario studies are used,] at least the breadth of existing opinions can be represented. (Interviewee #7)

Although the interviewees perceived energy scenarios developed by research institutions to be the least biased, they also considered them the least influential in terms of their relevance for future energy system developments. This suggests that scenario users also factored in the perceived institutional power of an organization publishing an energy scenario when deciding whether it was worthwhile to interact with that scenario. Notably, the perceived legitimacy of a scenario study seems to be mainly based on publishing intuitions, whereas its credibility and salience are more directly related to the actual content of scenario studies (see 3.4 and 3.5).

3.3. Utility executives consider energy scenarios to be relevant, but only few have specific use purposes

The overall perceived salience of energy scenarios was reflected in the reported knowledge of a wide range of scenario studies. All interviewees considered energy scenarios directly relevant either to their respective work or to the energy industry as a whole. Despite this popularity of energy scenarios, indicating that salience is a key factor impacting the use of energy scenarios among utility representatives, a relative lack of specific scenario use purposes was evident. Not all interviewees were able to describe concrete scenario use purposes (see Table 3). One who could, the representative of a large public utility, stated that the aim of using energy scenarios was to stress-test corporate strategy:

For us, extreme scenarios are particularly relevant. We will somehow be able to master everything else, but with extreme energy futures, we will have trouble. (Interviewee #14)

Compared to the absolute number of identified use cases, the variety of use cases is considerable, ranging from trend scouting to public outreach or business model development. While this exemplifies the different dimensions of usefulness that energy scenarios might have for utility executives, the fact that each purpose was only relevant for one or two interviewees each, indicates that there is a large potential to increase the usability of energy scenarios. Furthermore, the use purposes cover a whole spectrum of interaction with energy scenarios, ranging from purely informative and open-ended purposes to more clearly defined purposes, such as the extraction of data for internal modeling activities.

Table 3
Identified use purposes.

Use purpose	Description	Examples identified in the interviews	Interviewee
Extracting data	Using data as input for quantitative analyses or internal modeling activities.	"In our case, modeling was based on […] these figures for total sales development, we took that from this study."	2; 12; 17; 18; 21
Developing strategy & business models	Develop strategies and business models based on the scenario	"Information about future developments, which then flow into the business plan, that then comes from such studies."	1;5
Stress testing strategy & business models	Comparing existing strategy & business models with extreme scenarios to identify potential risks	"For us, extreme scenarios are particularly relevant. We will somehow be able to master everything else, but with extreme energy futures, we will have trouble."	14
Public outreach	The scenarios are used for external communication	"That you can say to the customer: Look, we are on the path that the federal government is actually aiming for and that the VSE also supports."	2;5; 20;21
Understanding energy systems and markets	Improve knowledge and stay informed without specific focus	"… it's about internal know-how, knowing what's going on."	5;7; 8; 10
Trend scouting	Follow the development of specific technologies, political- or societal developments	"What is going on in the whole expansion of renewables. Wind and geothermal […] How does their perspective change?"	12
Anticipating public policy	Deducing policy developments from scenarios of actors perceived to have a lot of agency	"We sometimes brought [these scenarios] in for certain things, to see what the Swiss Federal Office of Energy (SFOE) was working for with their scenario studies"	5;6
Legitimizing decisions	Defend or rationalize internal and external decision processes	"We show that we can take care of that. We support consultations from the city and, using scenarios, contribute our technical opinion"	1; 6

3.4. Complex means credible: the social construction of credibility among scenario users

The interviews revealed two vastly different understandings of what constituted a credible energy scenario. While the interviewees unanimously acknowledged that assessing the credibility of scenarios with their respective data sources and assumptions was challenging, most focused on the results of modeling exercises—that is, the energy futures projected by the scenarios. This group included many interviewees working for utilities that did not have their own modeling resources. To them, the degree to which a scenario's projected energy future aligned with their personal expectations played a key role when assessing its credibility. Several interviewees following this rationale stated that the position of the electricity industry association *VSE* and discussions with colleagues helped them form opinions on the credibility of energy scenarios. In this context, many interviewees put forward similar arguments about modeling assumptions that were deemed unrealistic. This concerned, for example, the scenarios issued by the SFOE, which generally assume a wide availability of electricity imports in the future. Multiple interviewees considered this too optimistic due to the perceived rising tensions and uncertainties in the relationship between Switzerland and the European Union.

