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Scenarios for the hydrogen market and strategic options for MNEs

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Aim: The purpose of this article is to investigate how hydrogen-based energy will be implemented in the future economy and to find strategic options in the future hydrogen market for multinational enterprises (MNEs) active in the energy sector.

Design/Research methods: The current literature on hydrogen production tends to focus on the technical and cost aspects, while there is limited attention on how one could implement hydrogen in the future. In this explorative research, interviews with experts formed a basis and the scenario planning methodology was used.

Conclusions/findings: The three scenarios that were developed are based on the potential strategies of the European Union, which are Hydrogen Independence, Cost Optimization, and Energy Security. Based on a literature review, five key characteristics that will impact the functioning of the future hydrogen economy were selected. By using notions from the environmental- and positioning schools of Mintzberg, strategic options for MNEs were identified in each scenario. In all three scenarios, the implementation of hydrogen-based alternatives will differ. Besides this, the strategic options that MNEs can obtain will also change.

Originality; value of the article: This article helps us understand how hydrogen-based energy sources will be implemented into the economy, taking on board the priorities of the European Union. Furthermore, it gives managers of MNEs guidance to identify strategic options that fit alongside their firms' strategy. Finally, this research gives an incentive for future research as, on several topics, the interviewees could not find consensus.

Keywords: Hydrogen Market, Scenario Planning, Renewable Energy Sources (RES), Strategy, Multinational Enterprises (MNEs).
JEL: L22, L25, Q40, Q47.

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1. Introduction

Whereas the implementation of renewable energy sources (RES) started with wind and solar a few decades ago, hydrogen-based energy is not yet widely used. Nevertheless, hydrogen production is seen as a promising way to battle global warming. Over the last couple of years, the cost of hydrogen production has decreased due to increasing investments in R&D of hydrogen and a decline in the cost of other RES (Timmerberg, Kaltschmitt 2019). Besides, the social acceptance of hydrogen-based energy is steadily increasing, and policymakers are focused on supporting a carbon-neutral society based on hydrogen (Kovac et al. 2021). Now that hydrogen production will become an economically feasible option, countries start exploring strategies and roadmaps on how to implement hydrogen into their economy (Lebrouhi et al. 2022).

Based on the hydrogen technology goals of the European Commission (EC 2022), several European countries will not produce enough hydrogen to meet domestic demand (Nuñez-Jimenez, De Blasio 2022). So, to realize the goals of the EU and to decarbonize the economy countries need to trade. However, there are many obstacles in creating an international hydrogen market. An example of how things go is the process to create an internal European market for electricity which started 20 years ago but is still not realized (Pepermans 2019).

The current literature tends to focus on the potential of hydrogen and describes what is required to create a (national) hydrogen economy. Only in a few cases, the literature addresses the possibility of creating an international hydrogen market. Schlund, Schulte, and Sprenger (2022) as well as Westphal, Dröge, and Geden (2020) explain the international dimensions of the hydrogen market and the need to internationally cooperate from the German perspective. In both papers, the authors agree on the importance of international cooperation, bilateral agreements and international trade. However, according to Hancock and Wollersheim (2021), much of the hydrogen technology literature is still dominated by technical, engineering and economic (demand/supply) analysis, to the exclusion of ethics, governance, policy, politics and international trade/diplomacy. Furthermore, according to Mulder, Perey, and Moraga (2019), too little attention has been paid to the implementation of hydrogen technology into an economy. As hydrogen will have another position in the future energy mix than other energy carriers, implementing hydrogen into the economy is significantly different from solar and wind energy (Rosen, Koohi-Fayegh 2016). Therefore, it is not evident that hydrogen will function properly as a complementary RES next to wind and solar energy from the beginning.

This research aims to explore how hydrogen-based energy could be implemented into the future economy by using the scenario planning methodology. The scenario planning is based on the priority that the EU has regarding its hydrogen policy. According to Nuñez-Jimenez and De Blasio (2022), the EU can prioritize their strategy based on *hydrogen independence*, *cost optimalization* and *energy security*. Next to these three scenarios, five key characteristics that will determine the functioning of the market have been chosen based on the literature study. The key characteristics represent the development of the European market, the role of hydrogen in the energy mix, the final consumer, the pricing and the chemical composition. Next to the implementation of hydrogen-based energy, the aim is to explore the strategic options for MNCs in each scenario in the future hydrogen market. The positioning- and environmental school notions of Mintzberg (1990) were used to identify the strategic options for multinational enterprises (MNEs) in the future hydrogen market.

Taking all this into consideration the overarching research question is: *How could hydrogen-based energy be implemented into the economy and how could multinational enterprises strategically position themselves in a hydrogen economy?*

To answer the research question properly, a qualitative research design applying the scenario planning methodology is used by conducting semi-structured interviews with in-field professionals. The qualitative nature of the study made it possible to be more flexible in gathering the data during the interviews. Rather than having a lot of respondents, the focus was on getting in-depth insights from experts. Based on the three scenarios and five key characteristics, a questionnaire was developed. All interviews are transcribed and coded.

The interviews brought to light that in each of the scenarios, the implementation of hydrogen technology will change. The priority of the EU in terms of strategy will determine the future business environment in which the MNEs will operate. The business environment changes in each scenario and so will the strategic options that MNEs can acquire. While the hydrogen market is still in an early development stage and there are still some unknown factors, this research has formulated distinctive characteristics of the future hydrogen market for each scenario and identified strategic options for MNEs.

In the next section, the literature review is presented before going to discuss the methodology that was used during this study. The findings are provided next. The following section includes the results as such, the analysis of the results the limitations and implications of this research and options for future research. In the last section, the concluding remarks can be found.

