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a semi-structured literature review

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REVIEW

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The development of social science research on smart grids: a semi-structured literature review

A.-R. Kojonsaari* and J. Palm

Abstract

Background Smart technologies, such as smart grids, are emerging as indispensable aspects of an energy transformation and come with hopes of more sustainable resource use. A substantial amount of research has examined the technical, economic, and environmental implications of these technologies, but less attention has been paid to their social aspects. For the smart grid projects to be realised, studies that include the actors who are supposed to implement the visions are needed.

Results A semi-structured literature review was conducted to investigate the state of social science literature on smart grids and identify the main research avenues and research gaps by addressing a broad research question: "What kind of knowledge is produced in social science studies on smart grids?" We retrieved peer-reviewed articles from the Scopus and Web of Science (WoS) databases up until 2022 and mapped them in terms of features such as topic, design, method, and theory.

Conclusions We found that knowledge development in social science studies on smart grids followed a pattern where most research focused on visions; professionals and users; and smart technologies in homes with a geographical focus on Europe or the USA. We identified six research gaps related to an overly vague definition of the smart grid and the need to include more diverse actors and geographical places to advance our understanding of the smart grid. There is also a lack of studies relating to energy democracy, the resistance of smart grids and the centralised–decentralised nexus of the smart grid. These less studied areas can bring in new knowledge that enhances a deployment of a smart grids supporting not only technological development, but also society and users.

Keywords Smart grids, Social science, Semi-structured literature review

Background

The European Union's (EU's) Green Deal states that by 2030 greenhouse gas (GHG) emissions should be reduced by at least 50%, and by 2050 there should be no net GHG emissions [1]. The energy sector is central to this transformation, and relevant measures will include increases in the electrification of infrastructure, such as transportation, renewable electricity generation, and penetration of information technology (IT), which allows for more flexible and less hierarchical infrastructure management [2–6]. This development will require the gradual evolution of distribution networks from passive to active and the development of so-called smart grids [7]. Smart and innovative technologies will be important facilitators of this transition.

Earlier smart grid research has commonly used the European Commission's definition of the smart grid as "an electricity network that can intelligently integrate

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the actions of all users connected to it … in order to efficiently deliver sustainable, economic and secure electricity supplies" [8]. Many smart grid definitions are characterised by the notions of two-way information flows and automation. Raimi and Carrico [9], for example, described smart grid technology as follows: "Smart grids are modernized electrical grids that use information and communications technology to gather and act on information, such as information about the behaviours of electricity providers and consumers" (p. 73). Many studies do not explicitly define the smart grid, but imply that it is a distributed energy system that enables grid-serving flexibility (e.g. [10–12]). Most definitions emphasise the technical aspects of connecting Information and Communications Technology (ICT) with the energy system, particularly the opportunities afforded by two-way information flow and automation. Earlier research has dealt with private costs in relation to smart grids, rather than the social costs, even if recent research has started to look into also social costs as a barrier for smart grids deployment [13]. Most definitions do not incorporate social aspects into technical descriptions or even include any people in them [14], even though a smart grid obviously has many social implications. Reinders et al. [15] state, for example, that social factors such as social acceptance are often considered uncertainties and therefore assessed on their own and seen as something separated from the smart grid technology. The smart grid discourse has traditionally overemphasised technology while overlooking social considerations and their incorporation into technocratic visions [16]. Lovell [17] observed that smart grids throughout history have had a problem when it comes to implementation, and their potential has even now not been fully realised. One reason for this lack of realisation is the decoupling between the social and the technical, where those who are supposed to implement these visions are not included in either the definition or the imagined futures.

State of the art of social implications

Although previously neglected, that the smart grid has many social implications is recognised by a growing body of literature [18], most of which emphasises its sociotechnical character [19]. Wolsink [20], for example, drew attention to the sociotechnical when defining the smart grid as "a sociotechnical network characterized by the active management of both information and energy flows, in order to control practices of distributed generation, storage, consumption and flexible demand" (p. 824). This definition recognises that a smart grid is constituted by a sociotechnical network, and this article will align to this definition. However, this rather new sociotechnical discourse brings in new questions and issues concerning the development of smart grids. For example, Verbong et al. [21] raised several critical questions, such as the following: "Despite these promises, it is unclear what 'smart grids' exactly constitute, how they should be implemented, and what their effect will be on the reliability and costs of the electricity system" [21]. Similarly, Skjølsvold [22] questioned how all the high ambitions for smart grid implementation will be achieved if attention remains chiefly on technical efforts. Kojonsaari and Palm [23] criticised the technocratic dominance of the decision-making process concerning the smart grid, emphasising the need to consider diverse perspectives and interests when developing any future smart grid. Skjølsvold and Lindkvist [24] suggested that "perhaps it is now time to seriously re-think whether the problem at hand is really a technological challenge in need of a social component" (p. 49). Expanding social science research on the smart grid, however, raises new questions and concerns, applying new perspectives to the field. This has spurred our interest in exploring this research in depth to see what issues have been addressed and what new knowledge and questions have been contributed. How has the social science perspective advanced our knowledge of the smart grid?

This article reviews the academic social science literature on smart grids to determine what kind of knowledge has been produced. The main research questions are the following: What issues have been in focus? Can any trends be discerned in this research? What has been overlooked, and which research gaps can be identified?

The article is organised as follows. Sect. "Methods" presents the methodological design and data collection methods. In Sect. "Results", we synthesise the data and analyse the trends and themes (e.g. geographical scope and theoretical aspects) identified in the dataset. Lastly, Sect. "Discussion" presents the conclusions, proposes avenues for future research and discusses the limitations of this study.

Methods

This article reviews the social science literature on smart grids, meaning that we are interested in earlier research on smart grids in relation to social processes, organisations and institutions. We wanted to discover how smart grids have been studied from a social science standpoint and what topics have been addressed, considering when, where, and in what ways this matters for the development of the field. We chose to focus on research on social aspects, hence no hypothesis was proposed; rather, the study method was designed to be exploratory and qualitative, as that best served our aims.

