The Road to Infinite Clean Energy

Exploring scenarios for the European energy market and the future of the fusion value chain

Martin von Koch and Ludvig Thornberg

DIVISION OF INNOVATION | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

NOVATRON

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Abstract

The transition to sustainable energy sources is a critical challenge facing Europe as it aims to achieve net-zero greenhouse gas emissions by 2050. This master thesis explores the potential role of fusion energy in the future European energy market, focusing on Novatron Fusion Group's strategic positioning within this evolving landscape. The study uses a mixed methods approach, combining both qualitative interviews with quantitative analysis to determine how the fusion industry might develop until 2040. Through a stakeholder analysis the study identified 15 stakeholders within a possible fusion value chain. Among these stakeholders national efforts, private fusion producers, joint international efforts, suppliers of technology and fuel were deemed to be *key stakeholders*, essential for the success of fusion. Furthermore, the study identified 9 macro trends shaping the European energy market until 2040. Based on expert ratings of the trends, a scenario analysis was conducted, resulting in 4 scenarios with the two axis *level of geopolitical instability* and *level of increased and improved energy storage solutions*, showing a possible future of the European energy market. The scenarios showed several different opportunities for fusion to enter the European energy market and become part of the energy mix. The most favorable scenario for fusion energy was given when there is a high level of geopolitical instability and energy storage solutions have not reached significant breakthroughs, providing Novatron many different opportunities for their business. However, in other more unfavorable scenarios, Novatron may need to adapt both their customer base and their geographical presence to become competitive.

Keywords: *Fusion energy, Scenario analysis, Stakeholder analysis, European energy market, Value chain, Macro trends, Energy storage, Geopolitical instability*

Sammanfattning

Övergången till hållbara energikällor är en kritisk utmaning som Europa står inför när de strävar efter att uppnå netto nollutsläpp av växthusgaser till 2050. Denna masteruppsats utforskar fusionsenergins potentiella roll på den framtida europeiska energimarknaden, med fokus på Novatron Fusion Groups strategiska positionering inom detta föränderliga landskap. Studien använder en blandad metodansats som kombinerar både kvalitativa intervjuer och kvantitativ analys för att fastställa hur fusionsindustrin kan utvecklas fram till 2040. Genom en intressentanalys identifierade studien 15 intressenter inom en möjlig värdekedja för fusion. Bland dessa intressenter ansågs nationella insatser, privata fusionsproducenter, gemensamma internationella insatser, samt leverantörer av teknologi och bränsle vara *nyckelintressenter*, avgörande för fusionens framgång. Vidare identifierade studien 9 makrotrender som formar den europeiska energimarknaden fram till 2040. Baserat på experternas bedömningar av trenderna genomfördes en scenarioanalys, vilket resulterade i 4 scenarier i form av en 2x2 matris med de två axlarna *nivå av geopolitisk instabilitet* och *nivå av ökade och förbättrade energilagringslösningar*, som visar en möjlig framtid för den europeiska energimarknaden. Scenarierna visade flera olika möjligheter för fusion att komma in på den europeiska energimarknaden och bli en del av energimixen. Det mest gynnsamma scenariot för fusionsenergi uppstod när det finns en hög nivå av geopolitisk instabilitet och då energilagringslösningar inte har nått betydande genombrott, vilket ger Novatron många olika möjligheter för deras verksamhet. Däremot, i andra mer ogynnsamma scenarier, kan Novatron behöva anpassa både sin kundbas och sin geografiska närvaro för att bli konkurrenskraftig.

Nyckelord: *Fusionsenergi, Scenarioanalys, Intressentanalys, Europeiska energimarknaden, Värdekedja, Makrotrender, Energilagring, Geopolitisk instabilitet*

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Firstly, we would like to express a big thanks to our incredible supervisor Kajsa Ahlgren Ode at the division of Innovation at Lund University, for all the valuable guidance and support throughout this project. Secondly, we would like to express our warmest appreciation to our supervisor Philip von Sagebaden at Novatron Fusion Group. Our weekly discussions have been enjoyable and your input has been a great contribution to this project. We would also like to thank the rest of the Novatron team for an amazing collaboration on such an interesting topic and for participating in our workshop.

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Lund, May 2024

Ludvig Thornberg and Martin von Koch

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List of Acronyms and Abbreviations

MeV	Mega electron volt
LCOE	Levelized cost of electricity
TSO	Transmission system operator
DSO	Distribution system operator

1 Introduction

The introduction chapter provides the background, purpose, and scope of the thesis. Furthermore, the research questions are presented and the deliverables and delimitations of the project are outlined.

1.1 Background

Society relies strongly on energy for everything from transportation to charging your phone. While primary energy consumption is steadily increasing (primary energy is the energy that is extracted from nature without being subjected to any forms of human transforms), the need for clean energy (energy that is not created from fossil fuels) in the future is apparent (Dunlap, 2021). In 2022, the primary energy consumption grew 1.1% compared to 2021, a 2.8% increase compared to pre-covid levels. Fossil fuels are still a large part of the global energy production. About 80% of the primary energy produced in 2022 came from oil, coal and natural gas (Energy Institute, 2023). However, the supply of fossil fuels is not endless, current estimates suggest that oil and natural gas have a lifetime of about 50 years while coal supplies may last well into the 22nd-century. (Dunlap, 2021). Furthermore, the combustion of fossil fuels contributes to environmental problems, one of the more pressing concerns being global warming. During 2022, CO2 emissions reached a record high of 39.3 billion tonnes (Energy Institute, 2023). Substitutes of fossil fuels include renewable energy sources such as solar, wind, hydro, geothermal and other forms of renewable energy. Renewables are becoming more prominent and they accounted for about 14% of primary energy production globally, a 14% increase from the previous year when excluding hydro (Energy Institute, 2023). While renewables are a great substitute for fossil fuels, they are still quite inconsistent and can highly depend on the season (solar produces more energy during summer months for example). Another alternative to fossil fuels is nuclear energy which accounted for about 5% of primary energy production in 2022, a 4.4% decrease since 2021 (Energy Institute, 2023). While the current nuclear energy provides a consistent source of power in the form of fission energy (the splitting of atoms), it comes with a few concerns such as reactor security and disposal of nuclear waste (Dunlap, 2021).

Another nuclear alternative is fusion power, which is often referred to as the safe alternative to fission power (Dunlap, 2021). Fusion is the merging of light elements, such as hydrogen isotopes, to create heavier elements, such as helium, releasing energy in the process. It is the same reaction that occurs in the sun, providing the earth with the energy to sustain life. A lot of energy in the form of heat and pressure is required to make the fusion reaction possible. These conditions can be found in the center of the sun but are difficult to recreate on earth (Chatzis, Barbarino, 2021). A lot of research has been conducted into the different ways to produce fusion energy and one of the more promising alternatives is magnetically confined fusion which uses magnets to keep the plasma, a mixture of high energy hydrogen isotopes which acts as the fuel for the reaction, in place (Dunlap, 2021).

Fusion energy might not only be a safe alternative to fission energy. It might also become an economically viable alternative to other sources of energy, even reaching the most cost-effective source of clean energy by 2050 (Dietz et al., 2022). Interest in fusion energy has recently surged and several private companies have joined multi-national fusion projects in the race for fusion energy. Since 1992 about 40 companies have been founded worldwide, where half believe that fusion power will be delivered to the energy grid during the 2030s (Fusion Industry Association, 2023a). This increase in privately funded and developed fusion projects, in combination with new technology and better computer simulations, indicate a turning point for fusion power and could accelerate the development of commercially viable fusion energy (Dietz et al., 2022). During recent years a laboratory in the US achieved a net positive energy output twice, meaning the fusion reaction provided more energy than was put into it. This is a major breakthrough but there is still a long way to go to harness fusion energy for commercial use (The Guardian, 2023).

One company that has high ambitions for commercial fusion is Novatron Fusion Group. Founded in 2019, Novatron is a Swedish company that aims to deliver commercial fusion power to the grid in the next decade (Novatron Fusion Group, 2024a). They intend to use a mirror machine, a kind of fusion reactor, and by utilizing symmetry they aim to generate a stable magnetic confinement for the plasma with a less complex design compared to other reactors, thus minimizing costs. The stable magnetic confinement provides the possibility of a continuous output of energy, compared to other reactors that might use a start-and-stop approach, making it easier to add fuel and remove by-products during the reaction. (Novatron Fusion Group, 2024b)

For Novatron to be able to successfully penetrate the European energy market it is essential to understand the importance of stakeholders along the fusion value chain and the development of the European energy market. During 2022 the European energy market had a surge in energy prices as a result of environmental factors, limiting supply of natural gas and low nuclear output in France (Schülde et al., 2023). At the same time Europe is transitioning to clean energy and is looking to have net-zero greenhouse gas emissions by 2050 as a part of the EU Green Deal (European Commission, n.d). To understand future trends in the European energy market and the potential development of fusion energy, a scenario building and stakeholder analysis can be conducted. Scenario building constructs possible future market conditions, while stakeholder analysis identifies key players within the fusion value chain. By conducting both analyses, one can categorize these stakeholders and discuss how they, along with Novatron Fusion Group, might navigate and position themselves in the future energy market based on the created scenarios.

1.2 Purpose

The purpose of the project is to identify and categorize stakeholders in a potential fusion value chain, create future scenarios for the European energy market in 2040, understand the implications each scenario has on fusion energy and form recommendations for how Novatron Fusion Group can navigate effectively within each scenario.

1.2.1 Research questions

In order to assess the purpose, three research questions were formulated:

1. What distinct categories of stakeholders does a potential fusion value chain consist of?
2. What scenarios for the European energy market in 2040 can be created based on identified macro trends?
3. What implications do each scenario have on fusion energy and the identified stakeholders?

1.2.2 Deliverables

The project will provide an overview of the key stakeholders within the fusion industry network today and their development until 2040. Moreover, a scenario analysis of the European energy market in 2040 will be created, including an in-depth discussion on the implications each scenario has on fusion energy. The project's deliverables will include a final report, a summarizing article, a comprehensive PowerPoint of the project, and an oral presentation held at the Faculty of Engineering at Lund University during the spring of 2024.

1.3 Delimitations

This master thesis aims to examine the European energy market and how it might develop in the coming 15-20 years. Therefore the rest of the world outside the EU is not taken into consideration and the macro trends identified only apply for the European energy market. Thus the findings of this report can not be applied for any non-EU energy market.

1.4 Outline of the thesis

Chapter 1: Introduction

The introduction chapter provides the background, purpose, and scope of the thesis. Furthermore, the research questions are presented and the deliverables and delimitations of the project are outlined.

Chapter 2: Methodology

In the second chapter the methodological framework of the study is presented. It explains the research strategy, research design and how the data is collected and analyzed. Moreover, the project's work process and trustworthiness is illustrated.

Chapter 3: Literature review

The literature review gives an overview of the European energy market and the state of fusion energy today. Furthermore, current published literature is examined and presented. This chapter sets the context for the following chapters.

Chapter 4: The fusion value chain

This chapter examines and, through a stakeholder analysis, categorizes the stakeholders in a proposed fusion energy value chain. It evaluates the current significance of these categories of stakeholders and how they might develop up until 2040.

Chapter 5: Development of the European energy market up until 2040

This chapter explores the evolution of the European energy market up until 2040. It investigates how the mix of energy sources might develop and identifies key macro trends that influence this development.

Chapter 6: Scenarios for the European energy market in 2040

In this chapter, the two macro trends most suited to serve as the basis for the scenario analysis are selected to create scenarios for the European energy market in 2040. Moreover, each scenario's implications on fusion energy is evaluated.

Chapter 7: Discussion

This chapter discusses the contributions of the findings in the study. It aims to explain the effect each energy scenario has on the stakeholders in the fusion value chain and provides recommendations for how Novatron Fusion Group can adapt its business accordingly. Moreover, the trustworthiness of the study as well as suggestions for future research is presented.

Chapter 8: Conclusions

The final chapter concludes the findings of the study and answers the research questions presented in chapter 1.

2 Methodology

In the second chapter the methodological framework of the study is presented. It explains the research strategy, research design and how the data is collected and analyzed. Moreover, the project's work process and trustworthiness is illustrated.

2.1 Research strategy

Höst, Regnell & Runeson (2006) describe a research project as being either descriptive, exploratory, explanatory or problem solving. An explorative project aims to provide an in-depth explanation to a new topic (Höst et al., 2006). This thesis project is of an exploratory nature since it aims to categorize stakeholders, deliver a scenario analysis based on a set of macro trends and discuss strategies for the delivered scenarios.

According to Williams (2007) there are three common research approaches: quantitative, qualitative and mixed methods. Quantitative research involves a numeric or statistical approach to the research design and is appropriate when the data used in the research is numerical. Qualitative research is a holistic approach that involves discovery and is appropriate to use when the data is of a textural nature (Williams, 2007). To be able to prioritize between stakeholders and trends while also including relevant insights to why a certain prioritization is made, a mixed methods approach is used in the project. The mixed method approach is, according to Johnson & Onwuegbuzie (2004), a natural complement to traditional qualitative and quantitative research, an important aspect is its use of several methods and different approaches (Johnson, Onwuegbuzie, 2004).

Malhotra (2017) explains in "Strategies in Research" that there are four different research strategies: inductive-, deductive-, reproductive- and abductive research strategy. An abductive research strategy is used to construct theories that are derived from scientific language, meanings, and accounts in the context of everyday activities. It provides an understanding to why a certain problem or event occurs, rather than providing an explanation to the cause of the problem/event (Malhotra, 2017). In this study trends are identified with the help of a PESTEL framework and expert opinions. Furthermore, the study uses scenario analysis and a stakeholder analysis to investigate the development of fusion energy in the European energy market. Therefore, the study uses proven theory to investigate a topic, indicating an abductive research strategy.

2.2 Research design

Research design is, according to Leavy (2017), a structure or plan for your research. Johnson & Onwuegbuzie (2004) describe several designs for the mixed methods research approach. Designs that are across-stage usually include a qualitative phase and a quantitative phase. For example, one can collect qualitative data but do a quantitative analysis. There are also within-stage designs which could take the form of a questionnaire with open-ended questions (qualitative) and a rating scale (quantitative) (Johnson, Onwuegbuzie, 2004). This thesis project will use a within-stage design to extract qualitative answers using open-ended questions about both stakeholders and trends as well as quantitative data by ranking the mentioned trends and stakeholders on different criteria.

Baker (2017) describe three main research designs within quantitative research: experimental-, quasi-experimental- and descriptive design. A descriptive design collects information to develop theory or identify trends without manipulating any variables (Baker, 2017). In this thesis, a descriptive design was used to analyze the quantitative data and extract trends and relationships without manipulating variables.

Creswell et al. (2007) identify five main qualitative research designs: narrative research, case study, grounded theory, phenomenology, and participatory action research. Case studies are appropriate when the researcher has a case bounded by time or place to provide information (Creswell et al., 2007). Since the project focuses on fusion energy, its development on the European energy market and has a set time frame for the scenario analysis, a case study will be used to handle qualitative data.

2.3 Work process

An overview of the master thesis is presented in figure 1, showing the flow of the work process and how the different sections of the project were integrated. The number in each column represents its corresponding chapter in the project report.

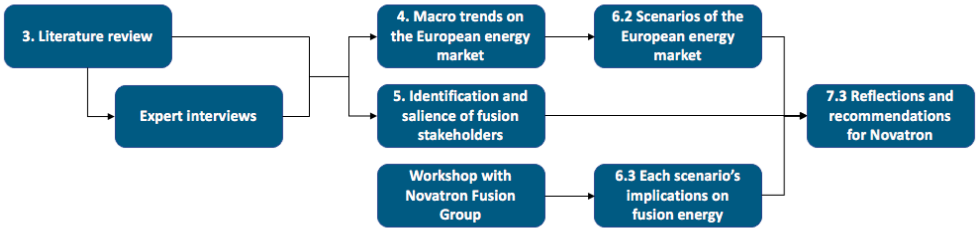

Figure 1: The work process of the master thesis

2.4 Data collection

According to Denscombe (2010), there are four main research methods for qualitative data: questionnaires, interviews, documents, and observations. This thesis utilizes documents and interviews. Initially, a literature review of the studied area was conducted by gathering information from various documents. Following this, semi-structured interviews were carried out. In interviews with energy experts, macro trends and their impact on the future of the European energy market were explored. Each trend was rated quantitatively for the scenario analysis. In interviews with fusion experts, the fusion value chain was mapped and the individual stakeholders discussed and rated quantitatively for the stakeholder analysis.

2.4.1 Literature review

Denscombe (2010) highlight that an important part of a project report is to review material and information that already exists within the field of study. The research that was conducted in the project should build upon previous knowledge rather than duplicate already existing work. It should be clear how the information that is gathered relates to the previous research (Höst et al., 2006).

The literature review was an iterative process involving different activities that are alternated. These activities included determining key search words, conducting searches and constraining selection of data. Initially, the focus of the literature review was to gain a comprehensive understanding of the field of study. Later on, as the research questions became increasingly clear, a more narrow approach of reviewing literature was carried out. Upon reaching the results, it was crucial to revisit and evaluate the findings in relation to the existing research (Höst et al. 2006).

In this project the literature review was two-fold. Firstly, it aimed to provide an in-depth understanding of fusion as a potential energy source. This involved grasping how the fusion reaction works, identifying its relevant costs, and assessing how far the development of fusion energy has come today, exploring different types of fusion reactors and their underlying technologies. Moreover, to understand how a potential fusion value chain might look, it was essential to gather information on what steps there are in the fusion energy process and what type of actor might be responsible for each step. This search was carried out by gathering publicly available information, preferably from peer-reviewed academic journals and books. However, as the commercial fusion industry has not yet been established, information had to be complemented from published reports and articles. The findings of this review can be found in chapter 3.2.

The second part of the review focused on understanding the current state of the European energy market and exploring potential future scenarios for the market. Information gathered to depict the European energy market today was largely quantitative and was obtained from governmental organization's statistical publications. To explore future scenarios, a combination of academic research and reports from energy related organizations was utilized. The findings of this review can be found in chapter 3.1.

Search engines used for this literature review included LUBsearch and Google Scholar. Key search words were "stakeholders", "suppliers", "fusion industry", "fusion reaction", "fusion reactors", "cost of fusion", "energy sources", "energy consumption", "infrastructure", "energy production", "available energy", "scenario analysis", "energy scenarios Europe" "European energy market".

2.4.2 Interviews

In this project, the main method for collecting primary data was to conduct expert interviews. Interviews are an effective data collection method when the topic is complex and subtle and the researcher needs to gain insights into people's opinions, feelings and experiences (Denscombe, 2010). Interviews typically take three formats, being structured, semi-structured or unstructured, depending how structured and formal the interview is. (Denscombe, 2010).

In this thesis, interviews were conducted within two topic-areas. The first topic-area involved the fusion value chain, while the second topic-area focused on macro trends likely to impact the European energy market until 2040. The interview guide for both topic-areas can be found in Appendix A. Both topic-areas explored markets not yet in existence, instead occurring in a future setting. Therefore, qualitative data, reliant on people's opinions and feelings was suitable, making interviews a fitting research method. Moreover, a semi-structured interview format was optimal for both topic-areas. The interview structure contained the same core questions for all interviewees, yet certain questions remained open-ended, prompting experts to elaborate on the topics themselves.

For the energy interviews, the primary objective was to examine how the European energy market might develop in the future. This resulted in two main sections of the energy interviews. The first section involved examining macro trends affecting the European energy market up until 2040. In the process of identifying key drivers to a specific change, the PESTEL analysis framework can be used to uncover issues, and is an effective model for ensuring exhaustiveness in the data collection. The framework examines six macro-environmental factors: political, economic, social, technological, ecological and legal (Whittington et al., 2010). In the energy interviews, the experts were initially asked to provide macro trends they believed would impact the energy market the most. Subsequently, the researchers employed the PESTEL framework to prompt experts to identify further trends within each respective PESTEL factor. This approach made it more likely that the experts considered every possible trend that could potentially have an impact on the European energy landscape. The experts were then asked to rate each trend they provided on a scale of 1-7, alongside the trends that were previously identified in the literature review, on their potential impact on the European energy market and how certain they are that the trend would be realized. Regarding the rating on level of impact, 1 represented "no/very little impact" spanning to 7 representing "extremely high impact. For the rating on level of certainty, 1 indicated "highly uncertain" and 7 "highly certain". To achieve an appropriate amount of steps, as well as a neutral option, the rating scale was chosen.

The second section of the energy interviews involved asking the energy experts to predict how each energy source might develop up until 2040, and the driving factors behind it. The discussion was guided by four main driving factors that were identified in the literature review:

- Cost
- Development of technology

- Resource availability
- Environmental impact

Cost refers to the cost of producing the energy with the specific energy source. Technological development refers to innovations that improve the efficiency of the energy source. Resource availability means to which extent the energy can be physically produced. Lastly environmental impact highlights the effects of energy production on the environment, mainly in terms of carbon dioxide emissions and effect on the local surrounding.

For the fusion interviews, the experts were firstly asked about if they believe fusion will become a viable option in 2040. They were also asked about fusion's main costs, challenges and benefits. The experts were then asked to identify the stakeholders they believed were most important for the fusion value chain once fusion energy is commercially available. They were then presented with the fusion industry's value chain obtained from the literature review and asked to rate each stakeholder's level of power and interest in the success of fusion as an energy source on a scale of 1-7. In this rating 1 indicated no/very little power/interest and 7 indicated extremely high power/interest. They were also asked how each stakeholder would develop until 2040 and if their rating would change in this time.

The selection of the experts to interview was an important aspect of the credibility of the gathered information. When research is primarily qualitative and requires specific knowledge from interviewees, a purposive sampling method is fitting. In this method, the researchers identify the information needed and seek out experts that are willing to participate and possess the knowledge to provide the necessary information (Etikan, 2016). For the fusion interviews, the experts had various backgrounds being either investors, in academia, or working at joint international efforts within the fusion industry. In the European energy segment, the interviewees consisted of university professors conducting research within the energy field, future studies experts and professionals working in energy related industries. A total of approximately 30 experts were contacted. The researchers aimed at contacting experts in various European countries. However, nine out of the ten experts interviewed were located in Sweden, since these experts responded to a much higher extent. The researchers were also unable to schedule with experts with political backgrounds, both in Sweden and at the EU level. These people either did not respond to the interview invitation or answered that they were too busy to participate. See table 1 for the complete list of experts that were interviewed.

Table 1: List of experts interviewed

Name	***Organization***	***Role***	***Relevance of being interviewed***	***Topic-area***
Karin Ericsson	Lund University	University professor and study director within environmental and energy systems	Over 20 years of research experience in environmental and energy systems.	Energy
Erik Herngren	Kairos Future	Senior Partner, Government, NGOs and Built Environment	Over 30 years of experience of conducting trend analysis and scenario planning for various sectors.	Energy
Lars Nilsson	Lund University	University professor within environmental and energy systems	Worked as a researcher in the field of energy systems analysis, and energy and climate policy analysis for more than 25 years.	Energy
André Månberger	Lund University	University professor and senior researcher within environmental and energy systems	Conducts research on the connection between transitioning to more sustainable energy systems and security issues.	Energy
Andreas Regnell	Vattenfall	Senior Vice President and Head of Strategic Development	Spend the last 13 years conducting long term outlooks of the energy market.	Energy
Andreas Stubelius	Adect	Senior Consultant	20 years of experience from the energy sector, including business, company and strategy development.	Energy
Hannes Sonnsjö	Lund University	Doctoral student within environmental and energy systems	Conducts research within electricity grid regulation, energy transition, climate change, energy security, industrial competitiveness.	Energy
Klaus Mogensen	Copenhagen institute for future studies	Associated Partner	An experienced futurist focusing on how the role of scientific and technological advances will play on all aspects of future societies.	Fusion

Anna Åberg	Chalmers University of Technology	Senior researcher within Science, Technology, and Society	Historian of technology in the fields of energy and resource history, with a particular focus on fusion research.	Both
Stefan Östlund	KTH Royal Institute of Technology	Vice President, international relations	Has been a part of InnoEnergy since its creation and has sat on the board for 6 years. Also works academically at KTH.	Both
Pär Strand	Chalmers University of Technology	Professor, Department of Space, Earth and Environment, Chalmers University of Technology	Has long experience with plasma physics. Has been modeling and simulating JET plasmas for over 30 years.	Fusion
Ingvar Eriksson	EIT InnoEnergy	Investment- and Asset Manager	Experience within tech and innovation investments. Is part of the board at Novatron	Fusion
Akko Maas	ITER	Science Coordinating Officer	Has been working for ITER, the biggest fusion initiative, for over 5 years.	Fusion

2.5 Data analysis

2.5.1 Stakeholder theory

To first be able to approach an analysis of stakeholders, one needs to define what a stakeholder is. A stakeholder is, as first introduced by Freeman 1984 (2010): "any group or individual who can affect or is affected by the achievement of the firm's objectives". However, Mitchell et al. (1997) write that this is one of the broadest definitions because it leaves the notion of stake and field of possible stakeholders open to include virtually anyone. In contrast, Clarkson (1995) provides a narrower definition of stakeholders as voluntary or involuntary risk-bearers, with voluntary risk bearers having invested some form of capital in the firm and involuntary risk-bearers being placed at risk by the firm's activities. The difference between the narrow view of stakeholders and the broader view is that the narrow view is based on the reality of limited resources, time and attention for managers to be dealing with the stakeholders in question, while the broader view captures the fact that a firm may impact or be impacted by a multitude of entities (Mitchell et al., 1997). Stakeholder theory, according to Mitchell et al. (1997), then attempts to form the question: "which groups are stakeholders deserving or requiring management attention, and which are not?" (p. 855). Essentially this approach focused on the identification and salience of stakeholders. In this thesis both internal and external interviews were conducted to get an understanding of who the stakeholders in a proposed fusion value chain could be.