In contrast, few interviewees relied on information that was less prominently placed in scenario reports to evaluate their credibility. For these users, the ability to reproduce scenario results was key; accordingly, they focused on the specific building blocks underlying the scenario projections, such as data sources, modeling assumptions, and model frameworks. These interviewees were predominantly users with high levels of modeling competence working for large utilities. As these users required access to input data and assumptions, transparency and open source principles were crucial for them.

Thus, few interviewees had the interest or resources to delve into scenario reports to fully understand them. In fact, according to half of the interviewees, one had to be part of the scenario development process to understand how the results were produced. Most of the remaining interviewees stated that at least a profound conceptual understanding of how the different energy system models operate was necessary.

No [participation is not necessary], but I would say that to be able to understand energy scenarios, you need to have developed at least one yourself, from start to finish. Only then do you know where the critical levers and things that make a difference are. (Interviewee #11)

As most utility representatives did not consider an understanding of the development process or knowledge of the various modeling inputs necessary, they were often not aware of the distinctive properties and methodological trade-offs associated with particular model families. For example, most interviewees did not differentiate between bottom-up and top-down models.

On an even more fundamental level, many had difficulty grasping the idea that scenarios generally represented multiple futures without associated possibilities—a paradigm highlighted by most energy scenarios. Nine interviewees considered it necessary for scenarios to provide an indication of their likelihood. For others, probabilities went against the "what if" logic that is fundamental for many scenario activities. However, one interviewee's statement highlighted that also users who did not want scenarios to explicitly specify probabilities often did so implicitly when they were being used:

It is my job as the reader and interpreter of a study to attribute a certain probability to it. I can only do this if I have as much transparency as possible about what happened in the development process. Using those [scenarios] generates added value for me. (Interviewee #11)

While several utility representatives mentioned that the complexity of the underlying models a made them hard to grasp, they did not wish for simpler presentation or easier to understand communication formats. Interviewees expected energy scenarios to represent energy system developments comprehensively, Many interviewees are of the opinion that energy scenarios can thus only be conveyed in long and well-documented reports consisting of highly structured numerical annexes.

I always read these [scenarios] when I need help with decisions, and . . . [this] always means that things need to be quantified. This is also why I expect scenario reports to have a certain structure and level of detail. (Interviewee #3)

Besides wishing scenario studies to be as comprehensive as possible, interviewees thus wanted the scenarios to be as detailed as possible. From their perspective, energy scenarios should provide information on all kinds of scales and contexts, ranging from international price developments to regionally downscaled deployment projections for different energy technologies or grid usage patterns. While the interviewees were aware that this posed the challenge of balancing breadth and depth for modelers, most interviewees stated that they preferred energy scenario studies that provided as much information possible. While the interviewees were often interested in specific information provided by energy scenarios—for example, technology developments or demand projections—they generally appreciated systemic approaches. In fact, most emphasized that understanding key energy transition developments required a consideration of complex systemic linkages—for example, between policies and technologies—that could often be explored only *via* scenarios.

Conversely, qualitative presentation formats, such as storylines or narrative-based pathways, were often deemed inappropriate for presenting results.

Fancy-looking graphs and so-called innovative scenario result communication approaches make me suspicious. I trust old-school reports with a solid quantitative basis. (Interviewee #9)

We thus identified a strong belief in the superiority of quantitative scenario methodologies and reporting formats, even though very few users actually used numerical outputs. This might be linked to utility representatives' educational backgrounds, which are often related to engineering or economics.

4. Discussion

Recent research shows that to understand the usability of energy scenarios, scenario users' perceptions and beliefs are as important as the scenarios themselves and their underlying modeling characteristics [17, 57]. Despite a growing research interest in participative modeling activities, most scenario use cases can be assumed to be practiced outside dedicated modeler–user collaborations. Very little empirical knowledge of such use cases exists [58]. Hence, there is a need to address the gap in interests, capabilities, and resources between scenario developers and the recipients of scenario-based information, as suggested by Garb et al. [14]. Our results indicate that neither the selection nor the use of scenarios followed standardized procedures. Instead, subjective assessments, largely dependent on each utility representative's personal experiences and preferences, played a key role in the selection and use of energy scenarios. Among interviewees, the initial scenario selection is primarily guided by the perceived legitimacy of the publishing organizations, and not the scenarios or underlying modeling activities. This is important because it suggests that knowledge system criteria, and particularly the perceived legitimacy of a scenario study, do not necessarily only apply to the published knowledge (e.g. the scenarios), but to the producer of that knowledge (e.g. the publishing institutions).

