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Exploring the view of experts on the governance of the science-policy interface. The case of nuclear fusion in the EU.

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Abstract

Energy transitions are key to tackling climate change, but in the latest decades they have been hindered by a lack of public acceptance for new energy technologies. This has turned them into complex problems, a type of policy issues that are often solved by starting a dialogue between experts and the public. The science-policy interface offers an arena where such dialogue takes place, but how energy experts approach it remains largely understudied. This thesis has shed some light on the point of view of energy experts through the case study of nuclear fusion, whose acceptance represents a typical example of a complex issue. Fourteen semi-structured interviews with European fusion practitioners have revealed that they are mostly aware of the issues of public acceptance, but they will leave the science-policy interface to a few peers. Such limited involvement is unusual for modern scientific communities. Still, further research is needed to clarify whether this and other energy experts communities share such an attitude towards the science-policy interface.

Keywords: science-policy interface, energy transitions, nuclear fusion, public acceptance, practitioners.

List of abbreviations

CIGS……….Centre for Interdisciplinary Gender Studies
DEMO……...DEMOnstration Power Station
EEA………...European Environmental Agency
EU…………European Union
EURATOM...European Atomic Energy Community
F4E………...Fusion For Energy
IAEA……….International Atomic Energy Agency
IEA………....International Energy Agency
ITER……….International Thermonuclear Experimental Reactor
NGO……….Non-Governmental Organisation
UNEP……...United Nations Environment Program

Word count: 17 570

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1. Introduction.

1.1 Climate change, energy transitions and the role of nuclear fusion

The energy transitions from fossil fuels to sustainable energy sources are some of the most critical challenges of the coming decades. Climate change has established itself as one of the most urgent and potentially catastrophic issues to face in the industrial age (Busby, 2018), and a clear link between containing global warming and the decarbonisation of energy has emerged (IPCC, 2014, IEA, 2020). Energy-related sectors as a whole are the single largest emitter of greenhouse gas emissions on the planet. While energy production alone is estimated to generate 34% of total emissions (IEA, 2020; UNEP, 2020), such a share rises to 78% if all consumption is included in the calculation (Zelli et al., 2013; IPCC, 2014; EEA, 2020). Furthermore, energy consumption is expected to double in 2050 compared to 2010 owing to industrialization in developing countries (Zelli et al., 2013; EUROfusion, 2018). As a result, energy is and will remain the most significant contributor to climate change, and as such it is the sector where transitions are most needed to tackle emissions (IPCC, 2014).

Quite significantly, energy production is also the only human sector that has visibly reduced its emissions since 2010 (UNEP, 2020). Despite high costs and dependence from existing infrastructures making innovation particularly difficult (Knapp & Pevec, 2018), energy is undergoing several radical changes (Parker et al., 2019). Renewables are projected to cover 90% of new energy production installations in the following decades, while the production and consumption of fossil fuels have been hit hard by the pandemic and are not expected to return to pre-2020 levels (IEA, 2020).

While encouraging, experts still consider these changes to be insufficient to contain climate change (UNEP, 2020, IEA, 2020). Besides, renewables alone cannot provide a constant flow of energy as fossil fuels have done so far, which means that a reliable source is still needed as part of the energy mix (Hamacher et al., 2013). In the short term, the available solutions include energy storage, low-emitting fossil fuels and nuclear power (Usher, 2019; de Groot et al., 2020). As to the long term, many governments are strongly pushing the research on a new technology that is also nuclear but uses a process that is the opposite of current technologies. It is nuclear fusion or, as often referred to in the literature, simply fusion.

Nuclear fusion harnesses the tremendous amount of energy created by fusing the atoms of two specific hydrogen isotopes, deuterium and tritium (IAEA, 2015; 2018). So far, nuclear power has been based on fission, which involves separating atoms (Steinber, 2020). In order to perform fusion, it is necessary to produce unimaginably high temperatures in the order of millions of Celsius degrees, whose production and control are a complex engineering challenge (IAEA, 2015; 2018). Still, if this source became viable, experts say it would produce clean, reliable, abundant and safe energy with little to no waste or radiation (Ongena & Ogawa, 2016; Spangher et al., 2019). Furthermore, since fusion is powered by hydrogen, one of the most abundant elements in the universe, its fuel would not deplete in time (Ongena & Ogawa, 2016).

As fusion is an extremely complex and expensive technology, in order to fulfil its promise world powers such as the United States, China, the European Union, Russia, India, and Japan are building together a single experimental reactor called ITER. (IAEA, 2015; 2018). If ITER experiments proved successful, the introduction of fusion as an energy source is expected to come around 2050-60 (IAEA, 2018). These results are coming too late, according to a number of authors, who believe that the impact of nuclear fusion on the energy market might not affect the fight against climate change (Ongena & Ogawa, 2016; Knapp & Pevec, 2018; Spangher et al., 2019). However, if fusion should prove a clean, powerful, sustainable and endless source as it is pictured, it is expected to provide a permanent replacement to fossil fuels in the energy mix to make up for renewables' intermittency (Hamacher et al., 2013).

1.2 Energy transitions as a complex problem: the science-policy interface

Fusion is just one of the more promising new energy technologies that are being developed and deployed to decarbonise energy (Usher, 2019). Surveys show that the public opinion in Western countries strongly supports energy transitions to fight climate change (Batel & Devine-Wright, 2015; Olsen, 2016). Despite that, in the last decades, some hostile reactions from the public to new energy installations have been observed, affecting both renewables, fossil fuels and nuclear power (Kasperson & Ram, 2013; Batel & Devine-Wright, 2015; Olsen, 2016; de Groot et al., 2020). Communities that are chosen to host new energy facilities, in particular, have often successfully opposed energy projects and hindered the deployment of new energy technologies (Batel & Devine-Wright, 2015; Olsen, 2016). While selfishness and lack of knowledge were initially blamed for such attitudes, deeper studies have highlighted that the desire to be included in decision making and reap some of the benefits of energy facilities are better explicative factors (Kasperson & Ram, 2013; Batel & Devine-Wright, 2020).

Despite that, energy transitions and experimental technologies are mainly dealt with by the energy sector as technical issues (MacArthur, 2016). Considerations on their viability are of scientific and engineering nature, and few scenarios consider whether renewables, nuclear fusion or other technologies will be socially accepted as an energy source (Geels et al., 2017). Expert knowledge, however scientifically sound, is not deemed credible per se to convince host communities of the safety and benefits of energy technologies (de Groot et al., 2020). The way communities frame the technology's impact differs from the experts' understanding of it, creating a political conflict that experts will usually fail to identify (Wesselink et al., 2013; Boscarino, 2016).

The fact that technical issues and scientific uncertainty about new energy technologies meet with a lack of acceptance from the public makes energy transitions a "complex problem", i.e. a policy issue where scientific uncertainty meets political divisions (Rittel & Webber 1973; Greenwood, 2010; Valkenburg & Cotella, 2016). The standard solution for experts would be to spread technical knowledge so that policymakers and other stakeholders can make their decisions on how to address the problem (Rudd, 2015; MacArthur, 2016). Nevertheless, in the context of a complex problem, the fact that such knowledge becomes politically contentious obliges experts to drop their traditional role of "pure researchers" and communicate, advise or produce knowledge with social and political actors (Pielke, 2007; Rudd, 2015; Saarela, 2019).

In the last decades, particularly in continental Europe, scientists and experts from different fields have become increasingly aware of the fact that complex issues require them to take up these non-standard roles (Rudd, 2015; Saarela, 2019). As a result, several formalised processes and organisations have been set up to allow experts to do so without deviating from their professional standards. Taken together, they form the so-called science-policy interface, a neutral arena where science and society can discuss decisions while keeping science and politics separate (Guston, 2001; Lang & Thomas, 2012; Wesselink et al., 2013).

Many disciplines have dealt with how the science-policy interface has contributed to tackling complex issues, from biodiversity preservation to climate change (Thompson, 2015; Frost et al., 2017; Turnhout et al., 2019). Still, there are not enough studies dealing with how experts regard and approach interfaces (Spruijt et al., 2014; Rudd, 2015). Some empirical studies have been carried out in specific fields, such as ocean management (Rudd, 2015) and forestry (Saarela, 2019). However, when it comes to energy transitions, no similar research has still been attempted to the author's best knowledge. Since the science-policy interface requires scientists to commit a part of their professional work (Rudd, 2015; Saarela, 2019), getting to know their view on public acceptance and on their role in it is key to understanding if and how the science-policy interface is functioning in the energy transitions.

Because nuclear fusion is extremely uncertain both from a technical and political point of view, it makes for a good case of a complex problem in the energy sector. As an experimental technology very far in the future, the acceptance of fusion has been largely neglected, although its research is mainly funded with public money (Prades López et al., 2008). Since the 90s, the European Union has been the only ITER member to commission several socio-economic studies on the attitude of its public towards fusion (Ingelstam, 1999; Borrelli et al., 2001; Prades López et al., 2008). As a result of EU patronage, most literature on fusion acceptance is focused on the European public. Apart from such geographical limitation, no studies have focused explicitly on how fusion experts perceive acceptance and their role in it. Focusing on fusion practitioners working at the European level means filling two literature gaps then: the general gap on the role of energy experts in the science-policy interface and the specific one on the role of fusion experts in their sectoral interface.

1.3 Research aims and questions

This thesis represented a first step towards understanding the position of practitioners vis-à-vis the public in the context of energy transitions. It aimed at filling the gaps found in the literature in several ways. Firstly, by including the point of view of practitioners on science-policy interfaces. Secondly, by identifying the meanings practitioners associate with the role of scientists in society. Finally, by understanding how practitioners approach other stakeholders when working on new energy technology.

The focus of the research was on how fusion practitioners engage with stakeholders outside their peer community, which will be referred to as “fusion community” throughout the thesis. Stakeholders can be defined as any organisations, groups and individuals who are somehow concerned with fusion development (Prades López et al., 2008; Pirolli, 2010). In order to analyse how practitioners interact with stakeholders at the science-policy interface, the former’s roles have been classified according to the typology of Pielke (2007), as revised by Turnhout et al. (2013). The typology distinguishes the possible roles of experts according to two variables: the kind of interaction experts have with policy actors and the kind of information they share with them.

Based on the research aims and the analysis framework, the thesis pursued three main practical objectives. First, it targeted how fusion practitioners frame the public acceptance of fusion. Second, it explored whether and how they interact with stakeholders outside the fusion community, and finally what kind of scientific information they share with such stakeholders.