2.5.2 Stakeholder salience

Since the identification of stakeholders can be quite broad, as Freeman's (2010) definition shows, there is value in narrowing the view. This thesis firstly identifies stakeholders in a potential fusion value chain in line with the definitions from Freeman (2010) and Clarkson (1995). The thesis then incorporates the power/interest matrix, which was presented by Johnson and Scholes (2008), as a form of salience. This method uses stakeholder mapping which "identifies stakeholder expectations and power and helps in understanding political priorities". Furthermore, it underlines two issues: how interested a stakeholder group is in shaping the direction and decisions of a project or organization according to their own expectations and whether the stakeholder has the power to do so (Johnson, Scholes, 2008). In this thesis, interviewees were asked to rate stakeholders' power and interest on a scale from 1 to 7. Here, 1 indicated no/very little interest or power, while 7 denoted extremely high interest or power. The responses could be utilized to compute a weighted average for each stakeholder and attribute. Subsequently, these averages could be graphically represented in a power/interest matrix to highlight variations among stakeholders. During the rating of stakeholders, interviewees were also given the opportunity to expand on the factors influencing their rating. This provided a rationale to the placement of stakeholders in the power/interest matrix. Furthermore, interviewees were asked about the development of the stakeholders up until 2040 and if their rating would change.

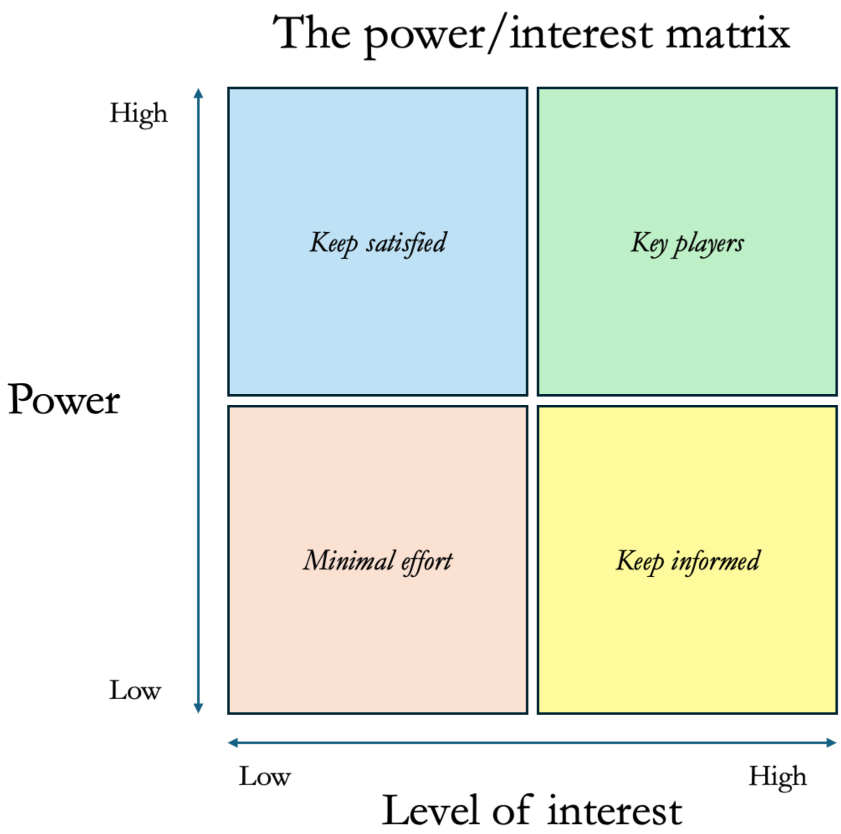

Figure 2: The power/interest matrix adapted from Johnson & Scholes (2008)

The power/interest matrix gives an indication to the type of relationship that the organization might establish with the stakeholder group in each quadrant. The acceptability from *key players* are of high priority since these players have a high power to influence, but are also very engaged in the organization's decision making. Stakeholders in the *keep satisfied* quadrant are also important. These stakeholders have a high power to affect decisions but might not be as involved as other stakeholders. However, they may move into the key players quadrant over time and affect decision making, which may not be desirable, hence they should be kept satisfied. The same situation but to a lesser extent can be applied to stakeholders in quadrant *keep informed*. The matrix indicates if the company's stakeholder governance aligns with reality and if a repositioning of stakeholder groups is required (Johnson, Scholes, 2008).

2.5.3 Scenario building

Scenario building is a strategic foresight method that is used to navigate complex socioeconomic and environmental challenges across various sectors and decision making-levels (Wiebe et al., 2018). It is used to understand how the future might turn out and to create strategies that are adaptable to different uncertainties (Carbonell et al., 2017). It involves creating representations of potential futures, known as scenarios, that addresses possible implications of certain events and actions that may occur in the future (Wiebe et al., 2018).

In line with the theory presented by Bishop, Hines and Collins (2007), in this thesis, the first step of the scenario building process was to identify key trends that would impact the future of the European energy market. These key trends can be in the form of uncertainties, implications and driving forces on a specific market. The trends were identified in the literature review and through interviews with relevant experts within the explored field. Once the trends were identified, they were assessed against a set of predefined criteria so that they can be prioritized, based on their level of uncertainty, as described by Bishop, Hines, and Collins (2007). In line with the theory presented by Sandal (2024), experts were used to rate each trend numerically in terms of uncertainty and potential impact. Expert judgments are usually the primary driver for scenario building and the quantification helps in putting a numerical value on the judgment (Bishop, Hines, Collins, 2007).

The next step was to understand how the identified trends interacted with and influenced one another (De Jouvenel, 2000). This resulted in four categories of trends: certain, dependent, influencing, and selected trends. Certain trends were trends rated certain enough to be expected to occur in each scenario. Dependent trends were trends that were highly affected by the realization of other trends. Influencing trends were trends that were not certain but did not have enough underlying information to be used as a basis for the scenario analysis. Selected trends were the trends that were not rated to be certain and have enough underlying information and impact on the European energy market to be selected as the basis for the scenario analysis. In accordance with the theory from Bishop, Hines and Collins (2007), these two trends were selected as axes in a 2x2 matrix, known as the GNG matrix. Within each axis, two cases were considered: one where the trend is realized and one where it is not. This created a 2x2 matrix that depicted four future scenarios based on the possible outcomes of the two trends. (Bishop et al., 2007). After the scenarios were created, the characteristics of each scenario was presented.

Following the creation of the European energy scenarios, a workshop was organized with four employees from Novatron Fusion Group to examine the implications each scenario has on fusion energy. The discussion centered around the following questions for each scenario:

- Do you agree with the reasoning for this scenario? If not, what would you change?
- What does this scenario mean for Novatron's business?
- How might this scenario affect key stakeholders which in turn may affect Novatron?
- What are the tipping points, defined as the thresholds of entering this scenario, that, once crossed, means Novatron will have to act?
- How likely is this scenario to occur?

2.5.4 Generative AI

During the course of this study, several generative AI tools have been used to assist the researchers. Primarily, two AI tools have been utilized: ChatGPT and Sana Labs AI assistant. These tools served two primary purposes. Firstly, the tools were used to brainstorm ideas in initial stages of the literature review. Chat GPT was used to brainstorm ideas on stakeholders in the fusion value chain and to find trends that impact the European energy market. These ideas served as inspiration to do further searches and find sources that provided a more detailed explanation. Secondly, both Chat GPT and the Sana Labs AI assistant were used to edit and rephrase text that the researchers produced. This helped in making the language more clear and consistent throughout the whole study.

2.6 Trustworthiness

According to Denscombe (2010) it is essential to demonstrate the credibility of the research. It needs to be shown that the findings of the study are based on practices widely regarded as bases of good research. One approach to evaluate the credibility of the research is to analyze the validity, reliability, generalisability and objectivity of the study.

Validity refers to the accuracy, precision of the data and how well it addresses the research questions (Denscombe, 2010). In the literature review of this thesis, peer reviewed sources were prioritized to the highest possible extent. The quantitative information was accessed from official EU-governmental websites and databases. All collected data were checked against multiple other independent sources to empower its validity. Furthermore, interviews were conducted exclusively with experts possessing relevant experience, and key findings, including identified macro trends, were discussed with multiple experts to mitigate bias.

The reliability implies the consistency and neutrality of the study, ensuring that it would provide the same results in a different occasion under similar conditions (Denscombe, 2010). In this thesis the methods used and decisions taken during the project were well documented and shown in the project report. The exact methodology of the research was described and illustrated in a detailed manner. Consequently, the thesis is considered to be open for audit and thereby possesses a reasonable level of reliability.

Generalisability implies that the findings from the research are applicable to other similar research areas rather than being unique to the particular studied case (Denscombe, 2010). This report enhanced generalizability by constructing scenarios not only specific to fusion energy, instead encompassing the broader European energy market. Each macro trend was examined in isolation from the context of fusion energy. Consequently, the findings are also insightful for the other energy sources currently in the European energy mix or emerging energy sources such as fusion energy. Likewise, the fusion value chain does not circulate around Novatron Fusion Group, and instead tries to capture the entire value chain of the fusion industry, making it insightful for all fusion stakeholders.

The fourth and final aspect of credibility is objectivity, which refers to the absence of bias introduced by the researcher conducting the study (Denscombe, 2010). To maintain objectivity in this thesis, the researcher approached the study with an open mind, taking aside personal values and beliefs when evaluating the data. Moreover, all primary data from the interviews, regardless if it fitted into the analysis, were taken into consideration.

3 Literature review

The literature review gives an overview of the European energy market and the state of fusion energy today. Furthermore, current published literature is examined and presented. This chapter sets the context for the following chapters.

3.1 The European Energy Market

3.1.1 The electrical energy value chain

To get an understanding of how the European energy market works and is interconnected, it is examined how electrical energy flows from where it is created to the end consumer. Figure 3 describes the electrical energy value chain. The electrical energy value chain includes the activities that are required for the production, distribution and consumption of electrical energy. There are five major steps in the process which different actors in the value chain are responsible for. These five include: fuel procurement, electricity generation, transmission, distribution and the end consumer. On a global scale, and particularly within Europe, the sectors responsible for generation, transmission and distribution have been vertically integrated due to economies of scale and the large investments that are required. (Bamber et al., 2014; European Commision, 2024a)

Figure 3: The electrical value chain. (Bamber et al., 2014)

The initial step of the process, fuel procurement, can be divided into three main categories: fossil fuels, nuclear energy and renewable energy sources. Within Europe, the fuel used to produce predominantly consists of renewable energy sources, including hydro, solar, wind and biofuels. (Bamber et al., 2014) The energy mix in Europe is further discussed in section 3.1.4. These fuels serve as inputs to various electricity-generating technologies. (Bamber et al., 2014)

The second step of the process is to generate electricity from the selected fuel. The generating technologies are very specific to the type of fuel they use. For instance, photovoltaic (PV) systems are commonly utilized for solar energy generation. These are often placed on rooftops, in fields or in building facades. The PV system consists of solar panels made up of many photovoltaic cells that are able to convert sunlight into electricity. In a wind turbine, the kinetic energy in the wind causes turbine blades to rotate around a rotor axis, which in turn rotates a generator that ultimately converts the mechanical energy to electrical energy. (Bamber et al., 2014)

The third step of the value chain is the transmission systems which serves as a link between the generation plants and the distribution systems. (Bamber et al., 2014) The transmission network consists of high voltage power lines that transfer the electricity to areas of demand. (EWEA, 2024) This network is structured as a grid designed to withstand multiple line failures simultaneously. Transmission system operators (TSOs) are responsible for managing this high-voltage grid. (Bamber et al., 2014) One example is Electricite de France SA (EDF) which is an integrated electricity provider that provides generation, transmission and distribution of electricity. (Global Data, 2024)

At some point, electricity needs to be delivered to homes, businesses and other customers. This is the responsibility of distribution system operators (DSOs), which manage local distribution networks (EWEA, 2024). Distribution systems are separated from transmission systems because it prevents small local failures from being widely transmitted. Additionally, the electricity that is being delivered to the end customer needs to be of lower voltage in order to be safe. The energy loss is higher when the electricity travels at lower voltages but because the power lines of the distribution network cover much smaller distances, the energy loss is reduced. (Bamber et al., 2014) EON is Europe's largest DSO with around 700 000 kilometers of electricity grids in nine European countries. (EON, 2024)

Finally, electricity reaches the end consumer, where it is utilized to power various electronic devices or converted into other energy forms such as heat or light. The end consumer can be private households, but also businesses, schools, industrial buildings and other entities. (Bamber et al., 2014)

3.1.2 Energy infrastructure in the EU

In order to adhere to energy policies and climate objectives, the EU and its member states work toward achieving a more integrated energy system. It is a high priority that all Europeans can access secure, affordable and clean energy. The EU actively supports a variety of cross-border energy infrastructure initiatives that are designed to generate, store and deliver energy efficiently. These projects interconnect the energy infrastructure of the member states, incorporate renewable energy sources and clean technologies into the EU's energy system, and reduce imports of energy from third-party countries (European Commission, 2024b; Eceee, 2023).

A central aspect of the integrated energy system is interconnectors - cross border cables that link together national power grids. This system alongside the shared market rules that the EU has set up creates the integrated European electricity market. This allows for electricity to flow freely over the continent in line with supply, demand and price signals. It was in 2022 the largest interconnected grid in the world with its around 600 million users connected by over more than 400 interconnectors. The interconnected system helps make the electricity supply secure, keeps costs down, and reduces the reliance on gas (Cremona, 2023).

3.1.3 Mix of energy sources

The energy that is available in the EU is the sum of the energy produced within the EU and the net energy imported from countries outside the EU. The net energy imported is the difference between the energy imported and the energy exported between the EU and the outside countries.

3.1.3.1 Gross available energy in the EU

Figure 4 illustrates the gross available energy in the EU sorted by energy fuel between 2013 and 2022. As the graph shows, oil and petroleum products have over time had and still in 2022 have the largest share of the available energy. Figure 5 shows the gross available energy in 2013 and 2022, highlighting that oil and petroleum products had the largest share at 37% of the total gross available energy in the EU in 2022. The largest increase between 2013 and 2022 is accounted by renewables and biofuels that increased from 13% to 18%, moving from the smallest energy fuel to third largest (Eurostat 2023a; Eurostat 2023b).

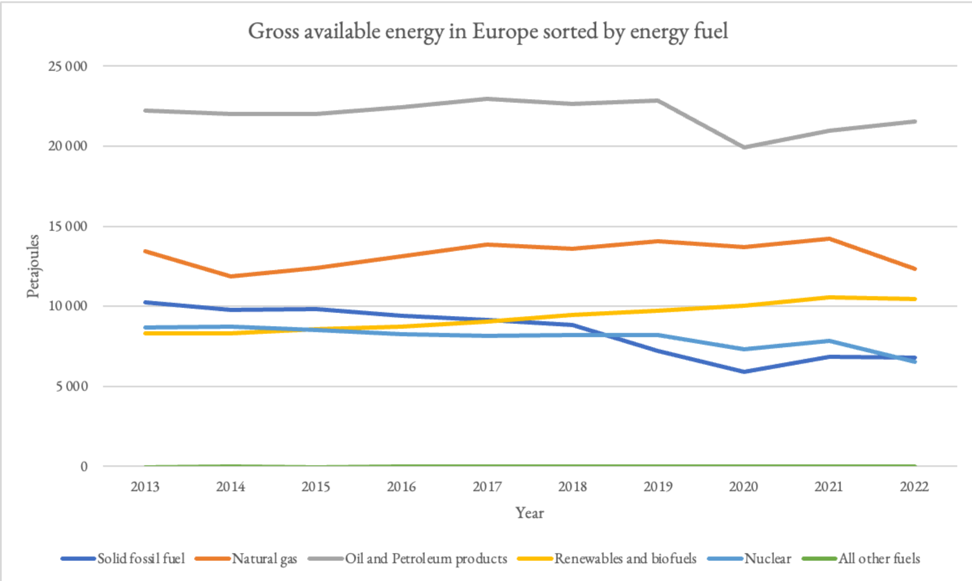

Figure 4: Gross available energy in the EU sorted by energy fuel from 2013-2022. (Eurostat 2024a)

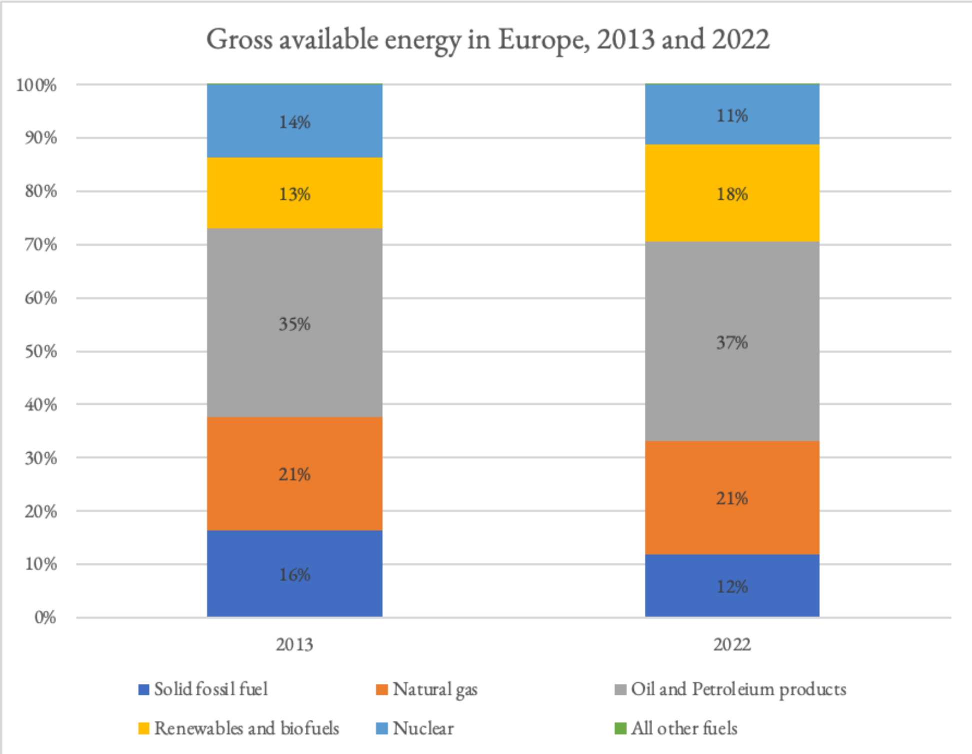

Figure 5: Gross available energy in the EU sorted by energy fuel in 2013 and 2022. (Eurostat 2024a)

3.1.3.2 Energy production in the EU

Figure 6 displays the energy production in the EU between 2013 and 2022. As the graph illustrates, the production of all energy fuels besides renewables and biofuels have decreased during the period, whereas renewables and biofuels have increased. Figure 7 shows the energy production for 2013 and 2022. In 2022 renewables and biofuels accounted for 43% of the total energy produced in the EU, nuclear had a share of 28%, solid fossil fuels 16%, natural gas 6%, oil and petroleum products 3% and all other fuels accounted for 3%. Renewables and biofuels together with nuclear make up 71% of the total energy produced in 2022 (Eurostat, 2023b).

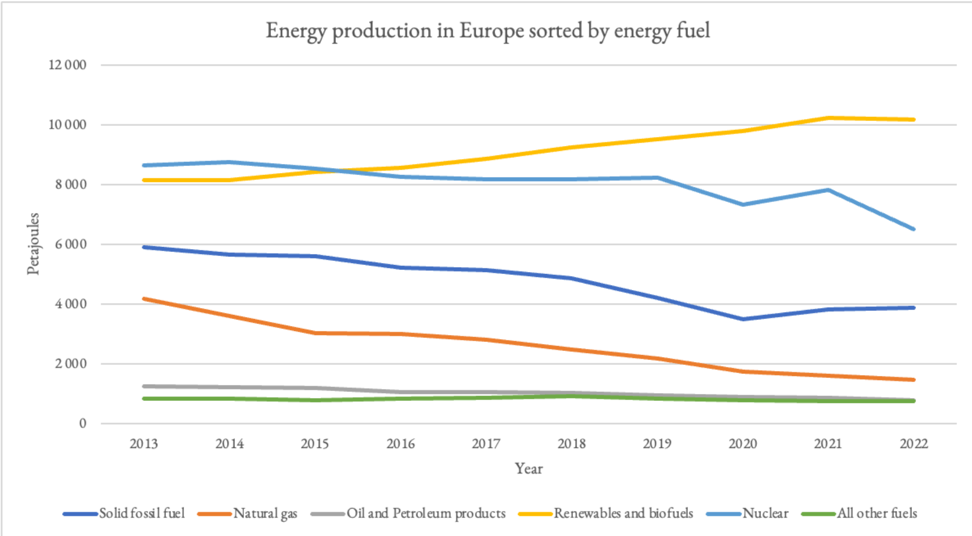

Figure 6: Energy production in the EU sorted by energy fuel from 2013-2022. (Eurostat, 2024b)

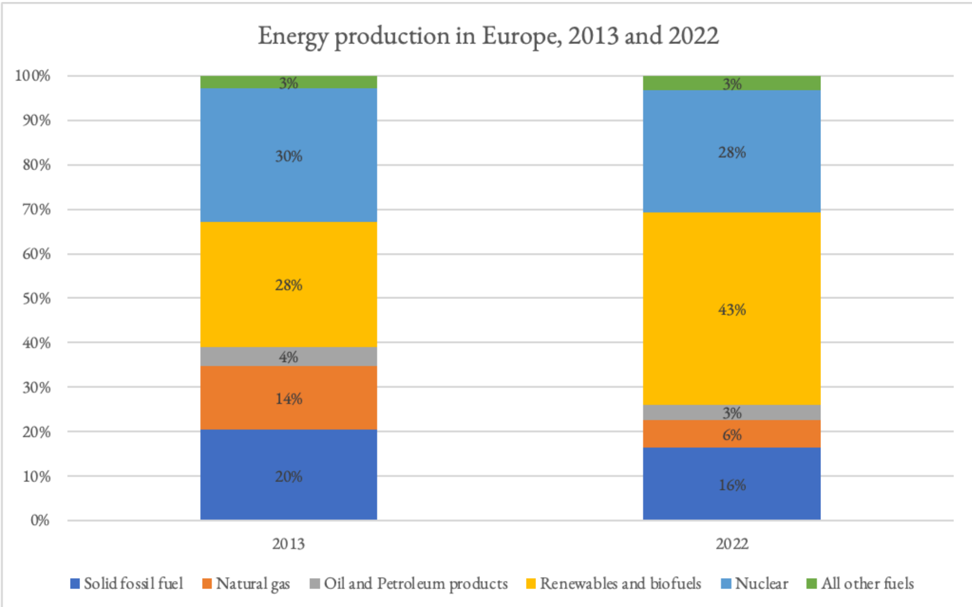

Figure 7: Energy production in the EU sorted by energy fuel in 2013 and 2022. (Eurostat, 2024b)

3.1.3.3 Net energy imports in the EU

Figure 8 illustrates the net energy imports within the EU categorized by energy source from 2013 to 2022. Net energy import is defined as the difference between imports and exports for each energy fuel. As the figure shows, oil and petroleum products exhibit the highest net energy imports. Throughout the 10-year span, this level has remained relatively constant, whereas the number for natural gas has increased during the period. Figure 9 displays the net energy imports in the EU in 2013 and 2022. In 2022 oil and petroleum accounted for 58% of the net energy imports, natural gas for 33%, solid fossil fuels 8% and all other fuels 1% (Eurostat 2023b).

