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Predictors of public attitudes towards fusion energy in Europe

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1. Introduction

World energy consumption is expected to grow considerably over the next fifty years as the world's population expands and developing countries become more industrialised [1]. To meet this growing energy demand in a clean, secure, and affordable way, governments are looking to invest in (or to incentive private investment in) innovative ways of producing energy. Although varying between countries, these efforts have tended to include attempts to make fossil sources of energy, like coal and natural gas, cleaner (e.g. through carbon capture and storage); investment in nuclear fission power plant; and a rapid expansion of renewable energy capacity [1,2]. Alongside this, there has also been growing interest in research, development, demonstration and deployment (RDD&D) of nuclear fusion energy (hereafter 'fusion') [3,4].

While still an experimental energy technology, fusion has been touted as a potentially sustainable, safe and clean source of energy [5,6]. This is because the fuel used to run fusion (two isotopes of Hydrogen called deuterium and tritium) is available and abundant; fusion is 'carbon neutral' at point of generation; and while fusion does produce some radioactive waste, it is significantly lower-volume, shorter-lived and less-radioactive than that produced via nuclear fission power plants. Furthermore, due to the way fusion operates, there is no prospect of catastrophic nuclear meltdown.

The potential of fusion has led to considerable international collaboration and investment in developing the technology and demonstrating its commercial viability. For example, ITER (International Thermonuclear Experimental Reactor) is currently being built in the south of France. ITER is a collaboration between 35 nations (including China, US, Russia, Japan, Korea, India and the European Union) and when constructed it stands to be the first fusion plant capable of producing sustained, net-surplus energy during operation. ITER is due to be fully commissioned in December 2025 and is anticipated to be the forerunner to DEMO, a fully functioning demonstration power plant capable of supplying electricity to the grid (due to be operational by around 2050) [7–10].

While fusion has its proponents, the financial backing that it has received (and continues to receive) has proven divisive. Some question whether controlled fusion power generation will ever be possible [11], others query the potential risks to the environment and human-health associated with fusion, and still others argue that the vast sums of money spent on fusion might be put to better use on more proven, more readily-available technologies (e.g. renewables, demand-reduction technologies) [12]. The disagreement that exists over the feasibility and desirability of fusion as a power generating option raises important questions about the nature of public and broader social acceptability of the technology.

1.1 Public perceptions of fusion

Within westernised democracies, publics are known to provide a steering influence on policy and siting decisions relating to prospective energy technologies and projects [13–15]. It is therefore important to understand public attitudes and beliefs about energy technologies [16]. Research into public attitudes towards fusion is currently limited, with only a handful of scientific articles, reports and conference proceedings on the subject published to date [e.g. 11,16–20]. The research that has been completed tends to highlight the relatively low levels of public awareness and understanding of fusion but the generally high levels of support for the concept, at least in principle [17,20]. For instance, in 2002 a pan-European survey on energy options, issues and technologies showed that while respondents had significant difficulties in understanding fusion, the majority supported research into the technology [22].

This generally positive image of fusion has been also found in public discourse about the technology on the Internet. A study on the nature of online content about fusion by Oltra et al. [12] found that this content was predominantly positive, with fusion generally presented as a solution to the energy and environmental challenges of future society and a superior form of nuclear energy (versus nuclear fission). Similar results were found in a media analysis of fusion content by Schmidt et al. [21]. Contrary to nuclear fission, fusion was generally portrayed as a safe, clean and unlimited source of energy, although reservations were aired about the research costs, technological feasibility and the timescales for commercial demonstration and deployment.

The research conducted to date has also shed some light on the conditions underpinning public support for fusion. Qualitative research by Prades et al. [20] on lay perceptions of nuclear fusion, for example, showed that people are willing to accept financial investment in nuclear fusion research to the extent that it is not seen to affect investment in renewable energies. The study also showed that when participants were presented with information about fusion from fusion scientists and environmentalists, they tended to adopt a more ambivalent position towards the technology. This would suggest that exposure to information about the pragmatic realities of fusion served to quell some of the general, less-informed enthusiasm for the technology.

Other studies have investigated the branding effect that the terminology associated with fusion can have on perceptions of the technology. For instance, Horlick-Jones and colleagues [18] illustrated the stigmatizing effect that the 'nuclear' label tends to exert upon people's attitudes to fusion, due to the powerful collection of negative images and ideas (e.g. catastrophic nuclear disaster and nuclear proliferation) that come associated with the term. This work on 'branding' has been recently extended to investigate other potentially stigmatising properties of the terminology associated with fusion. For instance, Jones, Yardley and Medley [19] investigated lay-public perceptions of the proposed use of depleted uranium as a means of storing the tritium (Hydrogen-3) used to power fusion reactions. The authors found generally positive attitudes towards fusion in samples from two European countries (i.e. UK and Germany) but also a mildly stigmatizing effect of the term 'depleted uranium' on these attitudes. This stigmatizing effect was, though, partially reversed by the provision of information clarifying the actual nature and purpose of depleted uranium within fusion processes.

Taken together, the small volume of research conducted into lay-perceptions of fusion to date indicates that people are generally unfamiliar with fusion and – while typically positive to the concept of fusion and investment in the technology – attitudes at this time are relatively weak and are susceptible to the subtleties in how the technology is presented or described (i.e. 'framed') [23–27]. This argues in favour of employing research approaches that reflect the challenges of reliably and validly assessing lay-perceptions of unfamiliar topics. For instance, a methodological challenge associated with investigating lay-attitudes towards unfamiliar and complex attitude objects (like fusion) is the likelihood of measuring ‘pseudo opinions’ [28,29]. Pseudo opinions are essentially weak evaluative judgements that are based upon a person’s incorrect beliefs and/or assumptions about the attitude object in question. Research shows that such opinions are highly changeable in response to new information and not particularly directive of behaviour, making them potentially unhelpful as a guide to ‘true’ (i.e. informed) public opinion towards the attitude object [30,31].

