Fusion energy: a deeper look into attitudes among the general public

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Abstract

Already in the 1990's, the Fusion Project Evaluation Board recognised the need for social research to gain understanding on public opinion towards fusion and on elements that can contribute to build trust among the different actors in the field. The SERF program (Socioeconomic Research on Fusion) was then started. In 2014, public awareness and acceptance of fusion energy was re-confirmed by EUROfusion as crucial, for both sociological research and the fusion community. Given that fusion is not a hot issue among most publics, it is little known and distant from daily life, properly researching public attitudes towards fusion entails important methodological challenges. To address these challenges, this paper uses a combined qualitative-quantitative approach to examine public attitudes towards fusion. Data were collected with open and closed questions included in a survey among Belgian adults (N=365 respondents who said they had previously heard of fusion energy), using Computer Assisted Personal Interviews. The quantitative analysis showed that the most influential predictors of attitudes towards fusion are the attitudes towards nuclear energy, the attitudes towards science and technology, and the perceived importance of costs and time needed to develop fusion energy. Our qualitative evidence confirms that nuclear fission does play a key role in the sense making about fusion, as a key device to define fusion was its comparison with fission (either as a new, different, nuclear or as a still dangerous nuclear). The results also showed some evidence that a new 'fusion brand' emerged spontaneously among the survey participants; respondents who mobilised the new brand referred to fusion as endless and clean energy that could solve our energy problem, and as scientific progress. Based on results, we discuss implications for fusion research and development.

Keywords:

Fusion energy, awareness, public attitudes, survey, mixed-methods approach, public acceptance.

1. Introduction

Following the request of the First Fusion Project Evaluation Board (FPEB, 1990) of accompanying fusion R&D with some research on economics, and with the request of the 2nd FPEB (1996) of extending economic research to social sciences, the EC started in 1997 a program on Socio-Economic Research on Fusion (SERF). The program, funded by the European Fusion Development Agreement (EFDA), aimed at understanding the social and economic conditions that can transform the expected scientific success of fusion into an energy supply option and a market success.

A dedicated task on Fusion and the Public Opinion was launched as a proper research effort, not as a mere public relations exercise on behalf of fusion energy or fusion research. This concentrated on gaining understanding on how the public perceives fusion, what kinds of understanding is possible, and what elements can contribute to build trust among the different interest groups in the field (Ingelstam, 1999). In 2005, the SERF Status Report (Tosato, 2005) collected the findings from interdisciplinary expert teams across Europe from 1997 to 2005, including social studies on risk perception and trust, public opinion towards fusion, public participation and governance, and their implications for fusion. The Report stressed the need for longitudinal public opinion studies as well as for informed public debates with lay publics. The (very) limited public awareness about fusion and the associations with the fission program were already identified as key research challenges for social scientists.

A subsequent comprehensive review of the existing evidence concerning lay understanding of fusion carried out within SERF (Prades et al, 2007) confirmed that 'public opinion towards fusion' needs to be acknowledged as something that cannot be easily measured. To address this challenge, qualitative methodological approaches that allow members of the public to *engage* with information about fusion technology were designed and implemented in the UK and Spain (Prades et al, 2008). The methodological design, combining elements of research and engagement, comprised reconvened focus groups, diaries in-between sessions, and elements of problem structuring methods. The method proved highly efficient both in eliciting lay understanding of fusion and promoting public engagement. Results showed that members of the public are perfectly able to reason about complex technical matters, but adopt a wider viewpoint that includes besides technological considerations, value judgments and matters that are relevant to their everyday lives. It should be noted that group-based qualitative research methods do generate in-depth, quality and rich data (Seale, 1999; Bloor et al., 2001), but the evidence cannot be claimed to be statistically representative. Therefore, assessing public attitudes towards fusion by means of survey based research was identified as key research topic for the 2014-2018 SES Program.

2. Background

A number of large-scale surveys have addressed attitudes to fusion energy. For instance, the 2002 Eurobarometer on "Energy: options, issues and technologies" (EUROBAROMETER 169, 2002) evaluated public opinions concerning the main goals of fusion energy (e.g. increased safety, less radioactive waste). The study showed that while these goals were not always clear, the public tended to support the research on nuclear fusion. Almost 60% of the EU citizens responding to the 2002 Eurobarometer were of the opinion that much more research and development is needed to confirm the potential of this technology. The same study showed that fusion energy was perceived as efficient, but at the same time more expensive than other technologies, notable renewables and hydroelectric power, and deemed not so good for environment (only 5% of the respondents thought that fusion is one of the two technologies that are best for environment, while 67% agreed that this is the case for renewables). The most recent cross-national study in 20 EU countries and Ukraine (November 2018) concluded that at least three out of ten respondents reported having heard of fusion energy (Oltra et al., 2019). Overall 36% respondents considered fusion energy as "important" or "very important", with highest levels of support for fusion energy in Romania, Ukraine, Bulgaria, and Finland (around 80%), and lowest levels of support in Austria and Belgium (54%).

Several studies in the literature investigated acceptance (decision to act in favour/against), acceptability (general attitude), or relative preferences concerning energy technologies such as fossil fuels, solar, wind, ocean, gas, biofuel, hydroelectric or nuclear power (see e.g. Huijts et al, 2012;

Visschers and Siegrist, 2014). However, only a limited number of studies (e.g. Oltra et al, 2019) include fusion energy.

In this context, the main challenge for large scale surveys dealing with unknown and unfamiliar energy technologies is that of measuring "pseudo opinions" and "non-attitudes" (de Best-Waldhober et al. 2009a; L'Orange et al. 2011). For instance, it has been shown that despite the fact that survey participants may know little about the energy technology (for instance Carbon Capture and Storage, hydrogen or nuclear fusion), they may still express an opinion. Consequently, their views tend to be unstable and very sensitive to contextual change (de Best-Waldhober et al. 2009b; Fleishman et al. 2010; Malone et al. 2010).

The fundamental methodological challenge in research on lay attitudes towards unknown and unfamiliar energy technologies is, hence, to avoid merely assessing pseudo-opinions. This study aims at combining qualitative and quantitative analyses in order to provide a deeper insight into the public understanding and reasoning about fusion technology and its application for electricity production. The quantitative analysis is based on data from a survey with a large sample of the Belgian adult population (N=365) which, through an improved design, paid special attention to the problem of "non-attitudes" (see Malone et al., 2010, in relation to public surveys on CCS). This part of analysis tested which among a number of potential predictors, including socio-demographic variables (gender, education), attitude towards science and technology, attitude towards nuclear energy, perceived relative importance of the negative and positive aspects of fusion energy development, and salience of the energy issue- are potential determinants of attitudes towards fusion energy. The qualitative research part probed pre-existing images and mental associations with fusion energy on the basis of answers given to an open question in the survey.
The reminder of the paper summarises key results from previous research on fusion and formulates the research hypotheses of this study; it describes the methodological approach employed; and illustrates our results. Finally, the conclusions and implications of this study are presented.

