The role of nuclear energy in the sustainable energy system transition: a scoping review into the complexity of decision-making trade-offs and public participation in the UK

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Abstract

Purpose – Nuclear energy is a contested topic, requiring trade-offs in energy independence, ethicality and uncertainty. Anthropogenic climate change complicates these decisions further, with nuclear energy competing with other low-carbon and sustainable energy sources. Decisions about nuclear energy's role, as part of a sustainable energy system, must be made in cooperation with all stakeholders. However, it is unclear how the public is involved in these decisions in the UK. This study aims to address this gap, exploring the degree to which public participation has occurred in the UK.

Design/methodology/approach – This paper conducted a scoping review of public participation in UK nuclear energy decision-making in the context of sustainable energy transitions, where the government retains and promotes nuclear energy as part of a sustainable energy system. Following a systematic literary search, this paper reviewed 28 academic and grey literature documents.

Findings – Public participation has primarily been conducted as consultations rather than active participation. There is limited evidence that consultations have meaningfully contributed to politically and

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socially responsible (i.e. individuals and groups working together for community benefit) decision-making, with public opinion on nuclear energy's role being divided and is influenced by how it is framed.

Originality/value – Social aspects of nuclear energy development have historically received less attention than environmental and economic elements; the role of engagement and participation is relatively rare. Modern literature reviews in this context are largely absent, a gap this paper originally contribute to. This paper suggest ways in which how effective, inclusive engagement process could contribute to a fairer, responsible decision-making process and energy system in the UK.

Keywords Transition, Climate change mitigation, Responsible, Public participation, Nuclear energy, Sustainable system

Paper type Literature review

1. Introduction

The necessary transition to a low or zero carbon society to address the climate emergency is well-known (IPCC, 2014). With energy generation being one of the largest emitters of greenhouse gases (IPCC, 2014; EEA, 2020), the concept of nuclear fission as a virtually carbon-free energy source (IEA, 2019) seems an attractive and responsible transition option. Countering this proposition are the transgenerational trade-offs and ethical concerns that relate to radioactive waste disposal, such as the long-term deterioration of waste containment in above and below ground repositories and community concerns over disposal-facility siting.

Research on the role of nuclear energy (NE) suggests that retaining or even adding NE capacity could make a valuable contribution to sustainable energy systems (SES hereafter), climate change mitigation (CCM) and addressing both environmental and energy demand challenges (Çağlar *et al.*, 2024), whilst preventing a reliance on fossil fuels and complementing renewable energy sources in the short- to medium-term (Kang *et al.*, 2020; Siqueira *et al.*, 2019; Suman, 2018). Similar to other nations, the UK is currently grappling with an energy transition, one that will meet carbon reduction targets of 80% by 2050, based on 1990 levels. As of 2021, the UK generated 20% of its power from NE, with 15 plants in operation (Butler and Bud, 2018; WNA, 2021). Following an energy policy review in 2006 (DTI, 2006), the UK /Government advocated new nuclear build as a strategy for increasing electricity generation from low-carbon sources. The UK is investing heavily into both nuclear fission and fusion energy, outlined in the *"Ten Point Plan for a Green Industrial Revolution"* (HM Govt., 2020a) and the recent government white paper *"Powering our Net Zero Future"* (HM Govt., 2020b). In this context, energy system sustainability is increasingly dependent on its ability to utilise low-carbon technologies to mitigate anthropogenic climate change (ACC hereafter) and contribute to achieving "Net-Zero" goals. This includes up to £1.7 billion to bring at least one large-scale nuclear project to a final investment decision, £210m into small nuclear reactors and a new £120m Future Nuclear Enabling Fund to provide targeted support towards further nuclear projects as part of the Net-Zero Strategy. As a result, new nuclear reactors are currently being constructed at Hinkley Point in Somerset, England and more are in various stages of proposal and planning (HM Govt., 2020b). Nuclear energy is also being developed to contribute towards meeting international development goals, such as the United Nations Sustainable Development Goals (UN SDGs), due to the potential for it to address multiple goals including as affordable and clean energy (SDG 7), industry, innovation and infrastructure (SDG 9), responsible production and consumption (SDG 12) and climate action (SDG 13). For proponents of the technology, the generation of "cleaner" energy in the form of NE represents a technological tool to address CCM through more responsible production of low-carbon energy. Internationally, it has also

been argued that NE is important if SDGs are to be achieved, such as in Brazil (Çağlar *et al.*, 2024).

Whilst there is a substantial body of literature on public participation relating to nuclear new build and decommissioning (Bond *et al.*, 2004; Duvic-Paoli and Lueger, 2022; Hoti *et al.*, 2021), siting (Keleher, 2017; Krütli *et al.*, 2010; Turcanu *et al.*, 2014) and waste disposal (Brunnengräber and Di Nucci, 2019; Elling and Nielsen, 2018; Huang and Chen, 2021) across several countries, the degree to which the public participates in decision-making on NE, in the context of sustainability via CCM, remains broadly unknown – despite research showing that these are complex trade-off decisions in the public interest (Bian *et al.*, 2021; Corner *et al.*, 2011; Pidgeon *et al.*, 2008; Pralle and Boscarino, 2011). This review contributes to addressing this limitation in current understanding. Public stakeholders are important to include and collaborate with from a responsible research and innovation perspective, such that the transition towards a SES is "socially and technologically acceptable" and creates shared responsibility and mutual responsiveness between "energy system actors and local communities" (Koirala *et al.*, 2018, p. 571; also see Correljé *et al.*, 2015; Stilgoe *et al.*, 2013; Carbajo and Cabeza, 2018). This review holds value in that it highlights whether the processes of and opportunities for engagement of such stakeholders have been historically effective and sufficient, thereby identifying where future procedural improvements may be required.

To address this, we conduct a scoping review with the aim of collating the academic and grey literature on decision-making processes related to NE development, which:

- involves stakeholder groups, with a focus on citizens; and
- discusses NE in relation to/or as a trade-off for CCM.

Specifically, our scoping review aims to identify, summarise and analyse this literature, reporting the extent to which such practices are performed, the degree of participation used (e.g. consultant vs full participatory designs) and the results of evaluations.

We focus on public engagement in the UK, because this context is a particularly interesting case. As shown above, the UK is currently sustaining, if not increasing investments into NE, which makes it especially important to investigate whether the public has been adequately involved in these decisions. We focus on NE generation in the UK, CCM and nuclear trade-offs rather than nuclear technology in general. Our contribution is a modern, critical review of the literature and current thinking in this area, whilst highlighting the directions in which future research on participatory decision-making and the trade-off framing should proceed and questions it should pursue regarding the role of NE in a sustainable energy transition in the UK. Due to the current developmental and therefore engagement status of nuclear fusion technologies, this is not a focus of the current review. Rather we focus on more established NE technologies where engagement processes have taken place over several decades and have been studied to a much greater extent than emerging, undeveloped NE technologies.

There are well-known examples of historic catastrophes related to NE generation (Espluga *et al.*, 2018), and public opinion towards the technology has always been complex and multidimensional, with a multitude of cognitive and emotive factors driving risk perception (Espluga *et al.*, 2018; Gupta *et al.*, 2019; Konrad and Espluga, 2018). In the past, some countries have included participatory processes in decision-making related to NE (Espluga *et al.*, 2018), and frameworks have been suggested to guide processes like this (Whitton *et al.*, 2015). So far however, most processes have involved consultations rather than actively engaging citizens (Charnley-Parry *et al.*, 2017; Konrad and Espluga, 2018), with decision-making often perceived to be a top-down, large-scale process (Espluga *et al.*,

2018), with too little emphasis on the local communities that are impacted by NE developments or that rely on them for employment (Whitton *et al.*, 2016). The most impactful citizen-led events, incidentally, were those in social movements opposing or delaying nuclear sites (Cotton *et al.*, 2019). This suggests that although there are some efforts to engage in participatory practices, these are not yet common and are not implemented well enough to be able to provide just and fair energy-related decision-making.

Global CCM introduces another highly complex set of challenges, equally associated with intergenerational trade-offs. Some stakeholders are aware of this conflict of interest, and struggle to reach a consensus regarding the future role of NE in this regard (Cotton *et al.*, 2019). A similar picture is emerging for citizens, who place importance on both general attitudes to NE and its meaning for CCM in their assessment of the technology (Konrad and Espluga, 2018; Pidgeon *et al.*, 2008; Vainio *et al.*, 2017). It is necessary for governmental decisions regarding NE at least to consider, if not make central, citizens' opinions in order to achieve both ecological and social sustainability of energy generation and supply. In the UK, the last major decision on the role of NE in the energy mix was taken in 2006 and 2007 as part of the government's energy policy review (see DTI, 2006). Considering that over fifteen years have passed since strategic governmental decisions on NE, and with global issues of ACC and low-carbon/zero carbon transitions only increasing in importance, a modern, inclusive discussion of its role in a sustainable national energy system is important and overdue.

