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Who Is in and How? A Comprehensive Study on Stakeholder Perspectives in the Green Hydrogen Sector in Luxembourg

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Abstract

Green hydrogen has the potential to contribute to the decarbonization of the fossil fuel industry, and its development is expected to increase in the coming years. The social dynamics among the various actors in the green hydrogen sector are studied to understand their public perception. Using the technological innovation system research approach for the stakeholder analysis and the qualitative thematic analysis method for the interviews with experts, this study presents an overview of the actors in the green hydrogen sector and their relations in Luxembourg. As a central European country with strategic political and geographic relevance, Luxembourg offers a timely case for analyzing public perception before the large-scale implementation of green hydrogen. Observing this early stage allows for future comparative insights as the national hydrogen strategy progresses. Results show high expectations for green hydrogen in mobility and industry, but concerns persist over infrastructure costs, safety, and public awareness. Regional stakeholders demonstrate a strong willingness to collaborate, recognizing that local public acceptance still requires effort, particularly in areas such as clear and inclusive communication, sharing knowledge, and fostering trust. These findings provide practical insights for stakeholder engagement strategies and theoretical contributions to the study of social dynamics in sustainability transitions.

Keywords: risk perception; energy transition governance; stakeholder perceptions; social acceptance

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1. Introduction

Luxembourg, like other countries, is committed to achieving its climate goals cost-effectively. Among the technologies that can help decarbonize and reduce emissions, hydrogen is expected to play an important role in future solutions. The possibility to produce and consume hydrogen without emitting CO_2 and its wide availability in water are two of the main factors that make it an attractive solution, to the point of considering it as something that will contribute to the achievement of the goals set by the Green Deal in terms of shifting from fossil fuels to clean (renewable energy [1]). To give an overview, hydrogen is typically classified into several "colour" categories depending on the source and production process. Gray hydrogen is produced from fossil fuels (mainly natural gas) through steam methane reforming, releasing CO_2 into the atmosphere. Purple hydrogen uses electrolysis powered by nuclear energy. Blue hydrogen uses the same process but incorporates carbon capture and storage to reduce emissions. Turquoise hydrogen is produced via pyrolysis of methane, generating solid carbon instead of CO_2.

Yellow hydrogen refers to electrolysis powered by grid electricity, which can include a mix of sources, and black or brown hydrogen is derived from coal or lignite and is the most carbon-intensive form. Green hydrogen, in contrast, is obtained from renewable energy sources such as wind and solar energy using an electrolyser, and its only byproduct is water. Consequently, its production is almost emission-free, which is why it attracts the most interest from policymakers, scientists, and investors [2,3]. These color codes are not always standardized across countries, but they offer a practical shorthand to indicate the climate impact of hydrogen production methods.

Luxembourg is a desirable market for developing green hydrogen due to its central geographical location in Europe. As a small country, it is adaptable in terms of politics and legislation. In recent years, Luxembourg, along with its neighboring states, including France, Germany, and Belgium, has supported the development and advancement of numerous projects and initiatives in the hydrogen sector [4]. The main goals to achieve have been transitioning towards green hydrogen to avoid the creation of decarbonization knowledge gaps, developing cross-border infrastructures to import green energy on a sufficient scale and scope, and studying and increasing the social acceptance of projects related to the energy transition. Thus, Luxembourg offers a convincing case due to its small scale, central European location, and transnationally integrated energy governance. Furthermore, its geographic central position places it at the heart of several cross-border hydrogen initiatives. In fact, Luxembourg can serve as an interesting example due to its geographical location. Many European countries will have to import hydrogen, partly via Rotterdam or France. Possible pipelines in the European network will also pass through Luxembourg or be connected to it. In addition to its role in production and use, Luxembourg is also interesting as a transit region for hydrogen. Moreover, as hydrogen projects in Luxembourg are still in their early stages, the country provides a vantage point to observe emerging opportunities and challenges before they become widespread with large-scale implementation. Investigating stakeholder perspectives at this early phase allows for the identification of perceived barriers, potential collaborations, and enabling conditions, offering valuable insights not only for Luxembourg but also for other European regions preparing to scale up green hydrogen infrastructures.

Overall, Luxembourgish emissions could be avoided in the three priority sectors: (A) industry, (B) transport, and (C) future-proof integrated energy systems. In particular, the industry has identified an annual consumption of fossil hydrogen of around 450 tons. Substituting presently used fossil fuels with renewable hydrogen should constitute an intermediate objective, allowing for gas emissions savings of up to >5000 tons (CO_2) per year. Although substantial research has examined the technical feasibility of green hydrogen [2,5], fewer studies address the societal and stakeholder dimensions of its deployment [6,7]. Understanding these dynamics is crucial for countries with specific socio-political contexts, such as Luxembourg, where small-scale governance and transnational interdependence shape the energy landscape.