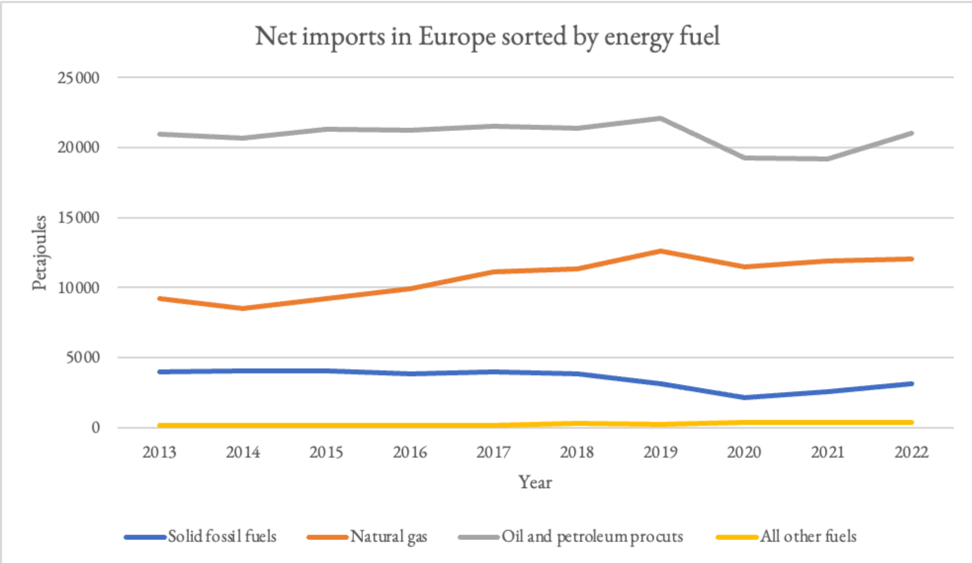

Figure 8: Net energy imports in the EU sorted by energy fuel from 2013-2022. (Eurostat, 2024c; Eurostat 2024d)

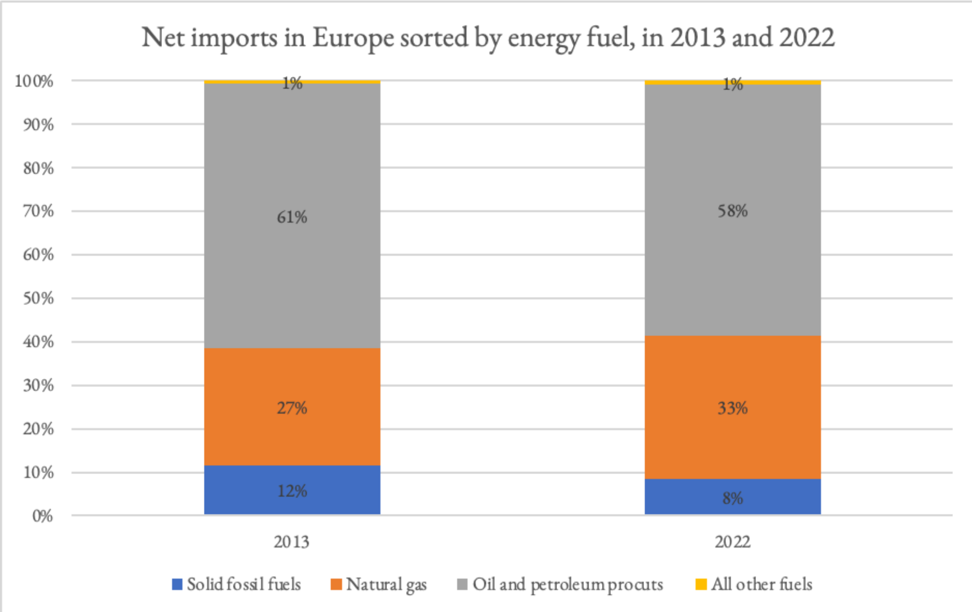

Figure 9: Net energy imports in the EU sorted by energy fuel in 2013 and 2022. (Eurostat, 2024c; Eurostat 2024d)

3.1.3.4 Share of energy production and net energy imports in EU

Figure 10 shows the total gross available energy in the EU split by energy production and net energy imports from 2013 to 2022. As the graph illustrates, the share of net import is slightly larger every year during the time period and was 61% of the gross available energy in 2022. (Eurostat 2023b)

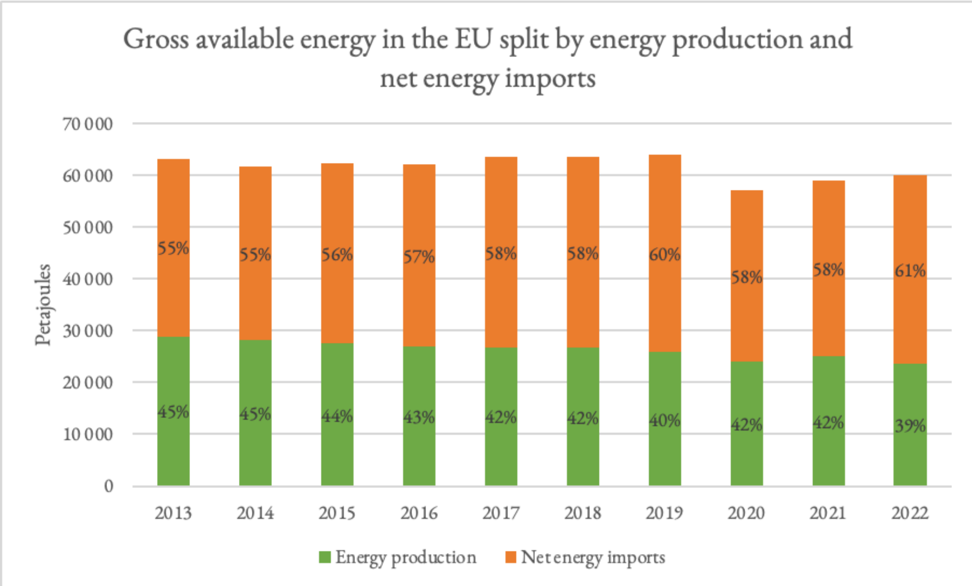

Figure 10: Gross available energy in the EU split by energy production and net energy imports

3.1.4 Mix of electricity sources

Figure 11 displays the electricity generation (total of 2 775 TWh) in the EU categorized by electricity source. As the figure shows, the share of renewable electricity sources (hydro, solar, wind) has grown significantly over the past 10 years. In 2023 renewable sources accounted for a record high share of over 40% of the total EU electricity mix, when including renewables in the category "other". Wind and solar energy are the main drivers for this increase and accounted in 2023 for a record high 27% of the EU electricity. Moreover, wind reached in 2023 the milestone of surpassing gas for the first time. (Ember, 2024)

During the same period the share of fossil fuels has decreased, driven by the reduction in coal usage. In 2023 fossil fuels accounted for less than a third of the EU's electricity generation. Between 2022 and 2023 fossil fuel generation fell with 209 TWH (-19%). The large fall can be explained by the rise of solar and wind generation which accounted for 43% of the drop. Decline in electricity demand accounted for 45% of the fall. The decline in electricity demand can be explained by the increase in electricity prices in 2022 following the energy crisis in Europe in 2021. (Fernandez Alvarez, 2023) However, given the rising electrification it is anticipated that this decrease in demand will not continue in the forthcoming years. The rest of the fall can be explained by hydro generations rebound after a significant drought in the year before. French nuclear generation also bounced back after multiple plants were out of service for a period of time. Figure 12 depicts the share of EU electricity generation categorized by source for the years 2013 and 2023. (Ember, 2024)

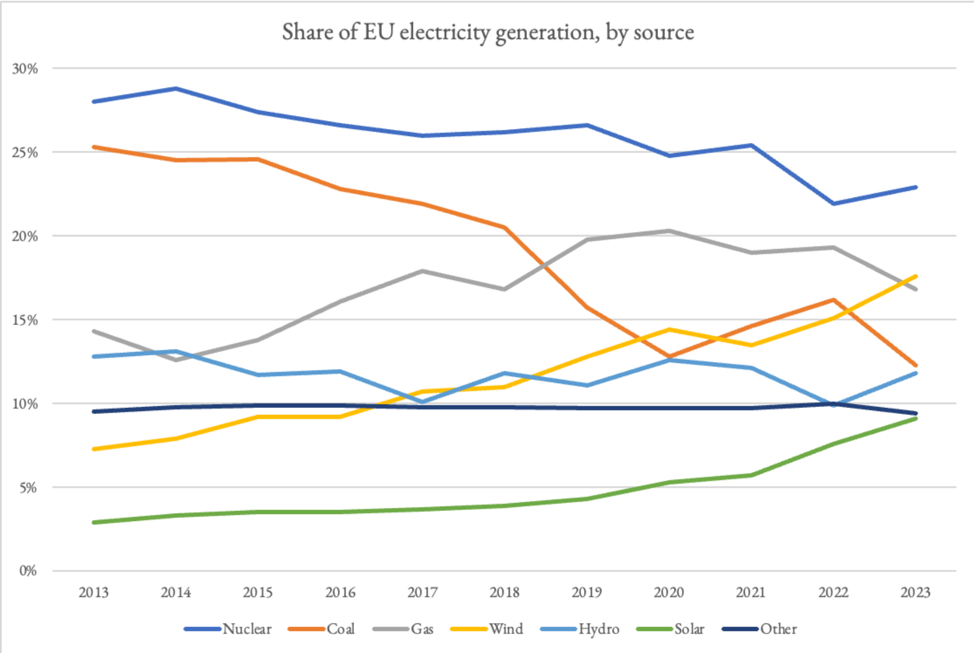

Figure 11: Share of EU electricity generation, by source. 'Other' includes bioenergy, other fossil and other renewables. (Ember, 2024)

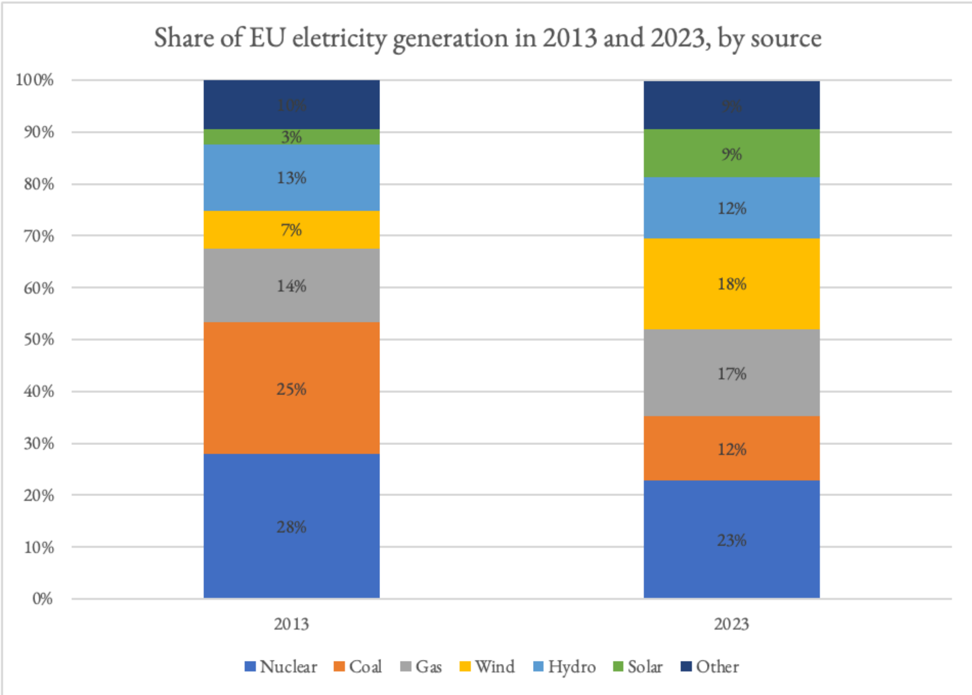

Figure 12: Share of EU electricity generation in 2013 and 2023, by source. 'Other' includes bioenergy, other fossil and other renewables. (Ember, 2024)

3.1.5 Final energy consumption

Final energy consumption is the total energy consumed by end-users, such as households or industries (Eurostat, 2018). Figure 13 shows the final energy consumption in the EU categorized by sector. As the figure illustrates the sectors transport, households and industries are the main main energy consumers in the EU. In 2022, 95% of the energy consumption within the transport sector was road transport, while domestic rail, air and water transport only accounted for about 2% of the energy consumption (Lapillonne et al., 2022). For households in 2021, space heating dominated accounting for 64% of energy consumption in the category. Water heating (15%) and lightning & electrical appliances (14%) were the two following subcategories (Eurostat, 2024f). In 2021 within the sector industry, the top five industrial sectors with highest final energy consumption were chemical and petrochemical industry (21.5% of the total final energy consumption in the EU's industry in 2021), the non-metallic minerals industry (14.1%), the paper, pulp, and printing industry (13.6%), food, beverages, and tobacco industry (11.6%) and the iron and steel sector (10.2%) (Eurostat, 2024g).

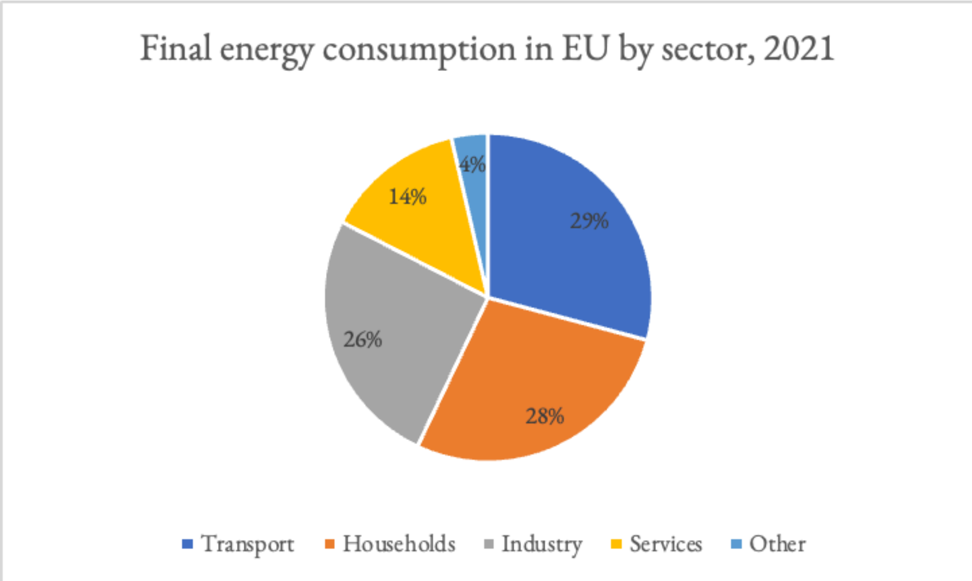

Figure 13: Final energy consumption in EU categorized by sector. (Eurostat, 2024e)

3.1.6 Geopolitical factors

There is a strong correlation between geopolitical risk (the potential for political events in different geographies to impact economic and operational outcomes) and the European electricity market. Through studying the development of electricity spot prices in Germany, France and Denmark alongside a geopolitical risk index between January 1, 2015 to January 1, 2023, it was found that the geopolitical risk index closely resembled the electricity prices. It was especially notable in 2022, where a substantial increase in geopolitical risk was followed by a record-breaking surge in electricity price volatility (Saadaoui, Jabeur, 2022; Caldara, Iacoviello, 2022).

One key impact that geopolitical risk has is that it causes supply disruptions. Political tensions or conflicts interrupt fuel supply or damage critical infrastructure which leads to electricity shortages which in turn increases electricity prices. Moreover, geopolitical risk can induce fluctuation in electricity demand, driven by changes in economic activity and consumer behavior. Additionally, currency fluctuations and investors sentiment towards the market can affect the price of imported and exported electricity between European countries (Saadaoui, Jabeur, 2022).

3.2 Fusion energy

Fusion energy has been known to humans ever since the 1920's when Arthur Eddington suggested that stars draw their energy from fusion of hydrogen into helium. The understanding of fusion energy continued with Hans Bethe's (1939) work "Energy production in stars" where Bethe introduced both the CNO-cycle (Carbon-Nitrogen-Oxygen cycle) and the proton-proton cycle, two of the main fusion reactions that generate energy in the cores of stars. Further research into fusion energy eventually resulted in the ambition to bring this source of energy to earth, with serious experimental work being conducted in the 1950's which resulted in the development of different types of fusion reactors (Dunlap, 2021; EUROfusion, 2024a). Dunlap (2021) writes in his paper "Energy from nuclear fusion" that fusion energy has been proposed to be an inexpensive and limitless source of energy without adverse environmental, safety and security concerns. However, fusion energy has proved to be one of humanity's greatest challenges and development time estimates for commercially viable fusion energy became longer and longer during the late 1900's. "Fusion is always 30 years away" is a famous phrase which stems from these delays (Takeda et al. 2023). In the following section a theoretical background to how the physics of a fusion reactor works and how the fusion energy landscape looks like today is presented.

3.2.1 Physical reaction

Fusion energy is the most common energy producing reaction in the universe and is what produces the power in stars (EUROfusion, 2024a). The energy from fusion reactions has its basis in Einstein's mass-energy relation,

$$E = mc^2 \tag{3.1}$$

where E is energy, m is mass and c is the speed of light. When combining atoms (fusion) or splitting atoms (fission) there can occur a change in mass. Then, according to the conservation of energy, there must be some energy added or released from the reaction by the following formula,

$$E = \Delta mc^2 \tag{3.2}$$

where Δm is the difference in total mass before and after the reaction (Dunlap, 2021). The energy released in a fission or fusion reaction is a direct result of the change in mass after the reaction which in turn is a consequence of the change in binding energy in the atom. The binding energy and the related strong force are explained further in appendix B. For the particles to undergo fusion, they need to be very close to each other. For this to be possible the particles need to have a lot of kinetic energy, which in other words means there needs to be incredibly high temperatures (around $2x10^7$ K) and high pressure, usually caused by gravitational forces. These conditions can generally be found in the core of stars but are difficult to replicate on earth (Dunlap, 2021; Fusion for Energy, 2024).

Since different elements have different binding energies some fusion reactions produce more energy than others. In the Sun, the most common energy producing reaction is the fusing of four hydrogen nuclei with one proton each (^1H) into one helium nucleus with two protons and two neutrons (^4He). The complete reaction is referred to as the proton-proton cycle or p-p 1 cycle. The whole cycle involves a series of reactions and produces a total energy of 26.7 MeV when including the annihilation between positrons and electrons (Dunlap, 2021; The Editors of Encyclopaedia Britannica, 2021). However, most serious fusion research centers around the d-t (deuterium-tritium) fusion reaction,

$$d + t \rightarrow {}^4He + n \qquad 17.6\,\mathrm{MeV} \tag{3.4}$$

where d is a deuteron (the ^2H nucleus), t is a triton (the ^3H nucleus) and n is a neutron (Dunlap, 2021). The reason for this reaction being used instead of the p-p 1 cycle, the most common reaction in the sun, is the fact that the p-p 1 cycle releases energy too slowly to be a viable source of energy on earth (Dunlap, 2021). Since the gravitational pressure found in the core of stars cannot be recreated on earth, the reaction occurs at temperatures of $2x10^8$ K (Fusion for energy, n.d). A problem with the d-t fusion reaction is that 80% of the energy produced is stored as kinetic energy in the neutron. This energy is hard to harness since the neutron is neutral and does not react with other charged particles. The released neutron can also cause materials in the reactor to become radioactive as well as lose its structural integrity (Dunlap, 2021). However, research is currently being made in using the neutrons to create tritium, this will be covered in section 3.2.3.

3.2.2 Fusion reactors

The interest for using the fusion reaction as a means of producing energy on earth started to grow in the 1940's. Through research during the 1950's, scientists from different parts of the world started to develop various methods of starting and containing a fusion reaction on earth, as a first step to producing energy. These methods can be described by two categories: magnetic- and inertial confinement fusion. In this thesis, more focus will be put on magnetically confined fusion (Dunlap, 2021).

Magnetically confined fusion started in the 1930's when William Harrison Bennet (1934) published a theoretical paper on what is now known as the pinch effect. The pinch phenomenon arises from an interaction between a current running through the plasma (a state of matter where atoms are stripped of their electrons due to the high temperature) and a magnetic field that the current produces. The current of particles are then pinched together by the magnetic field, increasing the pressure in the plasma to prompt a fusion reaction, as well as shielding the inner walls of the reactor from the extreme temperatures of the plasma. The pinch effect was used during post-world war II research into fusion energy and would eventually evolve into mirror machines, stellarators and tokamaks, the latter two being the most popular reactors today (Dunlap, 2021; Liley et al., 2023). For the interested reader, the reactors are explained in appendix C.

3.2.3 Technology required

3.2.3.1 Superconducting magnets

There are a lot of different components and technology needed to create a magnetic confinement fusion reactor. Clearly, to be able to confine the plasma one needs magnets that produce strong magnetic fields, concentrating the plasma and shielding the inner walls from contact. However, to be economically efficient for commercial use, Dunlap (2021) proposes in his paper "Energy from nuclear fusion" that a transition needs to be made to superconducting magnets that use less power to produce strong magnetic fields. However, to be able to achieve a superconducting effect, one needs superconductive material which is cooled to very low temperatures. To cool the superconductors one needs cryogens in the form of either liquid hydrogen for normal superconductors or liquid nitrogen for high temperature superconductors (Dunlap, 2021).

3.2.3.2 Heating of the plasma

Furthermore, to be able to heat the plasma to desired temperatures several methods are typically used. As mentioned in appendix C, ohmic heating is commonly used with the tokamak and is basically heat from resistance when a current is going through the plasma (Ongena, Koch, Wolf, et al., 2016). However, due to instabilities in the plasma when increasing the current, a complementary heating method must be used. A common alternative is neutral-beam injection. In a nutshell, this method of heating uses fast neutral particles that are injected into the plasma. The particles become ionized through collisions with other particles and transfer their energy to the plasma, raising its heat (Ongena, Koch, Wolf, et al.

2016). Another notable heating method is auxiliary heating. This method uses electromagnetic power to create oscillations of the plasma particles which can then transfer energy throughout the plasma through collisions between particles (Ongena, Koch, Wolf, et al. 2016)

3.2.3.3 Breeder blankets

As mentioned, most fusion projects center around the deuterium-tritium (d-t) reaction. Deuterium is a naturally occurring isotope of hydrogen but tritium is non-stable and radioactive and must be created artificially (Dunlap, 2021). There is currently around 20 kg of tritium in the world, currently produced as a by-product of fission reactors and used to increase the yield of nuclear weapons. A modest 1000 MW reactor would use 0.38 kg of tritium per day, therefore it would be beneficial if tritium could be created on site of the fusion reactor. Using equation (3.4) one can see that a product of the d-t reaction is a neutron. This neutron can be used to create tritium by the following reaction,

$$n + {}^{6}Li \rightarrow {}^{4}He + t \qquad (3.5)$$

where ^{6}Li is the nucleus of a lithium atom with 3 neutrons. To be able to create this reaction, a technology called a breeder blanket can be used. This technology will use the neutrons created through the fusion reaction to create more tritium to be used in future reactions. The technology is currently under development and will be tested through international projects such as ITER (Dunlap 2021).

3.2.3.4 Power plant

To be able to harness the energy produced from a fusion reactor and turn it into electricity a thermal power plant needs to be built in connection to the reactor. In a thermal power plant the energy released from the type of fuel utilized is used to heat water, turning it into steam. The fuel used to generate energy can be fossil fuels that undergo combustion, or nuclear fuels which undergo fission or fusion to generate energy (Sarkar, 2015). The high-pressure steam then enters a steam turbine and expands, reducing its pressure. This low-pressure steam can then be converted into water through condensation and recycled to the plant (Sarkar, 2015). The steam turbine is used to convert heat energy into mechanical work, generating electricity by spinning the turbine blades which in turn runs a generator (Sarkar, 2015; Student Energy, n.d.). Nuclear power plants can be adjusted to meet energy demands. This is done by limiting the amount of steam that goes through the turbine and could be used to meet both seasonal demand differences and short-term fluctuations in market prices (U.S. Department of Energy, 2020).

3.2.4 Cost

Entler, et al. (2018) writes in their paper Approximation of the economy of fusion energy that fusion energy has a high probability to become the cheapest and cleanest energy source since the end of this century for an unlimited time onwards. In their paper, they approximate the cost of building a nuclear power plant based on the fusion power plant model DEMO2, a conceptual design for a plant connected to the ITER tokamak reactor (EUROfusion, 2024b). The final results compare the investment costs, levelized cost of electricity (LCOE) and the total cost of electricity (TCOE). LCOE and TCOE express the cost of electricity including the investment costs relative to the total quantity of electricity generated during the whole lifetime of the plant, where TCOE also includes the external costs. These external costs can be evaluated based on damage to human health, effects on ecosystems and biodiversity, and the impact on resources and depletion. The investment costs, LCOE and TCOE are presented in figures 14, 15 och 16.