2. Methods

2.1 Eligibility criteria

Following on from the context laid out above, we aimed to identify documents which addressed decision-making processes in the UK, adhering to three core criteria:

(1) presenting data that obtained the perspective of citizens, residents or other members of the public;

(2) on NE; and

(3) within the context of CCM or the zero carbon transition.

We focused on records from 2006 onwards because we were interested in documenting citizen involvement following the 2006 UK Energy Review (DTI, 2006). This marks an important time point because whilst cleaner coal, oil and gas and renewable sources of energy were seen as essential for the future, the review acknowledged that electricity generation capacity replacement issues could arise due to the planned shutdown of several nuclear power stations over the following two decades. Therefore, the UK Government concluded that NE was necessary to fulfil a role in reducing emissions but also in ensuring electricity generation capacity and diversity, especially in ensuring sufficient base-load generation. Further, the year 2006 has been described as a starting point for the discourse on NE as a part of CCM (Arlt and Wolling, 2016). Results in English, German or Russian were included, and only records presenting new data were eligible, which excluded reviews.

2.2 Search strategy

Because the aim of this scoping review is to identify any instances of citizen involvement in decision-making, we implemented a search strategy that was focused on both academic and grey literature. The searches were performed in April and May 2021.

We searched for literature in four steps. Firstly, academic databases, both interdisciplinary and psychology focused (Web of Science, PsycInfo, Scopus), were

searched using search terms detailed in Table 1; secondly, grey literature databases (Open Grey, ProQuest, Social Science Research Network) were searched using the same keywords. Thirdly, relevant stakeholders were identified using past research on NE in the UK (Butler and Bud, 2018) and experience within the research team. The websites of those stakeholders were then searched using the same keywords, using built-in search engines or Google custom searches, and including Boolean operators as far as search engine functionality allowed. Finally, in a fourth step, recent decision-making processes such as those on new nuclear power stations and the search for a fusion energy plant site (UK AEA, 2024) were searched manually to identify any additional documentation. Table 1 shows the keywords used in the searches. As a scoping review, our study is not as wide-reaching as a systematic review (see Munn *et al.*, 2018), hence our review is focused on published and accessible literature rather than those studies and reports that are unpublished, under peer review or pre-publication.

2.3 Screening

An overview of the selection process and number of results per stage is given in Figure 1. Firstly, records from the different search steps were combined into an overall database and duplicates removed. Then, abstracts were screened based on the eligibility criteria presented above. Where no abstract, summary or other description of contents was present, the documents were searched for the terms in Table 1 and included if at least one keyword from each column was in the document. On some occasions, one search result led to multiple documents that needed to be screened, in which case each of the additional documents were added to the database and screened individually.

Next, the resulting eligible records were screened based on their full texts and using the same eligibility criteria as above. In this step, reasons for exclusion were noted and are presented in Figure 1.

Nuclear energy	AND	Climate change mitigation	AND	Citizen involvement
Synonyms included with OR:		Synonyms included with OR:		Synonyms included with OR:
Nuclear energy		Climate change		Citizen
Atomic energy		Global warming		Resident
Nuclear power		Climate crisis		Community
Atomic power		Climate catastrophe		Grassroot
Fission power		Zero carbon transition		Participation
Fusion power		Energy transition		Participatory
Nuclear fission power		Low-carbon transition		Consultation
Nuclear fusion power		Net-zero energy		Consulting
Thermonuclear fusion		Zero emissions		Trade-offs
Thermonuclear power		Zero carbon		Trade offs
Nuclear waste		Green energy		Decision-making
Atomic waste		Clean energy		Decision-making
Small modular reactor		Sustainable energy		Risk perception
European pressured advanced gas cooled reactor		Clean power		Reasoning
		Green power		Risk assessment
Reactor		Clean electricity		Public opinion
Reactor core		Green electricity		Public attitude
Fukushima				Public perception

Source: Created by authors

Table 1. All search terms and synonyms used within the themes of nuclear energy, climate change mitigation and citizen involvement for the scoping review process

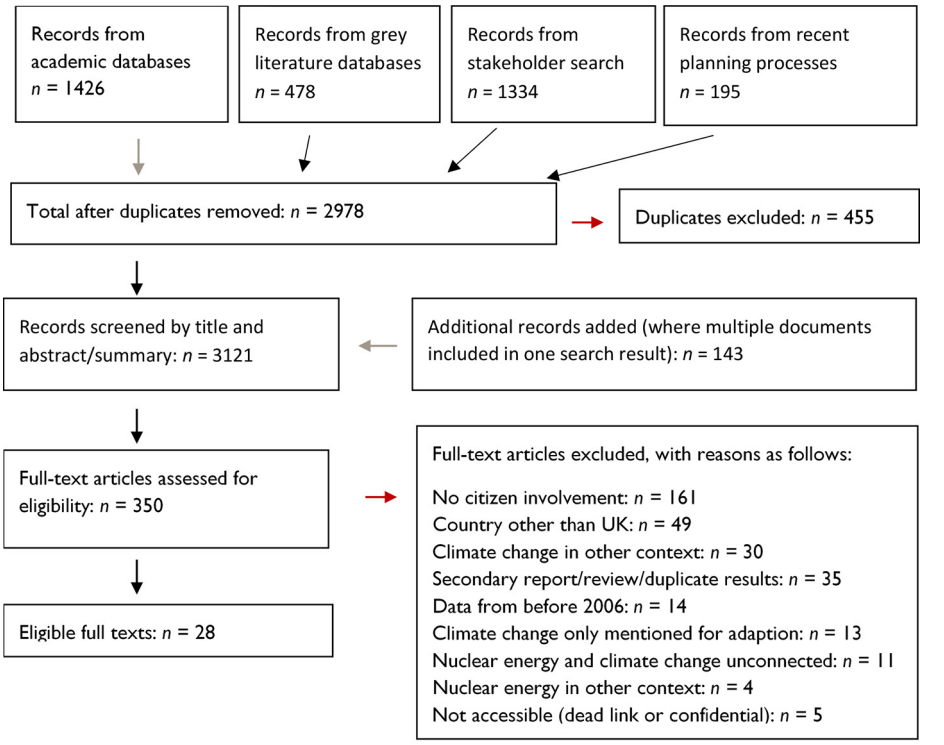

Figure 1.
The screening and selection process used in this scoping review

Sources: Created by authors; adapted from PRISMA flowchart (Moher *et al.*, 2009)

3. Results

The search resulted in 3,433 records, the majority of which came from academic databases ($n = 1{,}426$) and stakeholder websites ($n = 1{,}334$), followed by grey literature databases ($n = 478$) and searches of recent planning processes ($n = 195$). Removing 455 duplicates and adding additional records where multiple documents were identified ($n = 143$), resulted in a corpus of 3,212 records to be screened. Screening first by abstract, summary or keywords, then by full text, resulted in a final 28 eligible texts.

Below, information from the records is presented in categories according to their degree of citizen involvement. In total, 22 of the identified records were research papers or reports with no direct contribution to decision-making processes, one was research conducted by the UK Government to contribute to policy formation and five were documents from governmental consultations.

3.1 Government literature and research

Six documents describing processes involving the UK Government were identified in the search and are presented in Appendix 1. One is a summary of responses to the second consultation of the 2006 energy policy review (BERR, 2008). This second consultation was mandated by a High Court decision in 2007 ruling that the first consultation was insufficient in providing a fair consultatory process (EWHC, 2007). As this scoping review focuses on decision-making processes after the 2006/2007 energy policy review, the responses to this

consultation will not be discussed in detail here. However, a comprehensive evaluation of the consultation and its integration into policy was conducted by Warburton (2009). In summary, Warburton finds that that the consultation was generally satisfactory, and its results were mostly integrated into policy. However, it was clear that the purpose of the consultation was to test a pre-existing governmental preference or decision, rather than come to a collaborative decision with stakeholders.