The risk of assessing ‘pseudo opinions’ in the context of energy technologies has generated research interest. For instance, de Best-Waldhober and colleagues [30] assessed uniformed vs. informed attitudes towards Carbon Capture and Storage (CCS) using a traditional survey vs. information-choice questionnaire (ICQ), respectively. An ICQ counters the likelihood of assessing pseudo opinions by first presenting respondents with a policy-relevant decision context (e.g. future generation of clean, secure and affordable energy) and structured, textual information relevant to the problem [32]. Participants are then helped to evaluate the attitude object (e.g. fusion) in relation to the policy problem, thus providing responses from a more informed standpoint. Within de Best Waldhober et al.’s study [30], participants within the ICQ condition formed more stable attitudes towards the technology.

In sum, alongside qualitative methodologies (e.g. interviewing, focus groups) that afford researchers with opportunity to provide substantive information to participants before assessing attitudes, ICQs are often seen as a viable means of assessing attitudes towards novel technologies, while reducing the prospect of assessing pseudo opinions.

1.2 The current research

The current study sought to build upon the existing literature on public perceptions of fusion by examining *informed* public attitudes in large, demographically-representative samples of four European countries (i.e. Austria, Finland, Spain and the United Kingdom). In addition to providing descriptive details of the extent of support (or opposition) for fusion in these countries, we also statistically examined the key determinants of this support and investigated what impact the information provided within the survey had upon participants' attitudes.

Our study had three core aims:

1) To provide an initial assessment of attitudes (Time 1, T1) towards fusion in each of the four countries; comprising a comparative analysis of the affective (feeling-based) and cognitive (belief-based) determinants of these attitudes.
2) To investigate the extent of any attitude-change in each country following the provision of information about the relative advantages and drawbacks of investment in fusion and fusion research.
3) To model some key antecedents of participants' *informed* attitudes (Time 2, T2) towards fusion, including their evaluation of the relative advantages and drawbacks to investment and comparative preferences for investment in other options.

2. Method

2.1. Participants and Survey Design

An online ICQ-based survey of lay-public attitudes towards fusion and fusion research was administered to 900 people in each of four countries within the European Union (November 2018): Finland, Austria, Spain and UK. Distribution to a representative sample of each population (age and gender) was coordinated by an established survey company (Norstat UK Ltd.) via their online participant panels. All participants were required to be aged 16 or over. The four countries were selected based on national attitudes towards nuclear (fission) energy that had been previously registered in international polls [32]. These polls register Finland as being most favourable to nuclear energy, Austria to be least favourable and Spain and the UK to have more intermediate levels of support (as well as being the home nations of the authors).

Table 1 outlines the general demographics of the participants in each country and their initial self-claimed awareness and familiarity with fusion. The figures serve to confirm the large and diverse sample of participants recruited in each country. Indeed, there was good balance of male and female participants in each country and good spread of participants across the different age groups. Overall, the modal participant was male, aged 50-64, had not received a university education and was unfamiliar with fusion. The general pattern held across the four country groups but with some differences. Notably, the modal Austrian participant was female, a greater proportion of Spanish participants had a university versus non-university education, and most Finnish participants claimed to have heard for fusion.

[TABLE 1 ABOUT HERE]

2.2. Measures and materials

In addition to assessing some basic demographic details (including gender, age, education) and a closing debrief, the ICQ consisted of four core sections designed to investigate public attitudes toward fusion energy and research. We provide details of the items of direct relevance to the current paper only. Fuller details of the survey can be found in the Supplementary Material associated with this article.

2.3.1 Baseline awareness and familiarity with fusion

Participants were informed that the survey would focus on fusion, described as *"…an experimental technology that could be used for power generation and that works by fusing together atoms in order to release energy"*, before being asked if they had heard of fusion (Yes, No) and how familiar they were with fusion (1 = not at all familiar; 4 = very familiar).

3.2.2 Assessment of informed attitudes

Section 2 provided participants with a very basic outline of the characteristics of fusion before inviting them to state their initial attitudes towards the technology.

The information (377 words) provided was selected from websites, factsheets and newspapers and aimed to represent the type of information that a citizen could acquire via a basic information search for fusion online. The information was produced alongside technical experts from EUROfusion (www.euro-fusion.org) to ensure appropriate balance and accuracy in the claims being made about the technology. Fusion was introduced as something that *"…could be* *an important long-term energy source to complement other options"* and a short description of how fusion generates power (including efforts to delineate it from nuclear *fission*) was provided. The benefits of fusion as *"…an almost inexhaustible and clean source of energy"* were outlined alongside the drawbacks of fusion being a complex and commercially unproven technology.

Participants' initial attitudes (T1) to fusion as a potential energy source were then assessed (1 = very poor; 5 = very good), followed by a series of 5-point semantic differential scales designed to assess participants' affective responses to fusion (4-items, e.g. *"To what extent does fusion energy evoke the following feelings in you: worry --- tranquility"*) and their beliefs of the relative costs, risks and benefits of the technology (7-items, e.g. *"What are your beliefs and expectations regarding fusion technology? I think that fusion would be: "technologically unviable* --- *technologically viable"*). The four affect items had excellent internal reliability (Cronbach's α = 0.9) and so were combined to form a single composite variable (*fusion-affect*). The same was true for the belief-based items (Cronbach's α = 0.9) and so these were combined to form a single composite variable (*fusion-beliefs*).

