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UNDERSTANDING THE ROLE OF SCENARIOS IN SWISS ENERGY RESEARCH

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Abstract: Energy scenarios link long term policy goals to near term decisions and may thus guide the transition to more sustainable energy systems. Yet, systematic empirical analyses of how energy scenarios are understood and used by relevant actors are rare. This working paper addresses the situation in Switzerland, where several competing public energy scenarios have been developed by different organisations in reaction to the government's decision to phase out nuclear power. The analysis focuses on the energy research community, which has a double-role in the dissemination of scenario-based insights: On the one hand, researches develop energy scenarios which may in turn be used by decision-makers in policy and industry to create or assess action alternatives. On the other hand, many researchers are scenario users themselves. We conducted 13 structured in-depth interviews with energy researchers. The sample covers a broad field of institutions and disciplinary backgrounds, including economics, engineering, geography, sociology and law.

We find that while most researchers do use energy scenarios, there are essentially two contrasting types of scenario use among them: One group of researchers, which we labelled *divers*, is interested in very specific data and assumptions that it wants to fully understand. A second group, which we labelled *sailors*, refers to the results of a scenario analysis in a more general manner. We identified different interpretations of scenario content between *sailors* and *divers*. These discrepancies are a result of the highly specialised modelling activities on which energy scenarios are based on. Implicit knowledge that is generated during the development process of energy scenarios is inaccessible to most scenarios users.

We therefore conclude the study with a discussion about the usefulness of participative stakeholder involvement and scenario documentation that is adjusted to the interests and competencies of its users. Because energy scenarios increasingly serve as a scientifically derived information basis for societal debates about energy transitions, their use needs to be studied more extensively.

Keywords: scenarios, energy systems, energy policy, modelling, transition, Switzerland

Content

1 INTRODUCTION

The Swiss Energy Strategy 2050 (ES2050) was developed in 2013 as a consequence of the decision by the Swiss Federal Council and the Swiss Parliament to phase out domestic nuclear power production. It aims both for a massive expansion of renewable electricity production and a reduction in energy demand in order to achieve the envisioned energy transition at minimum cost (Bundesrat, 2013). These ambitious political goals require profound changes in the energy system. This does not only refer to energy infrastructure, it also impacts the different energy system actors (Verbong & Geels, 2007): Energy companies need to reroute large streams of investments, policy-makers need to adapt the legal framework, voters must approve these changes, researchers need to focus on developing innovative technologies and tools to support the transition, and both energy producers, and consumers must fundamentally rethink their roles (Blumer, 2014).

In order to guide and align the many different actors, mental models of the energy system and its future development can play a key role. They support the various actors in identifying problems and potential decision alternatives, as well as in assessing and selecting those alternatives (Patton, Sawicki, & Clark, 2015). In particular, shared mental models can be catalysts in political processes that intend to convert collectively established and administrated structures (Rohrbeck & Schwarz, 2013), as are prevalent in the energy system. Being formalized descriptions of plausible (i.e. consistent) future states of a system (Gausemeier, Fink, & Schlake, 1998), scenarios can influence the formation of such mental models (Glick, Chermack, Luckel, & Gauck, 2012). Consequently, scenario development is recognised as a form of collective learning in the strategic management literature (Berkhout, Hertin, & Jordan, 2002; Bood & Postma, 1998). If enough decision makers adhere to a certain scenario and act accordingly, it can develop a considerable transformative power (Hughes, 2013).

Before this backdrop it comes as no surprise that the Swiss ES2050 is closely tied to a scenario study. It is called *Energy Perspectives* (Prognos, 2012) and was commissioned by the Swiss Federal Office of Energy (SFOE). It comprises a model-based analysis of the development of the Swiss energy demand and supply mix until 2050 based on three different scenarios. One of these scenarios – called *Politische Massnahmen des Bundesrats* – served as a reference for the development of the ES2050. The *Energy Perspectives* is, however, not the only long-term scenario-study of the Swiss energy system. There exist a handful of such studies, which have been developed by different academic and non-academic institutions after Fukushima. A meta-analysis by the Paul Scherrer Institute (PSI) compares all these scenario studies and finds considerable differences between them in terms of modelling approach, assumptions and results (Densing, Hirschberg, & Turton, 2014). The impact of these scenario studies for the decisions by the various actors of the Swiss energy system are, however, not yet well-understood.

The goal of this study is to make a first step towards a better understanding of the impact of energy scenarios in transition processes. In particular, this study analyses the use and interpretation of energy scenarios by researchers. That is because the energy research community is an important actor group in the energy transition. Although devoid of direct decision power concerning the development of the energy system, research has a relevant double-role in the dissemination of insights from energy scenarios (see Fig. 1). On the one hand, there are a number of research groups that develop and validate energy scenarios, which may in turn be used by decision-makers in administration and industry to create or assess action alternatives. On the other hand, many researchers are scenario users themselves. This means that information stemming from scenarios impacts their research findings, which again informs decision makers that ultimately shape future energy systems. For this reason, there is value in reflecting on the way in which scenarios are developed, used and interpreted by the energy research community. What is more, the importance of energy research in Swiss energy policy was underpinned by the action plan *Koordinierte Energieforschung Schweiz*. This program provides funding of about 200 Million Swiss Francs for universities across Switzerland to promote energy research in the years 2013 to 2016 (Bundesrat, 2012). The major share goes to the National Research programs 70 and 71 by the Swiss National Science Foundation and to eight so-called Swiss Competence Centers for Energy Research (SCCERs).

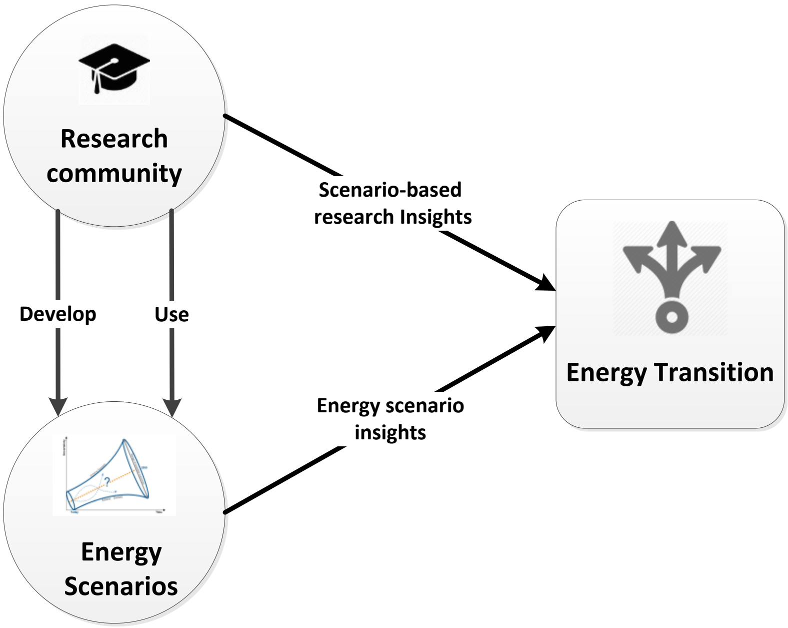

Fig. 1 The double role of the research community in the dissemination of energy scenarios: Researchers are both users and developers of energy scenarios, which makes their insights highly relevant for actors in administration or industry who use scenario-based insights to make decisions that impact energy systems.

2 BACKGROUND

2.1 Functions and typologies of scenarios

The colloquial meaning of the term scenario refers to “*what could possibly happen*” or “*a sequence of events, especially when imagined*” (Merriam Webster's Dictionary, 2016). In contrast to that broad colloquial meaning, scenario analysis has become a more specific method in science and policy-making (van Notten, Rotmans, van Asselt, & Rothman, 2003). For the purpose of supporting public policy and planning, scenario analysis approaches were introduced in the 1950’s in the US and France (Bradfield, Wright, Burt, Cairns, & Van Der Heijden, 2005). In the 1970s, the oil and gas company Shell started using scenarios to detect future developments that were relevant to the company’s strategy (Burt, 2007). Other popular case-studies that illustrate how the scenario-planning method was used include examples of British Petroleum, British Airways, Electrolux, and the insurance group Nationwide (Moyer, 1996; Ringland, 2008). In these examples, scenarios were used as tools to guide decision-making in the face of an uncertain future, which is shaped by a large number of risks and interdependent developments that cannot (or only partially) be influenced.