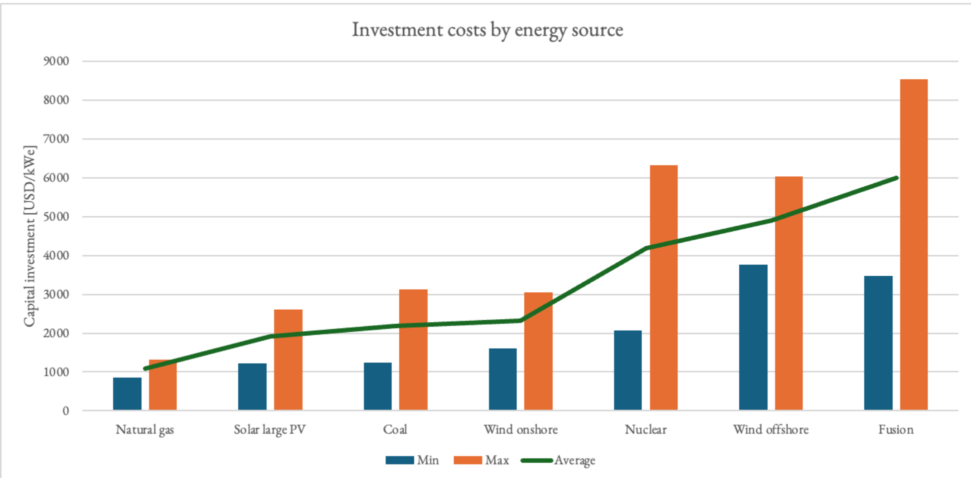

Figure 14: Investment costs by energy source, numbers extracted from Entler et al. (2018)

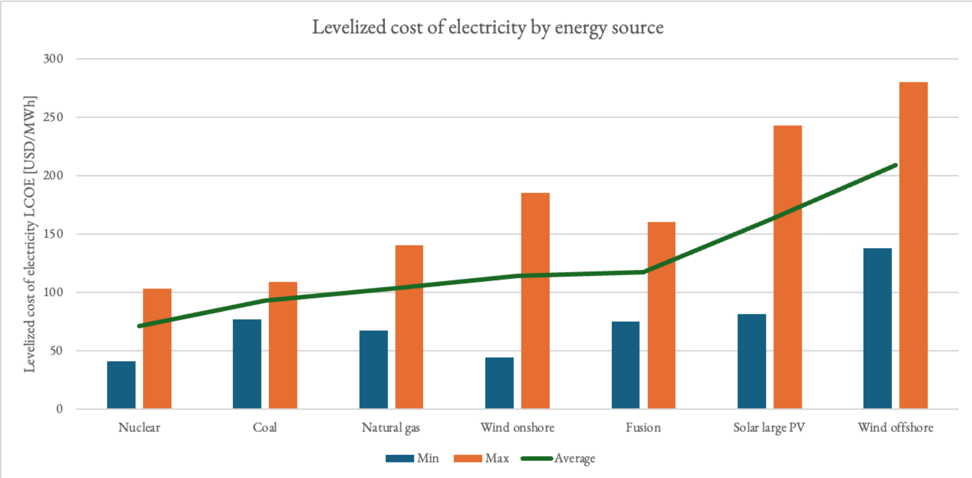

Figure 15: Levelized cost of electricity by energy source, numbers extracted from Entler et al. (2018)

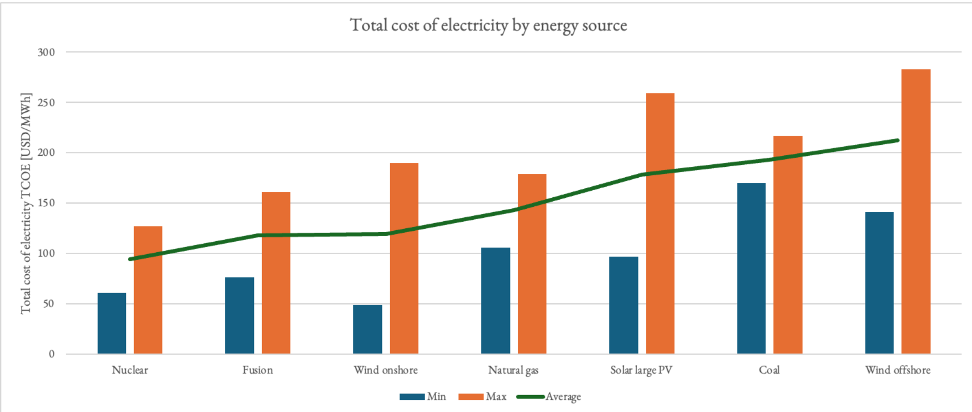

Figure 16: Total cost of electricity by energy source, numbers extracted from Entler et al. (2018)

As can be seen from the results, fusion power has the highest capital investment compared to other energy sources. However, fusion power has a lower levelized cost of electricity than solar large PV and wind offshore mainly caused by production costs when including subsidies. Furthermore, when including the evaluated external costs one can see that the total cost of electricity increases for fossil power plants and nuclear power plants while fusion and wind are fairly unchanged. Using this comparison, fusion power is expected to be a competitive option to other energy sources, even though it has a high investment cost. At the same time it is difficult to predict the development of fusion energy. The results are based on the plans for the DEMO2 power plant and costs must be reevaluated when the first fusion power plant is in place. (Entler et al. 2018)

However, the data presented in Entler et al. (2018) is taken from a 2015 study and recalculated on 2018 levels. According to IEA/NEA (2020) both solar, offshore wind and onshore wind have an LCOE which is competitive to gas and new nuclear. Based on the graphs provided in that report the median 2020 LCOE levels in Europe was approximately (in USD/MWh) 70 for gas, 70 for nuclear, 50 for onshore wind, 90 for offshore wind and 68 for large scale solar (IEA/NEA, 2020). This indicates that the LCOE has dropped for renewable energy sources, highlighting that the recalculated 2015 LCOE done by Entler et al. (2018) may not be comparable with today's costs, especially for renewable energy sources.

3.2.5 Fusion power today

To understand how fusion power will develop in the future it is crucial to understand where fusion power is today. From recent breakthroughs and large international projects to ambitious initiatives and private companies, all have a role to play in the road to commercial fusion energy.

3.2.5.1 Fusion projects

There are many fusion projects around the world, each contributing their part to developing fusion energy. As of 2022, about 130 fusion projects were operating, under construction or being planned, where 30 of those were private companies (International Atomic Energy Agency, 2022). According to the Fusion Industry Association (2023a) around 40 private fusion companies were active during 2023 One of the more notable projects is ITER, a joint collaboration between China, the European Union, India, Japan, Korea, Russia and the United States. The idea was launched in 1985 and the tokamak, which is ambitioned to generate 500 MW of power, is currently under construction in Cadarache, France (ITER, 2024). Another notable fusion project is the Joint European Torus (JET) which has laid the groundwork for the science and construction of ITER. Initially JET was a joint undertaking of the European community, but as of now The United Kingdom is responsible for JET. The tokamak reactor is set to be decommissioned in early 2024 (European Commission, Directorate-General for Research and Innovation, 2022; Culham Centre for Fusion Energy, n.d.).

3.2.5.2 Technological advancements

Vattenfall wrote in their article *Excess energy from fusion – "A major breakthrough"* (2023) that after two successful experiments there is reason to believe that fusion power at scale could become a reality. The two experiments that they wrote about were conducted at the Lawrence Livermore National Laboratory in California. The experiments used lasers to start a fusion reaction and both experiments generated an energy output which was greater than the energy used to start the reaction (Vattenfall, 2023). In another article written by Whiting and Torkington (2024) several recent technological breakthroughs are discussed. Among these are the implementation of AI to help control a tokamak fusion reactor. At the National Fusion Facility in San Diego scientists were able to use AI to reduce plasma tearing which would disrupt the fusion reaction. The artificial intelligence controller paves the way for developing stable operational scenarios of high performance for future use in ITER (Seo et al. 2024). The article written by Whiting and Torkington (2024) also mentions the milestone set by the Joint European Torus (JET) during its final experiment before decommission. During the experiment scientists achieved a reaction during 5 seconds which produced 69 megajoules of energy, enough energy to heat 5 bathtubs of water and a new world record in the amount of energy produced by a fusion reaction (Stallard, 2024).

3.3 Stakeholders in the fusion value chain

In a study done by the Fusion Industry Association (2023b), a proposed supply chain for the fusion industry is explored. In this study, 26 private fusion companies were questioned about their spending on the supply chain. The spending is presented in figure 17.

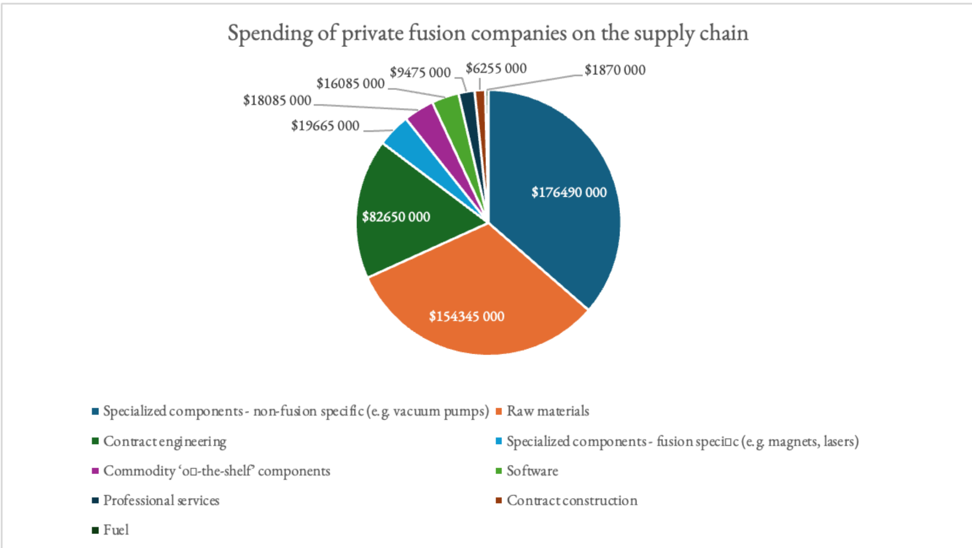

Figure 17: Private fusion companies' spending on different parts of the supply chain as adapted from the Fusion Industry Association (2023b)

Furthermore, the study found that private fusion companies expect demand to increase for all components from the value chain. Fusion specific specialized components will see big increases whereas raw materials will only see incremental increases. Furthermore, fusion companies were asked about their concerns regarding supply constraints and currently see low constraints for all components. As the companies scale their production of fusion they see the highest constraint in both semiconductors and gaseous fusion fuels such as deuterium and tritium. However, the study highlights that many fusion companies do not see the supply of fuel, in particular tritium, as a concern because the fusion companies themselves plan to generate tritium during operation with the use of tritium breeding. Additionally, some European fusion companies expressed concerns regarding the supply from geopolitically unstable countries. However, the study found that these concerns are varied and contrary to what people outside the industry might think, there are generally limited concerns regarding geopolitical supply risk. This is because there are no critical components that are highly constrained or come solely from a geopolitically unstable country and where such risks exist they are deemed manageable (Fusion Industry Association, 2023b)

In another report released by the Fusion Industry Association (2023a), private fusion companies were once again surveyed about the fusion industry. In this report, the majority of respondents believed that the first fusion plant to deliver power to the grid would be first operational in the period 2031-2035. Furthermore, respondents believed that the major challenges for fusion before 2030 were mostly technical challenges, such as achieving a good energy efficiency or solving tritium breeding, or challenges regarding funding. However, after 2030 respondents believed that these challenges would decrease, especially the challenge of funding, and other challenges such as geopolitical challenges, nuclear regulation or full life cycle issues, would increase (Fusion Industry Association, 2023a).

There are limited academic reports on stakeholder analyses within the fusion industry. However, there are stakeholder analyses on other energy sources which can be comparable with fusion energy due to the similarity of business activities, distribution and customers. In a study by Guðlaugsson et. al. (2020), a classification of stakeholders within the development of sustainable energy in Iceland was made. Guðlaugsson et. al. (2020) identified 9 stakeholder groups. The stakeholders identified were rated along the two criteria power and interest, to further cluster the stakeholders. The stakeholders and salience by Guðlaugsson et. al. (2020) is presented in table 2.

Table 2: Stakeholder salience level and cluster characteristics (Guðlaugsson et. al., 2020)

Stakeholders	***Salience level***	***Cluster characteristics***
Decision-makers	High	Players
NGOs	Low	Crowd
Professional interest	Medium/high	Context setters/players
Landowners	Low	Crowd
Fuel importers	Low	Crowd
Energy producers	High	Players
Distribution and transmission	Medium	Subject
Public and small business owners	High	Players
Industrial users	High	Players

The cluster characteristics players, context setters, subject and crowd correspond to the categories key players, keep informed, keep satisfied and monitor as presented by Johnson and Scholes (2008).

3.4 Scenarios for the European energy market

Various academic publications were examined to get an understanding of what current theory scenarios for the European there are and how they are constructed. Weber (2014) provides an in-depth examination of the European energy market with a focus on the integration and implications of fluctuating renewable energy sources. It explores various scenarios up to the year 2050, which are developed based on different policy approaches and market conditions. Firstly, critical variables that significantly impact the energy system were identified. Some examples of these were demand fluctuations and fuel prices. Then a stochastic model was used to represent uncertain parameters. Scenarios were constructed based on different combinations of key uncertainties and each scenario represented a plausible future state of the world that reflected different assumptions about how these uncertainties would resolve. Each scenario incorporated specific policy and market conditions that could affect the deployment and integration of renewable energy sources. This included subsidies for renewable energy, carbon pricing, regulations on emissions, and incentives for technology development.

5 scenarios were identified. Scenario Conflict assumes continued conflicts of interest and objectives within Europe, leading to a fragmented approach to energy policy and market development. Scenario Climate-Policy is characterized by a strong focus on reducing greenhouse gas emissions, with a target of a 95% reduction by 2050 compared to 1990 levels. In Scenario Climate-Market, the same ambitious environmental objectives as in the Climate-Policy scenario are pursued, but relying more on market mechanisms rather than direct policy support after 2020. Scenario Efficiency focuses on economic efficiency, envisioning a competitive market environment that fosters innovation and reduces distortions. Scenario Secure Growth prioritizes security of supply to support continued economic growth, focusing on domestic energy sources and diversified sourcing to reduce dependency on imports.

4 The fusion value chain

This chapter examines and, through a stakeholder analysis, categorizes the stakeholders in a proposed fusion energy value chain. It evaluates the current significance of these categories of stakeholders and how they might develop up until 2040.

When discussing a possible future industry it is important to know which actors might be included in that industry's value chain. Fusion energy is currently not commercially available. However, if it were to enter the European energy market there are both differences and similarities to the value chains of other existing energy sources. In this chapter, a possible value chain for fusion energy, from suppliers to end customers, will be proposed and discussed. The proposed value chain is based on internal meetings with Novatron Fusion Group and external interviews with experts.

4.1 Overview of the fusion value chain

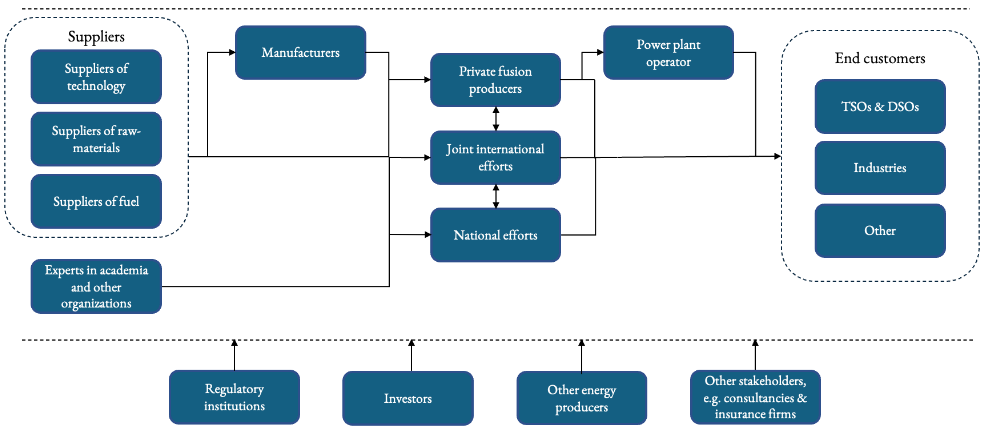

Figure 18: An overview of the stakeholders in a possible future value chain for fusion energy

With the overview presented in figure 18, one can see several stakeholders connected by arrows. The arrows represent the exchange of a product or service which can include expertise, technology, materials, investments, energy, etc. The main value chain is represented inside the dotted lines while boxes outside the dotted lines are stakeholders who may affect the fusion industry but are not directly connected to the value chain.

Firstly, in the main value chain inside the dotted lines, private fusion producers, joint international efforts and national efforts are at the center. This is where the main concept of fusion is being developed and new fusion technologies are being innovated. Private fusion producers focus on designing fusion reactors for future commercial viability, driven by profit incentives. In contrast, international collaborations and national efforts prioritize scientific advancements, moving fusion power closer to reality without the pressure of profitability. However, experts agree that both private fusion producers, joint international efforts and national efforts are necessary for fusion to succeed. There is constant information sharing between all three parties, symbolized by a double-sided arrow connecting them.

The fusion developers receive supplies in the form of raw materials, technology and fuel for the reactor. Competence is received from experts from academia or other organizations, a sort of supplier of know-how. Preceding the fusion developers in the value chain are manufacturers specializing in reactor construction. These manufacturers may be responsible for constructing either the entire reactor or specific components. They may also help manufacture power plants. Alternatively, fusion developers may choose to handle reactor manufacturing in-house. The manufacturers and fusion developers must receive raw materials, technology and possibly fuel for construction, therefore an arrow is connected from these suppliers to both manufacturers and fusion developers. The energy released from the fusion reactors, that the fusion developers operate, will most likely be converted into electricity to be used by end customers. This requires a power plant connected to the fusion reactor, which can either be operated by a third party or by the fusion developers themselves. Therefore, an arrow is connected to “Power plant operator” and to “End customers”. The fusion reactor or the electricity created from the power plant will be delivered to the end customers which includes TSOs (transmission system operators) and DSOs (distribution system operators), industries and other customers. TSOs and DSOs are represented by state electrical grids as well as electrical companies. Industries include the steel industry. Other customers are for example space corporations using fusion in space ships or for military applications e.g energy for submarines.

Beyond the primary value chain, other stakeholders may influence the fusion industry. Regulatory institutions, for instance, can either impede or accelerate the development of commercially viable fusion energy. As noted in section 3.2.4, fusion reactors require a significant capital investment for construction. In this context, investors play a crucial role by providing the funds required for reactor completion, ongoing operation, and further development. Furthermore, since fusion power is a source of energy which may compete with other energy sources on the European energy market, there may be efforts from other energy producers to either lobby decision makers to slow down the development of fusion, or make their own investment in fusion power to enter the industry. There are also other stakeholders who may affect the fusion industry, such as consultancies, maintenance companies, insurance companies, etc.

4.2 Actors in the fusion value chain

To categorize stakeholders crucial for achieving commercial fusion power, some were grouped together based on their similar positions in the value chain while others were separated due to the importance of their individual positions. The category “Other energy producers” were separated into renewable power, fossil power and fission power due their individual positions in the value chain being of interest. In contrast, potential customers, including power plant operators, TSOs and DSOs, industries and other customers were consolidated into a single category called customers/distributors, owing to their shared role as customers even though their individual businesses vary. The actors presented in the value chain are categorized and described in table 3.

Table 3: Description of the stakeholder categories

Type of stakeholder	***Description***	***Example***
Suppliers of know-how	Suppliers of know-how deliver competence in the form of talent and research to fusion companies	Often include universities or non-profit organizations. *KTH, Aerospace Corporation, Fusion Energy Insights*

Type of stakeholder	***Description***	***Example***
Suppliers of raw-materials	Supply raw-materials that are robust enough to withstand the extreme heat produced from the fusion reaction.	Includes engineering companies and mining/quarrying companies *Sandvik AB, Thyssenkrupp, Midwest Tungsten Service*
Suppliers of technology	Provides advanced technology such as magnets, automated control, lasers, simulation software, vacuum systems etc.	Includes engineering firms, energy firms, software firms and nuclear technology firms *General Atomics, COMSOL*
Suppliers of fuel	Supplies fuel to be used for operation of the reactor magnets, breeder blankets and for the fusion reaction itself	Suppliers of deuterium, tritium, lithium and cryogenics. Usually gas or chemical companies. *Linde gas, SQM, Albemarle*
Manufacturers	Manufacturers can assist in designing, building and installing the reactor. They can also offer maintenance services and testing.	Usually engineering and technology firms with a niche in high tech engineering projects *ENERCON, ALSYMEX*
Private fusion producers	Developers of commercially viable fusion energy. Usually with innovative solutions and with a short time to market scope.	Private fusion producers are usually spin off startups building on ideas from research institutions *Novatron Fusion Group, Helion Energy, Commonwealth Fusion*
Joint international efforts	Funded research projects usually involving several countries to accelerate the development of fusion energy.	Can include multiple governments, non-profit organizations or institutions *ITER, JT-60SA, NIF*
National efforts	Research projects that are funded by single nations to develop fusion for long term energy security.	Governmental institutions that may be members of international collaborations *UKAEA (UK), IPP (Germany)*
Customers/ distributors	Customers purchase valuable by-products like Helium, Tritium, or neutrons, as well as licenses or electricity for direct use.	Various potential customers such as TSOs, DSOs, industries, power plant operators, space agencies, etc. *E:on, Vattenfall, NASA, Tesla*

Type of stakeholder	***Description***	***Example***
Regulatory institutions	Sets the framework for which fusion power can operate within. Sets standards for safety, waste disposal and economic viability	Governments, institutions, international organizations. *IAEA, DG ENER, EURATOM, EUROfusion, Fusion for Energy*
Investors	Essential in providing funds for all stakeholders, but in particular private fusion companies and joint international efforts	Global companies with energy in their value chain, private-, public- and public-private investors. *Tesla, Equinor Ventures, Euratom, EIT InnoEnergy, Sam Altman*
Renewable power	Producers of energy using renewable sources such as solar, wind and hydro.	Companies ranging from large scale production to smaller local production. *Vattenfall, Svea Solar, Vestas*
Nuclear power	Producers of energy that uses the splitting of atoms, fission, rather than fusion. No greenhouse gas emissions are released but produce radioactive waste.	Usually operated by utility companies, energy corporations, government agencies or independent power producers. *Fortum, Vattenfall, E.on, EDF*
Fossil power	Companies utilizing fossil fuels like coal, oil, or natural gas for energy, including both those refining fossil fuels and those generating electricity.	Typically includes global companies vertically integrated across multiple segments in the fossil fuel industry. *Shell, BP, Equinor, TotalEnergies*
Other stakeholders	Other stakeholders may affect fusion development in a myriad of ways ranging from insurance to consultancy within legal issues.	Can include legal or management consultancies, insurance companies, financial institutions, media etc. *Accenture, Lloyds, Pillsbury Winthrop Shaw Pittman LLP*

4.2.1 Stakeholder analysis

4.2.1.1 Expert rating of stakeholders

The stakeholder categories outlined in 4.2 served as a foundation for the rating in the interviews. Figure 19 displays the average of the experts' rating of stakeholders.

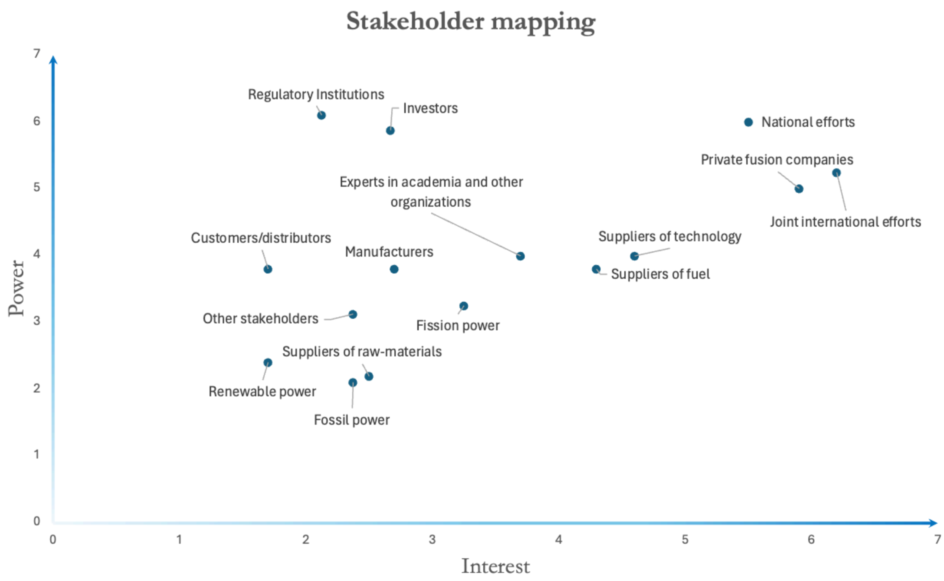

Figure 19: Mapping of the stakeholders presented in 4.2 based on rating from interviews

4.2.1.2 Rationale to rating

While some participants provided exhaustive explanations of their reasoning, others provided brief comments after having completed their rating. This section aims to outline the overarching rationale behind each stakeholder's rating. The rationales are presented in table 4.

Table 4: Rationale to rating in figure 19.

Stakeholder	***Rationale to rating of interest***	***Rationale to rating of power***
Suppliers of know-how	Attitudes may vary, but those who focus on fusion typically have high interest in its success since it enhances their reputation.	While not decisive for fusion's commercialization, they play a crucial role in supplying skilled personnel and hold some influence in this regard.
Suppliers of raw-materials	Fusion won't be their sole market, and failure in this sector won't cripple them. Nevertheless, it represents a new avenue for revenue.	Certain materials are crucial for fusion reactors, yet the success of fusion does not hinge solely on these suppliers.
Suppliers of technology	The fusion industry offers significant market potential for these suppliers, though their technologies could also find applications in other markets.	Suppliers hold vital expertise for advanced fusion technology, despite facing fierce competition in the market.
Suppliers of fuel	Fusion offers lucrative prospects for these suppliers, potentially becoming a major revenue stream alongside their other markets.	Their products are crucial but largely off-the-shelf, with many existing suppliers and potential newcomers if fusion succeeds.
Manufacturers	While they have the potential to secure significant contracts in the fusion industry, it's unlikely to be a central aspect of their business.	Specialized expertise in fusion could grant them a pivotal role in the value chain, but most manufacturers lack such influence.
Private fusion producers	These companies aim for success from the start. If fusion fails, they risk severe limitations and possible demise, unless their technology finds alternative markets.	Most experts agree that private initiatives are crucial for fusion's success, though some argue they are overly reliant on large-scale fusion projects for development.
Joint international efforts	Like private fusion companies, joint international efforts wouldn't launch without aiming for success. With substantial investment, they're too big to fail.	Early-stage joint efforts are vital for fusion development, but as commercialization nears, private developers will dominate the market.
National efforts	Nationwide initiatives with governmental investments in fusion are vital to propel the industry forward.	Nations benefit from securing unlimited green energy but may also prioritize other projects like fission or renewables.