3.2.3 Evaluation of consequences

Section 3 was designed to aid participants in evaluating some of the anticipated consequences associated with investment in fusion, thereby providing them with a deeper (i.e. more informed) understanding of the advantages and drawbacks of investment in RDD&D of the technology. Participants were provided with information on, and were required to rate, six characteristics of fusion on a 5-point scale (1 = very negative; 5 = very positive). These included: (1) Long timescales to commercial deployment (*timescales*); (2) Low dependency on scarce resources (*resource reliance*); (3) Low contribution to climate change (*climate change*); (4) Price/cost of electricity (*cost of generation*); (5) The necessity for new installations, including new prototype power plant (*new installations*); and (6) the low risk from radioactive waste (*radioactive waste*).

Table 2 outlines the text that participants received relating to each of the six consequences for investment in fusion. Each characteristic was evaluated individually, with the presentation order of the characteristics being randomised. The information was translated into the national language of each country studied.

[TABLE 2 ABOUT HERE]

3.2.4 *Final attitudes and comparative preferences*

Participants ended the survey by restating their (informed) attitude (T2) towards fusion as a potential energy source (1 = very poor; 5 = very good) and how much they (dis-)agreed that investment in fusion should be redirected towards: (a) renewable energies (e.g. solar, wind, biomass), (b) energy efficiency and saving, and (c) conventional energies (e.g. nuclear, gas, coal) (1 = strongly disagree; 5 = strongly agree).

3. Results

3.1. *Initial awareness, familiarity and attitudes towards fusion*

Consistent with prior literature, most participants in Austria, Spain and the UK claimed *not* to have heard of fusion *before* commencing the survey (51.1-60.0%, see Table 1). The exception to this was in Finland where a small majority (53.6%) claimed to be aware of fusion. Despite most participants in Austria, Spain and UK purporting not to have heard of fusion, they still claimed to have some familiarity with the technology. It is possible that this 'familiarity' was derived from the outline information provided about fusion at the start of the survey.

Respondents' initial attitudes (T1) towards fusion in Finland, Spain and the UK were, on average, moderately positive. The exception was in Austria where mean attitudes were ambivalent and did not differ significantly from the attitude-scale mid-point (3.0), $t(829) = .534$, $p = .594$ (see Table 3) The same pattern held for both the *fusion-affect* and *fusion-beliefs* measures, also.

[TABLE 3 ABOUT HERE]

Welch's one-way between-subjects ANOVAs (with Bonferroni post-hoc comparisons) were used to compare mean *fusion-affect* and *fusion-belief* constructs in each of the four countries. The analysis of differences in *fusion-affect* was significant, $F(3, 1880.97) = 64.97$, $p < .001$. Austrian participants had significantly less positive feeling (i.e. were more ambivalent) about fusion than those in each of the other nations (Mean Diffs. ≥ .48, SE = .04, *ps* < .001). Finnish participants felt most positive about fusion, although they were statistically comparable to those in Spain and the UK (Mean Diffs. < .09, SE = .04, *ps* > .256). There was no difference in the Spanish and British participants (Mean Diff. = .00, SE = .04, $p = 1.000$).

The analysis of differences in *fusion-beliefs* was also significant, $F(3, 1882.95) = 163.19$, $p < .001$. Austrians held more ambivalent beliefs about the value of fusion relative to those in other nations (Mean Diffs. ≥ .56, SE = .04, *ps* < .001). Finnish participants held significantly stronger positive beliefs about the value of fusion than those in Spain (Mean Diff. = .10, SE = .04, $p = .029$) and the UK (Mean Diff. = .12, SE = .04, $p = .007$). There was no difference in the Spanish and British participants (Mean Diff. = .02, SE = .04, $p = 1.00$).

3.2. Perceived consequences of developing fusion energy

Welch's one-way between-subjects ANOVAs were used to compare mean responses to each of the six *proposed consequences* of fusion that participants were asked to evaluate during the survey (see Table 3). The analysis revealed significant differences between the four countries on each of the six items (*Fs* ≥ 23.29, *ps* < .001), which were explored with reference to the post-hoc comparisons (using Bonferroni adjustment).

Timescales to development. On average, timescales to commercial deployment were viewed ambivalently by participants (Overall Mean = 2.93, SD = 1.03). The post-hoc comparisons revealed that Austrians were more likely to agree this was a drawback (Mean Diffs ≥ .26, SE = .05, *ps* < .001), with the Spanish, Finnish and UK participants being statistically equivalent in their evaluations (Mean Diffs ≤ .13, SE = .05, *ps* ≥ .05).

Climate change mitigation, resource reliance and cost of generation. Participants in all countries were generally positive about fusion in relation to its capacity to: (a) address climate change (Overall Mean = 3.99, SD = 1.02); (b) generate electricity at a competitive price (Overall Mean = 3.61, SD = 1.00); and (c) because of its low reliance on scarce resources (Overall Mean = 3.91, SD = 0.94). In terms of *climate change*, Finnish participants were significantly more favourable than participants in the other countries (Mean Diffs ≥ .26, SE = .05, *ps* < .001). UK participants were more favourable than the Spanish (Mean Diff. = .14, SE = .05, *p* = .031), and the Austrians and Spanish being statistically comparable (Mean Diff. = .03, SE = .05, *p* = 1.00).