Broadly, literature reviews collect and synthesise existing research in a more or less systematic way [25]. A semi-structured review often looks at how research in a selected field has progressed over time [26]; this methodology was the best for our purposes, as we sought to tease out the overarching storylines in the data. Following Bryman's [27] method of incorporating some elements of a systematic review into a narrative review, a rather broad guiding research question was formulated: "What kind of knowledge is produced in social science studies of smart grids?" This question narrowed the scope enough but not too much as it allowed us to omit studies that were only technically oriented, while including studies addressing the technology–social science nexus. The review concentrated on knowledge development in research, combining the study of smart grids with analyses of social structures and relationships. This includes studies of interactions between the smart grid and households, such as how smart grids are envisioned, and material participation.

This review will outline trends in earlier research, while also identifying the research gaps and reflecting on them. A semi-structured method was found to be the most appropriate approach for addressing the research problem.

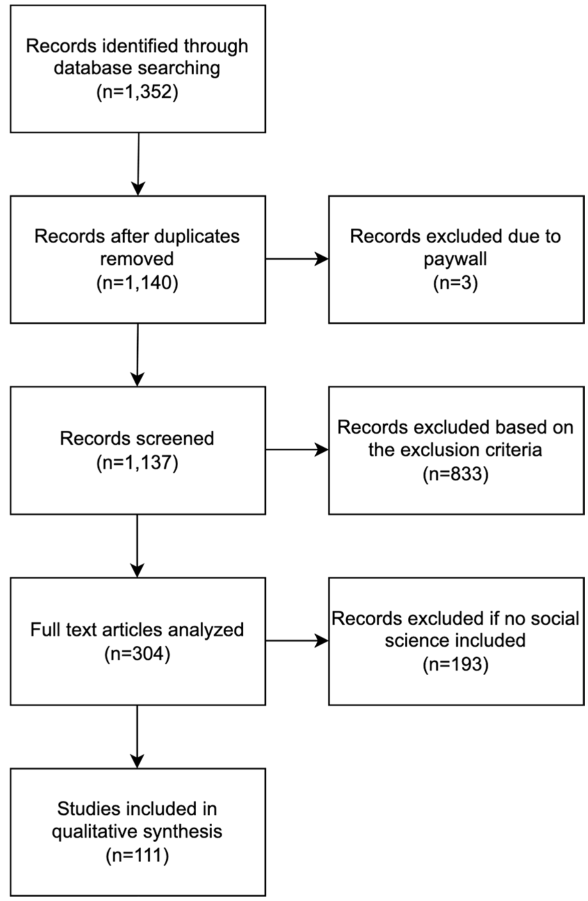

Fig. 1 The literature review workflow used to identify the 111 papers included in the review

Selection and exclusion of articles and quality criteria

We chose to limit the study to academic articles published in peer-reviewed journals. The articles were retrieved in May 2022 from two databases: Scopus and WoS. The search tools in the two databases are slightly different, thus we describe here our search process in detail. Scopus is a citation database from Elsevier for peer-reviewed literature, whereas WoS is a paid-accessed platform owned by Clarivate. Both have broad coverage [28] but cover slightly different publications, which rationalises including them both. There were, however, many overlaps as can be seen in Fig. 1 below. The search term used was "smart grid", in line with the overall purpose of the review. In Scopus, we searched for the term "smart grid" within "Article title, Abstract, Keywords". In hindsight, we should have chosen to search only within the abstract, since the search we used led to some of the results mentioning "smart grid" only as a keyword even when the article did not focus on smart grids. In addition, we limited the search to articles and reviews, including only social science and excluding all non-English-language material, leaving us with 859 results. The search tools in WoS allowed us to be more precise. In WoS, we also used the search term "smart grid" and limited the search to English-language articles or reviews. We chose the following categories: architecture, history, philosophy of science, public administration, sociology, communication, social issues, social sciences, interdisciplinary, urban studies, regional urban planning, environmental studies, international relations, geography, and multidisciplinary sciences. This was done to narrow the results to those within the scope of our study. We did not use a limiting time span, but included all years in the database and were left with 493 results.

In total, searching Scopus and WoS resulted in 1352 hits. After merging the results from the two databases and removing duplicates, 1140 hits remained. Three articles were excluded in this phase because they were paywalled, and this left 1137 records, which we subsequently screened. The workflow process is visualised in Fig. 1.

Initial screening was performed by reading the abstracts and sometimes the introductions of the articles, together with a quick scanning of the full article. If the records were solely technical or made no mention of social sciences, they were excluded. This screening resulted in a total of 304 relevant articles, which were further examined with respect to smart grids and social science. After reading and analysing the full-text versions of these articles, those that focused solely on technical issues and did not have a social science perspective were excluded. We were left with 111 articles.

We individually evaluated and subsequently excluded studies that were purely technical or techno-economically oriented and did not address any social aspects, such as those focusing on specific technologies (e.g. ZigBee), financial or environmental feasibility (without mentioning social aspects), business models (based on the technology, i.e. system performance, without mentioning social aspects), software-defined networking (SDN), buildings, encryption, optimisation, routing, technical and economic synergies, technical simulations, economic cost–benefit analysis, load control or other technical engineering subjects, algorithms, technology roadmapping, investment planning strategies, fuzzy logic, IT (e.g. performance analysis), system management, network problems, numerical simulations, law, modelling, and technical scenarios.

We are aware that the inductive nature of this review has its limitations. The task of finding the exclusion/inclusion balance involved considerable iteration when reading the papers and applying the exclusion criteria. While the semi-systematic nature of this review allowed us to go through all the papers, it became clear that the identified field overlaps with many others and that our scope would encompass studies from these fields as well. We therefore needed to find a common denominator for all the studies and chose "social aspects", i.e. studies that focus on the social aspects of the smart grid. As a result, teaching/education articles were excluded because they mainly dealt with engineering education, which was not within the scope of our review. We also excluded scenarios mainly discussing technological pathways for the future and not analysing social aspects per se.

Semi-structured analysis

The 111 selected articles were classified based on their themes. The study was exploratory in character, and the inductive analysis involved data-driven categories. It is recommended that literature reviews be organised in relation to, for example, concepts, themes, theories, or disciplines [29], and this was done in the analysis. According to Hammersley [30], even the simplest rule-following entails an element of interpretation, and we kept this in mind when exploring the material and searching for themes. The coding enabled us to see the data in a different light, giving us "tools to think with" [31] (p. 32). When rearranging the data, we also teased out certain narratives. Sovacool et al. [29] noted that a narrative review provides an exploratory evaluation of the literature or a subset of the literature in a particular area. We started to categorise the data according to different themes and geographical categories and tease out different themes or storylines. Our own observations were also included in one specific coding section.

