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The clock is ticking: Understanding the 'mixed feelings' about fusion energy in Europe

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A R T I C L E I N F O

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A B S T R A C T

If it can be made to work, fusion energy offers the potential for unlimited, clean energy. This prospect has seen substantial investment in the science and engineering behind fusion in order to demonstrate its viability. As key societal stakeholders, the opinions and actions of publics can shape the success of emerging energy technologies. To date, however, there have been relatively few studies focused on the public acceptability of fusion. The current study provides insight into public perspectives about fusion in five European countries (Belgium, Hungary, Italy, Slovenia and Spain). Using a qualitative 'World Café' type method, participants (n = 10–25 per country) were provided with basic and balanced information about fusion, before being invited to discuss the risks, benefits and drawbacks of the technology and investment in its development. Transcripts from each World Café were subject to template analysis. The results indicated that while awareness of fusion was low in each country, participants were broadly supportive of fusion. This support was, however, tentative due to its commercially unproven nature. This stimulated questions about the value of investment in the technology, particularly given the urgency of addressing climate change. While there was some variation in the sub-topics raised and discussed in each country, the principal themes raised were broadly comparable. These findings add to our systematic understanding of the 'mixed feelings' held about fusion and have implications for future public engagement and communication efforts relating to the technology.

1. Introduction

The need to decarbonise power generation, while ensuring availability and affordability of supply is leading to innovation in terms of how electricity is generated and supplied in Europe [1–3]. Alongside investment and expansion in renewable generating capacity and, in some countries, nuclear fission and cleaner coal technologies (e.g. Carbon Capture and Storage), fusion energy (or nuclear fusion) is also receiving attention and research investment [4]. While currently unproven as a commercially viable option for power generation, proponents of fusion assert that, if successful, it holds the potential to be a sustainable and abundant energy source. Current projections from the fusion energy community suggest that a fusion power plant capable of reliably supplying energy to the grid, should be a realistic possibility in the second part of this century provided some key milestones for research, development and demonstration are achieved [5].

The current study was designed to qualitatively investigate the public acceptability of fusion energy in Europe. It reflects the importance of considering public perspectives within the research and innovation cycle of new technologies [6]. Our focus is upon exploring the

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nature of public opinion towards fusion energy and, in particular, the roots of the caveats that people place upon investment in fusion as a prospective electricity-generating option [7]. In this paper we first outline the industrial context and the importance of social acceptance to technological innovation, including an appraisal of extant research into public perceptions of fusion energy. We then outline and report the findings of World Cafés held with lay-publics in five European Union (EU) countries. We conclude that the caveats people hold about fusion energy principally stem from its commercially unproven nature, thereby raising concerns as to the relative value of continued investment in the technology in the context of climate change.

1.1. Industrial context

Nuclear fusion reactions are the reactions that power and sustain our Sun and other stars. Research into fusion energy is seeking to replicate these reactions on Earth. While classed as a nuclear technology, the processes of nuclear fusion differ from those of nuclear fission. While nuclear fission splits atoms (typically Uranium-235) to release thermal energy (which can then be harnessed to generate electricity), fusion works by combining ('fusing') two isotopes of hydrogen (deuterium and tritium). It is nuclear fission that is used to power the world's current fleet of nuclear power plants.

If it can be made to work, fusion is deemed to hold certain advantages over fission. These advantages particularly relate to things like the risks of nuclear meltdown, the availability of the fuel, and the production of radioactive waste [8,9]. There is no risk of nuclear meltdown with fusion, as the fusion reaction stops rapidly and automatically in the event of technical failure. The deuterium needed to power the fusion reaction is essentially unlimited and methods of tritium production and storage are advancing. And while fusion would generate some radioactive waste, there would be less of it and it would be less radioactive and shorter lived than that from nuclear fission [10,11]. Despite these advantages, however, fusion energy remains contentious. For example, questions have been raised about the high level of research and development investment it is receiving, its long commercialisation timescales and, ultimately, its viability as a future energy source [12]. Accompanying these technical debates are questions about the extent to which fusion energy will be publicly and politically endorsed; and how social acceptability might vary with respect to national context (e.g., economic growth, geo-political issues, power-generating portfolios, and domestic energy resource endowments) [7,13].

EUROfusion is a European consortium for the development of fusion energy. Thirty-one fusion research organisations in 26 European countries are supported and founded by EUROfusion on behalf of the European Commission's Euratom Programme, complementary to Horizon Europe [14]. The United Kingdom, Norway and Switzerland contribute to the activities with their national budget for research on fusion, instead. The EUROfusion programme is designed to deliver upon the 'roadmap to the realisation of fusion energy', initially published in 2012, advancing fusion research in order to lay the scientific groundwork for future fusion facilities called ITER and DEMO [5]. ITER ("the way" in Latin) is an experimental device under construction in Cadarache, in southern France. The EU, United States, China, India, Korea, Japan and Russia have been collaborating for 35 years to build and operate ITER, which should be capable of producing a sustained fusion reaction and thus net surplus energy. This is an important step in proving the feasibility of fusion as a large-scale energy source [9]. As ITER's successor, DEMO is scheduled to be a demonstrator fusion reactor capable of supplying net surplus energy to the electricity grid (although not at the price and volumes of a commercial power plant). DEMO is expected to be operational around the mid-part of this century. Beside the European programme, other public and privately funded fusion programmes are advancing in the research and development of fusion worldwide. Examples are the UK national programme for fusion energy [15], the Fusion Energy Sciences (FES) programme in the US [16], and the Fusion Industry Association (FIA) with regard to the private start-ups that are increasingly populating the field of fusion research [16,17].

Running parallel to the scientific and technological advancements in fusion energy, there has been a long-standing programme for socio-economic research on fusion, initiated in the 1990's [19]. The present study forms part of this socioeconomic studies research programme, which recognises the importance of considering the 'public face' of fusion as a key constituent of the research and innovation agenda for this technology. We introduce this literature below, before summarising the studies that have focused upon the nature and determinants of public perceptions and attitudes towards fusion energy. The introduction ends by outlining the rationale for the current study, the research context and the central research questions.

1.2. Social and public acceptability of innovation

Frameworks of social acceptance increasingly recognise that the way in which a technology is perceived and responded to varies as a result of the societal actors who are engaged or affected (e.g. political actors, stakeholders, public) and the level at which the technology is considered (e.g. socio-political, community, household/market) [19–21]. Thus, when assessing the 'social acceptance' of emerging technology options, like fusion, it is important to delineate the societal actor(s) and level(s) to which your research relates. It is equally important to be clear on whether one is discussing issues of acceptance or acceptability, given that that former term tends to be reserved for behavioural responses to a given technology rather than stated attitudes [22–24].

Within the current study, our focus is on understanding attitudes (acceptability) among members of the general public (actor-group) towards the concept of fusion in principle (socio-political level). Forming an understanding of the nature and antecedents of the public acceptability of fusion (like other energy and non-energy technologies) is important given the influence that publics can have on the fate of technology [6,20,25–27]. This is particularly true within Westernised democracies (like the countries of interest to this study), where publics are more empowered to influence decision-making at both national and community levels (e.g. through electoral voting or local activism), and where consumer preferences can affect the deployment, use and commercial success of technologies at the household level [28–30].

Many studies attest the ethical precedence and value of considering (and integrating) the opinions, perspectives, and knowledge of different publics (alongside other societal actors) into the research and development (R&D) cycles of emerging (and established) technologies [29,31]. An open, inclusive and participatory approach to decision-making is also consistent with drives towards responsible research and innovation (RR&I) practices that are gaining in precedence in Europe (e.g. via the EU 'framework programmes' to which EUROfusion is affiliated) [32]. Moreover, there now exists a rich literature on the nature and determinants of public attitudes towards a range of technologies [33], including energy infrastructures [23,33,34]. This literature is invaluable in profiling not only the factors that are likely to be important in how publics think about and respond to a given technology, but also in providing guidance on how public engagement and communication activities should be designed in order to promote more informed, critical and engaged discussion about which technologies should be backed, in which contexts, and where they should be sited.

In a review, Boudet [27] classified the common determinants of public attitudes towards energy technologies into a taxonomy comprising four broad groups of factors: technology, people, process and place. *Technology* factors relate to the perceived social, economic and environmental risks and benefits of the technology. *People* factors are the socio-demographic factors (e.g., gender, age, ethnicity) found to share relationships with risk and benefit perceptions; *Place* factors recognise the contextual influences that affect risk and benefit perceptions (e.g. place identity, proximity to centres of population); and *Process* factors reflect the characteristics of the decision-making process (e.g.

transparency, consultation, collaboration). In addition to the broad taxonomies of key factors, compiled by the likes of Boudet and others [28,35], other researchers have sought to produce causal frameworks and models designed to explain how these factors likely relate to and influence one another [24,37]. For example, following a review of the literature into public attitudes towards low carbon technologies, Huijts and colleagues [24] produced their Comprehensive Technology Acceptance Framework (CTAF). This framework identifies *attitudes* as a primary determinant of people's intentions to accept a technology, as well as being a key mediator of the influence on intentions afforded by the concepts of trust, affect (emotion), perceived costs, risks and benefits, and perceptions of procedural fairness. The CTAF (or derivations of the model) has since been widely used in studies designed to better understand the nature of public attitudes towards several emerging energy technologies, such as nuclear fission [38] and grid-scale energy storage [35].

On the basis of the growing body of research conducted into the public (and wider social) acceptability of energy technologies, we now have a relatively mature understanding of the nature and antecedents of public attitudes towards a number of emerging low-carbon energy-technology options. A case in point is Carbon Capture and Storage (CCS), where a concerted research effort over the last 10–15 years [33,38,39] has told us much how CCS is viewed in different national contexts, at different scales (e.g., local, national) and among different societal groups of actors (e.g., publics, stakeholders). In turn, this has led to the creation of public communication and engagement materials and interventions, designed to promote informed discussion of CCS and its intended application [40–42]. The same cannot be said for fusion energy, where the existing literature currently lacks breadth and maturity. As a yet unproven energy option, there is much that we still do not know about the nature of public attitudes towards fusion. The current study aims to directly address this gap.

1.3. Public perceptions and attitudes towards fusion

Research into public attitudes towards fusion has been sporadic, with only a handful of rigorous studies being conducted into the topic, supplemented by periodic national polls of public opinion [7,43–48]. The body of research that does exist shows that public attitudes towards fusion tend to be broadly favourable, although commonly caveated by a lack of familiarity with the technology and/or concerns about its technical feasibility, timescales to commercial deployment, and its relative risks and benefits versus investment in more proven low-carbon options, like renewables [46,49].

This cautious endorsement of fusion can be viewed through the lens of attitudinal ambivalence or conditional acceptance (or more accurately 'conditional acceptability'). Attitude ambivalence is a state in which people hold a mix of positive and negative feelings about the same attitude object [50–52]. Ambivalent attitudes, because they are characterised by holding 'mixed feelings' towards something, often means that they are weaker and held with less certainty, and are thus less predictive of a person's behaviour [53]. Ambivalent attitudes also tend to be more malleable, with an increased susceptibility to persuasive appeals, or even more transient states (e.g. a person's mood) [53–56]. Conditional acceptance (or acceptability) – and related concepts like reluctant acceptance [57] – is somewhat different, in as much as people are likely to be more certain of their attitudes, but associate any endorsement of the technology with conditions or caveats (*"It is okay, so long as…"*).