With regards to *cost of generation*, the Finnish were most favourable (Mean Diffs ≥ .30, SE = .05, *ps* < .001). The Austrians were significantly least favourable (Mean Diffs ≥ .14, SE = .05, *ps* ≤ .020). The UK and Spanish participants were comparable (Mean Diff. = .06, SE = .05, *p* = 1.00).

In terms of *resource reliance*, Austrians were least positive (Mean Diffs ≥ .60, SE = .05, *ps* < .001). Finnish participants were most positive – although statistically comparable to UK participants (Mean Diff. = .11, SE = .05, *p* = .071) – and the Spanish and UK participants responses were comparable (Mean Diff. = .02, SE = .05, *p* = 1.00).

Need for new installations. Participants were generally favourable about the need for more installations (Overall Mean = 3.39, SD = 0.99), although Austrians were ambivalent on this measure and were least positive overall (Mean Diffs ≥ .37, SE = .05, *ps* < .001). The Finnish were most positive (Mean Diffs ≥ .16, SE = .05, *ps* ≤ .005) and the UK and Spanish participants were comparable (Mean Diff. = .09, SE = .05, *p* = 1.00).

Production of radioactive waste. In contrast to the other measures, there was a more distinct hierarchy in participants' responses about the production of radioactive waste (Overall Mean = 3.07, SD = 1.35). Austrian participants evaluated this consequence negatively and were statistically distinct from the more ambivalent Spanish participants (Mean Diff. = .42, SE = .06, *p* < .001). The UK participants were mildly positive and significantly distinct from the Spanish (Mean Diff. = .26, SE = .06, *p* < .001), while the Finnish participants were significantly more positive than the UK participants (Mean Diff. = .45, SE = .06, *p* < .001).

3.3. Attitudinal response to participation in survey

A 4 (country: Austria, Finland, Spain, UK) x 2 (Time: pre-information [T1], post-information [T2]) repeated measures ANOVA with Greenhouse-Geisser correction (including Bonferroni corrected comparisons) was conducted. This analysis was designed to test whether participants' general attitudes to fusion were affected by participating in the survey. For the relevant means and standard deviations associated with these analyses, see Table 3.

There was a small but significant main effect of Time, $F(1, 3396) = 23.55$, $p < .001$, $\eta^2 = .007$, with T2 attitudes being significantly more positive than those at T1. There was also a small but significant main effect of country, $F(3, 3396) = 88.98$, $p < .001$, $\eta^2 = .073$. These main effects were qualified by a significant time*country interaction, $F(3, 3396) = 4.62$, $p < .003$, $\eta^2 = .004$.

Analysis if the estimated means revealed that there was a nominal change in attitudes among the Austrian participants (Mean Diff. = .011); a small enhancement in attitudes within the UK (Mean Diff. = .035) and Spain (Mean Diff. = .052); and a more notable improvement in attitudes among the Finnish participants (Mean Diff. = .127).

3.4. Preference for investment in alternative energy options

Welch's one-way between-subjects ANOVAs (with Bonferroni post-hoc comparisons) were used to compare mean *preferences for investment* in each of the four countries. For the relevant means and standard deviations, see Table 3.

Energy efficiency and saving. The analysis of preferences this option was significant, $F(3, 1880.79) = 36.20$, $p < .001$. On average, participants were preferable to investment in energy efficiency (Overall mean = 3.45, SD = 0.98); however, the Austrian participants rated this option as significantly more preferable than those in the other nations (Mean Diffs. ≥ .22, SE = .05, $ps < .001$). Finnish and UK participants were statistically comparable in their evaluations of this option (Mean Diff. = .01, SE = .05, $p = 1.000$) and were both significantly *less* preferable to this option as compared with the Spanish (Mean Diffs. ≥ .20, SE = .05, $ps < .001$).

Renewables. The analysis of preferences for this option was significant, $F(3, 1881.41) = 56.53$, $p < .001$. Overall, participants were more favourable to investment in renewables over fusion (Overall mean = 3.62, SD = 1.00). The Spanish and Austrian participants were statistically comparable in their preferences for this option (Mean Diff. = .06, SE = .05, $p = 1.000$) and the Finnish and UK participants were comparable (Mean Diff. = .11, SE = .05, $p = .164$). The Spanish and Austrian participants' preferences significantly exceeded those in the other two countries (Mean Diffs. ≥ .34, SE = .05, *ps* < .001).

Conventional generation. The analysis of preferences for this option were also significant, $F(3, 1880.38) = 60.71$, $p < .001$. Overall, participants disagreed that this option was preferable to fusion (Overall mean = 2.34, SD = 1.07). Interestingly, the Finnish and Austrian participants agreed in their evaluations of this option (Mean Diff. = .10, SE = .05, $p = .290$) and were significantly *less* favourable to those in the other nations (Mean Diffs. ≥ .38, SE = .05, *ps* < .001). The Spanish and UK participants were comparable in their evaluation of this option (Mean Diff. = .09, SE = .05, *ps* = .463).

Taken together, participants considered investment in fusion to be preferable to investment in conventional power generation (e.g. Coal, Gas, Nuclear Fission), but less preferable to renewables and energy efficiency. The biggest preference for alternative investment was among the Austrian and Spanish participants.

3.5. Overall evaluation and attitude towards fusion energy research

Finally, we ran a multiple linear regression analysis (pairwise deletion) to identify what predicted informed (T2) attitudes to fusion among the nations most (Finland) and least (Austria) favourable to the technology. The independent variables included in the analysis were: (1) T1 attitudes; (2) the *fusion-affect* and *fusion-beliefs* items; (3) perceived consequences for developing fusion (6-items); and (4) preferences for investment in renewables and/or energy efficiency (2-items).