Scenario-development techniques vary greatly. There are a large number of different methodological approaches summarized under the label scenario planning or scenarios analysis (Martelli, 2001). Numerous studies have presented methods to classify scenarios with respect to their general design (for example, Bazmi & Zahedi, 2011; Bishop, Hines, & Collins, 2007; Henrichs, 2010; van Vuuren, Kok, Girod, Lucas, & de Vries, 2012; Wilkinson &

Eidinow, 2008). These scenario typologies can serve as useful guides on how a scenario or a group of scenarios and their insights can be interpreted. Thus, they may facilitate the choice of a scenario out of a range of existing ones that is appropriate for a specific purpose. A popular typology by Börjeson, Höjer, Dreborg, Ekvall, and Finnveden (2006) proposes to distinguish three classes of scenarios, which reflect possible purposes of scenarios: First, there are so-called explorative scenarios which answer the question *"What can happen?"*. Second, there are so-called normative scenarios, which answer how a specific target can be reached. Finally, there are so-called predictive (or probabilistic) scenarios. These address the question *"What will most likely happen (given a set of assumptions)?".*

Common to most scenario methods is the shared understanding of a scenario as a plausible future state of a system that is composed of realizations of a handful of key factors (Fink & Schlake, 2000; Kosow & Gaßner, 2013; Mietzner & Reger, 2005). These factors are identified and selected based on their power to drive future developments of the system in question. This process is often supported by consulting system experts and key stakeholders (Amer, Daim, & Jetter, 2013). Therefore, scenario studies can be seen as contributions to societal decision and governance processes. In that sense, Pulver and VanDeveer (2009, p. 9) understand scenarios as "boundary objects" that link social spheres such as science and non-science. In this linkage, scenarios are not limited by the setting of the existing socio-technical system. Transformative or disruptive elements that might be shaped by the values and ideas of the scenario developers can be incorporated (Hughes, 2013). As a consequence, participation in the scenario development process is crucial for the formation of mental models. For scenario users that are not part of the development process, only the explicit information included in scenarios (i.e. the results), is available as knowledge base (Islei, Lockett, & Naudé, 1999). Conversely, if scenario users are directly involved, ideas and experiences stemming from the development process, so-called implicit learning or tacit knowledge can be established (Reber, 1989). In that sense, the main benefits of a scenario approach may not necessarily be its outcomes but rather that its development process serves as a catalyst for knowledge exchange between relevant actors and serves as an arena for discussion (Kosow & Gaßner, 2013, p. 39-42).

2.2 Energy scenarios and their reliance on models

Due to the large number of relevant actors, long planning and investment horizons, as well as structural interdependencies, contemporary energy systems are extremely complex (Pfenninger, Hawkes, & Keirstead, 2014). As a consequence, most energy scenarios rely on numerical energy models (i.e. highly structured representations of the energy system) in order to ensure plausibility and consistency (Zafeiratou & Spataru, 2014). Thus, it comes as no surprise that the increase in computational power in the 1990s has fuelled the use of scenarios in the energy context (van Beeck, 1999). Nowadays, model-based energy scenarios are used in nearly all industrialized countries (Chiodi et al., 2015; Cochran, Mai, & Bazilian, 2014). TIMES and MARKAL type models, which belong to the most popular model families (see Jebaraj and Iniyan (2006) for an overview), have been used in more than 150 institutions in 63 countries (Remme, 2012). Moreover, many international policymaking processes are shaped by energy scenarios. Examples include the scenarios of the Intergovernmental Panel on Climate Change (IPPC, see Moss et al., 2010 for an overview), the International Energy Agency (IEA, 2015) or the EU (European Commission, 2012) Energy scenarios can be based on a wide number of different modelling approaches that vary in their purpose (e.g. forecasting, backcasting, simulation, optimization), target audience (policy makers, scientists, general public), regional coverage (local, national, international) or modelling paradigm (top-down, bottom-up) (Herbst, Toro, Reitze, & Jochem, 2012).

Given the complexity of energy systems, there are no universally applicable modelling approaches; there are only more or less appropriate models for particular tasks. However, model choice may be of crucial importance with respect to the policy implication of a scenario study. For example, Chiodi et al. (2015) found a direct link between the use of particular models by governments and the resulting policy decisions in several countries. Mainly the discrepancy between the antithetic paradigms of top-down energy models (e.g. system dynamics, general equilibrium and econometric models) and bottom-up energy models (e.g. multi-agent, optimisation, simulation or partial equilibrium models) have induced controversial discussions (Herbst et al., 2012). Top-down energy models try to depict an economy as a whole and assess aggregated effects of energy policies, often in terms of monetary costs. The advantage of top-down energy models is that they allow accounting for feedback effects concerning economic growth, employment, or welfare. These models are highly influenced by neoclassical economic theory, as markets are assumed to allocate resources rationally (Edenhofer, Lessmann, Kemfert, Grubb, & Köhler, 2006). Due to their focus on macroeconomic developments, top-down models are ineffective in assessing technological progress (Wilson, Grubler, Bauer , Krey, & Riahi, 2013). Bottom-up models, in contrast, focus on technological development, innovation, a cost-efficient use of investment costs from a societal perspective (thereby including externalities) as well as inter-sectoral changes and synergies. In general, bottom-up models tend to indicate lower costs to climate change mitigation than top-down models (Springfeldt et al., 2010). Following this logic, Karjalainen (2014) find it problematic that most public administrations and economists have tended to rely on top-down models when assessing the costs and benefits of acting on climate change.

2.3 The variety of Swiss energy scenarios

In Switzerland, a large diversity of modelling approaches is applied by both academic and non-academic institutions to develop energy scenarios. Table 1 provides an overview of the most relevant model-based energy scenarios for Switzerland (for more details, see Densing et al. (2014). These are hybrids in the sense that they consist of a mix of modelling approaches. They have distinctive properties and put varying levels of detail to different aspects of the energy system (Densing et al., 2014). This is illustrated by the way these models determine how key factors, such as the future electricity generation mix and associated costs, are computed. In the *Energy Perspectives* study for example, the capacity development of renewables is pre-determined by scenario-specific assumptions (i.e. defined by the model developers) and therefore outside of the modelling scope. Moreover, costs do not impact technology deployment as they are estimated ex post, i.e. after the generation mix has been determined. In contrast, the PSI-electricity scenario study – which is based on a TIMES model (see Loulou, Goldstein, and Noble (2004) for a description of the model) – tries to find a cost-optimal mix of energy technologies (Kannan, Turton 2012). To be able to achieve this, multiple energy demand sector sub-models (e.g. heating, lighting, kinetic energy) are used to generate energy demand pathways. These demand sector trajectories serve as input for the capacity planning model which optimizes energy supply technologies using a cost-effective combination of technologies and energy carriers (e.g. fuel choices). In contrast to the *Energy Perspectives*, costs play an essential role for the resulting electricity generation technology mix in the PSI-electricity scenario study.

This example shows that, detached from the discussion about differences between bottom-up and top-down energy models, there exist very different approaches to model (and therefore represent) certain aspects of energy systems that scenario users need to be aware of if they want to use scenario-based insights in a meaningful way. Moreover, Swiss energy models frequently rely on the output of other energy scenarios to compute own results.

Hence, many of the resulting scenarios energy scenarios combine explorative, predictive and normative elements. As a consequence, most conventional scenario typologies offer little guidance to users of recent energy scenarios.