Remaining documents contain a very limited picture of citizen involvement since 2007. Instances where NE is discussed in the context of CCM include when individuals question the role of nuclear technologies in the energy system and the validity of the decision for new nuclear build (Dean, 2019; DECC, 2011; Rogers, 2020). Two of these are letters from individuals contributing to a consultation about Wylfa Newydd (Dean, 2019; DECC, 2011; Rogers, 2020), stating that the site would be better used for renewable energy and that renewable energy is more economic and effective. The third is the government summarising and responding to consultation contributions on the revised draft National Policy Statement for Energy Infrastructure (DECC, 2011). Here, several individuals favour other energy sources over NE, to which the government responds by referring to the 2006/2007 energy policy decision asserting that new nuclear should be part of the energy system. The government also emphasises that the contribution of NE is dependent on the decisions of private companies and investors, not the government.

A very recent example of citizen engagement is documented by Greenpeace (2020), who describe results from a UK citizen assembly initiated by the UK House of Commons. Over six weekends, 108 individuals learned about climate change and possible solutions from a large range of experts and deliberated on the best ways to address it. Greenpeace state that regarding the national energy mix, renewables were seen as a better option than NE, being cleaner, low cost and proven to work. The full report (Climate Assembly UK, 2020) further details that support for NE from attendees was at 34%, with 46% disagreement; compared to 95% support for offshore wind, 81% support for solar power and 78% for onshore wind. With regards to NE, participants noted that the main benefits are a low environmental impact, scale and reliability. On the contrary, it was seen as inflexible and expensive compared with other energy sources, with the added issue of disposal of nuclear waste. It must be noted that the government is not obligated to integrate the results from this citizen assembly into its decision-making.

Finally, the Department for Business, Energy and Industrial Strategy conducted a quarterly public attitudes tracker survey (BEIS, 2020). In the first quarter of most recent years, a question on NE and climate change was included. They show that agreement with the statement "nuclear energy will help combat climate change in the UK" is decreasing, recording 30% agreement in 2020 (33% in 2019 and 2018, 36% in 2017 and 35% in 2016). As with the citizen assembly, the government is not obligated to use these results in decision-making, although the polls are conducted at least to inform policy.

There have been few instances since the 2006/2007 energy policy review where the UK Government has actively sought citizen opinions on the role of NE in CCM. Specifically, there are two instances (public attitudes tracker and the citizen assembly) where this issue is addressed, both with the purpose, but not the obligation, to inform governmental decision-making. In the other three instances (Wylfa Newydd and Energy Infrastructure), the role of NE as a CCM tool was questioned by individuals as part of consultations, which did not originally address this issue.

Regarding public opinion on NE, both the public attitude tracker and the citizen assembly register show that about a third of participants support NE as a CCM tool, with overwhelmingly larger support for renewable energy in the citizen assembly (78%–95%). It

is interesting to note that both "educated" opinions, as part of the citizen assembly (where participants are provided with a range of educational material) and "uneducated" or lay opinions as part of the public attitude tracker, result in approximately the same level of support for NE.

Further details on public opinion and its determinants will be discussed in the following section, which presents results of independent research studies and reports. These reports do not have a direct influence on government or energy industry decision-making processes, yet they may still provide background information for such decision-making and are therefore relevant to this review.

3.2 Independent research and reports

A total of 22 research reports were found which addressed NE in the context of CCM, which are detailed in Appendix 2. Four studies were conducted by Ipsos Mori for the Nuclear Industry Association (Ipsos Mori, 2007, 2008, 2009, 2010) who surveyed a sample of approximately 2,000 participants for each study that were representative of the population. For example, Ipsos Mori state that "interviews were carried out on an Omnibus survey and the data weighted to reflect the population of Great Britain" (Ipsos Mori, 2009). Among public attitudes towards NE and the nuclear industry, some questions were related to CCM. For example, 25% considered the lack of CO_2 emissions a major benefit of NE in 2007, followed by 19% in 2009 and 2010. In addition, 23% in 2007 supported new nuclear build to replace decommissioned stations, followed by 43% in 2009 and 47% in 2010, although only the 2007 question referred to phasing out fossil fuels. The 2008 report consisted only of a short article with no detailed figures available.

Following on from Ipsos Mori's findings, results reveal doubt about whether there is a strong association between NE and CCM in the mind of the general public. When asked whether NE was a low-carbon option, only about half agreed with the statement, with 42% indicating that they were not sure or did not know (Goodfellow *et al.*, 2015). Similarly, when discussing fusion technology, UK focus groups made virtually no mention of climate change or ACC (Horlick-Jones *et al.*, 2012). However, awareness of climate change benefits of NE was linked to increased support in another study (Wang and Kim, 2018). It may be that there still is a lack of consideration of climate issues within energy planning. In two studies, participants judged issues such as price, security of supply and other environmental issues such as land and water contamination as more important than fighting climate change (OECD NEA, 2010; Youds, 2013). Results therefore suggest that ACC only played a minor role in judging energy alternatives if low-carbon attributes are not highlighted by researchers.

Evidence is mixed on whether advertising or promoting the climate benefits of NE increases support for NE with the general public. Jones *et al.* (2012) found that a climate frame led to more support for NE in only one of three studies and only when information on the current energy mix was given. However, the Nuclear Energy Agency – reporting results from the Eurobarometer – states that outlining climate-change benefits increased support for NE from 33% to 44% in the UK (OECD NEA, 2010). The Financial Times, requesting reader responses about the energy transition, states that 40% of its UK readers supported NE in this context (Kavanagh, 2018). However, this is a self-selecting sample, and results should therefore be interpreted with care.

There is increasing evidence that expressing support for NE as conditional (i.e. if it helps mitigate ACC) leads to a much stronger agreement than unconditional support. For instance, support for NE was higher when expressed as conditional to mitigate the effects of climate change or energy security both for samples from the general public (Corner *et al.*, 2011;

Poortinga *et al.*, 2013, 2014) and those living close to NE plants (Venables *et al.*, 2009). Conditional support was between 47% and 60% in a number of surveys from 2005 to 2011 (Poortinga *et al.*, 2013, 2014); similarly, Pidgeon *et al.* (2008) reported that 41% of participants would rather accept NE than live with climate change consequences, and more than half agree with building new nuclear power plants if it will help mitigate the effects of climate change. This conditional support was shown to be decreasing leading up to 2011, although this was also accompanied by a decrease in support of other CCM options (Poortinga *et al.*, 2014). Corner *et al.* (2011) also found that support for NE is inconsistent and complex, if more positive than in previous years.

Overall, results strongly suggest that support for NE is often conditional on benefits to ACC. It is, however, unclear how strong these benefits are perceived to be. There is, for example, consistent evidence showing that other energy options are preferred to NE for the goal of addressing ACC. In 2008, only 14% of participants chose NE when asked to select three options to tackle climate change, with a strong preference for renewable energy and lifestyle changes (Pidgeon *et al.*, 2008). Similarly, around 70% of participants thought that we should not fixate on NE for CCM before exhausting all other options (Poortinga *et al.*, 2013), and NE was the least endorsed low-carbon technology in another study (Youds, 2013). When surveying secondary school pupils, Skamp *et al.* (2019) also found that only 10% would pay more for NE to address climate change and 48% thought it to be effective in reducing climate change, compared to 23% and 63% for renewable energy sources. It should be noted, though, that only 61% of those UK pupils stated that they believed that climate change was real.

Two studies further emphasised that preferences must be discussed within the context of the whole energy system. For example, workshops and discussions conducted in two studies showed that support for any one source, including NE, was dependent on its role in the energy system and highly dependent on local contexts (Demski *et al.*, 2015; Thomas *et al.*, 2018). Combined with the results above, this research suggests that support for NE should always be assessed within the context of other energy generation sources and a SES.

Finally, several studies analysed how different levels of climate-change concern and pro-environmental values related to support for NE. In general, the evidence indicates that those with higher general pro-environmental values are less likely to show support for NE (Corner *et al.*, 2011; Wang and Kim, 2018). In regard to climate-change concern, results are somewhat consistent until framing is introduced: Roddis *et al.* (2019) showed that high concern for climate change was related to a decreased support for NE; Sonnberger *et al.* (2021) found increased concern to be related to a less favourable attitude to NE; and Corner *et al.* (2011) found participants with higher climate concern were less likely to accept NE unconditionally, but when framed as "reluctant acceptance", higher climate-change concern was related to increased support for NE.

In summary, the published research demonstrates that NE is not universally associated with low-carbon benefits and issues other than ACC are still more influential on energy supply decisions. When researchers provided information on the low-carbon potential of NE, some evidence suggests that support increased, but results remain inconclusive. In particular, the type of support seems to matter, so that more people (including those concerned about ACC) seem to feel able to express a reluctant acceptance of NE than conditional or unconditional support. This suggests there is a high proportion of ambivalence or discomfort associated with NE as an energy source. This is further substantiated by relatively consistent evidence showing that other options for addressing ACC, primarily renewable energy, are supported much more broadly across studies.

