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What are the barriers to implementing green hydrogen in the decarbonization of the Dutch Container Glass Industry?

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Abstract

Manufacturing container glass for the food and beverages sector, the Dutch container glass industry is a leader in implementing cutting-edge technology, energy efficiency, sustainability practices, and quality. The paper was guided by the question: "What are the barriers to implementing green hydrogen in the decarbonization of the Dutch Container Glass Industry?" The study finds technological, infrastructural, social, economic, and other challenges as lack of master plan and lack of political and regulatory support, as the main barriers in the transition from natural gas to green hydrogen. To be more specific, the difficulties include the lack of commercialized green hydrogen, technical difficulties in the glass industry for fuel switching, and the lack of hydrogen and the electrical grid to support the delivery and production of green hydrogen. The cost of hydrogen compared to fossil fuels, customer pressure, lack of skilled labour, and the need for significant investments in the Dutch container glass industry as well as electrical and gas grids to accommodate green hydrogen fuel are additional barriers. Lastly, lack of a master plan to align all the stakeholders, unavailability of subsidies, funding, and focus for the disruptive transition process in the green hydrogen implementation in the Dutch container glass industry are missing. The chance of decarbonization of the Dutch container glass industry is feasible and possible, but this requires a lot of commitment, time, investment, and security of supply. The study provides policy and industry recommendations for more socially and environmentally sustainable production of container glass in the Netherlands.

Keywords: Green Hydrogen, Container Glass Industry, Transition Management, Decarbonization, Netherlands

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Glossary

Concept	Definition
Container Glass	Glass industry for container packaging such as bottles, jars, drinkware.
Decarbonized glass industry	Desired state of the glass industry that runs on green hydrogen or fossil free.
Energy Transition	Green hydrogen shares for the heavy industry, specifically the Dutch container glass industry, and the measures taken by stakeholders for its development and promotion.
Infrastructure	Hydrogen pipeline for connection with the glass industry.
Landscape	Institutions, actors that influence the green hydrogen development and glass industry decarbonization, target for future for the decarbonization of the industry.
Niche	The current stage of green hydrogen development for the Dutch container glass industry
Regime	Fossil fuel-based dominance in the heavy industry.
Technology	Fossil fuel switches to green hydrogen in the glass melting process.

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1. Introduction

1.1. Importance

The container glass industry for beverages and the food industries has been growing exponentially and there is a high demand in the market for glass (Papadogeorgos & Schure, 2019). However, glass manufacturing is a relatively energy-intensive process that consumes between 4 to 17 GJ of energy for a ton of glass produced (Leisin, 2022). One of the world's most productive industries, the glass sector produces the most product per capita (Eurostat, 2011). To process heat, approximately 80% to 90% of natural gas is used, which makes the European glass-making industries one of the leading causes of the CO_2 emission (Fiehl et al., 2017). Consequently, there is massive pressure for achieving deep decarbonization by 2050 in the container glass industry.

The Dutch glass industry has been a pioneer in using the latest technologies, energy efficiency measures, world-level quality, and environmental performance (VNG, 2012). Ardagh Group constructed the world's first batch preheater in 1997, Libbey installed the first melting furnace that is entirely based on thermochemical in 2017, and Owens-Illinois installed the world's first oxy-fuel furnace in Europe in 1994, all of which were firsts in their respective fields (Van Valburg, 2017). All these installations are located in the Netherlands, distinguishing the Dutch glass sector as a pioneer in comparison to the rest of the EU countries.

In addition, the Netherlands has also kickstarted the hydrogen revolution. By 2030, the European Commission wants member states to ensure that green hydrogen accounts for more than half of all hydrogen used in industry as part of the Fit for 55 package (CE Delft, 2022). The Fit for 55 package is a bundle of initiatives to reform and revise EU legislation as well as launch new initiatives with the purpose of aligning EU policies with the Council and European Parliament's on climate goals (EU, 2022). Because of the energy intensity of glass production, hydrogen use in the production process in glass industry like other heavy industry will be a more sustainable solution. Fossil hydrogen generation in the Netherlands is the second greatest in Europe, giving the country a considerable edge in hydrogen consumption (Koneczna & Cader, 2021). In addition, the Netherlands' gas grid network is among the most modern in the world, which connects most area of the country, and as a result, they have amassed a wealth of knowledge and competence in the monitoring, management, and storing of natural gas (Enterprise Agency et al., 2022).

Green hydrogen is a clean, green, and decarbonization substitute fuel for non-renewable carbon-emitting sources like gas and oil. Manufacturing industry in the Netherlands is highly developed which will aid in making crucial components for electrolysers (Enterprise Agency, 2022). The heavy industry can benefit from the fuel switch as green hydrogen. Using green hydrogen as the primary energy for melting the glass and creating a significant breakthrough in the decarbonization of the Dutch container glass industry is a most. Currently, hydrogen has not yet been adopted by the container glass industry. The world's first trial project using the hydrogen technology in glass production was done in Liverpool city in the Pilkington glass plant in 2021. This trial attempted to float glass by using hydrogen and completely replacing the natural gas (HyNet, 2021), but not much of the details on the result is published.

This study aims to provide an insight into the barriers to implementing hydrogen in the Dutch container glass industry. Green hydrogen barriers, such as financial and technological obstacles, will be discussed in this study, focusing on the container glass industry in the Netherlands to illustrate their full-scale application. Following this, the research question is "What are the barriers to implementing green hydrogen in the decarbonization of the Dutch Container Glass Industry?"

Based on the interview with different stakeholders, barriers on the technological level are the development of electrolyzers for the production of green hydrogen, the effect of fuel switch to green hydrogen on the glass quality, production process, and furnace design. Further, on the infrastructural level, the development of the gas grid to hydrogen grid, the electrical grid to facilitate the green hydrogen production, and the network to couple with the glass industry is the existing challenges. For the economic aspects, the commercialization of the green hydrogen electrolyzers and the availability of abundant cheap green hydrogen is a key for the glass industry to use green hydrogen as a green and sustainable fuel source. Further, other barriers were also seen, as all sectors are moving towards the same decarbonization goal; the Dutch glass industry sees that the focus, priority, governmental support, and subsidies on this transition are shallow. A clear vision, strategy, pathway, and plan connecting all stakeholders is missing in the current discourse. Also, the availability of workforce and investment in all areas like the glass industry, grid, equipment suppliers, and its completion can hinder the availability and use of green hydrogen in the process. Therefore, based on the findings, this study proposes a set of new practices and policies that would smoothen and quicken this sustainable energy transition.

1.2. Contribution

The contribution of this study is threefold. First, there have been several studies that focus on the glass industry in the Netherlands, and there has been several studies that focus on hydrogen in the Netherlands. However, no studies have combined the two so far. This study merges these two topics, which provides an innovative insight into the container glass industry that has not been researched before.

Second, this thesis will contribute to the understanding of what is available in the market, what barriers exist to green hydrogen, and the decarbonization of the Dutch container industry. It will bring all relevant aspects and create a nexus between a specific sector and green hydrogen implementation for decarbonization. Knowledge in this area has been available in parts that talk about hydrogen economy, green hydrogen, hydrogen in the Dutch industry, decarbonization options in container industry, and energy efficiency in glass sector. There is a gap in the literature on the relation between green hydrogen with a focus on a specific industry, and whether the industry is capable of decarbonizing or not has not yet been laid out. This thesis will explore and investigate the perspectives of the stakeholders in this transition to decarbonization. Overall, this thesis will provide a clear path toward the Dutch container industry decarbonization, provide insight into the barriers, and contribute to delivering some possible approaches to overcome the obstacles.

Third, the originality of the data collected and used for this paper will contribute to the literature of the glass industry and its sustainable production. Various current key stakeholders and industry experts will be involved, including the niche development companies. Because I have insider access to these relevant stakeholders, the data's availability and insightfulness are better. This will help future researchers get an insightful understanding of the existing situation and support their research and further contribute to the literature.