Table 1

Overview of Swiss energy scenario studies, based on Densing et al. (2014).

Title	**Short title**	**Publishing institution/ Modelling organisation**	**Year**	**System scope**	**Number of scenarios**
Die Energieperspektiven für die Schweiz bis 2050 (Prognos, 2012)	Energy Perspec-tives	BFE/ Prognos AG	2012	Energy	3 demand scenarios, 9 in total
Wege in die neue Stromzu-kunft (VSE, 2012)	VSE	Verband Schweizerischer Elektrizitätsunternehmen (VSE)/ Pöyry	2012	Electricity	3
Energiezukunft Schweiz (Andersson, Boulouchos, & Bretschger, 2011)	ETH	ETH Science Center	2011	Energy	3
energy [r]evolution (Teske & Klingler-Heiligtag, 2013)	Green-peace	Greenpeace Switzerland/ German Aerospace Cen-ter	2013	Energy	1
Cleantech Energiestrategie (Barmettler, Beglinger, & Zeyer, 2013)	Cleantech	Swisscleantech Business Association/ Foundation for Global Sustainability	2013	Energy	1
Transformation strategies to-wards a sustainable Swiss energy system – an energy-economic scenario analysis (Weidmann, 2013)	PSI-energy	Nicolas Weidmann, PhD Thesis (PSI/ETH)	2013	Energy	3
The Swiss TIMES Electricity Model (Kannan, Turton 2012)	PSI-electricity	Paul Scherrer Institute (PSI)	2012	Electricity	3
SCS-Energiemodell (SCS, 2013)	SCS	Super Computing Sys-tems (SCS) AG	2013	Electricity	7

3 METHODS

3.1 Sampling

Face-to-face interviews with representatives of 13 different research groups were conducted. Due to the variety in which scholars use scenarios (Raskin et al., 2005), and because the-matic foci and disciplinary perspectives influence how a scenario is understood (Pulver & VanDeveer, 2009), the goal was to capture a whole spectrum of scenario users. To that end, we compiled a list of all research groups funded by or associated to one of the two largest[1] Swiss energy research programs under the action plan *Koordinierte Energieforschung Schweiz* (Bundesrat, 2012). On the one hand, these are the National Research Programs (NRP) 70 (Energy Turnaround) and 71 (Managing Energy Consumption) issued by the Swiss National Science Foundation. On the other hand, these are the eight Swiss Competence Centers for Energy research issued by the Commission for Technology and Innovation. In

[1] Combined, the NRPs 70, 71 and the SCCERs receive about 118 million Swiss Francs in funding between 2013 and 2016 by the federal government.

total, the list included more than 200 research groups with very heterogeneous fields of study that are part of over 30 research institutions in Switzerland. On this basis, a sample of research groups were selected that covers the heterogeneity of Swiss energy research in terms of institutions and research programs, as well as the educational backgrounds, thematic foci and competencies of the interview partners. Table 2 provides an overview of the characteristics of the research groups represented in the sample. The sample covers both NRPs, all SCCERs, nine different institutions, four scientific disciplines, and a variety of thematic foci.

Table 2

Characterization of the interview sample, which consists of 13 research groups and 19 individual researchers.

Institutions	3x Swiss Federal Institute of Technology (ETH), 2x École polytechnique fédérale de Lausanne (EPFL), 2x PSI, 1x University of Basel, 1x EAWAG, 1x Lucerne University of Applied Sciences and Arts (HSLU), 1x University of Applied Sciences and Arts of Southern Switzerland (SUPSI), 1x University of St. Gallen (HSG), 1x Zurich University of Applied Sciences (ZHAW)
Energy Research Programs[2]	SCCERs: 8x CREST, 2x FURIES, 3x Mobility, 2x SoE, 1x EIP, 1x FEEB&D, 1x BIOSWEET, 1xHaE NRPs: 6x NFP70, 4x NFP 71
Educational background	4x economics, 4x engineering, 2x geography, 1x law, 1x sociology, 1x life sciences
Field of study	1x macro-economic energy policy, 1x regional energy systems, 1x system integration of new renewables, 1x national energy systems, 1x agent-based energy infrastructure modelling, 1x public acceptance of technologies, 1x innovation studies and innovation dynamics, 1x visualisation of energy scenarios, 1x distributed energy hubs, 1x applied PV development, 1x future transport sector, 1x national electricity system, 1x energy transitions from a judicial perspective
Modelling competencies	4 of the interviewed groups are energy scenario developers, 4 groups use modelling techniques in their research (but their research output is not a scenario), and the 5 remaining interview groups are not directly involved in modelling or scenario-development activities.
Gender	16 male, 3 female
Positions	10 professors/ group leaders, 3 Postdocs, 6 PhDs

3.2 Interviews

The 13 interviews were held between October 2015 and February 2016. They lasted between one and two hours and were conducted either in German (8) or English (5). They were recorded and transcribed for further analysis. German interviews were translated to English. Three of these interviews were group interviews, meaning that the total number of interviewees was 19. A written interview guide was used. The interview consisted of four parts (see Table 3), two of which were qualitative and two of which were quantitative.

[2] Some research groups are associated to multiple research programs.

Table 3

Overview of the four interview phases.

Phase	Goal	Content
1) Introduction	Getting to know the interviewees and their perspective on energy scenarios	Educational background of interviewee(s), thematic research focus, research interests, partners in industry and academia, type of research output that is generated
2) Existing Scenarios	Overview of the relevance of selected Swiss scenario-studies for the interviewees	Rating knowledge of scenarios on a scale ("I/we do not know this scenario"/ "I/we know this scenario, but do not use it"/ "I/we use this scenario")
3) Information needs concerning energy scenarios	Overview of individual researchers' interest in different aspects of energy scenarios	Rating relevance of key factors on a scale ("Not relevant for research" / "Used as an input for research" / "Used as intermediate between input and output" / "A generated research output")
4) General discussion of scenarios	Understanding how and why energy scenarios are used	User-perspectives on scenarios, decision-making rationales that underlie the use of scenarios, limitations of scenario use, the role of joint scenario activities and reference scenarios, the importance of transparency and open source models

In the first part, interviewees were informed about the goal of the study as well as the structure of the interview. Furthermore, they were asked about their work in general, and, more specifically, about their group's use of scenarios and prospective information in their research.

The goal of the second part was to identify the relevance of existing energy scenario studies for Swiss energy researchers. For that we prepared eight cards, each referring to one large-scale Swiss energy scenario (based on a study by Densing et al. (2014)). Participants were asked to assign them to one of three categories – (i) I/we don't know this Scenario, (ii) I/we have (at least partially) read the scenario, but neither me nor members of my research group have used it for research purposes, and (iii) I/we have used the scenario for research purposes. In the latter case, interviewees were asked to specify how they used that scenario. Furthermore, they were asked to provide any other energy scenario studies relevant to their research, including international studies.

The aim of the third part was to better understand which key factors or, more generally, what kind of prospective information present in energy scenarios was relevant to the research of the interviewees. Participants were presented with 23 potential key factors identified from an extensive literature review of existing energy scenario studies (see Table 4). The goal of the selection of key factors was to cover a wide range of issues. The key factors were also printed on cards and given to the interviewees to assign them to one of four categories. The options given were (i) factor is an input for my/our research (ii) factor is an output of my/our research, (iii) factor is an intermediary product of my/our research, and (iv) factor is irrelevant to my/our research.

The fourth part consisted of an open discussion of issues around scenarios. Some themes addressed specifically were (i) usefulness and relevance of energy scenarios in research context, (ii) requirements for energy scenarios in terms of transparency, accessibility and documentation, (iii) suggestions to improve the usefulness of energy scenarios, and (iv) the challenges and opportunities arising from participative scenario development in general and joint energy scenarios developed by different modelling groups in particular. In addition, interviewees were encouraged to bring up own topics of interest.

Table 4

Overview of the cards used during the interviews with key factors of prospective information that are based on an extensive literature research.

