DTU Library

Experts, stakeholders, technocracy, and technoeconomic input into energy scenarios

Andersen, Per Dannemand; Silvast, Antti

Published in:
Futures

Link to article, DOI:
10.1016/j.futures.2023.103271

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Futures 154 (2023) 103271

Contents lists available at ScienceDirect

Futures

journal homepage: www.elsevier.com/locate/futures

Experts, stakeholders, technocracy, and technoeconomic input into energy scenarios

Per Dannemand Andersen [a,*], Antti Silvast [b]

[a] Technical University of Denmark. Department for Technology, Management and Economics, Produktionstorvet 424, DK-2800 Kongens Lyngby, Denmark

[b] Lappeenranta-Lahti University of Technology LUT, Yliopistonkatu 34, 53850 Lappeenranta, Finland

ARTICLE INFO

Keywords:
Experts and stakeholders
Energy scenarios
Energy modelling
Science and technology studies
Technocracy
Technology foresight

ABSTRACT

This paper confronts the broad question of the nature and quality of the contributions of experts, stakeholders, and the wider public to the development of detailed techno economical inputs used in scenario analyses used for discussions and decisions on the green energy transition and science, technology and innovation (STI) policies in general. The study focuses on stakeholder inclusion in developing the Danish Energy Agency's technology catalogues. The technology catalogues forecasts technoeconomic data up to 2050. The study reviews some well-recognised issues related to the inclusion of experts and stakeholders. The study contributes three new insights. First, a better understanding is developed of how expert and stakeholder inclusion in developing front-end inputs for energy models and scenarios aligns expectations and builds a shared understanding of detailed technoeconomic data. This shared understanding establishes a level playing field for wider public debate on visions for the future energy system. Second, a pragmatic approach is demonstrated for stakeholder inclusion in contexts – such as developing technology catalogues – with limited resources and only a few actors available for consultation. Third, the paper presents the argument that the concept of technocracy can bring useful insights for analysing expert and stakeholder inclusion in longterm energy planning.

1. Introduction

Countries all over the world have set ambitious targets for CO2 reductions. Following policy targets set by the European Union, Denmark has set a target of a 70% reduction in greenhouse gas emissions by 2030 from 1990 levels. Furthermore, Denmark aims to be independent of fossil fuels by 2050. These policy targets require a dramatic and rapid transition of the country's energy system. While there is cross-party political consensus in Denmark on these goals, the details in which these targets may be reached are still contested and debated. As policy-makers and scholars know, there are multiple technoeconomic pathways for the transition to a sustainable energy system (Rosenbloom, 2017). In this sense, the future is open-ended: the number of potentially promising innovations and initiatives surpasses those that will eventually prevail. To support the debate on this open-ended future, the Danish Energy Agency develops model-based scenarios to uncover different technoeconomic pathways to achieve climate goals. The scenarios describe alternative futures and their implications. The scenarios and their consequences are used as a foundation for debates and decisions on the green transition and related science, technology and innovation (STI) policies.

* Corresponding author.
E-mail address: pean@dtu.dk (P.D. Andersen).

https://doi.org/10.1016/j.futures.2023.103271
Received 3 February 2023; Received in revised form 13 October 2023; Accepted 16 October 2023
Available online 18 October 2023

The Danish Energy Agency develops 'Technology Catalogues' as front-end inputs for energy models and scenarios. The technology catalogues comprise state-of-the-art knowledge and prospects for various technologies, including assessments (or forecasts) of future technoeconomic data for different time horizons up to 2050. The process to establish the datasets is described in a set of guidelines developed by the Danish Energy Agency. It includes traditional participatory foresight methods such as defining the technology, finding and selecting experts and stakeholders, generating expert reports, making extrapolations, holding stakeholder workshops, consulting the wider public, and disseminating the results.

All appraisals of technology involve diverse stakeholders to determine the wider impact of the scenarios on policy-making and society (Stirling, 2008). A wealth of studies exist on stakeholder involvement in scenario planning in energy and sustainable development (Volkery, 2008; Kowalski, 2009; Sheppard, 2011; Palacios-agundez, 2013; Gramberger, 2014; Upham et al., 2014; Andersen et al., 2021). Nevertheless, stakeholder involvement in producing front-end input and other data for these scenarios has rarely been studied. There are studies on participatory processes in energy systems modelling (McDowall, 2014; McGookin et al., 2021). These studies have discovered a range of unresolved questions, such as the tensions between real-world impact and research outputs, and stakeholder representativeness (McGookin et al., 2021). Even in these studies, however, the focus tends to be on the modelling process itself rather than on the production of technoeconomic data for use with the models.

In fact, development processes leading to plausible and reliable technoeconomic data for future energy technologies are not trivial. There is a lack of studies on such data, particularly for emerging technologies (Fodstad, 2022). Stakeholder inclusion is often focused on the first phases of scenario processes for providing data and expert assessments of the data, and securing ownership from key stakeholders (Andersen et al., 2021). Nevertheless, few studies exist on forecasts and other front-end inputs for models and the development of scenarios (Venturini et al., 2019).

This paper confronts the broad question of the nature and quality of the contributions of experts, stakeholders, and the wider public to detailed technoeconomic inputs for scenario analyses used for discussions and policy decisions on the green transition and STI policies in general. The paper addresses this overall research question as follows. In Section 2, we discuss two theoretical frameworks and their bearing on the overall research question. In particular, we have focused on this literature's view of four coherent issues: stakeholders and experts; time, resources and power asymmetries; biases and overoptimism of experts; and technocracy. Section 3 presents the research methodology and practical approach of the study. Section 4 presents the empirical context. The section describes the process and organisation of developing the technology catalogues, including an analysis of the types of actors and stakeholders who are involved in the process. Section 5 presents our findings and a discussion in relation to the issues raised in Section 2. Finally, Section 6 includes the discussion and conclusion.

2. Theoretical framework

The theoretical framework of this paper draws from two coherent and established research fields relevant to the research questions. First, we draw on the literature on foresight, scenario planning and stakeholder involvement in scenarios. Second, we consider studies on public engagement in science and technology. The literature in both fields is vast and rapidly increasing. Both fields of literature have analysed the tension and dilemmas concerning stakeholder inclusion in scenario planning. This section aims to position our research in relation to some of the newest discussions in these fields relevant to our study.

2.1. Stakeholders and experts

There is extensive literature on foresight, scenario planning and stakeholder involvement in scenarios. Scenarios are widely used as a method to engage stakeholders in 'strategic conversation' (van der Heiden, 1996) on exploring uncertainties, plotting alternative futures, and devising resilience policy and strategy options (Cairns, 2013; Ramirez & Wilkingson, 2016). In particular, there is a body of literature on stakeholder involvement in scenario planning in the domain of sustainability and energy system transition. The literature on this topic has documented that involving stakeholders and citizens in debates and research about science and technology is crucial to secure an impact on actual policy-making and produce societal outcomes in general (Chilvers et al., 2018; Sovacool, 2020; Andersen et al., 2021; McGookin et al., 2021). However, the concepts of both experts and stakeholders are contested and debated (Stirling, 2008; Freeman, 2010; Frewer, 2011; Fischer, 2014; Colvin et al., 2016; Miles, 2017). The debate concerns who participates in the processes and how these participants are included in the processes. Questions concerning how knowledge is recognised as expertise and how that knowledge is mobilised in society have for decades been debated in literature on expertise, contested expertise, and expert-lay relations, especially in science and technology studies (STS) (Åkerman, 2020). These discussions point to critical questions: who counts as an expert; why are they considered experts; and what does this mean in terms of processes such as technology appraisal? In addition, studies have indicated that the very distinction between who is an expert, a researcher, and a stakeholder has become blurred and that these terms are increasingly used interchangeably (Andersen et al., 2021).