4. Discussion

The aim of this review was to identify and document any instances where citizens are involved in decision-making on the role of NE in the zero carbon and SES transition. Following a scoping review of both the academic and grey literature, 28 documents have been identified. Six of the documents describe Government consultations or surveys, and 22 documents comprise independent academic papers and research reports.

4.1 UK Government literature

There is limited evidence within government documents of citizen involvement in NE decision-making since the energy policy review in 2006/2007. At this time, polls and studies recorded that approximately 75% of public respondents "expressed a preference for renewables over nuclear energy" (POST, 2007, p. 2). From our analysis of government literature, the dearth of citizen involvement aligns with an awareness that on matters of energy security and ACC in particular, NE has persistently been less favourable than renewable energy options. Even where such issues have facilitated a slight increase in public support for NE over the years, support levels have remained below that for renewable energy. Issues of radioactive waste and potential risks to human health and environmental integrity have negatively influenced public support for many years and was highlighted again at the time of the energy policy review (POST, 2007).

Despite these long-term public views of NE and the reduction in citizen involvement in decision-making over the past 15 years, in recent Government Energy White Papers (HM Govt., 2020b) NE is deemed a "clean energy" technology and is seen as an essential component of the UK's energy system. The UK Government is proposing to invest a further £385m of funding to the Advanced Nuclear Fund to realise the development of Small Modular Reactors and the construction of a demonstration Advanced Modular Reactor. It is notable that this Energy White Paper – articulating government strategy for energy generation and provision over the next decade – contains no specific references to citizen or public engagement and/or involvement in energy decision-making and CCM in the government's energy vision. Rather, the historical norms of expert-led "stakeholder engagement" and "consumer engagement" on specific matters associated with the Government's vision are briefly proposed.

It is unclear whether long-standing levels of NE, especially in comparison to renewable energy technologies, have influenced the UK Government's approach to limited citizen engagement, despite a statement by the World Nuclear Association that public support in the UK for nuclear has "remained positive" (WNA, 2021). As recent findings from the online "research data and analytics group" YouGov indicate, engaging UK citizens on the role of NE in the overall "energy mix" in current times may not unveil the opposition that previous polls have indicated. According to a recent YouGov survey (Smith, 2021), approximately two-thirds of surveyed UK citizens believe that NE should contribute to the UK's climate change strategy. Such findings from recent polls only appear to strengthen the case for citizen involvement in decision-making on the role of NE, rather than a focus on the traditional, expert-led approach of "stakeholder engagement" or "consumer engagement" on specific areas (see HM Govt., 2020b). Thus, questions abound as to the reasons why nuclear-related citizen engagement has rarely been undertaken by the UK Government, especially as the volatility of foreign gas markets, reaching Net-Zero emissions by 2050 and the proposed decreasing reliance on fossil fuels are urgent issues (Swinford and Wright, 2021).

With regards to recent public consultations on NE matters, public knowledge and awareness of consultation periods and the opportunity to comment and ask questions are limited to the UK Government website and consultation sites such as Citizens Space. These

processes include the Environment Agency's three month consultation on the generic design assessment (GDA) of the UK HPR1000 reactor design (designed by General Nuclear System Ltd) from January to April 2021 (EA, 2022) and the UK Government's three month consultation on the regulatory framework for fusion energy from October 2021 to December 2021, covering issues such as occupational and public health and safety, environmental protection, planning consent and safety and safeguards for radioactive material (BEIS, 2021a). The former period of consultation resulted in only 52 responses, whereas responses to the latter are still under review and are yet unknown. A low response rate suggests limited public awareness and knowledge of such consultation processes and opportunities to comment and question, also raised in prior GDAs such as the Advanced Boiling Water Reactor in the UK in 2015. This indicates potential shortcomings and areas for significant improvement with regards to public awareness of such opportunities to be involved and to respond to consultations. This also highlights opportunities for future research, exploring how such opportunities for citizen involvement could be both more effectively advertised and more successfully exploited. For this, evaluations were carried out as part of a public dialogue project to review and improve public involvement in design assessments of nuclear reactors for potential new nuclear power stations (Whitton *et al.*, 2016). During this 2015 project, participants raised the dilemma of the public actively seeking out opportunities such as public consultations versus these opportunities being actively and widely promoted to increase awareness by stakeholders such as the government or regulatory bodies.

Until recently, the only discussion of the role of NE has been initiated by citizens in consultations on related matters, to which the government responded by referring to the 2007 decision to support new nuclear build. The extent of NE in the national energy mix has been highly dependent on the decisions of private investors and companies; the case of the Wylfa Newydd Nuclear Power Station development in North Wales exemplifies this. The project to build a new nuclear power station on the Isle of Anglesey, on a site adjacent to the Wylfa Power Station that closed in 2015, has faced continued funding uncertainty to the point that Horizon Nuclear Power (HNP) – the UK project developer owned by Japanese company Hitachi – withdrew its application for a Development Consent Order for Wylfa Newydd. Hitachi decided to end business operations in September 2020 following its decision to suspend operations in January 2019 due in large part to a failure to reach a funding agreement with the UK Government. The case demonstrates that despite strong support locally and opposition nationally, the problem of securing financial backing for the scheme was the main factor that prevented the project from going ahead. The site is still being managed by HNP, but development has ceased.

Cases such as the latter one may contribute to an argument against the need for further government review, including engagement with citizens. Companies such as HNP and Électricité de France, both nuclear project developers in the UK, have conducted multiple public consultations in the last decade and relatively recently (e.g. HNP, 2018; EDF-CGN, 2019) but have stopped short of actively involving citizen stakeholders in site or project-related decision-making processes. It seems that "public consultation" remains the norm for the UK Government when engaging with citizens on energy issues. This was further demonstrated in the summer of 2021 when the Department for Business, Energy and Infrastructure Strategy and Ofgem (the UK energy regulator) issued two joint consultations on establishing an expert, impartial Future System Operator (BEIS-Ofgem, 2021a), reforming the energy code governance system BEIS (2021b), and issued a consultation on the deployment of large-scale and long-duration electricity storage (BEIS-Ofgem, 2021b). Evidently, on matters of energy and technology especially, the number of energy-related consultations is increasing whereas the degree to which citizens can impact decision-making

appears to have remained relatively static. In short, the approach resembles citizen involvement but at arm's length.

The tendency of the government to consult and its apparent reluctance to engage in more open forms of dialogue echo the observations of Cowell and Devine-Wright (2018), in that there is a broad tendency in the UK with regards to public engagement for energy infrastructure "towards closure in what is open for discussion in decision-making processes" (p. 513). It is difficult to gauge from individual objections to NE the extent that these are represented in the broader public. Some insight can come from more recent engagement with the public, both by the government and by independent research. Firstly, two recent instances were identified where the Government did explicitly explore public views on the role of NE in CCM – as part of a citizen assembly and the public attitude tracker. In both, approximately a third agreed that NE would help mitigate ACC, with support decreasing over the recent years. The citizen assembly especially, spoke very strongly in favour of renewable energy, and almost half disagreed or disagreed strongly with the need for NE in CCM. There is no obligation on behalf of the government to integrate these findings in their decision-making; the results do strongly suggest, however, that support for NE may be weak, especially when compared to other renewable energy options.

However, international examples from other democratic nations indicate that, when governments use more engaging approaches to nuclear decision-making, it *can* serve to both demonstrate and reinforce democratic principles even when strong opposition exists. For example, Chung (2020) detailed the approach of the South Korean Moon (Jae-in) government in deciding whether to proceed with additional nuclear power plant development after halting construction on power stations that had already received $1bn of investment. This democratic approach took the form of a deliberative poll involving a representative sample of 500 citizens in September 2017. On course to the final poll, the group convened for several days and included both neutral and non-neutral individuals. The group was involved in a series of discussions on several topics that were broadcast nationally. As a result of the poll on 15 October 2017, the government resumed development on two selected plants whilst cancelling plans to construct six other nuclear power plants, avoiding violence between environmental groups and nuclear advocates. Whilst the poll faced criticism from groups on either side of the debate, it represented a distinct shift, and a first genuine attempt, in "broadening and deepening public engagement" (Chung, 2020, p. 415) with regards to energy policy. In future research, we will broaden our research to explore the international literature and understand how relatively positive experiences can contribute towards informing modern, democratic deliberative approaches to public participation in UK energy decision-making and policy-making.