Category	Factors
Supply	Energy, Electricity, Installed capacity (generation technology mix), Imports (e.g. price, availability, type)
Demand	Energy, Electricity, Per sector
Cost	Total (e.g. in terms of GDP percent), Per energy carrier (e.g. fuel price), Relative generation cost, Discount rate
Infrastructure	Grid properties (e.g. connections to neighbouring countries), Lifespan of energy technologies, Reliability (e.g. power system stability)
Regulation	Market design, Subsidy schemes (e.g. feed-in tariffs)
Consumers	Public opinion, Environmental awareness, Prosuming
Socio-Demographics	Gross domestic product (GDP), Population Growth, Transport mode (e.g. means of transport, kilometers per person)

3.3 Data analysis strategy

While the second and third parts of the interviews were analysed quantitatively, the interview transcripts of part one and four were analysed inductively for recurring themes brought up by the interviewees. In particular, the goal was to capture the diversity of uses of energy scenarios in research. To that end, an analysis framework was applied that acknowledges the architecture of energy scenario studies (see Table 5). This allowed differentiating distinct layers of information that may be relevant for scenario users.

As energy scenarios are usually based on quantitative models, the first level of the scenario architecture refers to the representation of the energy or electricity system (i.e. the model framework). The model framework not only determines the data needed as model input but also the format and resolution of that data, as well as the design of the interfaces between various sub-models. There exist several discrete energy model families (see section 2.2) which are used to develop national or international energy scenarios.

The second layer contains the scenario-specific model inputs. This includes data and assumptions that are being set by model developers and which are usually quite interwoven and hard to separate: While a lot of energy models use input data that can be accessed from statistical offices or specific databases, they often also use assumptions, e.g. for the model parametrization or for making the available data compatible to the requirements of the specific models (e.g. by interpolation).

The third layer consists of the output of a modelling activity. This is what is often referred to as actual scenarios. The results generated after a complete simulation, optimisation or backcasting run of an energy model belong to this layer. The model output includes the information that presents and describes the transition towards a future energy or electricity system.

It is a common practice in scenario development that several versions (e.g. pathways for business as usual, accelerated and delayed developments), each describing plausible futures, are generated (i.e. more than one scenario is produced). This exemplifies what sets apart the scenario definition by Gausemeier from that found in Merriam Webster (see Chapter 1) as it explicitly postulates that scenarios have to come in sets in order to be useful in cases of uncertainty. Collectively, scenarios that are based on the same model form a scenario study (fourth layer) that offers a consistent and more comprehensive outlook.

Table 5
Illustration of the energy scenario study architecture, which was used to structure the analysis of the interview transcripts.

Part	Name	Description	Examples
1	Model framework	A structured representation of the whole energy system or one of its sub-parts (e.g. energy production, energy consumption, consumer behaviour) as well as interlinkages with other sectors (e.g. economy, climate policy).	MARKAL, TIMES, CEPE, EXPANSE, GEMINI-E3, MERGE-ETL (see Mathys, 2012 for a CH-specific overview).
2	Model inputs	Model inputs are exogenous variables in the form of data or assumptions that are required to simulate/backcast/optimise. Assumptions can be described as credible but debatable beliefs about future states, developments or interdependencies (Micic, 2006). As heuristic statements of belief assumptions allow for reducing complexity and uncertainty and form the basis of strategic decision making.	See Table 4 for a list of potential model inputs retrieved from a literature review of Swiss energy scenarios.
3	Model outputs	The output of a modelling activity, commonly referred to as "scenarios". Energy scenarios illustrate future developments of the energy system (e.g. energy supply and demand of a country or region) by setting boundary conditions through the model framework and scenario-specific model inputs (data and assumptions) to endogenously simulate the effects of policy and technology choices.	The scenario *Politische Massnahmen des Bundesrats* of the *Energy Perspectives* or the *noClimPol* scenario of the PSI-electricity scenario study
4	Scenario study	A set of individual scenarios that have been produced with the same energy model and that are published in a single report, often including a management summary of the most important scenario results and model properties. Scenarios usually exist in sets of two or more, which provides them with a more holistic nature than other approaches that study the future.	The complete set of 9 scenarios reported in the *Energy Perspectives*

4 RESULTS

This chapter describes the results of the interviews with 13 Swiss energy research groups. Section 4.1 addresses how researchers use energy scenarios, while section 4.2 presents the issues brought up by the interviewees that that concern the interpretation of energy scenarios.

4.1 Use of energy scenarios

4.1.1 Energy scenarios are seen as relevant decision-making support tools

The interviewees generally agreed that energy scenarios are of considerable relevance to their research. Most of them further believed that scenarios represent a fruitful way to engage in structured thinking about possible future developments of the energy system. In particular, testing a variety of pathways in which the energy system may develop in terms of technical and socio-economic factors was commonly regarded as a key purpose of energy scenarios. What is more, many of the researchers thought that scenarios are useful tools for decision-making in the near term. In particular the interviewees who develop energy scenarios tended to regard these as a means to communicate complex research insights to decision-makers in policy and industry. These interviewees also explicitly mentioned the general public as one audience for their research. At the same time, most scenario developers made clear that there are inherent limitations to energy scenarios. For example, a scenario should not be regarded as a projection of the most-likely development, but rather as one possible outcome under certain assumptions.

> "Our idea is not to forecast how the future evolves; our idea is to provide insights for decision-makers. Whether to […] invest in a technology is their decision. We can say if you invest, this is the resulting supply mix and these are the impacts your decision may have. (Interviewee 5)

Only one interviewee expressed doubts about the general usefulness of scenarios as a way to explore the future of the energy system. However, the same interviewee relativized these concerns by also pointing out that scenarios – if used correctly – may in fact help structure discussions and decisions about the future development of the energy system.

> "One may wonder where the belief that scenarios are useful or unbelievably important is coming from. Such a conception is only possible if you have a very linear understanding of strategic planning, or innovation and decision-making processes in general." (Interviewee 8)

The relevance of scenarios for the researchers is also reflected in their use of scenarios (see Fig. 2). All but two of the interviewed research groups have, in their work, made reference to the results or data of at least one of the existing Swiss energy scenario studies. Of those who do, all said that they have used the *Energy Perspectives*, albeit in some cases in combination with other studies[3]. In contrast, the remaining scenario studies have each been used by no more than two of the interviewed research groups. Hence, the *Energy Perspectives* is by far the best known of the Swiss energy scenario studies. In fact, only one interviewee stated to have never taken a look at it. The ETH, VSE and both PSI scenario studies are known by more than half of the interviewees (seven out of 13 researchers). The studies issued by Swiss Cleantech (four have read it) and Greenpeace (three have read it) are the least known Swiss scenario studies among the group of eight that were presented to the interviewees.

Only two of the research groups have worked with Swiss energy scenarios that were not included in the set presented to the interviewees. In both cases this was the Swissmod study (Schlecht & Weigt, 2014). A few interviewees also used information provided by international energy scenarios, such as the IEA World Energy Outlook (IEA, 2015), the Intergovernmental Panel on Climate Change's emissions scenarios (Nakicenovic et al., 2000), the EU 2050 Roadmap (European European Commission, 2012) or the World Energy Council (World Energy World Energy Council, 2013).

[3] Two of the eleven interviewees which did use the *Energy Perspectives* stated to have referred to the *Botschaft des Bundesrats* in their work, which is in turn based on the *Energy Perspectives*.