These objectives were reflected in the research questions and sub-questions that guided the empirical research for the thesis:

- *How do fusion practitioners perceive the functioning of the science-policy interface in fusion development?*
    - *How intensive is the interaction of fusion practitioners with external stakeholders?*
    - *What kind of information do fusion practitioners share with stakeholders?*
    - *How do fusion practitioners share information with stakeholders?*

- *How do fusion practitioners perceive their role concerning the science-policy interface of fusion development?*
    - *How do they perceive the public attitude towards fusion?*
    - *What kind of roles should fusion practitioners play in the interface?*
    - *Are there any challenges for practitioners in interfacing with external actors?*

The findings of the thesis are expected to enrich several parts of the literature. A first contribution is to the studies on the governing of energy transitions, for which the thesis explores for the first time the point of view of energy experts.
By doing so, a second contribution is also given to the literature on the science-policy interface, adding a new case study on the opinion of experts.
Finally, the thesis also contributes to the specific literature on fusion acceptance by focusing on the point of view of fusion practitioners as a case study.

1.4 Research method

The data sources for this thesis were fourteen semi-structured interviews with fusion practitioners working for EUROfusion, Fusion For Energy and Euratom. As a first study exploring the point of view of energy experts on the science-policy interface, interviews have been chosen over other methods in order to allow participants to express their own ideas and highlight variables or concepts that may be neglected by existing literature on the science-policy interface.

In the analysis phase, the recordings of the interviews have been transcribed. After that, they have been coded through the software Atlas.ti. Finally, they have been interpreted in the light of the Pielke-Turnhout typology.

1.5 Research outcome

The results of the interviews show that the fusion community in the EU adheres to the traditional “linear” approach of energy experts towards the science-policy interface based on one-way scientific communication. Its outreach is often limited to those political, industrial and academic stakeholders working already on fusion development. The general public features as a desired audience, but so far fusion communication has not reached more than a niche of technology enthusiasts.

As in the other studied scientific communities, the science-policy interface of fusion is dominated by *pure researchers*. Other roles of the Pielke-Turnhout typology can be identified, most notably *science arbiters* and *issue advocates*, while *honest brokers* and *participatory knowledge producers* seem to be absent.

However, unlike other scientific communities, fusion practitioners do not seem to take up different roles depending on their work needs. The vast majority keeps focusing on pure research, while those researchers who want to take part in the interface need to cope with several professional challenges. Such practitioners resort either to use their free time or to drop their research work altogether and become full-time interface professionals.

Overall, fusion practitioners are generally aware of public acceptance and its importance for the development of fusion. However, there is a consensus that only some practitioners take part in the science-policy interface. Many interviewees underlined that ITER has already set in motion several changes in the attitude of their peers towards external stakeholders. The fusion community is now increasingly open, it communicates more effectively and cooperates closely with its stakeholders. In time, they said, this will bring fusion researchers to engage more in the interface.

1.6 Structure of the thesis

The thesis report is structured along four chapters:

1. The first chapter includes a review of the literature on the science-policy interface and on fusion acceptance. Based on the literature review, the chapter introduces the analysis framework adopted for the research.

2. The second chapter reviews the research context of the thesis, the research method that was adopted and how it was implemented.

3. In the third chapter, the results of the interviews are presented and discussed in detail.

4. The concluding chapter recapitulates the research, reaches some conclusions and highlights some key points for further research.

2. Literature Review and Analysis Framework

2.1 Energy transitions as a complex problem

In the literature on policy issues, the core of most problems is identified as lying either on a lack of knowledge or a lack of consensus (Hoppe, 2010). In the former case, scientific research can provide decision-makers with the necessary knowledge to solve the issue through a so-called linear process: science is turned into policy. In the second case, political debate can compromise diverging social values (Hoppe, 2010; Valkenburg & Cotella, 2016). Still, many contemporary policy issues involve so much scientific uncertainty and so many spill-overs that finding a consistent solution through the two traditional methods does not function anymore (Valkenburg & Cotella, 2016). Such issues have been referred to by Rittel & Webber (1973) as “wicked problems”. These are problems where:

“*normative uncertainty renders controversial or ambiguous what kind of expertise should be enrolled to solve the factual puzzles, and the factual uncertainty renders unclear what the political debate should be conducted about. [...] there is no clear point at which the problem can be seen as solved nor an unequivocal solution.”* (Valkenburg & Cotella, 2016; p.3-4).

In the literature, they are referred to in multiple ways, from “complex problems” to “unstructured problems” (Hoppe, 2010). This thesis adopts the term “complex problems”, which is the most common form throughout the literature. The most notable examples of such problems are global issues having side effects on multiple economic, political and social sectors, such as climate change (Hoppe, 2010) and the Covid-19 pandemic (Moon, 2020). In these cases, solutions are being designed based on conflicting scientific studies and diverging political values, and their spill-overs affect almost all policy sectors, multiplying the interests and the variables to consider (Hoppe, 2010; Moon, 2020).

Energy transitions seem to feature some characteristics of complex problems, as systemic changes in the energy sector impact most aspects of contemporary human life (Valkenburg & Cotella, 2016). Energy transitions are complex because they involve multiple actors (ex. producers, grid managers, consumers), multiple social values (ex. energy security, sustainability, democratic decision-making), uncertain knowledge and an unclear relationship between knowledge and policy-making (Valkenburg & Cotella, 2016). Furthermore, the need to cut emissions and the exhaustion of fossil fuels is compelling the sector to find new renewable energy sources (Parker et al., 2019). This, in turn, requires renewing current infrastructures to adapt them to the characteristics of renewables and solve the issues related to these new sources, particularly their intermittency (Parker et al., 2019).

In Europe, all these technical transitions occur in a normative context where the public strongly supports emission cuts (Batel & Devine-Wright, 2015). Despite that, single communities and individuals who are asked to host facilities are often opposed to energy installations, whether based on fossil, nuclear or renewable sources (Kasperson & Ram, 2013; Fournis & Fortin, 2017; De Groot et al., 2020).

Multiple explanations have been advanced in the literature for this phenomenon. One first theory around the 90s was the NIMBY (Not In My BackYard) hypothesis, which explained local opposition based on individual selfishness and lack of information within host communities (Olsen, 2016; Batel & Devine-Wright, 2020). Recent literature has increasingly challenged this hypothesis, focusing on specific community characteristics (Peterson et al., 2015; Fournis & Fortin, 2017) and the economic, financial, health, environmental and democratic considerations of individuals (Olsen, 2016; Devine-Wright & Sherry-Brennan, 2019). This literature highlights that being unable to obtain public acceptance has brought even the more technically viable energy projects to fail, slowing down the introduction of new energy technologies as a whole, particularly wind and solar energy (Ogilvie & Rootes, 2015; De Groot et al., 2020). The main conclusion is that energy transitions must be addressed both on the technical and on the public acceptance side to progress (Upham et al., 2015; Batel & Devine-Wright, 2020).

At the practical level, as in most complex problems, practitioners have addressed public acceptance by changing the way energy transitions are governed (Steurer et al., 2013; Valkenburg & Cotella, 2016). Within energy transitions, top-down decisions and information sharing have long been the preferred governance approach (Valkenburg & Cotella, 2016). However, in the last decades, the persisting lack of public acceptance within host communities convinced authorities and energy companies to include host communities as beneficiaries of the profits of energy plants. This is done through financial compensations, for instance, which are granted either to individuals or the local authorities (Olsen, 2016; Devine-Wright & Sherry-Brennan, 2019). Another common solution is co-ownership of the plants, where the energy company and community members both hold a part of the property (Olsen, 2016; Baxter et al., 2020). Finally, directly engaging community members in decision-making is used when opposition lies in a democratic deficit (MacArthur, 2016).

These different approaches are often conceived as a bridge to foster public acceptance while host communities get accustomed to the energy plants (Wilson & Dyke, 2016; Baxter et al., 2020). It is a common belief both among scholars and practitioners that public acceptance of energy technologies follows a U-shaped curve trend, starting high before the plants are built, diminishing when they are being built, and increasing again once the host community realises no hazards occur (Wilson & Dyke, 2016; Baxter et al., 2020).

Still, both the U-curve hypothesis and the use of bridge measures to foster public acceptance have been challenged in the literature because political, cultural, and communication considerations are also determinants of acceptance that should not be neglected (Batel & Devine-Wright, 2015; Upham et al., 2015; Wilson & Dyke, 2016). In particular, compensations and public engagement per se are not accepted in all communities uncritically (MacArthur, 2016; Devine-Wright & Sherry-Brennan, 2019). Their acceptance relies quite significantly on how they are portrayed by the companies and how they are perceived by the communities (MacArthur, 2016; Devine-Wright & Sherry-Brennan, 2019). If these instruments are regarded as acknowledging the community's role, they are likely to be accepted (Devine-Wright & Sherry-Brennan, 2019). However, if they are regarded as a form of bribery or manipulation, they are likely to foster an even stronger rejection of the energy project (Devine-Wright & Sherry-Brennan, 2019).
Thus, the specific political conditions of each single host community add a further layer of complexity to the public acceptance of new energy technologies (Upham et al., 2015).

This general overview of some of the most salient findings concerning the governing of the energy transitions in the literature already shows the high degree of complexity involved in this issue. Still, most of these findings are related to energy projects concerning established technologies, such as solar power, wind turbines (Ogilvie & Rootes, 2015; Wilson & Dyke, 2016; Baxter et al., 2020), nuclear plants and fracking (de Groot et al., 2020). Here, most of the technical issues regard energy infrastructures rather than energy production (Parker et al., 2019), making public acceptance the main issue to deal with.

Where energy transitions remain a genuinely complex problem is whenever new energy technologies are involved (Upham et al., 2015). In that case, neither technical knowledge nor public acceptance are established, making the future of the technology strongly reliant on the interactions between the experts, the public, the media and politicians (Upham et al., 2015).

Experts, for instance, often regard themselves as objective knowledge providers, which brings them to taking for granted the salience and the meaning of their studies for politicians and the public (Lidskog, 2014; Rudd, 2015). This is particularly true in the energy sector, which strongly values expert knowledge and is often closed to considerations from outside their domain (MacArthur, 2016).

As to the public, when a novel technology is being talked about, they tend to build so-called "quasi-opinions" on it, i.e. a first judgement based on the information filtering to them (Upham et al., 2015). Most information on the new technology is produced by experts, who are usually considered a credible source (Lachapelle et al., 2014). Still, the literature has highlighted that the public does not passively accept the information it receives from experts at such an early stage (Lachapelle et al., 2014). Acceptance is generally stronger among those members of the public whose personal political values are in line with the information surrounding the technology, while it is refused when such values are challenged by the technology (Lachapelle et al., 2014). These different groups create their own quasi-opinions on the technology, which soon evolve into diverging frames, i.e. "*verbal or visual messages that highlight specific dimensions of policy issues to influence individuals' perceptions of those issues*" (Andrews et al., 2017; p.262). Frames compete with each other to influence the way the majority of the public views the technology (Boscarino, 2016), determining whether it is supported or dropped (DiPalma, 2014).

Both when frames are created and when they compete, the role of mass media is decisive (McCombs, 2014; DiPalma, 2014; Vliegenthart et al., 2018). The media filter and deliver the information produced by experts, and they have a crucial role in determining which aspects are highlighted (DiPalma, 2014). How the technology is going to be portrayed depends on whether or not the available information fits with the dominant discourses established in the media (Lachapelle et al., 2014). Later on, when different groups within the public opinion create diverging frames, it is still to the media to give more importance to one frame or the other, making it more influential (DiPalma, 2014).