3. Previous findings and hypothesis

3.1. Public understanding and conceptualisation of fusion energy

Qualitative research in Spain and the UK (Prades et al, 2007; 2008), confirmed that nuclear fusion is poorly understood by European citizens. A minority of participants acknowledged some familiarity with the word 'fusion' but were not able to describe its main characteristics or make some sense of it, at the outset of the research. In this context of very little awareness, fusion was conceived as a 'promising' energy source: abundant, alternative to current energy sources, and 'almost' renewable. The unknown and long-term side effects, wastes, and the high level of investments were revealed as the key concerns in participants' discourses about fusion.

Horlick-Jones et al (2007a) highlighted the complexity of the lay reasoning processes about technological and risk issues, suggesting four broad modes of reasoning (Horlick-Jones et al, 2007b). When there is very limited knowledge, *simple categorisation* is used to capture the essence of the technology in terms of everyday categories, or at least categories with which people have some shared familiarity, including metaphors like 'contamination' or 'pollution'. *Brand-based* reasoning is also relevant with very limited knowledge, but when the label in question ('nuclear', 'natural', …) has a powerful set of images and meanings associated with it. *Structural-calculative* processes arise when citizens start to learn about the context of the technology, and they use such details (e.g. location or partners) to make sense of the technical devices (low information rationality). Lastly, reasoning *grounded in technical knowledge* occurs when citizens learn more about the technology in question, leading to greater incidence of reasoning based upon specific technical knowledge.

In this context, previous research points out that perceptions of nuclear fusion, being based upon rudimentary knowledge, are strongly shaped by the existing understanding and imagery associated with the nuclear industry, and with the fission programme (Prades Lopez et al, 2007; 2008). In this regard, recent qualitative research to explore the influence of the word 'nuclear' in shaping lay reasoning about fusion (Horlick-Jones et al, 2012), suggested that: a) the 'nuclear brand' (negative resonances in terms of fear, stigma, etc.) was relevant but not as prominent as could be expected; b) the 'new nuclear framing', i.e., the reluctant acceptance" of nuclear power to tackle climate change, did show up, but relying on the "supply" argument; i.e., the perception of nuclear energy as the only energy source that, despite its drawbacks, can guarantee the world's energy supply and, c) there is evidence on a new 'fusion brand' (endless and clean energy that could solve our energy problem; top international research and scientific progress; pioneering organizational enterprise, and novel international frameworks).
Considering these findings from previous qualitative research and keeping in mind the nature of the qualitative evidence in the present study (i.e., answers to an open question without receiving any information on fusion), we expected that the simple categorization practices to be the dominant mode of reasoning of the respondents to our survey. Additionally, the responses to the open question were expected to substantiate the occurrence of the new fusion brand emerging among the participants' answers, as well as the role of nuclear fear/stigma in the participants' images of fusion.

3.2. Factors potentially associated with attitudes towards fusion energy

Several factors might influence, directly or indirectly, public attitudes towards fusion, for instance positive affect, negative affect, perceived costs, perceived risks, perceived benefits, perceived fairness of the decision process to implement a technology (e.g. in terms of participation of different stakeholders to the decision process) and perceived fairness of the distribution of risks, benefits and costs (see Huijts et al, 2012 for a comprehensive review).

Perceived benefits and perceived risks have been shown to strongly influence attitudes towards existing, as well as new and emerging technologies (e.g. Siegrist, 2000; Currall et al, 2006; Visschers et al., 2011; Visschers and Siegrist, 2013; Kristiansen et al., 2016), with the former being typically more influential than the latter. Terwel et al (2009) conclude for instance that the perceived benefits of CCS (Carbon Capture and Storage) dominate people's attitudes toward this technology, regardless of the potential downsides. In addition, even after a nuclear accident, social acceptance of nuclear energy remained largely determined (more than 90% variance explained) by the perceived benefits and risks (Visschers and Siegrist, 2013). Past research also suggests that social trust (e.g. in scientists, risk regulators and operators) and affect (emotions) influence the perceived risks and benefits of technologies which, in turn, influence public attitudes (Visschers and Siegrist, 2013; Visshers et al 2011; Huijts et al., 2012). Furthermore, there is evidence that people do not consider risks and benefits individually. For instance, the study of Currall et al (2006) on nanotechnology applications suggests that when the benefits are low, consumers are more concerned about risks than benefits, when benefits are high. However, the connection between abstract research and likely benefits of technology, especially an emerging one that is largely unknown, may not be easily made by citizens (Worcester, 1999).

Specifically for fusion, Oltra et al. (2019) found that trust and attitudes towards nuclear energy and attitudes towards science had a significant effect on the acceptance of fusion energy; the effect of these variables was indirect, in the sense that attitudes towards nuclear energy and towards science influence trust, which in turn influences perceived benefits of fusion energy and affect. This study also showed that perceived benefits, affect and – to a lesser extent, personal relevance had a moderate influence on the global evaluation of fusion. As described earlier, the unknown and long-term side effects, the potential pollution and wastes, and the high level of investments were revealed in past research as the key concerns in participants' discourses about fusion. Specifically, for the Belgian population, the study by Perko et al (2016) suggests that the most frequently encountered negative aspects related to fusion presented in the Belgian media in the time period 2000-2015 were the rising costs and the distant promise of nuclear fusion as an energy source. Consequently, in our study we tested:

> *Hypothesis 1a: the more importance given the **fusion development costs** as a negative aspect of fusion energy development*, *the less positive will be the attitude towards fusion*.
>
> *Hypothesis 1b: the more emphasis is laid on the **long time** needed to bring the technology to an operational level, the less positive will be the attitude towards fusion energy.*

Following Visschers et al (2011), whose study suggests that acceptance of nuclear energy is mainly influenced by perceived benefits for a secure energy supply and, to a lesser extent, by perceived benefits for the climate, we tested in our study whether:

> *Hypothesis 2: the more importance is given to the ability of fusion to provide **nearly unlimited energy**, in comparison with other benefits, the more positive will be the attitude towards fusion energy.*

Attitude towards science and technology has been suggested as a potentially explanatory variable for attitudes towards new technologies. Besley and McComas (2015) point out in a study of nanotechnologies and nuclear energy, that the "*generalized views about science and science decision-makers – in addition to issue-specific concerns – are central to understanding opinion dynamics*" concerning emerging technologies. We therefore tested whether:

> *Hypothesis 3: the general **attitude toward science and technology** is positively associated with the attitude towards fusion energy*.