4.2 Independent academic literature

Results from independent research studies highlight that support for NE can be complex and depends on the way it is presented. Firstly, it is not clear how aware citizens are of the association between NE as a low-carbon source of energy and CCM. Several studies found that a minority considered the lack of carbon emissions as a benefit of NE (Pidgeon *et al.*, 2008; Ipsos Mori, 2008; Poortinga *et al.*, 2013; Goodfellow *et al.*, 2015), and others suggest criteria such as price, energy security and even other environmental issues are more influential in energy decision-making than climate change (e.g. OECD NEA, 2010; Poortinga *et al.*, 2014; Horlick-Jones *et al.*, 2012). This could explain why individuals with strong pro-environmental values tend to be universally opposed to NE, whereas those with strong climate-change concerns are more variable in their views. We argue that these persistent conflicts of opinion and perspective, combined with the dearth of open debate and

opportunities for resolution on specific issues, reflects an engagement and decision-making system that is restrictive and unfair by design. Cowell and Devine-Wright (2018) argued that this has the impact of restricting scrutiny and therefore critical public inquiry, stating that the "government orchestration of infrastructure decision-making has tended to work to delimit public scrutiny, especially for any issue that is "systemic or non-local" (p. 514). The more exclusive and "expert-designed, expert-led" approach to NE engagement may not only delimit public scrutiny on systemic issues but may also have limited capacity to hear, respond to and integrate the needs and priorities of local communities, such is often the case in more "bottom-up", co-designed and collaboratively facilitated processes (Chilvers and Longhurst, 2016; also see Seyfang and Smith, 2007).

Furthermore, researchers have argued that the term "local communities" can create issues of public reframing. The term has been used during engagement processes to frame local publics as local communities in receipt of project-related benefits, rather than diverse active and invested citizens (Cowell and Devine-Wright, 2018) who may hold justified and important concerns. Youds (2013) highlights such dilemmas, whereby government-led or technocratic processes of NE decision-making may fail adequately or effectively to involve citizens such that they fail to identify and address priority issues, ultimately coming under criticism and sacrificing procedural trust. The author finds that although climate change is regarded as an important issue of consideration, issues such as land and water contamination are a priority, and that broadly speaking there is little trust in government to make good energy policy decisions. Hence, government-designed and government-led decision-making processes on NE, without effective and legitimate involvement of UK citizens, risk being perceived as untrustworthy and risk citing politically popular issues (e.g. ACC, energy security) as being of greatest importance, without appropriately acknowledging issues that local citizens prioritise. The importance of local context and impact when considering nuclear as an energy option is also highlighted by Thomas *et al.* (2018).

When explicitly asked about the potential of NE to mitigate climate change, the available evidence is mixed. It appears that phrasing support for NE as conditional on climate-change benefits, or phrasing support as "reluctant acceptance" or "conditional support" leads to an increase in support (Corner *et al.*, 2011; Venables *et al.*, 2009). First, this highlights the importance of framing, particularly when discussing contested technologies in the context of global-scale challenges. Nisbet (2009) detailed this in the context of climate change and its relevance for public engagement, such that "the public health implications of climate change have emerged as a potentially powerful interpretive resource for experts and advocates" (p. 22). Secondly, this indicates that people are aware and somewhat uncomfortable with the drawbacks of NE and are engaging in making trade-offs when deciding on the role of NE. Thomas *et al.* (2018) articulated the difficulties of such trade-offs when NE is considered alongside other energy options within an "energy system" framework, albeit for an imaginary town by role-taking participants. Advantages such as it being a "tried and tested technology" that will likely create diverse employment opportunities and contribute to meeting emissions reduction targets are weighed against more localised disadvantages such as safety concerns, impacts on tourism due in part to landscape pollution (i.e. negative visual impact or eyesore), and potential long-term economic and environmental detriment.

Similarly, Wang and Kim (2018) find that individuals with strong environmental preferences and "environmentalism" are likely predictors of lower acceptance of NE (and higher acceptance and support of renewable energy), as others have posited (Spence *et al.*, 2010; also see Clulow *et al.*, 2021). Broadly speaking, across the 27 countries studied, Wang and Kim's (2018) study found higher NE acceptance to be associated with "perceived benefit,

trust, knowledge" (trust being found to be the primary factor influencing acceptance variation) whilst lower acceptance was associated with perceived risks. In addition, the authors find that NE acceptance is positively associated with "the share of nuclear power and amount of energy supply", whereas acceptance is negatively associated with "environmentalism and ideology (progressive)" (p. 16).

In their comparative study between the UK and Australia on the impact of political ideology on public attitudes towards energy technologies, Clulow *et al.* (2021) found that where progressive ideologies and environmental consciousness are associated with decreased acceptance of NE, this may prove problematic for future NE expansion. This is particularly relevant should a significant proportion of the younger generation be politically progressive and environmentally aware when they reach voting age. However, the issue of CCM and extreme reductions in emissions planned for the UK up to 2050 may counteract this and in fact bolster support for NE as "a low-carbon energy option" and critical component in the quest for Net-Zero. We recommend more research in this context, working with young people to explore various future scenarios and different framings and their impact on preferred energy futures and trade-offs.

The trade-offs associated with NE may explain why there is much more unanimous support for renewable energy, comparable to the results of the citizen assembly shown above. Results also suggest, however, that the utility and support for any one energy source should always be assessed within its context of the energy system, as there are individual, local, regional and global factors influencing such decision-making processes. Researchers recognised the need to consider energy technologies as belonging to and operating within a whole energy system over a decade ago, recommending a shift away from individual, isolated technology assessments, whilst also highlighting lack of understanding of public perceptions, values and attitudes towards energy system change (Clulow *et al.*, 2021). The research of Demski *et al.* (2015) on energy system change further demonstrates the need for reconsideration of single energy generation technologies within a vast and complex system. The outcomes of online surveys and in-person workshops support a shift to considering technologies collectively within a system, rather than pitting them against one another, especially in the context of CCM, energy security and the scale of system development required. Support for technologies was dependent on placement within this system and the future trajectory. The notion of whole energy systems has also been conceptualised at the community level by some researchers as part of discussions to move away from the centralised model of a whole energy system towards multiple, distributed energy systems accommodating local-scale energy needs more effectively in the form of "integrated community energy systems" (Koirala *et al.*, 2016).

5. Gaps and recommendations

We have demonstrated that public opinion on NE as a part of CCM is diverse, complex and rarely unanimously positive. In several studies, NE is perceived as an important tool to combat ACC and reduce energy-related carbon emissions (OECD NEA, 2010; Poortinga *et al.*, 2013, 2014; Skamp *et al.*, 2019), and similarly in newspaper-based studies (Kavanagh, 2018). Other studies have found the effect of framing CCM on NE support to be less clear and predictable (Jones *et al.*, 2012). Whereas some researchers have observed very little acknowledgement of ACC as a factor towards support for NE, issues such as energy security did feature in focus group responses (Horlick-Jones *et al.*, 2012). A relatively recent study considering the UK context conversely finds that, from a representative sample of 1,033 UK citizens (other countries were also surveyed in the study), participants with higher concern for climate change held less supportive and favourable attitudes towards NE (Sonnberger

et al., 2021). Another relatively recent study – involving over 48,000 participants in a public attitude tracker survey – has concurrently reported this association between high climate-change concern and low NE support amongst citizens (Roddis *et al.*, 2019). This appears to be a more common finding in more recent research, in comparison to studies conducted over five years ago.

We suggest that this latter observation indicates an evolution of public attitudes and technology framing that we argue is both worthy of further research and indicative of why continually employing consultative-based engagement processes that avoid difficult questions on changing public sentiment are insufficient. We find that UK citizens have not been significantly engaged in government decision-making on this issue for more than a decade, and therefore evolving public opinions, attitudes, priorities and perspectives towards systemic and local issues are unlikely to be adequately understood and considered during engagement design processes. Of particular importance, considering the increasingly urgent need for action to address the climate crisis, the reengagement of UK citizens to devise a socially and environmentally just energy transition is critical. This review has identified several challenges and recommendations for this re-engagement.

5.1 Need for up-to-date participation and research

A promising development in citizen participation to address ACC was made through the citizen assembly, conducted by the UK House of Commons in 2020. This represents a move towards active participation and more effective engagement that would appear to commit to acknowledging, responding to and acting upon the findings. However, commitments to action are absent and represent a future point of necessity if deliberation processes are to be deemed legitimate and worthy of personal investment. A distinct shift beyond the consultative norm of nuclear-related engagement towards legitimate participation, priority exploration and active public involvement (collaboration in some instances) may contribute to enhancing trust and confidence in nuclear decision-making, by strengthening procedural justice and the acceptance of resultant decisions (see Whitton *et al.*, 2015, 2016; Koirala *et al.*, 2016). Fair and just outcomes from decision-making are more probable when openness, transparency, accountability and process-based fairness is established and longitudinally maintained (Whitton *et al.*, 2018). While decisions such as investment in new nuclear build are long-term and cannot be renegotiated constantly, a balance should be found that allows citizens and policymakers to consider the landscape of the climate crisis and evolving technology of both NE and its alternatives. This is also important within the context of meeting the UN SDGs (e.g. SDG 7,12 and13), given that NE is argued by proponents to contribute to the generation of "cleaner" energy, CCM and more responsible production of low-carbon electricity.