To implement hydrogen technologies on a large scale, it is necessary to consider the relationship between stakeholders and the public perception of green hydrogen infrastructures. In most studies focused on the social perception of hydrogen fuel cells, hydrogen mobility, and its infrastructure (e.g., hydrogen fuel stations), hydrogen technologies have primarily been evaluated as neutral to positive, while participants' knowledge of familiarity and experience with these technologies was relatively low [8]. However, only a few publications have systematically identified and analyzed stakeholders in the hydrogen market. In detail, some review articles have previously identified the views of hydrogen groups based on interviews or surveys [9], including at the national level, such as in Denmark [10] and Germany [11].

As mentioned, Luxembourg serves as a significant starting point for the development and utilization of green hydrogen thanks to its geographical location, national decarbonization goals, and involvement in various green hydrogen projects. However, there is a lack of local studies that provide a deeper understanding of social and stakeholder perceptions regarding green hydrogen. Using a Technological Innovation System (TIS) research approach, this paper aims to address the research gap in the ongoing discussions about green hydrogen development in Luxembourg by methodically assessing the perspectives of hydrogen market stakeholders and analyzing the associated opportunities and risks. The TIS framework is a key approach in sustainability transition studies [12–15], which provides a methodological approach for studying and analyzing the main actors involved in innovation and transition research. In particular, TIS offers insights into the development opportunities for new technologies and helps identify potential obstacles.

The TIS framework has traditionally been used in innovation and policy studies [12,14,16]. However, it is particularly valuable from a social-psychological perspective because it enables us to analyze the interactions among actors within institutional structures. Additionally, it helps clarify how shared meanings and perceived risks influence the operating system.

In this study, we interpret stakeholder dynamics not only in terms of their structural positions but also as relational processes that are shaped by social norms, perceptions of fairness, and trust [17–19]. In detail, stakeholders in the green hydrogen sector and their impact on hydrogen development have been analyzed after conducting a thorough literature review that included academic articles, gray literature, project assessments, reports, websites, news articles, and expert interviews. Based on these insights, we identify the main opportunities and barriers within the hydrogen supply chain. Additionally, we examine the relationships among stakeholders crucial for a successful transition to hydrogen. Thus, the green hydrogen transition is approached from a perspective that goes beyond technical and economic factors. Our focus is on understanding how social acceptance is shaped by the relationships, perceptions, and values of different stakeholder groups. This allows us to uncover deeper mechanisms of trust, resistance, and engagement, which are crucial for the successful implementation of renewable energy infrastructures. Thus, recent studies in sustainability transitions and network governance highlight that network centrality is closely linked to stakeholder influence, trust-building, and collaborative capacity in complex innovation systems [20,21]. Actors with high centrality are more likely to act as connectors across organizational boundaries, shaping information flows and facilitating coordinated action. In energy governance networks, central stakeholders often play a critical role in aligning visions, fostering trust, and enabling cross-sectoral collaboration, especially in emerging sectors like green hydrogen, where regulatory frameworks and public expectations are still evolving [22]. In conclusion, the primary goal of this study is to enhance the understanding of both the opportunities and challenges facing hydrogen development in the national context, capturing the dynamics of the sector in Luxembourg. Our findings contribute to identifying key factors that may influence the country's hydrogen development while shedding light on the perceptions of important stakeholders, their interactions, and their roles within the hydrogen network. As highlighted in recent interdisciplinary research [23], energy transitions involve not only technical infrastructures but also narratives, perceptions, and institutional dynamics. Understanding how stakeholders perceive and frame hydrogen technologies, particularly in the early phases of implementation, is essential to prevent unintended social or environmental consequences [24]. With this in mind, when developing new technologies, it is essential to take a holistic view of sustainability criteria, i.e., economic, ecological, social, and governance criteria, and to clearly identify these in public discourse so that well-founded and informed opinions can be formed [25]. This paper contributes to the growing field by offering an analysis of national and regional actors involved in the hydrogen landscape in Luxembourg.

The remainder of this paper is organized as follows: In Section 2, entitled "Green Hydrogen Development in Luxembourg and Neighboring Countries: A European Perspective," we provide a comprehensive outline of the green hydrogen sector in Luxembourg. Section 3, "Goals, Research Questions, and Hypotheses," outlines the scope of our research. In Section 4, "Methodology," we introduce the methodology employed, along with the methods for data collection and analysis. Section 4 is divided into three paragraphs: "Stakeholder identification," which carries out a systematic identification of the actor groups; "Categorization of the Stakeholders in Luxembourg," which aims to create an overview of the actors divided into main categories; "Stakeholder Analysis and Mapping," which explores the interactions among stakeholder groups. Finally, Section 5, "Interview Analysis and Discussion," offers an overview of the interview results and their subsequent discussion.