Evidence for both ambivalence and conditional acceptance have been identified in relation to a number of emerging technologies, e.g. carbon dioxide utilisation [58], nanotechnology [59], wind power [60], biotechnology [61], pharmacogenomics [62], phytoremediation [63], and robotics [64], including in some of the formative work on fusion energy [44]. For example, Prades and colleagues [44] reported that attitudinal ambivalence tended to follow the receipt of information about fusion within their focus groups (as people were exposed to contrasting opinions and details about the risks and benefits of fusion energy), but that this tended to be supplanted by conditional acceptance towards the end of the sessions, as participants acknowledged the benefits of fusion but wanted assurances that any risks would be mitigated and managed and that investment in renewables was not undermined.

It is also clear from the extant work on public attitudes towards fusion, that self-reported (and objective) knowledge and awareness of the technology is typically very low, particularly when participants first start polls or studies. This tends to render their attitudes pliable and open to persuasive influence. Evidence of the current pliability of people's attitudes towards fusion comes from research relating to the stigmatising effect that the 'nuclear' prefix has on these attitudes [45]. The known impact of this terminology on public perceptions has led the industry to favour dropping the nuclear prefix, and to refer to the technology as 'fusion' or 'fusion energy'. This move is analogous to decisions taken in relation to (nuclear) Magnetic Resonance Imaging in the 1980s [65]. The impact of this simple, nominative (re-)branding indicates the current malleability of public opinion towards fusion energy, and again signals the importance of developing and delivering well-tuned public communication and engagement efforts.

While one should not fall foul of simplistic *knowledge deficit* thinking, there is good evidence that the provision of some information about the nature of fusion and its associated risks and benefits, can serve to improve the *quality* of people's attitudes towards the technology (e.g. attitude certainty or stability), as well as tending to exert a positive impact on the overall favourability of the technology [65-67]. The power that the provision of even a small amount of information can exert on public attitudes towards fusion was evidenced by Jones et al. [7], who investigated the impact that the proposed use of depleted uranium as a fuel store for fusion energy had on attitudes within the UK and Germany. The study identified that attitudes in both nations would improve following the brief information that differentiated fusion from fission, with a similar improvement seen in attitudes as information about the nature of depleted uranium was provided. Importantly, beyond showing the impact that information could have on expressed opinions, Jones et al. [7] also identified some cross-national differences in public attitudes towards fusion, with the German cohort being consistently less favourable towards fusion than the UK cohort within the study. The authors reasoned that this greater scepticism could relate to differences in national energy policies regarding *fission* in each country, which were at the time (and continue to be) less favourable in Germany vs. the UK [68]. Support for this conclusion comes from studies that have identified the importance of general attitudes towards nuclear energy as being a (indirect) determinant of attitudes towards fusion [45,49]. Also, in a recent article, Jones et al. [13] compared attitudes towards fusion in four European countries (Austria, Finland, Spain and the UK) and found that preferences for fusion tended to mirror national attitudes towards fission (i.e. being most favourable in Finland and least so in Austria).

The extent of the cross-national differences and similarities in public attitudes towards fusion is something that requires further investigation. Understanding and addressing patterns of (in-)consistency in public attitudes is important in validating the transferability of findings from one national context to others and holds related relevance for those developing public communication and engagement programmes pertaining to fusion, particularly those with an international reach (e.g. International Atomic Energy Agency; EUROfusion). Of the handful of studies that have specifically conducted cross-national comparisons of attitudes, there is a mixed picture regarding points of similarity and divergence. For example, Horlick-Jones et al. [45] and Prades et al. [48] who qualitatively investigated attitudes within Spanish and UK samples purported there to be general similarities in the perceived risks and benefits discussed by the groups (while also highlighting that Spanish participants tended to be slightly more supportive). These early findings are supported by specific comparisons drawn between Spanish and

British attitudes within the Jones et al. [13] study, where participants' affective and belief-based judgements about fusion (e.g. its timescales to development and abilities of fusion to address climate change, at a competitive price) were broadly identical. It was only in terms of considerations of the production of radioactive waste where there was divergence between the nations, with UK participants being more positive about this potential drawback.

1.4. The current study

The current study sought to better understand public attitudes towards fusion in Europe by qualitatively examining the opinions of lay-publics living in five EU countries affiliated with the EUROfusion programme (Belgium, Hungary, Italy, Slovenia and Spain). These countries were selected as they were the home nations of the researchers – thereby facilitating the design and delivery of the World Cafés – but they also provided a broad spectrum of opinion from across four different European regions: Southwest (Spain); Southern (Italy); Central (Slovenia and Hungary); and Western (Belgium). Prior research has also established these nations as holding quite different global/headline attitudes towards fusion and fission [13,45].

The study was exploratory and designed to (a) elucidate and better understand the anticipated ambivalence or caveated acceptance towards fusion held within each nation; and (b) to look for similarities and differences in the drivers of fusion acceptability in each country. A World Café method – first piloted in Portugal by Delicado, Prades and Schmidt [69] – was used in order to conduct the research, with separate events held in each participating nation between December 2021 and April 2022. While the current study was funded by the EUROfusion programme, the researchers remained agnostic about the prospects of fusion in their exchanges with participants.

2. Methods

2.1. Research approach

Drawing upon the relaxed and open conversational ambiance of a café, the World Café method is designed to be an inclusive, constructive and participatory means of qualitative data collection and/or organisational change management [70]. World Cafés are designed to facilitate the structured exploration of topics and exchange of ideas, often within large heterogeneous groups [71]. While often used outside of academia, the method has also been used extensively for academic research [71–74]. In a typical World Café, key questions relating to the focal topic(s) are discussed in small groups (e.g., 4 or 5 persons) sitting around café-style tables, often with the provision of drinks and snacks, and with the periodic movement of persons between tables to allow for more interaction and exchange of ideas between attendees. Ultimately, the key points (e.g., concepts, learning, discoveries, etc.) from the small group conversations are noted and then shared and discussed with the whole group.

The current study followed this 'small-group to larger-group' discussion template within each national context. However, due to the unfolding COVID-19 crisis (occurring at the time of the research), some of our World Cafés had to take place online. While the discussions were held successfully, this format necessarily affected the café ambiance and restricted participant movement during both the face-to-face and online sessions. Outlined below is a fuller account of the procedure that was applied within each country. Facilitators of the World Café sessions were provided with a common guidance framework (or agenda) and set of PowerPoint slides, to foster greater consistency in delivery between national contexts (see Supplementary Material). Country-specific deviations from the procedure are highlighted where appropriate. All World Cafés were audio-recorded and were held in the native language of the country within which they took place. Ethical approval for the research was sought from the ethics committees of the participating institutions.

2.2. Participants and recruitment

Recruitment of participants varied with respect to national context; however, in all cases the purposive intent was to recruit a diverse group of participants in terms of gender and age. No pre-existing knowledge of fusion was required in order to participate. Recruitment in Spain was achieved using a professional recruitment company, while in Belgium, Italy, Hungary and Slovenia a mix of posting on professional or community organisations' email lists, institutional web-pages and Facebook was used. Details of the number of participants and their general demographic (age, gender) are shown in Table 1.

2.3. Materials and procedure

Here we present brief details of the core elements of the World Café procedure. A schematic diagram of the core aspects of the procedure are also documented in Fig. 1. For fuller details of the World Café, see the Supplementary Materials.

2.3.1. Introduction

The agenda for the session was outlined, including the aims and objectives for the session, a brief outline of the nature of a World Café, and details of ethical rights and pseudonymisation. Participants were informed that the research was courting the views of publics within multiple European countries. Participants were then invited to introduce themselves to each other and outline what attracted them to the session.

2.3.2. Contextualisation

Participants were told that the context for discussions was the future of energy supply in Europe. A brief introduction to the energy trilemma was provided, designed to highlight the challenges facing societal leaders in ensuring that future energy portfolios simultaneously address the issues of environmental sustainability, energy security and energy equity (in terms of affordability and access). It was argued that the merits and demerits of different sources in addressing the trilemma would mean that a combination of sources would be required, and that different nations were favouring different mixes due to variability in their access to natural resources, their geopolitical contexts, and energy histories.

The focus of the World Café on *electricity generation* was emphasised. Participants were presented with a pie chart illustrating the energy sources comprising the 2019 European Union electricity generating mix, and talked through this mix with reference to tackling the energy trilemma. The 2020 electricity mixes for Belgium, Italy, Slovenia, Spain and Hungary were then presented to illustrate how participating World Café nations were generating electricity and showcasing the diversity and difference of their generating mixes.

Table 1
Participant demographic and session delivery details for the Word Cafés.

	Belgium	Hungary	Italy	Slovenia	Spain
Date	February 2022	April 2022	February 2022	December 2021	December 2021
Number of participants	16	11	10	11	25
Gender (Male: female)	14:2	6:5	9:1	6:5	13:12
Age range (years)	40+	19–87	20–61	21–65	18–70
Online or face-to-face	Face-to-face	Face-to-face	Online	Online	Online
Incentive	None	Voucher	None	None	€40

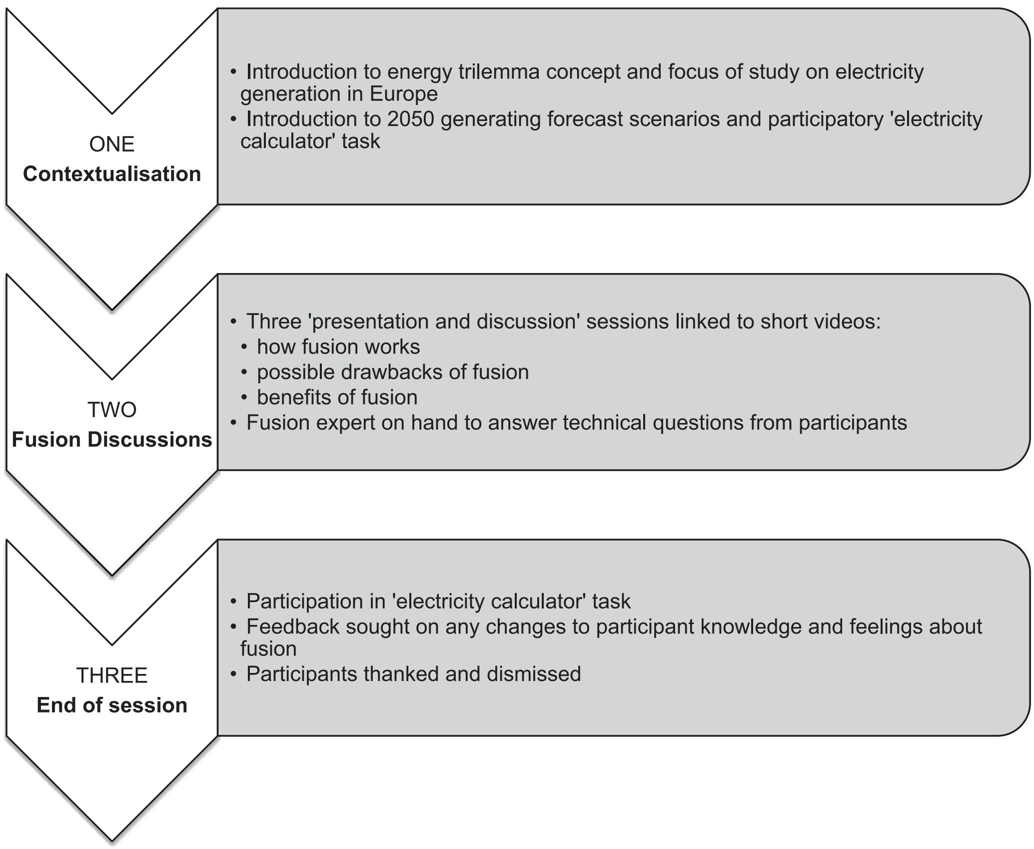

Fig. 1. The running order for the World Café.