1.3. Structure

The thesis starts with the literature review section in which general background about the Dutch container glass industry and green hydrogen is provided. Following this, outline and expound on the theoretical framework is the foundation for this thesis, namely transition management. This theory is particularly relevant because this involves implementing the change or transition through systematic planning, organizing, and implementing the shift towards green hydrogen in the Dutch container glass industry without affecting the continuity of the business during the process of this change. Following the literature review in section 2, the methodology section is section 3, which discusses the topic selection, data collection, limitations, and interview. Section 4 presents the findings. The findings are divided into five categories: the technological dimension discusses the barriers to the glass industry technology and electrolyzers for green hydrogen. The infrastructural dimension discusses the barriers on the gas and electrical grid, whereas the social dimension discusses about customer pressure and lack of skilled manpower. The economic dimension discusses the obstacles on the investment cost of this transition, electrolyzers, and the green hydrogen path. Lastly, the fifth category in section 4 discusses other challenges seen in lack of master plan and lack of political and regulatory support. In section 5, I discuss the theoretical discussion to link the findings to the transition management theory. In section 6, I show the practical evaluation of the transition management based on the findings and provide recommendations. Lastly, in section 7, I conclude my paper provide a conclusion and something more that can be done in this area for future research.

2. Literature Review

2.1. Dutch Container Glass Industry

Industrial sectors in the Netherlands accounts to roughly 40% of the energy demand and a quarter of carbon dioxide emissions (Reuters, 2018). In general, glass is a diverse segment that produces packaging formats for tableware glass, fiberglass, beverages, food, glass wool, pharmaceuticals, and much more. Glass production is very intensive and consumes roughly 4 to 17 GJ/t (Leisin, 2022). The Dutch glass sector has long been regarded as a leader in the use of cutting-edge technology, energy-efficiency measures, world-class quality, and environmental performance, among other attributes (VNG, 2012). In recent years, glass has become increasingly popular, and its use as a packaging material in the beverage and food industries has increased substantially due to its advancement (Papadogeorgos & Schure, 2019).

The European container glass manufacturing industry is distributed across 23 countries with 162 manufacturing plants. The major players in the container glass industry are Owens-illinois Inc, Ardagh Packaging Group PLC, Gerresheimer AG, Vidrala SA, and Piramal Glass Ltd (Mordor Intelligence, 2022). In the Netherlands, Ardagh Group and Owens-Illinois (OI) are the only container glass industry. Container glass accounts for approximately 75% of the total CO_2 emissions produced by the Dutch glass sector (VNG, 2017). An overview of the glass industry in the Netherlands with its CO_2 emission is shown in Table 1. As seen in Table 1, Ardagh and Owens-Illinois, produce the most CO_2 compared to other glass industries in terms of volume (CO_2 kt/year). These both glass sectors are categorized as the container glass industries. If we look at the Ton CO_2 /ton glass melted, we see that the container glass is much more energy efficient than other glass industries, but the production of glass kt/year makes the container glass industry significantly important for CO_2, emission. Container glass emits around 75% of total CO_2 emissions in the Dutch glass industry; thus, it is vital to decarbonize this industry. The decarbonization of container glass with its highest CO_2 emission will ultimately lead to the decarbonization of the other types of glass industry industries like table, isolation, and glass fiber industry due to similarity in the melting process of the glass by use of fossil fuel.

Table 3. CO_2 emission per glass industry 2017

	Container Glass		Table Glass	Isolation Glass wool	Glass Fiber
Company Name	Ardagh	Owens-Illinois	Libbey	St Gobain	EGF
CO_2 kt/year	153	172	27.5	56.5	40.5
Glass kt/year	500	530	42.5	60	77.5
Ton CO_2/ton glass	0.3	0.3	0.6	0.9	0.5

(VNG, 2017)

The melting of the glass in the furnace accounts for about 75 % to 80 % of the total energy usage (Tapasa et al., 2012). Natural gas is the primary source of energy in the glass industry, which accounts for roughly 80% to 85% of the total energy used, and the rest is electricity (Tapasa et al., 2012). The melting process where the raw material and recycled glass is melted to form liquid glass, followed by the process of refining which brings the molten glass to a quality level are the major CO_2 emission areas due to the use of natural gas as the energy source. Realizing and achieving the energy efficiency measures as well as decreasing energy intensity is a difficult task (WEF, 2018). With the goal of taking more serious measures toward carbon neutral economy, a plan to reduce greenhouse gas emissions has been published by the Dutch government as part of the Climate Agreement on June 28th 2019, where an ambitious target of 49% CO_2 emission reduction by 2030 for industry compared to 1990 (ISPT, 2019). Ahead of that, on June 10th, 2018, the plan for the Climate Act was unveiled, with the reduction target of CO_2 up to 95% by the year 2050 (ISPT, 2019). The carbon tax further puts added pressure on the polluting industries to achieve these ambitious targets (Pieters, 2019).

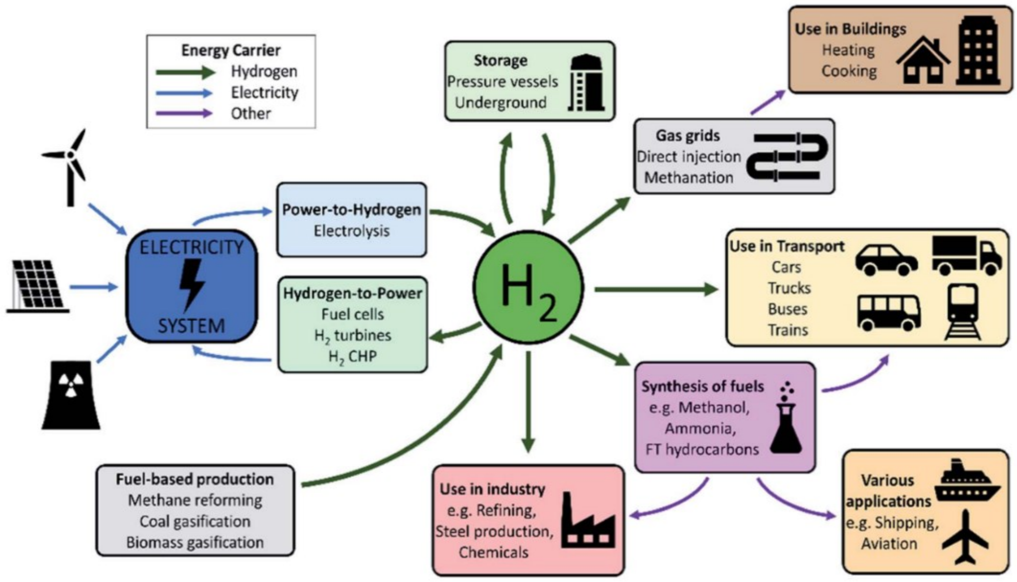
2.2. Green Hydrogen

Hydrogen is a form of energy that is more sustainable compared to natural gas and based on the ways its produced, it can also be fully carbon neutral. Hydrogen can be classified into three categories, namely Grey, Blue, and Green (WEF, 2021). The grey hydrogen is produced by burning fossil fuel and CO_2 is released, the blue hydrogen is the same as grey hydrogen but here the CO_2 is captured and stored, so there is no direct emission of CO_2 in the atmosphere, whereas green hydrogen is produced by water electrolysis method which splits water into hydrogen and oxygen using the renewable energy, so no CO_2 is emitted in the whole process (Hague, 2021). As surplus renewable energy like solar, hydro, and wind gets cheaper, the green hydrogen production will also increase significantly (WEF, 2021).

The European Union has set a goal by year 2050 of cutting overall greenhouse gas emissions by 95% below 1990 levels (Energy Roadmap 2050 Energy, 2022). Decarbonization is entirely doable, according to the European Commission, and can be less expensive in the long run than existing measures. This would ensure less exposure to fossil fuel price volatility, import dependency, and, most importantly, that current energy power plants can be decommissioned in the coming years. Therefore, these transitions are environmentally significant, and social and monetary investments should be accounted for to minimize carbon-intensive assets.

Hydrogen has a high energy density and low greenhouse gas emissions, which makes it a preferable energy carrier in the heavy-duty and industrial sectors (Quarton et al., 2019). Thus, massive developments in the hydrogen sector with storage and transportation facilities open great flexibility for industries. Hydrogen as a fuel source can be made via fossil fuel or biomass, but water electrolysis is a green hydrogen solution that is entirely CO_2 friendly. As seen in Figure 1, hydrogen has a wide variety of users, and the production of hydrogen itself can be done in several ways too. Hydrogen key usage in this paper would be focusing on green hydrogen production via renewable energy and the direct use of hydrogen in the industry, thus replacing the traditional fossil fuel like oil and natural gas.