Scenarios from publishers with a demonstrated history of energy scenario development are the most likely to be used. Scenario users prefer studies from institutions with previous scenario iterations, as this allows them to use past receptions and feedback from colleagues and industry leaders as indicators of the credibility of new studies. This suggests that the use of scenarios, especially evaluations of their credibility, are socially embedded activities. In this context, exchanges with other scenario users can highlight particular aspects of energy scenarios—often very specific assumptions or results. In this sense, the discursive elements shaping model development [59,60] can also be identified. The process could create a feedback loop that reinforces the focus on a limited scenario space. Similar effects have been identified to influence the science-policy interface of the IPCC's climate mitigation scenarios [85]. However, our results show that utility executives are aware of the variety of existing energy scenarios, even if they only use a fraction of them. Whether this finding applies to energy scenarios more generally could be addressed in future research, as hybrid "story-and-simulation" approaches bridging academic disciplines have become more prominent in sustainability research [61–63].

Continuous efforts by energy modeling communities and simultaneous advances in computational power have led to the development of more detailed and sophisticated energy system models. Today, multiple modeling approaches (e.g., backcasting, simulation, and optimization), foresight purposes (e.g., explorative, normative, and predictive), and scopes (time horizon, featured topics, and geographical scales) offer potential scenario users a variety of distinct characteristics and intended use propositions [64]. Similarly, modeling communities call for more transparent development processes and open-source content [68–70]. While these efforts highlight the value and uniqueness of scenario modeling approaches from a developer perspective, it is unclear to what degree users profit from these advances in the technical sophistication and differentiation of energy system modeling [17]. This question is especially relevant for our study analyzing how utility executives perceive and interact with externally developed energy scenarios. In line with Parson's [65] finding, we find that most interactions with energy scenarios are neither institutionalized nor linked to a specific use purpose. In the interviews, what Weiss [91] calls 'enlightenment' use purposes (i.e. when knowledge helps decision makers to understand the world better) are far more common than 'instrumental' scenario use purposes that directly inform specific decisions. In addition, the use purposes *legitimizing decisions* is consistent with what Hertin et al. [92] coined *political use* purposes in which knowledge is put forward as a way of providing justification for a decision already taken. This does not necessarily mean, however, that the differentiation and sophistication of energy system models is not very relevant for users. For some users, the complexity of contemporary energy modeling practices and the corresponding complexity of energy scenarios might limit their usability [66]. Nevertheless, the credibility associated with the continuous advances in energy system modeling represent a key quality for why users refer to energy scenarios in the first place. The interviews show that there is a high demand for credible information about the energy future. Thus, an increased support for how external users could interact with energy scenarios could also benefit their usability and lead to more 'instrumental' use purposes. Against this background, practical guidelines centered around specific use purposes could foster more engagement between modeling communities and external user groups, leading to an increased awareness of the variety of modeling approaches on the one hand, and the information needs of decision-and policymakers on the other. What needs to be considered is that when scenarios are published, they travel into the field of practitioners and do not bring with them a self-contained technical or scientific understanding of their findings [67]. In this sense, scenarios are not ready-made "solutions" but are incorporated into preexisting use contexts and user perspectives of the energy future. To date, the relevance of energy scenarios within the Swiss energy industry is not indicative of a match between what energy scenarios provide and what scenario users need, but of an increasing need for reliable information about future developments in challenging and uncertain times.