The challenges of stakeholder inclusion present a range of ontological and epistemological choices concerning how participation is understood. Chilvers and Kearnes (2020) summarised this research and recognised two different and potentially incompatible research interests. The first is a normative interest in participation in science and democracy, including questions about 'good' participation, inclusiveness, and representation, which often assumes the stakeholders are already known. These stakeholders exist independently of attempts to engage them. The second is a constructivist approach, which indicates that the public is involved and produced by intervening in public problems (Chilvers & Kearnes, 2020). While Chilvers and Kearnes (2020) seek to move beyond the normative, or 'realist', perspective and replace it with a constructivist approach, the literature on stakeholders and inclusion partly blurs this distinction and pursues both ends. In the book 'Stakeholder theory: The state of the art', stakeholders are defined broadly as '*those* *groups or individuals who can affect or be affected'* (Freeman, 2010, p9). In this study, we also assume a broad definition of stakeholders and include all those actors included in or affected by the process and its outcome. In this definition of stakeholder, we include both experts and non-experts. Furthermore, we draw on a recent typology (Andersen et al., 2021) that suggests five ideal types of stakeholders in scenario planning: experts, stakeholder representatives, personal stakeholders, remarkable people, and citizens. Hence, defining who counts as a 'stakeholder' is a conscious choice in scenario processes, and these choices have consequences for the 'best' answers that the processes can find.

2.2. Future technoeconomic data for energy planning

The literature typically reports on three main approaches using future technoeconomic data to assess long-term energy planning – with or without stakeholder engagement. One approach is based on extrapolations from historical development. Historical data can be obtained in different ways, e.g., public documents of actual projects (Rubio-Domingo & Linares, 2021). The projections or extrapolations from the historical data can then be determined based on time, size of plants, or accumulated installations. In the latter case, the concept of learning curves—or experience curves—is used to assess cost reduction or performance improvements as a function of accumulated installations (Junginger et al., 2010). Extensive literature exists on learning curves (Samadi, 2018), but there seem to be no – or very limited numbers of – examples combining the learning curve approach and participatory approaches. Another approach is expert elicitations (Wiser, 2016; Verdolini, 2018). In a recent study on the cost of wind energy by 2050, 140 global wind energy experts contributed to a survey on the future levelized cost of wind energy for 2019 and for the three future time horizons of 2025, 2035 and 2050 (Wiser, 2021). A third approach uses Delphi surveys, a form of expert elicitation with an extra methodological element of iterations based on feedback from earlier rounds. In a study on wind power in Turkey, the respondents were asked, for example, when the event of '50% reduction of wind energy generation cost per kWh' would be realised (Celiktas & Kocar, 2010, 2012). Other approaches comprise the inclusion of experts, stakeholders and the wider public through workshops or similar participatory events. In practice, the processes consist of combinations of different approaches. Common for the three approaches and the mentioned examples is that the complexity of their analyses is much more limited than is the case for the technology catalogues. Most often, the referred approaches and examples only consider one dimension of future development: development in the cost of energy. As explained in Section 4.1, the energy catalogues contain a range of technoeconomic data, including technical parameters, economic parameters and, in some cases, environmental impacts. As an example, the data for medium-sized (80 MW) combined heat and power contain 39 parameters (DEA, 2016, p142–143).

2.3. Time, resources and power asymmetries

A classical challenge for stakeholder inclusion in scenario planning is that the invited stakeholders cannot prioritise and allocate their own time and resources to contribute (Videira et al., 2009; Carlsson, 2015). This is, for example, a challenge in relation to small business owners who cannot afford to spend the needed time on workshops (Videira et al., 2009). Other studies find that some experts and stakeholder representatives of NGOs or public authorities are fatigued by being repeatedly included in all stakeholder involvement (Andersen et al., 2021). Studies have also shown that professional stakeholder representatives are more persistent in their opinions than other stakeholders (Makkonen et al., 2016). A related challenge is the involvement of individuals who lack the educational background or cultural traditions to participate in such processes (Bizikova et al., 2012; Karger, 2013). Together, this creates power asymmetries among stakeholders. Due to available time, resources, formal competencies or traditions, some stakeholders can affect processes and their outcomes more easily than others.

In addition to the challenge of power asymmetries, the literature has discussed the concept of 'power distance'. That is how the less powerful members of organisations and institutions accept and expect that power is distributed unequally (Hofstede & Minkov, 2010; Andersen & Rasmussen, 2014). The power asymmetries between experts and other stakeholders might be enhanced in cultures and traditions with a high power distance. On the other hand, power asymmetries might be levelled out in cultures and traditions with low power distance. The case in this paper is a Danish context with a very low power distance and a long tradition of consensus-seeking among stakeholders (Andersen & Rasmussen, 2014). An older study of democracy and power in Denmark concluded that the power gap in Danish society has almost disappeared. The reduced power gap also applies to the citizens' relationship with experts, whose authority has faded (Togeby, 2003). This affects how the legitimisation of processes and their results are secured. Legitimisation might come not only from experts' assessment of future development but also from a consensus among key stakeholders. An American study of the future of nanotechnology found that establishing plausibility is a crucial element of future-oriented deliberative practices (Selin, 2011). The mentioned study also suggested that this plausibility must be locally defined by including stakeholder communities.

2.4. Biases and overoptimism of experts

The literature has established that experts tend to be overoptimistic about the future development of the area – or technology – in which they are experts (Tversky & Kahneman, 1974; Tichy, 2004). This dilemma tracks with well-known heuristics that identify biases in expert elicitation: "*the assessment of self-rated top experts tend to suffer from an optimism bias due to the experts' involvement and their underestimation of realisation and diffusion problems*" (Tichy, 2004, p431). This has been described as a "desirability bias", which occurs when experts or stakeholders systematically estimate a future event more positively or negatively according to their individual sense of the desirability of an event (Winkler & Moser, 2016). A classical work on the Delphi approach found that shorter-range forecasts tend to be optimistic, whereas longer-range forecasts tend to be pessimistic (Linstone & Turoff, 1975). This finding is supported by newer studies (Winkler & Moser, 2016; Markmann, 2021). A recent review of expert biases in technology foresight confirmed this and suggested three strategies to mitigate such expert overoptimism (Bonaccorsi et al., 2020). However, the review concludes that there is a need for more research and experimentation with combinations of mitigation strategies.

2.5. Technocracy and performativity

The foresight literature has discussed the question of technocratic versus citizen-participatory processes in futures research (Tapio, 1996; Tapio & Hietanen, 2002). A significant critique has been that public engagement is merely a "therapeutic exercise" at the project level (Tapio, 1996, p464) or aimed at securing a commitment from key stakeholders (Andersen et al., 2021). That said, discussions about technical details requiring a high degree of expertise are sometimes invisible in the wider public debate. Some scholars have suggested the concept of "technocratic internationalism" (Schot & Lagendijk, 2008; Kaiser & Schot, 2014). They argue that the builders of European infrastructures sought to "depoliticise" the transnational networks they sought to control by distancing their efforts from the effects of the world wars and seeking a "technocratic" form of internationalism rather than one that is influenced by individual countries and EU institution building (Kaiser & Schot, 2014). To this end, this tradition talks about the importance of rules created by organisations, committees, and experts. These bodies work by producing standardised and putatively shared understandings about liabilities, rates, and data, which then become resources for building infrastructures in various locations but in an uniform manner. This work on "technocratic internationalism" can be seen in several developments, including rationalising the electricity supply, cross-border transportation, and communication infrastructures (e.g., Henrich-Franke, 2018).