Next, the results from the analysis will be presented and structured in relation to the themes found.

Results

In this section, we synthesise the records and present our results in relation to the overall trends and themes identified in the analysis (see also Additional file 1 for a classification and summary of key variables in the reviewed literature). Below, we first discuss the challenges the reviewed research faces in studying a smart grid that has not yet materialised, and then reflect on the geographical scope of the research. This is followed by a discussion of the reviewed studies' theoretical foci.

Studying an emerging but non-existent smart grid

The earliest study in our dataset is from 2012, and the field has since then continued to develop. The peek year for relevant publications was 2015. Four papers were published in 2013, eight in 2014, and 19 in 2015, after which there was a dip in the number of published articles (see Fig. 2).

The early years of social science research on smart grids were characterised by uncertainty regarding exactly how the pathway to a low-carbon electricity economy would unfold, where the variations between how different disciplines imagined smart grids were discussed: "Engineers, sociologists, and economists all emphasize different aspects of the emerging smart grid and its users" [32] (p. 283). One reason for this was that few smart grids had been established, opening up many potential development paths. The lack of existing smart grids available to study was also discussed as a barrier to research in the field:

> *Researching the societal implications of smart grids faces similar problems to that of other new technologies (e.g. biotechnologies, nanotechnologies) in gaining insight into sociotechnical systems that do not yet exist. The uncertainty of future technologies necessitates defining them for research participants. In doing so the context and framing used can have a large influence on responses. [33] (p. 22)*

A result of this lack of actual smart grids is that several studies instead concentrated on visions and imaginaries of the future manifestations (e.g. [34–36]). In these studies, documents were examined or different professional stakeholders, most commonly those with a background in engineering or economics, were asked how they envisioned the future grid. When analysing the visions, the researcher then identified some possible pathways but also considered what actors and

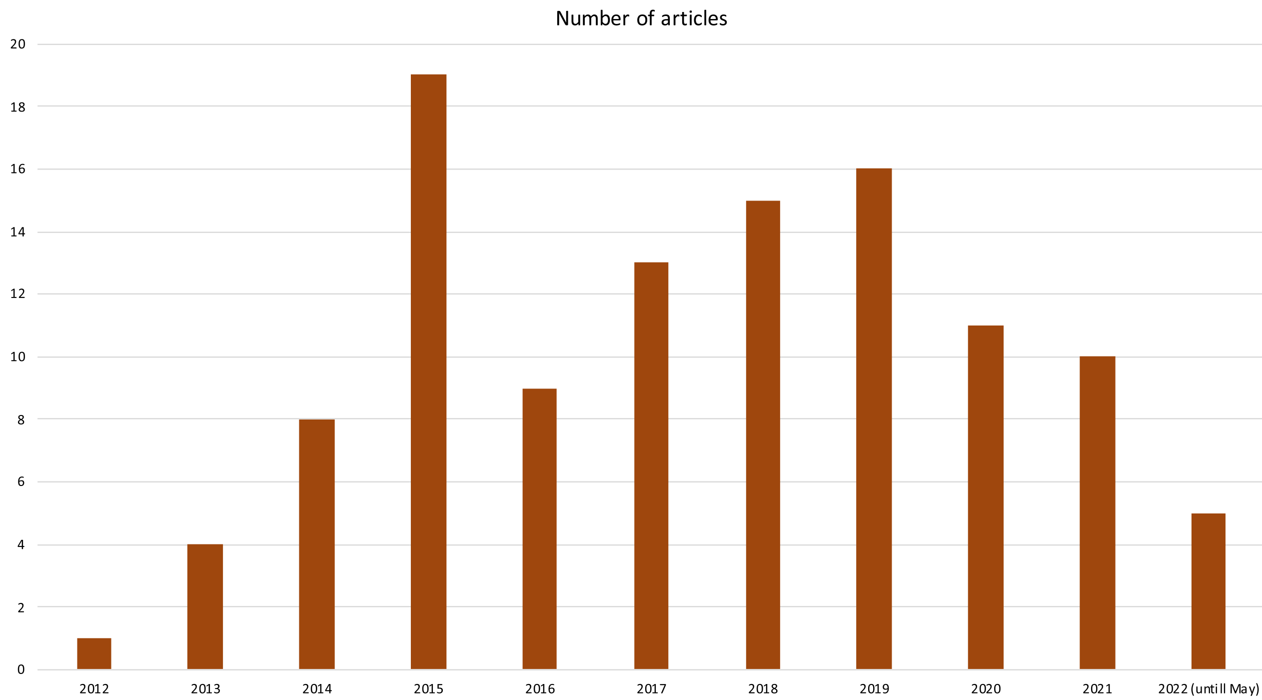

Fig. 2 Number of relevant articles published since 2012

issues were included in and excluded from the visions. The idea was that the visions have the power to become political goals and legitimate technological choices, making them relevant from a political perspective [11, 35, 37].

An absent or vague definition has, of course, the implication stated above, namely that it is difficult to explore actors' perceptions of the smart grid because researchers must first define the phenomenon for the interviewees; however, by proposing a definition, the researchers risk influencing how the smart grid is imagined. A vague definition can engender confusion, resulting in one overlooking of differences between conceptions of smart grids, differences that may be important for understanding how smart grids will emerge. On the other hand, a vague definition is not necessarily problematic, because there is no common understanding of what a smart grid is. When reading the papers, we noted that, although many lacked a definition, this was seldom a problem. To follow the analysis, it was often sufficient for the article to describe the smart grid in vague terms, but this lack of definition might become more of a problem when the smart grid starts to emerge and more detailed comparisons and analyses become possible and productive. A possible limitation of the current study is thus that, as smart grids continue to mature, research might begin using more specific terms and focus on specific aspects of it, such as flexibility. Nevertheless, all things considered, the study at hand aims at analysing the specific studies that focus on smart grids.