Finally, politicians play a role in influencing how the information stemming from experts is interpreted to create the frames and promote a specific frame to make it dominant (Vliegenthart et al., 2016).

These framing processes have been observed in several complex problems, particularly highly uncertain environmental issues such as climate change and biodiversity loss (Watson, 2005; Wesselink et al., 2013; Spruijt et al., 2014). Since science has been, and still is, the only sector capable of identifying and monitoring most environmental issues, it is also the primary source of information about them (Watson, 2005; Wesselink et al., 2013; Spruijt et al., 2014). Still, such information is interpreted and framed differently when it reaches the political arena, making policies differ from scientific conclusions. According to the literature, in most experts' opinion, scientific conclusions should be translated into policy in a linear process, as in every structured problem (Wesselink et al., 2013). Most often, experts do not consider that the impacts of the policies they suggest are so significant as to increase the complexity of the problem (Wesselink et al., 2013). The issue is then: how can science inform policy-making in order to address complex issues?

Since the 90s, two responses have been given to the cooperation between science and policy, one at the academic level and one at the applied research level.

First, within academia, a new discipline has been created, called “sustainability science” (Lang & Thomas, 2012). This discipline attempts to tackle complex problems by creating legitimate, salient, credible, and meaningful knowledge for politics and society (Lang & Thomas, 2012). It does so by including scientific knowledge from all the relevant disciplines and non-scientific knowledge from the stakeholders involved in the problem (Lang & Thomas, 2012; Mino & Kudo, 2020). The resulting process is often called “co-production”, and its output is a form of knowledge that is both scientifically sound and politically relevant for the issue at hand (Guston, 2011; Hoppe & Wesseling, 2014).

Second, at the applied level, the solution that has been found to let science and politics dialogue are science-policy interfaces, i.e. *“social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making.”* (van den Hove, 2007; p.815). These processes are set in place to allow science to inform policy-making while avoiding both the scientification of politics and the politicisation of science (van den Hove, 2007; Wesselink et al., 2013). They often result in the creation of ad hoc organisations, commonly referred to as boundary organisations (BOs) in the literature, where both science and policy actors are represented and reach common framings. (Guston, 2001; Hoppe, 2010; Hoppe & Wesselink, 2014).

2.2 Studying the roles of experts in the science-policy interface

In the context of the science-policy interface, the role of experts in policy-making has taken up a wide range of possible forms (Spruijt et al., 2014). Traditionally, science has informed decision-making through a linear approach, according to which science produces knowledge independently while society and politics make their decisions based on the available scientific knowledge (Lang & Thomas, 2012; Wesselink et al., 2013). Since complex problems have emerged, working in co-production and boundary organisations has required scientists to “get out of laboratories” and deal with other stakeholders, opening up several possible ways to manage such interaction. Many typologies and theoretical models have been advanced to identify and classify such roles (Saarela, 2019). In sustainability science, the most influential one is the typology advanced by Pielke in 2007. Pielke’s theory defines a spectrum of roles scientists can take when interacting with non-scientific actors based on two variables: the intensity of the interaction and the type of knowledge that is shared with policymakers (Pielke, 2007). This results in four ideal-typical roles of scientists:

1. *"Pure scientist",* who refuses to interact with non-scientific stakeholders and focuses on furthering scientific knowledge for its own sake.
2. "*Science arbiter*", who interacts sporadically with policy actors to clarify the specific technical doubts of political actors on the issue at stake.
3. "*Issue advocate",*who interacts intensively with policy actors and puts scientific evidence at the service of one cause in a political debate.
4. "*Honest broker*", who interacts quite often with policy actors in order to provide a comprehensive summary of (ideally) all available knowledge and options on their policy issue.

Since Pielke's typology does not explicitly include co-production, Turnhout et al. (2013) have enriched it with a further role:

1. "*Participatory knowledge producer*", who interacts very intensively with the stakeholders involved in the policy issue to co-produce joint knowledge that can serve both science and policy.

Table 1 summarises the roles of the typology and their characteristics.

Role	Activity	Interaction with policymakers	Form of knowledge/information provided
Pure scientist	Focusing on knowledge production and facts	No or minimum interaction	Mainly scientific data
Science arbiter	Answering specific questions posed by the policymakers/decision makers	Low/restricted	Scientific data acquired from various sources
Issue advocate	Promotion one specific solution	Intermediate—intensive	Mainly arguments
Honest broker	Expanding and clarifying the range of alternative solutions	Intermediate—intensive	Alternatives based on various knowledge sources
Participatory knowledge producer	Addressing problems and developing solutions, joint knowledge production	Intensive	Co-produced knowledge

Table 1: Saarela, 2019; p.83.

The ratio behind the choice of a specific role on the part of scientists lies in the nature of the issue at hand (Pielke, 2007; Saarela, 2019). For example, technical problems only require experts to provide knowledge to policymakers as pure scientists or science arbiters (Pielke, 2007; Wesselink et al., 2013; Saarela, 2019). Complex problems, on the contrary, require scientists either to side with a policy proposal as an issue advocate, propose a range of scenarios and solutions as honest brokers, or engage in co-production with non-expert stakeholders (Saarela, 2019).

Recent surveys have shown that most scientists, especially in Europe, are aware of the need to take up different roles, and they are ready to engage in co-production and boundary organisations when an issue proves to be complex (Rudd, 2015). Research has also revealed that in most cases co-production is activated and promoted by the expert community, even if the need for it comes mostly from other stakeholders (Lang & Thomas, 2012). Despite that, such empirical findings are still rare in the literature on science-policy interfaces (Spruijt et al., 2014; Rudd, 2015). Whether or not scientists are willing to engage with other stakeholders to address a complex issue is still primarily deduced through theoretical models (Spruijt et al., 2014; Rudd, 2015).

Such a gap in the literature is particularly relevant when dealing with energy transitions. As already highlighted, energy experts are found to be closed to dialogue with other stakeholders even though the lack of public acceptance of new energy facilities has turned energy transitions into a complex problem (MacArthur, 2016). Still, no research has clarified so far the specific attitude of energy experts towards the science-policy interface. Consequently, scouting the attitude of energy experts towards the interface could be vital both to understand how transitions have been governed so far and how they could be governed in the coming years to implement emissions-reducing energy technologies.

In order to overcome the research gap in the literature on energy transitions, this thesis has explored how energy experts engage with science-policy interfaces in a field that remains highly uncertain both on the technical and the public acceptance side: fusion energy. Similar empirical studies have already been carried out in other sectors, from ocean sciences (Rudd, 2015) to forestry (Saarela, 2019). Using the Pielke-Turnhout typology as theoretical guidance, the thesis has tried to understand how the members of the fusion experts community conceive their role as knowledge providers.

Since scientists are the key actors in activating and managing the science-policy interface, finding out how they conceive their role may be a first step in revealing how the interface is being managed in fusion development. Covering energy transitions through a particular case such as fusion can offer both a new insight into the science-policy interface and a specific view on how practitioners handle the complexity of energy transitions.

3. Research Context and Method

3.1 The case of nuclear fusion development in the European Union

Nuclear fusion can be briefly defined as a technology that makes use of the high amount of heat generated by the fusion of two atoms as a source of power (Ongena & Ogawa; Horvath & Rachlew, 2016; Spangher et al.,2019;). In nature, this process takes place inside stars, including the Sun, and it requires millions of Celsius degrees and a similar amount of years (IAEA, 2018; 2019). In order to "speed it up" for human consumption, research has been carried out since the 1950s inside experimental facilities to create temperatures dozens or hundreds of times higher than those found in the Sun and heathen up a fuel of hydrogen isotopes to have it release more energy than what is used to run the process (IAEA, 2018). This effort has posed several challenges in terms of containment of the fuel, management of the extreme temperatures and stability of the reaction (Ongena & Ogawa; IAEA, 2018). Many theoretical issues have been solved, but most remaining issues will only be addressed by operating the first reactor prototypes (IAEA, 2015, 2018).

Despite its challenges, fusion development is being firmly supported by governments and multinational organisations around the world, including the European Union (EU), the United States, China, Russia, India and Japan, which jointly finance the construction of the first International Thermonuclear Energy Reactor (ITER) prototype in France (IAEA, 2015, 2018). Construction started in 2007 and is expected to be completed in 2025 (IAEA, 2018). ITER is planned to produce a stable fusion reaction by 2040 (IAEA, 2018). Subsequently, its findings are planned to be used in another prototype, the Demonstration Power Plant (DEMO), which will test the use of fusion to create energy for the grid (IAEA, 2018). If DEMO proves marketable, fusion is expected to become commercially available around 2050 (Hamacher et al., 2013; IAEA, 2018). Some private developers claim to make it available even earlier, possibly by 2030 (The Economist, 2019). Whatever the timeline, fusion promoters defend that this technology can become a powerful, clean, and reliable energy source to entirely replace fossil fuels (Varandas, 2008; EU, 2017; IAEA, 2018; Spangher et al., 2019).

Nuclear fusion is probably the best contemporary example of a new energy technology that might face acceptance issues. While technical developments are underway, requiring billions of euros of public investments each year (IAEA, 2018), the public is still mostly left out of fusion development (Prades López et al., 2008). The European Union and, to a lesser degree, Japan, are the only ITER members who have been surveying the public perception of fusion since ITER was being designed in the late 90s (Eurobarometer, 2007; Prades López et al., 2008; Turcanu et al., 2020).

In the EU, in particular, the last, and by now obsolete, survey showed that in the mid 2000s around 56% of the public had already heard of fusion in some way (Eurobarometer, 2007) Still, such results are flawed by the fact fusion is largely confused with fission by the public (Schmidt et al., 2014). When it is discussed or covered in the media, it is mainly portrayed as a technological prowess that remains distant in the future (Schmidt et al., 2013; Oltra et al., 2014). Besides, scientists and experts are the only ones who have the floor in the media, resulting in a highly technical debate (Borrelli et al. 2001; Schmidt et al., 2013).

A serious concern in the literature is that, as nuclear technology, fusion is immediately associated with the stigma surrounding traditional nuclear fission after the Chernobyl and Fukushima disasters, which arouses scepticism among those who have little to no knowledge of it (Horlick-Jones et al., 2012; Jones et al., 2019; Turcanu et al., 2020). Even though the media have been found to remark the difference between the two and compare fusion positively with fission (Schmidt et al., 2013; Oltra et al., 2014), the distinction is not established in the lay public (Schmidt et al., 2014). When asked if they would like to host a reactor in their local community, people are particularly scared by the nuclear label, leading to the same kind of aversion that has been observed for fission (Prades López et al., 2008; Turcanu et al., 2020).