We have conceptual ground to claim that these different kinds of expertise even change what they are trying to measure, such as innovation policies for R&D investment and growth (Schot & Steinmueller, 2018). For instance, recent energy policies in Europe and all around the world have emphasized the importance of energy economics and market design in addressing energy issues (Silvast, 2017), but capitalistic thinking is itself arguably increasingly techno scientific (Birch, 2017). Financial cost benefit analyses and conceptions about efficiency are examples of techno-economic techniques and ideas that underpin research and innovation policies, sometimes implicitly, sometimes as an explicit normative goal for progress. STS scholarship (Silvast, 2017) approaches the assumptions of such techniques and ideas and as potentially performative: economic knowledge is not merely describing the economy and markets – although that is its explicit aim – but when in use, may also lead to producing those objects that it describes, at least for a time. In the case of technology catalogues, one should hence examine whether they not only contain the 'actual costs' of future technologies or whether, and if so how, they may play a role in bringing those costs about.

3. Research methodology

The research behind this paper took place during the spring of 2022. The research was based on mixed methods, including desk studies of documents and interviews with key actors. Documents include publicly available information from the relevant institutions and actors and internal communication (e.g., emails from the Danish Energy Agency to stakeholders).

The study was originally designed to include 12–15 interviews partly covering a general overview of the development and use the data in the catalogues and partly covering detailed insight into two particular technologies. Due to the lack of availability of many of the selected interviewees, only six interviews were carried out. However, these six interviewees represent a variety of very experienced developers, administrators and users of the technology catalogues. They were all Danish with broad insight into the Danish energy sector as well as international experiences. The six interviewees were:

- An energy systems expert with six years of experience in developing and administering the energy catalogues for a public authority
- An energy planning expert with nine years of experience in developing and administering energy catalogues for a public authority and a private company
- A professor in energy systems analysis with 15 years of experience in the use of technology catalogues and similar data
- an energy technology analyst in a consultancy with more than 35 years of experience in developing and using technology catalogues and similar data
- An energy analyst in a consultancy with 20 years of experience in developing and using technology catalogues and similar data
- A leading figure in Danish energy technology development during the past 40 years.

The interviews were semi structured, following an interview guide with open-ended questions. The interviews lasted from 45 min to 1 h 30 min. Each of the interviewed actors was asked a set of questions focusing on the following themes:

- The use of technology catalogues (e.g., how the technology catalogues are used and by whom)
- The production of technology catalogues (e.g., the quality of the data of the catalogues, peer review practices)
- Stakeholder inclusion (e.g., identification of typical stakeholders)
- Wider public (e.g., role taken by public and political issues in developing the catalogues)
- Development suggestions (e.g., most challenging and critical issues in the catalogue process)

The interviews were held in English, recorded, and directly transcribed via MS Teams. Content analysis was performed by critically reading the raw transcriptions of the interviews and then qualitatively grouping them into main themes as they emerged from the interview responses and the discussions themselves. For the paper, we selected quotations from the interviewees to exemplify our general observations. A weakness of this approach is that while some interviewees may express themselves in a clear and citable manner, others might express the same viewpoint but in a way that is difficult to quote directly. Therefore, some of the interviewees are quoted more than others in Section 5 of this paper.

A similar approach using content analysis informed our reading of relevant policy documents: we read the primary documents, as identified by our interviewees and connections to this work, and the matised essential explanations of how the technology catalogue methodology works. The use of policy documents in this research is mainly descriptive, and we do not seek to critically analyse their discourse in this instance.

4. The technology catalogue concept and its methodology

The Danish Energy Agency's (DEA's) technology catalogues aim to establish a level playing field for discussions and decisions related to energy planning and to provide transparency in long-term energy studies. Following this objective, DEA also aims for the data to be commonly accepted by all – or the most important – actors. In practice, the technology catalogues are currently distributed over eight types of technologies (as of April 2023):

- Generation of electricity and district heating (418 pages, 24 technologies)
- Heating installations (109 pages,
- Renewable fuel (335 pages, 22 technologies)
- Energy storage (234 pages, 12 technologies and group of technologies)
- Carbon capture, transport and storage (151 pages, 7 technologies)
- Industrial process heat (122 pages, 12 technologies)
- Energy transport (152 pages, 6 technologies and groups of technologies)
- Heavy-duty vehicles (80 pages, 3 groups of technologies)

For each type, a variety of individual technologies are included. The report on 'Generation of electricity and district heating' currently contains 24 different chapters/technologies, e.g., offshore wind, open cycle gas turbine and electric boilers. For each technology, the report includes a standard set of information: contact information for who developed the chapter, a qualitative description and a data sheet. The qualitative descriptions comprise the present state of the technology and future prospects, including assessments (or forecasts) of future technoeconomic data for the time horizons of 2020, 2025, 2030, 2040 and 2050. The technoeconomic data typically contain technical parameters (e.g., average unit size, outage percentage, technical lifetime, regulatory ability) and economic parameters (e.g., CAPEX and O&M). If relevant, the assessments also contain environmental impacts (e.g., emissions of SO_2, NO_x, and particles). As an example, the data for medium-sized (80 MW) generators producing heat and power and fuelled with wood chips include $16 + 13$ technical parameters (e.g., warm start-up time in hours), five environmental parameters (e.g., NOx emission in g per GJ fuel) and five financial parameters (e.g., fixed operations and maintenance cost in €/MW/year) (DEA, 2016, p142–143). For each of the parameters, the catalogue contains data for time horizons of 2015, 2020, 2030 and 2050 as well as uncertainty levels for 2020 and 2050. The quantitative data sheets, available in Excel files for easy access by users, supplement the qualitative description.

The quantitative descriptions and the data sheets are used in three ways. First, they are used in long-term scenarios for energy system planning in Denmark. Such front-end input (or technoeconomic assumptions) for energy system modelling and long-term scenarios can be considered one type of scenario: predictive forecasts (Börjeson, 2006). Second, the data are used in shorter-term decisions on heating and district heating at the municipal level. The data on district heating and the heating components are used in connection with the heating regulations and the municipal planning of district heating in Denmark if no project-specific data for similar cases are found. Third, the data can be used as a quantitative reference for discussions and policy-making on subsidies for newer technologies in energy and innovation policy mixes. In addition, the data and the methods behind the data have become internationally influential and utilised as a more detailed and updated alternative to projections generated in scholarly research (e.g., (Rubio-Domingo & Linares, 2021; Wiser, 2021)) and by international institutions, e.g., IEA and IRENA. As expressed by an experienced energy modeller in a consultancy:

> Interview A: "…they don't have the same depth as a Danish catalogue has in terms of the detail."

Based on the approach of the Danish Energy Agency, similar energy technology catalogues have been developed for the Nordic area by Nordic Energy Research (Kofoed-Wiuff, 2021) and for India in a governmental India-Denmark Energy Partnership (CEA & DEA, 2022). In this sense, the data of the technology catalogue and the processes behind it are a standardised part of the infrastructure of energy planning. As expressed in the foreword to the Indian Energy Technology Catalogue by the chairperson of the Central Electricity Authority Government of India: "*The technology catalogue may. be used as a standardised database comprising of inputs from across the Indian power sector*" (CEA & DEA, 2022). Furthermore, in the same foreword: "*The … catalogue has been reviewed by key stakeholders from the Indian power sector and Government institutions to ensure that the information is latest and according to Indian conditions*." This indicates that the approach of stakeholder inclusion is a part of this scalable infrastructure.

In the literature, other examples can also be found on catalogues of energy and climate technologies (e.g., Ariztia et al., 2023).

4.1. Organisation and actors

As the overall project owner and sponsor, the Danish Energy Agency (DEA) is responsible for the general framework for the technology catalogues and the processes involved in developing the data. DEA provides staff and an annual budget for the activities.