When the scene is not definitively set, this allows for greater possibility concerning what can be discussed and how. By the end of the studied period, a smart grid was often treated as synonymous with a distributed energy system. However, early in the review period, there were more studies that had not yet chosen this path, such as an early study on the 'SuperSmartGrid' [37]. In this study, the authors argued for the development of a SuperSmartGrid that could apply the advantages found in the SuperGrid, i.e. the transmission infrastructure, and the SmartGrid, i.e. a distributed system with local control and independence, which permits local accountability for demand. Nevertheless, the study identified significant technological and socioeconomic conflicts of interest between the SuperGrid and SmartGrid, thus policy makers and Transmission System Operators (TSOs) must act strategically, and strong policy intervention will be needed to allow both the SuperGrid and SmartGrid to evolve. Most reviewed studies have focused solely on the smart grid as a distributed system, ignoring the centralised system or simply advocating a distributed smart grid. Blarke and Jenkins [37] noted that the SuperGrid and SmartGrid require different and conflicting technological, institutional, economic, and social pathways for system design. An optional future scenario is that they would converge, making combined studies of decentralised and centralised system development crucial to avoiding a lock-in effect in smart grid research.

The domination of case studies from Europe and the USA

Moving on to a review of the geographical focus of the studies (see Fig. 3), we notice that from 2012 there is only one study from Asia, by Mah et al. [38], a widely cited case study from Hong Kong using telephone surveys to study consumer perceptions of a specific smart grid development. A focus on Asia is not that common in the corpus, with European case studies dominating the spotlight, followed by US ones. European studies do not always focus on a specific country, but when they do, countries located in northern Europe are dominant. Most empirical studies were conducted in the UK (15), Germany (11), and the Netherlands (11). Moreover, in recent years, the number of articles conducted in Denmark (11) has increased. Some of the other Nordic countries, such as Norway and/or Sweden, are addressed in 10 of the articles. The high number of studies focusing on specific countries might be an indication of a cultural tradition where it has been established to analyse sociotechnical aspects. The reasons why some countries are underrepresented and absent in our dataset can furthermore be related to what focus points have been established within higher education, and what kind of research has been prioritised by funding bodies. It is also possible that in some countries the sociotechnical characterisation of a technology has not been raised as an issue of political or public interest, i.e. the smart grid has been considered a purely technological project, rather than a sociotechnical one that influences almost every aspect of a society.

Studies from the UK often treat smart metering and demand–response practices, with a preference for early adopters [33, 39–44]. The starting point for these studies is how the technology influences energy use and can contribute to, for example, a more flexible consumption pattern. This starting point likely also influenced the theoretical perspective chosen for the analysis, a matter to which we will return below. The papers from the Netherlands are dominated by household studies, often in combination with a social practice theory perspective (e.g. [21, 45]). More recent studies have also considered more cooperative forms of household engagement and energy communities [45, 46]. For instance, the studies from Germany often concern the Energiewende and the attendant energy landscape. The Energiewende supports decentralised renewable energy, combined heat and power, and energy efficiency [47]—all key aspects of the smart grid—with a smart network being seen as a tool or facilitator of the transition or 'Energiewende'. In German research, smart meters and how they can be used to accommodate more variable production have been a central issue. As part of the Energiewende, the federal parliament passed

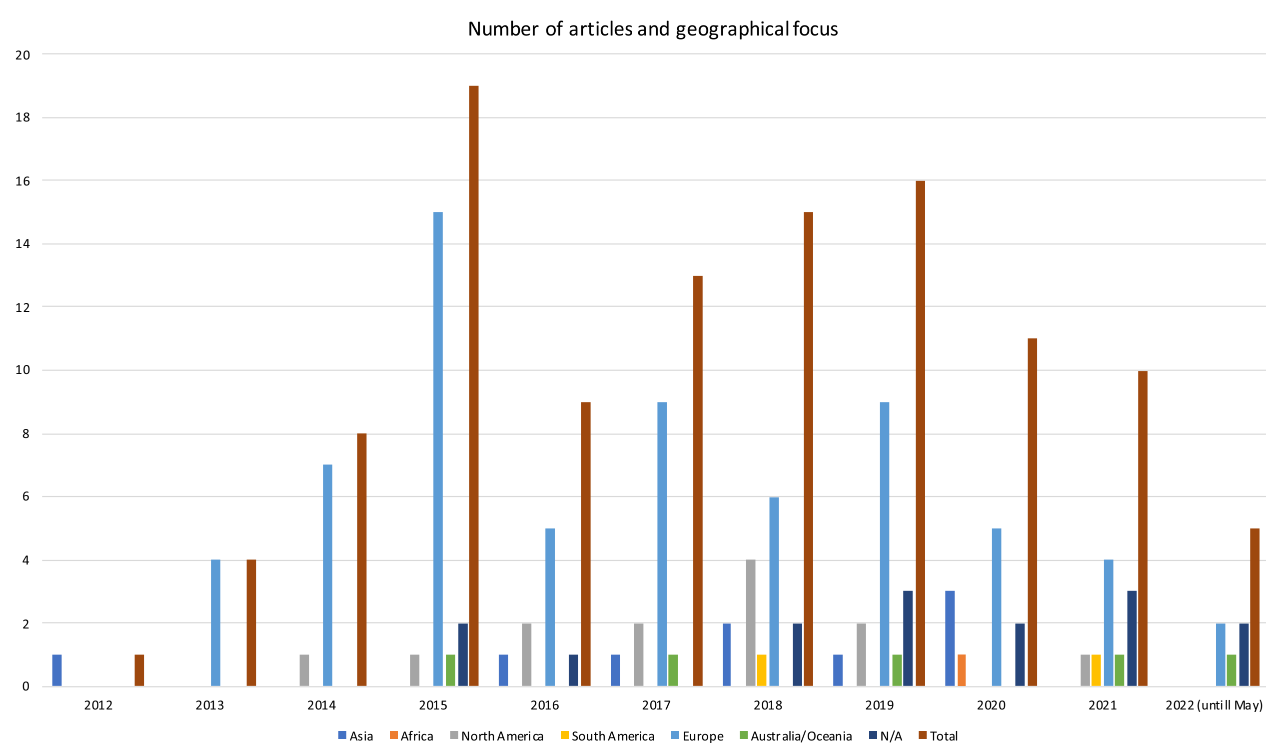

Fig. 3 The geographical focus of the relevant studies by continent

the Act on the Digitalisation of the Energy Transition in 2016, calling for development of a smart meter infrastructure, called the Smart Meter Gateway, contributing to the focus on smart meters in the studies. The studies from the Nordic countries have emphasised the envisioned smart grid and material participation in it. When material participation is considered, the researchers apply an 'object-oriented' or 'device-centred' perspective [48] where attention is paid to the role of technologies and material objects in everyday interactions with the energy system.