2. Literature review

2.1. Renewable energy transitions

In the literature on the RE transition, many researchers speak of a so-called "window of opportunity". According to Verbong and Geels (2007), we cannot rely on RE innovations alone A regime change is needed to create a "window of opportunity". Verbong and Geels (2007), are skeptical that a regime change will occur without a shocking event that will change public opinion. The windows of opportunities arise following acute "focusing events" such as oil and nuclear crises, as argued by Stokes and Breetz (2018). According to Pollitt (2012), the presence of a focusing event will be necessary as the question is whether the consumers are ready to bear the switching costs to the new energy source.

Fouquet and Pearson (2012) found that when the new energy source or its related technology offered enhanced characteristics including ease of use, flexibility and cleanness, exclusivity, novelty and status, consumers are willing to pay for it. But also, high prices of incumbent energy sources are a reason for consumers' shift to new sources of energy. So, the presence of high energy bills provides a window of opportunity for the enactment of new legislation argue Stokes and Breetz (2018). Besides, RES have no emissions, are good for the environment and part of the SDGs goals.

In light of previous transitions, Taalbi (2021) found that waves of innovation (in technical transitions) have taken place during periods of investment downturns and structural crises during the 1930s, 1970s, and 2010s. Landscape pressures alone will not be enough the battle global warming. The Paris Agreement and the Ukraine war will speed up the energy transition in which hydrogen will have a crucial role.

2.2. Hydrogen-based energy

Since the start of the energy transition towards RES, hydrogen has not played a central role, yet. Over the last decades, solar and wind energy developed rapidly, even before the switch towards RES (Kovac et al. 2021). Both energy sources have achieved a prominent place in most countries' energy mixes. Where the most important function of solar and wind is to generate electricity, hydrogen will have another function in a country's energy mix. According to Rosen and Koohi-Fayegh (2016), hydrogen will become one of the dominant energy carriers. The main function of hydrogen is transporting energy from the place of production towards the place of consumption. Furthermore, hydrogen can be used to store energy and as a fuel or converted electrical energy (Rosen, Koohi-Fayegh 2016). Therefore, hydrogen is a logical choice to choose to replace fossil fuels as it is a complementary energy carrier to electricity (Scott 2008), as well as solar and wind energy (Sadik-Zada 2021).

In the last decades, a lot of R&D has been conducted on green hydrogen, which seems to finally pay off now. The main benefit that green hydrogen has above other "colours" of hydrogen is the fact that it has no emission (Sadik-Zada 2021). The share of green hydrogen is growing and, based on previous RES-based technological development, it will be price competitive to the polluting grey hydrogen production in just a decade (Kovac et al. 2021). Due to all the investments, the cost of hydrogen has declined by more than 50% in the past five years (Sadik-Zada 2021). According to the Hydrogen Council (2020), the price of green hydrogen will drop between 30% and 70% by 2030. This, in combination with the declining cost of RES, the increasing cost of fossil fuels and public support for clean energy sources contributes to increasing interest in hydrogen.

Over the last decades, hydrogen has gained popularity and is now seen as one of the solutions in battling climate change. However, hydrogen has other functions and characteristics than solar and wind energy have and thus it is not evident that hydrogen will be adapted to the economy without any problem. According to Mulder et al. (2019), the attention of most researchers focuses on the financial and technical feasibility of hydrogen plants. However, little attention has been paid to the implementation of hydrogen technology into an economy. In the short- middle- and long term literature provide a indistinct path towards hydrogen technology implementation.

In the Green Deal (2019) the EU has committed itself towards net-zero emissions (Seck et al. 2022). Hydrogen has been recognized by the EU as a key commodity in achieving that goal (Lebrouhi et al. 2022). For the creation of a green hydrogen economy in Europe abundant RES is required. However, the effectivity of RES differs a lot across the EU. For one, the effectivity of solar panels is locational bound. The weather circumstances differ across regions and have an impact on the effectivity of RES. This is called the capacity factor (Mulder 2020). The capacity factor of solar panels is higher in a sunlit country such as Spain than it is in the Netherlands. Besides, the Netherlands has a much higher population density than Spain, resulting in less suitable areas for large-scale solar or wind farms in the Netherlands. Consequently, the cost of RES and the ability to produce RE differs across countries.

The rollout of an international hydrogen market is not yet self-evident. Several critical hydrogen technologies are still in the early stages of development (IEA 2021). Large investments along the entire supply chain are essential to decrease the total cost of transporting hydrogen (Gallottini et al. 2021; Lebrouhi et al. 2022; Schlund et al. 2022; Seck et al. 2022; Westphal et al. 2020). Next to large investments, the creation of an internal market is critical. Instead of different national pathways and roadmaps a uniform set of standards would pave the way for gradual development of an internal hydrogen market (Van de Graaf et al. 2020; Westphal et al. 2020). Finally, Europe has to make strategic choices as the geopolitical landscape shifts. The energy security of Europe will not be defined by the access to fossil fuels, but it will be depending on the access to hydrogen (Schlund et al. 2022; Van de Graaf et al. 2020).

Most of the literature acknowledges that Europe will become a net importer of hydrogen (Gallottini et al. 2021; Lenivova 2022; Raksha et al. 2020; Bünger et al. 2020; Timmerberg, Kaltschmitt 2019). The demand for hydrogen will be higher than the domestic supply. However, according to Mulder et al. (2019), importing hydrogen from North Africa will not be economically feasible for at least the Netherlands. Besides, Nuñez-Jimenez and De Blasio (2022) argue that Europe can be hydrogen independent meaning that there would be enough domestic production facilities to meet the internal demand.

According to Nuñez-Jimenez and De Blasio (2022), the EU has three choices in determining its strategy which are *hydrogen independence, cost optimalization* or *energy security.* The decision that the EU takes regarding the hydrogen strategy will have impact on the implementation of hydrogen into our future economy and thus on the functioning of the market and the environment businesses need to operate.