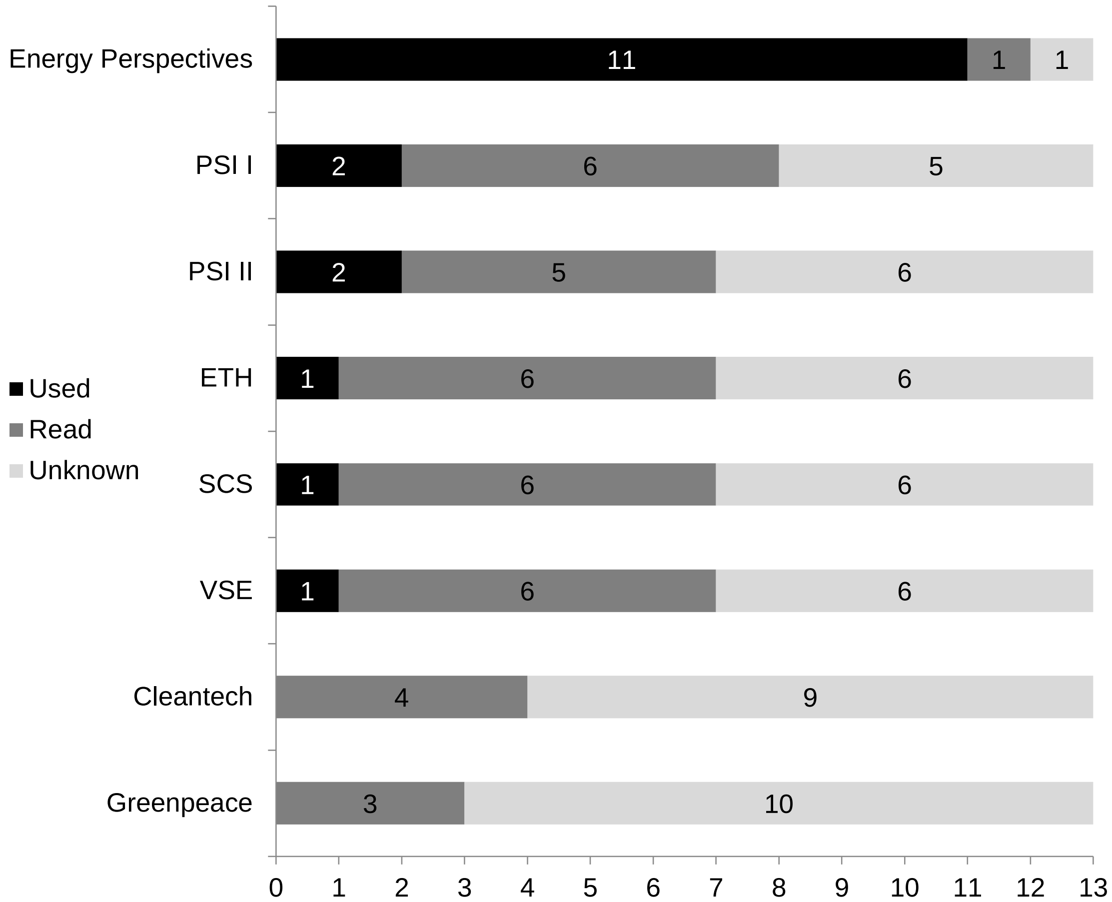

Fig. 2 Summary of how eight different Swiss energy scenarios the interviewed research groups (n=13) have used in their research, which ones they have (at least partially read) and which ones they do not know at all.

4.1.2 The diverse use of prospective information

As a consequence of the interviewees' diverse research foci, the key factors relevant to the different research groups are very heterogeneous (Fig. 3): While a specific factor (such as the electricity supply mix) may be a key input for one researcher, the same factor can be irrelevant to another.

In addition, the interviews revealed that the level of aggregation and temporal resolution of these key factors can vary considerably within disciplines (and sometimes even between projects of the same researcher). For this reason, assessing the overall relevance of individual factors was impracticable for some interview partners. That is why the second sorting task could only be completed by eight interviewees.

> It is difficult for me to decide whether these categories are relevant. For example electricity demand […] would need to be divided into smaller categories for me […]. (Interviewee 9).

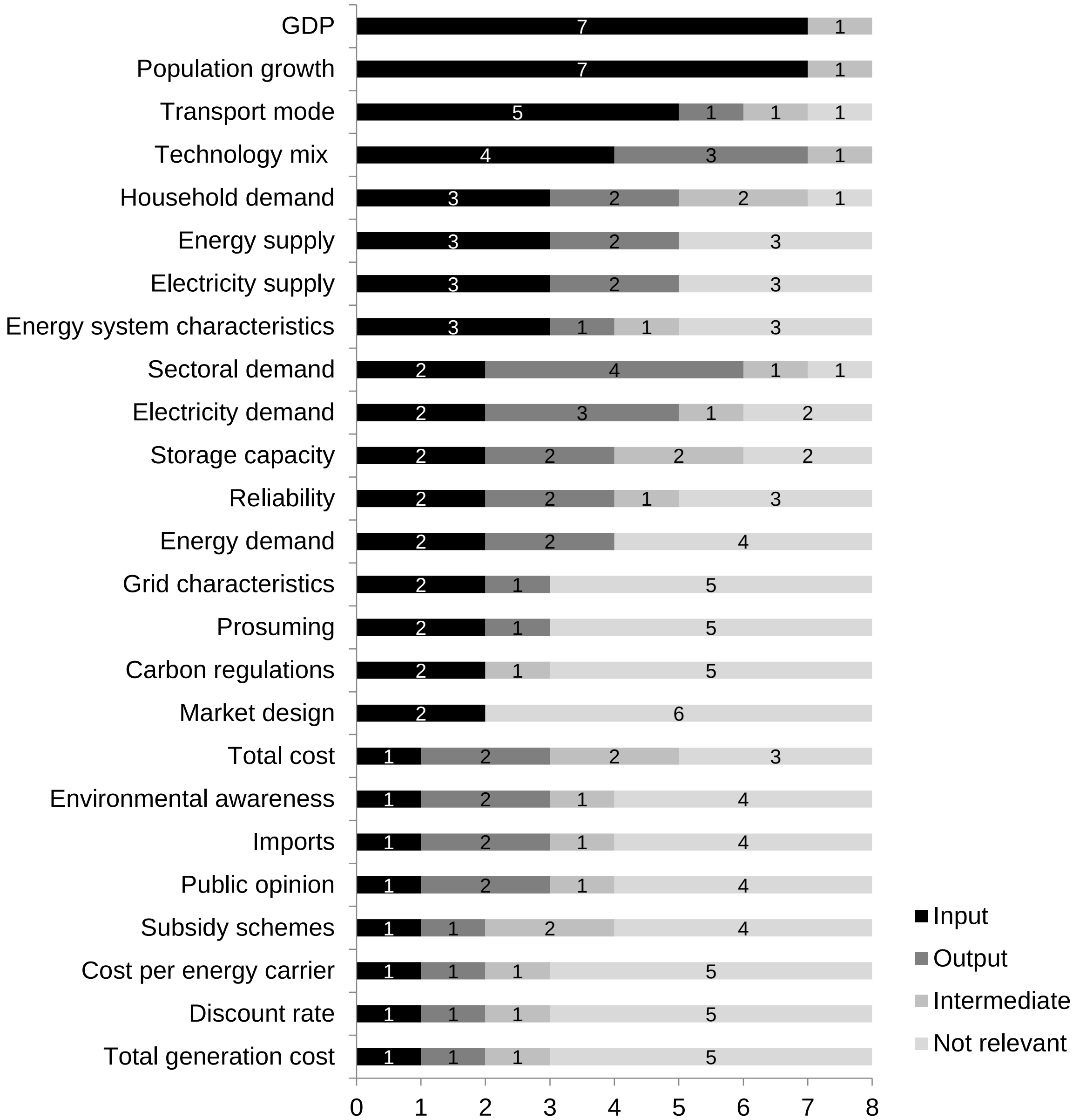

Fig. 3 Overview of how the interviewed research groups (n=8) rated key factors of energy scenarios.