Previous studies (Horlick-Jones et al, 2012) highlighted associations of fusion energy with the military applications of nuclear technologies and with the fission program, and the frequent brand-based reasoning used to make sense of the largely unknown fusion technology.

Consequently, we tested whether:

> *Hypothesis 4: the **attitude towards nuclear energy** will be positively correlated with, and a strong predictor for, the attitude towards fusion energy.*

Furthermore, the Eurobarometer 262 (2006) found greatest support for a number of energy technologies (solar, wind, ocean energy, biomass, hydroelectric) among those consider that reducing energy consumption is a very important issue in their country (Eurobarometer 262, 2006). Research by Horlick et al (2012) suggested that 'new nuclear framing', i.e., the reluctant acceptance" of nuclear power, may not only rely on its ability to tackle climate change, but also on the 'supply' argument. The latter refers to the belief that nuclear energy is the only energy source that, despite its drawbacks, can guarantee the world's energy supply. We therefore tested whether:

> *Hypothesis 5: the higher the* ***concern about energy supply****, the more positive the attitude towards fusion energy.*

Finally, subjective knowledge about a technology has been shown in some studies to play a more important role in the acceptance of new technologies than factual knowledge (House et al., 2004) and to be positively associated to acceptance of energy technologies (Duan, 2010). In their review on psychological factors influencing sustainable energy technology acceptance, Huijts and colleagues (2012) point out that subjective and objective knowledge have different impact on the acceptance of a new technology, with the former being more influential. Furthermore, experience may have a moderating effect on the relationship between the aforementioned factors and attitudes towards a technology. In our survey, we have tested whether self-reported familiarity was correlated with the attitude towards fusion energy.

> *Hypothesis 6: self-assessed* ***familiarity*** *with fusion energy is positively associated with attitudes towards fusion energy.*

4. Method

4.1 Sample

Data used in this study originate from a larger survey on nuclear issues collected with a sample of N=1028 Belgian adults, and representative for (18+) Belgian population with respect to gender, language, age, region, education, province and level of urbanisation (Table 1).

Data were collected in September and October 2015. The data collection method employed was Computer Assisted Personal Interviewing, with interviews carried out at the home of the respondents and the answers being directly recorded on a portable hard disk. The field work was performed by a market research company with professional interviewers.

Table 1. Socio-demographic characteristics of the sample

Variable	Categories	Belgian population 18+ (N=8871,000) (%)	Survey sample (N=1028) (%)	Respondents who heard about fusion (N=365) (%)	Respondents recalling (partially) correct inform. on fusion (N=178) (%)
Gender	Men	48.5	50	68	72
	Women	51.5	50	32	28

Age	18-34	26.90	21	20	21
	35-54	35.0	38	43	39
	55-64	15.7	21	20	24
	65+	22.4	20	17	16
Education	Lower (primary & lower second.)	29.5	26	13	10
	Intermediate (higher second.)	40.4	42	40	32
	Higher	31.0	32	47	58

A filter question posed by the interviewer at the beginning of the fusion section revealed that 365 out of the 1028 respondents had heard of nuclear fusion. The remainder of the questions on fusion energy were asked only to these 365 respondents who said they had previously heard of this technology. As illustrated in Table 1, men and respondents with higher education are overrepresented in the subsample of 365 respondents who reported they had heard of fusion compared to the Belgian general population. respondents.

4.2 Survey design

The design of the survey section related to nuclear fusion is summarised in Fig. 1. The section concerning fusion energy was introduced by the interviewer as follows: "*So far I have asked you questions about nuclear energy, which is created in current nuclear power plants by the process called nuclear fission*. *Now I would like to ask you some questions about a different source of energy, namely nuclear fusion or fusion energy."* Questions about fusion were integrated in a larger survey on radiological risks and nuclear energy. Prior to the fusion related questions, the survey included questions related to salience of the energy issue in Belgium, risk perception and confidence in authorities related to a number of radiological and environmental risks (including e.g. accident in nuclear power plant), attitude towards science and technology, attitude towards nuclear energy, confidence in the management of nuclear risks, perception of the Fukushima accident, citizens' involvement in radioactivity measurements, position of political parties with respect to nuclear energy and decommissioning.

An essential methodological challenge in survey research on public acceptance of new energy technologies is avoiding the mere assessment of pseudo opinions. In order to address this issue, a multi-fold approach was taken. A first filter question probed whether respondents had heard of nuclear fusion. This filter question was asked after the nuclear energy topics had already been addressed. The remainder of the fusion questions were asked only to the N=365 respondents who gave a positive answer to this question. Next, the survey probed the automatic mental associations and implicit attitudes (Galdi et al, 2008) through an open question: "*Can you describe in few words what have you heard of nuclear fusion energy?*". Next, following de Best-Waldhober et al (2009b), the interviewer provided neutral information about the technology (see full text in Annex 1).

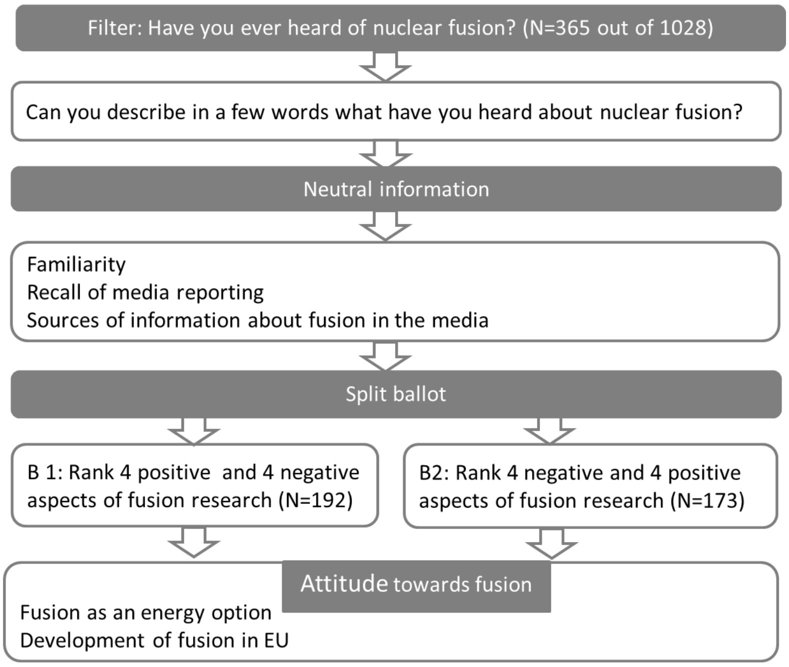

Fig. 1 Design of survey section about fusion energy

The answering category *"I don't know"* was allowed for all questions in the survey in order to not force the respondents to make an uninformed choice.