Figure 1. An overview of the most important hydrogen production and use pathways



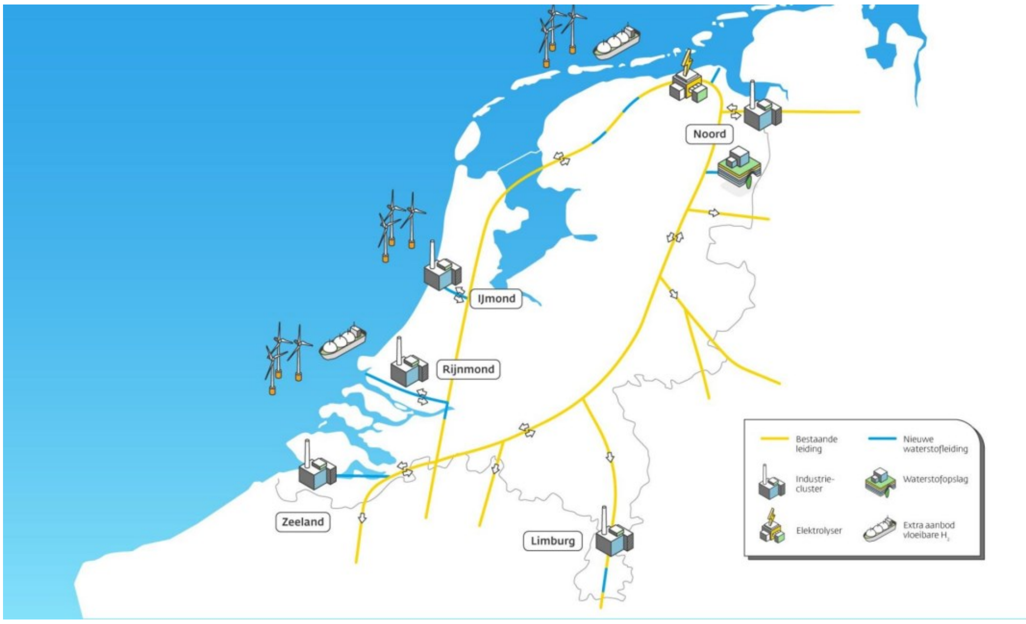
(Quarton et al., 2019)

Fossil fuel and oil production are expected to peak in the next two decades and then decline as the discovery of new wells diminishes (Renne & Fields, 2013). Political issues such as warfare and cartel control will determine the day-to-day market situation, and inevitably, prices will increase (Adolf et al., 2019). In this sense, new renewable alternative energy sources must be well matured to meet the future demand of energy consumption. The European Union demonstrated its interest in hydrogen as a critical influencer in the Paris Agreement to reduce CO_2 emissions.

By 2050, it is predicted that hydrogen would account for roughly 14% of the EU's total energy mix, up from less than 2% now (EC, 2018). The European Commission unveiled the European Green Deal in 2019, which aims to make Europe a climate-neutral region by 2050 (EC, 2019). The European Green Deal is an endeavour that will last three decades to transform all policy sectors in the European Union towards climate neutrality by 2050 by acknowledging the rising relevance of climate change for Europe and its businesses, commerce, and government (Tamma et al., 2019). This ambitious plan includes the Hydrogen Strategy for a Climate-Neutral Europe, which targets to make widespread hydrogen use a reality by 2050 to reach carbon neutrality by that year (EC, 2020).

The Netherlands has commissioned the grid operator Gasunie to construct a hydrogen pipeline to distribute hydrogen to industrial clusters around the country. The proposed national hydrogen infrastructure, according to Gasunie, will be the first large-scale natural gas pipeline retrofit, saving money by utilising the current network for 85% of the backbone, and will be finished by 2027 (Brooks, 2021). This pipeline would make transporting hydrogen less expensive and potentially help the hydrogen industry grow. Brooks (2021) informs that the Dutch government is seizing the opportunity to become a hydrogen hub in Europe, and Rotterdam and Groningen industrial areas are backbone of hydrogen channel where many of operational and planned hydrogen projects are placed. As presented in Figure 2, the five industrial clusters are linked to each other and with foreign countries, and also with storage facilities for the hydrogen. The cluster will be maintained and repaired as necessary, and some new infrastructures are also expected (Gasunie, 2021).

Figure 2. Five industrial hydrogen cluster



(Gasunie, 2021)

2.3. Transition Management

One of the useful theoretical discussions in understanding hydrogen energy transition is the transition management perspective. Transition management can be understood as a reflexive governance approach that seeks to impact society dimension by encouraging experimenting with many actors, studying, and searching for ways to create a better future (Loorbach, 2010; Grin et al., 2010). Four distinctive spheres comprise the transition management framework, which are characterized as strategic, tactical, operational, and reflexive spheres (Loorbach 2007, 2010; Loorbach, Frantzeskaki & Avelino, 2017).

The first sphere as defined by Loorbach (2010) is the strategic activities involving long-term objectives and a vision. This sphere is also the transition arena. Via dialogues on sustainability, norms, and values this will support in cultural shift in a society. One of the most crucial steps in this technique is the usage of the transition arena, which brings together a diverse collection of change agents in an informal but well-organized setting (Roorda et al., 2012). The participants engage in meetings to develop new ideas and share visions and stories linked to their everyday practices. At the strategic level, the use of the transition scenario conceptual tool can help to engage and align stakeholders, as well as helping in developing more robust plans by predicting deviations from trends (Sondeijker, 2009). In other words, stakeholders or actors' involvement in this paper will be essential, and this will be done via semi-structured interviews.

Tactical activities, as defined by Loorbach, Frantzeskaki & Avelino (2017), are actions that carry out a transition strategy toward the desired goal through interacting with stakeholders to create and coordinate a new vision at the regime level. Investments, rules, infrastructure change, and structural change are part of it, and interaction between actors and negotiations is pervasive. This spear is also called the transition agenda sphere. Understanding the hurdles that hinder the vision is likewise crucial in the second sphere, as is working towards a path that supports the goal by suggesting appropriate modifications.

The third sphere Frantzeskaki et al. (2012), and Loorbach (2017) defines is the operational activities, which include activities connected to experiments at the niche level, frequently emphasizing radical and disruptive ideas. The transition trials must be compatible with the vision and transition routes that have been defined. Transition experiments are one-of-a-kind, high-risk endeavours that have the potential to provide a significant breakthrough.

Frantzeskaki & Avelino (2017) discusses the fourth sphere is the reflexive sphere which includes monitoring, assessing, and evaluating the continuing policies as well as continuous social development. To begin with, the participants in the transition arena need to be observed in terms of their behaviour and networking activities as well as their alliance building and commitments. The agreed-upon actions, goals, initiatives, and instruments of the transition agenda should be supervised. It is important to look at transition trials in terms of both new information and how it is conveyed, but also in terms of the social and institutional learning that is taking place. Finally, it is necessary to keep tabs on the progress of the transfer, as well as any obstacles or opportunities for growth. As a consequence of the interaction and cooperation among the numerous parties involved, integrating review into each phase and degree of transition management can develop a social learning process.

Criticism also focused on the atypical position of the researcher in the transition management process, according to Loorbach (2007). As part of the structural change process, researchers must have both a helicopter view and an actor view of being a change agent. The researcher's next goal is to influence the process through new management concepts so that the transition process may be accelerated, for example, by co-creating a transition arena. Loorbach (2007) examines all of these varied tasks for the transition researcher and says that it is difficult to distinguish between these positions in practice.

There has been a misinterpretation and conceptualization of the transition. Transition management has been utilised for a bigger social transition, focusing on societal transformations rather than technological innovation, as presented by Shove and Walker (2007). They have also challenged the rigidity of historical transition analysis, which might be applied to socio-technical examples, such as Geels (2002) study on patterns and processes underpinning socio-technical transitions. Management of transition places a high priority on analysing how institutions and individuals are attempting to influence the process of change (Loorbach, 2007). Transition managers, according to Shove and Walker (2007), are expected to oversee the transition; nevertheless, command and control or a top-down strategy will not work. Managing entails making room for first movers, enabling them, forming a long-term vision, questioning ideas within the current regime, producing creative ideas, empowering them by growing knowledge and removing hurdles, scaling up trials, and enhancing them with a breakthrough all lies within the transition management jurisdiction (Rotmans, 2006).

The benefits of transition management include the provision of viable stages that are not immediately disruptive and the formulation of desirable futures and objectives in the pursuit of policies for the development of the new system. In the context of structural change, the transition management strategy is meant to handle the social dynamics. Additionally, the timing and means by which this transition can be implemented are discussed. An issue of social justice and a need for long-term solutions are the beginning points for effective transition management (van der Bosch and Rotmans, 2008). Transition management focuses on several levels of stakeholder involvement, experimentation, learning, and adaptation as key change drivers to reach a desired social outcome in our socio-technical systems.