Nevertheless, several patterns can be observed. First, factors that are relevant to the development of energy systems but are not at its core (such as GDP, the development of the modal split or population growth) tend to be used as exogenous input parameters and hence taken from external sources. Second, many key factors are only relevant to a few researchers. This includes primarily non-technical parameters like environmental awareness or public acceptance, but also regulatory issues. Third, the comments by the interviewees made it clear that regulatory factors were among the most controversial ones when it comes to their definition. For example, whilst for some interviewees the term subsidy schemes was detailed enough to say whether this plays a role in their research, others needed the factor to be more disaggregated to be able to give a meaningful answer (e.g. into technology-specific feed-in schemes).

4.1.3 Use of different scenario architecture parts

Among the interviewees, the use of three scenario architecture parts can be differentiated. Some researchers make reference to scenario outputs as a whole rather than to individual key factors, meaning that whole scenario studies are the part of interest. Researchers who did this typically needed to employ a convincing description of a low-carbon energy transition. One that is plausible, in both technological and social terms. In this case, the scenario use helps underpinning the practical relevance of a particular field of study (e.g. revolving around an energy technology) and hence illustrating current or future research needs. If used in such a way, no references to specific assumptions or data of scenario studies are made. In fact, some of the interview partners were not even aware that scenario studies, like the *Energy Perspectives*, typically comprises several scenarios. Yet, it also does not really matter for the purpose of their research. For them, it suffices to demonstrate the potential of a certain technology or the relative importance of a particular subject area:

> "Energy scenarios are of course an important argument for the type of research that we do. But more in the background […] whether a scenario predicts 5% more or less market share of a technology is irrelevant for us. It's more about the order of magnitude." (Interviewee 2)

The second part of the scenario architecture which was used by interviewees is specific model outputs. Interviewees that use this part typically focused on one or more key factor from a variety of scenario studies.

> "Some numbers, for example GDP and the population, the heated floor space, those are key inputs that we want to have [...] it is easiest for us to just take these numbers from scenarios." (Interviewee 6)

The researchers that refer to specific model output (e.g. in the form of numerical scenario results) demonstrated to have a detailed understanding of the strengths and weaknesses of the individual energy scenarios including detailed implications following from assumptions and model frameworks. They often combine the results of more than one scenario study, as they want to display the range of possible future developments:

> We do not only use one number from a certain scenario, we do actually look at the variations across many scenarios to see how sensitive the assumptions are that we are using." (Interviewee 5)

A third part of the scenario architecture that is used by the interviewees is model inputs (i.e. data & assumptions). For users of this part, scenarios are credible sources for future states and developments of key factors, as well as interdependencies between them.

> I don't really look at the results to see how much PV there will be in 2050 […] all the studies will have differences there. I rather look how much potential PV is given in these studies. (Interviewee 13a)

Apart from a better comparability of the outputs of different models, interviewees that make use of input parameters of other scenarios also pointed out that data from other scenarios is often available in an adequate temporal granularity, which is often not the case with other data sources. This part of the scenario architecture was predominantly used by researchers that develop energy scenarios themselves and thus have considerable knowledge about energy models and scenario-development. Some of them also stated that it is in fact just the inputs of other scenario studies that are relevant for them, while the actual modelling outputs were out of their scope of interest. That is because they do their own computations – however, with their own model, data and assumptions.

Eventually, one pattern that could be observed was that the use of energy scenarios was almost always limited to a single part of the scenario architecture. Users who are interested in models inputs are not interested in model outputs and vice versa. Interestingly, none of the interviewees stated to use the modelling framework of a scenario. Many scenario users stated to have a limited knowledge of energy models and their specific modelling frameworks. In contrast, interview partners who are scenario developers themselves stated that model frameworks are structurally so different that it is difficult to directly use them for own modelling activities.

4.2 Interpretation of energy scenarios

4.2.1 Publishing institutions serve as seal of quality

Mainly interviewees without advanced modelling or scenario-related know-how pointed out that they find it difficult to select an appropriate scenario from the variety of existing ones. In this selection process, the publishing institution of a scenario seems to be of relevance, as it is used as an indicator of a scenario's quality by many interviewees. This is well-illustrated by the *Energy Perspectives*, which were commissioned by the SFOE: One reason for the *Energy Perspectives* being clearly the most-widely used energy scenario among the interviewees seems to be its official status.

> "The only advantage of the Prognos scenario is that it is endorsed by the government." (Interviewee 5)

> "If you want to be policy-relevant, you have to use Prognos. It was commissioned by the Swiss Federal Office of Energy." (Interviewee 13a)

Hence, what is seen as an advantage of the *Energy Perspectives* is that referring to this particular scenario study does not require justification. Meanwhile, if a researcher refers to any other study, they are expected to provide arguments for why they did not use the *Energy Perspectives*. This may be a main reason for the dominant role of that particular scenario study among Swiss energy researchers.

> "Sometimes it is very hard to find data, but if I take Prognos, the official government data, people usually don't ask any further questions. That doesn't mean that Prognos is the most viable analysis, it is just a strategic choice to fill our need." (Interviewee 4)

The scenario study commissioned by Greenpeace (and implemented by the German Aerospace Center) provides a contrasting example: While several of the interviewees that were familiar with that particular study highlighted its sophisticated modelling approach, they also shied away from referencing a Greenpeace scenario in a scientific paper, in order to not seem biased.

> "Their [i.e., the Greenpeace scenario study] modelling approach is pretty solid, but I will not use it for my analysis. It would just not look serious." (Interviewee 6)

4.2.2 Different understandings of transparency and its implications

During the interviews, discussions about the role and importance of transparency in energy scenarios kept coming up. Overall, scenario users unanimously regard transparency to be a core requirement of energy scenarios. Moreover, the call for transparency seems to be equally strong among scenario developers and scenario users. But the understanding of transparency in the context of energy scenarios varies considerably across interviewees. Among researchers who develop energy scenarios, the term transparency primarily refers to making the model inputs and framework used in the scenario development publicly available. This is to help potential users interpreting the scenarios.

> "It is our philosophy to be transparent. In our report you can not only see all the assumptions, but also the modelling framework. You may have a different view of the future than I have, but if we are using the same calculator we can understand each other. If we don't know which calculator is used, everything is more complicated." (Interviewee 5)

However, scenario users without a detailed modelling know-how might be unable to make use of this type of transparency: One interviewee made the point that even with access to all data and the source code of the underlying model it would still be impossible to completely understand what is going on in a model-based energy scenario due to a lack of competencies in that field.

Moreover, one interview partner said that due to missing competencies, they did not know anything about the models and calculations behind the *Energy Perspectives*:

> „We use it blindly, because this is the reference case that everyone knows. And that's also why we use it, but not because we really understand it."
>
> (Interviewee 4)

While all of the interviewees were generally in favour of more transparent energy scenarios, it is also clear that this does not come without a cost on the side of scenario developers. For example, a comprehensive model and high-quality input data are de facto assets for researchers which may provide a negative incentive for being transparent. What is more, the documentation of models and the preparation of data in adequate detail to be of use for other researchers take a lot of time and effort. Hence, although the interview results make clear that scenario developers generally agreed that sharing data and model code are beneficial, resource constraints seem to be the main reason for why some models are not yet open source:

> „We're not yet there to publish the model in an understandable way. And we should do that the right way, because otherwise transparency will be lacking on this level. Until now, we just did not find the time to do it." (Interviewee 12c).

As it is the most widely used energy scenario in the sample, the *Energy Perspectives* also was scrutinised in greater depth than others. Consequently, the interviewees' transparency-related issues mostly concerned that particular study. Three main aspects were criticized. First, the proprietary model framework, which has been developed by a consulting company, was commonly regarded as the main reason for the missing transparency. Interviewees pointed out that not all necessary information is visible to scenarios users, which is why several interviewees referred to the *Energy Perspectives* as a "black box". In particular because the *Energy Perspectives* study was issued by the Swiss federal government, many researchers remarked that they don't understand why not all the information is accessible.