2.3.3. Electricity generating scenarios

Two sets of alternative *global* electricity generating scenarios were presented to participants: the IEA scenarios for 2050 [75] and a set of unpublished EUROfusion (SES) scenarios for 2050, 2070 and 2100 (see Supplementary Materials). These scenarios presented participants with perspectives on prospective global energy-system configurations and were designed to encourage participants to consider how global reliance on different technology options (including fusion) might fluctuate over the next century. Participants then completed a brief participatory task, where they were asked to create their preferred electricity generation mix for Europe from 10 energy sources, including Fusion.[1] As responses to this 'electricity calculator' task are not a primary focus for the current article, the findings of this task are not discussed further.

2.3.4. Fusion discussions

To gauge baseline levels of knowledge about fusion, participants were asked to comment on what they knew or had heard about fusion before attending the World Café. To ensure that all participants had a basic knowledge of fusion before beginning the discussion, they were then shown the first of three short videos, which introduced fusion energy and how it works, from the perspective of the fusion energy research community. This video was produced by Fusion for Energy (F4E), which is the EU organisation overseeing Europe's contributions to the ITER programme [76]. Before proceeding with the World Café, participants provided feedback on the video (e.g. in terms of its general quality and understandability, etc.).

Participants were then shown brief written statements about fusion energy that highlighted the perspectives of four key stakeholder groups (i.e. ITER, Fusion Scientists, European Leaders and Environmental NGOs). These statements were designed to showcase the debate that exists around the value of research and innovation investment in fusion energy. Participants had the opportunity to ask questions to a technical expert in fusion energy, with a specific focus on the technical aspects of how fusion works.

The second of the three videos was then shown. This video was created by the EUROfusion-SES team in collaboration with scientists from the wider fusion research community. It introduced participants to some of the possible drawbacks of (a) the technology; and (b) investment in the research and development of fusion. Voice-over or subtitles in the national languages were produced to make the information (originally developed in English) equally accessible to all participants. After this video, participants were invited to discuss what they had seen in small, mediated groups, before returning to the plenary 'room' to outline the key emergent themes resulting from their discussions. Questioning focused on whether participants' first impressions had been changed following the video, which drawbacks (if any) stood out, whether they wished to question any of the listed drawbacks and whether they wished to raise other drawbacks not mentioned.

The same 'presentation and discussion' format then occurred for the third and final video, created by the EUROfusion-SES team, on the positive aspects of the technology and benefits of investment in fusion as an energy option. Participants again had an opportunity to ask the technical expert questions about fusion, with a broader line of questioning about fusion also allowed at this stage. Participants then repeated the 'electricity calculator' task. The World Café ended with participants being asked how much they now felt they knew about fusion, their feelings about the technology and whether they had any further questions. They were then informed about what would happen with the data from the World Cafés, before being thanked and dismissed.

2.4. Data analysis procedure

The audio-recordings from the World Cafés were transcribed and then analysed using a form of thematic analysis called Template Analysis [77]. Template Analysis is a form of hierarchical coding strategy that can be applied to different forms of textual data (including focus group and interview transcripts, etc.). It rests upon the development of a structured coding template grounded in informed a priori expectations and/or the analysis of a sub-set of data. This coding template is then applied to the full dataset, but retains the flexibility to be revised and refined as it is used. There are six stages to template analysis: familiarisation with the accounts to be analysed; a priori theme generation and/or preliminary coding of the data; clustering of emergent themes; definition of initial coding template; application and refinement of initial coding template to subset of data; and finalisation of template and application to full dataset (although the 'final' template can still undergo further revision in response to the data). For more information regarding the practice and epistemological position of Template Analysis, see Brooks et al. [77].

In the current study, the coders from each of the participating countries (A.G. for Italy; C.O. for Spain; U.L for Slovenia; J.K., R.G. and C.T. from Belgium; and Z.F. for Hungary) first familiarised themselves with the transcripts from the World Café. Coders then attended a meeting where an initial set of themes were identified and agreed. These themes were derived from an appraisal of the extant literature on public perceptions and attitudes towards fusion, established models of technology acceptance (e.g., [24], combined with initial inductive coding of the transcripts (i.e. by reading the transcripts and informally documenting emergent themes). This list of themes formed the basis of the initial coding template, which was then fully and systematically applied to the transcripts from the World Café.

The analysis focused solely on the Fusion Discussions sections of the World Café (i.e. where participants were discussing the costs, risks and benefits of fusion). In accordance with flexibility afforded by Template Analysis, the template was revised and updated in response to the coding process and any major revisions were discussed fully among the coding team. Systematic reliability analysis of the coding (e.g. intercoder reliability) was not performed in this study. Use of such analysis was deemed to be inconsistent with the interpretivist nature of this qualitative study [78]. The collaborative and discursive approach to designing, testing, and modifying the coding template ensured that all coders had a mutual understanding of its use, adding credibility to the coding process and study findings. The final coding template is available in Appendix A and also displays where references were made to each (sub-)theme in the different World Cafés. To ensure consistency across nations, analysis was performed manually, with exemplar quotes being extracted from the transcripts to support the (sub-)themes in question, before being translated to English. The accumulated responses within the final coding document were then studied for core thematic areas, which are used to structure the results section.

3. Results

The results section is structured in accordance with a series of four latent questions (key themes) that appeared to underpin participants' discussions within the World Cafés: (1) is fusion really a 'dream' technology; (2) what will fusion cost and who pays; (3) can fusion really help to address climate change; and (4) how does fusion compare with fission? Although there was nuance in how they were expressed, the majority of the core themes and sub-themes discussed within the World Cafés were broadly consistent across the countries studied (see Fig. 2 for a schematic diagram of these sub-themes). Where cross-national differences arose, these are highlighted in the following analysis.

[1] In the electricity calculator, people created the preferred electricity generating mix for Europe from 10 options: Coal, Natural Gas, Oil, Wind, Solar, Hydropower, Nuclear power (fission), Fusion Energy, Import, and Other. The category of 'Other' allowed participants to specify any other form of electricity production not included in the list (e.g. from Hydrogen). Participants were required to meet 100 % of demand by distributing 20 'units' (each representing 5 % generating capacity) between the sources. The only restriction was that participants could not be reliant on just one source, but had to distribute reliance between at least two of the available options. Participants were given a brief written descriptive outline of each of the energy sources before beginning the task (see supplementary materials). They were told there were no wrong or right answers, and that they should distribute the units to create their personally preferred mix. There were no forecast timescales for the task. After individually completing this task, participants discussed their mixes and the rationale for their decisions with the other attendees.

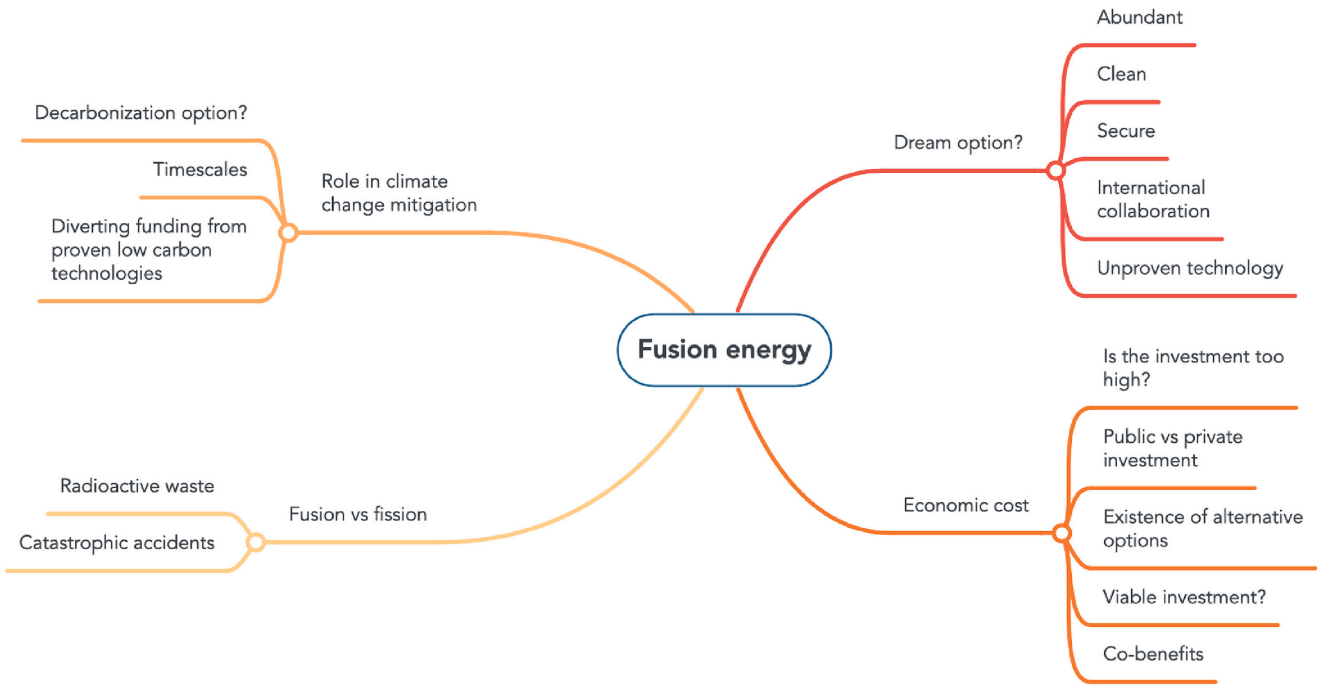

Fig. 2. The key themes and sub-themes common to World Café discussions in each of the five participating countries.

3.1. Is fusion really a 'dream' option?

Participants in all groups were generally positive about nuclear fusion, referencing an interest in the technology, and hope and optimism for its use in the future:

> *"I think it's a very good idea and I hope that in the future it can be done"* (Slovenia)

> *"Nuclear fusion … that's a dream for me. I would love that"* (Belgium)

> *"…if they will manage to get it, [nuclear fusion] will have so many advantages so that it will really be one of the most important players for producing energy in the future"* (Italy)

This general positivity was found to principally relate to the status of fusion as a prospective, abundant, clean and secure energy source. Some participants even drew parallels between fusion and renewables, assimilating it with the advantages of these low-carbon options and/or favourably contrasting it with the intermittency issues associated with renewables:

> *"… the main advantage is that the energy it generates can be comparable to renewable energy, that is, without being so, but it can be more or less comparable […] I understand that the level of pollution is quite clean, quite low, as if it were wind or solar energy"* (Spain)

> *"…the advantages [of nuclear fusion] are also in terms of energy, the continuity of energy, in respect to other renewables needing storage systems"* (Italy)

> *"As a positive point, what I also see is that, unlike the sun, for example, solar or wind energy from the air, of course, it does not always make air and it does not always make sun, unlike these two, in this case it is not intermittent, but […] there is always it and it goes directly to the power outlet"* (Spain)

Participants were also enthused by the extent of the international collaboration that is driving fusion research and development. Fusion was considered exemplary of how science should work, especially in the case of megaprojects like ITER. The value placed on international collaboration around fusion also led to some concerns in Belgium that political decision-making could prevent progress:

> *"…the strong technological cooperation that [nuclear fusion] research makes possible, I mean an international cooperation with many nations and many researchers. And this is the goodness of the scientific method"* (Italy)

> *"…fusion research is an example of international cooperation of all countries, they sit at the table, they do their best. And everything is coordinated […]. Global development of technology is positive, but it might also be disrupted by political stormtroopers…"* (Belgium)

While the international cooperation evidenced by the research and development of fusion was highly valued, there was also some concern in Belgium and Spain that the commercialisation of fusion might favour and strengthen richer countries, and therefore threaten international solidarity or create international inequalities (e.g. access to fusion energy and/or receipt and management of waste products).