Nuñez-Jimenez and De Blasio (2022) took the first step in analysing different paths the EU could take in meeting the hydrogen demand in 2050. This research will go a step further and analyses the implementation of hydrogen in each scenario. Furthermore, the study will try to find answers to the question of how firms can strategically position themselves in the first phase of creating a hydrogen economy.

2.3. Scenario planning

The scenarios in this research are based on the strategic choices the EU can make towards 2050. In 2050 the EU aims to be carbon neutral. Towards 2050 hydrogen production is labelled as a key priority (EC 2020). However, according to Nuñez-Jimenez and De Blasio (2022), a production goal for 2050 is missing ambition, while the goal for 2030 is set. The way the EU will prioritize its strategy will shape the hydrogen market towards 2050. Based on the Nuñez-Jimenez and De Blasio (2022) paper, three hydrogen-based energy scenarios were selected. According to Amer, Daim, and Jetter (2013), three scenarios are appropriate in a scenario planning study. In the following sections, the three scenarios are explained.

2.3.1. Hydrogen independence: scenario 1

In the situation of *hydrogen independence,* the EU will meet the domestic demand through internal production. According to Nuñez-Jimenez and De Blasio (2022), the total demand will be provided by countries with high production potential, such as Spain and Portugal. Countries with relatively low production potential, such as the

Netherlands and Germany, become net importers of hydrogen. To establish *hydrogen independence*, the EU needs to establish a well-functioning, fully integrated hydrogen network where cross-border trade between member states is possible. Without an integrated hydrogen network, member states will not be able to rely on the most competitive price available, but instead on the costlier domestic production. With higher costs for energy, countries will lose their competitive position on the world stage.

If the scenario of *hydrogen independence* is chosen as the leading strategy, the EU has to take energy security in mind. In situations of continent-wide low RE production and high demand, the EU should have enough storage facilities. The storage facilities would decrease the chance of disruption in the hydrogen supply.

2.3.2. Cost optimalization: scenario 2

In the situation of *cost optimalization,* the EU will meet the domestic demand by adding local production partners to the suppliers. Internal production will take place in countries where the cost of production is the lowest. The most favourable regional partners are located in North Africa, Norway and Iceland. The feasibility of this scenario depends on the ability of regional partners to fulfil the production potential. The EU could help to fulfil the production potential of these regional partners with long-term contracts and direct investments.

The downside of the *cost optimalization* scenario is the reliance on a few suppliers. With the *cost optimalization* scenario the risk of previous energy dependency and security supply risk could reoccur. The geopolitical power centre around energy supply will shift from Russia towards Northern Africa countries.

2.3.3. Energy security: scenario 3

In the situation of *energy security,* the EU will meet domestic demand by adding long-distance production partners to the suppliers. The level of energy security increases due to the diversification of hydrogen suppliers. Furthermore, the geopolitical power centre shifts from a regional focus towards a more balanced global focus. Potential partners are countries located in South America, the United States and Australia. To enable a global hydrogen market, it is important that the EU, in cooperation with global partners, sets international standards for the production, transportation and certification of hydrogen.

With longer supply chains, short-term disruptions could occur. Strategic storage facilities should be realized to meet short-term demand. Besides, the infrastructure of the hydrogen network will differ as more maritime transportation is necessary.

2.4. Key market characteristics

For the implementation of hydrogen production into the future economy we need to explore some of the key characteristics of the hydrogen market. These characteristics will determine how the market will function and how companies can position themselves in the global value chain. The impact of the key characteristics could differ in each scenario and have consequences for the implementation of hydrogen-based economy and strategic positioning.

The choices for the five key characteristics discerned below are based on the literature review. The basic elements of how to create a hydrogen economy in the short- middle- and long-term are clear. However, no real effort is made in researching the key characteristics and the impact they will have on the functioning of the market in each scenario. For this research, five key characteristics are selected, in line with the paper of Amer et al. (2013). In the following section, these key characteristics will be discussed.

2.4.2. Role in the energy mix

Whereas solar and wind energy have a place in most countries' energy mixes, hydrogen has not. Solar and wind energy are one of the most used RES carriers nowadays. There is no doubt that the share of hydrogen will also increase in the energy mix of countries (Kovac et al. 2021). In the strategic vision of the European Commission (2020), the share of hydrogen in the future energy is estimated to grow from the current 2% to 13-14%. However, while solar and wind energy are used to produce electricity, hydrogen can be used in different ways (Rosen, Koohi-Fayegh 2016). According to Rosen and Koohi-Fayegh (2016), the two main functions of hydrogen will be to transport and store energy. This could have serious consequences for the role of hydrogen in the energy mix. A lot of research has been done on the potential cost of storage and transportation of hydrogen (Gallottini et al. 2021; Lebrouhi et al. 2022; Mulder et al. 2019; Osman et al. 2022; Timmerberg, Kaltschmitt [ed.], 2019; order per publication year). However, no studies have been done on the position of hydrogen in the energy mix and how it could differ in the scenarios.

2.4.3. Final consumers

Currently, hydrogen is most used in transportation, heavy industry and to make fertilizer. However, now that hydrogen is seen as one of the key components in the RES carriers transition, the final consumers will most likely change. According to Martin, Agnoletti, and Brangier (2020), in the current literature, final users are seen as barriers instead of areas for innovation, mainly due to the objection to the energy transition. Due to the lack of research into the demands of end users of hydrogen, companies cannot properly position themselves along the value chain.

2.4.4. Pricing

According to Zheng et al. (2022), little attention has been paid to the pricing of hydrogen. For now, the cost-plus pricing method is leading, however, this pricing method comes with certain disadvantages (Mulder, 2020; Zheng et al. 2022). The cost-plus method lacks competitiveness and vitality as the price information used has a strong time-lag. The price of hydrogen tends to deviate from the actual market value as the production costs of renewable energy highly fluctuate. Besides, it does not give manufactures enough incentive to produce, which slows down the deployment of hydrogen. Furthermore, the cost-plus method could lead to monopolies. Next to the pricing method, the certification of hydrogen will play a factor (Van de Graaf et al. 2020; White et al. 2021). With the certification of hydrogen, the amount of carbon dioxide that was emitted during the production can be reflected in the price.