Customers/ distributors	Experts agree: customer interest in fusion's success will grow, but for now, reliable electricity is their top priority.	Potential customers lack the authority to influence fusion's success; their impact on decisions is limited as for now.
Regulatory institutions	Governments typically show low interest due to fusion's practical challenges and may already have invested a lot in other energy sources like fission power. Organizations like IAEA may show higher interest.	Fusion's commercialization relies on favorable regulations. However, experts find the current regulatory parity between fusion and fission, which exists in many countries, unfavorable.
Investors	Private investors seek quicker, less risky returns, often incompatible with fusion's timeline. Public investors, recognizing fusion's benefits, may invest to enable its development.	Investors have significant decision-making power as continuous investment is crucial for fusion's success, providing funds for R&D and infrastructure.
Renewable power	Renewable energy sources are rising independently of fusion's progress but could benefit from a secure baseload energy source during cloudy or windless periods.	Experts are divided on these companies' influence. Some argue their cost-effectiveness could affect decisions, while others disagree at this stage.
Fission power	Varies by country. Actors possess practical knowledge on nuclear plant operation, potentially leveraging it if fusion succeeds. However, fusion research typically progresses independently from fission which limits their interest.	In fission-heavy countries, companies wield significant influence over the energy system, potentially leading to resistance against fusion due to competition with traditional nuclear power.
Fossil power	Some companies have invested in fusion power to avoid being outcompeted if fusion becomes a reality, aiming to secure their position in the emerging market.	Driven by powerful global corporations with significant financial resources, which often influence decision-making to align with their interests.
Other stakeholders	There might be some interest in this sector for e.g insurance companies or legal firms because it is a potentially lucrative market.	Due to high competition there may be limited influence. However, insurance companies might hold power.

As discussed in 2.4.2 there are certain relationships to be kept with certain groups of stakeholders and depending on the stakeholder's power and interest, these relationships vary. Taking into account that stakeholders were rated on a scale from 1 to 7, the dividing line between actor groups in the power/interest matrix was intended to be positioned at 4. However, to be able to create relatively even groups, this dividing line is not exactly the same for the interest and power axis. Figure 20 displays the stakeholder salience mapping.

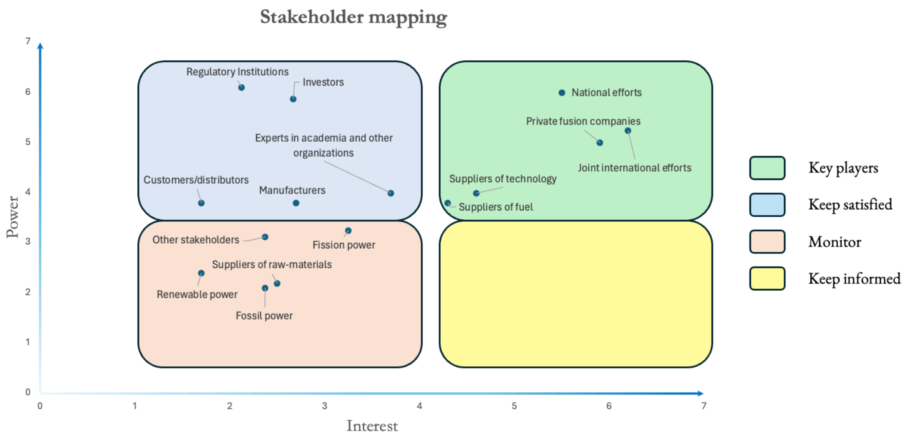

Figure 20: Positioning of stakeholders based on external interviews with experts according to the theory from Johnson & Scholes (2008)

4.3 Fusion in the coming 15-20 years

4.3.1 Development of actors in the fusion value chain

It is not only important to understand the actors' present position in the value chain, it is also of interest to know how the actors will move with regards to their interest/power rating. The answers are depicted in figure 21.

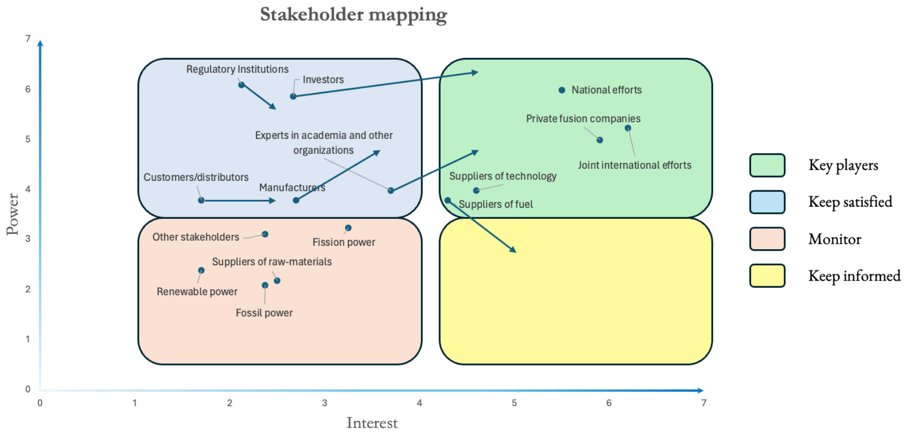

Figure 21: Development of the stakeholder's in the fusion value chain up until 2040 as visualized in the power/interest matrix.[1]

Experts agree that once fusion approaches commercialization and makes significant breakthroughs investors will start to realize the potential of the fusion industry. This means all types of investors will move in more rapidly and with larger investments. As of now, most investments come from public investors with a larger time frame. However, once a tipping point is reached, such as a significant breakthrough, the investment risk will decrease and private investors will make more frequent and larger investments in fusion.

Furthermore, fuel will continue to be an important factor of the fusion process. However, as fusion power scales up experts believe that fuel will become less expensive. More suppliers entering the market will lead to the development of a fuel production industry, reducing prices. Additionally, successful development of tritium breeding by fusion producers will result in the self-sustaining production of tritium during the fusion process. This will significantly reduce costs, as tritium is currently expensive. Conclusively, as the fusion industry scales up would mean that fuel producers will see a growing market, increasing their interest. However, since there is also expected to be more competition on the fuel market, the power that fuel suppliers have to influence decision making will decrease.

[1] A slight increase or decrease in power or interest corresponds to a change of 0.5 points in that direction, while a regular increase or decrease corresponds to a change of 1 point, a large increase or decrease corresponds to a change of 1,5 points and a very large increase or decrease corresponds to a change of 2 points.

Experts believe that when fusion approaches commercialization, there will be a greater need for competence. Consequently, experts from academia and other organizations will become more attractive in the industry. Some experts hope and believe that this will result in an increase in power for experts in academia and other organizations. Additionally, this stakeholder's interest is growing and will continue to do so in the near future as the fusion industry is becoming more attractive.

Regulatory institutions currently have a lot of power in realizing fusion power. This is because nuclear energy is currently heavily regulated and both fission and fusion is, in many countries, treated under the same regulatory umbrella as mentioned in table 4. Experts believe that pushback and lobbyism from fusion producers will eventually separate the two power sources in their legislative framework, providing more relaxed conditions for fusion power which in turn might slightly reduce the power that regulatory institutions have in the commercialization of fusion power. Furthermore, as fusion approaches viability, regulatory institutions may increase their interest in fusion power slightly due to it being a clean source of energy and might have to reconsider their current legislation.

Some experts believe that manufacturers will become more interested in the fusion industry in the future since the contracts are usually quite lucrative and as the fusion industry scales up or a certain tipping point is reached, these contracts will become more frequent. As fusion approaches commercialization, large industry conglomerates become increasingly attractive for fusion developers due to their competence in managing the complexity of building a fusion reactor, increasing their influence over the commercialization of fusion power.

Customers and distributors are expected to increase their interest when fusion nears commercialization since fusion will deliver additional fossil free energy to the grid. Experts believe that some customers might even be willing to pay extra for emission free energy as climate awareness increases.

Experts are divided on the development of the fusion developers. Some experts believe that joint international efforts will keep being an important player with a lot of influence over the commercialization of fusion power since they are too big to fail and that this will not decrease until 2040. Others believe that these international efforts will serve as competence hubs and that the production of fusion energy will be privatized, indicating that the joint international efforts lose some power while private fusion developers gain some power. National efforts were deemed to be important but scientists did not give any indication as to how these efforts will develop up until 2040. However, experts agree that all developers of fusion energy are important and will keep being *key players*.

4.3.2 Development of the fusion industry

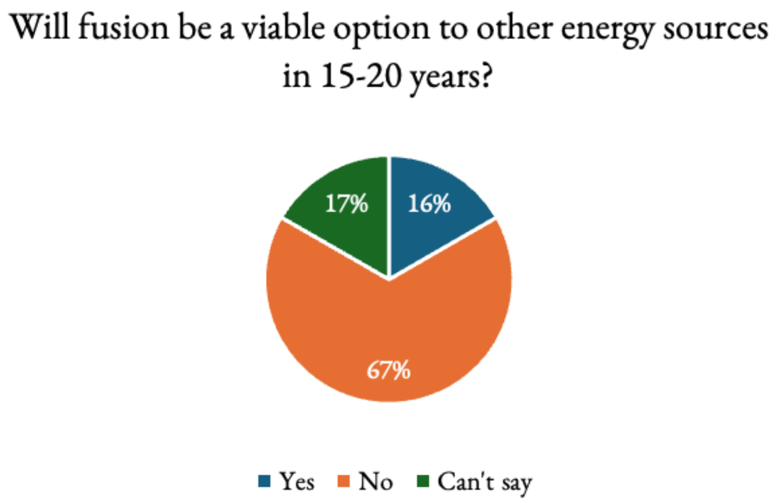

Figure 22: Expert opinions regarding if fusion will become a viable energy source in 15-20 years

Among the experts interviewed, there has been a split opinion on how fast fusion will develop, which is depicted in figure 22. A majority of the interviewees do not believe that fusion will become a viable option to other energy sources in 15-20 years. This is mainly due to the fact that fusion does not produce stable net positive energy today and even if experiments become successful in the near future it might take decades to scale up. There are a number of reasons for this. Fusion power needs to be cost effective, have political support, have public support and fit into the current electricity system that Europe possesses. Furthermore, power plants also have to be built which may take several years to approve and construct. However, some experts also believe that new technology in general might be developed under a long period of time before eventually having a breakthrough which rapidly increases the investments, development and adoption. An example of this are electric vehicles and jet engines on airplanes.

Fusion faces several challenges before being commercialized and interviewees pointed out their main concerns that needs to be addressed for commercialization to be possible. The issues that were mentioned are displayed in figure 23.

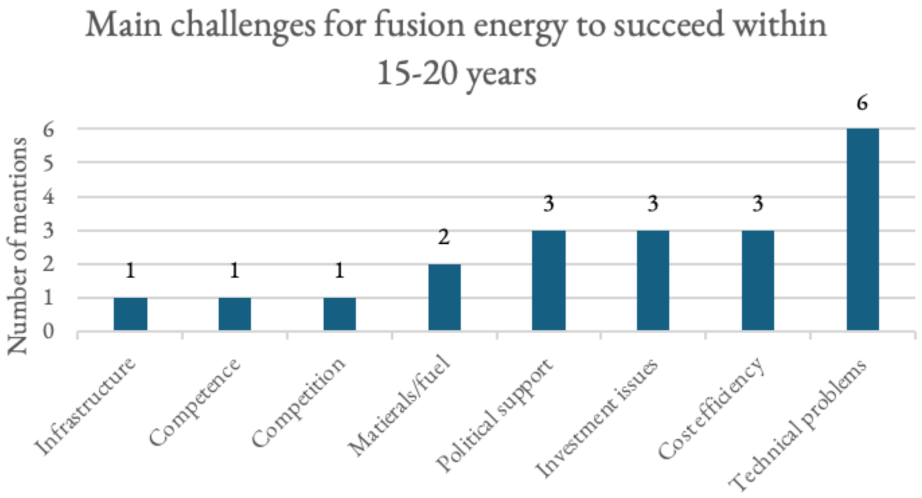

Figure 23: Main challenges for fusion energy to succeed within 15-20 years and their frequency of mention from interviewees

Every single interviewee mentioned technical problems as one of the main challenges for fusion to succeed. These problems include keeping the plasma stable, achieving net positive energy output, controlling neutron output, enabling breeding of tritium and keeping the extremely high temperature which make the reaction possible. Many interviewees also mentioned cost efficiency as a major concern for fusion. Since renewable energy sources are becoming more and more cost efficient it is crucial that fusion energy is able to compete with those sources of energy to enter the market. LCOE is crucial in this aspect since one needs to weigh investments, operational costs and other costs to the production of electricity during the plant's lifetime. For example, fission power is widely adopted even though it is becoming more expensive since it provides a stable and fossil free source of energy. Furthermore, interviewees believe investment issues are of high concern. Fusion power is still in development and requires ongoing investments to progress, especially due to the highly advanced technologies. Another very important aspect is making a durable and robust reactor. Achieving the high temperatures required for fusion requires materials capable of effective heat shielding in the reactor. Additionally, one needs materials to control the high energy neutrons produced from the reaction. Combining heat resistance and neutron control presents a big challenge for material scientists. Some interviewees also believe that it is essential that fusion receive political support in the form of more effective permit processes and less stringent regulations.

Interviewees also stated what they believed would be the greatest costs for fusion moving forward. Figure 24 depicts their answers.

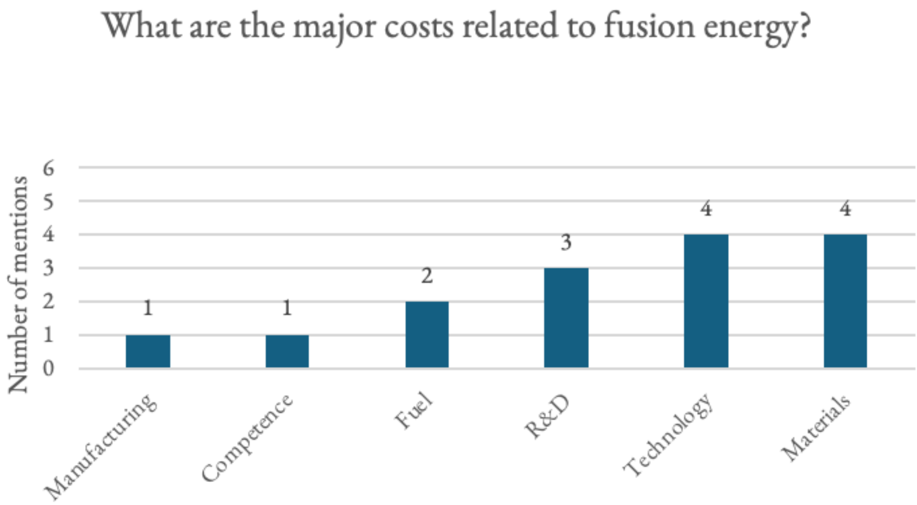

Figure 24: The major costs related to fusion power today and their frequency of mention from interviewees

At this stage of fusion development, interviewees believe that materials, technology and R&D in the form of experiments and research are the main cost drivers. However, some experts stated that the majority of these costs will disappear when the goal is reached and a commercial reactor is initialized. For example, as fusion power scales up, fuel costs are expected to decrease due to the production of tritium, an expensive element, within the reactor. At this stage, other costs will be of a higher concern, such as infrastructure, insurance costs, competence, maintenance, etc.

Interviewees also stated what they believe are the greatest advantages with nuclear fusion energy. The topics mentioned are shown in figure 25.

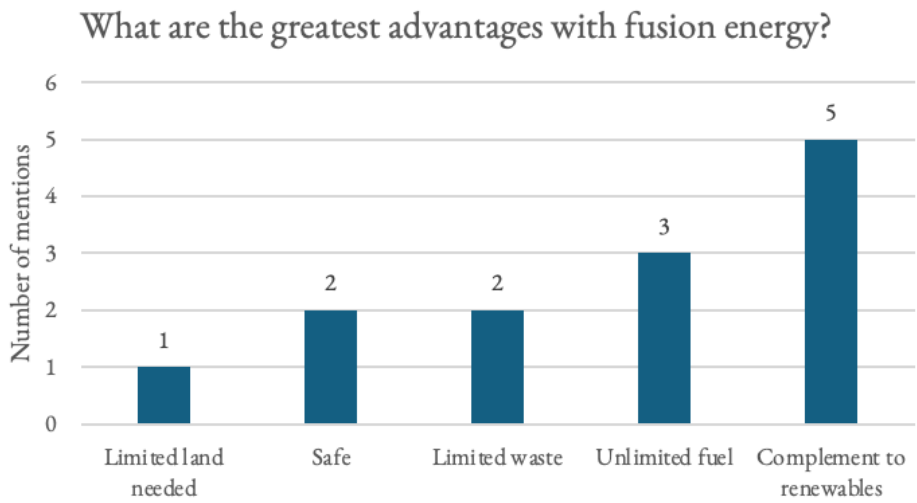

Figure 25: The greatest advantages with fusion energy and their frequency of mention

Experts mentioned several different advantages which motivates the pursuit of fusion energy. The near unlimited supply of fuel was mentioned as one of the main advantages of fusion energy. Since the tritium will be generated inside the reactor if breeding blankets are successful, in combination with the fact that deuterium can be extracted from seawater, experts view fusion energy as a near renewable source of energy. However, fusion is a stable source of energy while conventional renewables such as wind and solar are intermittent, another advantage that interviewees mentioned. These aspects motivate that fusion power is an important complement to renewables, as most frequently mentioned by interviewees. Furthermore, experts believe that it can supplement nuclear fission power, given its limited radioactive waste and higher safety. Fusion reactions naturally cease if something goes wrong, as compared to fission energy where uncontrolled reactions can lead to meltdowns. Lastly, the limited land occupation of a fusion reactor was mentioned, offering a competitive advantage to other energy sources.

5 Development of the European Energy Market up Until 2040

This chapter explores the evolution of the European energy market up until 2040. It investigates how the mix of energy sources might develop and identifies key macro trends that influence this development.

5.1 Development of the European energy mix

Figure 26 displays 9 energy expert's answers of how the various energy sources on the European energy market will develop as their part of the energy mix until 2040.

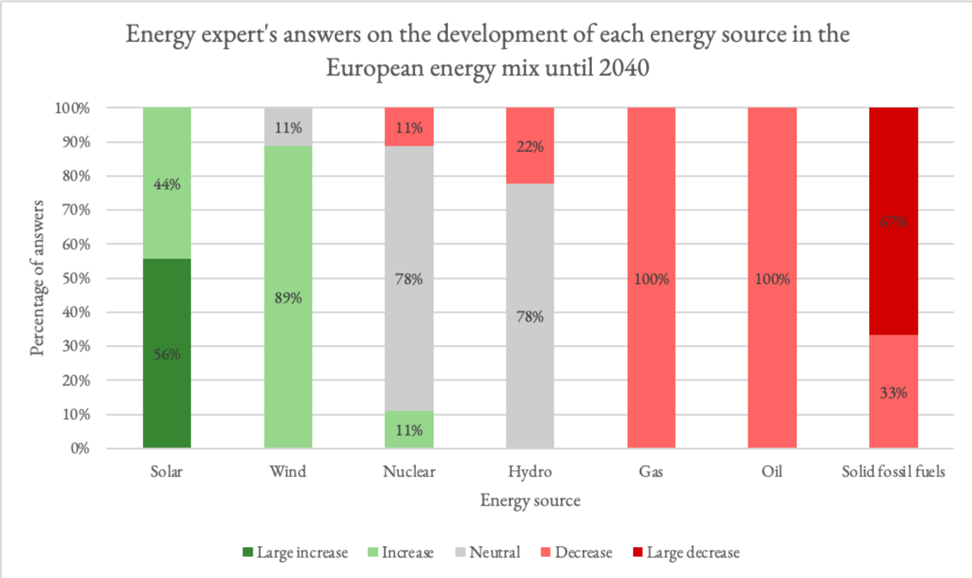

Figure 26: Energy expert's answers on the development of each energy source in the European energy mix until 2040

In table 5, the main driving factors for the development of each energy source is presented.

Table 5: The main driving factors for the development of each energy source

Energy source	***Main driving factors for development***
Solar	Each of the four drivers were mentioned as reasoning for the increase. The majority of the interviewees put *cost* and *resource availability* as the primary driver for the large expansion of solar power in until 2040. There was a consensus that the energy source has low *environmental impact*.
Wind	The majority of the experts mentioned low *cost* and *resource availability* as drivers for the increased level of wind power until 2040. There was a consensus that the energy source has low *environmental impact*.
Nuclear	Reasons for still being a relevant energy source in the mix include low immediate *environmental impact* in terms of carbon emissions. It also has a low land usage per energy output and is planable in terms of energy output. Why it won't increase is largely due to long term negative *environmental impact* in terms of waste management and potential nuclear disasters, as well as high overall cost compared to renewables. Complex permit processes also slow down its development.
Hydro	Going to stay constant in absolute terms and slightly as part of the energy mix. Consensus in *resource availability* being the limiting factor for its development, there simply aren't geographical locations where it can be

	expanded. Otherwise an attractive energy source.
Gas	Consensus regarding *environmental impact*, in terms of carbon dioxide emissions, being the main driver for its decrease. Additionally, reducing dependence on Russian gas is a key concern. In 2040, natural gas remains relevant due to challenges in fully replacing it in the transportation sector and in high-temperature industries such as chemistry.
Oil	Consensus regarding *environmental impact,* in terms of carbon dioxide emissions, being the main driver for its decrease. Will remain in 2040 largely due to being difficult to fully replace in some areas of the transport sectors including trucks, sea- and air transport.
Solid fossil fuels	Almost entirely phased out due to *environmental impact* in terms of carbon dioxide emissions and *cost* compared to the other energy sources.

Despite there being a consensus that both solar and wind will increase, their development was compared to each other by multiple experts. Several experts highlighted that wind won't increase as fast as solar because it is not as cost effective.

> *"The large cost decrease for solar power will continue and thus solar power will be cheaper than wind" - Energy expert*

Moreover, multiple experts pointed out opposition from the local surroundings against wind power systems as an obstacle for its development. This could lead to a limitation in resource availability, especially for land based wind power, which will make the energy source more difficult to scale.

For nuclear fission, experts brought up several issues that led to why it was difficult to predict its future in the energy mix, some even expressed "it is a tricky one". Multiple experts mentioned that several countries are actively investing in it and argue that the cost will decrease once it is scaled up. It is driven by high demand for planable and guaranteed energy, an area where solar and wind aren't as reliable. Although, experts highlight that it does not have the economy on its side. There are also concerns about the waste that it produces, that it is a complicated and expensive process. One expert believes that the fourth generation of nuclear power will be a possible solution to this, where the waste is handled in a much more efficient and environmentally friendly way. Moreover, there is skepticism regarding its safety and security from a geopolitical standpoint.

There is a consensus among all energy experts that all fossil fuel based energy sources will either "decrease" or "largely decrease" as part of the energy mix. This is mainly due to the environmental impact in terms of carbon dioxide emissions that the energy production of these sources implies. Although, until 2040, it will be difficult to fully replace these energy sources due to them possessing large advantages compared to other energy sources for some specific uses, such as in the transport sector or in the chemistry industry.

> *The coal will be totally phased out, both due cost, CO2 emissions and health effects" - Energy expert*

5.2 Macro trends affecting the European energy market

From the energy interviews, nine macro trends impacting the development of the European energy market until 2040 were identified. These are presented and described in table 6.

Table 6: Macro trends impacting the European energy market

Trend	***Description of trend***
A. Increased political governance to climate goals	Implies that the EU and its member states accelerate the process towards achieving the set climate goals, through incorporating further regulations that prevent carbon emissions.
B. Expansion of solar and wind power	Implies that solar and solar wind power will increase as part of the European energy mix.
C. Increased geopolitical security concerns	Implies that political tensions increase between countries in the world.
D. Increased resistance to local energy facilities	Implies a growing opposition or reluctance towards the expansion of energy infrastructure within local communities or regions.
E. Increased energy efficiency	Involves improving the efficiency of the energy usage across various parts of the energy value chain. It covers efforts to optimize energy production processes and reduce energy waste.
F. Improved and increased energy storage solutions	Refers to advancements in technologies and infrastructure for short- and long-term energy storage.

G. Increased electrification	Means increasingly replacing fossil fuel-based energy systems with electricity in various sectors including transportation, heating and in industries such as steel production.
H. Worsened climate conditions	Means that the climate becomes warmer and that natural disasters occur more frequently.
I. Increased investments in nuclear fission	Means increasingly replacing fossil fuel-based energy systems with electricity in various sectors including transportation, heating and in industries such as steel production.

Figure 27 displays the energy experts’ rating regarding each trend's level of impact on the European energy market if realized, and level of certainty of being realized.