In sum, the studies from the dominant countries in the field have empirically focused on smart meters and demand–response practices; households and (more recently) cooperative forms of household engagement; smart grids as part of the energy transition (Energiewende); the imagined or envisioned smart grid; and material participation.

The single-case study was the most popular method, although several articles presented multiple case studies. Studies of smart grid geographies [49] analysing the meanings of different contexts are under-represented and would be a welcome addition to the literature. Overall, the smart grid geography field is centred on Europe. Mah [50] addressed this problem in a study comparing China and Japan: "This study adds to a limited body of empirical work exploring energy transitions in a non-western context … by focusing on government–market dynamics" (p. 163). Nevertheless, there are some other studies outside Europe and the USA, such as Joo and Kim's [51] study, in which residents in South Korea were interviewed about the smart grid; Bertheau et al.'s [52] case study on the Philippines, which looked at the challenges associated with implementing renewable energy; and a few studies from Africa (e.g. [53]) and Latin America (e.g. [54]). More social science case studies outside Europe would, however, broaden our understanding of the smart grid and give more diverse insights into how smart grid solutions could be designed and used [55]. For instance, Khalid et al. [56] compared Denmark and Pakistan, concluding that it was beneficial to compare these "socioculturally contrasting contexts" because it helped expose established cultural and material structures and embedded practices and ideas. The case studies from outside Europe and the USA could also potentially bring new aspects to smart grid research. The authors concluded that their results had implications for international donor policy, which often supports off-grid solutions and could thus be questioned, as it might help delay more effective community solutions. This critique of international donor policy was a new issue addressed by this study, yet the domination of some geographical areas in the literature risks narrowing our understanding of how a smart grid can be designed (e.g. only as a distributed system) and emphasises certain features of the smart grid (e.g. early adopters' use of smart home appliances), while other relevant features (e.g. international support programmes) are overlooked or neglected. On the other hand, social science research on smart grids is an emerging field in which some research communities, such as the science and technology studies (STS) community, are frontrunners, and these communities have given the field a certain focus and played the important role of opening smart grid research to new questions and perspectives.

The domination of early adopters and professionals

The actor perspective has been evident since the first social science articles on smart grids and been an important counterweight to all technically focused research. There is, however, a quite narrow set-up of actors who have been in focus, where technical and economic professionals, together with the domestic users, have dominated. "The social" was often represented by including the users. For example, Verbong et al. [21] stated, "In this article, our goal is to shed light upon practices and perceptions of stakeholders on including users [i.e. "the social"] in the transition process towards smart grids" [21] (p. 124). Furthermore, in 2013, Gangale et al. [57] highlighted users by using a questionnaire to explore consumers' behaviour and new role as active participants in smart grid projects in Europe. They found an increasing emphasis on consumer engagement and that trust and confidence were central to energy providers' successful strategies to promote it. A common early observation was that the only aspects of a smart grid that can truly be smart are the people within it, and many highlight the challenges and obstacles facing users of complex smart systems; nevertheless, many also champion finding new innovative solutions to interact with the grid [e.g. 21, 58].

The material participation of users has also been examined in many studies, as mentioned above. The study objects are often smart home devices, such as smart meters, a mobile phone app, a rooftop PV installation, or an electric vehicle. Material participation through renewable technologies in the home is a recurrent topic, with the empowered and engaged citizen in the foreground. Ryghaug et al. [48] found that such physical and embodied experiences open up new ways for users to engage with and take responsibility for the future energy transition. Experiences with rooftop PVs or electric vehicles in the driveway represent new ways to engage with the grid, scripting certain behaviours and leading to proactive shifts in household electricity consumption [12, 59].

There is also criticism of smart grid proponents. We lack long-term studies of user interaction with the technology beyond a testbed or intervention period. Büscher and Sumpf [60], for example, found that it cannot be assumed, as proponents do, that the customers/public will simply shift their behaviour once they receive smart appliances, technologies, meters, etc.

Chadwick et al. [61], in their article dealing with household adoption and rejection, also highlighted mainstream energy consumers' lack of understanding in their critical review of the literature on household energy traditions. Furthermore, Calver et al. [62] interviewed households in Manchester, United Kingdom, and studied energy justice, while Milchram et al. [63] looked into energy justice.

Theoretical perspectives

Almost all studied articles applied a sociotechnical perspective, an overall aim of which has been to study the processes of social and technical change. The smart grid constitutes a typical sociotechnical system in which technology is so closely intertwined with its surroundings that differentiating the two is not meaningful [64, 65], which is why it seems reasonable that STS researchers have been among the first to explore smart grids. The sociotechnical system approach is the analytical lens through which the development of smart grids in society is understood. In the introduction to a special issue treating social science and smart grids, Skjølsvold et al. [22] identified two relevant strands of research concerning (1) sociotechnical imaginaries of the smart grid and (2) the human–technology relationship. The identification of these two strands is still very much valid, even though the field has widened and more perspectives have been introduced—a matter to which we return below.

Sociotechnical imaginaries and narratives

As discussed above, one dominant strand of earlier research concerns sociotechnical imaginaries and narratives. The concept of sociotechnical imaginaries, developed by Jasanoff and Kim [66], has been used as an analytical approach to examining visions and futures concerned with smart grids (e.g. [34–36]). This research emphasises the significant role of energy imaginaries, shaped mainly by past energy choices, in reconfiguring the energy system. Imaginary futures consist of elements capable of facilitating and influencing sociotechnical trajectories by projecting what futures are desirable and attainable based on current and anticipated knowledge. In this research, the visions rather than the actors are emphasised, and the main contribution is better knowledge of how powerful visions can be for legitimising political ends and technological choices. Sociotechnical narratives' implications for decision-making in energy policy have recently been discussed by Libertson [67].

The human–technology relationship

Kloppenburg and Boekelo [68] referred to the energy social sciences as an established field in its own right, where the focus is on the users/citizens: "The energy social sciences (ESS) have examined how these developments have generated new possibilities for citizens to engage with energy and participate in the energy transition" (p. 68). They further mentioned that it is imperative for ESS to contribute to the responsible design and development of new energy infrastructure.