A second point of criticism related to transparency was mostly brought up by scenario users with a modelling background. Many of them were confused by the structure of the reporting style of the 900-page scenario study:

> "[…] the information is mostly somehow there, but sometimes it is also in the annexes so you really have to spend hours and hours to find the information or to get some values. That does not just concern some assumptions, but some basic factors that you need, for example the efficiency of technologies or the capacity factors of a wind turbine or the efficiency of a PV panel." (Interviewee 6)

Directly related to this point, interviewee 1 mentioned that:

> "It is quite difficult to understand how the model was pieced together. So I understand that it is a big model but you can at least visualize sub-models […]." (Interviewee 1).

Finally, several researchers stated that they had contacted the developers of the *Energy Perspectives*, to get information about assumptions or data sources. Yet, their requests were turned down.

4.2.3 Contrasting perspectives on energy scenarios

To adequately deal with the uncertainties present in the energy system, and its future development in particular, many researchers spoke out on the merits of a diverse set of scenarios:

> „… [scenarios] can all display different expectations and interests. In that sense, a scenario also is an echo-room, a tool through which actors can communicate." (Interviewee 8)

In particular researchers that are primarily scenario users emphasized that energy scenarios can only unfold their full potential if they are considered collectively. This is confirmed by the circumstance that the overwhelming majority of interview partners have consulted more than one scenario study.

> "I think it is really important to not just focus on […] scenarios by a single institution. Because we don't know what the future looks like. Of course there has to be a finite numbers of scenarios that we can look at, for cognitive reasons, but then I think it's important to open the scenarios we have up to ideas that other scenarios do not cover." (Interviewee 7)

However, as seen in section 4.1, only a small minority of researchers eventually use more than one energy scenario study in their work. In most cases, the scenario *Politische Mass-*

nahmen des Bundesrats, one of the three scenarios in the *Energy Perspectives* study, is the single scenario referred to. Paradoxically, there exists a diversity of energy scenarios that is complimented by most interviewees, but unused at the same time.

A reason why users shy away from using a selection of different energy scenarios might be that some don't feel confident integrating energy scenarios that they don't completely understand. During the interviews it became clear that there indeed are knowledge gaps between scenario developers and users. For example, many scenario users without pronounced modelling competencies criticized that the treatment of uncertainty was insufficient in energy scenarios:

> "I would like to have more information. For example uncertainty ranges or certain statistical parameters. What is the standard deviation here or which interval is most-likely? (Interviewee 4)

In particular, the lack of an uncertainty range in electricity generation mixes and other trajectories given in most energy scenarios was criticized:

> "2050 is a fairly long time frame and the fact that it [the energy demand] always is just a thin black line is really astonishing. Probably it would have been more honest if an uncertainty range that gets bigger and bigger would have been included." (Interviewee 7)

In contrast to that, several interviewees who develop own energy scenarios emphasized that their energy scenarios are not forecasts. Thus, they do not claim to provide any kind of probability. Rather, the results should be seen as plausible *what-if* projections under the assumption that all factors considered develop exactly as outlined in the scenario. In addition, scenario developers mentioned that the robustness of a scenario is addressed through rigorous sensitivity-testing of selected uncertainties (e.g. versions of key factors that have a large influence on the outcome of a scenario).

Another point where the interview partners revealed contrasting opinions are collaborative scenario activities[4]. There are different ideas concerning the purpose and target of such cooperations among scenario developers. Some scenario developers primarily want to share data and improve communication whilst others want to go one step further and coordinate scenario activities by agreeing on a set of assumptions and key factors. Among some scenario users who do not develop scenarios there is a wish to establish comparability in the field of energy scenarios through reference scenarios that merge existing models. However, scenario developers argued that different models cannot be integrated sufficiently to produce meaningful scenarios. Moreover, the interviews showed that what should be included in such a reference scenario is highly debatable.

[4] Example for such joint scenario and/or modelling efforts include the *SimLab* (http://www.simlab.ethz.ch/), a knowledge sharing platform that also hosts activities to bring scenario-developers together, and the *Swiss Energyscope* (http://www.energyscope.ch/), a virtual user interface to experiment with energy scenarios, that is roughly based on the *Energy Perspectives.*

5 DISCUSSION

5.1 Two main types of scenario users: *Sailors* and *divers*

The interviews with researchers illustrate that there is considerable heterogeneity in use of energy scenarios among Swiss energy researchers. Depending on the research project, different parts of the scenario architecture are of interest. However, there also turned out to be two distinctive user types of how researchers interact with energy scenarios.

A first group of scenario users would primarily refer to the output of scenario studies. We labelled these as *sailors*. The way in which these *sailors* use energy scenarios does not require them to understand what model inputs and frameworks were employed in the development process. As the interviews showed, this would also be quite challenging or even impossible for researchers without the adequate educational background and competencies. A lack of knowledge to understand energy scenarios in detail, resource limitations, a high level of trust and confidence in scenario developers, or simply a lack of interest in the technical aspects of energy system modelling are possible explanations for that approach to using scenarios brought forward by *sailors* during the interviews. As a consequence of this, a lot of information provided by the energy scenario architecture is irrelevant or even inaccessible for *sailors*. This is also why these users tend to refer to scenarios in an unspecific way. Hence, *sailors* often practice a heuristic approach to assess the quality of a scenario by relying on the institution that has published it.

In contrast, users with a lot of competencies in the field of energy scenarios, scrutinise energy scenarios more carefully. We labelled them *divers*. *Divers* want to fully understand the scenario information they are using in their research. They predominantly refer to the parts of the energy scenario architecture that may not be visible at first sight, i.e. the modelling framework or model inputs. Though the modelling frameworks are generally understood quite well by *divers*, they are mainly interested in the data and assumptions that were used to feed the respective energy model. As seen in section 4.1.3, the few researchers that use very specific model output also have a very detailed understanding of the information they extract from energy scenarios. Thus, being a *sailor* or a *diver* respectively is not determined by using a certain part of a scenario study, but to what degree this information is understood, contextualised and integrated in the research process.

Being a *sailor* or a *diver* respectively seems to be closely linked to the researchers' educational backgrounds and competencies. In particular, someone who does have modelling competencies and specific knowledge of energy system models has quite a different perspective on energy scenarios than someone who does not. The two different user types and their disparate access to scenario architecture parts can be illustrated by the metaphor of an iceberg: A scenario study's output lays above the water line, visible to all *sailors*. These comprise of projections of key energy system characteristics of interest to decision makers – such as energy consumption, energy supply mix, or cost. In many scenario studies, these parameters are complemented by qualitative information, such as narratives or names of specific scenarios to help make sense of quantitative model output. Typically, the tip of the iceberg represents those aspects of a scenario study that can be conveyed in an executive summary or synthesis report. But as with an iceberg, the larger parts of the process and the information of a scenario study remain below the water line, visible to *divers* only. This includes the modelling framework employed in the scenario study as well as the specific data and assumptions that served as inputs for the modelling activity.

Sailors and *divers* represent the scenario users' impetus to look into energy scenarios and understand the relevant parts. Advanced or lacking modelling competencies, dissimilar time constraints and varying reason for scenario use are associated with being a *sailor*, or a *diver* respectively. It is clear, however, that these scenario user types are neither distinctive nor exclusive, as interests and competencies vary gradually between users and research projects. For example, if well documented, information concerning key assumptions and data sources is easily accessible for *sailors* if they are willing to delve into the scenario report. Hence, it can be regarded as akin to the part of an iceberg that is just below the water line and is susceptible to analysis without specific (diving) equipment. Nevertheless, *divers* and *sailors* represent two ends of a spectrum, wherein lie the perspectives on using energy scenarios.