> *"…is fusion an element in increasing world solidarity or, on the contrary, does it strengthen the strong?"* (Belgium)

Indeed, the overall enthusiasm for fusion was often tempered with references to hidden and/or anticipated drawbacks of the technology:

> *"I mean, it's a dream technology, but there must be something [behind it]. It can't just be that good. It's never the case that everything is optimal right away. Yeah, there are probably some obstacles and I'm interested to know more about that"* (Slovenia)

Scepticism about fusion stemmed primarily from two sources: (1) participants' self-claimed lack of familiarity and knowledge about the technology (e.g. its objective risks and benefits), which led participants to lean heavily on the information supplied within the World Café; and (2) a recognition that fusion remains experimental and commercially unproven. While it was reasoned that fusion could be made to work, many participants had reservations that it might never do so, at least not in a commercially-viable sense:

> *"This technology doesn't exist yet. If this hadn't been discussed before, I would have thought that the only thing left now was to build such things"* (Hungary)

"… fusion sounds like science fiction […]. As much as I've read about it, it's always been that it's fiction, that it's not possible, that it's something that's very difficult to develop. It will surprise me if there is any breakthrough in this area" (Slovenia)

"The main drawback, for me, was mentioned at the beginning […] that we are nowhere near there yet. And that it's not certain that we're ever going to get to creating those conditions of 150 million degrees in a constant way and then get net positive energy from that" (Belgium)

"The difference between a working machine and a commercial working machine is still very big" (Belgium)

These two primary influences gave rise to a series of interesting discussions centred on three further latent questions: (a) what will fusion cost and who pays; (b) can fusion really address climate change; and (c) how does fusion compare to fission?

3.2. What will fusion cost and who pays?

The high financial costs of investing in the research and development of fusion were perceived as a key disadvantage of the technology. Firstly, there was concern about the level of the investment that would be required to prove the concept of fusion, and then commercialise it:

"The cost, I think this is the main one. We are talking about a very large investment, which is very long-term, which still needs more research, and a lot of machinery is needed to start and well, it's like a whole mountain" (Spain)

"...DEMO is going to cost a lot of money … But going from there to a nuclear reactor that is operated by a private commercial firm … we're a long way from that" (Belgium)

This general concern was underpinned, in some instances, by participants' perceptions that investment in fusion would be risky due to it being unproven, which led some to assert that backing more mature, low-carbon options might make for a more logical investment:

"The risk that it cost an enormous amount of money and ultimately it doesn't get realised" (Belgium)

"Certainly, because if that level of investment is going to be so, so great that supposing the case that it did not bear the expected fruit, then perhaps all that money would have been invested in these other energies that we already have to give them a better use" (Spain)

The financial costs of fusion also led to debate regarding who should pay for the investment in the technology. In Spain, in particular, this led to discussion over the role of state backing for fusion research. While some argued that the state should not spend public money on unproven technologies like fusion, others argued that state investment would be necessary if the technology were to be realised. The debate in Spain seemed to stem mostly from a lack of faith in the private sector to invest in fusion. While some argued that private companies would not risk capital investment on fusion unless there was a guarantee on a return of investment – so why should public money be risked – others believed that the lack of private investment left a gap that needed to be filled with public monies:

"So, a company does not pay for the investment of millions of euros at all. So, the only possible way, I think, even more so for many years to come, is to use public money, there is no other way because private companies are not going to invest in this" (Spain)

Most of the comments around the financial cost of fusion again related to the knowledge that fusion was unproven. In Hungary this raised the question of where to 'draw the line' on investment, particularly if the prospect of commercial fusion was to continue to elude scientists:

"How long can such a large-scale research series last? When do you say it won't work? How long can you invest money and work in this? It cannot be infinite". (Hungary)

In Italy, there was confidence that the longer-term costs of commercialising fusion could be reduced as a result of innovation in the sector (e.g. the creation of compact fusion reactors); however, this was again predicated on first proving the concept of commercial fusion. A participant in Belgium also asserted that proof that fusion was viable should be used as the 'green light' for public investment in the technology:

"…you cannot ask for a huge investment, and at the same time say, I don't know if this is going to work. You can demand, as long as you give a certainty… you have the product, and you have to be sure of the product you offer" (Belgium)

It was not the case that all participants were risk averse in terms of funding and investment. Some defended the epistemological position that 'research is always uncertain', and that uncertainty should therefore not stop governments from spending public money on ambitious scientific enterprises:

"If you don't give the right to fail, you should stop all research of any type from now on" (Belgium)

The prospect that fusion might fail as a commercial power-generating option was also not seen to wholly undermine investment in its development. While some cautioned against losing sight of the primary goal of fusion (namely obtaining a new source of sustainable energy), several participants, most notably in Spain, referenced the co-benefits that could come from investment in fusion research and development for other related scientific-technological fields, such as aerospace and space research:

"One thing that I found interesting is that fusion research can be applied to more areas, as he has also said… in aircrafts… they say that various technologies will be developed that are useful for other areas and this also seems very interesting to me" (Spain)

"When you make a spaceship, there are a lot of positive effects for the automotive industry, for the aerospace industry and so on. It certainly has positive effects on humanity. Now whether it will be all that nice remains to be seen" (Spain)

There were very few references made to the operational costs of fusion, with the topic only arising in Hungary (*"…it is expensive to produce fusion energy"*). It is possible that the magnitude of the costs associated with simply proving the concept of commercial fusion, detracted from considerations of the operational costs of the technology.

3.3. Can fusion really help address climate change?

The timescales for commercialisation of fusion were anticipated to be long in all countries. While concerns about long lead-in times to commercialisation of fusion are common, the relevance of these timescales in the current context were brought into focus by the associated and acknowledged timescales for decarbonising the energy sector. People reasoned that the target of decarbonising the energy sector by 2050 might be inconsistent with the outlined commercialisation timescales of fusion. It was not the case that the mismatch in timescales entirely undermined participants' desires for investment in fusion, however, there was a sense that placing faith in fusion to solve the decarbonisation issue could be foolish:

"… if the time horizon [for having a fusion commercial reactor] is set by 2050, it is worth nothing. I mean, according to the most optimistic estimates ITER will be achieved, though it is a prototype, not a commercial reactor, and therefore I think that it will be achieved after the [energy] transition that must lead us to net zero emissions. I do not say that we

should not allocate resources to this technology, on the contrary. However, it should not be something that we say 'ok, let's keep on using fossil fuels because then there will be nuclear fusion'. And by the way, it is not sure that it will be reached in time for allowing us to avoid a global warming with serious consequences for the planet and humanity" (Italy)

"I think the development of fusion is very slow or too slow […]. By 2050, when the first reactor is supposed to be commercially operational, I think we're going to be in serious trouble" (Slovenia)

For others, the mismatch in timescales was a source of frustration with the pace of fusion research and development. In Hungary, people speculated over whether this simply stemmed from financing issues, which could be corrected by a ramping up of investment, or if there were other reasons as to why the pace of development is so slow:

"Why can't we move faster? Why is the decade distance constant? What does it take? Material, people, money, creativity, technology? If the money that can be spent on fusion energy were suddenly doubled now, would that help? What is the limiting factor?" (Hungary)

The risks of backing fusion as a means of addressing climate change also led to concern in Belgium and Italy that it might draw funding from other more mature, proven low-carbon technologies:

"I also wonder how many resources will be necessary to develop the project, whether it can draw resources that may go to other [energy] sources, to projects at a more advanced level of development, projects that are more mature. For if we talk about 2050, knowing the current state of CO2 in the atmosphere, I mean further thirty years without certainties, in short thirty years at these levels, I do not know if the Earth system manages to resist" (Italy)

For some participants, it was the 'clean' nature of fusion per se, as opposed to its specific use in addressing climate change that was emphasised. For these people, the commercialisation timescales were seen as less of an issue. The status of fusion as a 'clean' source of energy typically seemed from participants contrasting it directly with fossil-based energy sources. In Belgium and Hungary some participants cautioned about the life-cycle carbon emissions associated with fusion, including those embodied in the construction of fusion reactors:

"…when people say this is an opportunity to be carbon neutral and then it's still dependent, first you have to start looking at all the products I need to build, […] how carbon neutral are they? Nobody takes that into account" (Belgium)

3.4. How does fusion compare to fission?

Nuclear fission was a touchstone for many participants in their considerations of fusion. Participants often spoke either directly or indirectly about the similarities and differences between fission and fusion, particularly regarding 'nuclear safety'. Where fusion was contrasted with fission, people tended to evaluate it more favourably. Where fusion and fission were assimilated, attitudes tended to be more negative. In general, participants in all countries perceived nuclear fusion as a better, less risky option than fission. It was not the case that people necessarily wanted a total abandonment of fission or felt that fusion was risk free, just that *relatively speaking* it was superior to fission, particularly given the anticipated benefits:

"I wouldn't completely abolish nuclear power, but I prefer fusion because it's a much more plentiful source" (Slovenia)

"There are a series of relative inconveniences that are minor to those of nuclear fission…in some way it is true that they minimise the risk in relation to fission and on the other hand, it also gives the feeling that will greatly increase the productivity of this energy. And of course, they are therefore relative drawbacks" (Spain)

One key discussion point was the production of radioactive waste, both because of its potential risks to human health and the environment, and its long-lived nature. Some participants used the issue of radioactivity as a means of questioning claims that fusion is an entirely 'clean' energy option. Where participants drew direct parallels with fission in this regard, opinions of fusion tended to be negative:

"…the biggest problem that arises with fusion nuclear power … is this radioactive waste, which is basically very burdensome for the environment […] And I have a serious concern about this waste" (Slovenia)

Where participants believed that fusion would produce less radioactive and less long-lived waste that fission, attitudes tended to be more favourable. Even where the prospect of radioactive waste was deemed to be less burdensome, however, it was still considered to be a main drawback to fusion:

"I see the issue of radioactive waste as an inconvenience, because, although it is not something like a conventional nuclear power plant, the risk is still there…" (Spain)

The shared radioactive risk of fusion and fission, also led some to espouse the benefits of non-nuclear technologies that would not come with this risk (e.g. renewables):

"…there are much less radioactive materials [with fusion compared with fission], but there is still zero risk such as wind or solar energy" (Spain)

The fact that fusion would generate radioactive waste led to pragmatic questions in Belgium and Italy around the challenges of managing the waste materials. Participants wished to know how much radioactive material would be generated, how it would be stored, and how it is made safe. These questions suggest that there may be a gap in public awareness on a highly contentious issue and raised the importance of engaging in public communication around the management of radioactive waste from fusion and safety issues more generally:

"…above all the most important fact is to try to spread the knowledge on this technology, so as to make it known to the general public. Otherwise, you risk finding yourself with beliefs that do not correspond to the real situation […]. The aspect of safety may be one of the main obstacles [to nuclear fusion] for common people" (Italy)

Related to radioactive risk, although less prevalent in discussions, was a fear of catastrophic accidents or explosions. Participants in Slovenia referenced Chernobyl and Fukushima when considering the risks posed by fusion. This might have been stimulated by ongoing national discussions about the safety of an existing nuclear fission reactor in Slovenia (at Krško). Concerns about explosions were sometimes tempered by participants' self-claimed lack of knowledge about fusion or a recognition that disasters like Fukushima are rare and unlikely. The former point, once again primed participants to consider the value of investing in public communication efforts. To the extent that fusion was deemed to be a good thing, such communication should help to debunk potential myths about the safety of fusion:

"… I don't know if there are higher temperatures, higher pressures, but that could lead to major explosions? I would be interested in such things, if anybody knows … They had it in Japan, but who would have thought that seawater would get in there: nobody. Lots of coincidences, one, the other, and then there we are" (Slovenia)

"After some nuclear disasters that have occurred in fission power plants, the doubt comes, doesn't it? Is this technology safe or not? Hence these doubts have certainly to be solved. To know means exactly to debunk these doubts" (Italy)

In Spain, part of the benefit of fusion over fission stemmed from the differences in the fuels being used to power the two types of reactor. Specifically, the use of Hydrogen was compared favourably with the use of Uranium, as it was seen as a safer option:

"The fact that they work with hydrogen and not with uranium as they usually do in nuclear power plants, is what really gives more security. I don't have any particular animosity towards nuclear energy either, everything and I know that obviously the few times that there have been nuclear accidents, because they can really be very strong, but well, for that reason, precisely because it is with hydrogen and that it is also hydrogen, because it can really cause so much, so much energy, I really think it is an option, it's a good option, isn't it?" (Spain)

That said, for some the radioactivity of tritium was still cause for concern, and the prospect that tritium facilities might be susceptible to external accidents or attacks was raised in Italy and Belgium:

"A problem may come from outside, as in the case of a plane crash, or anyway because of other problems coming from outside that could break down the walls and allow tritium as well as radioactive fumes to exit, even though they should not spread for many hundreds of kilometres far" (Italy)

"…what has not been given enough attention is another safety issue. Next to every nuclear fusion reactor, one has to have a tritium fabrication plant, hey. And that one is vulnerable. That one is fragile. If a plane falls on that, that's a problem" (Belgium)

In Slovenia, the prospect of military applications for fusion technologies (nuclear proliferation) was also mentioned as a potential security risk associated with fusion:

"…is it safe from a military point of view? That is to say, can this be abused to destroy the world?" (Slovenia)

3.5. Main cross-national differences

While care should be taken in deriving conclusions about cross-national differences in public attitudes towards fusion from this study, given its qualitative focus and the size and nature of our samples, it is noteworthy that certain topics of discussion were only raised or seemed to predominate discussions in certain groups. These points of divergence could be taken to reflect emerging differences in the societal discourse around fusion research in each national context and could provide a focus for future investigations.

In Belgium, for instance, the World Café tended to veer towards discussion of the political complexity and diplomatic delicateness of managing long-term international research projects, such as ITER. This could be taken to reflect the prominence of European Institutions (including the European Union) in Brussels, or the complex historic governance structure in Belgium. Interestingly, in this context, the political and bureaucratic arrangements between nations pursuing the demonstration and commercialisation of fusion was simultaneously seen as being a necessary condition for the success, but as something that would threaten or stymy the timely realisation of the programme. A primary expression of scepticism against the pursuit of fusion in Belgium was, therefore, connected to the issues posed by the politics of 'big science' projects, rather than by the technological progress that is still to be made:

"The main concern for me is the dynamics for technological cooperation … is it going to continue, or is it not going to be disrupted at some point by … political phenomena, political thunder?" (Belgium)

"So, the fear that the development of nuclear energy could be disrupted by a political storm. I do see that strongly present today. Whatever that storm is, how it is, how long it lasts, you can't form an idea of that, but keep in mind that there will be political storms in the next 50 years that could jeopardise 2050 [stated commercialisation date for fusion]" (Belgium)

In Italy, the World Café discussion was mainly focused on the remaining technical complexities of building an experimental reactor and a subsequent commercial fusion power plant. Fusion was generally anticipated to be a solution for helping to decarbonise the energy sector while providing a baseload of electricity to the grid necessary for the continuity of supply. As a consequence of this anchoring, the primary concern for the Italian participants were the timescales for realising fusion energy, given the pressing threat of the climate emergency:

"It is not sure that it will be reached in time to allow us to avoid global warming with serious consequences for the planet and humanity. Hence, we can say that it can be a valid technology, even though when climate change will already be an important and visible problem" (Italy)

In Spain, fusion was again anchored by the need to decarbonise the energy sector to urgently address climate change. This tended to prime concerns about the capital investment required to prove fusion as a viable concept, as well as the associated costs of building the experimental fusion reactor (ITER) and a commercial fusion power plant. In short, the economic value of investment (and payback on this investment) in fusion was raised as a key potential limitation. The financial risk of investing in fusion led to clear comparison with renewables, whose deployment was considered to be more immediate and thus less risky in the powering the energy transition:

"The cost, I think this is the main one [issue]. We are talking about a very large investment, which is very long-term, which still needs more research and a lot of machinery is needed to start and well, it's like a whole mountain. So, you have to see where the balance [of investment] is going…" (Spain)

In Hungary and Slovenia, the positive recognition that fusion could be a worthwhile investment was accompanied by concerns over its feasibility, and the health and safety risks relating to radioactive waste. For Slovenians, discussions around nuclear risk appeared to stem from debates around a current nuclear plant at Krško, which has received a lot of media coverage recently due to decisions around the operational extension of the plant, management of the legacy waste, and historic incidents at the site. Participants in Slovenia also referenced Chernobyl and Fukushima directly:

"The biggest problem that arises with fusion nuclear power […] is this radioactive waste, which is basically very burdensome for the environment […]. And I have a serious concern about this waste" (Slovenia)

While not explicitly referenced in Hungary, the proximity to Ukraine and the legacy of the Chernobyl incident might have also been anticipated to raise concerns around nuclear risk. Also, there is currently an active issue over how to manage radioactive waste from a nuclear power plant at Paks in Hungary, which could have bolstered this concern. That said, while Hungarians raised concern over the risks associated with radioactive waste, they did tend to view fusion energy as being preferable to fission in this regard:

"Radioactive waste is also produced here. Much less than in the fission power plant, but it is generated" (Hungary)

"Will there be radiation? Neutron radiation is produced. Even though compared to a conventional nuclear power plant, the danger is lower" (Hungary)

4. Discussion

The current study was designed to learn more about the roots of the mixed feelings that tend to accompany public discussions about fusion energy in Europe. It sits within a literature attesting to the value of engaging publics in discussion about technological innovation within the energy sector [20,21,28], and more specifically extends our base understanding of the emergent themes and perspectives that are driving public discourse about the role that fusion energy could and/or should play in a future energy system [13,44]. While there was nuance to how people in each country spoke about fusion energy in each country (see

Section 3), there was general consistency in the broad themes raised and discussed. Central in people's minds was the viability of the option, which then underpinned discussion about the relative value of financial investment in technology. Where there were more apparent areas of divergence, these tended to be informed by the specifics of the make-up of the World Café group and local national context (e.g. regional geopolitics, the state of national nuclear plants).

4.1. Key findings

The study confirmed that self-claimed awareness and knowledge of fusion was low among participants in each World Café. This was the case even though the participants were self-selected and thus might be anticipated to have a higher base-level of interest in the technology. The study also confirmed that the tone of the conversations in each World Café was generally positive, but that enthusiasm for fusion was tempered by questions about its viability and qualified by caveats placed upon support for investment in its R&D. Both of these findings aligned with our prior expectations about the likely nature of public attitudes towards fusion, derived from the extant literature [7,44–50]. The study findings do, however, also provide: (a) new depth to our understanding of these headline findings; (b) highlight avenues for future research; and (c) afford guidance on how the issues stemming from these findings might be addressed (e.g. for those seeking to promote more informed discussion about the role of fusion in a secure, decarbonised energy system). Each of these points will be discussed below.

4.1.1. Low awareness

While low self-reported awareness about fusion is a common finding [13,45,49], we feel that it is of particular importance in the current context for two key reasons. First, it argues in favour of the continuing need for concerted efforts to engage publics with fusion, particularly as the timelines for demonstration and commercialisation advance. Second, it validates the discursive methodological approach used within this study.

There is a recognised risk in research on unfamiliar topics that studies will register 'pseudo-opinions' or non-attitudes [79–81]. This is where people express an opinion towards an attitude object (in this case fusion) when they either do not hold an opinion or where their opinion is grounded in an erroneous or partial understanding of the target. It is generally not the case that people register such opinions maliciously, but rather they stem from a position of confusion, misperception or ignorance. Pseudo-opinions are oftentimes weak and thus dynamic, being subject to change as people learn more about the topic at hand. Pseudo-opinions can therefore be very different from a person's more informed attitudes about a given attitude object.

In light of the low levels of awareness and self-claimed knowledge of fusion, it is possible that the attitudes towards fusion registered in some polls and surveys are, in fact, pseudo-opinions. The positivity that is typically observed in these polls and surveys could thus be symptomatic of the prevailing 'holy grail' and technofix narrative that tends to frame media and social discourse of fusion [82,83], rather than a direct and informed endorsement of the technology. Importantly, our World Cafés enabled the provision of more detailed information than would typically be accessible to those completing a basic survey or poll. This provided space for learning, critical thought and discussion, and created a context within which more informed attitudes could develop. Anecdotally, although consistent with previous research [48], the provision of information in our study did appear to quell some of the early (uncritical) enthusiasm for fusion, moving some participants towards a more considered (albeit still broadly positive) attitudinal position.

4.1.2. Mixed feelings

Participants' discussions about fusion were typified by an expression of 'mixed feelings' about the technology. While they generally wanted to support investment in fusion – indicative of the hope that it could live up to its billing as a 'dream energy option' – as the World Cafés progressed, the realisation that fusion remains commercially unproven raised questions about both its viability and its desirability as a prospective energy option. In turn, this sparked debate as to the relative value of investment in fusion versus alternative, more mature options like renewables. This was especially true in the context of addressing the climate crisis, where participants were cognisant that the lengthy timescales for commercialising and then rolling-out of fusion would likely outstrip the 2050 targets set for decarbonising power generation. Notably, much of the critical discussion of fusion in the World Cafés was not overtly negative, but rather stemmed from a position of uncertainty or self-claimed ignorance about the technology and its relative risks and benefits. Thus, conversation tended to take the form (either implicitly or explicitly) of questioning regarding the potential pros and cons, as opposed to being driven by categorical beliefs or opinions.

Taken together, our findings can be seen to both confirm and extend those of previous studies. While the mixed feelings expressed in our World Cafés and the kinds of issues that were raised are consistent with other qualitative work on fusion [48], we go a step further by showing: (a) how core beliefs about the benefits and risks of fusion are broadly shared across five EU countries (as well as identifying some key points of difference in terms of what issues or aspects were emphasised); and (b) how perspectives on the relative value of fusion are maturing and evolving over time, particularly in response to unfolding world events and issues, most notably the climate crisis.

This latter point is exemplified in terms of how investment in the pursuit of fusion is seen to fit or conflict with the recognised need for urgent action on climate change. While there is debate within the fusion community as to whether it will be realistic option for decarbonising power generation by 2050, our participants often applied a 2050 frame when evaluating fusion. In doing so, this tended to stimulate direct comparisons between the value of investment in renewables versus fusion, and gave greater weight to concerns over the viability of fusion and timescales for commercialisation. While historically there are tongue-in-cheek references to fusion always being about '30 years in the future' [84,85], these comments took on a more consequential tone in this study as the participants acknowledged that key milestones for the decarbonisation of the energy sector now fall within this 30-year window.

Also, of note, was how fusion tended to be contrasted favourably with nuclear fission, as opposed to being assimilated with this divisive technology. This *might* be indicative that industry efforts to distinguish fusion from fission are beginning to gain traction in the public consciousness. That said, there was residual concern around the safety issues posed by fusion (particularly in terms of the production and management of radioactive waste) and investment in fusion was generally considered to be less preferable to investment in renewables (likely reflecting societal frames around the need for rapid decarbonisation). The apparent contrasting of preferences for fusion over fission in our study requires further investigation, particularly bearing in mind evidence showing how attitudes towards fission can guide attitudes towards fusion [13]. For example, it is possible that the uncoupling of fusion from fission in our study was a product of our chosen methodology (where information about fusion was provided) and the self-selected recruitment strategy (which might have attracted fusion sympathisers). What we can conclude with certainty, however, is that our World Café participants were able (or enabled) to actively differentiate fusion from fission, which ultimately held benefits for acceptance of fusion.