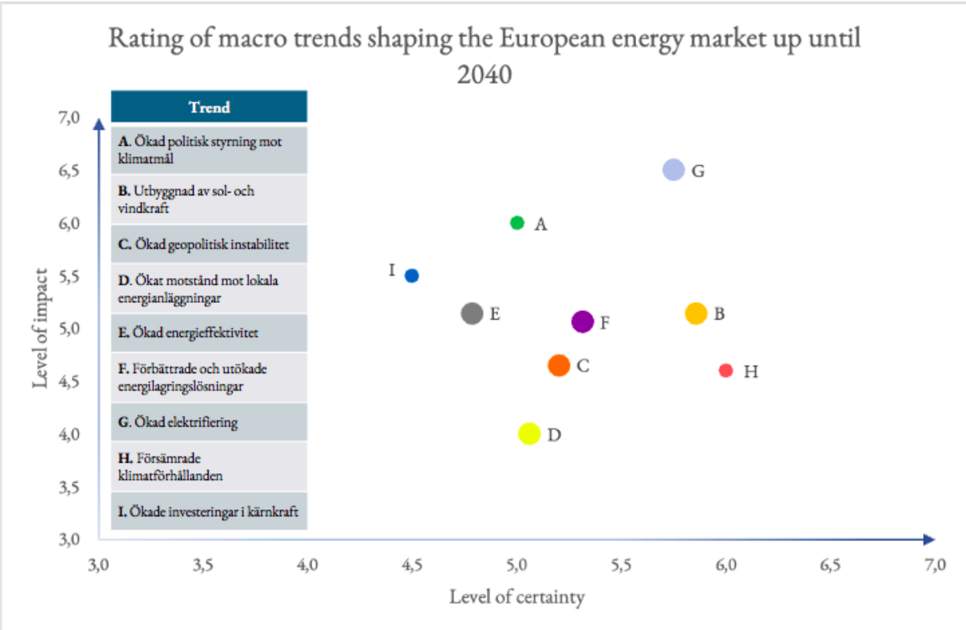

Figure 27: Rating of macro trends shaping the European energy market up until 2040. Large circle implies the trend was rated by more than 5 interviewees, and the small circle by 5 or less. There were a total of 10 interviews.

5.2.1 Trend A - Increased political Governance towards climate goals

Impact	6,0
Certainty	5,0
Ratings	4

The EU and its member states have the ability to steer the development of each energy source through administrative, informative and economic instruments. Administrative measures include regulations and permits that ensure its member states comply with energy policies. Information instruments are about informing the public and relevant stakeholders about energy-related issues and policies. Lastly, economic instruments like taxes and subsidies influence how expensive the different energy sources are. The expert agrees on the fact that if the EU and its member states were to steer legislation and regulations towards achieving the set climate goals faster, it would likely have a large impact on the development of the energy mix in Europe. The experts are also rather certain that the EU will keep pushing towards achieving the set climate goals, however how large this push will be and towards which energy sources this push is directed is difficult to say. It would highly depend on what measures the states take and would likely be different in various EU member states.

5.2.2 Trend B - Expansion of solar and wind power

Impact	5,1
Certainty	5,9
Ratings	7

The majority of the energy experts are aligned on the fact that solar and wind power will expand as their combined part of the European energy mix up until 2040. One major factor for this is that the technology behind the solar and wind power plants are expected to become cheaper and thus the energy will be cheaper to purchase. It is especially highlighted that solar cells will become much cheaper which motivates its fast development.

5.2.3 Trend C - Increased geopolitical security concerns

Impact	5,2
Certainty	4,7
Ratings	10

The discussion regarding geopolitical security has increased during the last years in Europe and likely will continue to do so, seeing where Europe and the rest of the world is today with war in Ukraine for example. One of the main issues discussed are about how dependent and reliant Europe's energy production should be on geopolitically unstable countries like China and Russia. The wind turbines and solar cells used in Europe today require magnets, neodymium and minerals, many of which are processed and refined in China. This reliance can be seen as a security threat as China has the opportunity to exploit industrial dependency for political and economic benefits. Another example of this is the dependency many EU states have on Russian gas supply. Furthermore, the EU's uranium supply for nuclear fission primarily originates from non-EU countries, including geopolitically unstable nations such as Russia. In geopolitically concerned times, there is also a risk of attacks targeting nuclear power plants due to their vulnerability as single points of target. Such an attack also has the potential to disrupt substantial electricity supply and spread radioactive radiation over large geographical areas.

This sparks the question regarding how self-sufficient the EU should be regarding its energy production. Experts believe it would have a large impact on the development of the European energy market but it is uncertain to which extent the EU can become self-sufficient since the reliance on outside countries is so large. Several EU-strategies regarding this are in development. One initiative aims to build up mineral production and processing in Europe. Another such EU-initiative is REPowerEU which aims to reduce the dependency on Russian gas. The solution involved securing supply gas from other third countries as well as trying to expand the domestic gas supply. Moreover, if the geopolitical situation were to escalate in the world, it is likely that the EU and its members would try to develop energy sources that can provide large amounts of stable energy, like nuclear and fossil fuels.

5.2.4 Trend D - Increased resistance to local energy facilities

Impact	4,0
Certainty	5,1
Ratings	8

According to the experts, an issue with building wind power plants, especially in the nordic region, is that there can be resistance from the local population, since they disturb the surroundings with its appearance and loud sound. This is a factor that might make land based wind more difficult to scale as more attractive spots, away from populations, are filled. Experts are rather certain that this resistance will continue to increase as wind power continues to expand in Europe. A possible solution to this problem is to provide some sort of incentive for the affected people, for example to get electricity for a cheaper price. This is especially true in the case when the generated electricity is not meant for the local surrounding and instead is to be exported to other countries. However, the impact of this is still considered rather low compared to the other identified trends. This is largely due to the fact that other factors such as demand for electricity are likely to be valued higher by the stakeholders in charge, such as the government and the energy providers, whereas the local opposition will have little power to influence.

The same logic can be applied for nuclear power, whose reputation got damaged in Europe following the Chernobyl nuclear accident in 1986. In recent years the public opinion has shifted up and down and is today largely different between the EU member states. However, to be able to expand an energy source it is important to have as little local resistance as possible. This is especially true for fusion power, should it become commercially viable, as its acceptance may be hindered by negative perceptions associated with fission power, despite their differences in several areas such as waste management and level of radioactivity.

5.2.5 Trend E - Increased energy efficiency

Impact	5,1
Certainty	4,8
Ratings	7

Increased energy efficiency implies that the efficiency of the energy usage across various parts of the energy flow chain increases. In energy production, this involves employing optimal energy sources, processes and technologies to maximize energy output from the fuel while minimizing the energy losses during electricity generation. According to the experts, there is also significant potential to become more efficient in energy consumption. LED-lamps can be used instead of incandescent bulbs. Modern buildings are constructed to have a lower demand for heating than older ones. Efficient energy management- and automation systems can be used in both residential- and industry buildings to optimize the energy consumption. Another important aspect is to utilize the waste heat that is generated in the different steps of the energy flow chain.

Experts are moderately certain that Europe's energy system will become more efficient. The increased energy efficiency will reduce the overall demand of energy and is therefore an important trend. However, predicting its impact on the development of the various energy sources is difficult, as it is uncertain which energy sources will become more efficient.

5.2.6 Trend F - Improved and increased energy storage solutions

Impact	5,1
Certainty	5,3
Ratings	8

Energy storage solutions aim to store energy either long term or short term, and the experts are rather certain this will increase to some extent. However, the type of solution and the magnitude of the increase remain more uncertain. The main benefit of storing energy is that it can assist in evening out demand when supply of energy is low from intermittent energy sources such as wind and solar power.

This implies that it will have a large impact on the development of the energy mix in Europe, if it is expanded.

For long term storage, hydrogen energy storage is a solution that several experts believe could expand in Europe in the coming years. It is a form of chemical energy storage in which electrical power is converted into hydrogen, and then converted back to electricity when needed. The solution is rather simple and most suitable when the energy needs to be stored over multiple days or longer, when other solutions become too expensive. Another solution of storing energy is pumped storage hydropower, which is an effective storing method but is today rather expensive.

Short term storage, on the other hand, aims to even out the difference in energy supply and demand, rather than to store the energy. The most common solution for this is storage in batteries, for example lithium batteries. In households and other facilities, smaller batteries can be used to save investments in large transmission systems. Larger battery solutions can be used for evening out the larger energy demand. However, it is uncertain how effective they can be, since they are expensive to operate.

5.2.7 Trend G - Increased electrification

Impact	6,5
Certainty	5,8
Ratings	6

Multiple experts highlight that the most important factor for the EU to reach its climate goals is to become increasingly electrified. The energy usage in Europe is not necessarily expected to increase but the extent to which electricity is used rather than other energy sources is.

Electrification will appear in several sectors including transportation, heating and certain industries. In transportation, electric vehicles will be the main driver for electrification. Steel production is an example of an industry that looks to become electrified. In the process of creating steel, green hydrogen can be used that is produced by renewable energy sources instead of using coal that emits CO_2. For heating, electricity and heat pumps can be used instead of heating with natural gas or oil, which also would reduce CO_2 emissions.

5.2.8 Trend H - Worsened climate conditions

Impact	4,6
Certainty	6,0
Ratings	5

As the climate becomes warmer due to increased levels of carbon emissions, more frequent natural disasters occur. More thunderstorms, rising sea levels and higher temperatures are such examples. Experts are certain that will continue to happen and that future energy infrastructure initiatives will have to take this into consideration. However, how this will affect the various energy sources is difficult to predict.

5.2.9 Trend I - Increased investments in nuclear fission

Impact	5,5
Certainty	4,5
Ratings	2

Some experts highlight that the EU might need to ramp up investments in expanding nuclear fission power to ensure a stable energy system capable of meeting the rising electricity demand. It serves as a stabilizing factor for the energy system that can produce energy when the wind is not blowing and the sun is not shining. Others mean that such an expansion is not necessary and instead that solar and wind power in combination with efficient storage solutions can solve this issue. Either way, fission power is more costly compared to solar and wind power. Therefore, fission power cannot be built solely on market principles. Energy producers would require a guaranteed price for electricity from the government, with subsidies covering the remaining costs.

Furthermore, investing in nuclear fission has alternative uses. In England, investments in nuclear fission are motivated by military purposes. Smaller nuclear fission plants can be used in submarines and the nuclear engineering expertise can be leveraged to produce nuclear weapons.

Moreover, public opposition to nuclear fission arises because of the radioactive waste it produces. One solution to this is fourth-generation nuclear fission technology. In this new generation of nuclear fission, the fuel is more easily recyclable for reuse, while also being less suitable for nuclear weapons. It leaves no long term waste and poses a reduced risk to accidents with severe consequences.

6 Scenario analysis for the European energy market 2040

In this chapter, the two macro trends most suited to serve as the basis for the scenario analysis are selected to create scenarios for the European energy market in 2040. Moreover, each scenario's implications on fusion energy is evaluated.

6.1 Selection of trends for the energy scenarios

Table 7 explains the rationale for the categorization of each trend.

Table 7: Rationale to the rating of each trend

Category	*Trend*	*Rationale for categorization*
1. Certain trends	***G.*** Increased electrification	High certainty rating of 5.8/7.0.
	H. Worsened climate conditions	High certainty of 6.0/7.0.
2. Influencing trends	***A.*** Increased political governance to climate goals	Only 4/10 ratings. Also difficult to predict which energy sources will be affected if this trend is realized.
	D. Increased resistance to local energy facilities	Low impact rating of 4.0/7.0.
	E. Increased energy efficiency	Rather uncertain with a rating of 4.8/7.0 based on 7/10 ratings. However, it is difficult to predict how the realization of this trend will affect the development of the various energy sources.
3. Dependent trends	***B.*** Expansion of solar and wind power	Depends on the realization of many trends including C and F. High certainty rating of 5.9/7.0 based on 7/10 rating. Therefore expected to occur to some extent in each scenario.
	I. Increased investments in nuclear fission	Depends on the realization of many trends including C and F.
4. Selected trends	***C.*** Increased geopolitical security concerns	5.2/7.0 in certainty. Rated by all experts. Many comments and different opinions on how this trend will affect the development of the energy sources.
	F. Improved and increased energy storage solutions	5.3/7.0 in certainty. Rated by 8/10 experts. If realized it has a clear effect on the development of the various energy sources.

The certain trends are certain enough to be expected to occur in each scenario. The influencing trends are not used as a basis for the scenario analysis and the rationale for this is described in table 7. These trends could potentially have been categorized as selected trends due to their low level of uncertainty. However, as table 7 describes, trend A did not have enough ratings and information from experts to be selected. Trend E was not selected due to the difficulty of predicting how the realization of the trend would impact the various energy sources. Trend D was not selected due to having a low rating of impact. The impact of these influencing trends will instead be commented on in each scenario. The dependent trends are highly affected by the realization of the selected trends which is elaborated on in each scenario. However, trend B. *Expansion of solar and wind power* has such a high rating of certainty (5.9/7.0) that it is expected to occur to some extent in each scenario. Selected trends were the trends that were not rated to be certain and have enough underlying information and impact on the European energy market to be used as the basis for the scenario analysis.

6.2 Scenarios for the European energy market 2040

With the trends to be used for the scenario analysis identified, the 2x2 GNG matrix can be created, see figure 28. Each scenario is given a title that summarizes the conditions it sets for the European energy market.

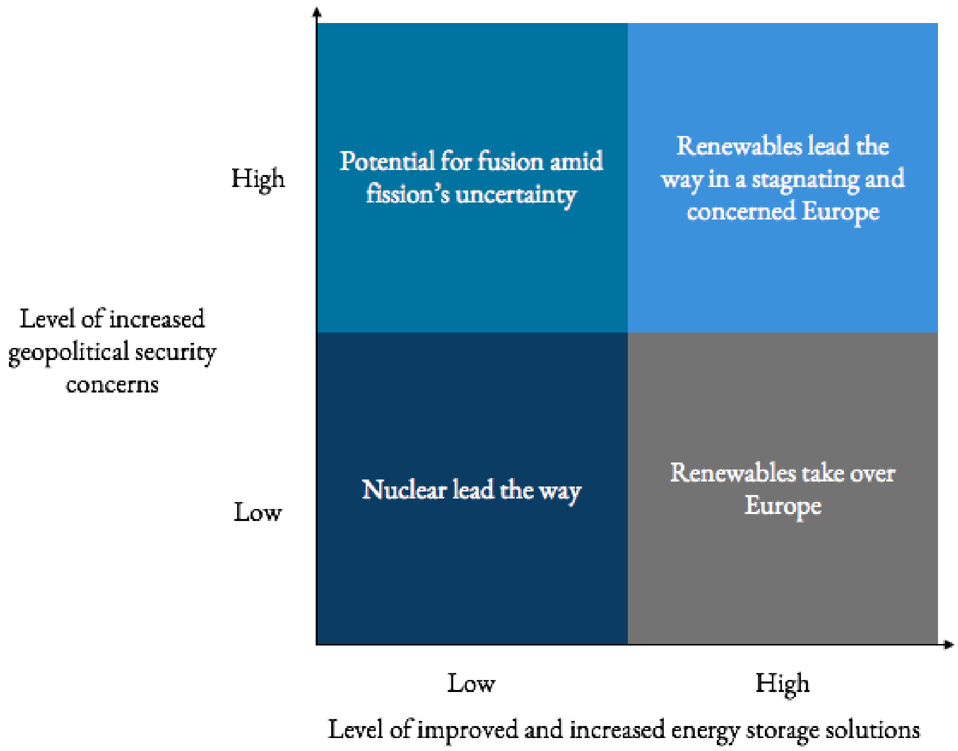

Figure 28: Visualization of each scenario in a 2x2 GNG matrix

The Y-axis represents the level of geopolitical security concerns. A high level implies that there are high political tensions globally. The X-axis represents the level of improved and increased energy storage solutions. A high level indicates that solutions for storing energy short term and long term have been successfully developed in Europe. The descriptions of each scenario are presented in figure 29.

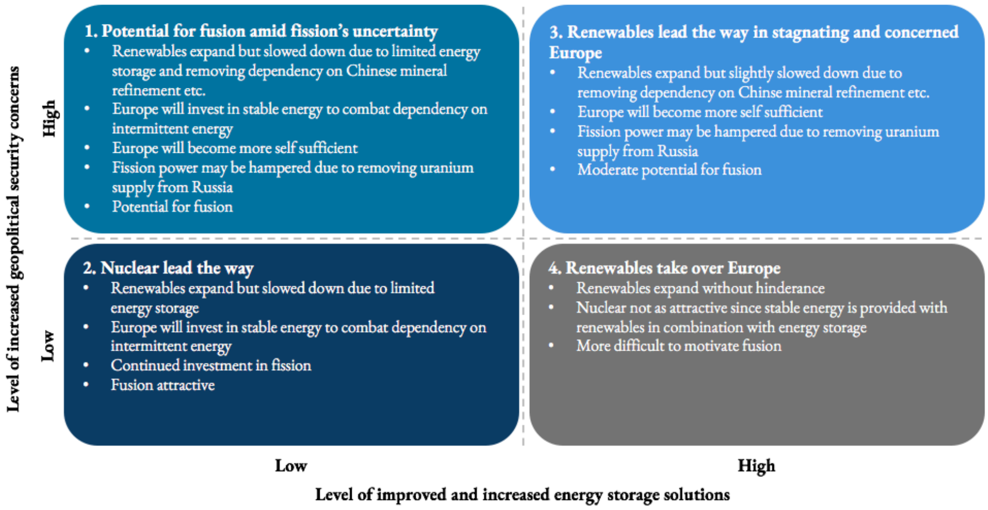

Figure 29: Scenarios for the European energy market in 2040 and their respective descriptions

6.2.1 Scenario 1 - Potential for fusion amid fission's uncertainty

Characteristics of scenario

- Energy storage solutions have not reached a level where they can sufficiently compensate for the intermittency of solar and wind power generation.
- Geopolitical concerns in Europe are high, leading the EU to lessen its energy system's reliance on geopolitically unstable countries and instead become more self-sufficient.

The increased electrification means that there is an increased demand for electricity. While solar and wind power expand, their growth is slowed down by the limitation of energy storage solutions. Their expansion is further hampered due to reducing the dependency on China for the processing of minerals used for wind turbines and solar cells. Instead the EU aims to utilize European minerals or import minerals for processing within the EU. However, this process will likely delay the expansion of solar and wind power as the EU needs time to reach the same level of competence and capabilities as China.

As the EU energy system lacks stable energy production, some other form of stable energy production is likely required. The primary options considered are fossil fuels or nuclear power. As described in chapter 5.1, fossil fuels are to be phased out due to emitting too high levels of carbon dioxide, leaving nuclear power as the primary option. Yet, uranium supply for the nuclear fission reactor comes from non-EU countries, including geopolitically unstable countries such as Russia. Potential reductions in these imports may hinder the development of nuclear fission power, as the uranium sourcing would have to come from within the EU or to be imported strictly from geopolitically stable countries.

Moreover, there is the threat of attacks on nuclear fission power plants, which could strike a further opposition against expanding the energy source. This scenario thus opens up opportunities for emerging energy sources, such as nuclear fusion power, to gain traction as an attractive option.

A further perspective can be gained when taking the influencing trends into consideration. If trend *A. Increased political governance to climate goals* materializes, governments may opt to subsidize nuclear fission power to gain stability in the energy system. Alternatively, they may support emerging energy sources, recognizing the limitation of the current energy mix to meet the increased electricity demand. If trend *D. Increased resistance to local energy facilities* is realized, it is likely even more difficult for nuclear fission to expand, since there is increased opposition against expanding the energy source, potentially paving the way for alternative energy sources. On the other hand, if trend *E. Increased energy efficiency* is realized, the surge in electricity demand may be mitigated, enabling the current energy mix to potentially cover the electricity demand without having to expand as much.

6.2.2 Scenario 2 - Nuclear lead the way

Characteristics of scenario

- Energy storage solutions have not reached a level where they can sufficiently compensate for the intermittency of solar and wind power generation.

- Geopolitical concerns in Europe are low. The EU does not strive for total self-sufficiency but rather relies on non-EU countries to supplement its energy system where needed.

While solar and wind power expand, their growth is slowed down by the limitation of energy storage solutions. Given the lack of stable energy production in the EU, some other form of stable energy production is likely required. Again, fossil fuels are to be phased out due to emitting too high levels of carbon dioxide, leaving nuclear power as the primary option. In this scenario nuclear fission does not have issues with the supply of uranium. There is also likely less public opposition against the energy source, allowing it to expand. However, drawbacks such as high cost and radioactive waste might affect its development. One solution to this would be to further invest in fourth generation nuclear fission which handles waste much more efficiently. Another option could be to invest in another emerging energy source that is either cheaper or provides other benefits, that also can account for the stability that is required in the energy system.

If trend *A. Increased political governance to climate goals* is realized in this scenario, governments may subsidize energy storage solutions so that they can expand further and cover the irregularities of solar and wind power. Another option is to subsidize nuclear fission to incentivize its expansion. The realization of trend *D. Increased resistance to local energy facilities* might impact this scenario if there turns out to be a strong opposition against building out nuclear fission power in Europe, where other emerging energy sources could become an attractive option. For nuclear fusion energy to be a viable alternative, separating its regulatory framework from that of nuclear fission energy would be essential, to gain its own reputation that underscores its advantages. Additionally if trend *E. Increased energy efficiency* is realized, again the surge in electricity demand may be lowered, enabling the current energy mix to potentially cover the electricity demand without having to expand as much.

6.2.3 Scenario 3 - Renewables lead the way in a stagnating and concerned Europe

Characteristics of scenario

- Energy storage solutions have been developed to efficiently assist in evening out demand when supply of energy is low from intermittent energy sources.

- Geopolitical concerns in Europe are high, leading the EU to lessen its energy systems reliance on geopolitically unstable countries and instead become more self-sufficient.

Solar and wind power expand and, with the potential to store generated electricity for use during periods of lower electricity production, short-term solutions like batteries can help regulate energy consumption while long-term options such as hydrogen storage serve as reserves during extended periods of low energy supply. However, the expansion of solar and wind power is slightly slowed down due to reducing the dependency on China for the processing of minerals used for wind turbines and solar cells, as in scenario 1. Europe will try to become more self-sufficient and process the minerals within the EU to the highest possible extent. The energy mix in this scenario is likely to be dominated by solar and wind power in combination with efficient storage solutions. However, the expansion will be slower which will likely delay the phasing out of fossil fuels and prolong the inclusion of nuclear fission power in the energy mix.

If trend *A. Increased political governance to climate goals* is realized the solar and wind expansion could accelerate through increased investment in creating EU-domestic mineral processing. Alternatively, subsidizing nuclear fission power may be an option if the shift of processing minerals in Europe is difficult. If trend *D. Increased resistance to local energy facilities* is realized, the expansion of wind power is likely to be slowed down, since it tends to disturb the surrounding population more than solar power. This would slow down the expansion of renewables and their expansion would primarily be driven by solar power. If trend *E. Increased energy efficiency* is realized, the surge in electricity demand may be mitigated, and solar and wind power would faster be able to cover the increased electricity demand.

6.2.4 Scenario 4 - Renewables take over Europe

Characteristics of scenario

- Energy storage solutions have been developed to efficiently assist in evening out demand when supply of energy is low from intermittent energy sources.
- Geopolitical concerns in Europe are low. The EU does not strive for total self-sufficiency but rather relies on non-EU countries to supplement its energy system where needed.

Solar and wind power can expand freely, with the potential to store generated electricity for use during periods of lower electricity production. Renewables in combination with efficient storage are likely to dominate the European energy mix and leave little room for other current energy sources to play a significant role. This energy system is stable, making investment in nuclear fission less likely due to its higher costs compared to solar and wind power. To compete with solar and wind power, an alternative that is equally environmentally friendly and cost-effective, or offers significant additional benefits, will need to emerge.

If *trend A. Increased political governance to climate goals* is realized the solar and wind expansion could accelerate through increased investments. If trend *D. Increased resistance to local energy facilities* is realized, the expansion of wind power is likely to be slowed down, since it tends to disturb the surrounding more than solar power. This would slow down the expansion of renewables slightly and their expansion would primarily be driven by solar power. If trend *E. Increased energy efficiency is realized,* the rise in electricity demand may be lowered, allowing solar and wind power to more rapidly meet the increased electricity demand.

6.3 Each scenario's implications on fusion energy

6.3.1 Scenario 1 - Potential for fusion amid fission's uncertainty

Overall, the Novatron employees agreed with the reasoning for this scenario. Fusion, as a stable energy source, is a viable solution to mitigate the intermittency of solar and wind power in the absence of developed energy storage solutions. Moreover, the supply of uranium for nuclear fission power needs to shift away from geopolitically unstable countries. One option is that Sweden could potentially provide uranium for all nuclear fission plants in Europe, since they have a high abundance of uranium. However, it would be time consuming and costly to build these mines and extract the uranium, likely slowing down the development of the energy source.

Furthermore, it was discussed that copper and rare earth metals used in solar and wind power plants are mostly supplied from outside the EU and that there will not be enough supply for all the wiring needed when building more solar and wind facilities. Therefore, shifting away from dependence on unstable countries could pose challenges for renewable energy initiatives in the EU. On the other hand, depending on how Novatron Fusion Group plans to use their product they may be more or less affected by this issue. The most likely path involves putting the solution in large electricity production facilities that only would require resistive magnets coupled with copper coils, which is a proven method used in other industries. This path could potentially supply the entire world with energy without affecting the price of these commodities. The other, less likely, path involves smaller fusion power plants on for example submarines, tankers or in smaller cities which would require much more advanced magnets that in turn require rare earth metals.

The discussion also addressed how the energy prices affect the attractiveness of fusion. In this scenario, the energy mix contains a low amount of cheap renewable energy sources due to the limitation of energy storage. With high geopolitical concerns, Europe is trying to reduce gas supply from Russia and likely results in rising energy prices. As fusion aims to become a cost-effective alternative to other energy sources, a higher energy price would make fusion more attractive.