On behalf of the DEA, a steering committee is responsible for the general decisions that prioritise resources allocation to the technology catalogue processes within the budget provided by the DEA. The steering committee consists of Heads of Divisions from DEA.

A reference group ensures that the technology descriptions remain relevant for the users and other target audiences. The reference group currently meets annually and has 23 members[1] representing experts and key stakeholders from industry associations and advocacy groups, companies, universities and other public institutions, as well as other users of the technology catalogues. When experts from advocacy groups are involved, DEA aims to ensure a balance between different interests.

A project group or working group is responsible for project management, including the maintenance and development of the technology catalogue and updates on the latest developments of the relevant technologies. The group also serves as the secretariat for the steering committee and the reference group. The project group consists of DEA staff – mostly energy analysts and others with expertise in energy technologies. For each work on technology, one analyst supplied by the team is responsible for collaborating with a technology expert (a consultant, see below) to publish or update the data. The staff of the DEA working with the technology catalogues do not work full-time on this project but estimate that they use 25–33% of their time on average.

External consultants with expertise in specific technology areas are hired to write background reports and data sheets in each case. Mainly, these consultants are selected through open and competitive tendering. However, the original consultant is often chosen to update existing datasets. Consultants can also be employees within the industry.

Users and other target groups include various firms, organisations, and individual experts. Most significant are Danish energy modellers at the Danish Transmission System Operator (TSO) Energinet, at consultancies specialising in energy system modelling and at universities and other research organisations. As mentioned above, the data are also used in municipal planning on district and individual heating. The descriptions and the data sheets are publicly available on the web pages of the DEA. No systematic analyses of national and international users are available. Nevertheless, the DEA has tracked web page traffic for approximately four years and found that its data were downloaded in more than 100 countries.

DEA maintains a mailing list of potential wider stakeholders (including consultants, users, and interested individuals). The list is updated on a running basis in two ways. Consultants or DEA staff suggest additional stakeholders and experts, and all interested individuals can enlist through a function on the DEA's homepage. The DEA maintains a matrix structure of the gross list of all stakeholders and technologies.

Stakeholders with special interests or stakes in particular technologies or chapters can be targeted more directly. Such groups are referred to as technology-specific reference groups.

4.2. The technology catalogue process

The process used for establishing the datasets is described in a set of guidelines developed by the Danish Energy Agency. It includes traditional foresight methods such as defining the technology, finding and selecting experts and stakeholders, expert reports, extrapolations, stakeholder workshops, wider public consulting, and disseminating the results. The method usually involves seven steps. See Table 1.

The first step is the identification of the need for new datasets. This need can be generated by the emergence of new technologies or the updates of existing technologies. A gross list of potential needs is maintained by the DEA and discussed with the reference group members. In January 2022, 23 technologies appeared on that list.

The next step is prioritisation among identified needs and the selection of projects. The DEA project group selects projects based on internal discussions within the DEA and a discussion with the reference group. In 2021, updates for seven technologies were finalised, and five were ongoing. The DEA project group is estimated to spend approximately 100 h on each technology/update on average. The third step is selecting a consultant to carry out the report for the chosen/prioritised technology. Consultants are selected through a tendering process where a few consultants (persons, institutions or companies) are invited to bid. For updates of existing datasets, the original consultant is often asked to do the updates; however, they are still hired through tendering. The fourth step is writing a draft text of the qualitative description and the datasheets. Earlier, the timeframe/contract for the consultant was on the order of 75–100 h. With increasing complexity and requirements, today's typical timeframe is 100–150 h, on average, depending on the scope of the technology in question. The draft report is typically written within 1–1½ months. During this phase, more time can be spent on technologies with interest groups with conflicting viewpoints. The qualitative description and datasheet for Offshore Wind contain 25 references; typically, company information (e.g., Siemens, Enercon), reports from research organisations (e.g., NREL, DTU), and international organisations (e.g., IEA, IRENA). The reference list in this chapter contains no references to traditional peer-reviewed publications. In contrast, approximately 1/3 of the 62 references for Hydrogen Storage are papers in international journals (e.g., Int. J. Hydrogen Energy). The fifth step is an iterative process of commenting on the drafts. This is done in three ways. The project group interacts with the consultant while drafting the text, and the final draft receives comments from the DEA staff. The draft is then

[1] As of January 2023.

Table 1
Overview of steps in the Technology Catalogue process and the key tensions and dilemmas.

#	Step/Phase	Involved actors	Tensions and dilemmas
1	Identification of needs for new datasets	Reference group, steering group	Fast technological development in some areas
2	Prioritisation among identified needs and selection of projects	Reference group, steering group	A limited annual budget
3	Selecting of consultant	Project group	Overoptimism of experts
4	Writing draft text and data sheets	Consultant	Resource constraints Securing legitimation/references
5	Iterative commenting on draft text and datasheet		Independent experts have limited resources Professional stakeholder representatives have resources
5a	Comments from the DEA - internal	Project group	to promote their interests
5b	Written comments from invited stakeholders and experts	Users and target groups, wider stakeholders	Biases among stakeholders Overoptimism of experts
5c	Discussion at a Deep Dive Workshop	Consultant, project group, technology-specific reference groups	
6	Revision of text and data sheet based on internal and external inputs	Consultant, project group	
7	Publication	Wider stakeholders/users	Limited interest among the wider public

submitted to specially invited stakeholders and experts in addition to a long list of the wider stakeholders from the list that the project group maintains. The email list of stakeholders contains several hundred addresses. The DEA typically receives comments from between 5 and 10 stakeholders for each consultation. However, this number varies a lot. For some heating technologies, more than 50 stakeholders submit comments. This broader call for comments does not follow the formal and regulated process for public hearings, as is typically used in connection to governmental legislation, municipal planning and similar events inviting public feedback. In addition, a 'Deep Dive Workshop' is sometimes arranged with invited stakeholders and experts if deemed relevant by the project group. For example, for a workshop on 'hydrogen production via electrolysis', 25 experts and stakeholders were invited. Initially, the Deep Dive Workshops were largely mandatory, but more recently, they have been replaced by a written process (Interview R). The text and data sheets are revised based on the inputs in the sixth step. The consultant adjusts the draft in dialogue with the DEA staff based on an overview of all comments. Finally, the text and datasheets are published on the DEA's web pages.

Table 1 gives an overview of the actors involved in each step or phase in the development of the technology catalogues. Furthermore, Table 1 contains the most important tensions and dilemmas that our study has revealed, and these are explained further in Section 5 of this paper.

5. Findings and discussion

5.1. Identification and involvement of experts and stakeholders

As mentioned in the introduction, more attention is needed to identify participatory processes in energy system modelling and on stakeholder groups' representativeness (McGookin et al., 2021). The process behind the Technology Catalogue is indeed participatory. However, it is not a wide participatory process with a focus on the cultural, ethnic, racial, gender and socioeconomic diversity of the participants. Wider civic inclusion is beneficial and even required in debating the long-term development of the energy system. Individual citizens can have opinions on energy consumers' behaviour or the challenges of heating buildings in 2050. However, technology catalogues contain detailed information and expectations about the future. As one of the interviewees formulated it:

> Interview M: "I'm not sure that Mr. and Mrs. Denmark is looking in the technology catalogues … I think they would find it kind of nerdy".