The complete list of fusion-related questions can be found as Appendix 1. These included self-assessed familiarity with fusion energy, recall of media reporting and sources of information about fusion, followed by a ranking in order of perceived importance of four positive aspects of fusion energy research and developments and four negative aspects of fusion research and development (see also next subsection), and attitude towards fusion energy. The choice of risks and benefits drew on main themes present in media reporting (Perko et al, 2016) and the communication by the international fusion research community (https://www.euro-fusion.org/fusion/). A split ballot was applied to alternate the order of presentation of positive and negative aspects (N=192 received first the positive aspects, while N=173 received first the negative aspects).

The measurement of dependent and independent variables is described below.

The dependent variable, **attitude towards fusion energy** was assessed using two highly correlated items (rho= -0.769, p<0.001) capturing i) respondents' opinion on fusion as an energy option, with answers on a 5-point Likert scale ranging from "very bad option" to "very good option" (F1) and ii) the extent to which the respondents' were favourable or unfavourable to the development of fusion in E.U. (5-point answering scale ranging from "totally in favour" to "totally against") (F2). The dependent variable was then constructed by summing up F1 and the inverted F2, thus ranging from 2 to 10, higher scores corresponding to a more positive attitude.

A pilot study carried out prior to the field work for our study (N=23), with in-depth discussions following the completion of the questionnaire, showed that respondents tended to have difficulties to score the potential risks and benefits of fusion energy on a qualitative importance scale and tended to either interpret these as knowledge questions (therefore frequently choosing the “I don’t know” answer) or score all items using the upper part of the scale (e.g. “extremely” or “very important”). Therefore, in the present study respondents were asked to rank potential risk and benefits rather than score them on an absolute importance scale. The aim was to investigate whether particular advantages or disadvantages come out as most important, and whether their ranking plays a role in influencing attitudes towards fusion energy.

Negative aspects of fusion research and development included four items: “nuclear fusion involves the use of radioactive materials”; “nuclear fusion takes too long to developed so it cannot solve the current energy problems”; “the money used for nuclear fusion could be spent on the development of renewables”; and “nuclear fusion facilities require large amounts of energy themselves to maintain the fusion process”. Respondents were asked to rank these aspects from most important (1) to least important (4).

Positive aspects of fusion research and development also included four items: “nuclear fusion will provide a nearly unlimited source of energy”, “nuclear fusion does not produce highly radioactive waste or very limited quantities”, “nuclear fusion is climate friendly because it does not produce greenhouse gasses”; and “nuclear fusion is safe because major accidents are not possible”. Respondents were asked to rank these aspects from most important (1) to least important (4) .

Attitude towards science & technology was measured with the question: “Overall, to what extent are you favourable or unfavourable to the development of science and technology”, with answers ranging from “totally in favour” to “totally against” (5-point Likert scale).

Attitude towards nuclear energy was measured with a similar question: “What is your opinion about the use of nuclear energy for electricity production?”, with answering categories identical to those used for the attitude towards science and technology.

Salience of the energy issue was measured with the statement "According to you, the energy supply in Belgium is currently”, measured on a 6-point Likert scale ranging from 1="no problem at all" to 6= "a very important problem".

Self-assessed **familiarity** with fusion energy was measured with the question “How familiar do you feel with the topic of nuclear fusion?”, with answers on a 5-point Likert scale ranging from 1=”not at all familiar “ to 5=”Very familiar”.

4.3 Coding of the open question

The answers given to the open question " *Can you describe in few words what have you heard of nuclear fusion energy* " were few words or small sentences describing associations or evocations, for instance, “*the opposite of nuclear fission, nuclear fusion is a new manner”*, *“interesting / misunderstood / future”* or *“it is the energy with the sun“*.

Classification of answers as "incorrect" was based solely on technical misunderstandings (e.g. splitting of atoms instead of fusion of atoms). This type of factual information was reviewed by two fusion experts. Answers that reflected only perceptions, for instance “is still dangerous”, were taken into account as “correct or partially correct answers” independently of their positive or negative undertone.

Further coding was done by two independent coders individually, without interaction (not in a group discussion session). In a first step, each coder produced his/her own coding categories[1].

The approach followed a combination of Analytic Induction (Silverman, 1993), in which data is interrogated to search for evidence for or against provisional hypotheses arising from the research questions), and Grounded Theory (Bloor, 1978; Bloor et al, 2002) which is sensitive to the possibility of new, unanticipated findings being identified.

The final codebook, including the categories listed in Table 2, resulted from discussion and agreement on the coding categories.

Table 2 Coding of the open survey question

Category	Specific codes
Nature of the evidence	1=No knowledge 2=Wrong / Erratic or inconsistent answer 3=Correct or partially correct answers
Prior images or evocations	1=Describing a process to produce energy 2=Describing a process in comparison to fission 3=Describing the fusion brand 4=Location
Modes of reasoning	1=Simple categorization 2=Technical knowledge
Undertone of arguments	1=Positive 2=Negative 3=Neutral

In a second step, the two coders carried out a new independent analysis in order to classify each response using the agreed coding categories. For each respondent, the main idea was selected and coded using one code in each category. Inter-coder agreement was calculated with SPSS 19 using the Kappa index test. The Kappa statistic produced a value of 0.97, indicating a very good agreement between coders. MAXQDA 12 software was used for the qualitative analysis, as it allows coding of text into different categories. It also provides main statistics on the number of quotes in each code and a graph of the code matrix.

5. Results

5.1 Level of knowledge / familiarity

Out of the 365 respondents who said they heard about fusion, 30% gave the “I don’t know” or similar response ("only the name”, “just heard about it”, “can’t describe it”), while others provided a very simple and non-significant description that could be deduced from the wording of the question (“belongs to energy”, “process used to produce energy” or “popular subject on the TV”).