4.2. Implications and applications

Our findings confirm that when scratching beneath the surface of people's headline attitudes towards fusion, there remain a plethora of logical, thoughtful and widely shared questions about the role that it could and/or should play in a future decarbonised energy system in mainland Europe. These questions appear to be strongly framed by the adopted sense of urgency around the need to mitigate climate change, while also being shaped by a self-claimed low level of understanding about the nature of fusion and its advantages and drawbacks. In many respects, these findings are consistent with those of other research looking into the public acceptability of other innovative low-carbon technologies (e.g. Carbon Dioxide Utilisation, [58]), where knowledge is also proclaimed to be low and where the technologies tend to be evaluated predominantly against their anticipated ability to address climate change. The findings are also consistent with prominent models of energy technology acceptance (e.g. CTAF, [24]) particularly in terms of illustrating how publics negotiate the complex balance of costs, risks and benefits when considering their attitudes towards fusion energy (see Fig. 2). Beyond this, however, the findings have specific implications for: (a) what can be concluded from the headline attitudes registered in other polls and surveys about fusion; and (b) strategies around how investment in fusion should be communicated to lay publics.

In relation to the first point, while participants' attitudes towards fusion tended to remain broadly positive throughout the World Café discussions, they were underpinned by a mixture of feelings about the technology. Many of the points raised took the form, implicitly or otherwise, of questions, which is indicative that participants' attitudes were still forming. How these questions are answered going forward, and by whom, will fundamentally shape the form and direction that attitudes towards fusion will take. This not only affirms the importance of the fusion community ramping up meaningful dialogue with publics around the nature of fusion and its place in Europe's future energy system – particularly given the important role that social acceptance plays in governing the fate of technologies in democratic states like those studied [20,26] – but also would warn against advocates of fusion being complacent about the apparent favourability of fusion captured in some polls and surveys.

In relation to the second point, our findings have implications for how the fusion community could frame the technology in public communication programmes. Based upon our findings, we argue that there is a widening gap in the public consciousness between addressing the proximal challenge of mitigating climate change, and the perpetually distant and (as yet) unproven benefits of fusion. As long as fusion remains unproven, and given the growing strength of climate framing in energy policy discourse, this discrepancy in 'psychological distance' (see [86]) will likely serve to increase scepticism about the value of fusion, and strengthen the public desire for investment of more proven low-carbon options (e.g. renewables). Essentially, while the fusion industry may not necessarily be pushing a climate mitigation frame when advocating the technology, the fact that the timelines for the commercialisation of fusion are seen to coincide with efforts to address climate change (as well as its status as an abundant, low-carbon energy option) are creating conflict in the public eye, which could be detrimental to support for the technology.

Two potential solutions arise from this finding. First, to the extent that climate framing will likely continue to pervade and shape the social discourse on European energy policy (particularly in the short-medium term), effort could be made to reduce the apparent conflict in the fusion development and decarbonisation timelines. Regular announcements that give a realistic sense of the advancements being made in the pursuit of commercial fusion [87] could help to lower the level of construal with which fusion is evaluated by publics; reducing its hypotheticality and helping to garner more public support. That said, there are risks with taking this approach, in that it (a) hinges upon a steady stream of 'good news stories' about advancements being made in fusion research; and (b) could lead fusion to become viewed as a more direct competitor to funding and investment in other 'proximal', and more favourable technology options (notably renewables), which might not benefit fusion.

A second solution would be to purposefully frame fusion using a post-2050 narrative. Fusion could be promoted as *the* means of sustaining a secure, affordable, decarbonised energy sector in the second half of this century, in the context of (a) an already expanded renewables sector; (b) projected rises in energy demand; and (c) drives to phase-out nuclear fission. Fusion could be emphasised as a logical, long-term successor to fission in supplying reliable baseload electricity to meet demand in an increasingly electrified world. As our findings suggest, while not viewed as risk-free, fusion compares favourably to fission and is commonly seen as analogous in scope and utility. While the aforementioned arguments for fusion have been made elsewhere, we propose that there might be value in trialling a more strategic and systematic programme of public communication built around this narrative. The use of emphasis framing has been shown to affect public support for other energy technologies [88–90], and given the malleability of public attitudes towards fusion at this time, there is genuine potential for this post-2050 framing to register impact. While a purposive post-2050 frame could play into public concerns about the viability of fusion, it could also mean that investment in fusion is viewed as more complementary (and less competitive) to investment in renewables, which might further enhance support.

Taken together, we believe that the depth of discussion held within our World Cafés, combined with the nature of our findings, advocate for the promotion of more forums allowing for two-way public exchanges about the future of fusion energy in Europe (and beyond). For proponents of fusion, we also warn that the messaging used within these interactions should evolve. In particular, the intended (or unintended) focus on climate change and concurrent efforts to decarbonise power generation in such messaging *could* negatively affect public attitudes: creating unachievable timescales for commercialisation and detracting from the more realistic purpose of fusion, which is to sustainably meet growing energy demand in an already decarbonised system. These hypotheses around the evolution of messaging do require further research though.

4.3. Limitations and future directions

There are several limitations to the current study which mean that care should be taken when transferring or applying the findings to other groups or contexts, but which also offer interesting avenues for further investigation.

First, while the study was designed to explore the attitudes of lay-publics in five EU countries (and succeeded in generating rich and nuanced discussion about fusion), the small and self-selected nature of the samples mean that they should not be taken as representative of the wider public opinion in their respective nations. It would, thus, not be advisable to draw strong conclusions about the nature (or direct comparability) of public opinion in each nation from our findings. This is further compounded by limitations to the details about the socio-demographic make-up of the participants recorded in this study (e.g. educational attainment was not logged although might be anticipated to affect responses) and the fact that the World Cafés operated slightly differently in each country due to the ongoing COVID-19 pandemic. A logical step would be to test the findings of the current study using a methodology better suited to providing more generalisable data, and affording greater opportunity for cross-national comparisons. This could include broadening the scope to include to other European (and non-European) nations, and particularly those that might be anticipated to have a greater familiarity with fusion technologies (e.g., France, as host of ITER). One option would be to invest in an online, pan-European survey employing an information-and-choice approach [91,92]. Using this approach, which also tackles the issue of recording pseudo-opinions, alongside stratified sampling for key socio-demographics (e.g. age, gender, ethnicity, education), would provide a stern test of the generalisability and comparability of our findings. Such a survey could also feature a quasi-experimental element designed to examine the impact of the suggested re-framing options on comparative preferences for investment in fusion (e.g. the post-2050 narrative).

Second, our article introduced two related but competing explanations for the mixed feelings that are commonly expressed in relation to fusion: attitudinal ambivalence and conditional acceptability. While this study was designed to elucidate more about the thematic roots of these mixed feelings, it was not specifically designed with the intent of differentiating between these two attitudinal positions. Nor was it suitable for measuring attitude strength and certainty or charting how participants' attitudes evolved over time in response to the receipt of information within the World Cafés. These remain key foci for further empirical investigation.

On the basis of anecdotal evidence from our study and the results of other studies [43,47], one might hypothesise that: (a) participants should enter discussions about fusion holding a relatively positive but poorly informed (and thus weak) attitude towards fusion; that (b) this would then shift to a position of critical ambivalence as people are introduced to (balanced) information about the technology; before (c) rebounding to a more confidently held position of caveated acceptance after the information has been negotiated and assimilated into knowledge structures. Such 'flip-flopping' has been previously observed in a study examining how information designed to delineate fusion and fission (and to provide clarification on the use of depleted uranium in tritium storage), affected attitudes in both the UK and Germany [7].

It is an open question, however, as to whether such 'positive rebound' is guaranteed in relation to discussions about fusion. For example, one could argue that while attempts were made within our study to be impartial (e.g. by presenting participants with information about both the benefits and drawbacks of fusion), the presence of the fusion expert in the World Café, as well as participants' awareness of the pro-fusion sponsor of the study (EUROfusion), might have conspired to positively influence attitudes. It would thus be valuable to test whether the same dynamics would unfold in a similar study, where participants are exposed to the views of a fusion sceptic. Arguably, in this situation, one might expect attitudes to remain more ambivalent or take on a more confidently held negative position.

5. Conclusion

The public acceptability of emerging technologies plays a major role in their real-world deployment and success. This qualitative study was designed to shed light on the mixed feelings that tend to accompany public discussions about fusion. Across World Cafés held in five EU countries, we identified: (a) low levels of self-claimed awareness of fusion; and (b) four latent questions that pervaded conversations and that drove the caveats that people would place on their tentative support for fusion. Despite some national variation in the sub-themes discussed, the thrust of the questions was similar in each country, with critique principally stemming from the commercially unproven nature of fusion. This then raised questions about the relative value of investment in a future European energy system, particularly given the proximal threat of climate change. The findings have implications for public engagement and communication efforts relating to fusion (e.g. highlighting the current malleability in attitudes and suggesting means of framing the technology in public discourse). The study also opens up new avenues for investigation, including the need to evaluate whether the sentiment expressed in these World Cafés is shared among larger and more representative samples of each nation, and to understand more about the dynamics of attitude formation towards fusion in response to the provision of information.

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CRediT authorship contribution statement

Christopher R. Jones: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Christian Oltra:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alessio Giacometti:** Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Vanja Čok:** Visualization, Methodology, Investigation, Formal analysis, Data curation. **Janez Povh:** Methodology, Investigation, Data curation. **Ursa Lamut:** Methodology, Investigation, Formal analysis, Data curation. **Gaston Meskens:** Methodology, Investigation, Formal analysis, Data curation. **Joke Kenens:** Methodology, Investigation, Formal analysis, Data curation. **Robbe Geysmans:** Methodology, Investigation, Formal analysis, Data curation. **Catrinel Turcanu:** Data curation, Formal analysis, Investigation, Methodology. **Zoltan Ferencz:** Data curation, Formal analysis, Investigation, Methodology. **Maria Teresa Orlando:** Data curation, Formal analysis, Investigation, Methodology. **Chiara Bustreo:** Funding acquisition, Investigation, Project administration.

Declaration of competing interest

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Data availability

Data will be made available on request.