In this case, stakeholder inclusion focuses on expertise and stakeholder representation and not on wide civic participation. There is a broad and somewhat unrealistic intention for participatory processes of recognising and involving "all the active users". Being a stakeholder is defined via activity in the technological field rather than by any other criteria, such as being impacted by the technology in question. Hence, in some cases, the DEA uses the stakeholder concept rather strategically – choose people who can practically contribute to the technology catalogues and who would complain if not included. Using an earlier stakeholder typology (Andersen et al., 2021), we find three types of stakeholders involved in the processes. The most dominant are stakeholder representatives: professionals employed by or representing organised interests. That comprises individual firms, industry associations, consumer organisations, lobby organisations, municipal organisations, and others. The representatives often have deep and extensive expertise in the relevant technology and its use. At the same time, they lobby for particular interests. It is part of their professional job to participate in reference groups and contribute to such processes. The second type is individual—and in most cases independent—experts. Experts are typically university professors or staff at research organisations. A third type is 'remarkable people', individuals with much experience, deep knowledge, and personal integrity. Only a few such remarkable people are involved. They might see their contribution as a personal obligation, and they allocate time to contribute if they find it needed. As an interviewee formulated it:

Interview R: "It was typically companies or organisations sending replies. I believe we had a handful of private individuals who [were participating] for the sake of their own interest, but it was not something common. The far majority are organisations, companies, research institutions or even universities".

This leads to the observation that the processes behind the technology catalogues favour - and rely on - technocratic evidence making. In Section 5.5, we will further examine this.

5.2. *Time and resources*

Being a stakeholder is also conditioned by the time available and rewards from doing, for example, a review. It is not straightforward that all stakeholders have the same amount of time to put into pro bono review work, for example. This can affect the resulting data in the technology catalogue and its acceptance. In many traditional scenario processes, stakeholders are only required to allocate time to participate in the workshops. In the case of the technology catalogue process, the involved stakeholders also need to do more time-consuming preparation. In particular, the invited experts have difficulties allocating as much time as they might need:

Interview M: "I think that a lot of people don't have the time to comment on it in detail."

Interview A: "To be honest…it's also busy times, and if you are not particularly involved in that specific technology…I find it difficult to commit the time."

On the other hand, we find that stakeholder representatives and remarkable people have fewer challenges in allocating time. Part of a stakeholder representative's job is to express their organisations' views and seek influence. Other concerns drive the few independent agents engaged in the process: sheer interest in the technology and overall values of helping the sustainable transition and society more generally. An interviewee reported this about one of the highly engaged individuals:

Interview R: "He's giving us good input…whenever he can, and he's very engaging."

Time and money are two essential boundary conditions of the whole catalogue process. It takes time (and salary) to review and produce catalogues, and only some of this work is reimbursed. Pro bono contributions (paid by the organisations of the persons involved or individuals themselves) shape the catalogues and might create a bias problem. Those who suggest that certain updates or new technologies be considered first might also have a stake in responding to and supporting their own technology. The time spent is influenced by the knowledge held: the more one knows about a topic, the more time one spends on that topic; the less one knows, the more one becomes a generalist who does not even try to comment on substance.

5.3. *Biases and overoptimism*

The interviews found several examples of biases due to the overoptimism of experts and stakeholders. Those "drawn into" a technological field want to present the costs and performance of that field in a way that supports the continuation of that field.

Interview M: "The problem is that [those] who know most about the technology are often the people who like companies… selling this technology or developing this technology. So they are completely in love with this technology."

Interview A: "The main challenge is that those people that know about these technologies also typically have an interest in the same technology. … They also have an interest in showing the technology in a good light usually and maybe being a bit optimistic about the cost, being a bit overoptimistic about the performance."

Such overoptimistic experts can underestimate practical difficulties and estimate lower cost in advocating for this particular technology. However, stakeholder representatives, who also advocate for a specific technology, are optimistic about the technology in the long term but claim that costs will be higher and performance lower in the short term to argue for sustained or even increased public subsidies for that technology.

Interview A: "We have also in some rare cases seen the other way around that there have been some stakeholders which gave suspiciously high prices for some technologies which indicated maybe a request that…or indication if they could show these high costs may be, (subsidy) levels would also be higher. …That is, in my opinion, the most tricky part in it…to find unbiased information."

These two biases are different in nature. The overoptimism of experts is probably unconscious, whereas stakeholder representatives' bias towards the interests of their own (lobby) organisations is probably very conscious. These biases are dealt with or mitigated by the DEA in at least three ways: during discussions in the deep-dive workshops, by presenting provocative data to stakeholders, and by a bilateral meeting with technology manufacturers that are thought not to disclose the newest data for rapidly emerging technologies.

Interview R: "We would then use the deep dive workshop as a method to weed out the worst inconsistencies."

Interview R: "For example. we have based this on these sources and that would definitely provoke some stakeholders who were otherwise keeping their cards close to the chest to say no."

These mitigation strategies differ slightly from those reported in a recent review of expert biases (Bonaccorsi et al., 2020). This difference is probably because not only experts but also wider stakeholder groupings are involved. It must be added that in a small country such as Denmark, with a relatively small population of experts and stakeholders affiliated with each technology, most of the involved persons know – or know of – each other and of their individual preferences and interests. In this sense, there is a high level of transparency in stakeholders' interests and viewpoints. Furthermore, due to the low level of power distance in society, it might be relatively easy for stakeholders to establish direct dialogue.

5.4. Rapid technological change and scenario dependency

The quick pace and unpredictable nature of innovation keep the catalogues in a constant state of development, especially with technologies that are seen as developing rapidly (e.g., PVs and hydrogen storage, and as opposed to established technologies such as gas-fired boilers and district heating, which we could sample for comparison). One of the interviewees thought that rapid updates were the greatest challenge for the technology catalogues:

> Interview M: "We have superfast development on the costs of technologies."

The speed of technological development also affects the sources of information. For more slowly developing technologies, robust data can be found in the academic literature. For fast-changing technologies, industry sources (e.g., manufacturers, developers, consultants) have the most up-to-date and thus most relevant information. In either case, the catalogues seem to be 'performing' (Birch, 2017; Silvast, 2017) a consensus on the projected costs and data for specific technologies, producing a shared reference point for actors who establish what data are trustworthy.

Furthermore, much knowledge is not formal or explicit and can only be shared through direct dialogue.

> Interview K: "A lot of the knowledge about these technologies is kind of tacit knowledge, and it lies with the companies. It's not necessarily written [down]."

> Interview K: "You need to find some information which is very industry-specific, and information might also change a lot from today and just two years ago…. You will rarely find it in a published paper or something like that. It's just getting too old."

The term 'tacit' was used by one of the interviewees. The use of this term probably does not strictly follow the definition in the literature (e.g., Polanyi, 1966; Nonaka & Takeuchi, 1995). The interviews showed two dimensions of the 'tacit' quality of some contributions from experts and stakeholders. First, the shared knowledge is tacit in the meaning used widely in the literature; namely, it is not codified but based on company experts' personal, experience-based assessment, their access to the newest insights and probably also their intuition. Second, some of the dialogue and shared information is based on a firm's internal and confidential knowledge of state-of-the-art technology and on their plans for future developments. In both cases, there needs to be mutual trust between the actors. The project group must trust noncodified knowledge provided by experts in firms, and firm representatives must trust that strictly confidential background information is not published.

The DEA does not apply the European Union's concept of technology readiness levels (TRLs) (European Commission &, 2015) but uses a 4-stage classification of the relevant technologies according to how fast they change. Even then, the DEA is limited by a fixed annual budget to update descriptions and data sheets. The reference group is involved in prioritising which technology updates are needed.

It is well known to most actors that the rate of innovation, measured as development in technoeconomic data, depends on the market's growth. This is often expressed as learning curves. A learning rate (or progress ratio) is included in the technoeconomic data for some technologies. A key question then concerns factors outside market development.