To further pave the way for fusion energy, stakeholders in the value chain can play a vital role. Governments could use regulatory instruments to accelerate the commercialization of fusion as an option to safeguard European energy production. Another enabler is national efforts that could make large investments into fusion if they were to believe it could secure European energy production. Moreover, technical advancement by either private fusion actors, national- or joint international efforts could motivate investors to put further capital into fusion.

6.3.2 Scenario 2 - Nuclear lead the way

There was a general consensus regarding the description of this scenario, with a clear focus on the fission-fusion debate. However, as in scenario 1, it was clear that fusion, as a stable energy source, is a viable solution to mitigate the intermittency of solar and wind power in the absence of developed energy storage solutions. Novatron employees highlighted that even though nuclear fission is an attractive option, investments in research and development are about five times higher for fusion than fission, suggesting a long term preference of the fusion technology. It is also important that the regulatory frameworks are separated for fission and fusion. This has already been implemented in the UK and is likely to follow in the rest of Europe, starting with France and Germany where fusion has made the greatest progress. In this scenario, the reliance on Russian gas is less of an issue, resulting in a slower phase-out process and lower energy prices. This will reduce the hesitation of searching for new energy sources to add to the grid and thereby set a higher requirement for a low levelized cost of electricity for emerging technologies like fusion.

6.3.3 Scenario 3 - Renewables lead the way in a stagnating and concerned Europe

Once again, it was emphasized in this scenario that Europe is striving to phase out its reliance on Russian gas supply. This will lead to higher energy prices, providing greater potential for fusion energy to establish itself. Moreover, Novatron employees were skeptical about the feasibility of completely replacing fossil fuels, which currently make up over 70% of the European energy mix, with renewables combined with energy storage. To be able to scale solar and wind power to such an extent, an enormous amount of concrete, steel and other material goods will be needed. Numerous construction sites need to be established. The same applies for storage solutions, which must be implemented across the entire grid rather than in just isolated instances such as cars or homes. When comparing materials required per terawatt-hour, renewables demand significantly more than fusion power. Therefore, for fusion energy to be competitive, it is essential to focus on reducing capital costs and extending depreciation times.

6.3.4 Scenario 4 - Renewables take over Europe

There was a consensus that in this scenario the price of energy would be the lowest since the energy mix is dominated by renewables and there is no immediate push to phase out Russian gas supply. The urgent need to mitigate climate change is instead the main driver for phasing out fossil fuels. However, this transition means that there is a need for a stable energy source since it will be difficult to cover the entire demand with renewables in combination with energy storage. In this case, fusion energy is likely to adopt a more regional approach. Countries that lack stable energy production such as hydro and nuclear fission, nuclear fusion will likely be an attractive target. One example of this is Germany, which is one of Europe's largest markets. They can’t build hydro power plants and are opposed to nuclear fission power plants, making fusion power an attractive option.

6.3.5 Further discussions

The likelihood of each scenario occurring was also discussed. There was a consensus that scenario 1 and scenario 2 were the most probable. There is a large push to phase out fossil fuels and the electrification of various industries in Europe means that there is an increased demand for electricity. A significant part of the energy production needs to be planable. It is unlikely that the entire demand can be met solely with solar and wind power combined with energy storage since it requires substantial quantities of commodities, rare earth metals, and construction sites. Furthermore, there is a very large difference between the amount of energy storage that exists today compared to what is needed. Additionally, existing storage solutions are not effective enough, highlighting the need for substantial technology advancements to disrupt the market. Between scenario 1 and 2, Novatron employees lean toward scenario 1 being more probable. The geopolitical situation in Europe today is becoming increasingly unstable, which may drive efforts to become less dependent on geopolitical unstable countries and instead be more self-sufficient.

Lastly, tipping points of entering each scenario was discussed. One tipping point of reaching a high level of geopolitical concerns could be that the EU decides to completely cut the dependency of Russia for gas and uranium supply. Another event that could strike higher geopolitical concerns would be if a nuclear fission disaster were to occur. To reach a high level of increased and improved energy storage solutions, Novatron employees believe an entirely new technology for storing the energy would need to be developed. Current technologies have limitations that make them unlikely to meet the entirety of the electricity demand that will emerge. A solution that doesn't not contain commodities or minerals from geopolitically unstable countries, is not too expensive and can efficiently store energy is required, which does not currently exist.

7 Discussion

This chapter discusses the contributions of the findings in the study. It aims to explain the effect each energy scenario has on the stakeholders in the fusion value chain and provides recommendations for how Novatron Fusion Group can adapt its business accordingly. Moreover, the trustworthiness of the study as well as suggestions for future research is presented.

7.1 Contribution of findings

7.1.1 The fusion value chain

There are currently a limited number of articles that discuss a complete value chain for the fusion industry as well as the salience of the stakeholders involved in that value chain. However, in chapter 3.2.6 a similar stakeholder analysis conducted by Guðlaugsson et. al. (2020) is presented. The article defines and classifies nine stakeholder groups in relation to sustainable energy development in Iceland. Among the stakeholders, similarities to the stakeholders presented in table 3 can be seen. For example, decision-makers are similar to regulatory institutions, fuel importers are similar to suppliers of fuel, distribution and transmission are similar to customers/distributors, professional interest is similar to experts in academia and other organizations, etc. Similarly to the findings of this report is that decision-makers were deemed to have a high power to influence decision making. However, they were also deemed to have a high interest which differs from the results of this thesis. This could be a result of the difference in context behind the questioning where the report from Guðlaugsson et. al. (2020) focuses on sustainable energy development as a whole and this thesis focuses on fusion energy, an energy source which is in its early development compared to other energy sources and which consequently gains less interest from decision-makers/regulatory institutions. The study from Guðlaugsson et. al. (2020) includes distribution and transmission, industrial users and public and small business users. This is a more specific picture about potential customers and there might be a point to include these categories as separate to see their respective influence on the realization of commercial fusion. However, this thesis did not include too many actors to gain generalized insights. It would be interesting to further investigate potential customers in future studies.

In another report presented in chapter 3.2.6 by the Fusion Industry Association (2023b). Similarities between the proposed value chain for the fusion industry can be seen when looking at the supply chain spending which is presented in figure 16. While the figure does not show categories of suppliers but rather cost categories, one can draw conclusions as to which type of supplier may be responsible for a certain cost category. One can assume that suppliers of technology might be responsible for both fusion specific and non-fusion specific specialized components as well as software. Contract engineering and contract construction services would probably be supplied by manufacturers in this thesis. Professional services could be supplied from experts within academia and other organizations, fuel would be supplied by suppliers of fuel and raw materials from suppliers of raw materials. Commodity components is a category that might need to be captured as well. The category is defined as “off the shelf” products and an extension of the value chain could include suppliers of commodities to capture this cost category as well. However, some commodities might also fall under the presented supplier categories.

A separate report from the fusion industry association (2023a) was also presented in chapter 3.2.6. Interestingly, in this report private fusion companies believe that the first fusion power plant will deliver power to the grid by 2031-2035 while the experts interviewed in this thesis were more skeptical. A reason for this is that the companies surveyed in the study by the fusion industry association were all private companies, relying on investments during this stage of fusion. In this thesis, no experts from private fusion companies were interviewed. The experts interviewed in this thesis were investors, scientists or employees of ITER. This could provide a more restrained image of the time to commercialization while representatives from private fusion companies might have a more positive outlook both due to their ambition and to uphold a positive image to investors. Furthermore, private fusion companies believe that the biggest challenges are technological challenges and funding challenges, which coincides with the results in this thesis. Interestingly, private fusion companies do not believe that geopolitical challenges pose a big threat which is shown in both reports from the fusion industry association (2023a; 2023b).

Finally, this thesis explores the development of fusion from a diverse set of experts. The thesis provides a clear proposition of a fusion value chain and categorizes the stakeholders based on their salience, an analysis which few if any scientific reports have done. A comparison can be made to other geographical regions and industries to find similarities and differences, as has been done with the paper from Guðlaugsson et. al. (2020). Furthermore, this thesis investigates the development of the identified stakeholders up until 2040, contributing to an understanding of how different stakeholders will have to position themselves in the fusion industry and which stakeholders will be of most importance in the future.

7.1.2 Scenarios for the European energy market

To understand the academic contributions of the scenario analysis in this report, it is first put in context to existing similar literature. As outlined in section 3.4, in a study by Weber (2014), a scenario analysis for the European energy market was conducted. Weber's scenario analysis was based on a set of predefined uncertainties, similar to the ones in this thesis. The trends then acted as the base for what then became scenarios with varying conditions that affected the European energy mix in different ways. Nonetheless, distinctions arise when comparing Weber's scenario analysis with the one conducted in this thesis. Weber's approach involved identifying trends through a literature review, and only included trends that had a direct impact on the fluctuating renewable energy sources. Instead, this thesis relied on the insights of experts to identify key trends. The broad scope of trends ensured that a holistic approach was taken.

Furthermore, while Weber (2014) used a stochastic model to generate scenarios based on key uncertainties, resulting in five distinct scenarios, this thesis adopted a different approach. Here, experts rated each trend based on its impact on the European energy market and certainty of being realized. Moreover, whereas Weber's focused on the trend's implications of fluctuating renewable energy sources, this thesis broadened its scope to include trends that were influential across the entire European energy market. Where the scenarios in Weber's study were tailored to influence fluctuating renewable energy sources, the scenarios in this thesis were adapted to influence all energy sources in the European energy mix. The scenarios were then analyzed from a perspective of fusion energy.

Considering these factors, it is evident that the trends identified in this master thesis can create a variety of scenarios for the European energy market, depending on the reasoning for the selection of base-trends in the scenario analysis. It also presents a holistic approach of macro trends that will affect the European energy market up until 2040.

The scenario analysis creates future representations of how the European energy market might develop in the future. By offering a forward looking perspective, this research aids key stakeholders, such as energy providers and regulatory institutions, in anticipating and preparing for significant shifts in the energy landscape. Moreover, it enables them to develop strategies that can effectively navigate these shifts and position themselves advantageously for the future.

Unlike general energy market studies, this thesis specifically discusses the implications each energy scenario has on fusion energy. The information contributes to both academic knowledge and practical applications by bridging the gap between theoretical energy market studies and the specific needs of the fusion energy sector. The practical recommendations targeted for key fusion stakeholders can help drive the adoption and success of fusion energy in the European market.

7.2 Reflections and recommendations

The results from interviews with both fusion experts and energy experts have resulted in a mapping and prediction of the development of stakeholders in the fusion value chain as well as scenarios on the European energy market 2040. How these two results affect each other, what this means for a private fusion company and recommendations as to how to adapt to each scenario will be discussed below.

7.2.1 Scenario 1 - Potential for fusion amid fission's uncertainty

Fusion experts believe that investors will increase their interest in fusion energy as the development of the energy source continues. This is supported by the fact that fusion power is faced by lower barriers of entry to the energy market due to the limping of other energy sources. Although private investors most likely will be more reluctant to make risky investments during uncertain times, fusion energy will be a more attractive option to other energy sources due to the fact that it is mostly unaffected by the geopolitical supply constraints. Furthermore, experts expect suppliers of fuel to lose power but gain interest in fusion energy. It is possible that tritium suppliers might lose some interest in this scenario because military applications are looking more and more attractive. However, this will most likely not affect the fusion producers that are looking to create their own tritium in the reactor, but it emphasizes the importance of solving tritium breeding. Additionally, lithium suppliers might move their interest from the power storage industry to the fusion industry since the power storage industry did not reach significant breakthroughs, motivating the increase in interest for fuel suppliers. Regulatory institutions will most likely keep a lot of power due to the geopolitical instability. However, they will probably increase their interest in fusion by more than what is predicted by fusion experts because of the high energy prices coming from a limited energy supply, which is a consequence of the complications for renewables and fission power. This could possibly move regulatory institutions into the *key players* category. To further pave the way for fusion energy, other *key players* in the value chain can play a vital role. National efforts could drive large projects for fusion if they were to believe it could secure European energy production. Moreover, technical advancement by either private fusion actors, national- or joint international efforts could motivate investors to put further capital into fusion.

If this scenario is realized it is important for Novatron to capitalize on the complications of other energy sources. Novatron must convince regulators that there is no chance of Europe being self-sufficient without fusion and to separate the regulatory framework from fission power highlighting the differences between the two energy sources. Furthermore, it is important to attract both public- and public-private investors by highlighting the fact that the fusion value chain is not affected by the constrained supply from outside of the EU. In this scenario Novatron also has many different business opportunities. They could produce electricity directly to the grid, sell their product to electricity producers or, if they manage to succeed with tritium breeding, become suppliers of fuel to both other fusion producers and the military industry. Lastly, it is important to secure good supplier relations since the competition for European suppliers may become fierce. This is especially important for suppliers of technology due to their presence in the *key players* category.

7.2.2 Scenario 2 - Nuclear lead the way

Since there are limited storage solutions, Europe is in need of stable energy. As fission is already implemented in Europe's energy system it will most likely be the first choice for stable energy, given there is limited local opposition. This might move fission power into the *keep satisfied* category of stakeholders because they gain more control of the energy market and get more power to affect the commercialization of fusion power. Furthermore, investors might focus their investments on fission power plants, limiting their interest in fusion. However, fusion is still interesting as an alternative for stable energy, especially in countries where local opposition to nuclear fission is greater. Since Europe is geopolitically stable investors might also take bigger risks. Because nuclear fusion and fission are similar in the way they operate power plants to generate electricity, there will be greater competition for power plant manufacturers. However, there will also be more competence on how to run power plants as well as more interest in nuclear research in general, aligning with predictions of experts in academia and other organizations moving into the *key players* category. Since fission and fusion are very different in the technology and fuel required for the respective reactors there will be no competition for these kinds of suppliers. Tritium may even become more prominent since fission power plants may be able to sell it as a by-product to fusion developers.

For private fusion companies such as Novatron it is important to capitalize on the momentum of nuclear energy. Private fusion will benefit from collaborations with fission to share power plant expertise and share the market for stable energy. At the same time it is important to lobby the regulatory institutions to separate the regulatory framework that governs fission power from fusion power. Furthermore, Novatron should target countries where local opposition to fission power is strong or is developing negatively to act as a stable alternative to renewables. In countries where local opposition to fission is lower it might be a good idea to sell the reactor to fission companies already having the expertise on how to run power plants. Furthermore, since energy prices are lower than in scenario 1 it is now important to reach a higher electricity efficiency and lower investment costs to bring down the levelized cost of electricity to motivate investors.

7.2.3 Scenario 3 - Renewables lead the way in a stagnating and concerned Europe

Since Europe can not buy Russian gas, energy prices will be higher giving some leeway for fusion to enter the market. Investors will keep some of their interest in fusion but most will move towards renewables. Renewables will gain more power over the energy system, possibly moving into the *keep satisfied* category since they may affect the development of commercial fusion. Since energy storage solutions are effective and the electrification of Europe is a fact, fossil producers will lose a lot of power in Europe, possibly gaining interest in other energy sources such as fusion moving toward the *keep informed* category. Fission power producers may continue their operation of current power plants but they will most likely not have the support to scale due to the unstable geopolitical situation.

In this scenario private fusion companies such as Novatron should aim their businesses to geographical locations where renewables face either local opposition or encounter limiting environmental conditions, such as low wind or frequent cloud cover. Even though storage solutions exist, the energy must be transported to these locations which may be very expensive, motivating the use of fusion power. Furthermore, Novatron could seek investment or sell their product to other energy producers such as producers of fossil power and fission power due to them losing influence in the European energy market. Additionally, it is important to secure European suppliers as discussed in scenario 1.

7.2.4 Scenario 4 - Renewables take over Europe

This scenario might impose the biggest barriers for fusion to enter the European energy market. Both producers of renewables and fission power may in this scenario gain power in the context of realizing commercial fusion, but renewables more so than fission. However, in countries such as Germany where there is an opposition to fission power and limited wind there may be possibilities for fusion or other emerging energy sources to act as a complement to renewables. In this scenario investors' interest in fusion may be lower than experts expect due to the high barriers of entry, remaining in the *keep satisfied* category. Regulatory institutions may continue to have a slightly lower interest in fusion since renewables are working well. Experts from academia and other organizations may also have a lower interest than expected since there is lower opportunity for fusion to penetrate the market and less people educate themselves on the subject.

In this scenario private fusion companies like Novatron face big challenges to scale. It is important to find public- or public-private investors looking for long term investments, as they may realize that more energy is needed in the future regardless of how the market looks today. Furthermore, it is important to target geographical areas with limited stable energy, an opposition to fission power and little space for solar, wind or hydro. Additionally, it may be of interest selling fusion energy to industries that have an interest in having their own supply of energy. An example of this could be large electric car manufacturers like Tesla, supplying their charging stations with fusion power. Another example are the steel industries who are looking to electrify. If significant magnet breakthroughs are made fusion may also be used in miniature scale, producing power for single electric vehicles or airplanes.

7.2.5 Further reflections

The theory from Johnson and Scholes (2008) provides a good mapping of stakeholders in a general industry. However, depending on the lifecycle stage of the industry some adjustments might be suitable. Because the fusion industry is currently under development and does not exist commercially this might affect how the salience of stakeholders should be made. For example, from chapter 4.2.2 it is shown that experts believe that the most important challenge to solve for fusion to succeed within 15-20 years are technical problems, shortly followed by investment issues, political support and cost efficiency. Technical problems are closely linked to funding since research needs to be made to make advancements in technological development which in turn requires money from investors. Political support can also be linked to regulatory institutions providing leeway for fusion to develop. Furthermore, both investors and regulatory institutions were rated high in their power but lower in their interest by experts, but still seem to be very important for the success of fusion. Therefore, the model from Johnson and Scholes (2008) might take this into consideration, prioritizing power over interest for industries that are in early stages of development or have not yet matured. This would mean that stakeholders with a lot of power but lower interest are also deemed as *key players* with a higher salience, such as the case for investors and regulatory institutions. The revised mapping could look like figure 30.

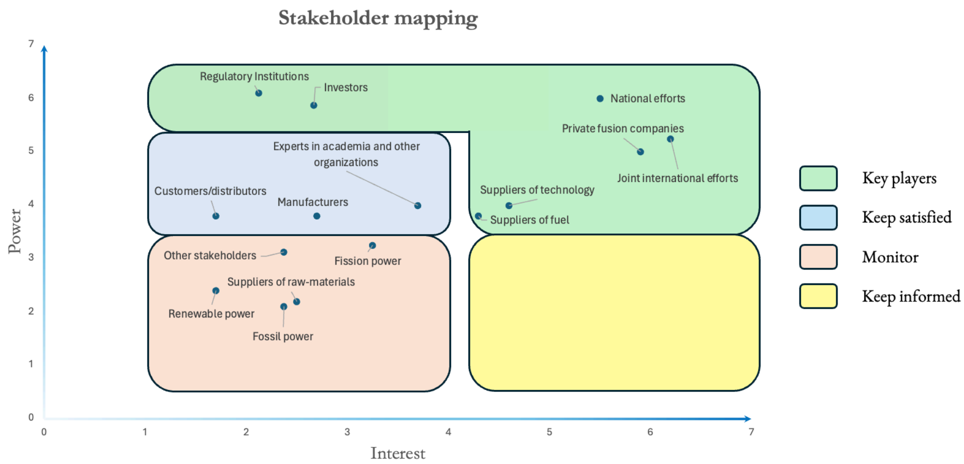

Figure 30: An alternative mapping of the stakeholders in the fusion value chain based on the ratings from experts and adapted to the theory from Johnson and Scholes (2008)

7.3 Trustworthiness

The majority of the findings in the thesis rely on the information the expert's provided in the conducted interviews. In selecting these experts, the researchers were thorough to ensure their backgrounds were relevant, the sample size was sufficiently large, and that a diverse range of experts was represented, to mitigate bias. For the European energy market segment, 10 interviews were conducted which were thought to be a high enough number, although additional interviews could have increased to validity. These experts possessed varied competencies, spanning academia, governmental organizations and private actors, within the energy sector. However, the researchers were unable to schedule interviews with experts with political background. This would have given the perspective of a regulatory stakeholder that possesses high power to influence how the European energy market might develop. This would have further broadened the range of backgrounds of the interviewed experts and thus strengthened the trustworthiness of the scenario analysis. Moreover, 9 out of 10 experts were located in Sweden. This may have led to a bias in overestimating the significance of the Swedish energy market when evaluating aspects related to the broader European market. One example of this can be seen in the rating of *Trend D. Increased resistance to local energy facilities*, which the one expert outside Sweden rated as having much lower impact compared to the rest of the experts. This is likely because this is a larger problem in Sweden compared to the rest of Europe.

Additionally, in the energy interviews, some trends that were brought up by experts in first interviews were prompted to the later interviewees to get additional rating and insights. This could have introduced some bias by prompting the experts, and could have been mitigated by circulating the final trends to all experts via email for validation of their reasoning and ratings.

For the fusion interviews, the sample size was smaller with only 6 interviews conducted. Increasing this number could have increased the validity of the ratings and qualitative insights provided. The fusion experts that were interviewed had different professional backgrounds within the fusion industry, being either investors, in academia, or working at joint international efforts. However, most of the experts were stakeholders in the fusion value chain, implying that they assessed their own organizations, potentially introducing bias. Additionally, the majority of fusion experts were based in Sweden, indicating a potential bias towards Swedish perspectives. Expanding the sample size and including experts from all stakeholder categories could have reduced the bias. However, since the fusion industry is not commercially viable yet, there is a lack of experts within the field and it was therefore difficult to find enough experts with the relevant background.

7.4 Suggestions for future research

During the course of the project, the researchers came across many potential areas to explore further but were constrained by time limitations. One notable constraint was the limited number of conducted interviews. Future research could use the same approach as this study but aim to interview a larger number of experts, with a greater geographic spread. This would offer a broader comprehension of European viewpoints regarding both the European energy market and the fusion industry, instead of solely relying on experts from sweden. Moreover, the scope of this study was limited to the European energy market and fusion energy within Europe. Future investigators could expand this scope to be global, examining the evolution of the worldwide energy market and identifying macro trends shaping it. This broader perspective could potentially offer further insights to regions where emerging energy sources such as fusion might be attractive.

Based on the findings regarding fusion energy's potential to be integrated into the European energy mix, several areas of further studies emerged that were out of the scope for this study. This study attempted to gather information on fusion's levelized cost of energy and compare it to other energy sources. However, as new technologies evolve these numbers quickly become outdated, which future researchers could try to estimate new estimates of. Additionally, the study identified fusion and fission energy operating under similar regulatory frameworks across European countries. The process of establishing a distinct regulatory framework for fusion is a great enabler for the energy source. Future researchers could investigate how different regulations affect the pace of development and what policy incentives are most effective in promoting fusion energy.

Lastly, the macro trends identified and energy scenarios created were constructed objectively based on expert's input, without being influenced by fusion energy. This gives further researchers the opportunity to explore other emerging energy sources like wave power, bioenergy or geothermal energy and understand the necessary steps for their integration into the European energy landscape.

8 Conclusions

The final chapter concludes the findings of the study and answers the research questions presented in chapter 1.

8.1 Short summary

The purpose of the project was to identify and categorize stakeholders in a potential fusion value chain, create future scenarios for the European energy market in 2040, understand the implications each scenario has on the fusion industry and form recommendations for how Novatron Fusion Group can navigate effectively within each scenario. The project identified a range of stakeholders that together formed a value chain for the fusion industry. Each stakeholder's salience was determined through a stakeholder analysis, resulting in several "key players" crucial for the success of fusion energy. Moreover, interviews with energy experts formed nine macro trends, which were rated for their potential impact on the European energy market and likelihood of realization. Two trends, "Increased geopolitical security concerns" and "Increased and improved energy storage solutions," were selected to be used as basis for the scenario analysis, resulting in a 2x2 matrix outlining four plausible scenarios for the European energy market in 2040. Furthermore, the implications for the fusion industry and its stakeholders were evaluated and recommendations for how Novatron Fusion Group can strategically navigate in each scenario were determined.

8.2 Answering research questions

To fully address the general research questions, each sub question is answered separately.

8.2.1 RQ1

What distinct categories of stakeholders does a potential fusion value chain consist of?