For both countries, all 11 items shared significant correlation with dependent variable and so were included in the analysis final analysis. We excluded 25 and 14 participants from the

Finnish and Austrian samples, respectively, based upon high Mahalanobis distance estimates. Otherwise the assumptions for linear regression were met.

Finland. The regression model (see Table 4) accounted for 69% of the variance in T2 attitudes. Analysis of the beta-coefficients identified T1 attitude to be the strongest unique predictor. Beyond this, participants beliefs about the value of fusion (*fusion-belief*), alongside their consequence evaluations for the *resource reliance*, *radioactive waste*, *climate change*, and *cost of generation*, were retained as significant positive predictors. Evaluations of *timescales* and *new installations* were not retained in the model, nor was *fusion-affect* or preferences for renewables or energy efficiency.

Austria. The regression model (see Table 4) accounted for 77% of the variance in T2 attitudes. T1 attitudes were again the single strongest predictor. Beyond this, *fusion-affect* and participants' consequence evaluations (except for *timescales*) were retained as positive predictors. Participants' preference for renewables was retained as a significant negative predictor, and preferences for energy efficiency was a marginal (although non-significant) negative predictor. *Fusion-beliefs* were not retained in the model.

[TABLE 4 ABOUT HERE]

3. Discussion

Consistent with the finding of previous studies [e.g. 16,19], our representative survey of lay-publics in four European countries (Austria, Finland, Spain, UK) revealed that: (1) overall awareness and familiarity with fusion was low-moderate; but (2) that attitudes (at Time 1, T1) were generally favourable. The exceptions to these general trends were in Finland, where a small *majority* of participants claimed to be aware of fusion; and in Austria, where overall attitudes were ambivalent. Overall, T1 attitudes to fusion between the countries followed the pattern anticipated during their selection (which was driven by historical polls on preferences for nuclear energy [33]): Finnish participants were most favourable, followed by the British and Spanish participants, and finally the Austrian participants. This contrasted with participants preferences for alternatives to fusion, where the trend was reversed. Specifically, while participants in all nations showed a preference for investment in renewables and energy efficiency/saving over fusion, this preference was strongest in Austria, and weakest in Finland.

The overall hierarchy in preferences for fusion was mirrored in the participants' initial cognitive (*fusion-belief*) and affective (*fusion-affect*) appraisals of fusion, as well as their appraisals of the various characteristics of fusion presented within the *consequence evaluation* task. Critically, though, the findings from the *consequence evaluation* task illustrated that the Austrian participants were *not* categorically objectionable to fusion on all grounds. While negative on the measures of *timescale* and *radioactive waste*, Austrians saw benefits to fusion in the context of *climate change*, *cost of generation* and *resource reliance*. These three dimensions interestingly map to the three components of the so-called 'energy trilemma' (i.e. the national need to invest in affordable, secure, and low-carbon forms of energy) [34].

Consistent with research critiquing the knowledge-deficit hypothesis of attitudes towards science and technological innovation [35–38], participation in the *consequence evaluation* task appeared to have only a small effect on participants' attitudes (T1 vs. T2). Moreover, the extent of any change appeared to correlate with the existing T1 attitudes of participants, i.e. Finnish participants showed the biggest change (+ 0.12); Spanish and British participants showed a small-moderate change (+ .03; + .05) and Austrian participants only a negligible change (+ .01). Thus, akin to a form of confirmation bias [39], participation in the *consequence evaluation* task appeared to further enhance the attitudes of those who were most positive towards the technology. This finding also fits with the observation that participants who were most favourable towards fusion tended to evaluate all *perceived consequences* (except for *timescales*) positively, while those who were least favourable showed a more mixed response to the information provided.

The regression analysis – conducted solely on the Finnish and Austrian participants – provided further insight into the nature of participants' attitudes to fusion; offering explanations for the cross-national differences in these attitudes, as well as insight into the impact that the *perceived consequence* task had on these attitudes.

Finnish attitudes appeared to be principally belief-based as feelings towards fusion (i.e. *fusion-affect*) were not retained in the regression model. The retention of *resource reliance*, *climate change*, *radioactive waste* and *cost of generation* – all of which were positively evaluated – suggested that these attributes were not accounted for in participants' entry (T1) attitudes or initial beliefs about fusion. It is likely that these attributes became seen by the Finnish participants as further reasons to support fusion, which could account for the moderate enhancement of attitudes between T1 and T2. Notably, Finnish participants' preferences for investment in energy efficiency and renewable technologies did *not* significantly detract from their attitudes towards fusion (T2). This could be taken as evidence that these participants saw fusion to be an important part of the future energy portfolio, alongside efforts to reduce demand and expand renewable generating capacity.

In contrast, Austrian attitudes towards fusion (T2) appeared to be more affect-based: being significantly predicted by participants' feelings about the technology (i.e. *fusion-affect*) but *not* by their initial beliefs (*fusion-beliefs*). As participants' feelings towards fusion were generally negative, this can help to account for the lower preferences observed for the technology (vs. Finland). As in Finland, *timescales* were not uniquely predictive of T2 attitudes. It is possible that the long lead-in times for commercialisation of fusion – being a commonly cited concern with the technology – were accounted for in T1 attitudes in both countries. The prospect of investing in *new installations* was predictive of T2 attitudes, although people were generally ambivalent on this characteristic. By contrast, *climate change*, *resource reliance*, and *cost of generation* were positively evaluated and were retained as predictors of T2 attitudes. While this could be taken as a direct endorsement of fusion on these grounds – and therefore could be leveraged by proponents of fusion as a means of engendering support for the technology (see below) – we argue that this might represent participants' more general desire for investment in a more sustainable energy system. Evidence for this conclusion comes from the retention of preferences for investment in energy efficiency/saving and the (marginal) retention of a preference for renewable investment.