In contrast, Skjølsvold et al. [69] identified the need for four reconfigurations: (1) knowledge reconfiguration in the design practice field—the research community needs to engage more in disseminating results to practitioners, and practitioners, developers, and designers need to engage more with diverse bodies of research; (2) material reconfiguration—established design and technology development processes and regimes need to be destabilised to bring in new ideas and innovations; (3) epistemic reconfiguration—instead of embedding social science in technical projects, epistemic reconfiguration should be the goal when social scientists "work on equal footing with engineers and programmers in development processes"; and (4) what could be called disciplinary reconfiguration—establishing and mainstreaming new routines for cooperation and integration between previously scattered knowledge communities (p. 7). Skjølsvold et al. [69] presented this schema in 2017, indicating that the field had by then become mature enough to consider the critical evaluation of the impacts of sociotechnical research on the development of the smart grid.

The field has had a user focus, especially in underlining behaviour and practices at home. Less attention, however, has been paid to company and industry processes. Hence, more studies of, for example, business anthropology or ethnographies inside companies could be a welcome addition to the field. An interesting study that has taken such a turn is that of Grandclément [70], who described working as a sociologist for seven years in the R&D department of an energy company. To achieve the reconfigurations that Skjølsvold et al. [69] identified, it would be beneficial to have more studies giving insider glimpses into energy companies and companies working on designing smart-grid-related technology.

The application of social practice theory (SPT)

A dominant theory used in many of the reviewed studies was social practice theory (SPT) (e.g. [19, 59, 69, 71, 72]). As early as 2014, Naus et al. [71] and Higginson et al. [42] examined smart grids, information flows, and emerging domestic energy practices. By using SPT, doings in relation to the smart grid can be studied by treating structure and agency as united in repeated performance, meaning that a proper understanding of a user agency's potential power needs to be related to established structures materialised as routinised behaviour [73]. A practice is routinised behaviour when it consists of three or four interconnected elements, where the number of elements identified, as well as how they are labelled, differs among the reviewed articles. All routines include forms of these elements: *materials* such as technologies, *competences* such as know-how, and *meanings* such as social norms and shared meanings. By applying SPT, researchers can describe how users enact and interact with the smart grid and detect or map patterns of interaction. The SPT approach suits the empirical focus in which users in homes and households have been rather dominant, as discussed above. SPT advances our understanding of how and why certain smart-grid-related practices occur and can enhance our knowledge of, for example, demand–response practices and flexibility. As mentioned earlier, few smart grids have been established, although there have been many testbeds and experiments in which users participate as early adopters, thus their interaction with the technology can be studied (e.g. [59, 72–74]). The roll-out of smart meters has also allowed smart meter practice to be studied in the home (e.g. [19, 39, 69]). Higginson et al. [42] noted that the study of domestic energy use requires that researchers combine the study of technology, with a focus on the individual as the change agent, and the social, in which agency inheres in a culture or society. An analysis of how the smart grid affects society and vice versa makes it important to recognise that both living and non-living things (e.g. people, technology, and their surroundings) are active and therefore share agency [42]. SPT is one theory with a potential to capture this complexity, but there are others such as the socio-material perspective, which we will examine below. A practice-based understanding of energy outside the home has also been expanded to encompass distribution system operators (DSOs), and Verkade and Höffken [36] have noted that:

> *A main characteristic of a practice-based perspective is that, ontologically, it places the practice itself center stage, rather than whoever is performing that practice. The collective that performs the practice can be a civic energy community, but also another organization, such as a market-based company, a public or government institution, or an organization from civil society. The point of focusing on the practice and 'leaving open' who the performing actor is, is not only inherent to practice theory, but it allows a perspective in which different organizations develop their own, sometimes competing, versions of collective energy practices. (p. 12)*

Theories other than SPT have the potential to analyse this sociotechnical interaction in everyday life, as done in the reviewed article, but only to a lesser extent. For example, Nyborg and Røpke [75] applied an actor-network perspective to illustrate how some societal groups were less willing to be enrolled by the ministry in the smart grid programme, and how the utility and significance of heat pumps were strengthened by smart grid development. Lazowski et al. [76] and Ford et al. [77] applied the energy culture framework to investigate household decision-making and energy behaviour in relation to smart grid contexts in Ontario [76] and New Zealand [77]. A version of household socio-material participation has been used in several studies [48, 78–80], and Hansen and Hauge [59] used the related notion of the script. Some have also discussed the need for more theory development; for example, Khalid et al. [56] reminded us that conceptualising practices as shared or socially differentiated entities in different cultural contexts calls for further theory development. In addition, Adams et al. [81] critically reviewed the use of 'social license to automate', where 'Social licence to automate' (SLA) provides a framework to understand the (mis)alignments between the expectations of actors within the energy systems and the household practices, sense of control and stake in the energy system. They argue that the concept of an SLA can bridge these domains.

Other theoretical perspectives applied

Sociotechnical pathway research discusses different routes that the electricity grid could take. Lunde et al. [3] used this approach in considering how different paths include different elements of the smart grid discourse, while highlighting different policies and strategies. One pathway was that of a European SuperGrid and the other was a decentralised energy system centring on local actors [3]. Another theoretical perspective we found in our data concerned governmentality, often drawing on neoliberal theories or critical studies. For example, Levenda's [82] case study in Texas discussed the problems of smart grid case studies, illustrating how urban entrepreneurialism alters the potential for active co-production, whereas Rosenfield [83] responded to Shelton et al.'s [84] call for studies of the actually existing smart city. Lovell [85] noted that "the most valuable insight provided by a governmentality lens for those interested in processes of technological change concerns the close two-way relationship between the rationalities and technologies of government" (p. 592). In another study, Laes and Bombaerts [86] explored neoliberal governmentality and energy communities, but there are not that many studies on how the technical issues of policy implementation have together influenced the emergence of smart grid policy in different countries.

There have been interdisciplinary research attempts to break the silos and combine knowledge from different fields, as often advocated by researchers. In this effort, a field such as geography can enable the integration of various perspectives. Kumar [87], for example, in a study of microgrids in India, reviewed some of the literature on social sciences and smart grids, and concluded by calling for a more social-scientific approach to smart grids. Kumar also highlighted the need to connect smart-grid-related problems early on in the design phase. This is also something that has been highlighted over the years by a range of researchers (e.g. [88–90]); they have been calling for design approaches that would script technologies to better align with the daily lives and diverse existing patterns of electricity use and understanding [24].