2.4. Application of Transition Management

Despite the debates around the transition management framework, it has been an essential and foundational framework for the Dutch government. During the Fourth National Environmental Policy Plan (NMP4), transition management was developed by the Dutch government as an official government policy (VROM, 2001). The NMP4 was hailed as a game-changing policy document because it made room for novel transition management policy experiments by upending established policies and practices (VROM, 2001). The NMP4 did not set goals, but instead stated broad social ideals that were seen as necessitating systemic changes and fundamental reforms (Rotmans et al., 2001). Even though only fundamental ideas were agreed, transition management was offered as a governance paradigm.

Transition Management use has been seen in various areas; in the policies of the Netherlands regarding agricultural production; in the policies of Flanders regarding living conditions; in the policies of regional governments; and at the programme and project levels of new initiatives. Many studies have examined the use of the transition management paradigm (Rotmans, 2006; Kemp & Loorbach, 2006; Kemp & Rotmans, 2005; Rotmans et al., 2001). It is a method for influencing governance actions in such a manner that they can lead to rapid change with a focus on long-term goals. Transition management may be defined as the study of how the public influences, coordinates, and collects actors in order to reinforce and support one another in order to contend with dominating agencies and practices.

In this paper, the transition management approach will be used as the foundational theoretical framework in discussing the energy transition from fossil fuel use to hydrogen in the Dutch container glass industry related to climate change and CO_2 emissions. Then the transition goal is to reflect societal aspirations. In this case, this would be clean, safe, and secure energy. Transition visions, which are system representations with attractive and imaginative technological and behavioural components, will be created to achieve the transition aim. Here, the visions involve (1) the adoption of the green hydrogen technology in the Dutch container glass industry and (2) whether it is applicable to the decarbonization of the Dutch container glass industry through an energy transition. The relationships between these two visions are complex, and this will be further discussed in the findings and discussion section.

2.5. Decarbonization and Green Hydrogen for Dutch Container Glass Industry

The Netherlands faces a considerable challenge and task to decarbonize its main five sectors: industry, electricity, transportation, built environment, land, and agriculture (PBL, 2020). Ambitions connected with the container glass industry's deep decarbonization need a move to revolutionary low-carbon technologies, product replacements, and circular production pathways on a scale and timeline never seen before (Quartz Business Media, 2021). Because of its applications in the varied industry with the greatest potential for emissions reduction, the glass sector will be critical in enabling the implementation of subsequent decarbonization policy, as well as the environmental benefits of glass, in the coming years (Glass Alliance Europe, 2021).

Zier et al. (2021) summarizes various solutions for partial or full decarbonization of the container glass industry includes heat recovery from waste, cullet usage, preheating combustion gas and oxygen, fuel substitution, batch and cullet preheating, heat to power, process intensification, batch selection, advance furnace control system, and batch reduction. In this thesis, I will be discussing the fuel switch or green hydrogen use for the decarbonization of the Dutch container glass industry. On the one hand, as hypothesized by Zier et al. (2021), fuel substitutions like hydrogen, biomass, electricity can only substitute fossil fuel and fully decarbonize the glass industry fuel source. Innovations, on the other hand, will, in the long run, lead to the development of new techniques and materials for glass manufacture that will allow for the economically capture and storage the carbon (Meuleman, 2017). Currently, different decarbonization potential for post-combustion electrification, carbon capture, and hydrogen use within the container glass industry is under research (Stormont, 2017). Green hydrogen produced from renewable sources is the most sustainable energy that is both the cleanest and sufficiently available in the long term among the diverse spectrum of fuel alternatives now available (IEA, 2019).

A number of technological and industrial level challenges have been identified. For example, Zier et al. (2021) explains that replacing fossil fuel with hydrogen in the combustion process in furnace results in entirely new combustion patterns and conditions that can compromise the quality of glass production. Zier et al. (2021) explains, hydrogen higher flame temperatures, changing flame lengths, and flame velocities, as well as lower emission factors influence heat transfer. Because of the greater flame temperature, there will be an increase in NOx emissions; however, this can be mitigated by oxy-fuel combustion (Ditaranto et al., 2013). Furthermore, Papadogeorgos (2019), in his paper, explains that hydrogen still has not proven applicability in the glass production industry. A large part of the problem has to do with foam generation due to the release of water vapor during hydrogen combustion, which has an impact on efficiency, energy usage, and the integrity of the oven (PB & DNV GL, 2015).

Moving onto hydrogen, the Netherlands is the second biggest producer of hydrogen after Germany and the biggest exporter of hydrogen in the EU member states based on the 2019 results (IndexBox, 2021). Hydrogen is a critical component of future energy systems in industrial applications; however, as seen in the EU, hydrogen use in the refining sector accounts for 50.5%, and ammonia production accounts for 30.3 % of the total hydrogen produced, thus covering approximately 81% of use (FCHO, 2019). The Fit for 55 package obliges all European Union members to ensure that green hydrogen accounts for 50% of all hydrogen utilized in the sector (CE Delft, 2022).

CE Delft (2022) argues that it is very challenging for various industries to adopt green hydrogen by 2030, especially if the Dutch industries plan to decarbonize the fossil fuel and fuel gases by using green hydrogen or low carbon hydrogen rather than direct use of hydrogen.

Decarbonizing the glass sector with hydrogen will almost certainly need more knowledge and experience than is now available, and there has been very little study on this issue in the Netherlands. The fact that players such as the government, non-governmental organisations, and the market are prominent actors in increasing the degree of acceptability has been demonstrated; however, further research to determine what drives the emphasis for all relevant actors is required (Kemp & Loorbach, 2005; Geels, 2011).

2.6. Research Question

As an alternative to the use of fossil fuels in the Dutch container glass industry, this thesis examines the potential obstacles to the development and use of hydrogen for this industry. This paper will respond to the following question: <u>What are the barriers to implementing green hydrogen in the decarbonization of the Dutch container glass industry?</u>

The thesis question states what barriers are present in the implementation of green hydrogen in the Dutch container industry. This also answers a big question regarding impediments to the decarbonization of the Dutch container glass industry. This research question combines all the aspects of green hydrogen and decarbonization concerning the Dutch container glass industry and aims to shed light on solutions. Overall, this research question will provide a clear path toward the decarbonization of the Dutch container industry and provide insight into the barriers and contribute to delivering some possible approaches to overcome the existing obstacles.

To answer this research question, five sub questions have been prepared:

a) What technological aspects hinder the adoption of green hydrogen in the Dutch container glass industry?
b) What infrastructural aspects hinder the adoption of green hydrogen in the Dutch container glass industry?
c) What social aspects hinder the adoption of green hydrogen in the Dutch container glass industry?
d) What economic aspects hinder the adoption of green hydrogen in the Dutch container glass industry?
e) What other challenges other than the ones listed above hinder the green hydrogen implementation in the Dutch container glass industry?

3. Methodology

3.1. Selection

The sector of the glass container business encompasses all the different types of glass jars and bottles that can be found in local department stores and supermarkets. The Dutch glass industry's CO_2 emissions are mostly accounted for by container glass, which accounts for 75% of total emissions (VNG, 2017). It gives a strong sense and urgency to see the product's complete life cycle decarbonization possibility, a massive consumer demand. The Dutch glass sector has been a trendsetter in terms of adopting cutting-edge technology, environmental performance, energy-saving measures, and global quality (VNG, 2012). The first melting furnace entirely based on thermochemical in 2017, the first batch preheater in 1997, and the first oxy-fuel furnace in 1994 has made the Netherlands a pioneer in the technology and innovation compared to the rest of Europe (Van Valburg, 2017). These are the prime reason for selection of the container glass industry and specifically in the Netherlands for its decarbonization.

3.2. Methods

The study follows Yin et al. (2018) qualitative research approach in exploratory case studies, which is reinforced with a variety of quantitative data. The method corresponds to the exploratory character of the research topic, and the goal is to get a comprehensive and detail understating of a current occurrence with the help of practical happening examples and results (Yin et al., 2018). Due to the exploratory character of the study topic, it is based on abductive reasoning and simultaneously it grants to-and-fro discussion of literature and theoretical perspectives. This will give researcher opportunity to gather a greater insight into the subject.