While *radioactive waste* was retained as a positive predictor in the model, mean evaluations of this characteristic were unambiguously negative among the Austrian participants. Indeed, it was evaluations of this characteristic that most clearly delineated the Austrians from the Finnish. When traded-off against the perceived benefits of fusion as an affordable, sustainable generating option, we feel that the prominence of concerns about *radioactive waste* can help explain the nominal overall change in attitudes observed among this sub-sample (T1 to T2).

The differences observed between the two countries in terms of their responses to the information about *radioactive waste* can also, perhaps, be taken to illustrate something about the assimilative vs. comparative way in which Austrians and Finnish processed this information. The text provided to participants about *radioactive waste* differentiated fusion from fission in a positive way (asserting that any radioactive by-products of fusion would be short-lived in comparison to fission). While Finnish participants responded favourably to this comparative framing (*"fusion is like fission, only better"*), the Austrians apparently responded in a more assimilative way (*"fusion is a hazardous nuclear technology, like fission"*), perhaps due to the common 'nuclear branding' these technologies share [18,19]. This explanation would certainly fit with the more 'affect' driven nature of the Austrians' attitudes and is arguably indicative of their perceptions of fusion being driven by an affect heuristic [40,41]; however, it is a hypothesis that requires further investigation as participants were not specifically asked to directly compare their preferences for fusion vs. fission when evaluating this attribute.

3.1 Implications

The current study represents the first detailed cross-national experimental survey of public perceptions of fusion energy research and, as such, there are several implications arising from the findings.

First, the findings of this study concur with those of prior research, surveys and polls [17,19,22], confirming that extant attitudes towards fusion across Europe are generally favourable. This was the case in all countries studied. Even among those who were least favourable to the technology (i.e. Austrians), attitudes to fusion (T1) were generally ambivalent and not negative. The findings also confirm that these favourable attitudes stem from a relatively ill-informed position; with awareness and self-claimed knowledge of the technology generally low-moderate.

We argue that this latter finding not only vindicates our use of an ICQ-based survey method (such that participants were commenting from a more informed position) but is indicative of the potential 'fragility' of positive attitudes towards fusion in Europe. For example, it appears that there is already ingrained scepticism about the timescales to commercial deployment of fusion (commercial fusion is often maligned as being always c.30 years in the future [42]). And, while raising peoples' awareness of the climate change, affordability and sustainability benefits of the technology might help to engender positively towards the technology (even among those who are more ambivalent, e.g. Austria), we feel that in the case helping to mitigate climate change in particular, there is now (ironically) a time-limit on fusion proving itself commercially before peoples' positivity towards the technology begins to wane. This is particularly likely in a context where renewables and energy saving/demand reduction were favoured options.

With this in mind, we would also argue that the time is ripe for proponents of fusion to engage and educate publics about the technology. There is certainly evidence of the value of programmes of meaningful engagement on enhancing public understanding of other innovative technologies (e.g. Carbon Capture Utilisation and Storage [43]). Moreover, it would appear from our findings that framing fusion in terms of its abilities to combat all angles of the energy trilemma would likely have broad appeal (even among those less favourable to the technology). However, while this suggestion does resonate with the ongoing efforts being made by the fusion community to communicate with publics about the technology (e.g. planned European Fusion Expo 2021), and while there is often a positive correlation between knowledge and attitudes [44]), there are recognised hazards to a belief that a knowledge deficit underpins rejection of technological innovation [35,36,38]. Rather, in addition to perceived and/or actual knowledge, public acceptance of technology is guided by myriad factors (e.g. perceived social norms, values, trust, etc.) [45]. Evidence for this was identified within this study where, among our Austrian sub-sample, (extant) visceral concerns about *radioactive waste* appeared to counteract the positive evaluations of fusion stemming from participants' assessments of the *climate change*, *cost of generation* and *resource reliance* attributes. Taken together we feel this finding provides further evidence of the need to tailor public communication efforts to recognise the context-specific circumstances of their planned introduction. For example, in the case of fusion, a significant national reliance upon nuclear *fission*, would appear to leave publics more amenable to the technology than in a country context where there no such historical and/or current reliance exists. These differences have been observed in other cross-national studies on fusion [19].

3.1.1 Limitations and future directions

Some limitations of our study should be discussed. First, while we provided participants with key information about fusion and helped them to evaluate the technology using the *consequence evaluation* task, we failed to include any checks to be sure that participants had understood and processed the information provided. It would be valuable in future studies to include an attention check measure to gauge participant involvement with the information provided.

Relatedly, the information provided within the study, while compiled with the help of fusion experts and designed to illustrate both the strengths and drawbacks of the technology, was concise (equivalent to about two A4-pages of text) and only described a handful of the technology's attributes. The extent and type of information provided was designed to reasonably equate to that which might be gleaned from a quick internet search about fusion. One could conclude, though, that the impact (or lack thereof) of the information included in our study on participants' attitudes might have been stronger (or qualitatively different) should participants have been given more and/or more detailed details about fusion. As alluded to in the introduction, the context within which a technology or issue is framed can influence how it is received by publics [46]. It could be that Austrian participants' responses within our study constituted a form of 'reluctant neutrality' (c.f. *reluctant acceptance*, Bickerstaff et al. [47]) fostered by couching fusion as a means of affordably and sustainably combatting climate change. In the absence of such framing, it is feasible that concerns about the production of radioactive waste might have pushed attitudes among our Austrian sub-sample in a more negative direction. As such, we feel that studies into the impact of framing on relative (i.e. comparative) preferences for fusion as a generating option (versus alternative investment options, e.g. renewables) would be a valuable avenue for future research.