2. Green Hydrogen Development in Luxembourg and Neighboring Countries: A European Perspective

Green electricity generation technologies include, but are not limited to, solar photovoltaics, concentrated solar–thermal, geothermal, or hydroelectric power plants, and wind turbines (on and offshore). Despite its potential, the large-scale production and use of green hydrogen face several technical and economic challenges [26]. These challenges include the high costs of electrolysis equipment, the requirement for substantial amounts of renewable electricity, and the lack of hydrogen infrastructure. To address these issues and fully realize the benefits of green hydrogen, concerted efforts are needed from policymakers, industry, and research institutions. These activities involve investing in research and development, creating supportive policy frameworks, and promoting collaboration and knowledge-sharing across various sectors and regions. More local studies are needed to provide a more precise overview of national differences and to understand how to address the needs of various countries and populations.

Across Europe, several countries are implementing national hydrogen strategies, each with ambitious targets and context-specific development paths. Overall, Germany and France are leading in green hydrogen development, emphasizing its importance as a key fuel source. Additionally, case studies have identified Northern Sweden, Germany, and France as prominent renewable energy centers [4]. In detail, in France, the revised 2024–2025 national hydrogen strategy aims for 4.5 GW of electrolysis capacity by 2030, with an expansion to 8 GW by 2035, supported by up to €9 billion in public investment. Projects such as La Mède (Air Liquide, producing 25 kt/year of renewable hydrogen from biogenic waste) and the GH2 Ambès electrolysis plant (GH2 SAS, Ambès, near Bordeaux, France—initial 100 MW phase, expanding to 300 MW) illustrate this industrial scale-up. In Germany, the national hydrogen strategy targets 10 GW of electrolysis capacity by 2030, with strong support for industrial decarbonization and cross-border hydrogen imports. The Netherlands also positions itself as a key hydrogen hub, with a large-scale project aiming to deliver 80,000 tons of green hydrogen per year by 2029, facilitated by port-based logistics and maritime infrastructure [27]. These data demonstrate that achieving a balance between supply and demand is essential for the success of local green projects.

Luxembourg has a national decarbonization strategy, and the use and production of green hydrogen are part of the ambition to achieve climate neutrality by 2050 [28]. Thus, renewable hydrogen can play a role in the integration of energy sectors in the long term. Initially, however, the goal is to use it in sectors that are difficult to decarbonize by direct electrification, such as heavy industry. This decarbonization potential corresponds to a demand potential for hydrogen, which could exceed 125,000 tons per year and reach 300,000 tons per year in Luxembourg. Furthermore, Luxembourg aims to collaborate with European Member States and third countries as part of its decarbonization strategy. This cooperation will focus on various aspects of green hydrogen projects. For instance, the Greater Region Initiative, which includes Saarland (Germany), Lorraine (France), and Wallonia (Belgium), involves converting a gas pipeline into a hydrogen pipeline. Additionally, the Benelux Union is conducting a joint study on the future of cross-border hydrogen infrastructure. The Pentalateral Energy Forum is involved in studies and joint political declarations, while the North Seas Energy Cooperation analyzes the optimal use and landing of offshore energy. The national German and French hydrogen strategies prioritize industrial scaling and infrastructure investments. These countries have already launched several multi-million-euro projects and aim to establish domestic hydrogen value chains by 2030. In contrast, Luxembourg's strategy emphasizes cross-border coordination and small-scale application, reflecting both its limited industrial hydrogen demand and its strong integration in European logistics and mobility networks. Notably, Luxembourg's involvement in initiatives (like the IPCEI Hydrogen) highlights its role as a regional connector rather than a primary producer. Furthermore, compared to neighboring countries, Luxembourg is pursuing a more deliberative approach, prioritizing environmental sustainability, regulatory clarity, and public acceptance before scaling. The National Energy and Climate Plan (NECP) of Luxembourg includes hydrogen in a long-term decarbonization perspective, with a specific focus on green hydrogen and its future role in transport and industry. Compared to more industrialized neighbors, Luxembourg lacks large-scale hydrogen consumers but compensates with strategic location, political stability, and strong cross-border logistics connectivity [27].

Given the significant developments in the national landscape, there is an increasing need to conduct studies that provide an overview of the local social situation and the dynamics among stakeholders in the green hydrogen sector. Thus, Luxembourg presents a remarkable case in the broader context of hydrogen development. Although its production and infrastructure are still in the early planning stages, the country has set ambitious goals. By examining its hydrogen discussions and stakeholder environment at this initial phase, we can gain insights into social perceptions and expectations before large-scale implementation begins. This will also allow us to compare the evolving dynamics of Luxembourg with those of more established hydrogen regions in the future.