> Interview K: "We have these high prices of raw materials, which can totally erode some of the assumptions that we would use in the traditional learning curve approach. And the ceilings in terms of availability of raw materials. And some other market dynamics that the learning curves do not take into account."

Hence, in addition to the challenge of rapid technological change, the current and projected technoeconomic data for energy technologies are also affected by changes in the strategic environment. Short-term projections are affected by the availability and cost of raw materials and components in the global market. At the time of this study, the COVID-19 situation and the war in Ukraine were among the most significant issues. In the longer term, factors such as the availability of rare earth materials and key components could affect the projections. Localisation of production, local salary levels, shipping rates and other issues related to global supply chains are also important issues. In this sense, long-term projections of technoeconomic data depend on the development in the global macro environment or scenarios for this development.

It seems clearly necessary for energy planning to analyse how the long-term assessment of technoeconomic data is scenario dependent. Furthermore, potential biases must be managed, especially those generated by the correspondence between the most up-to-date knowledge on some technologies and the tacit knowledge within the companies developing, producing and installing these technologies.

5.5. Different perspectives and understandings of scenarios

Involved actors and stakeholders have at least four understandings and uses of the term 'scenario'.

- First, each technology catalogue can be perceived as a scenario for that particular technology. Other inputs, such as forecasts of oil and natural gas prices – price scenarios – published by the International Energy Agency are also included in this type of scenario: a 'predictive forecast' (Börjeson, 2006).
- Second, scenarios are understood as ways to arrive at a certain future, e.g., a carbon-neutral energy system by 2050. For the Danish Energy Agency, scenarios are "*technically consistent models of the future energy supply, including transport, which meet specified political targets*" (Danish Energy Agency, 2013, 2014). Such scenarios can be affected by national policy-making. This understanding reflects what Börjeson et al. label as the 'normative transformative' type of scenario (Börjeson, 2006).
- Third, modellers often perceive parameter variations in their models as scenarios.
- Fourth, scenarios can be understood in the global macro environment for the (Danish) energy system by 2050 outside the influence of national policy-making, i.e., the 'explorative external' type of scenario (Börjeson, 2006).

This observation raises the need to create a common language among stakeholders and, in particular, to ensure that the terminology is understood by the users, policy-makers and wider public. This is especially true for those who are basing their discussions of long-term energy policy on the output from the technology catalogues and on energy system scenarios that use catalogue data.

5.6. Technocracy

In Section 2.5, we mentioned the question of technocratic versus citizen-participatory processes and the dilemma, that public engagement sometimes is merely a "therapeutic exercise". The technology catalogues favour – and rely on – technocratic evidence-making. Discussions are meant to be held at the level of data and methods, including assumptions on the plausibility of the projected cost and other data. We found, that such technocratic evidence making at data level, provides a levelled platform for discussing the results of modelling among modellers and for debating the future energy system among citizens and politicians.

> Interview M: "The moment we are more or less all using the same data we can we can get above that discussion and to the next level of the discussion".

However, it is a fundamental assumption that there exists a 'correct' forecast of the data. It is not *only* a matter of a plausible and negotiated future (e.g., Selin, 2006).

> Interview M: "I think that (it) helps build this consensus in society. Of course, it's also dangerous because if the technology catalogue is completely wrong and we are all using that, and that is highly problematic. So it also puts a lot of obligation on the technology catalogue to actually be trustworthy so that we can all use the same resource".

Technocracy also implies a consensus based on 'proper' and 'transparent' data on costs and performance. As mentioned in Section 2.5 rules created by organisations, committees, and experts as well as standards and shared data pools are important features of technocracy. We found that the process around the technology catalogues is also a format or mechanism to share data among stakeholders – energy technocrats – in the Danish energy sector and, in particular, to facilitate a dialogue between stakeholders and the Danish Energy Agency.

> Interview A: "This is also an opportunity for stakeholders to have a dialogue with the Danish Energy Agency."

This observation also goes the other way. The process is a formal opportunity for the DEA and other key stakeholders to have a direct dialogue with chief technology officers – and other technology experts – from Danish and international companies. These experts have a very detailed knowledge of present technologies and the likely prospects of ongoing research, development, and demonstration projects.

> Interview A: "but also use it as a way… to get their attention and to take part in the exercise…. It does take some time, and it's super often [the case that] these are busy people."

Moreover, there is an attempt to "export" the technology catalogues themselves internationally, both the text and data that can be downloaded from the Danish Energy Agency's web pages, as well as the process of developing such a dataset, for other countries, such as India. Therefore, the catalogues become an objective of "technocratic internationalism". Among the indirect benefits of the technology catalogues is international awareness of particular Danish manufactured technologies.

> Interview M: "[The goal is,] in a way, to promote Danish technologies more, I think, because I think (we) know a lot of good things."

A prominent critique of this approach is that both data and, in particular, the processes creating the data might be difficult to transplant to other contexts differing in the characteristics of energy systems, industry and cost structures, and traditions for policy development.

In summary, we suggest that the literature on "technocratic internationalism" (Kaiser & Schot, 2015) is pertinent for understanding and framing technological and processual infrastructure, as well as the kind of knowledge and expertise that they embody, for long-term energy planning and discussions on pathways towards sustainable energy systems. Furthermore, we see a need for more research on such technocratic processes across different national contexts and energy systems.

6. Conclusion and perspectives

This paper addressed an overarching research question on the nature and quality of the contributions of experts, stakeholders, and the wider public who provide detailed technoeconomic input to scenario analyses. We focused on those inputs that were applied when examining and making policy decisions on green transitions and policies around science, technology, and innovation.

We examined this question in a particular and new case: stakeholder inclusion in establishing technoeconomic inputs for energy scenario planning in Denmark. This inquiry led to several original contributions, which we now summarise.

In general terms, our results suggest that more attention should be given to how to mitigate the desirability biases produced by the engaged stakeholders, how to engage independent experts with limited resources, and how to handle a potential overrepresentation of professional stakeholder representatives and industry lobbyists in the process. This brings us to three particular findings.

First, our study contributes to a better understanding of how the inclusion of experts and stakeholders in the front-end inputs for energy models and scenarios aligns expectations and builds shared understandings and acceptance of detailed technoeconomic data. These aligned expectations establish a level playing field for wider public discussions on visions for the future in general and for future energy systems in particular. This is relevant when mission-oriented energy and STI policies require a coordinated, intensive, and long-term interaction between policy-makers, scientists, societal stakeholders and the wider public.

Second, the study demonstrates a pragmatic approach to stakeholder inclusion in contexts – such as developing the technology catalogues– where limited resources are available and only a small number of actors are available for consultation. It seems almost impossible to apply more advanced approaches (e.g., Delphi approaches or expert elicitations that were not studied in this paper) for the majority of technologies, complexity of data, and frequency of updates needed in the case of the Danish technology catalogues. A complete analysis of all factors affecting the future cost and performance of an energy technology across several scenarios is not possible, and this calls for pragmatic solutions.

However, there is still a need for further research and new knowledge to develop the catalogues themselves. Processes must be developed to include the qualitative approaches of global macroscenarios (explorative external scenarios (Börjeson, 2006)) and national scenarios to reach the political goals of 2050 (normative transformative scenarios (Börjeson, 2006)) with the quantitative approach of learning curves. This establishes the scenario dependency of the projected technoeconomic data. These analyses should ideally comprise a complete analysis of all factors affecting the future cost and performance of energy technology across several scenarios determined by anticipated developments and events in the global macroenvironment. The analyses should, again ideally, include combinations of quantitative (e.g., learning curves) and qualitative (expert and stakeholder assessments) approaches. However, future research should focus on approaches that are realizable within a normal policy context of resource constraints.