Similarly, research on public opinion and support for nuclear power has decreased in recent years, with much of the main work in this respect being conducted more than a decade ago (e.g. Corner *et al.*, 2011; Pidgeon *et al.*, 2008; Ipsos Mori, 2007, 2008, 2009, 2010; OECD NEA, 2010). As expected, there were also some notable opinion and attitude-related studies conducted following the 2011 Fukushima Daiichi nuclear accident (Poortinga *et al.*, 2013, 2014), and more recently a significant multinational study by Latré *et al.* (2017), in which the results from a WIN-Gallup International poll [1] were examined (the UK was not included in the poll). With regards to public opinion, Latré and colleagues determined that factors such as geographical proximity of the nation to Fukushima (i.e. nearer to), the salience of NE debate, and the ongoing construction of new nuclear power stations were all associated with decreased support for NE. Beyond these studies the literature reveals a dearth of modern studies in this vein. Considering the same changing decision-making

background as outlined previously, more up-to-date research on public attitudes towards NE in the UK would be beneficial in determining both general levels of public support as well as its conditions and contingencies. In particular, broad insights into how best to accommodate and work with the complexities of issues such as NE and ACC would be valuable and is discussed below.

5.2 Methodological and ethical challenges of citizen involvement

The results presented above demonstrate how public response can be impacted by various aspects, such as phrasing support as conditional or reluctant, whether information about the issue is provided and whether views are assessed within the larger context of energy systems. It is, therefore, important how citizen engagement processes are conducted. Research, as shown above, has informed these aspects of participation, but a greater quantity of studies and more current research is required to provided additional clarification, especially in the complex setting of CCM.

Pidgeon (2021) has developed four methodological challenges of engaging the public in the discussion around risks such as NE and climate change, which serve as a robust framework for guiding future research. For example, in instances of information provision, it should be both sufficiently in-depth to allow citizens to develop their own educated opinions whilst being sufficiently balanced as not to bias or influence these opinions. In the context of the current review, there exists the additional challenge of considering the pre-existing beliefs and associations participants hold on the issue, which may differ significantly depending on their exposure to the NE industry, technological familiarity with regards to scientific understanding or personal interest, or personal engagement and/or familiarity with CCM options. We recommend investigating whether these different prior beliefs lead to different perception of and engagement with information materials.

Further methodological challenges include facilitating an open discussion and deliberation, determining who to include in studies and how many participants are needed for meaningful findings and trying to identify underlying values that may influence personal views and positions. All of these issues, and those described above, should be considered when conducting, evaluating or investigating citizen involvement in decision-making processes to design more effective engagement practises, enhance procedural justice, strengthen decision quality and create fairer and more equitable outcomes for the range of stakeholders. Although it may be the case that participation is now "an institutionalized and routinized part" (Pallett *et al.*, 2019, p. 590) of scientific decision and policymaking, it is this prevalence that renders understanding participation as a critical determinant of "understanding environmental governance and policymaking in the 21st century" (Pallett *et al.*, 2019, p. 591). The recent research of Pallett and colleagues poses important considerations about how we conceptualise participation in the UK energy system, which for the foreseeable future will include NE, such as a posited move away from viewing participation as a "problem of extension" (see Collins and Evans, 2002) and instead as a "problem of relevance" (Marres, 2012). This is based on reconceiving public involvement in decision-making processes through public invitation (e.g. deliberative dialogues) towards instead accounting for "the multiple ways in which publics are already engaged" (Pallett *et al.*, 2019, p. 591) on issues or specific objects and developments and assessing their relevance to policymaking. This represents a process of participation mapping that the authors argue is of use to all energy system actors, including citizens, to enable them "to draw their own conclusions and make their own arguments, and to inform their actions and initiatives" (Pallett *et al.*, 2019, p. 610).

It is evident from the current literature on energy system engagement and participation that systemic change is required if we are appropriately and effectively to improve knowledge creation, decision-making quality and outcome legitimacy for NE in the UK. This will potentially require a tripartite execution of assessing existing attitudes and participation activities, underpinned by a commitment to understanding and integrating public knowledge and priorities, and ensuring alignment with and relevance to energy policymaking.

We find few instances since the 2006/2007 Energy Policy Review where the UK Government has actively sought citizen opinions on the role of NE in CCM. The two instances where this issue is addressed, in a public attitude tracker and during a citizen assembly, possessed the intention but, importantly, not the obligation to inform government decision-making. The role of NE as a CCM tool was not a constituent issue within public consultations, but rather was raised by individuals responding to the consultation. In both the independent and academic literature, we find that NE is, in part, associated with low-carbon benefits, but that issues other than CCM are more influential for participants when identifying energy preferences. When using the frame of "low-carbon" NE in communications and messaging, there is notable evidence indicating that public support increases, but this is not consistent across all studies. The type of support appears to hold significance, in that more people appear able to express a reluctant acceptance of NE rather than conditional or unconditional support. That is, if we must mitigate anthropogenic climate change impacts then we should use NE. However, there is consistent evidence that renewable energy options are the more highly favoured "low-carbon" options by members of the public. Hence, we posit that far greater effort should be made to plan more systematically; to consider all low-carbon energy generation technologies in broader, systemic discussions and debates about our future energy mix in the context of an emerging climate emergency and reality of necessary trade-offs. Many researchers similarly emphasise that NE and other energy generation options must be discussed collectively within the context of a SES and global scale challenges, rather than a technologically comparative and competitive format.

5.3 Limitations of current study

We acknowledge that the current study does possess certain limitations, that future research may find value in addressing. Firstly, due to the "scoping" nature of our review, it does not possess the depth or breadth of a full systematic review. As such, there may exist academic or grey literature that is relevant to this or a similar study that could be identified and examined in future systematic reviews. Secondly, our research timescale began in 2006, when an energy policy review was conducted in the UK and new nuclear build was considered as a strategy for increasing electricity generation from low-carbon sources. Future studies could extend this review period and conduct examinations of years and political terms prior to this, to further identify longitudinal changes and legislative evolution around NE and engagement. Finally, whilst our scoping review explores engagement within the NE context, it is limited to literature-based sources and accounts. We believe that there would be significant value in extending this study to include and explore the personal experiences and accounts of individuals that have participated in historic nuclear engagement processes, to more wholly understand their effectiveness and outcomes according to a variety of individual or group perspectives.

6. Conclusions

Anthropogenic climate change and the resultant emissions-based climate emergency require an urgent transition from predominantly fossil fuel-based energy generation to low emission energy options as part of a future-orientated, sustainable national energy system. Nuclear energy is seen by some as a proven and essential low-carbon energy generation technology contributing to CCM. Others are sceptical and/or oppose its continued use on ethical and safety grounds. The role of NE within a SES serves as a valuable example to consider in relation to ecological and social sustainability within the context of citizen participation, and the trade-offs necessary to achieve long-term planetary and societal well-being.

Broadly speaking, NE public engagement processes have taken the form of public or community "consultations" rather than actively engaging and legitimately involving citizens (Konrad and Espluga, 2018; Charnley-Parry *et al.*, 2017). This has commonly led to "decision-making" being deemed to involve top-down, expert-led and large-scale processes that insufficiently and ineffectively involve local communities that are impacted by NE developments or rely on them for important employment opportunities (Whitton *et al.*, 2016). On matters of energy and technology especially, we find the number of energy-related consultations increasing whilst the degree of citizen influence on decision-making appears relatively static, raising questions regarding how responsible and fair engagement process are. This approach resembles citizen involvement at arm's length. As a result, engagement process may be perceived as being technocratically controlled and community benefits perceived as democratically limited.

Efforts by the UK Government and NE developers to genuinely explore how and why citizens perceive and feel as they do about NE, anthropogenic climate change and trade-offs to manage social impacts are currently insufficient, highlighting process-related weaknesses with regards to responsibility and fairness. Hence, we argue the outcomes from engagement processes to inform decision-making are unlikely to be fair or legitimate for local communities. There is a persistent limitation with government and industry engagement processes, whereby "consultation" appears to be a participative benchmark with scant opportunity for robust, effective exploration of local citizen concerns and priorities through deliberative dialogue. We argue that new participative norms must be established. Moving beyond consultation towards genuine dialogue, collaboration and opportunities to influence decisions, to create opportunities to realise sustainable community benefits whilst confronting necessary trade-offs, is critical if we are to legitimately pursue a transition towards an SES that is socially just and responsible.