A reasonable pricing system will help in the implementation of hydrogen in the economy (Zheng et al. 2022). The pricing of hydrogen will have a lot of consequences for the daily operations of businesses. Furthermore, the roll out of the European market might have consequences for the pricing methods. In the case of *hydrogen independence,* the optimal scenario would be that there is one price for all EU Member States that are in the agreement. In the case of *energy security,* a situation with multiple import hubs and long-distance imports other factors could play a role in pricing the hydrogen production.

2.4.5. Chemical composition

In each scenario the production location of hydrogen shifts, resulting in different ways of transportation. In each case, the transportation route changes and so will the chemical composition of hydrogen (Gallottini et al. 2021; IRENA 2022; Schlund et al. 2022). The chemical composition of hydrogen will affect the whole global supply chain. Therefore, the strategy of the EU will have consequences on the chemical composition of hydrogen that is used throughout the EU and on the entire infrastructure and storage abilities.

2.5. Strategic positioning of MNEs

In the coming decades, the critical role that fossil fuels have will decline and RES carriers will become the most important energy sources of our economy. The way energy is produced, transported, stored and consumed will change. The energy transition from fossil fuels towards RES will cause a massive shift in the way businesses operate. Energy firms can no longer use the supply routes, oil refineries and power plants in the way they were used to. In the transition towards RES, energy firms need to develop new strategies to meet new standards, stay competitive and create value.

2.5.1. Transition towards RES

The transition towards RES is strongly policy driven by international organizations setting goals and pushing governments to install favourable institutional environments that foster innovation (Lumbye 2022). At the same time, the transition is strongly innovation-driven as leading firms are constantly trying to improve their developments and push their RES technologies. In that sense, firms and not states, are leading the way in parts of the transition towards RES (Lumbye 2022).

Incumbent firms in the energy sector, which according to Gómez-Bolaños, Ellimäki, Hurtado-Torres, and Delgado-Márquez (2022) are more and more MNEs, must change the way they conduct business if they want to stay competitive.

According to Breetz, Mildenberger, and Stokes (2018), incumbent firms could resist the technological transition as they do not want to become economic losers. Incumbent energy firms can develop corporate or political strategies and use their political power to shape the policy and regulatory standards that are set by the government (Novalia et al. 2021). However, incumbents can also respond to new market entrants by enhancing their technological competencies. Multiple studies have underlined the ability of incumbent firms of mixing and revise their strategies as they respond to new opportunities and do not take a defensive position alone (Novalia et al. 2021).

2.5.2. Ten schools of strategy by Mintzberg

As the transition is both policy- and innovation driven, this research uses notions of two of the schools of strategy distinguished by Mintzberg (1990). For the external business environment on which MNEs have limited influence, the environmental school view is used. For the internal business environment on which MNEs have enormous influence the positioning school view is used.

Each school represents a way a company can define its strategy. How a firm develops and determines its strategy differs in each case. Both internal and external factors have an impact on the development of a strategy. In the transition towards RES, both internal and external factors play a role. The environmental school, focusing on the external factors that drive strategy and the positioning school, representing a focus on the internal factors, are used in this research to answer the issue of how MNEs can strategically position themselves in the future hydrogen economy. The environmental school allows for a more reactive strategy and the positioning school is more proactive by nature. Both approaches will be related to the three scenarios.

3. Methodology

3.1. Research design

This research aims to explore how hydrogen will be implemented into our economy based on the strategy of the EU. Besides, the research investigates how MNEs can strategically position themselves in all three scenarios. As the hydrogen market is still immature and research is scarce, a qualitative method was applied. To answer the research question, the scenario planning methodology is used. Scenario planning has been used for strategic purposes by various MNEs over the last decades (Cornelius et al. 2005). Most market environments are complex and moving fast. The scenario planning methodology can help to understand the future market environment and to stay competitive.

Compared to other methods which are focused on achieving fixed results, scenario planning differentiates itself in terms of the outcome as it results in a set of possible ways to go forward while maintaining uncertainty (Wilkinson, Eidinow 2008). Furthermore, scenario planning differs from other research methods, as it results in different future situations instead of a prediction and forecast. Finally, scenario planning has an advantage over other methods as it is possible to provide a holistic and schematic overview of a future market respecting the current state of development (Meinert 2014).

The present research focusses on explorative scenarios, as the aim is to find out about "what can happen in the future" (Börjeson et al. 2006). Besides, the explorative scenario was chosen as it focusses on the long-term horizon (Börjeson et al. 2006). The explorative category can be further differentiated into external and internal strategic scenarios. Where companies do influence the internal strategic scenario, they do not influence the external scenario (Börjeson et al. 2006). In this study, the internal scenarios are discussed in reaction to the strategic positioning of the firm. The external scenarios are discussed with the scenario planning and the impact thereof on the business environment.

A qualitative approach was applied, because it is more flexible and explorative than a highly structured quantitative approach (Starr 2014; Yin 2009) Editor: swap order references. To benefit from flexibility, interviews were taken to gather new insights. According to Eisenhardt and Graebner (2007) and Yin (2009), interviews can be considered a highly effective way to obtain data, especially in an exploratory qualitative study such as a scenario planning. The interviews aim to gain extra insight into building new theories in light of the future hydrogen market. The nine interviewees are selected based on their knowledge and expertise of the topic. Furthermore, the research will aim to answer a "how" and "what" question which is according to Yin (2009) in line with exploratory qualitative studies. Finally, the inductive approach was used, as it is more open and seeks to build theory in areas that lack research (Burnard et al. 2008; Eisenhardt, Graebner 2007; Yin 2009).