Thus, even though fusion is still mostly depicted as a mere technical challenge, its funding and implementation show the same acceptance issues that make other energy transitions complex. Thus, it can be a revealing case study to see whether fusion experts are aware of these challenges and are already taking measures to make fusion socially accepted. Of course, the fact that fusion is scheduled to be implemented in three decades makes the case study quite peculiar, as one could logically expect that practitioners want to postpone social acceptance issues until fusion proves viable. Still, the fact that ITER is about to make the technology more visible than ever and no less in need of public funding could make experts' attitudes less predictable. Fusion could represent a unique long-term case study to test the theories of the literature on the experts' view on the science-policy interface. At the same time, it could inform the literature on fusion acceptance as to how experts regard the importance of public acceptance and what their role might be in building up acceptance for fusion to make research and implementation successful.

Among the ITER members that could be considered to study the science-policy interface of fusion, the most promising one seems to be the European Union. Through Euratom, its configuration dedicated to atomic energy, the EU has been a leading actor in the technical development of fusion since the 1970s (Varandas, 2008; Pero & Paidassi, 2013). As mentioned, the EU has also been the only ITER member to survey the lay citizens on their knowledge and acceptance of fusion, powering most of the existing literature on the topic (Prades López et al., 2008; Euratom, 2018; Turcanu et al., 2020). The EU is the most significant financial and material contributor to ITER and a major supporter of a multilateral approach to fusion development (Pero & Paidassi, 2013). Lastly, existing literature on fusion acceptance in the EU has not considered practitioners' view so far, which is a gap that is necessary to fill in order to cover both sides of the science-policy interface of fusion.

For these reasons, this thesis has explicitly focused on practitioners working at the European level to understand their perception of the science-policy interface.

While political decisions on funding and standards are agreed on by EU institutions through Euratom (EU, 2012), fusion research in the EU is managed through two main entities:

- *EUROfusion*: a research consortium formed by the national fusion research centres of EU Member States plus the United Kingdom, Switzerland and Ukraine. It features a legislative General Assembly made up of representatives of the consortium members, an executive Programme Manager and a Coordinator who acts as a connection between the European Commission and the consortium members (EUROfusion, 2021). EUROfusion succeeded in 2014 to the 1999 European Fusion Development Agreement (EFDA) consortium to coordinate fusion research among its members in several scientific fields related to fusion, from physics to engineering and social sciences (EUROfusion, 2018). As a consortium of researchers, its staff is mainly composed of experts, but it is accountable at the same time to both the European Commission, which is a political institution and scientific research centres.

- *Fusion For Energy (F4E)*: a joint undertaking that has been delegated the implementation of the ITER Agreement since 2007 (Pero & Paidassi, 2013; EU, 2015). It manages the EU contribution to the construction of ITER and similar prototypes (EUROfusion, 2018). As a joint undertaking, its organisation features a legislative Governing Board composed of two representatives for each EU Member State appointed by the government and the national fusion research centre, respectively. F4E also features an executive Director responsible for the day-to-day management and various advisory committees. F4E is an ad hoc executive entity, and the knowledge it produces is aimed chiefly at informing EU authorities on the advancements of ITER. Officially, the organisation is accountable to the European Commission and national governments (EU, 2015). Still, the fact that fusion institutes are represented in the Governing Council and expert committees also implicates some form of accountability towards the scientific community.

Being accountable to both political and scientific organisations, both entities feature an organisational structure that connects the fusion community with decision-makers. Thus, they are the main arena for the science-policy interface of fusion in the EU.
This qualified them as the main places where potential participants for this thesis could be found. Euratom officials were initially not considered, as they were deemed particularly difficult to access and possibly more concerned with policy than interfaces. Still, as described later in this chapter, some of them could eventually be involved.

3.2 Data Sources

The research for this thesis adopts a qualitative methodology based on semi-structured interviews. This type of interview follows a set of questions prepared by the researcher, but remains open to the flow of the conversation and any further questions that may come up with every single participant (Patten & Newhart, 2018).

The Covid-19 pandemic constrained the selection of a method that could be handled remotely. Therefore, the primary methods considered for this thesis included surveys, document analysis and interviews. Eventually, interviews were preferred over the other two for a number of reasons.

In the case of surveys, a target group such as European fusion practitioners is not so numerous for statistical standards (Harvey, 2010, 2011). Besides, this is the first research approaching this specific group in the context of a small branch of the literature on the science-fusion interface. This means there is not enough literature to inform the formulation and analysis of a survey. Interviews offer a flexible instrument for the first approach to a new group or field even when existing literature is scarce (Patten & Newhart, 2018), making them ideal for the case study of fusion in the EU.

As to document analysis, it would have required such sources as personal communications to discern the individual attitude of practitioners, which are hardly accessible. Most documents that were available to the author reflected the point of view of fusion organisations instead. Thus, interviews have emerged as the most practical and direct instrument to infer practitioners' point of view on the science-policy interface.

While having the ideal characteristics to provide data for this thesis, interviews also come with some issues that had to be considered before and during data collection.

First of all, getting access to potential interviewees is often an issue, as contacts may be difficult to find, and the target people may not have time for an interview (Lancaster, 2015; Harvey, 2011). As a result, interviews require a high degree of flexibility in terms of means and availability on the researcher's part (Harvey, 2010).

Second, part of the literature warns that the official role of a potential interviewee might be misleading (Mason-Bish, 2018). The people whom the researcher expects to be knowledgeable because of their role might turn out to have less experience than others holding a less prominent position (Mason-Bish, 2018). It is desirable then, especially for the first research in a field, to involve people from different positions to lower the chances of missing essential informers (Mason-Bish, 2018).

Finally, several intervening factors may influence the results of each interview, from power inequalities to the interview channel (face-to-face vs remote interviews), location, gender, ethnicity, the role of mediators, duration and transcription techniques (recording vs taking notes) (Novick, 2008; Harvey, 2010, 2011; Weinmann et al., 2012; Lancaster, 2015; Petkov & Kaoullas, 2016; Mason-Bish, 2018). The literature is not unanimous on how these and other factors may influence an interview, but it is desirable to keep track of them as much as possible.

All these points, which are not meant to be exhaustive of the issues of using interviews as a data source, were considered in designing the data collection and analysis strategy. In particular, the author tried to be as flexible as possible with participants, involve fusion practitioners from different backgrounds, and note the intervening factors. The rest of the chapter describes how data collection and data analysis were handled to that end.

3.3 Data Collection

The collection of interviews for this thesis took place between March and April 2021. The contacts of interviewees were found mostly through the social network LinkedIn and the official websites of the members of the EUROfusion consortium. The reason for that was that the websites of EUROfusion and Fusion for Energy did not provide any personal contact of their employees. As a result, the practitioners working for the two entities were reached via LinkedIn, which let the author reach fourteen EUROfusion and Fusion for Energy current employees. Each participant who took part in an interview was asked at the end if they wanted to share the contact of other colleagues who might be interested in the research. This yielded twelve more contacts of fusion practitioners from the two organisations, but also from Euratom officials.

Using a social network and asking people who already agreed to participate made it impossible at first to control what kind of people were being contacted. As stated in the previous section, though, a balance was sought in terms of involving practitioners having different backgrounds.

Firstly, concerning professional backgrounds, the author tried to engage people working as engineers and physicists, but also in other non-technical fields related to fusion such as social research and communication. Besides, several levels of the professional hierarchy, from top managers to trainees and PhD students, were tried to be engaged to vary the pool of answers.

Secondly, from a gender point of view, it was deemed desirable to involve an equal number of men and women in the research. The first fourteen contacts that were gathered reflected this diversification effort, but the response rate was higher from men working as officials or PhDs. Thus, a second round of invitations was carried out targeting practitioners working for institutes that are part of EUROfusion. Since most institutional websites published the contacts of their staff, this group was more easily accessible than EUROfusion and Fusion for Energy practitioners. In this second round, invitations were sent especially to managers and women, as their view was not sufficiently represented yet.

Overall, all the sources of contacts and the sorting of potential participants resulted in forty-four invitations. The potential participants were divided as follows according to their gender and position in the fusion community:

- 22 men (2 managers, 3 communicators, 9 engineers, 4 physicists, 3 PhDs, 1 other)
- 22 women (3 managers, 6 communicators, 3 engineers, 8 physicists, 1 PhD, 1 other)

Typically, managers, engineers, physicists and PhDs had a technical background, while communicators had a background in social sciences or journalism. The two “others” had a specific background that did not fit any of the preceding categories.

The invitations resulted in fourteen semi-structured interviews, with the following participants:

- 11 men (2 managers, 5 officials , 2 physicists, 2 PhDs, 1 other). Response rate: 50%.
- 3 women (1 manager, 1 engineer, 1 other). Response rate: 14%.

Overall, the desirable degree of variety of participants’ backgrounds was partly met, especially from the professional point of view. Participants belonged to all levels of the professional hierarchy, they had different levels of experience in the fusion sector, and they belonged both to physics, engineering, communication and management. Some of them even merge multiple characteristics, such as being an engineer coordinating social research on fusion, or being a physicist involved in scientific communication.

As to gender equality, it is immediately noticeable that the number of male participants is almost three times higher than the number of female participants. This situation was analysed more in depth by consulting the Centre for Interdisciplinary Gender Studies (CIGS) at Trento University. The author submitted to the CIGS the characteristics of the practitioners that were invited together with the text of the invitation in order to check them for some gender bias. The CIGS did not find any particular bias in the participants' selection and the text of the invitation. As a result, they concluded that the gender imbalance issue of the interviews may result from factors that are beyond the author’s control.

The interviews were held remotely using the meeting apps Zoom and Microsoft Teams. They mostly consisted of individual interviews, except for the one with the three Euratom practitioners, who preferred to be interviewed together. In that case, the same questions were asked to each one of them in order not to change the data gathering format. The language used in the interviews was English, except for two Italian practitioners who preferred to use their native tongue. Duration ranged from minimum twenty-five to maximum sixty-five minutes. The questionnaire touched upon three main themes: the practitioners’ perception of fusion public acceptance, the characteristics of the science-policy interface of fusion, and the role of fusion practitioners in the latter. All interviews were recorded with the explicit verbal consent of the interviewees, and they were later transcribed to carry out the data analysis. The semi-structured questionnaire and a table of the main characteristics of each interview can be found in Appendix A.

3.4 Data Analysis

The data gathered for this thesis have been analysed and interpreted in the light of the theoretical framework provided by the Pielke-Turnhout typology. The analysis and interpretation phases are two interlinked but distinct processes when working on qualitative data. The analysis phase is concerned with organising the data by dividing and re-assembling them consistently (Trent & Cho, 2014). The interpretation phase is a parallel step in which the researcher finds the meanings data express and compares them to other sources, literature, or common sense to identify meaning patterns (Trent & Cho, 2014; Patten & Newhart, 2018). The two processes occur in parallel in an iterative process where complexity is alternatively reduced and enlarged until a narrative of what the data reveal emerges (Saldaña, 2009; Patten & Newhart, 2018).