Although few concrete scenario use purposes emerged from the interviews, this does not necessarily mean that the overall influence of energy scenarios on utility executives is negligible. Nevertheless, we argue that research needs to develop a more comprehensive understanding of the users that are not part of the modeling activities or scenario development [71]. Science and technology studies have demonstrated that scenario-based projections can shape individual expectations and contribute to the creation of shared visions [72,73]. In this context, the lack of institutionalized scenario integration processes or standards observed in this study increases the interpretative flexibility with which utility representatives absorb scenario-based information. This could limit the ability of energy scenarios to stimulate holistic and open-minded discussions about plausible energy futures. In particular, it can reduce the explorative function of energy scenarios, which is often claimed to be one of their key purposes [74]. According to McCollum et al. [75], radically different futures should be considered more thoroughly in modeling exercises. Recent European price spikes and limited availability of electricity and gas due to the Russian attack on Ukraine and the widespread outage of nuclear power plants in France provide strong arguments for considering a broad range of possible futures. If this is not the case, energy scenarios risk serving conservative instead of their commonly assumed explorative purpose. This not only contrasts with the key benefits commonly associated with using scenarios, such as reducing cognitive biases and stimulating out-of-the-box thinking [76], but also raises questions about their usefulness as integrative and deliberative decision-making tools for the transition towards a renewable energy future.

With the exception of participatory scenario development case studies [77–83], which often differ sharply from typical empirical scenario use contexts, the development and use of energy scenarios are often conducted and analyzed independently from each other, and research attempts to either improve their development or support their use. This separation limits the consideration of the interdependencies between energy scenario development and use, particularly the power asymmetries and political ideologies shaping the creation and contestation of energy futures. These interdependencies are increasingly being critiqued in the context of integrated assessment models (IAM) and their reliance on negative emission technologies in 1.5° and 2° warming scenarios [84–87] but are still rarely considered in the case of energy scenarios.

4.1. Limitations and further research

In this study, we analyzed how utility executives perceive and interact with energy scenarios. Despite the inherent diversity in our sample which covers a large number of utilities, the Swiss energy industry is a relatively small community. This might explain the observed importance of social exchanges between scenario users. Forthcoming research could address the question whether similar effects can be observed within industries or management communities. Moreover, we described scenario use purposes as reported by the interviewees and not necessarily as actually practiced. Nevertheless, we are confident that our main findings—that is, the general relevance of scenarios to utilities and the importance of social contexts for their use—are valid and can provide important insights for future research. Future studies could observe the application of energy scenarios more closely, providing further insights into the presentation and communication of scenario content, how this influences their credibility and how it relates to specific use purposes. While our coding scheme attempts to adapt the knowledge system criteria by Cash et al. [47] to the case of scenario use, it is only based on corresponding examples we identified in the interviews. Particularly the distinction between legitimacy and credibility as well as whether users distinguish these criteria between the produced knowledge and publishing organizations need to be evaluated further. Combining empirical scenario use investigations with actor network analyses could advance our understanding of the social context of scenario use and the factors that ultimately determine their impact on energy transitions. To date, very little is known about how locally embedded and context-specific scenario use cases—be they in the energy industry or in other fields—and the globally connected modeling and scenario development communities are related to each other. While idealized participative approaches are often assumed, they are hardly the norm. Therefore, we call for more empirical analyses of the benefits and limitations of scenario use.

5. Conclusions

Social scientific research on the use of energy scenarios often focuses on highly participatory scenario processes with iterative and time-consuming collaborations between scenario developers and users. While this type of research is necessary for developing inter- and transdisciplinary collaboration best practices, it only captures a fraction of the existing scenario use cases. This study shows that publicly available energy scenarios play an important role in the Swiss energy industry. The relevance of energy scenarios in our sample and a similar relevance that can be assumed for other contexts due to the salience of energy and climate topics, suggest that a greater emphasis should be put on this type of energy scenario use. We provide empirical evidence that while energy scenarios are important sources of prospective information for utility executives, they can often not be linked to specific use purposes. Furthermore, *using* energy scenarios refers to a wide range of interactions that are often neither institutionalized nor standardized. Modeling communities and publishing organizations of energy scenarios could increase the usability of energy scenarios for users that are not part of modeling activities or scenario development through communication, visualization and interaction formats that specifically address external user groups. Similarly, more explicit guidelines for what and how particular energy scenarios could be used and what use purposes are beyond their scope would benefit these external users. To inform these suggestions, ex-ante and ex-post evaluations with external user groups that are considered target-audiences, such as utility representatives, journalists, politicians, or researchers, could be conducted. As the relevance of information about possible energy futures is likely to increase in the coming years, a basic understanding of what constitutes their usability for achieving a sustainable energy transition among political and business communities need to be established.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rset.2023.100046.

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