3.2. Data collection

To obtain an in-depth understanding of the future hydrogen market semi-structured interviews were conducted with in-field professionals. Theoretical sampling is chosen over random sampling (Glaser, Strauss 1967). Because of the qualitative nature of the scenario planning method, the focus lies on a small number of in-depth samples instead of a wide variety of samples (Saunders et al. 2009). The interviewees are chosen based on quality instead of increasing quantity. To assure quality, the case selection process aimed to find a broad range of interviewees who hold different positions and interests within the hydrogen market.

However, a simple questionnaire would not be sufficient to answer open the research question (Gillham 2000). The best option for exploratory qualitative research involves series of in-depth interviews with field-experts (Eisenhardt, Graebner 2007). To obtain the most value out of the interviews, these are done according to a semi-structured approach. A semi-structured approach is an ideal fit for the exploratory nature of the scenario planning methodology according to Saunders et al. (2009). The semi-structured approach gives the researcher the flexibility that is needed to clarify the answers of the interviewees if necessary. The questions are formulated openly so that the interviewee can come up with a broad and comprehensive response. As the main research question consists of two questions the answers of the interviewees might not be sufficient. Therefore the possibility to ask follow-up questions is essential. The open questions and the possibility to ask follow-up questions are in line with the qualitative research literature (Saunders et al. 2009). The researcher can guide the interview and ask specific questions and the interviewee has a chance to elaborate on answers (Kallio et al. 2016).

Some information on the interviewees is shared in Table 1 below. All interviewees have extensive knowledge of the hydrogen market and can be considered experts. Before the interview, the interview guide (see Appendix 1) was shared with the interviewees to comfort the interviewees and collect all the relevant data (McGrath et al. 2019). Next to the interview protocol, the guide included a small summary of the literature study to get familiar with the research. Besides, the questions for the interview were added.

Next to the interviews, secondary data was obtained from articles in leading journals, business reports, the European Commission and national governments. The articles are used to find the research gap and to control for biases in the interviews. Furthermore, the articles do strengthen the validity of this research (Yin 2009).

Table 1. Information about the interviewees

Interviewee	Company	Role of Company in	Function of Interviewee	Country
1	Company A	University	Researcher and lecturer	NL
2	Company B	Energy Supplier	Business Development Manager Hydrogen	NL
3	Company C	Energy Supplier	Project Lead Energy Market Green Gas	DE
4	Company C	Energy Supplier	Senior Project Manager	DE
5	Company D	Research Institute	Director Business Development	NL
6	Company E	Port	Business Manager Commercial Delivery	NL
7	Company F	Innovation Centrum	Director	NL
8	Company G	Consultancy Energy Sector	Consultant Hydrogen	NL
9	Company H	Applied Scientific Research Institute	Researcher and Consultant	NL

3.3. Data analysis

To obtain the required knowledge, interviews were conducted with a wide range of experts. To make sure that no data was lost, all the interviews were recorded and transcribed. To develop new views, the interviews were coded using the constant comparison method (Smulowitz 2017) designed by Glaser and Strauss (2017). The constant comparison method is an inductive data coding process where codes are formulated after you obtained the data (Mathison 2005). Therefore, the constant comparison method is a good fit for explorative research. Using the constant comparison method enables the researcher to come up with themes that will evaluate the implementation of hydrogen into the future hydrogen economy for each scenario. Besides, it will lead to a list of recommendations for managers on how to position themselves in the future market.

After transcribing the data, it was analysed by using codes (see Appendix 2 and Appendix 3). The codes are used to systematically understand all the obtained data. To start the coding process, open coding was performed. This type of coding highlights the relevant text passages, phrases and words of the interview. In the second step, the codes were categorized, for each of the key characteristics, into themes (Glaser, Strauss 1967). In this step, connections are made between the codes that closely resemble each other. In the last step, selective coding is performed to connect all the categories in one core category on which the conceptualisation is built.

Once the codes and themes are connected the researcher comes up with a view. Only when the researcher *"is convinced that the analytical framework forms a systematic substantive theory, that is a reasonable accurate statement of matters studied, and that it is couched in a form that others going into the same field could use"* (Glaser, Strauss 1967, p. xx).

The interviews were analysed using the constant comparison method, see Appendix 2 and Appendix 3). This method allows researchers to come up with new views built on data, in this case, the interviews. In the following section, the findings and implications for each scenario and the strategic positioning of MNEs are discussed based on the answers of the interviewees, see also Appendix 4.

4. Results

4.1 Three scenarios

Scenario 1: Hydrogen independence

The *hydrogen independence* scenario is characterized by two dominant players which are the demand centre in North-West Europe and production centres in Southern Europe, Scandinavia and around the North- and Baltic Sea. The production areas will not have abundant RES to match the growing demand. Due to the lack of supply, the price of hydrogen remains high which slows down the development of a hydrogen economy. The role of hydrogen will be limited in the economy. Only the heavy industry will be able to pay the price for hydrogen, which will then be used as a feedstock. Furthermore, hydrogen could be used for renewable intermittency and for balancing purposes in peak hours. The price must be made competitive by governmental support, either by promoting hydrogen with subsidies, or by making polluting options more expensive with taxes. The price will be based on a cost-plus method, where a profit margin is added to the cost of the production of electricity and infrastructure. The price of hydrogen will be electricity indexed for a long time. As there will be no excess production, no hydrogen trading index does appear. A market with in-transparent long-term contracts will emerge, separated in a fixed part and a flexible part. The transport of hydrogen will go through pipelines, as the geographical distance between the supply- and demand centres are relatively small. Therefore, the main chemical composition will be H2. Only for specific industries, other chemical compositions will be used.