The stakeholders identified can be seen in table 8:

Table 8: Description of the stakeholder categories in the fusion value chain

Type of stakeholder	***Description***	***Example***
Suppliers of know-how	Suppliers of know-how deliver competence in the form of talent and research to fusion companies	Often include universities or non-profit organizations. *KTH, Aerospace Corporation, Fusion Energy Insights*
Suppliers of raw-materials	Supply raw-materials that are robust enough to withstand the extreme heat produced from the fusion reaction.	Includes engineering companies and mining/quarrying companies *Sandvik AB, Thyssenkrupp, Midwest Tungsten Service*
Suppliers of technology	Provides advanced technology such as magnets, automated control, lasers, simulation software, vacuum systems etc.	Includes engineering firms, energy firms, software firms and nuclear technology firms *General Atomics, COMSOL*
Suppliers of fuel	Supplies fuel to be used for operation of the reactor magnets, breeder blankets and for the fusion reaction itself	Suppliers of deuterium, tritium, lithium and cryogenics. Usually gas or chemical companies. *Linde gas, SQM, Albemarle*
Manufacturers	Manufacturers can assist in designing, building and installing the reactor. They can also offer maintenance services and testing.	Usually engineering and technology firms with a niche in high tech engineering projects *ENERCON, ALSYMEX*
Private fusion producers	Developers of commercially viable fusion energy. Usually with innovative solutions and with a short time to market scope.	Private fusion producers are usually spin off startups building on ideas from research institutions *Novatron Fusion Group, Helion Energy, Commonwealth Fusion*

Type of stakeholder	***Description***	***Example***
Joint international efforts	Funded research projects usually involving several countries to accelerate the development of fusion energy.	Can include multiple governments, non-profit organizations or institutions *ITER, JT-60SA, NIF*
National efforts	Research projects that are funded by single nations to develop fusion for long term energy security.	Governmental institutions that may be members of international collaborations *UKAEA (UK), IPP (Germany)*
Customers/ distributors	Customers purchase valuable by-products like Helium, Tritium, or neutrons, as well as licenses or electricity for direct use.	Various potential customers such as TSOs, DSOs, industries, power plant operators, space agencies, etc. *E:on, Vattenfall, NASA, Tesla*
Regulatory institutions	Sets the framework for which fusion power can operate within. Sets standards for safety, waste disposal and economic viability	Governments, institutions, international organizations. *IAEA, DG ENER, EURATOM, EUROfusion, Fusion for Energy*
Investors	Essential in providing funds for all stakeholders, but in particular private fusion companies and joint international efforts	Global companies with energy in their value chain, private-, public- and public-private investors. *Tesla, Equinor Ventures, Euratom, EIT InnoEnergy, Sam Altman*
Renewable power	Producers of energy using renewable sources such as solar, wind and hydro.	Companies ranging from large scale production to smaller local production. *Vattenfall, Svea Solar, Vestas*
Nuclear power	Producers of energy that uses the splitting of atoms, fission, rather than fusion. No greenhouse gas emissions are released but produce radioactive waste.	Usually operated by utility companies, energy corporations, government agencies or independent power producers. *Fortum, Vattenfall, E.on, EDF*
Fossil power	Companies utilizing fossil fuels like coal, oil, or natural gas for energy, including both	Typically includes global companies vertically integrated

Type of stakeholder	*Description*	*Example*
	those refining fossil fuels and those generating electricity.	across multiple segments in the fossil fuel industry. *Shell, BP, Equinor, TotalEnergies*
Other stakeholders	Other stakeholders may affect fusion development in a myriad of ways ranging from insurance to consultancy within legal issues.	Can include legal or management consultancies, insurance companies, financial institutions, media etc. *Accenture, Lloyds, Pillsbury Winthrop Shaw Pittman LLP*

The further categorization based on the stakeholder salience can be seen in figure 31.

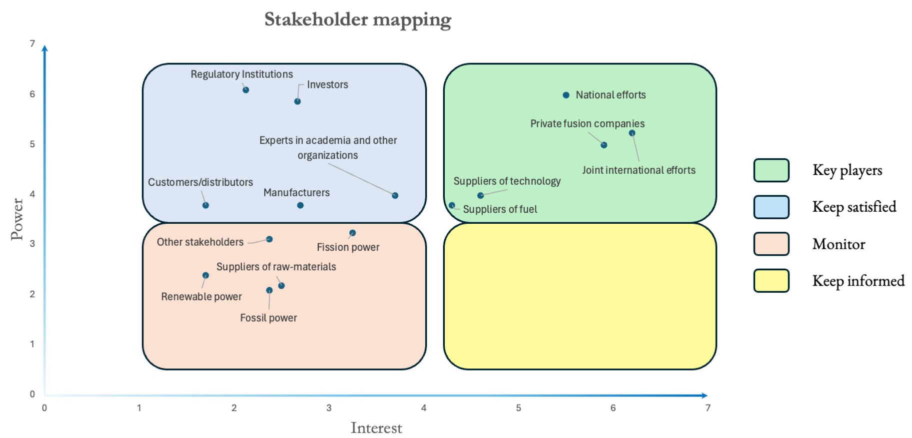

Figure 31: Positioning of stakeholders based on external interviews with experts and company representatives according to the theory from Johnson & Scholes (2008)

The development of stakeholders in the fusion value chain is illustrated in figure 32.

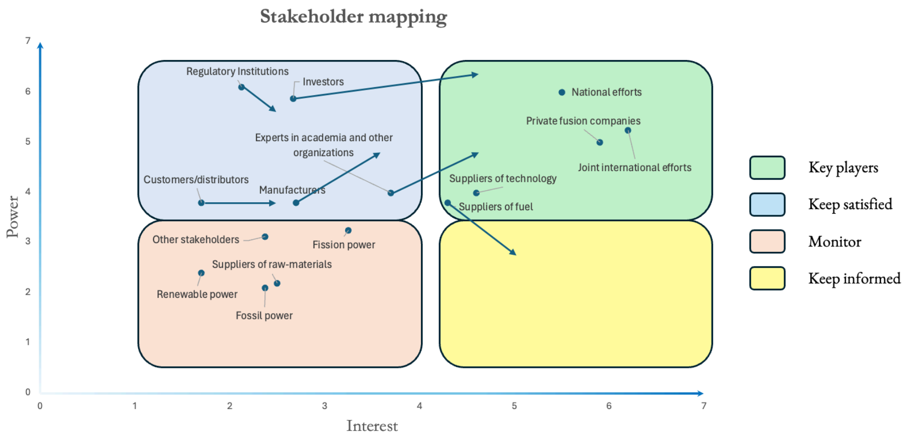

Figure 32: Development of the stakeholder's in the fusion value chain up until 2040 as visualized in the power/interest matrix.

8.2.2 RQ2

What scenarios for the European energy market in 2040 can be created based on identified macro trends?

The two trends "C. Increased geopolitical security concerns" and "F. Improved and increased energy storage solutions" were determined to be used as the basis for the scenario analysis. This created a 2x2 matrix, known as the GNG matrix, showing four plausible scenarios for the European energy market in 2040, displayed in figure 33. Each scenario is given a title that summarizes the conditions it sets for the European energy market.

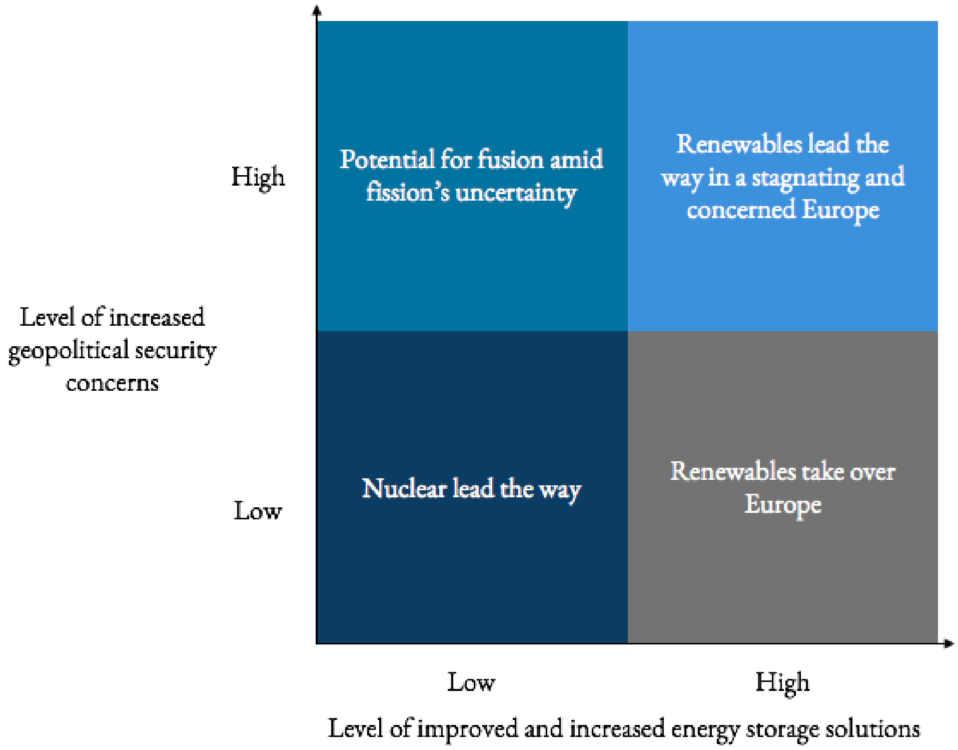

Figure 33: Visualization of each scenario in a 2x2 GNG matrix

The Y-axis represents the level of geopolitical security concerns. A high level implies that the EU:s energy system becomes less dependent on geopolitically unstable countries and instead becomes self sufficient. The X-axis represents the level of improved and increased energy storage solutions. A high level indicates that solutions for storing energy short term and long term have been successfully developed in Europe.

Figure 34 describes each scenario's effect on the European energy market.

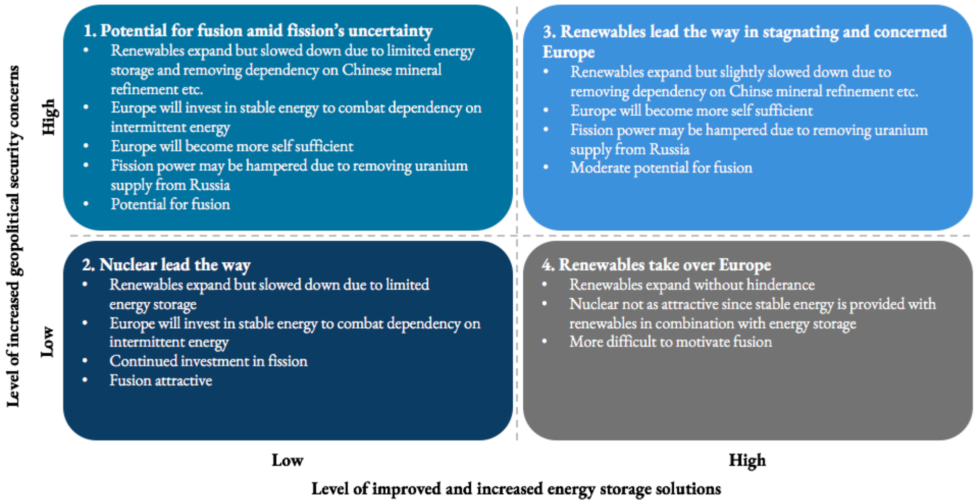

Figure 34: Scenarios for the European energy market in 2040 and their respective descriptions

8.2.3 RQ3

What implications do each scenario have on fusion energy and the identified stakeholders?

8.2.3.1 Scenario 1 - Potential for fusion amid fission's uncertainty

Implications on the fusion industry

- Supply of uranium for nuclear fission power needs to shift away from geopolitically unstable countries, likely slowing down the development of fission energy. Copper and rare earth metals used in solar and wind power plants are mostly supplied from outside the EU, shifting away from this could pose challenges for the expansion of renewable energy sources. Novatron is less opposed to these geopolitical risks due to not having the dependency on rare earth metals for their production.
- Fusion, as a stable energy source, is a viable solution to mitigate the intermittency of solar and wind power in the absence of developed energy storage solutions.
- With high geopolitical concerns, Europe is trying to reduce gas supply from Russia and likely results in rising energy prices. As fusion aims to become a cost-effective alternative to other energy sources, a higher energy price would make fusion more attractive.
- Fusion stakeholders

- Investors will increase interest in fusion energy due to the limping of other energy sources, moving them into the *key players* category.
- Regulatory institutions might move into the *key players* category due to an increased interest in fusion as a consequence of a limited energy supply driving energy prices upwards.
- Suppliers of fuel lose power to influence the fusion industry but increase their interest, moving them into the *keep informed* category.
- Technological advancements by national efforts, joint international efforts and private fusion companies may motivate investors to put further capital into fusion energy.

How Novatron can navigate in this scenario

- Convince regulatory institutions to separate fusion from the regulatory framework that governs both fusion and fission energy and highlight the need for stable energy.
- Secure investors by highlighting the fact that fusion energy is unaffected by geopolitical instability and can provide stable energy to the grid.
- Secure good supplier relations, especially technology suppliers, as there is a high demand for European suppliers.

8.2.3.2 Scenario 2 - Nuclear lead the way

Implications on the fusion industry

- Fusion, as a stable energy source, is a viable solution to mitigate the intermittency of solar and wind power in the absence of developed energy storage solutions.
- Nuclear fission is an attractive option, although investments in research and development are about five times higher for fusion than fission, suggesting a long term preference of the fusion technology
- For the success of fusion, it is important that the regulatory frameworks for fission and fusion are separated. This has already been implemented in the UK and is likely to follow in the rest of Europe, starting with France and Germany where fusion has made the greatest progress.
- The reliance on Russian gas is less of an issue, resulting in a slower phase-out process. Consequently, energy prices are lower. This will reduce the hesitation of searching for new energy sources to add to the grid and thereby set higher demand for levelized cost of electricity for emerging technologies such as fusion.
- Fusion stakeholders

    - Fission power moves into the *keep satisfied* as they gain more control of the energy market.
    - Investors generally take bigger risks due to a more stable geopolitical situation in Europe. However, some interest may be directed towards fission energy due to its strong position on the energy market.
    - Experts in academia and other organizations may move into the *key players* category due to an increased supply and demand for competence on the market.
    - Suppliers of technology and fuel are unaffected by the increased market potential of fission power. Tritium may even become more prominent.

How Novatron can navigate in this scenario

- Collaborate with fission power producers to share power plant expertise and benefit from the momentum of fission energy.
- Lobby regulatory institutions to separate regulatory framework for fission and fusion to provide some leeway for fusion power.
- Target countries where local opposition is stronger towards fission to act as a stable alternative to renewables.
- In countries where opposition to fission is lower Novatron should sell their product to fission companies, who already have the expertise on how to run power plants.
- Focus on reaching a high electricity efficiency, lowering the levelized cost of electricity.

8.2.3.3 Scenario 3 - Renewables lead the way in a stagnating and concerned Europe

Implications for the fusion industry

- Europe is striving to phase out its reliance on Russian gas supply. This will lead to higher energy prices, providing greater potential for fusion energy to establish itself.
- Skeptical about the feasibility of completely replacing fossil fuels, which currently make up over 70% of the European energy mix, with renewables combined with storage, implying that there is a need for further stability in the energy mix, with fusion energy as one potential option.
- When comparing materials required per terawatt-hour, renewables demand significantly more than fusion power. Therefore, for fusion energy to be competitive, it is essential to focus on reducing capital costs and extending depreciation times.

- Stakeholders
    - Renewables gain more power over the energy system, possibly moving into the *keep satisfied* category.
    - Fossil energy producers lose a lot of power in Europe, possibly gaining interest in other alternatives such as fusion power, moving them towards the *keep informed* category
    - Fission power will continue operation of already present power plants but might not have the support to scale since stable energy is provided by storage solutions.

How Novatron can navigate in this scenario

- Novatron should target geographical locations where local opposition or environmental conditions provide barriers for renewables.
- Novatron should seek investment or sell their product to other energy producers such as producers of fossil power or fission power.
- Novatron should secure European suppliers due to the geopolitical instability.

8.2.3.4 Scenario 4 - Renewables take over Europe

Implications for fusion

- The price of energy would be the lowest since the energy mix is dominated by renewables and there is no immediate push to phase out Russian gas supply. This will reduce the hesitation of searching for new energy sources to add to the grid and thereby set higher demand for levelized cost of electricity for emerging technologies such as fusion.
- The urgent need to mitigate climate change is instead the main driver for phasing out fossil fuels. However, this transition means that there is a need for a stable energy source, such as fusion energy, since it will be difficult to cover the entire demand with renewables in combination with energy storage.
- In this case, fusion energy is likely to adopt a more regional approach. Countries that lack stable energy production such as hydro and nuclear fission, nuclear fusion will likely be an attractive target. One example of this is Germany, which is one of Europe's largest markets.
- Stakeholders
    - Both renewables and fission have a lot of power in the context of realizing commercial fusion, possibly moving them into the *keep satisfied* category

  - Investors' interest in fusion is probably lower than anticipated by experts, potentially keeping them out of the *key players* category.
  - Experts from academia and other organizations may also stay in the *keep satisfied* category since fusion has a lower opportunity to penetrate the energy market which affects people's interest to educate themselves in fusion.

How Novatron can navigate in this scenario

- Find public or public-private investors looking for long term investments.
- Target geographical areas with limited stable energy, an opposition to fission power and little space for solar, wind or hydro.
- Sell fusion energy to industries that have an interest in having their own supply of energy. For example Tesla or the steel industry.

8.3 Final Remarks

It has been a pleasure writing this thesis. Fusion energy is a complicated but interesting subject and learning about how far research has come, as well as the potential of the energy source has been very exciting. Furthermore, it has been fascinating hearing about the predicted development of the European energy market. It has been challenging combining the two subjects but very rewarding. As a conclusion to this thesis, highlighting the importance of fusion energy, we would like to share a quote written on a pair of sunglasses provided by Novatron Fusion Group:

"A day without fusion is a day without sunshine"

Thank you.

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Appendix A

Interview Guide - Fusion Experts

Introductory questions - 5-10 min

Statements/intro

1. Is it okay if we record this meeting?
2. Would you like to stay anonymous?
3. Do you have a meeting after this one?
4. Present ourselves and our roles
5. Briefly introduce our project
    a. Fusion energy
    b. Scenario planning for the european energy market in 15 - 20 years
    c. Categorize actors using stakeholder analysis
    d. What role will fusion play in the future scenarios created
6. Are you more comfortable answering questions about fusion or energy?

Q1: Please briefly tell us about your professional background?

Q2: How well are you acquainted with fusion energy? Please give an answer between 1-7.

Questions about the development of fusion energy - 15-20 min

Q3: Do you think that fusion energy could become a viable option to other energy sources within 15-20 years? Why/why not?

Q4: What do you think are the major challenges for future fusion energy to succeed within 15-20 years?

Q5: What do you believe are the major costs related to fusion energy? Will they change in the coming 15-20 years?

Q6: What are the biggest advantages of fusion energy?

Overview of fusion value chain - 20-30 min

Q7: Who do you believe are the major players in a potential fusion value chain?

Q8: Do you agree with this representation of the fusion value chain? If not, what would you change?

Fusion producers

Q9: Could you describe what this stakeholder brings to the value chain?

Q10: How will its role develop in the coming 15-20 years?

Joint International Efforts
National Efforts
Private Fusion Producers

Suppliers

Q11: Could you describe what this stakeholder brings to the value chain?

Q12: How will its role develop in the coming 15-20 years?

Suppliers of:

- *Fuel*
- *Raw materials*
- *Technology*
- *Experts in academia and other organizations*

Investors

Q13: Could you describe what this stakeholder brings to the value chain?

Q14: How will its role develop in the coming 15-20 years?

Regulatory institutions

Q15: Could you describe what this stakeholder brings to the value chain?

Q16: How will its role develop in the coming 15-20 years?

Customers / distributors

Q17: Could you describe what this stakeholder brings to the value chain?

Q18: How will its role develop in the coming 15-20 years?

Other energy producers

Q19: Could you describe what this stakeholder brings to the value chain?

Q20: How will its role develop in the coming 15-20 years?

Other energy producers:

- *Renewable power*
- *Fossil power*
- *Fission power*

Manufacturers

Q21: Could you describe what this stakeholder brings to the value chain?

Q22: How will its role develop in the coming 15-20 years?

Rating actors 1-7

Q23: On a scale 1-7, how would you rate the following actors' interest in the fusion industry? How would you rate their power in the fusion value chain?

Stakeholder	***Interest***	***Power***
Joint international efforts		
National efforts		
Private fusion companies		
Suppliers of technology		
Suppliers of fuel		
Suppliers of raw-materials		
Experts in academia and other organizations		
Investors		
Regulatory institutions		
Customers/distributors		
Renewable power		
Fossil power		
Fission power		
Manufacturers		

Other stakeholders

Q24: Are there any other relevant stakeholders you want to discuss?

Q25: How will their role develop? Power/interest?

Potential others.

- *Consultants*
- *Insurance companies*
- *Maintenance*
- *Testing*
- *Inspection*

Finishing questions - 5 min

Q26: Are there any macro trends in the European energy market that could affect the development of fusion energy, either positively or negatively?

Q27: Is there anything else you would like to discuss regarding the development of fusion energy?

Q28: Can we reach out if we have any further questions?

Q29: Is there anybody else you believe that we should interview?

Interview Guide - Energy Experts

1. Introductory questions - 5-10 min

Statements/intro

1. Is it okay if we record this meeting?
2. Would you like to stay anonymous?
3. Do you have a meeting after this one?
4. Present ourselves and our roles?
5. Briefly introduce our project
6. Are you more comfortable answering questions about fusion or energy?

Q1: Please BRIEFLY tell us about your professional background?

Q2: How well are you acquainted with fusion energy? Please give an answer between 1-7.

2. Macro trends - 20-30 min

Q3: What macro trends are most important for the European energy market in the coming 15-20 years?

3.1 Political

3.2 Economical

3.3 Social

3.4 Technological

3.5 Environmental

3.6 Legal

Q4: Please rate the trends on impact on the European energy market and level of certainty?

3. Energy and electricity mix in the future - 15-20 min

Q5: Development of energy sources in the next 15-20 years?

a. Gas
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?
b. Oil
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?
c. Solid fossil fuels, coal
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?

d. Fission
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?
e. Wind
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?
f. Solar
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?
g. Hydro
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?
h. Biofuels
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?
i. Wave
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?

j. Other emerging opportunities – Thermal/Geothermal
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?
k. Fusion
    i. Technology?
    ii. Environmental impact?
    iii. Resource availability?
    iv. Price?

4. Finishing questions - 5 min

Q6: Is there anything else you would like to discuss regarding the development of the European energy market?

Q7: Can we reach out if we have any further questions?

Q8: Is there anybody else you believe that we should interview?

Appendix B

The mass of a bound system of particles m can be described by the sum of individual particle masses $\sum_i m_i$ that are non-interacting and the binding energy B according to the following formula,

$$m = \sum_i m_i - B/c^2 \tag{3.3}$$

The binding energy is the amount of energy required to separate the particles far enough so that they are non-interacting and released from the system of particles. Therefore, the mass loss in the bound system of particles can be explained by this binding energy as equation (3.3) shows (Dunlap, 2021). During fusion reactions in stars, lighter elements with a low binding energy are combined into heavier elements with higher binding energy. The number of nucleons (protons and neutrons) are the same before and after the reaction but because the heavier elements have a stronger binding energy, the total mass is reduced and energy is thereby released in the form of kinetic energy in line with equation (3.2) (Dunlap, 2021). The binding energy is a consequence of the strong nuclear force or commonly referred to as "the strong force" which acts on the building blocks of the atom (Dunlap, 2021). The strong force is the strongest force in the universe, overpowering the electromagnetic force which repels protons from each other due to their positive charge, holding the nucleons together in the nucleus. However, it only has an influence over very small distances so for distances larger than the nucleus of a medium sized atom it quickly loses influence and the electromagnetic force becomes stronger (Nasa Science, 2024). Since the strong force works on such small distances the particles that are supposed to fuse need to be very close to each other to undergo fusion. At the same time, the electromagnetic force repels particles with the same charge, i.e protons, which is referred to as the Coulomb interaction.

Appendix C

Mirror machines

Mirror machines were created to fix the problem of having the plasma unconstrained at the ends of a machine when using the pinch effect. Instead, the plasma would be confined in a magnetic solenoid which produces an increased magnetic field at the ends of the plasma stream. This would cause particles approaching the ends to be reflected, confining the plasma and protecting the confinement walls (Dunlap, 2021).

Stellarators

Another solution to confining the plasma is to bend the confinement chamber into a torus which, by wrapping the torus in magnetic coils, can produce a current in the plasma and confine the plasma along the current direction. However, this would create instabilities in the magnetic field and cause particles to drift away from the center of the plasma chamber. To solve this problem, Lyman Spitzer proposed the design of the stellarator during the 1950's. The stellarator would solve the issue of particle drift by changing the geometry of the torus into a figure-eight shape (Dunlap, 2021). Modern stellarators can achieve a steady state confinement of the plasma by creating a helical magnetic field around the torus. This can be done by different methods but modern stellarators often use asymmetric poloidal coils to achieve this helical magnetic field (Dunlap, 2021).

Tokamak

The tokamak was introduced by the Soviet physicists Igor Tamm and Andrei Sakharov as an alternate approach to the stellarator. The tokamak uses both poloidal coils to produce a toroidal magnetic field and a toroidal current to induce a poloidal magnetic field, the net magnetic field then becomes a helical magnetic field. With this configuration the particles in the plasma will move from the inside of the torus to the outside and the problem of particle drift as discussed earlier would average out. The current through the plasma not only helps create a magnetic field but also heats the plasma through ohmic heating (heat from resistance in the plasma). However, this current is induced by a changing magnetic field which is produced by ramping up the current in the central solenoid and ramping it down again (Dunlap, 2021). Therefore the reaction in the tokamak is pulsed, which could be unfavorable compared to the steady state fusion achieved in a stellarator (Dunlap, 2021). The tokamak is one of the machines which has had the greatest success in development, with several international projects using its design to create experiments for a better understanding of fusion power (Dunlap, 2021). Some of the more notable projects include the JET (Joint European Torus), JT-60SA (Japan Torus-60 Super Advanced) and ITER (International Thermonuclear Experimental Reactor) projects (Dunlap, 2021)