Third, we find that the concept of technocracy can bring useful insights for analysing the DEA technology catalogues and understanding their role and limitations in decision-making. Like technocracy in general, technology catalogues are built on the idea that energy transitions should be pursued by establishing a shared pool of data, including standardised methods for its collection, which then sidesteps the need to open up these data every time, for example, to political discourse. In this sense, the catalogues build a whole data infrastructure of their own but are also a basis upon which scenarios for energy transitions can be debated nationally as well as internationally. However, as the literature has shown, technocratic expertise also shapes the understanding of STI policies (Schot & Steinmueller, 2018), and there is a risk that technocratic expertise might also limit the technology catalogue-building process. Technocracy and implied positivism are often criticised and practically neglected models of futures studies (Tapio & Hietanen, 2002) and public participation more generally (Chilvers & Kearnes, 2020). Nevertheless, the use of these models to generate trustworthy data for debate and decision-making is still frequent, with wide-ranging potential impacts. We argue, therefore, for more research on such technocratic processes across different national contexts and energy systems.

The small number of interviewees is a limitation to this study but was inevitable given the short duration of our project (which lasted only six months). However, the interviewees had extensive experience, and their selection covered a variety of actors, including the development, administration and use of the technology catalogues. Hence, although not representative of all energy experts in Denmark or even all stakeholders of technology catalogues, the interview material has allowed us to gather rich and diverse information on the working processes around technology catalogues, including their many potentials, rationales, and limitations.

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.

Acknowledgement

An earlier version of this paper was presented at the Eu-SPRI 2022 conference: Challenging Science and Innovation Policy. We are grateful for the comments from the discussant, Matthias Weber, at that conference. We are also grateful for comments and suggestions from three anonymous reviewers.

References

Åkerman, M., et al. (2020). Expertise and its tensions. *Science and Technology Studies, 33*(2), 2–9. https://doi.org/10.23987/STS.91391

Andersen, P. D., Hansen, M., & Selin, C. (2021). Stakeholder Inclusion in Scenario planning—A review of European projects. In *Technological Forecasting and Social Change, 169*. Elsevier Inc.. https://doi.org/10.1016/j.techfore.2021.120802

Andersen, P. D., & Rasmussen, L. B. (2014). The impact of national traditions and cultures on national foresight processes. *Futures, 59*. https://doi.org/10.1016/j.futures.2014.01.013

Ariztia, T., Bravo, A., & Nuñez, I. (2023). Baroque tools for climate action. What do we learn from a catalogue of local technologies? *Tapuya: Latin American Science, Technology and Society, 6*(1). https://doi.org/10.1080/25729861.2022.2141015

Bizikova, L., Nijnik, M., & Kluvankova-Oravska, T. (2012). Sustaining multifunctional forestry through the developing of social capital and promoting communities'. *Small-Scale Forestry, 11*, 301–319. https://doi.org/10.1007/s11842-011-9185-8

Bonaccorsi, A., Apreda, R., & Fantoni, G. (2020). Expert Biases in Technology Foresight. Why they are a Problem and How to Mitigate them. In *Technological Forecasting and Social Change, 151*. Elsevier,. https://doi.org/10.1016/j.techfore.2019.119855

Börjeson, L., et al. (2006). Scenario types and techniques: towards a user's guide. *Futures, 38*(7), 723–739. https://doi.org/10.1016/j.futures.2005.12.002

Cairns, G., et al. (2013). Scenario Method and Stakeholder Engagement: Critical Reflections on a Climate Change Scenarios Case Study. In *Technological Forecasting and Social Change, 80* pp. 1–10). Elsevier Inc.,. https://doi.org/10.1016/j.techfore.2012.08.005

Carlsson, J., et al. (2015). Combining Scientific and Stakeholder Knowledge in Future Scenario Development — A Forest Landscape Case Study in Northern Sweden. In *Forest Policy and Economics, 61* pp. 122–134). Elsevier B.V.,. https://doi.org/10.1016/j.forpol.2015.08.008

CEA and DEA (2022) *Indian Technology Catalogue 2022. Generation and Storage of Electricity* . Available at: ⟨https://coe-osw.org/indian-technology-catalogue-on-generation-and-storage-of-electricity/⟩.

Celiktas, M. S., & Kocar, G. (2010). From potential forecast to foresight of Turkey's renewable energy with Delphi approach. In *Energy, 35* pp. 1973–1980). Elsevier Ltd,. https://doi.org/10.1016/j.energy.2010.01.012

Celiktas, M. S., & Kocar, G. (2012). 'Foresight analysis of wind power in Turkey'. *International Journal of Energy Research, 36*, 10.1002/e.

Chilvers, J. and Kearnes, M. (2020) *Remaking Participation in Science and Democracy*, *Science Technology and Human Values.* doi: 10.1177/0162243919850885.

Chilvers, J., Pallett, H., & Hargreaves, T. (2018). 'Ecologies of participation in socio-technical change: The case of energy system transitions'. *Energy Research & Social Science, 42*, 199–210.

Colvin, R. M., Witt, G. B., & Lacey, J. (2016). Approaches to identifying stakeholders in environmental management: Insights from practitioners to go beyond the "usual suspects. In *Land Use Policy, 52* pp. 266–276). Elsevier Ltd. https://doi.org/10.1016/j.landusepol.2015.12.032

Danish Energy Agency (2013) Energy scenarios for 2020, 2035 and 2050. Available at: ⟨https://ens.dk/sites/ens.dk/files/Analyser/energiscenarier_uk.pdf⟩.

Danish Energy Agency (2014) *Energiscenarier frem mod 2020, 2035 og 2050 (Energy scenarios towards 2020, 2035, and 2050)*. Available at: ⟨https://ens.dk/sites/ens.dk/files/EnergiKlimapolitik/energiscenarier_-_analyse_2014_web.pdf⟩.

DEA (2016) Technology Data. Generation of Electricity and District heating. Copenhagen. Available at: ⟨https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and⟩.

European Commission (2015) Work Programme 2014 – 2015, European Commission Decision. Available at: ⟨https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-ga_en.pdf⟩.

Fischer, A. R. H., et al. (2014). Expert involvement in policy development: A systematic review of current practice. *Science and Public Policy, 41*(3), 332–343. https://doi.org/10.1093/scipol/sct062

Fodstad, M., et al. (2022). Next frontiers in energy system modelling: A review on challenges and the state of the art. In *Renewable and Sustainable Energy Reviews, 160*. Elsevier Ltd,. https://doi.org/10.1016/j.rser.2022.112246

Freeman, R. E., et al. (2010). *Stakeholder theory: The state of the art.* Cambridge: Cambridge University Press.

Frewer, L. J., et al. (2011). The use of Delphi methodology in agrifood policy development: Some lessons learned. In *Technological Forecasting and Social Change, 78* pp. 1514–1525). Elsevier Inc.,. https://doi.org/10.1016/j.techfore.2011.05.005

Gramberger, M., et al. (2014). Stakeholder integrated research (STIR): a new approach tested in climate change adaptation research. *Climatic Change, 128*(3–4), 201–214. https://doi.org/10.1007/s10584-014-1225-x

van der Heiden, K. (1996). *Scenarios: the art of Strategic Conversation.* Chichester: Wiley,.

Henrich-Franke, C. (2018). Comparing cultures of expert regulation: Governing cross-border Infrastructures. *Contemporary European History, 27*(2), 280–300. https://doi.org/10.1017/S0960777318000139

Hofstede, G., & Minkov, M. (2010). Long- versus short-term orientation: new perspectives. *Asia Pacific Business Review, 16*(4), 493–504. https://doi.org/10.1080/13602381003637609

Junginger, M., van Sark, W., & Faaij, A. (Eds.). (2010). *Technological Learning in the Energy Sector*. Cheltenham, UK. Northhamton, MA, USA: Edward Elgar.