We argue that there should be a more concerted effort to consider all low-carbon energy-generation technologies in broader, systemic discussions and debates about our future energy mix in the context of an emerging climate emergency and reality of necessary trade-offs. Some researchers echo this, emphasising that NE and other energy generation options must be discussed within the context of a SES and global scale challenges, rather than a traditionally comparative "technology x versus technology y" format.

We arrive at several conclusions from our review. Firstly, nuclear-related consultation processes broadly restrict public scrutiny of both procedural and content aspects of decision-making. Progress towards more exploratory and open processes, with greater opportunities for debate, posing questions, receiving answers, knowledge sharing and open dialogue, would likely contribute towards greater procedural trust and fairer societal outcomes. However, engagement processes must enhance participation by moving beyond intent and towards commitment to citizen participation and influence. This is imperative if we are to ensure responsible research and innovation is conducted, whereby we legitimately understand the potential impacts of technological development and energy

generation on society and the environment, and whereby diverse energy stakeholders collaborate to enable shared responsibility and mutual responsiveness with regards to future developments. Furthermore, for many years the "comparative" model of energy technology assessment has prevailed. It is becoming increasingly apparent that discussions and debates on energy technologies may benefit from a SES approach, especially if emissions reduction and sustainability goals are to be met whilst ensuring reliable supply and energy security.

Secondly, trade-offs relating to NE and CCM must become more integrated into all policy-related discussions and evaluations of the UK energy system, which is not presently the case. Nuclear energy is viewed by some groups as reliable, familiar and essential if Net-Zero by 2050 is a remotely achievable proposition, whereas others perceive it as a contested, controversial energy source that should yield to technologies with fewer health, safety and legacy concerns. Growing evidence suggests that environmentalism and progressive political ideologies are strong predictors of low support and acceptance, whilst young people appear to be more concerned and worried about the impacts of ACC than those who are older. We argue for more transparent engagement processes for SES decision-making, such that tailoring of methods, information, engagement spaces and types of participation can occur based on those involved, leading to a more effective engagement exercise with participatory decision-making at its culminative end. This can also contribute to addressing the persistently weak public trust that exists towards the UK government to make good energy policy decisions, which may further delay the necessary transformational progress in the energy system to meet both evolving demand, increasing electrification, and 2030 and 2050 targets.

Thirdly, we conclude that processes of decision-making must involve a more considered approach to information provision in the first instance, before more extensive engagement. It should be both sufficiently in-depth to allow citizens to develop their own educated opinions whilst being sufficiently balanced as not to bias or influence these opinions. Beyond this, we argue that it is imperative to reflect upon and reconceptualise public participation and public engagement more broadly, such that procedural design is less to do with simply "doing more" (i.e. extension) and more to do with assessing what we are able to do that is most relevant to the policy challenges being faced (i.e. relevance). From a responsible research and innovation perspective, this would ethically strengthen both processes and outcomes. As a result, all energy actors can submit their own arguments and express their own priorities, leading to more deeply informed decisions and policies. Future academic research into such processes of participation may be able to build an evidence-based foundation to improved public consultation and policymaking. The gaps identified in this review will help to identify where such studies are most strongly needed.

Finally, we conclude that greater comprehension of priority issues and potential trade-offs should become more central to participatory frameworks. This could more effectively enable an intelligent recognition and comprehension of the multifarious requirements of an energy system transition that is both responsible and sustainable and which reflects the range of sustainability considerations it bases decisions and policies upon.

Note

1. "Global Snap Poll on Tsunami in Japan and Impact on Views about Nuclear Energy", running 21 March 2011, to 10 April 2011, involving over 23,000 people from 41 countries.

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Appendix 1

Table A1. Relevant UK governmental consultations documented identified during the scoping review (n = 6)

Record	Involved parties	Summary of results (relating to nuclear energy and climate change)
Wylfa Newydd consultation response, Jonathan Dean (Dean, 2019)	Individual, Welsh Government (Secretary of State)	• Individual response to governmental consultation on Wylfa Newydd • Stating that using the site for renewable energy would be better contribution to Welsh climate-change goals
Public Attitudes Tracker (BEIS, 2020)	UK Government Department for Business, Energy and Industrial Strategy, public	• Quarterly attitude survey by Department for Business, Energy and Industrial Strategy. Waves 33, 29, 25, 21 and 17 (first quarters) include questions on nuclear energy and climate change • Findings include in 2020, 30% agree that nuclear energy will help mitigate climate change (33% in 2019 and 2018; 36% in 2017, 35% in 2016)
The future of nuclear power: analysis of consultation responses (BERR, 2008)	UK Government Department for Business Enterprise and Regulatory Reform (BERR), consultation respondents (including individuals from public)	• Extension of 2006 energy policy review: additional consultation to test governmental decision of need for future nuclear build to address climate change and ensure energy security • Context: Previous consultation in 2006 ruled to be misleading, seriously flawed and manifestly inadequate and unfair by the High Court (Rogers, 2020) • Included written/online consultation, stakeholder events and public deliberative events. Majority of those responded were citizens. Qualitative consultation, with responses given in summary document • For evaluation, see also Warburton (2009)
The government response to consultation on the revised draft national policy statements for energy infrastructure (DECC, 2011)	UK Government Department of Energy and Climate Change, consultation respondents (including individuals from public)	• Response to Revised National Policy Statement on Energy infrastructure. Discussion of nuclear energy as part of energy mix on page 11f • Some respondents favoured other sources of energy over nuclear. Government responded by restating that nuclear power should be part of energy mix, and that private companies and investors will decide how much nuclear energy there will be in energy mix

(*continued*)

Record	Involved parties	Summary of results (relating to nuclear energy and climate change)
UK Citizen Assembly – Parliament asked ordinary people what the UK should do about climate change (Greenpeace, 2020)	Greenpeace, public, UK parliament	• Presents results from UK citizen assembly initiated by UK parliament: 108 participants learned about climate change and deliberated on solutions • Regarding energy mix, renewables were more popular than nuclear energy • Full report: Climate Assembly UK (2020)
Wylfa Newydd consultation response, Linda Rogers (Rogers, 2020)	Individual, Welsh Government (Secretary of State)	• Individual response to governmental consultation on Wylfa Newydd • Stating that there is no economic justification for new nuclear in terms of climate-change mitigation, with renewables more effective and economic

Source: Created by authors

Table A1.

Appendix 2

Table A2. Relevant academic studies and research reports identified during the scoping review (n = 22)

Record	Involved parties	Summary of results (relating to nuclear energy and climate change)
Nuclear power, climate change and energy security: exploring British public attitudes (Corner *et al.*, 2011)	Researchers, Ipsos Mori, public	• 1822 UK citizens interviewed by Ipsos Mori • Investigated whether public attitudes had changed as a result of framing nuclear power as low carbon in recent years • Attitudes to nuclear energy are somewhat more positive than previously but not consistently so, with a mix of opinions and uncertainty • Participants with higher environmental values and climate-change concern are less likely to unconditionally accept nuclear power • Conditional support (nuclear energy to address climate change or energy security) higher than unconditional support, but not related to pro-environmental values • Only when framed as "reluctant acceptance" were higher climate change and energy security concern (but still not general pro-environmental values) positively associated with support for nuclear power
Public values for energy system change (Demski *et al.*, 2015)	Researchers, Ipsos Mori, public	• Presents results from 2012 Ipsos Mori survey ($n = 2{,}441$) and six public workshops ($n = 68$) • Workshops were deliberative, with open group discussion, scenario tool and "day in the life" narratives. Focus on whole energy systems in the context of change required for CCM and energy security • Nuclear seen problematic in terms of waste and safety. Results discussed as part of energy systems, with support for any one energy source depending on its place in overall system and trajectory
Public perceptions of design options for new nuclear plants in the UK (Goodfellow *et al.*, 2015)	Researchers, public	• 1,304 UK adults surveyed about design of new nuclear plants • One question on low carbon, showing that half agree that nuclear energy is a low-carbon option, 19% not sure, 23% don't know
Investigating the degree of "stigma" associated with nuclear energy technologies: a cross-cultural examination of the case of fusion power (Horlick-Jones *et al.*, 2012)	Researchers, public	• Eight discussion groups (—eight to nine participants each) held in both Spain and UK • Topic of fusion technology and other issues associated with nuclear power. Researchers note that UK focus groups had virtually nothing to say about climate change – most pro-nuclear arguments were in terms of energy security