[1] Among the independent coders, one has long experience in qualitative research on fusion (being familiar with the underlying hypothesis) and the other has extensive experience in qualitative research on energy technologies but not specifically on fusion (without pre-conceptions).

As shown in Table 1, the respondents who could provide some correct information (49%) were predominantly male respondents with higher education.

Among the respondents who provided answers classified as “incorrect” (21%), the most common mistake was confusing fusion with fission energy, e.g. “splitting of atoms “, "it concerns uranium", or “it is the bursting of uranium atoms that generate energy”. Other repeated misconceptions were: confusion with particle accelerators (“to be able to look deeper in the structure of atoms"), with the technology used in medicine, or with the joining of different energy sources (“coming together of nuclear power plants and windmills”).

Most of the 365 respondents who said they had heard of fusion energy considered themselves not at all familiar (36%) or very little familiar with the topic (35%). Only 10% said they felt rather familiar or very familiar, and 19% felt moderately familiar. Furthermore, there was a low recall of the presence of fusion in recent media reporting: 31% (out of N=365) said they had not heard about fusion in the media in the past year, 44% said they heard once or twice, while 22% said they heard more than 3 times (4% even more than 10 times).

Self-assessed familiarity with fusion energy was significantly higher ($F(1,363)=61.44$; $p<0.001$ in one-way ANOVA) among the respondents who could recall some correct information about fusion energy ($M=2.45$, $SD=1.12$), compared to respondents who gave an incorrect answer or could not provide any information ($M=1.66$, $SD=0.79$). Recall of fusion reporting in the media was however not higher among those who could provide (partially) correct information about fusion ($p=0.4$ in one-way ANOVA test).

5.2 Prior images of fusion energy and mental associations

Taking into account the partially correct answers (N=178), four main mental associations or prior images of fusion could be distinguished among our participants: fusion as a process to produce energy (51%); fusion as a process related to nuclear fission (21%); fusion as a new and promising energy alternative (new fusion brand) (21%), and others, including location issues (7%).

Among the responses describing fusion as a process to produce energy (51%), two different modes of reasoning categories emerged:

- Simple categorization (66%): fusion as melting, joining, putting together; and fusion as a sun on earth: "it is a sort of sun that would be made - the same process as in the sun" or “this happens in the sun".
- Technical knowledge (33%): e.g. “fusion of hydrogen nuclei to produce helium”, “with magnetic protection, in magnetic field”, “extreme temperatures needed’. Quite elaborated responses could also be found, such as:
  - *"It's about using atoms of hydrogen type to obtain atoms of helium type and releasing a significant amount of energy; this fusion can only operate at very high temperatures"*
  - *"To reconstruct a star at a smaller scale on Earth. To fusion hydrogen atoms and helium + energy according to the formula $E=MC^2$"*
  - *"They try (among others in France) to imitate the process that occurs in the sun: two nuclei of H^3 (tritium) are fused by which helium is created. By doing this a lot of energy is released."*

When the survey participants describe fusion in comparison to fission (21%), the same modes of reasoning (from very simple to quite elaborate) could be found:

- 67% used very simple descriptions such as: “nuclear a bit cleaner”, “this is an alternative for the current nuclear energy or “opposite of nuclear fission”. Fusion is also associated with the problematic historical experience of fission energy (‘nuclear brand’), including references such as “it’s still risky”.
- 33% of the respondents used technical knowledge highlighting issues such as “less radioactive waste”, “more powerful” or “more energy capacity”:
  - *“this form produces much more energy than nuclear fission and therefore there is much less radioactive material needed, and would therefore be safer”*
  - *“Nuclear fusion is the opposite of nuclear fission. Can only be done under extreme temperatures/ Problem! Might succeed under magnetism/ experiments undergoing with variable results".*

Another 21% of our respondents conceived fusion as a ‘new and good technology’, in line with the so-called ‘new fusion brand’. Fusion is described as future progress; as a clean, safe, and unlimited energy; with little or no waste; and entailing new collaboration schemes between countries: “different countries working together”, “it's the best solution”, “it does not produce any radioactive waste”, “this is the energy of the future”.

Finally, a few respondents (7%) described fusion using other mental associations, including fusion energy facilities (“I think there is one under construction in France”).

Considering the undertone, results showed a generally positive tone, although there is some evidence of negative tones, usually linked to the fission branding.

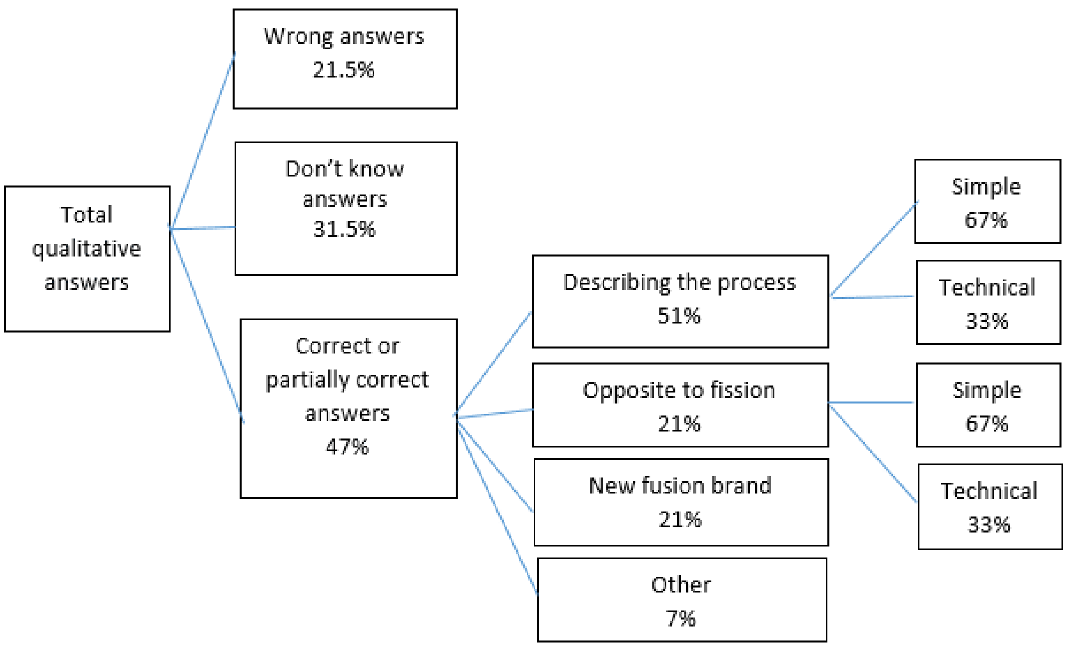

Fig. 2 Summary of the qualitative findings

In the remainder of the paper the respondents whose answers were classified as “correct or partially correct” will be referred to as Group 1 (N=178), whereas the other respondents who said they had heard of fusion but whose answers were classified as "incorrect" will be referred to as Group 2 (N=187).