Kaiser, W., & Schot, J. (2014). Experts, Cartels, and International OrganiZations. *Writing the Rules for Europe*. Palgrave Macmillan,. https://doi.org/10.1057/9781137314406

Karger, C. R. (2013). Citizen Scenarios for the Future of Personalized Medicine: A Participatory Scenario Process in Germany. *International Journal of Interdisciplinary Social and Community Studies, 7*(2).

Kofoed-Wiuff, A. et al. (2021) *Technology Catalogue*. Oslo.

Kowalski, K., et al. (2009). Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. In *European Journal of Operational Research, 197* pp. 1063–1074). Elsevier B.V.,. https://doi.org/10.1016/j.ejor.2007.12.049

Linstone, H.A. and Turoff, M. (1975) *The Delphi Method. Techniques and Applications* . Edited by H.A. Linstone and M. Turoff. Available at: ⟨https://web.njit.edu/~turoff/pubs/delphibook/delphibook.pdf⟩.

Makkonen, M., Hujala, T., & Uusivuori, J. (2016). Policy experts' propensity to change their opinion along Delphi rounds. In *Technological Forecasting and Social Change, 109* pp. 61–68). Elsevier Inc.,. https://doi.org/10.1016/j.techfore.2016.05.020

Markmann, C., et al. (2021). Improving the question formulation in Delphi-like surveys: Analysis of the effects of abstract language and amount of information on response behavior. *Futures & Foresight Science, 3*(1), 1–20. https://doi.org/10.1002/ffo2.56

McDowall, W. et al. (2014) *Reflecting on Scenarios*. Available at: ⟨http://www.ukerc.ac.uk/publications/ukerc-energy-systems-theme-reflecting-on-scenarios.html⟩.

McGookin, C., Ó Gallachóir, B., & Byrne, E. (2021). Participatory methods in energy system modelling and planning – A review. *Renewable and Sustainable Energy Reviews, 151*(November 2020). https://doi.org/10.1016/j.rser.2021.111504

Miles, S. (2017). Stakeholder theory classification: a theoretical and empirical evaluation of definitions. *Journal of Business Ethics*, 437–459. https://doi.org/10.1007/s10551-015-2741-y

Nonaka, I., & Takeuchi, H. (1995). *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation.* Oxford University Press.

Palacios-agundez, I., et al. (2013). The Relevance of Local Participatory Scenario Planning for Ecosystem Management Policies in the Basque Country, Northern Spain'. *Ecological Economics, 18*(3).

Polanyi, M. (1966). *The tacit dimension.* London: Routledge.

Ramirez, R., & Wilkingson, A. (2016). *Strategic Reframing: The Oxford Scenario Planning Approach.* Oxford: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198745693.001.0001

Rubio-Domingo, G., & Linares, P. (2021). The future investment costs of offshore wind: An estimation based on auction results. In *Renewable and Sustainable Energy Reviews, 148*. Elsevier Ltd,. https://doi.org/10.1016/j.rser.2021.111324

Samadi, S. (2018). The experience curve theory and its application in the field of electricity generation technologies – A literature review. In *Renewable and Sustainable Energy Reviews, 82* pp. 2346–2364). Elsevier Ltd,. https://doi.org/10.1016/j.rser.2017.08.077

Schot, J., & Lagendijk, V. (2008). Technocratic internationalism in the interwar years: building Europe on motorways and electricity networks. *Journal of Modern European History, 6*(2), 196–217. https://doi.org/10.17104/1611-8944_2008_2_196

Schot, J., & Steinmueller, W. E. (2018). Three frames for innovation policy: R&D, systems of innovation and transformative change'. *Research Policy, 47*(9), 1554–1567. https://doi.org/10.1016/j.respol.2018.08.011

Selin, C. (2006). Trust and the illusive force of scenarios. *Futures, 38*(1), 1–14. https://doi.org/10.1016/j.futures.2005.04.001

Selin, C. (2011). Negotiating Plausibility: Intervening in the Future of Nanotechnology. *Science and Engineering Ethics, 17*(4), 723–737. https://doi.org/10.1007/s11948-011-9315-x

Sheppard, S. R. J., et al. (2011). Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. In *Futures, 43* pp. 400–412). Elsevier Ltd,. https://doi.org/10.1016/j.futures.2011.01.009

Sovacool, B. K., et al. (2020). Sociotechnical agendas: Reviewing future directions for energy and climate research. In *Energy Research and Social Science, 70*. Elsevier,. https://doi.org/10.1016/j.erss.2020.101617

Stirling, A. (2008). 'Opening Up and Closing Down. Power, Participation and Pluralism in the Social Appraisal of Technology'. *Science, Technology & Human Values, 33* (2), 262–294.

Tapio, P. (1996). 'From technocracy to participation? Positivist, realist and pragmatist paradigms applied to traffic and environmental policy futures research in Finland'. *, Futures, 28*(5), 453–470. https://doi.org/10.1016/0016-3287(96)00019-5

Tapio, P., & Hietanen, O. (2002). Epistemology and public policy: Using a new typology to analyse the paradigm shift in Finnish transport futures studies. *Futures, 34* (7), 597–620. https://doi.org/10.1016/S0016-3287(02)00003-4

Tichy, G. (2004). The over-optimism among experts in assessment and foresight. *Technological Forecasting and Social Change, 71*(4), 341–363. https://doi.org/10.1016/j.techfore.2004.01.003

Togeby, L. et al. (2003) *Power and Democracy in Denmark. Conclusions*. Aarhus: Magtudredningen. Available at: 〈http://en.unipress.dk/media/2910259/87–7934-850–5_power_and_democracy_in_denmark.pdf〉.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: heuristics and biases. *Science, 185*(4157), 1124–1131.

Upham, P., Carney, S., & Klapper, R. (2014). 'Scaffolding, software and scenarios: Applying Bruner ' s learning theory to energy scenario development with the public. In *Technological Forecasting & Social Change, 81* pp. 131–142). Elsevier Inc.,. https://doi.org/10.1016/j.techfore.2013.05.001

Venturini, G., Hansen, M., & Andersen, P. D. (2019). Linking narratives and energy system modelling in transport scenarios: A participatory perspective from Denmark. *Energy Research and Social Science*, 204–220. https://doi.org/10.1016/j.erss.2019.01.019

Verdolini, E., et al. (2018). 'The future prospects of energy technologies: insights from expert elicitations. *Review of Environmental Economics and Policy, 12*(1), 133–153. https://doi.org/10.1093/reep/rex028

Videira, N., Antunes, P., & Santos, R. (2009). Scoping river basin management issues with participatory modelling: The Baixo Guadiana experience. *Ecological Economics*, 965–978. https://doi.org/10.1016/j.ecolecon.2008.11.008

Volkery, A., et al. (2008). Your vision or my model? Lessons from participatory land use scenario development on a European scale. *Systemic Practice and Action Research, 21*(6), 459–477. https://doi.org/10.1007/s11213-008-9104-x

Winkler, J., & Moser, R. (2016). Biases in future-oriented Delphi studies: A cognitive perspective. *Technological Forecasting and Social Change*, 63–76. https://doi.org/10.1016/j.techfore.2016.01.021

Wiser, R., et al. (2016). 'Expert elicitation survey on future wind energy costs'. *Nature Energy*. https://doi.org/10.1038/NENERGY.2016.135

Wiser, R., et al. (2021). 'Expert elicitation survey predicts 37% to 49% declines in wind energy costs by 2050′. *Nature Energy, 6*, 555–565. 〈https://emp.lbl.gov/publications/expert-elicitation-survey-predicts-37〉.