The *hydrogen independence* scenario has a restricting impact on the business environment, as only a fraction of the potential market can be served due to supply shortage. The restricting business environment has an impact on the ability of MNEs to craft their strategies to the new market environment and to obtain a strategic option. The market penetration is low, no spot market will be reached, a non-transparent price will occur, MNEs cannot operate without government subsidies and there is a chance of deindustrialization.

For MNEs, strategic options are centred around production clusters, as the EU relies on its production. Also, they are centred around industrial clusters to provide hydrogen to the industry or to crack hydrogen back to ammonia for some specific industries. Finally, they can go along with creating hydrogen buffers for renewable intermittency or peak hours. Crafting a new strategy and obtaining a position in the future hydrogen market would be most favourable for MNEs who are already supplying heavy industry with energy or feedstock or for MNEs who produce RES through sun and wind. New opportunities arise in storing, transporting and cracking hydrogen.

Scenario 2: cost optimalization

In the scenario of *cost optimalization*, regional production partners increase the total supply of hydrogen to the EU. The increased supply will have the following effects on the implementation of hydrogen in the future economy of the EU. The hydrogen economy erupts at a faster pace, meaning that the implementation of hydrogen accelerates. Ports will play an important role in the economy, as hydrogen will be imported through ships when intercontinental pipeline-based transportation is not possible. Demand centres will be connected to import hubs through pipelines, the European backbone. Where hydrogen is mostly used as feedstock in heavy industry in the *hydrogen independence* scenario, hydrogen will also be used as a source of energy in the *cost optimalization* scenario. The penetration of hydrogen into the economy will increase, incurring that the number of consumer segments grows. Next to the heavy industry, sectors like the steel and transportation industry will use hydrogen. Besides, countries could label some industries as “strategically important” and set up favourable policies. Next to the balancing role, hydrogen storage might be used for reasons such as security of supply, seasonal demand and trading commodity. The price of hydrogen will decrease as the regional production partners have a more favourable environment to produce hydrogen. The EU should support the production of hydrogen. Eventually, long-term contracts will disappear and a spot market will develop. The chemical composition will change as intercontinental pipelines are currently non-existent. Instead of pure hydrogen, other carriers such as ammonia and methanol will be imported through ports. Most of the cracking will be done in the ports and close to industrial clusters. In some cases, it might be favourable to use decentral cracking.

In the *cost optimalization* scenario, the business environment enables MNEs to operate in a more diverse market with more final consumers. The market will develop at a relatively high pace. However, there are certain limitations due to the limited supply, which will influence the ability to obtain a strategic position in the future hydrogen market, for example there is little potential in the process- and domestic heat and sectors other than industry and transport. Besides this, for a longer period, the price will remain high and non-transparent, whereas long-term contracts will exist before going to a spot market.

For MNEs, strategic positions are centred around ports where hydrogen carriers will be imported and cracked into hydrogen gas, as well as around industrial clusters to deliver hydrogen or to crack hydrogen back to ammonia in some specific cases. A new segment is the transportation sector. Finally, they can be found in creating hydrogen buffers for renewable intermittency and peak hours. However, to a lesser extent, the use of RES sources within the EU as the local production power has a higher capacity factor. For MNEs with experience in these industry and transportation segments, it would be less challenging to craft their current strategy to obtain a strategic option in the new hydrogen market. New opportunities require new strategies arise in storing, transporting and cracking hydrogen.

Scenario 3: energy security

In the scenario of *energy security,* the implementation of hydrogen into the economy will happen at a faster pace as the market will erupt in the early development stages. The emergence of a global market will foster innovation and the price of hydrogen will drop. Ports that will receive and crack hydrogen carriers play an important role in the future economy. Hydrogen will be widely used all across all EU members. Whether the EU will act as one entity in the global market and the actual level of cooperation between countries remains questionable. Hydrogen will fulfil its role as feedstock and as an energy source, not only in the heavy industry and transportation sector but also in all other sectors and the process- and domestic heat. While it is certain that hydrogen can be stored, the role of long-term hydrogen storage remains unclear and debatable. As the cost of transportation is only a marginal fraction of the total cost price of hydrogen, the price of hydrogen remains low in this scenario, especially since the production cost will fall. The price of hydrogen will follow the same route as in the other scenarios, but the time it takes to reach a spot market is shorter. The price of hydrogen will fluctuate due to the increased trading intensity and so there will be more strategic trading. In the early stages of market development, ammonia will be the main hydrogen carrier next to methanol and ethanol. As technology improves, other hydrogen carriers could become competitive, including liquid organic hydrogen carriers (LOHC) and liquid hydrogen. The transportation cost of liquid hydrogen is high, therefore it would be produced by local production partners.

In the *energy security* scenario, the business environment creates hardly any restrictions for MNEs operating in the energy sector, as hydrogen will be widely used. Hydrogen will be applied in all segments where fossil fuels are used nowadays. This is to the advantage of incumbent MNEs, with their own customer portfolio and strategy. The market will develop rapidly, which will cause a price drop and the establishment of a spot market. However, this will also lead to strong fluctuations in price and strategic trading.

For MNEs, strategic positions are in or around ports where hydrogen carriers will be imported and cracked into hydrogen gas. They can also arise in supplying hydrogen as an energy or in feedstock to companies across all sectors and in the process- and domestic heat. Furthermore, they can be found in trading optimalization and finally, in creating hydrogen buffers for the peak hours. For MNEs with experience in these market segments, it would be less challenging to analyse the hydrogen market and craft their current strategy into a new strategy to obtain a strategic option. New opportunities which require new strategies arise in storing, transporting, cracking and trading hydrogen.

4.2. Results: scenarios and strategy considerations

Table 2 represents an overview of the findings discussed above. For all three scenarios, Table 2 highlights the specifics of each key characteristics on the implementation of hydrogen.