5.3 Attitudes towards fusion energy

Overall, attitudes towards fusion energy among the 365 respondents who said they had previously heard of fusion energy were moderately favourable (M=6.8 on a scale from 2 to 10, SD=1.87), and the differences in attitudes towards fusion between respondents from Groups 1 and 2 were not statistically significant (p=0.2, in the one-way ANOVA test).

Differences in attitudes towards fusion energy were not statistically significant with respect to gender or education level, neither among respondents who could provide correct information about fusion (Group 1), nor among the remainder of respondents (Group 2). However, there were statistically significant differences with respect to the age category in both groups ($F(3,167)=4.6$; $p=0.004$ in one – way ANOVA test for Group 1; $F(3,172)=3.6$; $p=0.02$ in Group 2). For instance, in Group 1, attitudes towards fusion were more negative in the age category 55-64 (M=6.22; SD=2.24) than among respondents in the age category 35-54 (M=7.4; SD=2.00). Contrary to that, in Group 2, attitudes to fusion were more negative in the age category 35-54 (M=6.34; SD=1.45) than in the age category 55-64 (M=7.25; SD=1.64).

The key advantages of fusion were considered to be the promise that fusion "would provide a nearly unlimited source of energy" (35% ranked it as main positive aspect of fusion research and development in Group 1 and 36% in Group 2), followed by the "climate friendliness" of fusion energy (27% ranked it as main positive aspect in both Groups 1 and 2). The key negative aspects of fusion energy as indicated by the respondents related to the money spent for fusion research instead of the development of renewables (37% ranked it first in Group 1 and 39% in Group 2), and the use of radioactive materials (25% ranked it first in Group 1 and 28% in Group 2).

Attitude towards fusion was most strongly correlated with the attitude towards nuclear energy (Spearman's correlation rho=0.42, $p<0.001$) and the attitude towards science and technology (Spearman's rho=0.26, $p<0.001$). The more positive a respondent was about science and technology or nuclear energy, the more positive was the attitude he/she expressed towards fusion energy.

Attitude towards fusion energy was also associated, but to a lesser extent, to the self-assessed familiarity with the issue (Spearman's rho=0.16; $p=0.004$): respondents who reported being more familiar with the fusion energy tended to have a somewhat more positive attitude. At the same time, attitude towards fusion energy and media recall were not correlated.

With regards to the relative importance given to the positive and negative aspects of fusion, respondents who thought that the main negative aspect of fusion is the long time needed to develop fusion energy, or the fact that the process requires large amounts of energy, were generally more favourable to fusion than those who attributed more importance to financial aspects.

Neither the ranking of the various potential benefits of fusion energy, nor the importance given to the energy supply (in Belgium), were associated with the attitude towards fusion energy.

Finally, among respondents from Group 1, consisting of people with higher awareness of fusion energy, there was no statistically significant difference in the mean score of attitude towards fusion depending on whether the respondents were shown first the benefits and then the risks of fusion energy (p=0.6

in one-way ANOVA test). We can assume that once balanced information is presented, the order of presentation is less important. In Group 2 , the one-way ANOVA test showed ($F(1,174)=4.6$; $p=0.03$) that the attitudes to fusion where slightly more positive among respondents who were shown first the positive aspects ($M=6.94$; $SD=1.7$) compared to those who were shown first the negative aspects ($M=6.43$; $SD=1.4$). In other words, the order of presenting positive and negative aspects of fusion had a small influence in the direction of the first information presented, but only in the group of respondents who were less informed about fusion.

5.4 Potential predictors for attitude towards fusion energy

Linear regression was used to investigate the influence of potentially explanatory variables on the attitudes towards fusion energy. Two different regression models were run: one model for the respondents who could recall information about fusion energy (Group 1) and another for the remainder of the respondents who said they heard of fusion (Group 2). Both models are summarised in Table 3. Only those variables with a statistically significant correlation with the dependent variable were entered in the models. The answering category "I don't know" was treated as missing value.

The variables included in the model could explain about a quarter of the variance in attitude towards fusion energy in both groups of respondents. Attitude towards nuclear energy was the most significant predictor for both Group 1 and Group 2, whereas attitude towards science and technology was significant only in Group 1. The relative importance (rank) given to the long time needed to develop fusion energy as a negative aspect was significant only in the model corresponding to Group 1, i.e. those respondents who could recall some correct information about fusion energy. For these respondents, the more importance was given to the long time needed to develop fusion - relative to the other negative aspects – the more favourable was the attitude towards fusion. The relative importance given to the money spent for fusion instead of renewables was instead statistically significant only in the model corresponding to Group 2: the more importance was given to this aspect, the more negative was the attitude towards fusion.

Self-assessed familiarity was not statistically significant in either models, but the values of the confidence interval for the model coefficients suggest that it might have a positive effect on attitudes towards fusion among respondents who are less informed (Group 2).

The age category was significant in Group 1, with respondents aged 55-64 being less supportive to fusion as compared to those aged 35-54. In Group 2, while it did not come out as a statistically significant predictor, the confidence interval of the regression coefficient indicates that respondents in the age category 18-34 may be more positive towards fusion than those aged 35-54.