Desk research is employed in this thesis by viewing scientific literature, organizational and association reports, and governmental and non-governmental reports, including journals and news articles. Furthermore, this paper uses semi-structured interviews with essential stakeholders and representatives from enterprises, agencies, institutes, and organizations to serve as the primary data source. This form of interview is appropriate for this study's empirical character since it provides flexibility, new directions, and unique data collection.

3.3. Interviews

A semi-structured interview was done with all the relevant stakeholders, as presented in Table 2 below. A formal request for participation was sent in advance, and on its acceptance, questionaries were provided to all stakeholders. With most of the interview, one to one meeting was held and with some teams meeting was done. The interview time was scheduled for an hour, but the expectation was that all questions be covered within 30 to 45 minutes. All the relevant stakeholders were contacted via formal email and via LinkedIn. The interviewee was pre-informed that the interview was recorded, and consent was asked in all cases. There were no incentives to participate in any monetary or physical item, but this research result will be shared with them if they are interested in the outcomes. The detail interview questions are attached in appendix section 1.

This study combined the snowball or chain sampling method with purposive sampling. Below in table 2, I had a group of organizations and already predefined some selected participants in terms of their position, who are considered as the key stakeholders. Further, I had some organizations in Table 2 where chain sampling was done, where interviewees were asked to refer others who meet the criteria. In this paper, I needed experts who were aware on a technical level and on a transition level, who knew the Dutch market in terms of green hydrogen and in terms of the Dutch container glass industry. Thus, I came across a different chain of organizations and people who could contribute the most to this paper and support answering my research question.

Table 4. Interview Focus group

Organization	Interviewees	Position & Level	Information to gain
Glass Industry	Ardagh Benelux	Senior 1, Senior 2	Deep decarbonization of container glass industry, industrial technology, economics, strategy glass industry
Glass Industry & Hydrogen Group	AGP-E	Senior 1, Senior 2	Hydrogen deployment & Strategy in glass industry, hydrogen strategy in industry
NGOs, associations, and institutions	FEVE (glass association),	Senior 1	

	Celsian (R&D)	Senior 1	Deep decarbonization of container glass industry, technology & strategy, including short- and long-term plan
National Grid	Enexis (Electricity) & Gasunie (Hydrogen, gas)	Senior 1 Senior 1	Green hydrogen, development phase, strategy, plans for the industry, short- and long-term vision and ongoing strategy
Hydrogen niches company & Solution Provider	Lhyfe, Battolyser	Senior 1 Senior 1	The current stage of development of hydrogen and long-term strategy, technology

3.4. Research Limitations

The research on green hydrogen and its implementation in the Dutch container glass industry for decarbonization are both emerging topics. A lot of information on this area is constantly changing at a fast pace too. Due to this, during the time of the desk study, the research question was set and dependent on the available information.

The findings obtained from semi-structured interviews are subjective and cannot be generalized. The interviewees responded based on their experience and expertise, and the scope may be limiting considering that this study did not use a large sample quantitative analysis. The plan was to do around 10 to 15 interviews with stakeholders across different organizations. However, I could only conduct 10 interviews due to the un-availability of some stakeholders involved and the level of input they provided. Therefore, the findings cannot be generalized to a wider group of audience or industries other than the Dutch container glass industry.

3.5. Ethical Considerations

This research needed to interview experts with a focus on technologies and transitions who know the Dutch market in terms of green hydrogen and the Dutch container glass industry or energy-intensive industry. This is the only knowledge-based skill and criteria needed that was need in the research, and there were no other bars or exclusions. Semi-structured interview questions were sent to the interviewee prior to the meeting. Upon the acceptance for interview, they were fully aware of their contributions. Consent was also asked during the first 5 minutes of the interview that they agree with sharing the data, being recorded and how they want their information to be shared. As seen, there was no non-competent participants in this interview.

All the questionnaires were related to the real-world scenario and contain no behavioral analysis or observations on them rather based on facts, information, and transition scenarios. A one-to-one meeting with all interviewees was taken in an office, so that the communication and quality of data are higher and, in some cases, due to busy schedule of interviewee or covid issue teams meeting was organized.

The questions were open-end and the same for all participants and all questions are related to the research topic. It was just a full-on information-gathering session.

4. Findings

4.1. Technological Dimensions

Technological aspects in the decarbonization of the Dutch container glass industry using green hydrogen especially related to a few aspects, namely the development of technology and process within the glass industry to accommodate the use of green hydrogen instead of fossil fuel, the development of electrolyzers to facilitate the production of green hydrogen, the technological acceptance on glass industry processes for green hydrogen, and the infrastructure development surrounding it.

Many emerging and big companies have invested and developed electrolyzes for green hydrogen. If we look into green hydrogen electrolyzers and their technology readiness level (TRL) interviewee (Battolyser, Senior 1) explained its around 6 to 7, thus, we have two more steps before it can be efficient and fully commercialized, which means a wait of some years.

> By the middle of 2024, we plan to have our first commercial series production available, which would then be TRL9 products. Our conversion from that electricity to hydrogen is very efficient, much more efficient than existing government technologies. So, it's about 80% efficient. [Battolyser, Senior 1]

Looking into the Dutch container glass industry, which can be fueled both by electricity as well as green hydrogen, it is important to understand which fuel to use and how. Most importantly as discussed in the interview due to conversion losses from electricity to green hydrogen, the industry might need to shift more to green electricity.

> We need to focus on what needs to be fueled by hydrogen … because the majority will be electricity just because it is so much more efficient, and I don't see furnaces running on a 100% hydrogen (a) because that might be problematic with the 100% water vapor in the atmosphere and (b) green hydrogen will be the most valued and the most scare energy source even in the future and why waste energy in transition losses if you can apply electricity directly. [AGP-E, Senior 1]

In the glass industry, the know how's of the green hydrogen use on the burner technology, refractory material, quality of the glass, the lifetime of the furnaces, batch composition changes, foaming prevention, the design and future of furnaces development are very necessary, and they are all under investigation (Interview, AGP-E Senior 1; AGP-E Senior 2; Celsian Senior 1; FEVE Senior 1]. Unless all these barriers are solved, the use of green hydrogen in the glass industry will not be feasible on a large scale. Following the remarks, furnace repair and maintenance using the existing technology are already known and easy but implementing green hydrogen might have changed furnace design and operation. This creates much more aggressive and rapid work that must be done everywhere. Incorporating this and having all technology available for changes in all furnaces could be a significant challenge.

> If you increase the hydrogen share in the blend that might be more from operation point might be more costly. [Celsian, Senior 1]

> We just need to understand a little bit better how the combustion takes place, the chemistry, the length of the flame, the radiation coming from the flame, etc. [FEVE, Senior 1]

> For our implementation when we want to use it to combust, for our combustion process, there could be some technical issues as well, definitely, when going to 100% hydrogen. [AGP-E, Senior 2]

Green hydrogen at this early stage is very volatile regarding the security of supply, especially when the production is not abundant, and the grid is not well developed to connect. Our gas grid capable of using green hydrogen is ready and on standby, but the continuous supply of green hydrogen is a question mark on who can supply now and who can guarantee steady supply and long-term availability. Nor on the electrical side, do we have spare capacity to connect to sites to run the plant or use the excess to produce green hydrogen.

> In the beginning, but when we have like let's say hydrogen phase 1.0, the consumers they can experience some drop in pressure. [Gasunie, Senior 1]

> Prices are still very high according to what I hear. Availability is a big issue as well, so we don't have enough green hydrogen today in order to decarbonize fully or industries. [FEVE, Senior 1]

Following the remarks from the interviewee above, two main short-term barriers are identified: the blending of hydrogen in the network and the possibility of hydrogen usage in the Dutch container glass industry to run the process in stable manner. Development within the glass industry to be able to use green hydrogen or electricity or combined is ongoing. The current rapid development on electrolyzers is a matter of a particular time before it is highly efficient and fully commercialized. Overall, the interviewees expressed barriers to the technology but were not so concerned as the infrastructural and other obstacles presented.

4.2. Infrastructural Dimensions

Gas and electrical grid are critical in the Dutch container glass industry. The infrastructure dimension can be divided into, the gas grid that can be changed to supply green hydrogen, the electrical grid that can be used to make green hydrogen on-site or near-site, and the infrastructure for making the green hydrogen and its installation locations. All these aspects have been discussed in the interviews, and the challenges will be explained below with valid arguments from the interviewer.