Table 2. Overview of the scenarios and corresponding key characteristics

		Scenario		
		Hydrogen independence	Cost Optimalization	Energy Security
Key Characteristics	Creation of Market	• Small market • Slow market development • Production centres in South Europe and along the North- and Baltic Sea • Demand centre in North-West Europe • Pipeline-based transport	• Medium market • Relatively fast market development • Existing ports play strategic role • Central cracking by ports and industrial clusters • End goal is inter-continental pipeline	• Big market • Fast market development • Existing ports play strategic role • Central cracking by ports and industrial clusters • Uncertainty level of cooperation EU
	Role in Energy Mix	• Limited due to lack of supply • Only as an feedstock for heavy industry and balancing in peak hours • No use as energy carriers	• Still limited • Feedstock best option for decarbonization • Hydrogen will be used as energy carrier • No consensus over long-term storage	• Unlimited, role as feedstock, energy carriers and storage • No consensus over long-term storage
	End Consumer	• Only hard-to-abate industry – such as refineries	• Hard-to-abate industries • Industry and energy sector • Transportation • Differentiation strategic industries	• Wide penetration in industry and transportation • Process- and domestic heat • Differentiation between countries
	Pricing	• High prices due lack of supply • No spot market • Only long-term contracts – fixed and flexible part • Prices are based on electricity index • Lot of governmental support to make hydrogen competitive • Non-transparent market	• Low price of hydrogen • Spot market will eventually be reached in periods of oversupply. • Start with long-term contracts – fixed and flexible part • Governmental support needed in the beginning phase • More strategic trading and pricing	• Low price of hydrogen • Sport market will be reached fast • Start with long-term contracts – fixed and flexible part • Shipping cost only a fraction of the total cost price • Lot of strategic trading and pricing • Strong fluctuations in price
	Chemical Composition	• Transport will be pipeline based • Hydrogen gas • Only specific industries other chemical composition	• Without intercontinental mainly ammonia • Some cases methane or methanol • Central cracking to hydrogen gas	• Mainly ammonia • Depending on production location methane or methanol • Innovations could make LOHC or liquid hydrogen competitive. • Pure hydrogen from local production partners
	Feasibility	• Not feasible due lack of supply. (0/9)	• Not feasible due lack of supply (1/9)	• Feasible. Shipping cost only fraction of cost. (8/9)

Table 3 represents the influence of the environmental-reactive strategy and positioning-proactive strategy schools on the strategic options in the future hydrogen economy for MNEs. The environmental school highlights the business environment the MNEs must operate in, which could limit the options for MNEs to enter the new hydrogen market. The positioning school highlights positions in the new market which could be interesting for MNEs.

Table 3. Overview of the strategic options based on environmental- and positioning school notions

	Strategic Positions		
	Hydrogen independence	Cost Optimalization	Energy Security
Environmental School	• Restricting market environment • Low market penetration • No spot market • Non-transparent long-term contracts • Lots of subsidy • De-industrialization	• Limited market environment • Medium market penetration • Slow transition from long-term contracts to a spot market • Subsidy is needed in transition phase	• No restrictions on business environment • Complete market penetration • Rapid transition from long-term contracts to a spot market • High price fluctuation • Subsidy needed in transition phase
Positioning School	• Production clusters • Industrial Clusters • (De-) Central cracking • Storage facilities	• Ports • (De-) Central cracking • Industrial clusters • Transportation sector • Storage facilities	• Ports • (De-) Central cracking • Industrial clusters • Transportation sector • Process- and domestic heat • Trading optimalization • Storage facilities

5. Limitations and future research

The interview partners were chosen based on their knowledge and expertise about hydrogen production and market development. All the interviewees were able to provide rich insights into the implementation of hydrogen. The total number of interviewees ended at 9, which seems relatively low. However, because of the qualitative and exploratory nature of this research, there is no required number of interviewees needed as long as the researcher can argue that there is saturation in the answers. Still, there are a couple of interesting parties within the hydrogen sector, that could have shared some new insights but unfortunately did not play a part in this research. As this was an exploratory study the interviewees had all different backgrounds. In future research, it would be recommended to select the interviewees based on a specific area of expertise, as follow-up research will lose its exploratory nature.

Due to the open questioning and the wide range of areas of expertise of the interviewees, the answers during the interview varied. Because of the variation in the responses, counting the number of the same answers or doing a frequency analysis was not possible. Therefore, giving a comprehensive or precise answer on the percentage of the interviewees that would agree on a certain finding could not be achieved. To find statistically significant answers in future research, a qualitative study should be conducted.

The three scenarios used in this study were based on the recent study of Nuñez-Jimenez and De Blasio (2022). However, as explained, whereas the hydrogen market is still in an early development stage, but it is developing at a high pace. New developments emerged during the finalization of Nuñez-Jimenez and De Blasio (2022) study and this study. During that time gap, many new partnerships and policies were created with a focus on a global market, making the first and second scenarios a bit less relevant, as it seems for now at least.

Still, a few topics in this research remained debatable. As the *energy security* scenario is most likely to happen, research should focus on this scenario. Future research should focus on the EU and its cooperation, both internally on the creation of the European backbone and externally on the creation of a trading bloc to increase its market power. Additional research should be on the feasibility of long-term hydrogen storage. Furthermore, research should be done to see if multiple price mechanisms emerge based on chemical composition of hydrogen differences. Finally, research towards new hydrogen technology based business models for MNEs should be conducted.