In the analysis phase, data were organised through coding. A code is *"a word or short phrase that symbolically assigns a summative, salient, essence-capturing, or evocative attribute for a portion of language-based or visual data"* (Saldaña, 2009; p.3). Coding consists of associating codes to parts of the text to summarise what they deal with and access the information more easily when interpreting the data (Saldaña, 2009, 2014; Trent & Cho, 2014; Patten & Newhart, 2018). The transcripts of the interviews were coded with the software Atlas.ti using primarily descriptive codes, i.e. nouns that summarise the topics dealt with by interviewees in the conversation (Saldaña 2009, 2014; Trent & Cho 2014). Most of the codes were based on the variables of the Pielke-Turnhout typology and the themes of the questionnaire. Some others emerged from topics mentioned spontaneously by more than one interviewee. A complete table of codes can be found in Appendix B.

As for the interpretation phase, it usually involves many non-mutually exclusive techniques, including but not limited to: asking critical questions, seeking advice from other researchers, connecting to the literature or existing theories, accounting for power dynamics or reconnecting to one's personal experience as a researcher (Trent & Cho, 2014). In this thesis, the interpretation has taken place mostly by asking critical questions, connecting to existing literature and seeking advice from the author's supervisor. In addition, power dynamics between the interviewer and interviewees are challenging to account for in an exploratory thesis. As to their impact on the answers, the atmosphere of the interviews was informal and the topic limitedly sensitive, so that it can be presumed to have been relatively weak. Lastly, since this is his third research based on interviews, the author's past experiences have sharpened the critical analysis of the answers, but they are probably still too few to bias the findings.

4. Results

This chapter is going to relate and discuss in detail the results of the interviews with the fourteen European fusion practitioners. In particular, the first section relates how fusion practitioners describe the science-policy interface of fusion development. The second section reports how fusion practitioners view the public acceptance of fusion and their own role in the science-policy interface. The concluding section discusses the results of the first two in the light of the Pielke-Turnhout typology and other empirical studies on the role of experts in the interface.

4.1 The science-policy interface of fusion development

The European fusion practitioners who participated in the interviews unanimously defined their peer community as traditionally closed to external interactions. Fusion practitioners were said to be focused on their peers and the stakeholders closely related to fusion development. Interactions with less close stakeholders, such as the lay public, are marginal.

At the same time, most participants underlined that some considerable change has been underway in the last decades concerning the number and quality of interactions with non-scientific stakeholders, and they are mostly convinced that this trend will continue when ITER starts operations.

A crucial aspect most interviewees wanted to point out is that the fusion community is highly heterogeneous regarding their attitude towards the science-policy interface. The capacity and will to cooperate, interact or merely communicate with external stakeholders was said to vary from a fusion institute to another and from one fusion practitioner to another. Overall, every institute was said to somehow interact with external stakeholders, but only the largest can afford a dedicated department. As to the individual attitude of fusion experts, all interviewees could mention some examples of themselves or their colleagues' engaging with non-experts. Still, their prevailing impression was that a large majority of the fusion community is exclusively committed to pure research, and engaging with non-experts is neither required nor expected of a fusion scientist by the peer community.

Most interviewees tried to explain such an attitude in terms of the technical nature of fusion, coupled with its extreme complexity and long-term development.

All interviewees regarded fusion as an extremely challenging technological endeavour. It was said to require the most advanced knowledge, technologies, and materials humanity has, and still, there remains a high degree of uncertainty as to whether it will ever be accomplished. The degree of technical complexity is so high that it is difficult to make a non-expert understand what is at stake even before explaining fusion itself. Thus, the fusion community faces a significant challenge whenever it has to explain what it is accomplishing. It all appears as something incomprehensible for a non-expert and, in the case of sub-subjects, even for most fusion experts themselves. Because simplifying such complexity requires a considerable effort, the fusion community was said to be strongly discouraged from communicating unless it is strictly necessary.

Another common explanation for the community's attitude was that fusion practitioners work primarily on theoretical research and experimental prototypes. Since their work has not come to practical devices for public use so far, several participants said the community does not feel the need to interact with external stakeholders except when funding and reactor components are needed.

One last explanation turned the spotlight on the historical legacy of fusion research, which has long been associated with military research:

"[...] fusion used to be top-secret, so many of our members used to be institutes or parts of top-secret organisations. Because this is nuclear research, and it started [...] during the Cold War [...] at that time, of course, nobody had communication people, right? [laughs]"

Such overarching depiction of the fusion community as self-reflexive and closed to external engagement was coherently reflected in interviewees' narratives when describing how the fusion community concretely interfaces with external actors. The number and type of stakeholders, the kind of scientific knowledge the community shares with them and the formats it uses do not seem to depart from the initial description.

Starting from the stakeholders of the fusion community, those actors participants have worked with are all very close to fusion development and its value chain.

The most mentioned stakeholder was politics, in the form of national governments and European institutions, which are the almost exclusive funding providers of fusion research. Industry and other scientific fields, such as materials science, are also frequently dealt with as the designers and manufacturers of the specialised components of fusion reactors.

The least frequently mentioned stakeholders included the scientific press, universities, schools, and the lay public. The first three actors were said to be engaged to further the fusion community's academic work and find new potential researchers. As for the lay public, it was mentioned more as a desired audience than a real stakeholder.

One interviewee working on communication explained that:

"There is whom we'd like to be reaching, and there is the reality of whom we are actually speaking to. [...] What we are trying to do is reach the general public. But in reality, if you look at who we have actually been reaching, it's people in the fusion community or people who are interested in science, in energy, and also specifically in fusion."

Even the other fusion communicators who participated in the research stated their intended goal was to reach the lay public. Despite such intentions, the real outreach seems to be limited to people who are already close to, or knowledgeable of, fusion.

No matter whom it is addressing, the fusion community was said to interact almost exclusively through one-way communication about the latest discoveries or research needs. Initiatives where practitioners dialogue or interact more in-depth with external stakeholders were said to be rare. Each interface with a specific stakeholder differs to a certain extent from the others, but the common thread is that the fusion community approaches each stakeholder individually with enough information to further its own needs. This is usually done by the director of each fusion institute or, for the few institutes that can afford it, by one or more specialised departments. EUROfusion and Fusion For Energy, for instance, were said to have different offices dealing with one or more stakeholders each.
In some cases, individual fusion researchers participate in communication, but this was said to be an exception, as it will be discussed more in detail later in this chapter.

Because there was a high diversity of backgrounds and roles among interviewees, many could describe their experience with one or more stakeholders. In the case of political actors, for example, most participants could say that most often the management of fusion institutes is in charge of the interface. Around four interviewees also had some direct experience of it. Generally, it was said that all fusion institutes report to their national governments, or, in the case of EUROfusion and Fusion For Energy, to the EU. Reports were mentioned as the primary formal interaction channel, but being able to lobby policymakers and explain what fusion research is achieving and what it still needs is crucial. As a EUROfusion manager said:

"I am trying to go very hard to politicians to convince them "you really need to keep [funding] up at the same level otherwise we will never have fusion" [...] you need to catch the politicians in a few minutes [...] I try to focus on the real facts. I try to convey the message, what I want to get out of the politician. Because it's often me contacting them, it's seldom the

other way round. [...] Also, it's good to talk to politicians at the moment when you are not running for funds. Otherwise, they will think, "ah, these fusion guys always come when they need money"."

This and the other knowledgeable participants described the interface with politics as a one-way appeal where the fusion community has to convince politicians whenever funding is decided to keep funds flowing to its projects. Here, scientific knowledge must be extremely concise to be explained in a few minutes, and the preferred formats are face-to-face conversations, telephone calls, briefings and lobbying events. While the discussion was generally said to be focused on the practical results and potential of fusion, the fact that some political groups are opposed to nuclear power compels fusion directors to engage in a political discussion from time to time. In these cases, scientific evidence can be used to make a point for fusion development compared to other energy alternatives.

When it comes to industries, cooperation was activated whenever a new prototype such as ITER is being built. The interface was said to be managed through the supply contracts, which act as a means to transfer technical information from researchers to manufacturers. As a Fusion For Energy official related:

"These contracts become an interface through which we give information and receive feedback. The technical indications, designs, research, and the documents are the means to transmit information to the industries." [translated from Italian]

Since industries have a certain degree of expertise that is lacking in the fusion community, the interface was said to have become more interactive than in the other cases. The fusion community shares its technical specifications through the contracts, but it also receives feedback on improving the design and the materials it uses.

Finally, the interaction with the lay public and other actors, such as the scientific press, was said once again to be mostly limited to top-down sharing of more or less simplified technical knowledge, depending on the audience. As one interviewee summarised:

"you end up with the traditional science communication of press releases for the media, having open days and talks with you, explain what you have done. Maybe answer some questions, but mostly is A to B."

This quote effectively summarised the most common communication formats referred to by most interviewees, i.e. press releases, open days, and public conferences. They add to other top-down communication channels that were frequently discussed, such as institutional websites, official reports, social media posts, and experts' visits to high schools. Before the pandemic, there was also an annual exhibition for schools travelling around Europe, called Fusion Expo, which attracted thousands of visitors. Out of all these formats, only a couple of them were said to be interactive and engaging, particularly the guided tours and the school visits. As a EUROfusion communication official describes the impact of tours:

"[the guided tour] is very, very convincing, and the reason that it is is because they get the information, but they also get the passion from the persons delivering it. That makes a huge difference."

Still, interactive formats were said to be too time-intensive for practitioners to reach more than a few people at the time. The bulk of communication, which remains the almost exclusive interaction mode, was still said to be "A to B", to use the interviewee's words.

To summarise, the interviewees coherently depict the European fusion community as highly self-oriented. It shares essentially technical knowledge through traditional science communication channels, and its outreach is quite limited. The fact that all interviewees converge on such a narrative despite their diverse backgrounds and points of view is remarkable, and it seems to validate each other's account on the attitude of their peer community.

Despite that, multiple interviewees, especially those belonging to communication and management, observed that there have been several changes in the last decade, both in the attitude of the fusion community towards external stakeholders and the resulting communication efforts. Fusion practitioners are said to have received some external inputs that are gradually opening up the fusion community.

The most frequently mentioned input is the launch of ITER in 2007, making fusion practitioners work on a significant publicly visible project for the first time. A public consultation with the local community required by France to start building the ITER facilities was described as the first (and currently only) example of fusion practitioners having to engage with lay people to explain what fusion is and earn their approval. However, the consultation was said to be a very specific event that did not produce permanent expertise or scientific studies for the entire fusion community. ITER was also said to have strengthened the existing interface with some stakeholders, particularly industry after construction had to be delayed because manufacturers were not involved in the design of the reactor. As one interviewee related:

"[scientists] went to the manufacturer after everything was planned and said "make this". [...] what they didn't do was to drop an initial design, ask the manufacturer "does this work for you?" [...] one of the reasons [ITER] is so expensive, and so overtime is they didn't communicate with people in the industry and manufacturers."

This error was often mentioned as a learned lesson for the following prototypes, as a EUROfusion manager related:

"In EUROfusion, we are now making the conceptual design of DEMO, so the machine after ITER. We already want to have industry involved there because we… can make the design much better by involving industry from the beginning."