> Well, if you look into the existing infrastructure for gas, it is possible to reuse 85% of the existing infrastructure. [Gasunie, Senior 1]

> Our energy law doesn't allow us to supply blends towards the industry if it's on a public pipe. [Gasunie, Senior 1]

The existing gas grid is way more advanced and prominent than the electrical grid. Multiple discussions have been about using the current gas grid backup line or blending the hydrogen in the gas grid. As hydrogen-capable networks and grids are unavailable everywhere, the question of how to supply to all the Dutch container glass plants remains a question. Some can benefit from the hydrogen hub and being on the national hydrogen network and in the industry cluster for hydrogen. However, some are remotely located where the only possibility, as seen now, is to blend hydrogen in the gas pipe or change the gas network to hydrogen completely. Nevertheless, this poses a significant risk as this kind of network is also connected with end users or the community. This also means replacing or upgrading all household water boilers, heating system, and gas cooking systems, which is a near to impossible task in a short time.

> If you want to produce a green hydrogen you must have a electrolyze and you must have green electricity to make the hydrogen…. but you can't get the green electricity either because it's not there or more importantly the grid is not able to facilitate the need. [AGP-E, Senior 1]

> If all the plants want to use electricity instead of gas, I do not think we can provide that … then we have to rebuild the grid in the whole of the country. So that's not possible. So, we have to make choices [Enexis, Senior 1]

Green hydrogen production is currently limited to having an electrolyze in the glass plant and having green electricity to produce that. It is only a matter of cost, delivery, and availability of space to have an electrolyze in the plant. However, the big issue is that the grid cannot facilitate the green electricity needed to produce green hydrogen due to grid congestion (Pre-Announcement Congestion Management Noord-Brabant, 2021). It also makes sense for congestion as a sudden demand for higher electricity for the industry is seen as everyone wants to go electric or move to green hydrogen, creating a massive issue in the grid allocation.

> The electricity needed to produce hydrogen is such much more than we cannot get from the grid…. then we need to set up a plant, hydrogen plant and given the spaces we have available, I don't think that is a possible realistic scenario. [Ardagh Benelux, Senior 1]

For example, suppose a 15 MW natural gas furnace is converted to a 15 MW hydrogen furnace. In that case, we need roughly 40% more electricity, which would mean roughly 21 MW of electrical energy on top of the existing electrical requirement. This would be a nightmare for the electrical grid if everyone starts doing so, and if this is placed on site or near the site, the infrastructure to continuously support this need is massive and overloaded. This will look only interesting if there is a hydrogen grid and the green hydrogen is made on surplus, but as long as surplus electricity in abundant amounts is not available, the infrastructure barrier to support one or the other will be in a critical situation.

> If you want to go from 15 MW natural gas to 15 MW hydrogen, you would need about 40 % more electricity …. if you do this everywhere would be even a more serious load onto the grid. [AGP-E, Senior 1]

Following the arguments from all interviews, the gas and electrical grid currently cannot accommodate the green hydrogen requirement for the Dutch container glass industry. The gas grid is well advanced, but production on a sizeable abundant scale to supply at grid level is not yet there. Thus, electrolyzer solution on-site or near-site is an option but also impossible due to grid constraints and the space required for the installation.

4.3. Social Dimensions

The social dimension during the interview related highly with customer pressure where customers push for decarbonized and sustainable glass packaging, and the lack of manpower to perform this rapid transition towards decarbonization.

Direct purchaser, end use customers, as well as the public, demand and look for sustainable packaging. There is a significant push to go green from all sides. There can be a point where the public will stop accepting glass bottles that are not CO_2 free. This is a great message to scale and speed up the transition in the whole supply chain but also poses a significant thread on development if not all parties scale up simultaneously.

> If other customers' demands sustainable packaging …. social pressure is that high you won't to be able to sell a gas-fired furnace produce bottle any longer because people just don't accept it. [AGP-E, Senior 1]

The glass industry is already demonstrating the use of green electricity and green hydrogen to replace the existing fossil fuel. There is currently unavailability of abundant electricity or green hydrogen or available infrastructure in both grids, it is hard for the industry to give a clear message to the public or to the customers. Especially when the solution to implement is vague, open, unknown and investment in it is risky unless a clear path is available.

It is also seen that not all customers have the same vision and voice to excel and push toward carbon-neutral glass packaging. This can be because of factors like unavailability of technology, the uncertainty of the market, expected high price increase in their product, too small to make any difference. Also not being competitive in the market or different product range acts as a barrier that hinders the transition process.

> The Brewers they put a lot of pressure on glass. They want glass to be decarbonize [FEVE, Senior 1]

The most significant barrier we will see is the unavailability of skilled labour. New technology and green hydrogen, its mass implementation, and meanwhile the mass expansion of gas and electrical grid as well as furnaces rebuilt and changes to accommodate this transition at high speed requires massive workforce enforced at once parallel in this all sectors. Moreover, the complete supply chain will have a significant issue as everyone will want the same thing simultaneously, creating a massive delay in project completion. For example, we built the grid in the Netherlands in a time frame of approximately 120 to 150 years, and now with all the transitions happening, we look to triple the current profile in 10 years to supply everyone, which would be hard to do the job.

> If we have ten times as many workers to do the work, then the time would be shorter. [Enexis, Senior 1]

> We'll see bottlenecks also in talent, right where all the technicians coming from, we need to meet people that are electricians, we need installers, we need all sorts of technical folks at correctly helping install these systems. [Battolyser, Senior 1]

On the societal dimension, the interviewees' views reflect on the energy transition aspect, where on one hand, there is pressure from suppliers and customers to go green. On the other hand, the unavailability of infrastructure and technology hinders this action. The green hydrogen revolution needs more effort. Currently, this brings challenges with a lack of energy security on supplying stable hydrogen, abundant production of hydrogen, and lack of labor to perform the significant infrastructural changes to facilitate this transition.

4.4. Economic Dimensions

The glass industry operation and model use as much natural gas as possible. This is due to the current technological limitation and the economics behind gas and electricity prices. Given that green hydrogen is produced using electricity, the rising cost of electricity is negative to its market. The unavailability of abundant green hydrogen, the situation to upscale technological aspects in the glass plant with massive investment, the unavailability of a clear master plan and a very unfavorable return of investment combines to create a complex situation for the cost and acceptance of green hydrogen in the industry.

> Most industries don't really consider hydrogen until it's competitive with natural gas. They are able or they do want to pay a little bit more, but not 7 to 10 times more than natural gas. A level playing field with natural gas. I think my opinion is that that's the biggest barrier. [Gasunie, Senior 1]

More on the cost side, the glass industry heavily depends on hydrogen grid expansion so this can be supplied directly to the plant or electrical grid upgrade so that hydrogen can be produced in the glass plant itself. In both scenarios, there are huge investments and costs that no one can take responsibility for this uncertainty. Moreover, a key element would be the availability of green hydrogen or green electricity at a cost-efficient price or in comparison to the gas.

> Green hydrogen today would be too expensive simply because electricity is expensive… and second, the costs of electrolyzes today are still very high. [Battolyser, Senior 1]

It is seen that the glass industry needs a major or minor change in its furnace, furnace design, supply, and network, which also costs a fortune for the hydrogen transition. The economics now look unfavorable for the glass industry's continuous production using green hydrogen. This has also to do with the return of investment because the Dutch glass container industry is already very energy efficient.

> Europe are very efficient already in the production process ….. if you have to invest in new equipment, you better do it with a furnace that runs very bad because that return on investment is much bigger than if you would invest in the furnace which is very good. [Celsian, Senior 1]

> Availability and economics are strongly connected because scarcity in the market will lead to higher prices, so those two at the moment are big challenges. [AGP-E, Senior 2]

> we see that mostly the demanding side is not really making any hard decisions on using green hydrogen, because mostly of the financial reasons. [Gasunie, Senior 1]

The voice echoed in the interview by most interviewees focused on the cost of the green hydrogen not being competent with the gas price to perform the transition. It is also mentioned the unavailability of abundant hydrogen, infrastructure unavailability, and the massive cost needed for infrastructure to support green hydrogen, as well as for the industry to adopt it plays a vital role in the economics and speed of the glass industry to decarbonize. Furthermore, all this linked with a clear master plan is missing, adding more complexity to the equation. The lack of a master plan will be further discussed in section 4.5.1.

4.5. Other Challenges

4.5.1. Lack of Master Plan

Different stakeholders are involved in decarbonizing the Dutch container glass industry. It ranges from the government, the national grid on gas and electricity, electrolyzer companies, green energy producers, solar and wind developers, the glass industry, and its management, including customers. Everyone has their internal plan to accommodate and facilitate them in the best way. However, we miss seeing a global master plan that would incorporate this all, take control, and lead on this so that this transition can be regulated.