6. Conclusion

This research aimed to investigate how hydrogen production can be implemented in the economy and how MNEs could strategically position themselves here. This research has provided a scenario planning analysis based on the three scenarios of Nuñez-Jimenez and De Blasio (2022) and five key characteristics of the future hydrogen market. Also, this research has analysed the strategic option a firm can obtain based on the environmental- and positioning school notions of Mintzberg. The main takeaway is that in each scenario the implementation of hydrogen changes and so are the strategic options in the economy an MNE can acquire. The priority of the EU will shape the future business environment. While there are still some uncertainties about how hydrogen will be implemented into our economy, in each scenario distinctive characteristics are identified that will determine the functioning of the market. Firstly, in the *hydrogen independence* scenario, the hydrogen market will be small enabling only a limited number of MNEs to operate, as the strategy of the EU is restricting the options to implement hydrogen into our economy. Secondly, in the *cost optimalization* scenario, the number of hydrogen applications increases, enabling more MNEs to operate in the growing market which is still limited by the strategy of the EU. Thirdly, in the *energy security* scenario, the strategy of the EU allows hydrogen production to be implemented in all segments creating hardly any restrictions for MNEs to obtain new positions. In both production and importing process there will be opportunities for MNEs as the goal of the EU is to produce and import 10 Mt/year of green hydrogen (IEA 2022).

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Appendices

Appendix 1: interview guide

Information about the interview

A semi-structured interview will be conducted. The questions consist out of open and closed questions with possible follow-up questions to clarify the answers. The interview will be conducted in Dutch. If the native language of the interviewee differs from Dutch, the interview will be conducted in English.

Introduction interviewees

Goal of the research:

(1) Make a scenario planning in which the implementation of hydrogen into the future economy is discussed.
(2) Try to explain how the implementation of hydrogen could differ among the three scenarios and how businesses could strategically position themselves in the global value chain in each scenario.

Research question: 'How could hydrogen be implemented into the economy and how could multinational enterprises strategically position themselves in a hydrogen economy?'

Goal of the interview: To obtain extra information from experts that can be used to answer the research question. The research question can be divided into two questions: (1) the implementation of hydrogen; (2) the strategic positioning of companies. The interviews will be used to answer both questions. The obtained information will be used next to the literature study that is conducted by the researcher.

Practical: To enable the interviewees to get familiar with the research and to answer the questions as well as possible a short summary of the research is added in the appendix. Including an explanation of the three scenarios and the key characteristics that will define the implementation of the hydrogen. Next to the summary the questions are formulated. For each of the scenarios, five questions are asked.

Duration: Approximately 45 min.

Confidentiality: The interview will be confidential. If needed the interviewee can make adjustments to the transcription which will be shared after the interview. The interviewee will be shown as:

- Name: Interview A
- Job profession: Global Head Hydrogen
- Company: Location; number of employees; sector.

Data analyses

The recording starts once the interviewee gives permission. The audio records of the interviews will be transcribed in Word. Subsequently, the data will be coded using a constant comparison strategy. This process will lead to themes that will be used to evaluate the usefulness of the report and how it was used in practice. Besides, it will result into a list of recommendations for future improvement of the report and the implementation.

Summary of research

The researcher conducts a study on the future hydrogen economy. Current literature mainly focuses on the technical and cost aspects of hydrogen. The research will focus on how hydrogen could be implemented in the future economy and how companies could strategically position themselves along the value chain. The research applies the scenario planning methodology. Three scenarios were chosen, based on the strategy the European Union (EU) prioritizes. The three scenarios consist of energy independence, cost (optimalization), or energy security.

- *Hydrogen independence*: the EU prioritizes energy independence and will produce hydrogen domestically. The EU develops a self-sufficient internal hydrogen market. A potential downside is the fact that Europe does have periods of low renewable energy generation.

- *Cost optimalization*: The EU prioritizes low costing and will produce and/or import hydrogen as cheaply as possible. The domestic supply will be complemented by imports from low-cost hydrogen producing countries. Potential partners are countries located in Northern Africa, Ireland and Norway. A potential downside is the fact that Europe will become dependent on a small group of producing countries.
- *Energy security*: the EU prioritizes security of sourcing and cost optimalization by combining long-distance imports from export champions (Australia and the United States) with regional imports and internal production. Potential downsides are long-term contracts and delivery uncertainty.

In each scenario the implementation of hydrogen into the economy will differ. Next to the three scenarios five key characteristics will determine the functioning of the market and how companies can position themselves in the global value chain. Each scenario will have different implications for the key characteristics and the implementation of hydrogen into the economy. The key characteristics that will determine the implementation of hydrogen are:

- Creating a market: Regional clusters vs complete European market
- Role in the energy mix: Storage vs direct consumption
- Consumer: Who will be the consumer of hydrogen?
- Pricing: How will the price be determined?
- Chemical composition: How will hydrogen enter and be transported within the market?

The aim is to find out how these characteristics look like in each of the scenarios.

Questions

Personal details of interviewee

(1) Short introduction of the interviewee, the company and the position/role

Role of the company in the hydrogen industry

(2) What is the role of the company in the (future) hydrogen economy?

Hydrogen independence

(3) How will the internal European hydrogen market look like?

(4) What will be the main role of hydrogen in the energy mix?

(5) Who will be the end consumers of hydrogen?

(6) How will the price of hydrogen be determined?

(7) What will be the chemical composition of hydrogen in the economy?

Cost optimalization

(8) How will the internal European hydrogen market look like?

(9) What will be the main role of hydrogen in the energy mix?

(10) Who will be the end consumers of hydrogen?

(11) How will the price of hydrogen be determined?

(12) What will be the chemical composition of hydrogen in the economy?

Energy security

(13) How will the internal European hydrogen market look like?

(14) What will be the main role of hydrogen in the energy mix?

(15) Who will be the end consumers of hydrogen?

(16) How will the price of hydrogen be determined?

(17) What will be the chemical composition of hydrogen in the economy?

Closing question

(18) Which scenario do you think is most likely to happen? And why?

Potential follow-up questions could be asked to clarify the respondents answer on what the implications are for: (1) the implementation of hydrogen; (2) the strategic positioning of companies.