Two other inputs that were said to be changing the level of openness of the fusion community were the social media and the changing requirements imposed by the EU to grant funding.

Social media were said to have increased access to scientific knowledge while increasing fake news on fusion. Thus, practitioners feel the need to join the debate to avoid misconceptions and misinterpretations of their technology to gain ground. In the literature, this is confirmed by various media analyses on the debate surrounding fusion, which is found to be dominated by the contribution of practitioners (Schmidt et al., 2013; Oltra et al., 2014).

As to EU requirements, the interviewees who work on them said they have been increasingly aimed at making science more participatory by promoting what they call *citizen science*, a form of co-production. In this context, fusion research projects are also encouraged by the EU to communicate their results more effectively and engage citizens in their work. Until now, citizen science was said to be more of a trend promoted by the EU rather than a set of binding conditionalities. Its introduction was said not to have influenced the job of fusion practitioners so far, but it was expected to be increasingly part of the project requirements in the future EU funding programs. As a communication official summarised:

"So right now [citizen science] has been introduced, and it has been requested that we start thinking about it and we start taking it seriously. I think that the further we go along, the more we will have to show we are integrating it. We will have to show we are not only informing the public but also involving the public."

Overall, those interviewees who identified these inputs recognised them as part of a bigger change in the way science engages with the public. Traditional scientific communication was perceived to be obsolete after social networks have changed the way society communicates. Communication must be quick, and formats should be more interactive so that the audience remains attentive. In this context, fusion development is trying to adapt by renewing its events and communications to make them more interactive and appealing to the lay public. A commonly mentioned example was the renewal of Fusion Expo, which a communication official described as:

"[Fusion Expo] was the typical kind of scientific exhibition [...] we are trying to change that, and this Expo uses media, so different media, to tell a story [...] we are very deliberately trying to [...] transmit the passion that we have [...] but also the basic understanding of [fusion]."

A EUROfusion manager specified how the new Fusion Expo is going to have people confront even with political decisions on the energy mix:

"part of the exhibition is also that people download an app on their phone, with the app they can do many interactive kinds of games. They can decide the future,[...] like what kind of core, what kind of electricity mix, what is the energy mix... and then the program calculates what happens in 20-30 years from now, so people are confronted with the future."

Despite that, all these interactive activities were devised more to draw visitors' attention and facilitate learning than to engage them in a debate or in co-production. Top-down communication seems to remain the preferred interaction mode for the fusion community. Even those interviewees who were more open to a deeper interaction agreed that little more should be asked of fusion practitioners at this stage of fusion research. In the words of a communication official:

"I think it's normal. It would be early days for them from my side to actually ask them to invest in [external interaction] because it needs to take its course, and this is part of the course it is taking. Look, ten years ago, they would not consider doing much of what we do today, so... we have actually brought, I mean, content to people outside the community."

In summary, from the point of view of the majority of the participants in this thesis, the fusion community has always been traditionally devoted to pure research, and it should not change its focus for now. Fusion remains an almost exclusively technical challenge for all participants, and interfacing with external stakeholders is limited to satisfying the practical needs of fusion development. Some fusion researchers were said to be personally interested in communicating their knowledge to external stakeholders, and some practitioners work full-time on communication and external interaction. Still, these people were generally referred to as the exception in the fusion community. Despite this, most interviewees said the fusion community is experiencing a transition phase touching upon its communication style and the way it interfaces with external stakeholders. The external inputs provided by the launch of ITER, social media and society's expectations from science as a whole were said to be changing the way fusion practitioners communicate. The community was expected to open up to society gradually, and as soon as ITER starts operations, this was said to be not just desirable but necessary. For the time being, though, such change is at the initial phase, and it is not expected to affect the attitude of the majority of the fusion community towards forms of closer cooperation and co-production.

4.2 The role of fusion practitioners in the science-policy interface

The participants in the interviews showed a high degree of awareness of the public acceptance of fusion. Whether they had any personal experience of it or not, they mostly knew that only a niche in the public knows about fusion, and those who do generally have a favourable opinion of it. When it comes to their role as fusion practitioners in public acceptance, most interviewees thought the fusion community should probably do more to communicate about its technology. Still, such an effort should be preferably undertaken by professional communicators rather than current practitioners, who would face several professional and practical challenges.

Starting from the perception practitioners have of fusion acceptance, all interviewees did not doubt that most of the public is unaware of nuclear fusion. Whether they had ever discussed fusion with people from the lay public or just looked at the public debate, no participant thought that more than a fraction of the general population had ever heard of fusion. This impression aligns with existing studies on the public acceptance of fusion in Europe produced by EUROfusion. Still, participants did not quote scientific results to motivate their opinion, not even EUROfusion employees, with the sole exception of a practitioner who contributed to such studies.

However it emerged, the impression of practitioners also matched existing studies when discussing what the people who know about fusion think of this technology. Here, the majority of practitioners were aware that there is much confusion associated with nuclear fusion. In this context, they said it is hard for the public to have a general opinion of it, and it is hard for practitioners to understand what such opinion is.

They explained such confusion partly in terms of the conflicting information filtering to the public through the media, and partly in terms of the "nuclear" label, which immediately sparks a negative association with fission and the nuclear accidents of Chernobyl and Fukushima. Only science and technology enthusiasts, or *"techies"* and *"nerds"* to use the words of an interviewee, are said to be knowledgeable about fusion within the lay public.

As for the public opinion of fusion, the general impression was that the more people know about fusion, the more positive their opinion of it. This opinion is also in line with existing studies on public acceptance, but they were not directly mentioned once more. Some interviewees mentioned their personal experience with people who got to know about fusion during a conference or a guided tour. As one EUROfusion manager related:

"I am regularly giving lectures, also lectures to the lay public. Very often, people come to me and say, "wow! This is fantastic! I never heard of this! And this is really good. When can we get it?"."

Another EUROfusion official described how convincing a firsthand experience of fusion is:

"When they take that tour [of ITER], there is not anybody at the end that is not excited about the potential of fusion. And even the most rigid anti-nuclear politicians, once they have taken a tour, at the end of it they sort of say, "you know, I really wish that there was flexibility in the political structure that I am stuck within because this is fantastic. But because this is nuclear science, I have to be against it."

Much of this positive attitude was ascribed to the potential of the technology, but also to the established narrative of fusion communication about "creating a star on Earth" and "harvesting the power of the Sun", which is deemed very powerful. Some participants pointed out the power of such a narrative, while others were more aware of the issues stemming from being associated with nuclear fission. Still, all of them showed a high degree of awareness on the current state of the public acceptance of fusion, despite their different backgrounds and personal experiences with the public.

When asked whether and how the public acceptance of fusion may impact fusion development, interviewees once again converged on a similar interpretation. All of them talked about the linear process bringing a technology accepted by the public to be highly supported by politicians. This results in more funding if the technology is accepted, and less funding if it is not accepted, which is decisive for an expensive technology such as fusion. Most statements are on the subject are almost identical, as the following three from different interviewees show:

"politicians, they have public acceptance very close to their heart. When the public doesn't accept something, then the politicians would say "why should we go for it? I want to be re-elected in a number of years"."

"fusion is expensive, and fusion research relies on goodwill from politicians and from funders to fund the research. So, if there was a general opinion against fusion, then I guess we would have a harder time."

"I think with all technologies acceptance can affect development. I think it's really powerful, and it can shape what policymakers say "this is not making, I can save the investment"."

Such a description of public acceptance in very practical terms seems consistent with the general attitude of the fusion community towards external stakeholders that was reported at the beginning of the chapter. Public acceptance is regarded by the interviewees as another possible obstacle or opportunity for fusion development, depending on the direction it takes. Only one communication official decided to expand on his conception by mentioning three different aspects of fusion acceptance: the democratic accountability of science to society, the financial accountability of publicly-funded research in particular, and the fascination scientific research produces in the public. A few others mentioned a professional obligation of experts to be accountable for fusion research, but the majority did not linger on the topic.

Coming to the central question of this section: how do the participants consider their role in fusion acceptance? The predominant opinion was that the fusion community does play a vital role in the acceptance of nuclear fusion. Since this energy technology is highly complex and full of black spots, experts are deemed irreplaceable in helping policymakers and lay people understand and accept its potential role.

The opinion of interviewees started to be more varied when it came to defining where public acceptance stands among the priorities of fusion development right now. Here, around seven participants, which is a little more than half, considered it a high priority that must be, and is being, seriously considered by the fusion community. A couple of participants considered it an average priority, which remains less critical than the fusion's technical issues. Finally, around five participants considered it a low priority, either because they thought the fusion community is focused on pure research or because they believed it is too soon to start thinking about fusion acceptance until it has proved to be a viable energy source.

An even more diverse pool of ideas was expressed when the interviewees were asked how fusion practitioners can play a role in the science-policy interface. Here, all interviewees started reflecting on scientific communication. They rarely mentioned other forms of interaction, such as lobbying, advising or co-production. As discussed in the previous section, some of them have heard of other forms of interface, such as the co-production initiatives promoted by EU funding programs under the label *citizen science*. Despite that, only the communication officials dealing with European funds knew about *citizen science*, while most interviewees did not know either about this or other forms of alternative interface.

Since co-production is one of the two approaches in the literature to cope with a complex issue such as fusion acceptance, the idea of producing knowledge together with citizens was advanced towards the end of the interviews. Such research mode was immediately dismissed by almost all interviewees, whether they were knowledgeable about co-production before or not. Fusion is considered too technical and too reliant on engineering and physics to engage lay people in knowledge production as other scientific disciplines do. No interviewee believed there is room for co-production in any form in fusion development at the current stage. As one communication official said:

"[citizen science] is pretty much nothing, I would say. We are struggling, in a sense, to make our fusion experiments produce more energy than it takes to heat the reaction. That is still the challenge, and that is what we want to solve with ITER. Once that is done, I would expect more input [...]."

Thus, when interviewees thought about the role of practitioners, including themselves, in the science-policy interface, they reflected specifically on their contribution to scientific communication. Here, most of them thought that the current top-down communication activities of the fusion community are appropriate, and fusion practitioners should not engage more than they are already doing.

Some interviewees did raise some concerns, however. First of all, the existing formats were criticised for not leaving room for reactions or feedback. This was said to make it difficult for practitioners engaging in communication to say if they managed to convey their message, whether they are addressing politicians, industry, or the lay audience.

As one PhD student summarises it:

"one thing I noticed with fusion is we say we communicate a lot on what we are doing [...] The public has a lot of questions and concerns, but I very rarely find the form where both of those happen at the same time. Where the public asks their questions and concerns, and we give answers. [...] it might show there is a divide between what we think people think and what they actually think."

Other concerns regarded the limited outreach of existing communication and the risk that the existing association with nuclear fission and its accidents could confuse the public and endanger fusion acceptance.