> There must be a master plan. There must be somebody who points where locations can be, where we can expand, where Tennet can expand. [Enexis, Senior 1]

> So as long as the companies think that it will take five plus years they are reluctant to do some developments because it will take five years or more. If they think that they will have access to hydrogen earlier for example they will speed up that development. [Celsian, Senior 1]

> we do not know enough about financing and build infrastructure necessary and available when we need it. So, you have very clear target in 2030 but it's difficult to define for more than the next 16-18 months what you going to do realize it. [AGP-E, Senior 1]

> The hydrogen economy is not yet, how do you say it, it's not regulated. [Gasunie, Senior 1]

> The industry is waiting for a clear decision. [FEVE, Senior 1]

The hydrogen market or economy is not yet here. This has not yet been regulated. How will the prices look? Will this be coupled or decoupled with the gas price? On a higher level, the insight into how to deal with energy transition seems to be missing and how we keep this affordable for the industries to survive. It seems like the current transition is running on the hype rather than facts and seem to miss the coordination and strategic implementation at all levels.

4.5.2. Lack of Political and Regulatory Support

The Dutch Glass industry accounts for roughly 1 to 1.5 % of energy-intensive industries (Interview, Celsian Senior 1). Further in the interviewee various situations were shown as the Dutch container glass industry being too small to make any difference and secure funding's, subsidies. Also, the lack of master plan which we discussed in section 4.5.1 with approval cycles in all transition process being too long, barriers in infrastructure which regulated by government creates a complex barrier to move ahead with the implementation of the green hydrogen in the Dutch container glass industry.

> If you look at funding, subsidized programs we are always two small, they look at the big projects …. [Celsian, Senior 1]

The Dutch government owns the national grid, so this should be more straightforward to push them for the grid expansion. Considering that everyone is in the energy transition phase, this is more a chicken and egg story where the glass industry is in a circular loop where one is waiting for the other. There is also a fear and complete reliance on market forces in the Netherlands to act, but as we see, there is not a hydrogen market, so someone should act up.

> It's not the infrastructure that is holding us back or putting us back in time, it's mostly the permitting part. [Gasunie, Senior 1]

> Hydrogen you also will need to have a permitting process in place, and you will need an authority that actually knows how to deal with hydrogen and what it means. [AGP-E, Senior 1]

> Our approval cycles are still very, very slow and that's another difficult thing. [Battolyser, Senior 1]

Another thing is regarding the permits and approval cycles; we have many issues with our government to optimize and improve. We are just crossing the border, seeing another government able to have everything the industry wishes and support them. Dutch container glass industry and its solution should not be taken as one and just for the Netherlands, but this also represents a massive container glass industry that all of Europe can benefit so a European and global approach should be there. Even with existing infrastructure which can be reused, it is mostly the permitting part holding back.

5. Discussion

The findings show that there are multi-dimensional barriers that currently hinder the transition towards green hydrogen. Transition management is a useful theoretical tool in better understanding these challenges. Transition management is a reflexive governance strategy that aims to improve society by promoting experimentation with numerous actors, research, and the quest for better future solutions. The main four spheres of transition management are: strategic, tactical, operational, and reflexive. The findings from the interviews can also reflect the four spheres identified by the transition management perspective, which I will elaborate on below.

The other challenges related to the lack of a master plan and political and regulatory support tend to be within the realm of the strategic level. As the findings indicate, there is a lack of precise coordination, full stakeholder involvement, alignment, lack of policy and support from the government on supporting the glass industry, and lack of a clear master plan coordinating all stakeholders. This sphere involves long-term objectives and vision and is a transition arena where participants engage in meeting to develop new ideas and share vision and stories. Many of the interviews concluded that there is a lack of a clear master plan, involvement of all stakeholders, and support for the glass industry, which clearly shows that the transition arena and strategic level are not well organized.

The tactical sphere of the transition management resonates here mainly on the economic and infrastructure dimensions. These are actions carried out in a transition strategy toward a desired goal; interacting with stakeholders to create and coordinate a new vision at the regime level and understanding the hurdle that hinders the vision are crucial. Interviewee expressed that lack of proper infrastructure on the electrical grid, the hydrogen grid itself, the uncompetitive price of hydrogen against natural gas giving no playing field, availability of green hydrogen all hinders the vision and investment, rules, infrastructural change, structural change. Thus, the appropriate path towards the goal can only be reached by suggesting appropriate modifications in these areas.

To elaborate, the challenges that are in the technological dimension tend to be within the realm of the operational sphere. The fuel switch in the Dutch container glass industry from fossil fuel to green hydrogen, the combustion process, fuel blend, and the technological readiness level of electrolyzers to produce green hydrogen at the commercial and economic level by 2024 are all within this sphere. These are all about the transition experiments that are one-of-a-kind, high-risk endeavors and that have the potential to provide a significant breakthrough and decarbonize the Dutch container glass industry.

Lastly, the reflexive sphere of the transition management tends to lean toward the social dimension and lacks a master plan and lack of political and regulatory support. Findings informed by many interviewees that there is a strong demand for sustainable packaging, so customers, suppliers, and the general public have a very high level of awareness and pressure to see and follow developments happening in the glass industry to decarbonize. The glass and green hydrogen industries continuously monitor, assess and evaluate all possible scenarios. There has been seen a lack of a clear master plan, policies, and regulatory support to support the Dutch container glass industry. There are few transition trails ongoing on the glass industry side as well as on electrolyzer development which the sector is following, so learnings and required actions can be taken. This shows that monitoring, assessing, evaluating, and continuing with policies and continuous social development is in progress.

Transition management allows the grouping and reorganization of the existing barriers so that they can be perceived through a multilevel lens that incorporate multiple spheres that interact and complement each other. This allows us to understand the key stakeholders involved, make them aware of the existing hurdles, and align them together for the implementation of green hydrogen in the Dutch container glass industry. With the help of the transition arena, transition management process allows not only to understand the barriers but also develop a clear vision, plan, organize, and implement the change to reach the desirable goal of decarbonization of the Dutch container glass industry.

6. Practical Evaluation and Recommendations

The transition management framework will show the practical evaluation of the barriers to implementing green hydrogen in the Dutch container glass industry and recommendations is provided along with it.

6.1. Problem Structuring, Envisioning and Actors

The findings showed that the main problems with implementing hydrogen in the Dutch container glass industry are:

1. Lack of infrastructure in the electrical grid to accommodate the green hydrogen production.
2. Lack of abundant green hydrogen to be utilized in the gas grid and for continuous process.
3. Lack of economical commercialized electrolyzers.
4. The higher cost and scarcity of green hydrogen.
5. Within the glass industry, the unavailability of technology to run on green hydrogen.
6. The economic challenge is the massive cost of infrastructure upgrades on the grid side, on glass plants, and the challenge that comes with labor.
7. Moreover, lack of a clear master plan for hydrogen strategy in the glass industry, as well as unavailability of subsidies, funding, and focus on supporting the glass industry for the transition.

Massive pressure to achieve deep decarbonization by 2050 in the container glass industry exists. The essential actors but not limited to, in the decarbonization of the Dutch container glass industry are as follows.

- The Government of the Netherlands (Policies, funding)
- Local Authorities (Municipality and governmental bodies)
- Dutch gas, electricity, hydrogen grid, and network: Gasunie, Tenant, Enexis, Hynetwork
- European Union (Grand, funding, policies)
- FEVE (European federation of glass packaging making)
- Electrolyser Companies and support providers like Battolyzer, Lhyfe, and Plugpower.
- Renewable Energy Developers and Units (Solar & Wind & Others)
- Business Partners and glass industry management and investors.

A transition arena with all the key stakeholders is a must for problem structuring, envisioning, and working towards the same goal. Their inputs, feedback, engagement, and alignment will clearly understand the global aspect and help develop a robust plan.

6.2. Agenda Building and Networking

The current plan for the green hydrogen implementation in the Dutch container glass industry revolves around the availability of the abundant green hydrogen and the network creation so that this can be supplied to the glass plant directly. As all the problems and barriers are laid out, discussions should be made to understand and know which of the obstacles pose a major threat and takes the longest to transition and work it out with urgency along with addressing all the other problems that hinder the transition.