Some more recent studies have used assemblage theory [74, 91], which is an alternative way to approach sociotechnical configurations. Assemblage theory is a bottom–up framework that sees relationships between human and non-human actors as fluid. According to this perspective, agency is not in the hands of a few key actors but is widely distributed among the many components of an assemblage. By using assemblage theory, the outcome of the implementation and use of a smart grid is left open ended, not fixed, and can be constantly reinterpreted. This perspective has the potential to permit new analyses of both the development and use of the smart grid.

In an earlier systematic review of smart meter research, Sovacool et al. [40] found that almost two thirds of articles primarily discussed technical challenges; they also identified two important gaps related to social science approaches: social concerns and vulnerable consumers, and how consumers and others can resist smart meter adoption. These two gaps are also relevant to smart grid studies, which have not focused on vulnerable citizens and non-adoption.

Experimental studies

There are some interesting studies from recent years that experiment with methods and theoretical frameworks. For example, Hess et al. [92] argue for a comparative, sociotechnical design perspective in their experimental study with a multiple perspectives comparison. Furthermore, Trahan & Hess [93] outline three central challenges of digitisation, suggesting new directions in energy social science research as the future control of electricity develops along its digital pathway. Strengers et al. [94] use comic-strip scenarios as a method to disrupt energy industry futures. Through the article they urge the need to revise energy imaginaries, reminding us about the urgency of exploration and communication in order to meet the targets set in the Green Deal by 2030.

Discussion

The aim of this article was to analyse trends and knowledge gaps identified in social science research on smart grids. The trends discovered are presented in Fig. 4.

Theoretically, the dominant main perspectives have emanated from the STS field: sociotechnical imaginaries, the human–technology relationship, and social practice theory. When the smart grid did not exist physically, but only on the conceptual level, it was difficult to study actors' experiences of it. Sociotechnical imaginaries therefore fulfilled an important role in analysing the potential meaning and influence of the visions of smart grids for the energy system and society. When smart grid demonstrations and testbeds developed further, it also became possible to consider different actors' reactions. The roll-out of smart meters and the Internet of Things in Europe helped create active consumers who could interact with the grid, change their usage patterns, and become more flexible. This could make these early adopters important assets in demand–response practices and in understanding how households use electricity and related technology. Material participation became a common approach to understanding the users' interaction with the domestic technology. This also occurred at a time when practice theory had become a dominant theory in the energy field, hence practice theory became a popular perspective in smart grid research as well.

After the smart grid's initial existence as mere sociotechnical imaginaries, it developed beyond the first technologically oriented phase into demonstrations that could be tested by people. Accordingly, more attention was paid to how the smart grid was or would be governed, and theories relating to governing have started to become more common.

Another trend in the research analysed is that most studies have concentrated on the distributed smart grid, whereas there has been less examination of the centralised grid or the centralised–decentralised nexus. Most studies have also been case studies geographically located in Europe or North America.

Thus, several research gaps were identified, as shown in Fig. 5.

An absent or vague definition of the smart grid, or a technology-oriented definition, often results in overlooking different conceptions of the smart grid and contributes to disregarding aspects important to, e.g. actors who are supposed to implement it. The lack of definitions also makes detailed comparison between smart grid impossible. There are few studies that address how to define a