Overall, both the interviewees who were satisfied with existing communication and those who raised some concerns thought that communication should be strengthened. Nevertheless, they saw several limitations of fusion practitioners in taking part in it. The current formation and professional requirements of fusion practitioners were said to pose several obstacles. Most practitioners start their career either as nuclear physicists or engineers, and they are expected to stick to the academic requirements of their profession. Scholarly communication is included within such requirements, but any communication effort trying to reach beyond the academic world is generally said not to be considered as a professional activity. As a result, those fusion practitioners who have a personal inclination for spreading fusion knowledge beyond the academic world are said to do that in their free time as a purely voluntary activity. The interviewees could relate many such stories about themselves or their colleagues. A young engineer said, for instance:

"I know some people, they do some summer schools for students, so they participate in teaching activities, a little bit. But I think it is not really… I think it's not seen as a job description of today, at least not at the place where I work."

A physicist had a personal experience as a voluntary fusion communicator:

"I got a grant to do this outreach project to educate high school teachers and students about fusion energy.[...] the outreach project is not something I get money for, but it is something totally voluntary that I do.

The interviewees generally agreed that it is doubtful communication activities may become part of the regular job of fusion practitioners. This might happen only if funding requirements were changed, as the EU is said to be doing. Still, such a possibility was deemed potentially counterproductive by participants. Generally speaking, fusion research was not expected to benefit from engaging non-experts, and most fusion practitioners were said to have no experience or specific skills in communication. Interviewees from different backgrounds all agreed on these points. Even reconciling the career as a researcher with voluntary communication activities was considered to be extremely difficult. Several challenges were mentioned, from not being able to remain updated with the latest developments of fusion research to being recognised as a full-time communicator by peer researchers. According to the experience of a PhD student, at some point, one has to choose whether to continue working as a researcher or devoting their entire career to communication:

"You know, my boss at Fusion News [...] she now has to do the science on her own time because she is now a communicator. Something that worries me is if I said, "wow, I like this sort of interacting with the public thing, I want to do that a lot", I am kind of worried that it would mean ", that's what I do. I am no longer in science, that is what I do"

For these reasons, most interviewees do not think fusion practitioners can or should play a more substantial role in communicating their work. The most common proposal to improve existing communication was to delegate such a task to professionals who can bridge fusion science and society more effectively. This was put forward mainly by interviewees working as researchers or engineers, while communicators and managers did not mention it, possibly because they are already fulfilling that role. Other ideas included strengthening the lobbying capacities of the fusion community and being more active on social media. However, practitioners did not go beyond suggesting ideas like these, as they mostly perceived that effective communication requires forms of expertise they do not possess.

To summarise this second section, the European fusion practitioners who participated in the interviews were mostly aware of the state of public acceptance concerning their technology. They generally placed high relevance on public acceptance, and they acknowledged the importance it may have for successful fusion development. Interviewees were also aware that experts are the only ones who can effectively explain to the public what fusion is and what results it is achieving. The majority believed the fusion community is already doing enough in that sense, and only a few criticised its one-way communication approach. The predominant opinion is that it is not up to experts to engage with external actors personally, but some professional mediators should make fusion communication effective while allowing experts to pursue full-time fusion development.

4.3 Discussion

When analysing the results that have been reported so far, it is possible to obtain quite a clear picture of the way the fusion community interacts with external stakeholders.

Overall, the interviews portray the science-policy interface of fusion as an arena characterised by one-way communication and a clear division of roles among practitioners. The interviewees belonged to several levels and areas within fusion development, with the majority of them having a background in nuclear engineering and physics. Despite their different points of view, their prevailing impression was that most of their colleagues are exclusively working on pure research. Only a few practitioners would engage with stakeholders at the science-policy interface, and they would do so either as voluntary activities or a full-time profession.

Thus, a salient point that emerges from the interviews is that fusion practitioners do not take up different roles when engaging with the science-policy interface. A fusion professional has to choose between focusing their career either on research or the interface, and a third option fails to emerge from interviewees' narratives.

When it comes to the functioning of the science-policy interface of fusion, the predominant approach described by interviewees was one-way communication. Most of the time, such communication is addressed to specific stakeholders for instrumental purposes. Thus, scientific knowledge is shared to fulfil the immediate needs of the fusion community, whether it is the accountability obligation towards politics or finding the funds and talent to facilitate fusion development. General communication to the lay audience is also performed, but its outreach was said to be limited to people who already know about fusion. Finally, deeper interaction and exchanges of ideas with non-experts are rare, and they most often result in experts once again explaining instead of running a genuine dialogue.

From the point of view of the Pielke-Turnhout typology, such a description of the interface and the role of practitioners in it are consistent with the ideal type of pure researcher. This role seems to be pre-eminent in the fusion community and essentially exclusive among physicists and engineers engaged in research. These fusion researchers were rarely said to engage in activities that are compatible with other roles of the typology, and those who do so were said to either use their free time or face some professional challenges. Such challenges included not having communication activities recognised as part of their regular work, being identified by peers as pure communicators, and not being able to cope with the amount of updated knowledge needed to carry out fusion research.

The pre-eminence of the role of pure researcher is not rare for a scientific community. Empirical studies on other expert communities dealing with complex problems, such as ocean and forestry experts, suggest that this role remains ideally the preferred one among experts. Still, fusion practitioners seem to be able to stay pure researchers, while their colleagues in other disciplines are found to be pushed by external pressure to embrace different roles (Rudd, 2015; Saarela, 2019).

Despite pure research being by far the most common task in the fusion community, some activities described by the interviewees appeared to be compatible with other roles of the typology. Such activities are carried out mostly by the practitioners working on communication and management, who were said to be the ones in charge of managing the science-policy interface. What they do is filter the highly technical knowledge provided by their research colleagues and make it understandable to the audience they are addressing. Whenever such an audience includes politicians, industries, and the press, the latter may come up with questions. In that case, it is up to these practitioners to either provide answers or come back to researchers for clarifications. Such activities are less consistent with the ideal-type of pure researcher, and more with a second role, i.e. science arbiter. Most communicators and managers can be identified as such. However, they do act as science arbiters when direct communication with stakeholders is possible, which is a rare occurrence in the science-policy interface of fusion. Whenever there is not such a feedback mechanism, as in the case of the general public, communicators and managers genuinely acknowledged they have issues in understanding what formats and content can work to make fusion more understandable to those audiences.

Some specific tasks seem to be compatible with a third role as well, i.e. issue advocate. This one is almost exclusive to the directors of fusion institutes, who were said to use scientific knowledge to prove the results of fusion and lobby policymakers for funding. Officially, fusion managers brief politicians by delivering regular reports and delivering presentations. The formats and content used in such cases are highly simplified, as politicians do not have enough time to go in-depth on fusion development. However, informal events were also said to be commonly held to lobby policymakers in favour of fusion development. Lobbying is an activity one would expect from any scientific community, as funding is needed for all sorts of research. Still, since fusion is nuclear technology, lobbying in favour of it was deemed politically contentious, because some political positions strongly oppose nuclear power in general. Using the results of fusion research to attract more funding involves directors in a political debate, which is the characterising activity of issue advocates.

As for the remaining roles of the Pielke-Turnhout typology, i.e. honest broker and participatory knowledge producer, no activity related in the interviews seems to match them.

Concerning the role of honest broker, researchers, communicators, and managers stressed that fusion communication must be as honest as possible by underlining the benefits and downsides of the technology. Still, they never related an event or activity where they offered a complete picture of the state of the art of fusion development. Fusion communication was always described as targeted and purpose-driven, so that practitioners will always end up presenting one part of the story. This was primarily explained in terms of the extreme complexity of fusion development, which involves several sub-subjects that would require an extremely detailed explanation each. Making fusion communication understandable was said to be about simplifying the massive amount of available information, and presenting a complete picture was never said to be either required or performed.

Lastly, concerning the role of participatory knowledge producer, the participants in the interviews were all convinced that co-production has not only never been a part of fusion development, but also it might hardly ever be so. Fusion was said to benefit exclusively from the technical knowledge stemming from engineering, physics, material science, and other scientific disciplines. Therefore, co-producing knowledge with non-experts was not considered a viable option to advance fusion development. Co-production was thought to be desirable in the future to communicate fusion and possibly design fusion reactors, but there would be no room for it at the current stage.

Overall, fusion practitioners are said to embrace a limited number of roles in the science-policy interface, and to perform only the activities of one role at the time. The science-policy interface of fusion is characterised by traditional one-way scientific communication, and feedback channels are primarily open to fundamental stakeholders, such as politics and industry. As discussed in the literature review, such an approach has been the standard of the governing of energy for a long time (Valkenburg & Cotella, 2016). Experts have long produced knowledge to inform decision-making without any need for dialogue. Since such a linear process has been questioned by the lack of public acceptance for energy technologies, one of the aims of this thesis was to inquire on whether energy experts have changed their approach accordingly. The prevailing narrative of interviewees suggests that the fusion community strongly adheres to the linear approach to this day.

Despite that, according to several accounts the attitude of the fusion community has been gradually shifting in the last years. After decades of theoretical and experimental research, the launch of ITER was said to have worked as a catalyst of change. It made fusion research public for the first time, and exposed it to the same opening-up observed in science as a whole. It also provided a unique learning ground where the fusion community could test its interface with its stakeholders and learn from practice. Lessons from ITER were said to have affected several aspects of the interface. Fusion communication was renewed to become increasingly open, attractive and interactive. At the same time, the cooperation with the traditional partners, such as industry, was also said to be closer, more regular, and open to feedback. Managers and communicators suggested these processes are part of a transition in the way the science-policy interface of fusion is managed. Regarding its concrete impact, though, such transition was said to be at the initial phase and to have had no effects on the tasks and expectations of fusion researchers as a whole. The existing interface approach was not said to be in question, nor was it questioned by the interviewees themselves.

Compared to similar empirical studies in the literature, the results of this thesis show some differences between the science-policy interface of fusion and those of other disciplines, such as forestry and ocean studies. Unlike experts from such disciplines, fusion practitioners do not take up a diverse range of roles from the typology depending on the circumstances of their work (Rudd, 2015; Saarela, 2019). Other expert communities also have a strong preference for the role of pure scientist. Still, their members are compelled by the complex nature of their research focus to work with external actors to support decision making. The fusion community is required to do the same, primarily to support the construction of ITER, but those practitioners who engage with external actors tend to do it full-time. Only a few cases of fusion practitioners working partly on research and partly on the interface were reported, which is unusual compared to other expert communities.

One point where fusion practitioners had in common with their colleagues from other disciplines was the fact that they also appreciated the importance and the possible benefits of the science-policy interface. Still, because of the division within the community between those who work on fusion development and those who work on the interface, the physicists and engineers who participated did not regard the interface as something they should participate in. They appeared to be indifferent to the interface and regard it as a task for managers and communicators.