Table 3 Potential predictors for the attitude towards fusion energy

	Group 1: Recalled correct information about fusion (N=178)				Group 2: Heard of fusion, but could not recall (correct) information (N=187)			
Dependent: Attitude towards fusion energy (score 2 to 10, higher score=more positive attitude)	**β (Sig.)**	**Std. error**	**95% Conf. Int. for β**	**Colin. Stat. (VIF)**	**B (Sig.)**	**Std. error**	**95% Conf. Int. for β**	**Colin. Stat. (VIF)**
Attitude towards nuclear energy (higher score, more positive)	**0.61***** (<0.001)	0.12	(0.36, 0.85)	1.17	**0.59***** (<0.001**)**	0.098	(0.40, 0.78)	1.18
Attitude towards science & tech. (higher score means more positive)	**0.37*** (0.02)	0.16	(0.05, 0.70)	1.11	0.13 (0.3)	0.14	(-0.14, 0.40)	1.19
Nuclear fusion **takes too long** to develop […] (lower value means more important)	**-0.34*** (0.02)	0.14	-0.61, -0.062)	1.09	0.057 (0.6)	0.11	(-0.16, 0.27)	1.20
M**oney** [..] could be spent on development of renewables. (lower value means more important)	-0.13 (0.4)	0.14	(-0.39, 0.14)	1.17	**0.21*** (0.02)	0.09	(0.035, 0.39)	1.11
Familiarity with fusion energy (higher score, more familiar)	0.10 (0.4)	0.13	(-0.16, 0.36)	1.06	0.19 (0.16)	0.14	(-0.076, 0.47)	1.11
Age (18-34)	-0.58 (0.1)	0.39	(-1.34, 0.19)	1.3	0.52 (0.07)	0.29	(-0.046, 1.08)	1.23
Age (55-64)	**-0.84*** (0.03)	0.38	(-1.58, -0.10)	1.3	0.39 (0.2)	0.31	(-0.22, 1.00)	1.24
Age (65+)	0.20 (0.6)	0.43	(-0.64, 1.04)	1.2	-0.12 (0.7)	0.30	(-0.70, 0.46)	1.24
Ballot (first positive, then negative aspects)	Not included				0.24 (0.3)	0.21	(-0.17, 0.65)	1.05
Constant	**4.74** (<0.001)	1.00	(2.760, 6.712)		**3.07** (<0.001)	0.73	(1.64, 4.51)	
	N=171 Adj.R2=0.24 Sig. F change: p<0.001				N=176, Adj.R2=0.28 Sig. F change: p<0.001			

Reference category for age: 35-54; for ballot: present first positive, then negative aspects;
***p<0.001; ** p<0.01; * p<0.05

6. Discussion

The results confirm previous research (Prades et al, 2008; Horlick-Jones et al, 2012) suggesting that the general public has little knowledge about the topic of fusion energy. Only 35% of the respondents said they had heard of nuclear fusion, which is half of what was found in Eurobarometer 262 (2006), reporting that 68% of the Belgian population has heard of nuclear fusion. Results also show that men responded more often than women that they had heard of the technology, which is consistent with Eurobarometer 262 (2006). Interestingly, half of the respondents who said they heard of fusion were able to give correct or partially correct responses in the open question; however, most of the responses provided very simple and short information. This is important, considering that the question was formulated in a way that made it easy to deduct that nuclear fusion was something related to energy production. In the present study only 7% of the respondents gave technically qualified arguments about this energy technology, going beyond a simple categorization. This indicates that fusion energy remains difficult to grasp for the public, as it was years ago (Eurobarometer 169, 2002). Thus, our first qualitative hypothesis, stating that simple categorization practice is the dominant mode of reasoning, was confirmed.

Confusion between fusion and fission energy is quite frequent among the general public who expressed having heard of fusion energy. This is convergent with Perko et al (2016), whose study showed that nuclear fusion is relatively frequently mistaken for nuclear fission in Belgian media articles. Even journalists appear to have difficulties to distinguish between the two energy technologies. In addition, as the Fukushima nuclear accident of 2011 was associated in some media with a fusion reaction, this created additional confusion in post-Fukushima newspaper articles.

Our qualitative evidence confirms that nuclear fission does play a key role in the sense making about fusion, as a key device to define fusion was its comparison with fission (either as a new, different, nuclear or as a still dangerous nuclear). Another aim of the present research was to investigate whether the new 'fusion brand' emerged spontaneously among the survey participants, and we did find some evidence in this regard. Confirming our expectations, respondents who mobilised the new brand referred to fusion as endless and clean energy that could solve our energy problem, and as scientific progress.

The evidence in the literature concerning the influence of knowledge on attitudes towards energy technologies is mixed. Several studies suggest that knowledge has little or no effect on the acceptance of technologies (Ellis et al, 2007; Irwin et al, 1999; Turcanu et al, 2013). Still others reveal that low knowledge is associated with less support, but once people become knowledgeable, cultural predispositions such as environmental concerns, trust in technology or stewardship (i.e. human responsibility for nature) may become more important than knowledge for the acceptance of the technology (Achterberg et al, 2010). In our case, general attitudes towards fusion energy were similar among respondents who could recall some correct information about fusion, as compared with other respondents, confirming previous findings showing that increased knowledge does not necessarily lead to more acceptance of a technology. Qualitative research by Prades et al (2007) showed for instance that while lay perceptions and understandings of fusion change as citizens learn more, there are differences in the exact nature of change in that support for fusion is not directly related to assimilation of technical knowledge.

In order to investigate potential predictors for attitude towards fusion energy, two groups of respondents were considered: those having heard of fusion energy and able to provide either informed arguments or personal perceptions concerning fusion energy (Group 1, N=178) and respondents who said they had heard of fusion energy but could not provide any or incorrect information (Group 2, N=187). The independent variables considered could explain about one quarter of the variance in attitude towards fusion energy in both respondent groups.

Attitude towards nuclear energy was the most influential predictor overall, which is consistent with the results of the qualitative analysis. The more favourable was the attitude towards nuclear energy of the respondents, the more positive was their attitude towards fusion energy (Hypothesis 3 confirmed).

General attitude towards science and technology had a significant role, but only in Group 1, thus confirming the results of Besley and McComas (2015) for nano-technologies and nuclear power and Achterberg et al (2010) for hydrogen power. The more favourable was the attitude of informed respondents towards the development of science and technology, the more support they expressed concerning fusion energy (Hypothesis 4 partially confirmed).

Respondents were asked to rank in order of importance a number of positive and negative aspects of fusion energy research and development. The dominant frame in the Belgian media in the 15 years previous to the survey focused on fusion as a "social or political game" (Perko et al., 2016). However, the strongest associations or evocations encountered among the respondents who could recall some information about fusion energy were descriptions of the process in which fusion energy is produced, and references to fusion as the opposite of nuclear fission.