Second, there is the question of how representative, and thus how generalisable, the four study populations are. While there is no disputing the size and diversity of sub-populations recruited in each country, there is not guarantee that our use of quota sampling (based on age, sex and education) via internet panels means we recruited study samples that is truly representative of the national populations from which they are derived. We argue that further research to corroborate (or dispute) the current findings among independent samples of the nations investigated in this study is warranted.

Finally, there are also questions pertaining to the internal validity of the measures used within this study, particularly as some of these measures comprised relatively few items and/or were adapted using items from research into technologies other than fusion. That said, the measures used in this study were selected for their high face-validity and have proven to have acceptable internal consistency (Cronbach's alpha). Moreover, there are recognised commonalities in the factors governing lay-public acceptance of large power-generating technologies [13,45]. Special attention was also paid to the translation of the questionnaires into the various languages to ensure that the questionnaire was measuring the same concepts in the same ways across various populations of respondents.

4. Conclusion

The findings of this study provide critical, quantitative insight into public attitudes towards fusion in four European countries. Our findings confirm that while generally favourable, these attitudes vary significantly across countries, both in terms of overall preference for the technology (which would appear to correlate with broader societal perceptions of nuclear fission) and qualitive make-up. Notably, attitudes among those who were most favourable (Finland) tended to be more belief-based, with more affective influence shown among those least favourable (Austria). The findings also confirm the nominal impact that the *consequence evaluation* task had on preferences for fusion. That said, while not necessarily influencing participants preferences for fusion *per se*, the retention of many of the perceived consequences within the final regression models (over and above attitudes to fusion at Time 1) is indicative that participants' attitudes were were more informed and arguably therefore stronger and more stable following participation in the survey. Further research is now needed to test this assumption.

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Table 1. Key demographic characteristics of the study samples and initial self-claimed awareness and familiarity with fusion

Variable	Category	Austria (N = 830)		Finland (N = 849)		Spain (N = 872)		UK (N = 849)		TOTAL (N = 3,400)	
		n	%	n	%	n	%	n	%	n	%
Sex	Female	432	52.0	417	49.1	415	47.6	409	47.7	1,673	49.2
	Male	397	47.8	432	50.9	456	52.3	438	52.1	1,723	50.7
Age	18-29	149	18.0	166	19.6	144	16.5	151	17.8	610	17.9
	30-39	128	15.4	136	16.0	180	20.6	144	17.0	588	17.3
	40-49	171	20.6	149	17.6	185	21.2	165	19.4	670	19.7
	50-64	229	27.6	230	27.1	196	22.5	203	23.9	858	25.2
	65+	153	18.4	168	19.8	167	19.2	186	21.9	674	19.8
Education[a]	Non-university	631	76.0	431	50.8	388	44.5	483	56.9	1,933	56.9
	University	199	24.0	418	49.2	484	55.5	366	43.1	1,467	43.1
Awareness[b]	Yes	332	40.0	455	53.6	374	42.9	350	41.2	1,511	44.4
	No	498	60.0	394	46.4	498	57.1	499	58.8	1,889	55.6

Familiarity[c]	Not at all	45	13.6	29	6.4	38	10.2	39	11.1	151	10.0
	Slightly	221	66.6	334	73.4	268	71.7	223	63.7	1,046	69.2
	Familiar	60	21.9	82	18.0	60	16.0	72	20.6	274	18.1
	Very familiar	6	15.0	10	2.2	8	2.1	16	4.6	40	2.6

Notes. Where figures do not add up to 100%, this is due to respondents answering ‘other’

[a] Non-university includes: None completed; Up to GCSE/O-Level (or equivalent); Up to A-Level (or equivalent); Other qualifications/apprenticeships. University includes: Degree level or higher; Undergraduate (not Bachelors degree); Graduate (Bachelor’s degree); Postgraduate (Master’s, doctorate, PhD, etc.)

[b] Awareness of fusion: Before participating in this study, had you ever heard of fusion energy? (Yes; No)

[c] Familiarity with fusion: How would you rate your familiarity with fusion? (Not at all familiar – you know nothing about fusion power; Slightly familiar – You’ve heard about fusion power, read an article or watched a television feature about the technology; Familiar – You’ve some experience with fusion power, researched the subject for school, work, or personal interest; Very familiar – You consider yourself very well informed or expert in fusion power).

Table 2. Information provided to participants relating to the consequences of investing in nuclear fusion

Short theme title[1]	Full theme title[2]	Description provided
Timescales	***It will take years to build the technology***	Fusion power presents significant scientific and engineering challenges. So far, the main problem with fusion power generation is that it doesn't produce more energy than the electrical energy required to keep the reaction going. The first commercial fusion power plant, if ITER -the larger fusion experiment going on now- succeeds, is not expected to enter the energy mix before 2050.
Resource reliance	***Less dependence on scarce resources***	In a commercial fusion power station the fuel will consist of a mixture of deuterium and tritium. Deuterium is a stable hydrogen isotope. It is very abundant and may be cheaply extracted from seawater. Tritium can be produced from lithium, which is widely distributed in the Earth's crust. If used to fuel a fusion power station, the lithium in one laptop battery would produce the same amount of electricity as burning 40 tons of coal.
New installations	***New installations needed***	In order to implement this technology, demonstration plants would have to be built in the coming years. The next step for fusion research is the construction of the ITER, a large international fusion experiment in the south of France. The results will help guide the choice