(*continued*)

Record	Involved parties	Summary of results (relating to nuclear energy and climate change)
Public attitudes to the nuclear industry (Ipsos Mori, 2007)	Ipsos Mori, Nuclear Industry Association, public	• 1973 UK citizens interviewed by Ipsos Mori for Nuclear Industry Association in November 2007 • 25% consider no CO_2 emissions as a benefit of nuclear energy • 23% support newbuild NPS to phase out fossil fuels, 15% are favouring renewables/alternatives over nuclear energy
Public attitudes to nuclear energy 2008 (Ipsos Mori, 2008)	Ipsos Mori, Nuclear Industry Association, public	• 1989 UK citizens interviewed by Ipsos Mori for Nuclear Industry Association in November 2008 • Little detail available in report, but states that there is more support than opposition for new nuclear build, and that this support is based on energy security and CCM potential
Public attitudes to the nuclear industry (Ipsos Mori, 2009)	Ipsos Mori, Nuclear Industry Association, public	• 2,050 UK citizens interviewed by Ipsos Mori for Nuclear Industry Association in November 2009 • Biggest benefits of nuclear energy seen as CCM (19%), general impact on environment (19%), energy security (18%) and cost (17%) • 43% support new build to replace old plants
Public attitudes to the nuclear industry (Ipsos Mori, 2010)	Ipsos Mori, Nuclear Industry Association public	• 1980 UK citizens interviewed by Ipsos Mori for Nuclear Industry Association in November 2010 • Biggest benefits of nuclear energy seen as cost (20%), CCM (19%), energy security (19%) and general impact on environment (18%) • 47% support new build to replace old plants
Assessing the impact of framing on the comparative favourability of nuclear power as an electricity generating option in the UK (Jones *et al.*, 2012)	Researchers, public	• Study 1: 100 students. Using a climate frame (vs. focus on waste, energy security or control) prompted participants to use more nuclear power in energy mix • Study 2: 120 students, no information on status quo of energy mix given. Use of climate frame did not lead to increased inclusion of nuclear power • Study 3: 178 participants from general population. Climate framing (vs. control or security framings) did not significantly affect decisions about nuclear power inclusion
Improving carbon pricing is key to energy challenge, say FT readers (Kavanagh, 2018)	Financial times, readers	• Responses to FT call for opinions on energy transition (meeting global demand while mitigating climate change). 40% of 565 readers from UK • 60% of respondents support nuclear power in this context

(*continued*)

Table A2.

Record	Involved parties	Summary of results (relating to nuclear energy and climate change)
A multilevel approach to energy options across EU: the role of supra-national governance, values and trust (Mouro *et al.*, 2013)	Researchers, public	• 26,671 participants from 27 EU countries • Egalitarians and those who prefer lifestyle changes to address climate change are less willing to support nuclear energy than non-egalitarians and those who prefer technological solution
Public attitudes to nuclear power (NEA, 2010)	Nuclear energy agency, public	• Presents results from Eurobarometer and International Atomic Energy Agency poll (exact sample descriptives not given) • Price and security of supply are most important energy related issues (45% and 35%), followed by protecting environment (29%) and fighting climate change (13%) • Overall support was split, with only 20% support in Eurobarometer (but higher in UK than many other places) • In UK, outlining climate-change benefit increases support from 33% to 44%
Climate change or nuclear power – No thanks! A quantitative study of public perceptions and risk framing in Britain (Pidgeon *et al.*, 2008)	Researchers, public	• Representative sample of 1491 UK citizens • When asked to choose three actions to tackle climate change, only 14% of participants chose "expanding the use of nuclear energy". Nuclear power not perceived as a favourable energy source • However, 41% would rather accept nuclear power than want to live with the consequences of climate change and 54% agreed to build new nuclear power plants if it helps to deal with climate change • Overall, strong preference for renewable energy sources or lifestyle changes to address climate change
Public perceptions of climate change and energy futures before and after the Fukushima accident: A comparison between Britain and Japan (Poortinga *et al.*, 2013)	Researchers, Ipsos Mori, public	• Presents results from two Ipsos Mori (2005, $n = 1491$; 2010, $n = 1822$) and one British Science Association (2011, $n = 2050$) survey along with comparative data for Japan • Conditional support for nuclear energy (as climate-change measure) in Britain between 50% and 60% in all three surveys. Around 70% think shouldn't fixate on nuclear energy for CCM before exploring all other energy options
Public attitudes to nuclear power and climate change in Britain two years after the Fukushima	Researchers (UK Energy Research Centre), Ipsos Mori, public	• 961 UK citizens interviewed by Ipsos Mori in March 2013 • Conditional support for nuclear power, with 47% accepting it if it would help tackle climate change (and 52% for energy security)

Table A2.

(*continued*)

Record	Involved parties	Summary of results (relating to nuclear energy and climate change)
accident – synthesis report (Poortinga *et al.*, 2014)		• Conditional support for nuclear for climate-change, decreasing from previous years • But participants also less likely to support other alternatives over nuclear power, with participants now: – less likely to support exhausting all other climate-change mitigation options before turning to nuclear (74% in 2005 to 53% in 2013) – less likely to indicate that renewables are better for tackling climate change than nuclear (61%–78% in 2005) – less likely to indicate that reducing energy use through lifestyle changes and energy efficiency is better than nuclear power (from 76% to 63%)
Accounting for taste? Analysing diverging public support for energy sources in Great Britain (Roddis *et al.*, 2019)	Researchers (UK energy research Centre), UK government, public	• 48,304 participants from 23 waves of the UK Government energy and climate change public attitudes tracker • Nuclear energy had among the lowest rates of support (37.1%) and was significantly decreasing over time • Only high concern for climate change was negatively associated with support for nuclear power
Renewable and nuclear energy: an international study of students' beliefs about, and willingness to act, in relation to two energy production scenarios (Skamp *et al.*, 2019)	Researchers, pupils	• Survey of pupils approx. 11- to 16-year-old. $N = 12{,}627$ from 11 countries, sample size in England not stated • Only 61% in UK believed climate change was happening • 10% would pay more for nuclear energy to address climate change. About 48% believed nuclear energy would be effective in reducing global warming (compared to ~23% and ~63% for renewables)
Climate concerned but anti-nuclear: exploring (dis)approval of nuclear energy in four European countries (Sonnberger *et al.*, 2021)	Researchers, public	• Representative sample of 1,033 UK citizens, with 1001 from Germany, 1,010 from France, and 1,004 from Norway • For UK participants, increased climate-change concern was related to a less favourable attitude to nuclear energy
Using role play to explore energy perceptions in the United States and United Kingdom (Thomas *et al.*, 2018)	Researchers, public	• 52 citizens from different cities in UK • Workshop with role-playing: discussing and making decisions from role of councillors tasked with choosing energy infrastructure for fictional town

(*continued*)

Table A2.

Record	Involved parties	Summary of results (relating to nuclear energy and climate change)
		• Nuclear discussed among other energy options; strongly mixed responses for nuclear, climate-change targets as one of positive attributes. Different groups mixed in preferences, showing complex decision-making processes and dependence on local contexts
Living with nuclear power: A Q-method study of local community perceptions (Venables *et al.*, 2009)	Researchers, public	• 84 participants living near nuclear sites in UK • General support for nuclear power (e.g., would rather live next to NPS than coal), but also degree of reluctancy (reluctant, conditional acceptance as CCM tool)
Comparative analysis of public attitudes toward nuclear power energy across 27 European countries by applying the multilevel model (Wang and Kim, 2018)	Researchers, public	• Eurobarometer 72.2 survey ($n = 23{,}671$), with approximately 1,000 participants from the UK and each of other 27 European countries • In the UK, perceived risks were negatively associated with support of nuclear power, whereas perceived benefits, which included CCM, were associated positively • However, for total sample, environmentalism had negative association with acceptance of nuclear power
Sustainability assessment of nuclear power in the UK using an integrated multi-criteria decision-support framework (Youds, 2013)	Researchers, public	• Study 1: 627 UK citizens (convenience sample) • Support for nuclear mixed, and not related to ratings of sustainability indicators • Climate change recognised as challenge, but not as important as land and water contamination • Study 2: 231 participants in follow up from Study 1, with information materials for educated opinions given • Very little trust in government to make good energy policy decisions, very mixed and polarised support for new nuclear • Very negative when asked about new nuclear build within 50 miles of their home • Nuclear power least endorsed as low-carbon technology compared to alternatives

Table A2. **Source:** Created by authors

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