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Appendix A. The final coding template for the World Cafés, including an indication of which themes and sub-themes were referenced in each of the five participating countries

Level 1	Level 2	Level 3	BG	HU	IT	SP	SL
AFFECT (EMO-TIONS)	Positive	Feels right					
		Happiness					
	Negative	Fear					
		Anxiety					
		Other					
COGNI-TION (BELIEFS)	Costs	General cost					
		Expensive in capital investment					
		Expensive in research and development					
		Expensive in operation and maintenance					
		Personal financial cost (e.g. energy bills)					
		Worth the cost					
	Risks	It will not work/it is infeasible					
		Unproven technology					
		General accidents					
		Explosion/catastrophic breakdown					
		Radioactivity/radioactive waste as a risk					
		Timescales for development					
		Terrorism					
		Draws funding from other sources					
		Connection to military applications					
		Public objection/resistance					
	Challenges	Political delays decision					
		Not operational now					
		Complex technology					
		Centralized energy source					
		Environmental impact of a fusion reactor					
		Cooperation between countries					
		Scale of fusion reactor					
		Geopolitical issues and international energy policy					
		Radioactive waste as a challenge					
		Necessity/superfluity of fusion					
		Cooperation enabling efficient development?					
		Need for simultaneous development and deployment of energy storage technologies					
		Low carbon energy source					
		Stable/reliable energy source					

	Benefits of fusion or fusion research	Abundant energy source	■			■	■
		Dream option	■		■	■	■
		Reduces reliance on other sources	■				■
		Better (less risky) than fission	■		■	■	■
		Result of international cooperation	■	■	■		■
		Top science, stimulates S&T, advanced tech	■	■	■		■
		Preservation of knowledge	■	■	■		
		Safe energy				■	■
		Energy independence (e.g. diminishes geopolitical tensions)	■	■			
	Uncertainties	Impact on world solidarity	▒	▒		▒	▒
		Public acceptance	▒	▒	▒		
		Risk of accidents	▒	▒		▒	
		Access to knowledge	▒	▒			▒
		LCA of fusion development/cycle	▒		▒		
		Uncertainty about ratio advantages/disadvantages	▒		▒		
		Uncertainty about the feasibility	▒	▒	▒	▒	▒
		Who pays	▒	▒		▒	
		Societal desirability	▒				
TRUST	Trust in fusion scientists	Competence	░	░			░
		Integrity					░
	Trast in fusion stakeholders	Competence		░			
		Integrity		░			░
	Lack of trust in fusion scientists	Competence				▒	▒
		Integrity	▒				
	Lack of trust in fusion stakeholders	Competence					
		Integrity				▒	▒
JUSTICE	Procedural Justice	Past decisions based on limited knowledge	▒	▒			▒
		Consultation					
		Ability to influence decisions	▒				
		Willingness to allow for risk of failure	▒				
	Distributive justice	Fair siting of facilities	■				
		Energy consumption		■	■		

. (*continued*).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2024.103538.

References

[1] S.S. Bettin, Electricity infrastructure and innovation in the next phase of energy transition—amendments to the technology innovation system framework, Rev. Evol. Polit. Econ. 1 (3) (2020) 371–395, https://doi.org/10.1007/s43253-020-00021-4.

[2] G. Fulli, M. Masera, A. Spisto, S. Vitiello, A change is coming: how regulation and innovation are reshaping the European Union's electricity markets, IEEE Power Energy Mag. 17 (1) (2019) 53–66, https://doi.org/10.1109/MPE.2018.2872303.

[3] T. Hoppe, A. Butenko, M. Heldeweg, Innovation in the European energy sector and regulatory responses to it: guest editorial note, Sustainability 10 (2) (2018), https://doi.org/10.3390/su10020416.

[4] D. Webbe-Wood, Funding and financing commercial fusion power plants, in: W. Nuttall, S. Konishi, S. Takeda, D. Webbe-Wood (Eds.), Commercialising Fusion Energy: How Small Businesses Are Transforming Big Science, IOP Publishing, Bristol, 2021, pp. 4–8.

[5] EUROfusion, European Research Roadmap to the Realisation of Fusion Energy. https://euro-fusion.org/eurofusion/roadmap/. (Accessed 29 March 2023).

[6] M. Segreto, et al., Trends in social acceptance of renewable energy across Europe—a literature review, Int. J. Environ. Res. Public Health 17 (24) (2020) 9161, https://doi.org/10.3390/ijerph17249161.

[7] C.R. Jones, S. Yardley, S. Medley, The social acceptance of fusion: critically examining public perceptions of uranium-based fuel storage for nuclear fusion in Europe, Energy Res. Soc. Sci. 52 (2019) 192–203, https://doi.org/10.1016/j.erss.2019.02.015.

[8] Fusion For Energy, Merits of Fusion. https://fusionforenergy.europa.eu/merits-of-fusion-energy/. (Accessed 29 March 2023).

[9] ITER, Advantages of Fusion, Available, https://www.iter.org/sci/Fusion. (Accessed 29 March 2023).

[10] S.M. Gonzalez de Vicente, et al., Overview on the management of radioactive waste from fusion facilities: ITER, demonstration machines and power plants, Nucl. Fusion 62 (8) (2022) 085001, https://doi.org/10.1088/1741-4326/ac62f7.

[11] T.E.G. Nicholas, et al., Re-examining the role of nuclear fusion in a renewables-based energy mix, Energy Policy 149 (2021) 112043, https://doi.org/10.1016/j.enpol.2020.112043.

[12] T. Griffiths, R. Pearson, M. Bluck, S. Takeda, The commercialisation of fusion for the energy market: a review of socio-economic studies, Prog. Energy 4 (4) (2022) 042008, https://doi.org/10.1088/2516-1083/ac84bf.

[13] C.R. Jones, C. Oltra, A. Prades, Predicting attitudes towards fusion energy in Europe: results of a cross-national public survey in Austria, Finland, Spain and the UK, Energy Res. Soc. Sci. 75 (2021) 102028, https://doi.org/10.1016/j.erss.2021.102028.

[14] European Commission, Euratom Research and Training Programme. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/euratom-research-and-training-programme_en. (Accessed 29 March 2023).

[15] UK Government, Towards Fusion Energy: The UK Fusion Strategy. https://www.gov.uk/government/publications/towards-fusion-energy-the-uk-fusion-strategy. (Accessed 29 March 2023).

[16] US Department of Energy, Fusion Energy Sciences, www.energy.gov, https://www.energy.gov/science/fes/fusion-energy-sciences. (Accessed 29 March 2023).

[17] Fusion Industry Association. https://www.fusionindustryassociation.org/. (Accessed 29 March 2023).

[19] S. Barabaschi, et al., Fusion Programme Evaluation 1996. https://fire.pppl.gov/fp4_fusion_panel_final.pdf, 1996. (Accessed 29 March 2023).