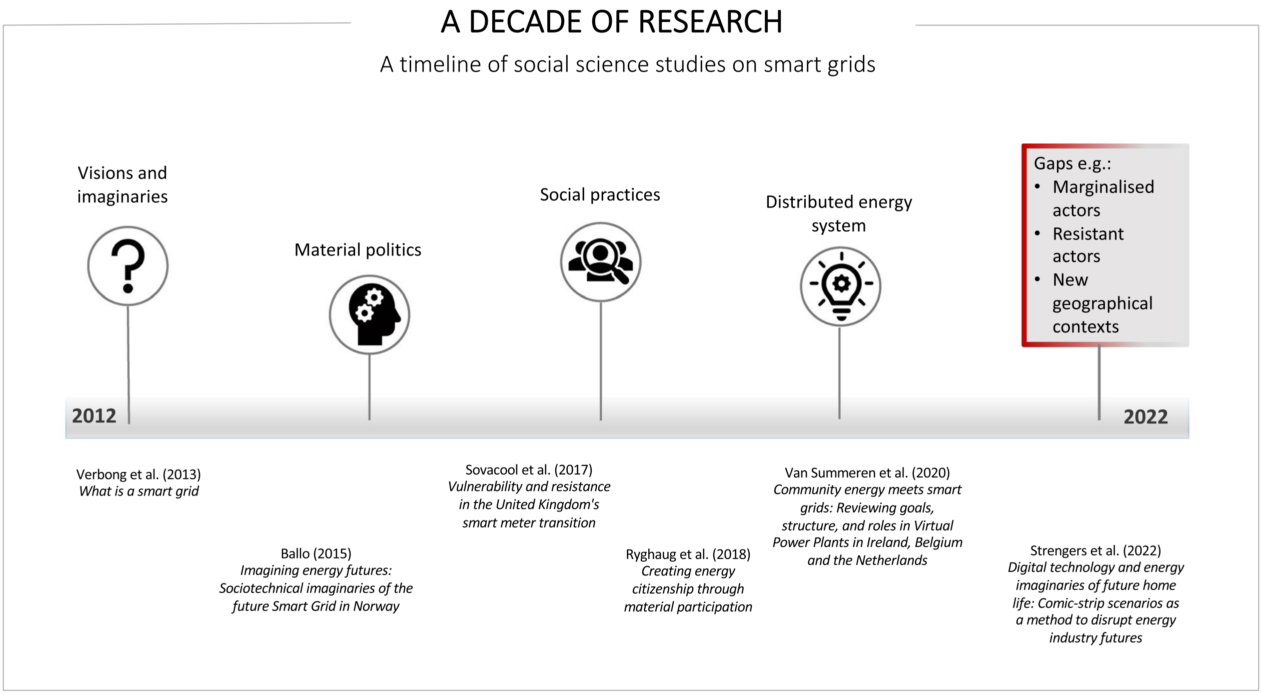

Fig. 4 Trends in earlier research and research gaps

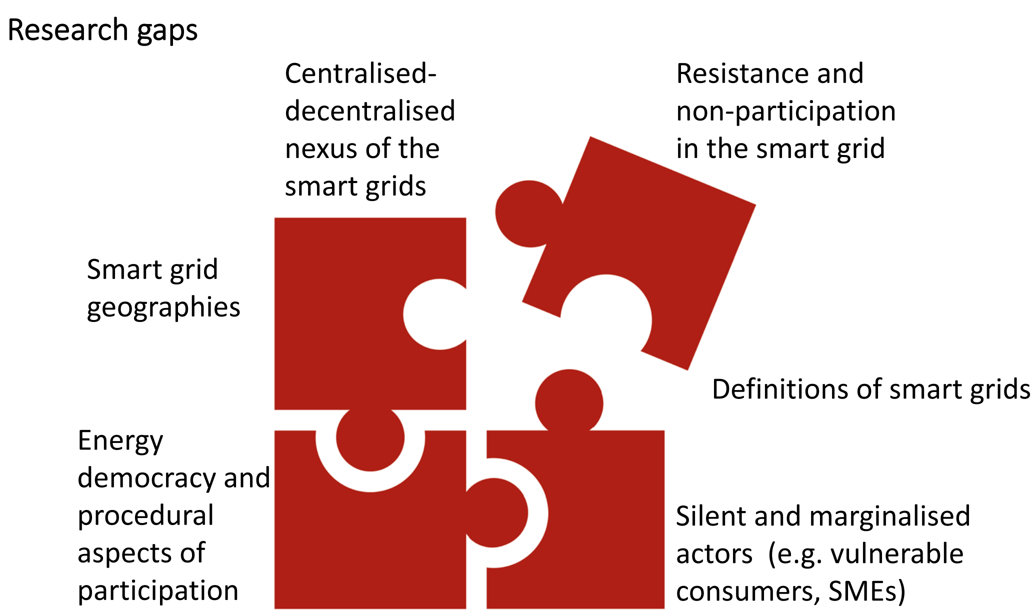

Fig. 5 Identified research gaps

smart grid in an inclusive way that covers its sociotechnical character and considers existing conflicting conceptualisations and understandings of the phenomena. This is important, because better integrating the social aspects into the design of the smart grid from the very beginning of the smart grid project would make them more socially sustainable.

One research gap relates to smart grid geographies and the trend with case studies concentrated on Europe and North America. In future research, it will be important to include the meanings and experiences of the smart grids in different contexts and have more case studies in the Global South. This would allow for more diverse insights and thus possibilities for more inclusive smart grid development.

Another research gap is the narrow range of actors studied. Technical and economical professionals are almost always present in the studies together with early adopters of smart technology. Future research should prioritise actors with other values, perceptions and experiences. Given the increased importance of energy in peoples' everyday lives, the inclusion of various actors is important from an energy justice perspective concerning who, for example, has sufficient resources in order to participate and who is represented in hearings and planning processes. There should also be a reflection on what kind of studies were absent; for example, there were not many studies focusing on gender roles. More studies with a feminist approach would help with the aim of including more diverse actors.

As electricity becomes increasingly embedded in all sectors of society, energy democracy clearly merits further study. From an energy democracy perspective, the energy transition is linked to a broader project of expanding political democracy in which the smart grid has the potential to re-inspire politically engaged citizen participation. This is something existing research touches on, but the democratic aspects could be highlighted and problematised much more explicitly. Consideration of more diverse actors and users is needed to advance our understanding of the smart grid, which should incorporate the perspectives of, for example, gender, other marginalised individuals, and SMEs as niche actors. The literature often captures the fact that relatively few early adopters interact with the technology and the social practices related to this. Few studies consider the procedural aspects of participation and issues of inclusion and outcomes.

Regarding material participation, how can a user opt out of the smart grid? Will it be possible to remain on grid but still avoid using related smart technology? Can one avoid taking part in grid automation? As yet, no study has explored the tensions between participation and non-participation in the smart grid. According to our data, some studies investigate how people participate in the smart grid, but far fewer studies consider their willingness to participate. This might, however, be due to the limitations of our study, as we excluded the field of psychology from our search.

As few studies examined centralised versus decentralised systems and their interconnected or conflicting development paths, the dominant focus on decentralised systems can be criticised for not reflecting the centralised energy system that most citizens experience in their everyday lives.

Smart grid research does, of course, benefit from developing incremental contributions, but assumption-challenging research is also needed. By focusing, for example, on marginalised actors, resistant actors or new geographical contexts, these less studied areas can bring in new knowledge supporting smart grid solutions to be developed, which also aligns with the actors actually implementing and using them.

Conclusions

We can conclude that research in social science studies on smart grids has followed a pattern where visions; professionals and users; and smart technologies in homes usually have been studied using case studies mainly focusing Europe or the USA. Six research gaps were identified and these were: the need of a clear definition of the smart grid, to include more diverse actors and geographical places, more studies relating to energy democracy and the resistance of smart grids and finally a lack of studies of the centralised–decentralised nexus of the smart grid.

Lastly, we want to acknowledge the limitations of the study and discuss alternative ways of conducting this type of review. The search terms are important and there are several search terms related to the smart grid that could have been used, such as "smart energy", "smart energy systems", "flexibility" or "community energy storage". The aim was, however, to capture how the social scientists have studied smart grids as a system, and we were not interested in how individual subsystems have been approached or analysed in earlier studies. Moreover, to place greater focus on parts of the system or different artefacts would have been interesting but that would have involved another kind of analysis than that aimed for here. Finally, due to the limited resources, we excluded non-English literature from our review, which may have resulted in a geographical bias.

Abbreviations

DSO	Distribution system operators
EU	European Union
ESS	Energy Social Sciences
GHG	Greenhouse gas
ICT	Information and Communications Technology
IT	Information technology
SDN	Software-defined networking
SME	Small and medium-sized enterprises
SPT	Social practice theory
STS	Science and technology studies
USA	United States of America
WoS	Web of Science

Supplementary Information

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Additional file 1. Studies included in qualitative synthesis.

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ARK and JP jointly carried out the review and drafted the manuscript. Both authors read and approved the final manuscript.

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Ethics approval and consent to participate

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Competing interests

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