To achieve this goal, interaction with key stakeholders who can support solving this barrier is necessary. In terms of the obstacles mentioned above, it is only a short time before the commercialized electrolyzes and the technological improvement in the glass industry to use green hydrogen are available at an economical price. Further to speed up investment, funding and subsidies can be provided. This goes the same for the lack of abundant green hydrogen, as this has to do with massive solar and wind park installations. With a clear master plan at all levels, especially governmental, the electrical grid issue can also be solved, but this takes a considerable effort and time.

6.3. Mobilizing and Implementation

The development of hydrogen networks and industry clusters as the backbone for hydrogen is rapidly progressing. Gasunie plans to make the first parts of the national network available by 2025 and connect the several industry clusters working with local industrial players on regional hydrogen networks (Gasunie, 2021). The current plan of 4 GW of hydrogen electrolyzer by 2030 has been recently proposed for 8 GW (Interview, Battolyser Senior 1). In green hydrogen production, many electrolyzer developers have their TRL 6 or 7 levels (Interview, Battolyser Senior 1). The electrolyzer industry is massively and rapidly performing in this area, with considerable investments in research and development to bring this to TRL 9. The expectations are that they will be fully commercialized in

2024/2025 (Interviews, Battolyser Senior 1; AGP-E Senior 1; Lhyfe Senior 1). All these activities show that green hydrogen will be available sooner, in abundance, and at a cost-efficient price.

Within the Dutch container glass industry, there are many actions and initiatives on discussion for experiments to be done to perform green hydrogen trials. Experiments on blending the hydrogen in the natural gas, burner replacement on existing furnaces to accommodate hydrogen, and flame and foam trials in glass furnaces hydrogen trials are in the pipeline (Interview, AGP-E Senior 1; AGP-E Senior 2; Celsian Senior 1; Ardagh Benelux Senior 1). All these activities are high-risk, one-of-a-kind endeavours that can be a significant breakthrough in the decarbonization of the glass industry by green hydrogen.

6.4. Evaluating, Monitoring and Adapting

As per the discussion with different stakeholders in the interview, it was seen that a clear master plan and a guide is missing, which leads, directs, enforces, monitors the whole transition process, and supports all the industry in this journey. Due to the current geopolitical situation, gas and electricity prices are high, which creates a significant uncertainty on how the community, developers, and industry will support this to achieve the transition goal as this creates inflation and energy insecurity. Thus, here some certainty on price development and balance is required so this can be adapted for transition. The strategy should be well defined and clear for the glass industry whether to proceed with electrification or green hydrogen as primary input or provide a wide range of options that can be promised, giving energy security and stability also giving a clear view on the elimination of the barriers.

Upon successful completion of trials and tests on the decarbonization of the glass industry by green hydrogen, a significant question arises on capex, investments, financial subsidy for the transition, permits, and compliance. All these activities should be well facilitated and supported by the government, required stakeholders, and the glass industry management to facilitate a quick transition. There is a strong desire for all to be committed to decarbonization, but the actions and actual plan for implementation are very vague, so this requires a massive effort from all sides.

7. Conclusion

7.1. Summary

To summarize, the Dutch container glass industry has its internal challenges and barriers that they are looking to address to be a front runner in the decarbonization strategy and implement green hydrogen. However, being a small industry, the governmental focus, subsidies for transition, availability of capital and investment, and permits hinder the adoption of green hydrogen and being a front runner.

In this transition, for the Dutch container glass industry, the most significant issue currently seen is green hydrogen's abundant and continuous availability, and this has to do mainly with the lack of proper grid connection in the gas/ hydrogen side, constraint grid on the electrical side where massive investment is required, and electrolyzers not being economical and fully commercialized that produce green hydrogen. Also, funds, subsidies, and massive investments must be made in the glass industry as well as the grid to support this transition so that the first movers can benefit from this. This poses a short-term risk for the development and improvement of green hydrogen use.

One preliminary remark provided by all key stakeholders resonates with the lack of a clear master plan that links all the stakeholders together and directs and supports them to follow a transition path. In many discussions, a 'chicken and egg' situation is dominant where one is waiting for another to make some transition. There must be a symbiosis between all key stakeholders in this transition, and government should support and lead the Dutch container glass industry. The Dutch glass industry is optimistic that it will be the decarbonized industry.

7.2. Future Research

With the transition management and discussion with stakeholders, the focus started with technological, infrastructural, and social aspect aspects. Other aspects like political, regulatory echoed in this discussion. Thus, future research topics on keeping the topic broad and open could yield aspect and barriers that do not limit the stakeholders.

Due to the current niche development in green hydrogen and the early stage of industrial decarbonization, this means a rapid change, which opens new challenges, barriers, and windows of opportunity, which can be further taken as a research topic to improve this paper.

The report is limited to the Dutch container market and Dutch green hydrogen, limiting the extent of problems and barriers compared to the EU. The Dutch market is a highly favourable market for the green hydrogen and container glass industry compared to most EU countries. However, the future line of work could be to access the EU market, which could be very interesting and provide a completely different picture.

In addition, in order to address the research limitation discussed in this paper, which was the lack of generalizability due to the use of small qualitative data, in the future research, a larger sample can be used to create dataset that is more widely representative of the population.

8. References

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Appendix

Section 1: Interview Questions

1. With the current fossil fuel regime and application of fossil fuel in all areas from heating to transport to industries, what do you think about the green hydrogen development in the Netherlands?
2. Are you optimistic that we will be fully co2 free by 2050 by using green hydrogen in all the above sectors? what are your views on this?
3. In the Dutch climate agreement, ambition has been set for 3 to 4 GW electrolyser's capacity by 2030. And plans have been already there for a total of 9.5 GW. The big question always is the availability of green electricity to generate hydrogen and the completion of the electrolyser project. What are your views on this and how optimistic are you?
4. What are the barriers that you see in the production of green hydrogen?
5. To discuss the barriers that are presented above and if not provided discuss economic, social, and technological barriers.
6. What are the barriers that you see in the implementation of green hydrogen?
7. To discuss the barriers that are presented above and if not provided discuss economic, social, and technological barriers.
8. Green hydrogen use is currently targeted to heavy industries like refineries and heavy industries with the biggest co2 emitters like tata steel. This shows also the limited availability and use. Do you think that this should also have a focus on all industries and funding and testing should be done in all industries that emit co2 so there is a full-scale plan?
9. What are your views on green hydrogen feasibility to be implemented in 2050 in all the industries?
10. Do you think that we will be ready by 2050 to fully switch the natural gas off the grid and move to green hydrogen? What are your views on this?
11. We discussed a lot of the barriers, and what in your view can be done to overcome the barriers. What solutions or recommendations would you provide? Focusing on green hydrogen and its availability on large scale.
12. What are your general views on the Dutch container glass industry in regard to decarbonization?
13. Decarbonization of the Dutch container industry provides a major challenge for the future furnace design and fuel switch, either a fully electric furnace or a furnace that runs on hydrogen seems only the possibility to fully decarbonize them. What do you have to say on this and what are the challenges that lie ahead?
14. What barriers do you think could hinder the decarbonization of the Dutch container glass industry with respect to energy source decarbonization? Especially the change from natural gas to green hydrogen or electricity.

15. Barrier's a discussion on the glass industry. If no barriers are defined to the above question, discuss technological, social, economic, and other aspects that would hinder the use of green hydrogen in the Dutch container glass industry.
16. What barriers do you think are there in relation to green hydrogen and bringing this to the Dutch container glass industry, when there is green hydrogen available, and the industry can also achieve this? Example: Economical factor-like 2 to 3 times more expensive than gas or something,
17. Do you see the future of green hydrogen in the Dutch container industry as decarbonization or some other alternatives is present? If so some overview on this and your views.
18. What do you think would be the future of decarbonization, will this be taken by full electrification or green hydrogen or a mix of both for industries? How do you see heavy industries' fuel sources?
19. We discussed a lot of the barriers, focusing on each barrier we discussed above, what solution or recommendation would you provide so that we can see the decarbonization of the Dutch container glass by use of green hydrogen?

Topic:
What are the barriers to implementing green hydrogen in the decarbonization of the Dutch Container Glass Industry?

To answer this research question, five sub questions have been prepared:

a) What technological aspects hinder the adoption of green hydrogen in the Dutch container glass industry?
b) What infrastructural aspects hinder the adoption of green hydrogen in the Dutch container glass industry?
c) What social aspects hinder the adoption of green hydrogen in the Dutch container glass industry?
d) What economic aspects hinder the adoption of green hydrogen in the Dutch container glass industry?
e) What other challenges other than the ones listed above hinder the green hydrogen implementation in the Dutch container glass industry?