[20] D. Baur, P. Emmerich, M.J. Baumann, M. Weil, Assessing the social acceptance of key technologies for the German energy transition, Energy Sustain. Soc. 12 (1) (2022) 4, https://doi.org/10.1186/s13705-021-00329-x.
[21] P. Upham, C. Oltra, À. Boso, Towards a cross-paradigmatic framework of the social acceptance of energy systems, Energy Res. Soc. Sci. 8 (2015) 100–112, https://doi.org/10.1016/j.erss.2015.05.003.
[22] R. Wüstenhagen, M. Wolsink, M.J. Bürer, Social acceptance of renewable energy innovation: an introduction to the concept, Energy Policy 35 (5) (2007) 2683–2691, https://doi.org/10.1016/j.enpol.2006.12.001.
[23] E. Adell, A. Varhelyi, L. Nilsson, The definition of acceptance and acceptability, in: T. Horberry, M.A. Regan, A. Stevens (Eds.), Driver Acceptance of New Technology, CRC Press, London, 2014, pp. 11–22.
[24] N.M.A. Huijts, E.J.E. Molin, L. Steg, Psychological factors influencing sustainable energy technology acceptance: a review-based comprehensive framework, Renew. Sust. Energ. Rev. 16 (1) (2012) 525–531, https://doi.org/10.1016/j.rser.2011.08.018.
[25] I. van de Poel, in: M. Franssen, P.E. Vermaas, P. Kroes, A.W.M. Meijers (Eds.), A Coherentist View on the Relation Between Social Acceptance and Moral Acceptability of Technology, Philosophy of Technology After the Empirical Turn, Springer, Cham, 2016, pp. 177–193.
[26] S.H. Lundheim, G. Pellegrini-Masini, C.A. Klöckner, S. Geiss, Developing a theoretical framework to explain the social acceptability of wind energy, Energies (Basel) 15 (14) (2022) 4934, https://doi.org/10.3390/en15144934.
[27] H.S. Boudet, Public perceptions of and responses to new energy technologies, Nat. Energy 4 (6) (2019) 446–455, https://doi.org/10.1038/s41560-019-0399-x.
[28] M. Bauer (Ed.), Resistance to New Technology: Nuclear Power, Information Technology and Biotechnology, Cambridge University Press, Cambridge, 1995.
[29] T.R. Peterson, J.C. Stephens, E.J. Wilson, Public perception of and engagement with emerging low-carbon energy technologies: a literature review, MRS Energy Sustain. 2 (1) (2015) 11, https://doi.org/10.1557/mre.2015.12.
[30] E. von Hippel, Democratizing innovation: the evolving phenomenon of user innovation, J. Betriebswirtsch. 55 (1) (2005) 63–78, https://doi.org/10.1007/s11301-004-0002-8.
[31] R. Owen, P. Macnaghten, J. Stilgoe, Responsible research and innovation: from science in society to science for society, with society, in: G.E. Marchant, W. Wallach (Eds.), Emerging Technologies: Ethics, Law and Governance, Routledge, London, 2020, pp. 117–126.
[32] S.H. Wilford, Responsible research and innovation: using the requirements tool for stakeholder engagement in developing a universal design for learning guidelines for practice, Sustainability 11 (10) (2019) 2963, https://doi.org/10.3390/su11102963.
[33] N. Gupta, A.R.H. Fischer, L.J. Frewer, Socio-psychological determinants of public acceptance of technologies: a review, Public Underst. Sci. 21 (7) (2012) 782–795, https://doi.org/10.1177/0963662510392485.
[34] N.M.A. Huijts, C.J.H. Midden, A.L. Meijnders, Social acceptance of carbon dioxide storage, Energy Policy 35 (5) (2007) 2780–2789, https://doi.org/10.1016/j.enpol.2006.12.007.
[35] C.R. Jones, P. Hilpert, J. Gaede, I.H. Rowlands, Batteries, compressed air, flywheels, or pumped hydro? Exploring public attitudes towards grid-scale energy storage technologies in Canada and the United Kingdom, Energy Res. Soc. Sci. 80 (2021) 102228, https://doi.org/10.1016/j.erss.2021.102228.
[37] C. Chen, X. Xu, L. Arpan, Between the technology acceptance model and sustainable energy technology acceptance model: investigating smart meter acceptance in the United States, Energy Res. Soc. Sci. 25 (2017) 93–104, https://doi.org/10.1016/j.erss.2016.12.011.
[38] J.L. Johnson, K.M. Kartchner, M.J. Maines, Crossing Nuclear Thresholds: Leveraging Sociocultural Insights Into Nuclear Decisionmaking, Springer, Cham, 2018.
[39] S. L'Orange Seigo, S. Dohle, M. Siegrist, Public perception of carbon capture and storage (CCS): a review, Renew. Sust. Energ. Rev. 38 (2014) 848–863, https://doi.org/10.1016/j.rser.2014.07.017.
[40] K. Witte, Social acceptance of carbon capture and storage (CCS) from industrial applications, Sustainability 13 (21) (2021) 12278, https://doi.org/10.3390/su132112278.
[41] P. Ashworth, S. Wade, D. Reiner, X. Liang, Developments in public communications on CCS, Int. J. Greenhouse Gas Control 40 (2015) 449–458, https://doi.org/10.1016/j.ijggc.2015.06.002.
[42] P. Ashworth, et al., Communication/Engagement Toolkit for CCS Projects. https://www.globalccsinstitute.com/archive/hub/publications/13571/publication-20110601-communication-engagement-toolkit.pdf, 2011. (Accessed 29 March 2023).
[43] C. Gough, S. Mander, Beyond social acceptability: applying lessons from CCS social science to support deployment of BECCS, Curr. Sustain. Renew. Energy Rep. 6 (4) (2019) 116–123, https://doi.org/10.1007/s40518-019-00137-0.
[44] A. Prades, T. Horlick-Jones, C. Oltra, J. Navajas, Cross-cultural Comparative Analysis of Lay and Stakeholder Reasoning About Fusion Energy in Spain and the UK. https://inis.iaea.org/collection/NCLCollectionStore/_Public/41/021/41021815.pdf, 2009. (Accessed 29 March 2023).
[45] T. Horlick-Jones, A. Prades, J. Espluga, Investigating the degree of 'stigma' associated with nuclear energy technologies: a cross-cultural examination of the case of fusion power, Public Underst. Sci. 21 (5) (2012) 514–533, https://doi.org/10.1177/0963662510371630.
[46] C. Oltra, C.R. Jones, A. Prades, The public acceptance of fusion energy research in Europe: results from a cross-national survey study, in: International Conference on Environmental Psychology, Plymouth, United Kingdom, 2019.
[47] C. Oltra, A. Prades, C. Jones, A. Delicado, L. Schmidt, C. Turcanu, Informed Public Attitudes Towards Fusion Energy in Europe. http://documenta.ciemat.es/handle/123456789/536, 2019. (Accessed 29 March 2023).
[48] A. Prades López, T. Horlick-Jones, C. Oltra, J. Navajas, Lay Understanding and Reasoning About Fusion Energy: Results of an Empirical Study, CIEMAT, Madrid, 2009.
[49] I. Čábelková, W. Strielkowski, D. Streimikiene, F. Cavallaro, J. Streimikis, The social acceptance of nuclear fusion for decision making towards carbon free circular economy: evidence from Czech Republic, Technol. Forecast. Soc. Change 163 (2021) 120477, https://doi.org/10.1016/j.techfore.2020.120477.
[50] C. Turcanu, A. Prades, R. Sala, T. Perko, C. Oltra, Fusion energy: a deeper look into attitudes among the general public, Fusion Eng. Des. 161 (2020) 111891, https://doi.org/10.1016/j.fusengdes.2020.111891.
[51] M. Conner, C.J. Armitage, Attitudinal ambivalence, in: W.D. Crano, R. Prislin (Eds.), Attitudes and Attitude Change, Psychology Press, London, 2008, pp. 261–286.
[52] P.L. Gardner, Measuring ambivalence to science, J. Res. Sci. Teach. 24 (3) (1987) 241–247, https://doi.org/10.1002/tea.3660240305.
[53] M. Conner, P. Sparks, Ambivalence and attitudes, Eur. Rev. Soc. Psychol. 12 (1) (2002) 37–70, https://doi.org/10.1080/14792772143000012.
[54] C.J. Armitage, M. Conner, Attitudinal ambivalence: a test of three key hypotheses, Personal. Soc. Psychol. Bull. 26 (11) (2000) 1421–1432, https://doi.org/10.1177/0146167200263009.
[55] G. Hodson, G.R. Maio, V.M. Esses, The role of attitudinal ambivalence in susceptibility to consensus information, Basic Appl. Soc. Psychol. 23 (3) (Sep. 2001) 197–205, https://doi.org/10.1207/S15324834BASP2303_6.
[56] D. Wang, F.L. Weisstein, S. Duan, P. Choi, Impact of ambivalent attitudes on green purchase intentions: the role of negative moods, Int. J. Consum. Stud. 46 (1) (2022) 182–199, https://doi.org/10.1111/ijcs.12663.
[57] K. Bickerstaff, I. Lorenzoni, N.F. Pidgeon, W. Poortinga, P. Simmons, Reframing nuclear power in the UK energy debate: nuclear power, climate change mitigation and radioactive waste, Public Underst. Sci. 17 (2) (2008) 145–169, https://doi.org/10.1177/0963662506066719.
[58] C.R. Jones, B. Olfe-Kräutlein, D. Kaklamanou, Lay perceptions of carbon dioxide utilisation technologies in the United Kingdom and Germany: an exploratory qualitative interview study, Energy Res. Soc. Sci. 34 (2017) 283–293, https://doi.org/10.1016/j.erss.2017.09.011.
[59] M. Kearnes, B. Wynne, On nanotechnology and ambivalence: the politics of enthusiasm, Nanoethics 1 (2) (2007) 131–142, https://doi.org/10.1007/s11569-007-0014-7.
[60] K. Langer, T. Decker, J. Roosen, K. Menrad, Factors influencing citizens' acceptance and non-acceptance of wind energy in Germany, J. Clean. Prod. 175 (2018) 133–144, https://doi.org/10.1016/j.jclepro.2017.11.221.
[61] J.L. Luján, O. Todt, Perceptions, attitudes and ethical valuations: the ambivalence of the public image of biotechnology in Spain, Public Underst. Sci. 9 (4) (2000) 383–392, https://doi.org/10.1088/0963-6625/9/4/303.
[62] M. Barr, D. Rose, The great ambivalence: factors likely to affect service user and public acceptability of the pharmacogenomics of antidepressant medication, Sociol. Health Illn. 30 (6) (2008) 944–958, https://doi.org/10.1111/j.1467-9566.2008.01116.x.
[63] A.K. Wolfe, D.J. Bjornstad, Why would anyone object? An exploration of social aspects of phytoremediation acceptability, CRC Crit. Rev. Plant Sci. 21 (5) (2002) 429–438, https://doi.org/10.1080/0735-260291044304.
[64] J.G. Stapels, F. Eyssel, Robocalypse? Yes, please! The role of robot autonomy in the development of ambivalent attitudes towards robots, Int. J. Soc. Robot. 14 (3) (Apr. 2022) 683–697, https://doi.org/10.1007/s12369-021-00817-2.
[65] G.M. Pohost, G.A. Elgavish, W.T. Evanochko, Nuclear magnetic resonance imaging: with or without nuclear? J. Am. Coll. Cardiol. 7 (3) (1986) 709–710, https://doi.org/10.1016/S0735-1097(86)80486-7.
[66] Z.L. Tormala, D.D. Rucker, Attitude certainty: antecedents, consequences, and new directions, Consum. Psychol. Rev. 1 (1) (2018) 72–89, https://doi.org/10.1002/arcp.1004.
[67] Z.L. Tormala, D.D. Rucker, Attitude certainty: a review of past findings and emerging perspectives, Soc. Personal. Psychol. Compass 1 (1) (2007) 469–492, https://doi.org/10.1111/j.1751-9004.2007.00025.x.
[68] P. Johnstone, A. Stirling, Comparing nuclear power trajectories in Germany and the UK: from 'regimes' to 'democracies' in sociotechnical transitions and discontinuities, SSRN Electron. J. (2015), https://doi.org/10.2139/ssrn.2744549.
[69] A. Delicado, A. Prades, L. Schmidt, World Cafè Methodological Design and Pilot, 2020.
[70] J. Brown, D. Isaacs, The World Café: Shaping Our Futures Through Conversations That Matter, Berrett-Koehler Publishers, Oakland, 2005.
[71] K. Löhr, M. Weinhardt, S. Sieber, The 'World Café' as a participatory method for collecting qualitative data, Int J Qual Methods 19 (2020), https://doi.org/10.1177/1609406920916976.
[72] A. While, B. Murgatroyd, R. Ullman, A. Forbes, Nurses', midwives' and health visitors' involvement in cross-boundary working within child health services, Child Care Health Dev. 32 (1) (2006) 87–99, https://doi.org/10.1111/j.1365-2214.2006.00597.x.
[73] E.L. Ritch, C. Brennan, Using World Café and drama to explore older people's experience of financial products and services, Int. J. Consum. Stud. 34 (4) (2010) 405–411, https://doi.org/10.1111/j.1470-6431.2010.00881.x.
[74] H. Schiele, S. Krummaker, P. Hoffmann, R. Kowalski, The 'research world café' as method of scientific enquiry: combining rigor with relevance and speed, J. Bus. Res. 140 (2022) 280–296, https://doi.org/10.1016/j.jbusres.2021.10.075.

[75] IEA, Net zero by 2050: a roadmap for the global energy sector – a special report by the International Energy Agency. https://unfccc.int/sites/default/files/resource/IEA_net_zero_by_2050.pdf. (Accessed 29 March 2023).

[76] Fusion for Energy. https://fusionforenergy.europa.eu/. (Accessed 29 March 2023).

[77] J. Brooks, S. McCluskey, E. Turley, N. King, The utility of template analysis in qualitative psychology research, Qual. Res. Psychol. 12 (2) (2015) 202–222, https://doi.org/10.1080/14780887.2014.955224.

[78] V. Braun, V. Clarke, Successful Qualitative Research: A Practical Guide for Beginners, SAGE Publications, New York, 2013.

[79] P.E. Converse, Attitudes and non-attitudes: continuation of a dialogue, in: E. R. Tufte (Ed.), The Quantitative Analysis of Social Problems, Addison, Wesley, 1970, pp. 168–198.

[80] L.V. Grant, J.W. Patterson, Non-attitudes: the measurement problem and its consequences, Polit. Methodol. 2 (4) (1975) 455–481.

[81] W.E. Saris, P.M. Sniderman, Studies in Public Opinion, Princeton, Princeton University Press, 2004.

[82] C. Oltra, P. Román, A. Prades, Media coverage of nuclear energy after Fukushima. http://documenta.ciemat.es/bitstream/123456789/91/1/IC1302.pdf, 2013. (Accessed 29 March 2023).

[83] L. Schmidt, A. Horta, S. Pereira, A. Delicado, The Fukushima nuclear disaster and its effects on media framing of fission and fusion energy technologies, in: 4th International Conference on Advancements in Nuclear Instrumentation Measurement Methods and Their Applications (ANIMMA), IEEE, 2015, pp. 1–11, https://doi.org/10.1109/ANIMMA.2015.7465637.

[84] N. Scharping, Why nuclear fusion is always 30 years away, in: Discover Magazine, 23 March 2016. https://www.discovermagazine.com/technology/why-nuclear-fusion-is-always-30-years-away. (Accessed 29 March 2023).

[85] G. Willmer, Dream of unlimited, clean nuclear fusion energy within reach, in: Horizon: The EU Research and Innovation Magazine, 27 June 2022. https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/dream-unlimited-clean-nuclear-fusion-energy-within-reach. (Accessed 29 March 2023).

[86] Y. Trope, N. Liberman, Construal-level theory of psychological distance, Psychol. Rev. 117 (2) (2010) 440–463, https://doi.org/10.1037/a0018963.

[87] J. Tollefson, E. Gibney, Nuclear-fusion lab achieves 'ignition': what does it mean? Nature 612 (7941) (2022) 597–598, https://doi.org/10.1038/d41586-022-04440-7.

[88] J.B. Bullock, A. Vedlitz, Emphasis framing and the role of perceived knowledge: a survey experiment, Rev. Policy Res. 34 (4) (2017) 485–503, https://doi.org/10.1111/ropr.12231.

[89] G. de Vries, B.W. Terwel, N. Ellemers, Perceptions of manipulation and judgments of illegitimacy: pitfalls in the use of emphasis framing when communicating about CO2 capture and storage, Environ. Commun. 10 (2) (2016) 206–226, https://doi.org/10.1080/17524032.2015.1047884.

[90] C.R. Jones, J.R. Eiser, T.R. Gamble, Assessing the impact of framing on the comparative favourability of nuclear power as an electricity generating option in the UK, Energy Policy 41 (2012) 451–465, https://doi.org/10.1016/j.enpol.2011.11.006.

[91] D.v. Knippenberg, D. Daamen, Providing information in public opinion surveys: motivation and ability effects in the information-and-choice questionnaire, Int. J. Public Opin. Res. 8 (1) (1996) 70–82, https://doi.org/10.1093/ijpor/8.1.70.

[92] C.A. Van der Salm, D. van Knippenberg, D.D.L. Daamen, A critical test of the choice questionnaire for collecting informed public opinions, Qual. Quant. 31 (2) (1997) 193–197, https://doi.org/10.1023/A:1004214500745.