5.2 Implications resulting from the contrasting scenario use

A research group that develops a scenario concentrates assumptions about the future state of a system into a consistent picture (Burt, 2007). During that process, implicit and explicit knowledge that forms the basis of strategic decisions gets produced. In that sense, scenarios facilitate the reformation of shared mental models in the form of collective learning (D'Aveni & MacMillan, 1990; Durand, 2003) among energy scenario developers. However, scenario users – and especially *sailors* –often do not have access to the development processes of scenarios due to the complex and highly specialised modelling part. Consequently, they often lack the valuable implicit part of knowledge from scenario development processes

It is clear, however, that many of the different perspectives between scenario developers and scenario users, which have been observed in the interviews, can be explained by the contrasting educational backgrounds, research interests and competencies of *sailors* and *divers*. To illustrate this, the different views scenario users and developers had on how uncertainties are and ought to be considered in energy scenarios (see section 4.3.2) can be used as an example. If such differences stay undetected, a false confidence about the numbers provided by energy scenarios might find their way into findings of researchers and ultimately into energy policy designs. Thus, not knowing how highly complex information is interpreted by users that produce policy-relevant insights can be dangerous (Carter et al., 2001). In fact, since energy scenarios are only suitable for the purpose they were developed for, their decision-support function is limited to a set of very specific questions. This is why an incorrect application of an energy scenario can result in significant misinterpretations (van Beeck, 1999).

To assure that energy scenarios are interpreted as intended, scenario developers need to be able to assume the perspectives of scenario users. A scenario-development process that seeks to involve all relevant stakeholders, as it is emphasized in most case studies of how firms and governments benefited from scenario planning, offers a potential solution (van Vuuren et al., 2012). It is argued that such participative approaches increase the transparency of scenarios because the envisioning of the future is a common activity (Chaudhury, Vervoort, Kristjanson, Ericksen, & Ainslie, 2012). Since users can take part in the development, they are more likely to understand how the scenarios are designed and what key factors impact the results, which in turn makes scenario-based insights more useful to them (Volkery & Ribeiro, 2009). The highly specialised and complex nature of energy scenarios and the modelling part in particular is, however, clearly an obstacle in that regard.

Furthermore, the mere fact that energy models were considered as *black boxes* by several of the interviewees suggests that scenario developers might have to put more effort into the presentation, visualisation and communication of their modelling activities, keeping in mind that scenario users are lacking the implicit knowledge of the scenario development. To date, however, scenario developers concentrate their resources mostly on the modelling part, and not on communication with their target audience (Pfenninger et al., 2014). Likewise, transparency is regarded as a cost with little direct benefits by most scenario developers. Scenario developers need to recognise that the documentation of the model is directly linked to communication with lay people and interested stakeholders (such as researchers and decision-makers) without modelling competencies. If scenario developers improve the transparency (and therefore accessibility) of their work, energy scenario can have a greater impact because misinterpretations can be reduced and insights can be transferred more effectively. In addition, an improved understanding of energy scenarios by users without modelling backgrounds would ultimately also benefit the quality of energy scenarios through increased evaluative mechanisms, which are mostly missing to date. In terms of resource management, all these mechanisms are, however, contrasting the applied logic of many research groups which is to focus on publication of research results. Nevertheless, the question whether a lack of evaluative mechanisms combined with a highly specialised modelling part leads to a narrow focus, missed uncertainties or a lower accuracy of scenario-studies in general, needs to be discussed more openly.

Until now, users without advanced modelling competencies are incentivised to select energy scenarios that are the least controversial (for example due to their official character), instead of the most appropriate and helpful scenarios for their specific needs. This is often achieved by relying on the reputation of the publishing institution. The resulting single dominant energy scenario study *Energy Perspectives* carries the risk that it is implicitly endorsed as the most suitable or most-likely scenario by users (McDowall, Trutnevyte, Tomei, & Keppo, 2014). In a recent retrospective analysis of energy scenarios, Trutnevyte, McDowall, Tomei, and Keppo (2016, p.5) found that "*the richest and broadest picture of uncertainty emerged when insights from multiple scenario studies by different organisations were combined*". This indicates that the existing variety of Swiss energy scenarios is valuable. Nevertheless, if users are unable to make use of this variety, energy scenarios will not be able to unfold their full potential as decision-making support tools. Instead of simply adding new scenarios, scenario developers should provide assistance or services to summarize, visualize or propose a small set of particularly useful scenarios for specific purposes (Trutnevyte et al., 2016).

5.3 Critical reflection and outlook

Being explorative and mostly qualitative in nature and because the topic itself is of very high complexity, the study at hand falls short of a comprehensive overview of the use of energy scenarios by Swiss researchers. Nevertheless, the fact that the sample of interview partners spans a wide field of scientific disciplines and that there were several recurring patterns in their statements suggests that the study does provide an important first step towards an impact assessment of energy scenarios.

Going forward, one approach may be to complement this study's' qualitative insights (e.g. the prevalence of the different types of scenario uses) by quantitative information. This could be achieved by a survey going to all energy researchers in Switzerland or internationally. The scope of such a survey could also be widened, for example, to include key decision makers in administration and industry. This would allow developing a better overall understanding of the impacts of energy scenarios. In choosing this approach, it needs to be considered that such a widening of the scope may also accentuate the challenges that originated due to the heterogeneities in understanding and knowledge of energy scenarios and models. This became apparent in this study when interview participants were asked to assess the relevance of selected key factors. Due to the different disciplinary terminologies and research foci, many key factors had to be explained extensively to the participants. Some of the researchers even felt unable to make an adequate classification.

Another interesting line of further research addresses the dichotomy of scenarios users on one hand (be it in academia, administration or industry) and energy scenario developers on the other hand. In fact, many of the interviewees stated that they intend to inform policy makers, but that they do not know to what degree their research is used in policymaking processes. Hence, a better understanding of how the information exchange between scenario developers and users might be a field worth studying.

6 CONCLUSION

Scenarios are regarded as important tools for informing and assisting both researchers and decision makers in the private and public sector. The high complexity of energy systems (and consequently energy models) led to a significant specialization in the development of energy scenarios. This working paper showed that the implicit knowledge that is generated in the development process of scenarios is inaccessible for most scenario users, which has various implications. In particular, one key divide seems to be between scenario users and scenario developers – a separation that conflicts with the intended purpose of scenarios known from other fields. Most importantly, a mutual understanding between *sailors* and *divers* who use energy scenarios differently is not always given. Due to dissimilar perspectives, capabilities and interests, *sailors* and *divers* interpret certain scenario-based insights unequally. In particular, the concerns regarding the treatment of uncertainty in scenarios comes from a misconception by certain scenario users of what the model output actually represents. Because researchers that have an overview of the whole scenario architecture and its actual use are mostly lacking, the publishing institutions of energy scenarios are used as anchors to guide the selection of energy scenarios. Since this method is usually not suitable to choose the most appropriate energy scenario for a particular task, it is hampering the capabilities of scenario users to acknowledge the large variability of existing Swiss energy scenarios with their unique modelling approaches and original properties. Furthermore, especially since empirical scenario use evaluations are rare, the knowledge gap between *sailors* and *divers* might be a reservoir for undetected misconceptions and misinterpretations of energy scenarios.

Due to these issues arising from this specialization, there is a need for more scenario expertise that can function as intermediate between the two perspectives. A close interdisciplinary collaboration between energy scenario users and developers might be needed. It is clear, however, that an energy scenario with a specific purpose, strengths and weaknesses will be interpreted differently by users with various educational backgrounds and interests. In that sense, there are limits to what degree implicit knowledge from the scenario development process can be made accessible to scenario users. At the same time, there will never be one single scenario that is able to fulfil the needs of all users. Nevertheless, instruments that ensure that the scenarios that are being developed are comparable with respect to some key parameters would be helpful, as scenarios are able to catalyse consensus-building between multiple societal actors through the identification of a mutually desirable path.

In light of the fundamental changes the energy transition is bringing about and the critical choices that precede these changes, energy scenarios are not just made for routine decisions by public administrations or energy companies, but also increasingly serve as scientifically derived information basis for societal debates among governments, energy companies, NGOs and the general public. The reception of scenario-based information by politicians and the general public possibly comprises even more room for misunderstandings than their decryption within the research community.

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