In summary, on one side the literature has revealed that scientists from multiple disciplines would ideally pursue pure research, but accept the science-policy interface as a part of their work. On the other side stand fusion scientists, who are still oriented towards pure research and leave the full-time managing of the interface to some of their colleagues, not all of whom are former scientists. The launch of ITER was said to have provided a first input to change, but the predominance of pure research and top-down communication have only marginally been affected. The interviewees tend to explain this state of things in terms of the pressing need for research to make fusion viable. Fusion is highly complex, it requires extremely specialised research, and even with that it will take decades to be made available. Even though the interface brings benefits to fusion research, engaging in basic research is still considered the most important activity for the fusion community.

Explaining the state of the science-policy interface of fusion in terms of the specific needs of fusion development makes for a convincing hypothesis, but it should not be accepted uncritically. What this first insight into the science-policy interface of fusion revealed is that the fusion community still adheres to the linear model, which has long been the standard of governing energy transitions. In spite of being subject to demands for more openness like the rest of science, fusion practitioners managed to keep their focus on pure research. They might be able to do so because of the special needs of their technology, as the participants defend, or maybe they are the proof that the linear model has all but disappeared among energy experts. Whatever the explanation, inquiring on the reason why the interface of fusion works in a specific way goes much beyond the scope of this thesis and its data. The insights that could be gathered from fusion practitioners are already quite rich. Such results answered the two questions of this thesis, but they left several black spots and open questions as well that might provide some inspiration for further research.

Thus, it will be the next concluding chapter to recapitulate the work done in this thesis and elaborate on how its results can inform the existing literature and inspire further research.

5. Conclusion

5.1 Summary of the thesis

In a global context where energy is undergoing a historic transition to lower its emissions, new energy technologies have become the object of complex problems as technical issues are coupled with a lack of public acceptance. When complex problems arise, the science-policy interface is usually advanced to facilitate decisions by offering an arena where scientists inform decisions and foster public acceptance while avoiding the politicisation of science and the scientification of politics. In the case of energy transitions, though, the science-policy interface does not feature among the common solutions to complexity. While the causes of that are still to be researched, the focus of the literature on the public acceptance of energy technologies lies exclusively with the public, politicians, and the media. What is missing is the point of view of the other side of the interface, i.e. energy experts, who play a crucial role in providing the technical knowledge to inform political decisions.

This thesis has tried to shift the focus by highlighting the perspective of energy experts on the science-policy interface. It has done so by choosing as a case study a technology that simultaneously enjoys a high level of technical uncertainty and an even higher degree of instability when it comes to public acceptance: nuclear fusion.

The thesis asked how the community of fusion experts perceives the science-policy interface and their role in it. This was done through fourteen interviews with fusion practitioners belonging to several branches of fusion development, from physics and engineering to management and communication. The interviews were then interpreted in the light of the Pielke-Turnhout typology, which classifies the different roles experts may take in the science-policy interface.

The results show that the fusion community interfaces with external actors mainly through one-way scientific communication. This linear approach has been the standard of the input of energy experts to policy so far, and the fusion community seems not to have departed from it. As in most scientific disciplines, the science-policy interface of fusion is dominated by Pielke's ideal-type of *pure researchers*. Still, a remarkable difference of the fusion community compared to other scientific communities is the clear distinction between pure researchers and other roles, such as science arbiters and issue advocates. Unlike experts in other fields, fusion practitioners do not seem to take up different roles depending on the necessities of their work. They are generally aware of the state of public acceptance and its importance for the development of fusion. However, there is a consensus that only managers and communicators should take part in the interface. Fusion professionals from different backgrounds generally agree that no effort should be asked of fusion researchers to engage in the interface until fusion reactors become a tangible technology. ITER has already set in motion several changes by opening the fusion community to communication, lobbying, and cooperation. In time, they said, this will bring fusion researchers to engage in the interface and work on public acceptance.

The specific characteristics of the science-policy interface of fusion could reveal a different attitude among fusion experts as a whole compared to experts in other fields. What marks the difference is not the approach to the science-policy interface, which has long been the standard among energy experts. Instead, it is the distance of fusion physicists and engineers from the science-policy interface, which is left to a little part of their peer community. Since the scope of the science-policy interface is to bring experts and non-experts at the same table, the creation of professional mediators between the two opens up new questions. Whether such a division of roles is part of the transition from linear science to other interface modes or whether it represents a new approach on its own is not clear from the literature.

5.2 Limitations of the research

If confirmed by further research, the results of this thesis could show that fusion experts do have a more indirect approach to the science-policy interface than other expert communities. However, generalising such results to the entire fusion community, or energy experts as a whole, can be highly contentious. Generally speaking, the research for this thesis suffers from some limitations that discourage generalisation.

Firstly, this thesis is the first exploratory research in the field of the science-policy interface from the point of view of energy experts. As a result, while being firmly grounded in the literature on the science-policy interface, it can refer to no similar studies, either in fusion or other energy sectors. Therefore, it would be premature to generalise its results.

A second limitation of this thesis is the sample of interviewees that have participated in the research, who may not be representative of the fusion community or energy experts. There are several flaws, from the self-selection of respondents to the gender imbalance among interviewees. As a result, it is impossible to determine how many voices and points of view that would have mattered for the thesis have been missed. Such flaws are inherent in choosing interviews as a data collection method. While being acceptable for the standards of qualitative research, they do hinder any generalisation effort, nonetheless.

Lastly, it cannot be excluded that the results obtained on the science-policy interface of fusion might be strongly tied to the unique characteristics of fusion development. Unlike most energy technologies, nuclear fusion is still under development, and it is expected that it will still be for the next three decades. This feature was considered from the beginning, and it strongly re-emerged in several interviews as a logical cause of the attitude of the fusion community towards public acceptance. Once again, a much stronger literature would be required to understand whether working on a technology under development might change the attitude of the expert community regarding public acceptance. Given the lack of other empirical studies on energy experts working on available technologies, an analysis of this point could not be part of this thesis, providing a further obstacle to generalisation.

5.3 Suggestions for further research

Overall, the scope of this thesis is not to provide definitive and generalisable conclusions on the role of energy experts in the science-policy interface. Rather, it is to stimulate the existing literature to broaden its research range to the position of such experts in governing energy. Given the importance of energy transitions for the future of climate action and human development, further research is urgently needed to better understand how experts' roles interact with decision-making, public acceptance and other political processes.

In particular, the literature on energy transitions should further inquire on complexity, and the role experts play in overcoming it. This thesis has revealed that the fusion community adheres to a traditional attitude towards the science-policy interface, and fusion experts are less engaged in it than experts from other fields. Further empirical studies on the science-policy interface could reveal if that is the case for other energy expert communities. If such a substantial distance of energy experts from the interface were widespread, it might offer a new way to explain why the science-policy interface has not been deployed to foster public acceptance of energy technologies. On the contrary, if the fusion interface should prove unique, it might be interesting to enquire on the possible reason for that, such as the hypothesis that being a technology under development makes the difference.

As for the research on fusion acceptance, this thesis has provided the first insight into the functioning of the science-policy interface of fusion, but further enquiries would be needed. A general suggestion for further research is that public acceptance should not be analysed as a topic that is distinct from the fusion community. The role of experts is critical in shaping how a new technology such as fusion is framed by the public. By opening the way, this thesis aims to stimulate further research on how the attitude of the fusion community towards the science-policy interface impacts the acceptance of fusion.

5.4 Final words

In conclusion, this thesis has highlighted how critical it is to listen to the point of view of energy experts not only concerning the technical aspects of energy transitions, but also when public acceptance is being discussed. The contribution of scientific and technical disciplines is considered the key to fostering public acceptance and overcoming complex problems. However, whether and how such a contribution will be given is too often assumed by the literature through theoretical models. Such a deductive approach leaves experts as the only major participants in the science-policy interface whose voice remains largely unheard.

Empirical studies are an ideal instrument to obtain a complete picture of the experts' possible contribution to the interface. It is only by letting experts express their perspectives, opportunities, and challenges in contributing to complex decisions that the science-policy interface can be fully understood. In the context of energy transitions as a complex problem, such a need for empirical studies is particularly pressing for their future development. If complexity will be effectively addressed, energy transitions will be able to deliver the decarbonisation humanity needs to tackle climate change.

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Appendix A: interviews

Table 2. Research participants

Position	**Background**	**Organisation**	**Interview date**	**Interview duration**
Phd student	Nuclear physics	EUROfusion	19.03.2021	49:30 min.
Purchase Official	Logistics	Fusion for Energy	21.03.2021	44:24 min.
Communication Official	Communication	EUROfusion	25.03.2021	58:35 min.
Manager	Nuclear engineering	EUROfusion	25.03.2021	47:19 min.
Communication Official	Journalism	EUROfusion	28.03.2021	58:07 min.
Communication Official	Social Sciences	Fusion for Energy	29.03.2021	45:28 min.
Manager	Nuclear physics	EUROfusion	06.04.2021	63.52 min.
Post-doc researcher	Nuclear physics	TKU (EUROfusion)	07.04.2021	35:20 min.
Phd student	Nuclear engineering	ERM (EUROfusion)	09.04.2021	32:19 min.
Official	Nuclear engineering	EURATOM	06.04.2021	62:02 min.
Official	Nuclear physics	EURATOM	06.04.2021	62:02 min.
Trainee	Energy	EURATOM	06.04.2021	62:02 min.
Manager	Nuclear engineering	EUROfusion	11.04.2021	52:43 min.
Researcher	Nuclear engineering	ERM (EUROfusion)	13.04.2021	23:56 min.

Semi-structured Questionnaire

- What is your role in fusion development?
- What are the first words coming to your mind concerning fusion?
- What do you think the lay public knows about fusion at this stage?
- What do you think is the opinion or opinions of the public on fusion?

- Do you think public acceptance can affect fusion development?
- Do you ever interact with non-experts when you work on fusion?
    - Are there any challenges or opportunities in interacting with each of these actors?
- How does the fusion community provide expert knowledge on fusion to non-experts according to your experience?
    - What approaches and formats are used?
- Have you ever heard of research modes in which experts produce knowledge with non-experts?
- Do you think they could play a role in fusion development?
- Do you think interface activities are in line with the current job description of practitioners?
- Where does public acceptance stand among the priorities of the fusion community according to you?
- Have you got any final remarks?

Appendix B: Codes used for the analysis

Code	Code groups
Communication: formats	Knowledge sharing
Communication: issues	Knowledge sharing
Communication: knowledge provided	Knowledge sharing
Co-production: examples	Co-production
Engagement with the public	Co-production
Fusion community attitude	Participants conceptions
Impact of acceptance	Public acceptance
Individual fusion conception	Participants conceptions
Interface ideally	Fusion-society interface
Interface now	Fusion-society interface
Interface past	Fusion-society interface
Interface with: other	Interaction strength
Interface with: politics	Interaction strength
Interface with: public	Interaction strength
Interface: challenges	Fusion-society interface
Interface: no external interaction	Interaction strength
Interface: stakeholder	Interaction strength
Link with fission	Public acceptance
Public awareness	Public acceptance
Public opinion	Public acceptance