The order of presentation of negative and positive aspects did not influence the attitudes towards fusion of the respondents that were more aware of fusion energy. An influence was noted among respondents who were not aware of fusion or had misconceptions about it: those who received first information about the positive aspects expressed slightly more positive attitudes towards fusion energy. An association was noted between attitude towards fusion energy and the choice of the most important negative aspect being either the long time needed or the money spent, but only one of these appeared in each of Groups 1 and 2. In Group 1, those who chose the long time needed to develop fusion energy as its most important drawback, thus focusing on the scientific uncertainty rather than the other disadvantages of fusion, had a more positive attitude than the other respondents (Hypothesis 1a rejected). Among respondents from Group 2, those who gave more importance to the money being spent on fusion rather than renewables as the main drawback of fusion energy development, tended to be more negative towards fusion (H1b confirmed). Models of reasoning about fusion were therefore different between the more informed and less informed respondents, respectively, although general attitudes were similar.

The relative importance of the different positive aspects of fusion was not associated with the attitude towards fusion energy (Hypothesis 2 rejected). However, the potential of fusion energy to provide large amounts of energy was recognized as the main benefit of fusion energy, followed by its climate friendliness, which goes in line with results from the study of Visschers et al (2007) on nuclear energy.

Contrary to expectations, salience of the energy provision was not associated to attitude towards fusion energy (correlation not statistically significant), therefore hypothesis H5 cannot be accepted.

Respondents who were more concerned about the energy supply in Belgium did expressed neither more, nor less support for fusion energy development.

Self-assessed familiarity with the topic of fusion energy was weakly correlated to attitudes towards fusion energy (H6 rejected). While it was not a statistically significant predictor, it is likely that it has a positive -albeit low- effect among respondents in Group 2 (95% CI=(-0.076, 0.47)), which would be a similar result with Duan et al (2010). This effect did not appear however, among the informed respondents (Group 1).

Gender was not associated with attitudes towards fusion energy. This is similar to Duan (2010) for carbon capture and storage (CCS) in China, but unlike Miller et al (2007) suggesting that women are less supportive than men to CCS in Australia, or Ansolabehere and Konisky (2009) arguing the women oppose more than men to the construction of new power plants (gas, nuclear, coal and wind) within 25 miles of their home in the U.S. Education was also not associated with attitudes towards fusion energy, which is similar to Ansolabehere and Konisky (2009). Opposite to this, studies on CCS suggest either lower acceptance (Duan, 2010 in China) or higher acceptance (Miller et al, 2007, in Australia) of CCS technology among highly educated respondents. With respect to age, certain categories (55-64 in Group 2) expressed a more negative attitude than other age categories (35-54). Opposite to this, Duan (2010) found no such relations for CCS and Ansolabehere and Konisky (2009) found that higher age was associated with less opposition for nuclear and gas power plants, but this effect was not significant for coal and wind facilities.

Limitations: The study had some methodological limitations. The fusion survey used in this study was part of a longer study on nuclear energy related issues; this could influence the nature of qualitative evidence collected through the open question, for instance by higher occurrence of associations with nuclear energy. Furthermore, the assessment of knowledge about fusion could be improved. In our study, when respondents expressed only their opinions, it was not possible to distinguish what was their level of knowledge about the technology. However, our study used self-assessed familiarity as a measure of subjective knowledge.

7. Conclusions

The present study is one of the first attempts to examine public attitudes toward fusion energy via survey research. Our study expands the current understanding of public perception of fusion energy and sheds light onto how prior attitudes influence individuals' evaluation of fusion. More research, especially in the form of well-adapted cross-national survey research (via e.g. deliberative polling, information-choice questionnaire or experimental surveys) is necessary to better understand informed public opinion of fusion energy. The provision of a better measure of informed public attitudes will provide the basis for a more reasoned public debate on energy issues. Future work should include comparative cross-country research as well as longitudinal analysis pre- and post-development of fusion infrastructures. There is also scope to examine attitude change by varying the media, source and framing of fusion information. Fusion engagement activities should be informed by attitudinal analysis of the local and national context in which efforts are made to promote fusion awareness. Further engagement initiatives should go beyond the deficit model and rely on more inclusive and interactive approaches, as knowledge – in itself- does not seem to make a difference (at least in the current context of none or very little familiarity with the technology). Fusion communication strategies should also frame the information about fusion in terms that are relevant to lay people, allowing for a suitable learning process. Future SES research will be conducted to generate meaningful methods and concepts to address these challenges.

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Annex 1 Fusion energy questionnaire (extract from a larger survey on nuclear issues)

So far I have asked you questions about nuclear energy, which is created in current nuclear power plants by the process called nuclear fission. Now I would like to ask you some questions about a different source of energy, namely nuclear fusion or fusion energy.

Have you ever heard of nuclear fusion? IF YES, continue	1. Yes 2. No 3. Don't know/ no answer
Can you describe in a few words what have you heard about nuclear fusion?	OPEN

Nuclear fusion is the process that produces energy in the core of the sun. Scientists are trying to reproduce this process on Earth in order to find new and efficient energy sources. Currently, research on fusion is taking place in many countries, including Belgium.

How familiar do you feel with the topic of nuclear fusion?	1. Not at all familiar 2. Very little familiar 3. Moderately familiar 4. Rather familiar 5. Very familiar 6. Don't know / No answer
How many times did you hear about nuclear fusion in the media in the past year?	1. Never 2. Once or twice 3. Less than 5 times 4. Less than 10 times 5. More than 10 times 6. Don't know / No answer

Split sample in 2 and present alternatively the risk and benefits.
What follows is a list of advantages of nuclear fusion. In your opinion, to what extent are these important to justify the continuation of research on fusion? Please rank them from the most important to the least important.

Nuclear fusion will provide a nearly unlimited source of energy.	Rank from most important (1) to least important (4)
Nuclear fusion does not produce highly radioactive waste or very limited quantities.	
Nuclear fusion is climate friendly because it does not produce greenhouse gasses.	
Nuclear fusion is safe because major accidents are not possible.	

What follows is a list of disadvantages of nuclear fusion. In your opinion, to what extent are these important to stop the research on fusion? Please rank them from the most important to the least important.

Nuclear fusion involves the use of radioactive materials.	Rank from most important (1) to least important (4)
Nuclear fusion takes too long to develop so it cannot solve the current energy problems.	
The money used for nuclear fusion research could be spent on the development of renewables.	
Nuclear fusion facilities require large amounts of energy themselves to maintain the fusion process	

In conclusion, what is your opinion about nuclear fusion as an option to produce energy?	1. Very bad option 2. Rather bad option 3. Neither a good, nor a bad option 4. Rather good option 5. Very good option 6. Don't know/ No answer
To what extent are you favourable or unfavourable to the development of fusion energy in Europe?	I am: 1. totally in favour 2. rather in favour 3. neither in favour nor against 4. rather against 5. totally against 6. Don’t know/no answer