		of materials for the design of DEMO, the prototype power plant that will follow the ITER experiment.
Radioactive waste	***Radioactive waste***	The fusion reaction releases neutrons. The neutrons would be quite dangerous to humans, but when the plant is turned off the production of neutrons ceases within milliseconds. The radioactivity in a fusion power plant will be confined to the power plant itself, there will not be any waste. Once the plant is decommissioned, the radioactive products are short lived (50-100 years) compared to the waste from a fission power plant (which lasts for thousands of years).
Climate change	***Contribution to climate change***	The only byproduct that is created during the nuclear fusion process is helium, which is not a greenhouse gas. So the contribution to climate change by generation of electricity would be greatly reduced through the use of this technology.
Cost of generation	***Price/Cost***	Although it is difficult to estimate the future cost of the electricity generated by means of fusion power, recent calculations suggest that a fusion power plant could generate electricity at a similar price to a conventional nuclear power station.

Notes. [1] Title used with the analysis; [2] Title as presented to participants

Table 3. Pre-information and post-information evaluations of fusion

	Austria (*N* = 830)	Finland (*N* = 849)	Spain (*N* = 872)	UK (*N* = 849)	Total (*N* = 3,400)
Fusion-affect (T1)	3.01 (0.97)	3.59 (0.81)	3.50 (0.94)	3.50 (0.88)	3.40 (0.93)
Fusion-belief (T1)	2.87 (0.67)	3.55 (0.70)	3.44 (0.84)	3.43 (0.81)	3.33 (0.88)
Fusion Consequences					
• Timescales	2.70 (1.00)	3.08 (0.99)	3.00 (1.04)	2.95 (1.05)	2.93 (1.03)
• Resource reliance	3.59 (1.06)	4.09 (0.84)	3.95 (0.89)	3.98 (0.90)	3.91 (0.94)
• New installations	3.06 (1.08)	3.61 (0.79)	3.45 (0.99)	3.43 (0.98)	3.39 (0.99)
• Radioactive waste	2.51 (1.36)	3.63 (1.12)	2.93 (1.35)	3.18 (1.32)	3.07 (1.35)
• Climate change mitigation	3.83 (1.06)	4.26 (0.79)	3.86 (1.12)	4.00 (1.04)	3.99 (1.02)
• Cost of power generation	3.40 (1.05)	3.90 (0.81)	3.54 (1.03)	3.59 (1.03)	3.61 (1.00)
Preference for alternatives					
• Energy efficiency and saving	3.72 (1.06)	3.28 (0.88)	3.50 (0.96)	3.30 (0.97)	3.45 (0.98)
• Renewable generation	3.86 (1.04)	3.35 (0.91)	3.80 (0.95)	3.46 (1.01)	3.62 (1.00)

• Conventional generation	2.05 (1.05)	2.15 (0.90)	2.53 (1.12)	2.62 (1.07)	2.34 (1.07)
Pre-information fusion attitude (T1)	2.98 (1.12)	3.63 (0.94)	3.40 (1.00)	3.54 (0.96)	3.39 (1.03)
Post-information fusion attitude (T2)	2.99 (1.12)	3.75 (0.87)	3.45 (1.00)	3.57 (0.96)	3.44 (1.03)
Mean Diff. in fusion attitude (T1 vs. T2)	+ 0.01	+ 0.12	+ 0.05	+ 0.03	+ 0.05

Table 4. Multiple linear regression model results for Finland and Austria

	Finland (*N* = 824)				Austria (*N* = 814)			
	Mean	Beta	T	Sig.	Mean	Beta	T	Sig.
T1 Attitude	**3.63 (0.92)**	**.48**	**16.45**	**< .001*** **	**2.98 (1.10)**	**.45**	**14.212**	**< .001*** **
Fusion affect	3.61 (0.77)	.02	0.73	.465	**3.03 (0.96)**	**.08**	**2.55**	**.011***
Fusion belief	**3.57 (0.68)**	**.14**	**4.40**	**< .001*** **	2.88 (0.66)	.01	0.40	.690
Timescales	3.11 (0.96)	.01	0.53	.597	2.70 (1.00)	.01	0.67	.506
Resource reliance	**4.13 (0.76)**	**.06**	**2.28**	**.023***	**3.62 (1.03)**	**.06**	**2.68**	**.008*** **
New installations	3.62 (0.76)	.04	1.84	.066	**3.07 (1.07)**	**.13**	**5.27**	**< .001*** **
Radioactive waste	**3.65 (1.10)**	**.11**	**4.57**	**< .001*** **	**2.52 (1.36)**	**.09**	**4.10**	**< .001*** **
Climate change	**4.29 (0.73)**	**.10**	**3.60**	**< .001*** **	**3.85 (1.03)**	**.10**	**4.23**	**< .001*** **
Cost of generation	**3.91 (0.77)**	**.08**	**3.35**	**.001*** **	**3.41 (1.04)**	**.12**	**5.25**	**< .001*** **
Efficiency pref.	3.36 (0.89)	.01	0.19	.851	**3.87 (1.02)**	**- .05**	**2.07**	**.039***
Renewable pref.	3.28 (0.87)	- .01	0.52	.602	3.75 (1.04)	- .05	1.92	.055
Model statistics	Adj. R^2 = .69, $F(11, 812) = 169.00$, $p < .001$				Adj.R^2 = .77, $F(11, 802) = 247.74$, $p < .001$			