Furthermore, while green hydrogen currently receives the most policy attention and funding, recent scientific literature has raised concerns about its short- and medium-term viability due to high energy requirements, costs, and infrastructure limitations [29,30]. At the same time, the discovery of naturally occurring so-called "white hydrogen" has sparked interest as a potentially more sustainable and cost-effective alternative; however, this option is still in the early stages of scientific and technological exploration [31]. These developments reinforce the need for critical and context-specific assessments of hydrogen pathways, not only from a technological standpoint but also in terms of governance, public engagement, and long-term sustainability.

To conclude, understanding the social perception of renewable energy and the dynamics between different stakeholders is crucial for successfully implementing renewable technologies [7]. However, no research has examined the interactions among stakeholders in Luxembourg. This study is significant for investigating the potential of green hydrogen in Luxembourg, as it addresses possible challenges.

3. Goals and Research Questions

This paper aims to contribute to the ongoing research and discussion on expanding the hydrogen market in Luxembourg. The objective is to assess the context of the hydrogen sector methodically, including the main actors and their relationships, and to identify their strengths and weaknesses. Thus, developing a new branch in the energy sector requires massive investments, evoking economic risks, and the stakeholders can underline these risks related to green hydrogen. The goal is to support further projects and decision-making processes by revealing a comprehensive view of hydrogen stakeholders. In addition, through an in-depth view of the public context, potential social obstacles can be proactively identified.

The research questions this study seeks to answer are as follows:

1. What is the current status of the green hydrogen sector in Luxembourg, and what are its key structural characteristics?
2. Who are the main stakeholders involved, and how do they interact within the hydrogen ecosystem?
3. What perceptions, expectations, and societal factors influence the acceptance or resistance to green hydrogen in Luxembourg?

These questions are formulated specifically concerning the Luxembourgish context. While they address broader themes relevant to the development of green hydrogen, they are grounded in the socio-political, geographical, and institutional characteristics of Luxembourg and shaped by the current national strategies and stakeholder landscape.

Based on the literature and preliminary context analysis, this study builds on two exploratory assumptions:

Assumption 1. *Stakeholders in the green hydrogen sector perceive economic and safety-related risks as major challenges to project implementation.*

Assumption 2. *Network centrality and trust are positively associated with expectations of stakeholder collaboration.*

Previous research (e.g., [32]) has explored the stakeholder concept within the context of hydrogen markets, primarily concentrating on identifying and analyzing the barriers and challenges that arise during the ramp-up phase of these markets. However, the scope of these studies tends to be quite narrow, often limited to specific sectors, such as the electricity industry [33], or targeting particular objectives, like the development of roadmaps or strategies for effective communication among stakeholders. Despite the critical importance of stakeholders in successful development, we did not find any existing literature that systematically conducts a comprehensive stakeholder analysis specifically for green hydrogen markets in Luxembourg. In light of this gap in the literature, our objective is to undertake a detailed and extensive stakeholder analysis of the green hydrogen market ramp-up in Luxembourg. By examining a diverse range of potential actors, we aim to provide valuable insights into their roles, interactions, and overall dynamics, thereby contributing to a more nuanced understanding of the factors that influence green hydrogen's successful development.

4. Methodology

Stakeholder analysis is a tool that helps to study the development of a market through the analysis of collaboration, communication, and knowledge exchange. The goal is to identify opportunities and challenges in a particular context by collecting and analyzing data on stakeholders [34]. In this paper, we use a broad definition of stakeholders, considering all groups and individuals who are by or can affect the hydrogen sector in Luxembourg [35].

Thus, innovations and their market development are a system that is an interconnected combination of technologies, infrastructures, organizations, markets, regulations, and usage practices that together provide societal functions [36]. This definition includes stakeholders of a hydrogen value chain as an organization or a specific association in the private and public sectors [37]. This study combines the TIS approach with stakeholder analysis and qualitative interviews, offering a novel triangulated framework for understanding social dynamics in niche energy markets. While stakeholder analyses are common in national hydrogen strategies [11], our approach integrates Social Network Analysis (SNA) with the Social Network Visualizer tool version 3.1. (SocNetV) [38] and thematic coding to assess both structural and perceptual factors.

The stakeholder analysis methodology used in this study is based on the work of [11] and [39], and has been adapted accordingly. This approach draws from innovation and transition research to identify and analyze key players in the green hydrogen sector. Stakeholder analysis is not a singular methodology; rather, it encompasses several sub-methodological steps (see Figure 1). Our research design ensures that each step of the stakeholder analysis is addressed through specific methodological approaches, thus avoiding the ad hoc determination of stakeholders. Additionally, because of overlapping elements within each qualitative research method, results are continuously validated and reviewed throughout the research process [40].

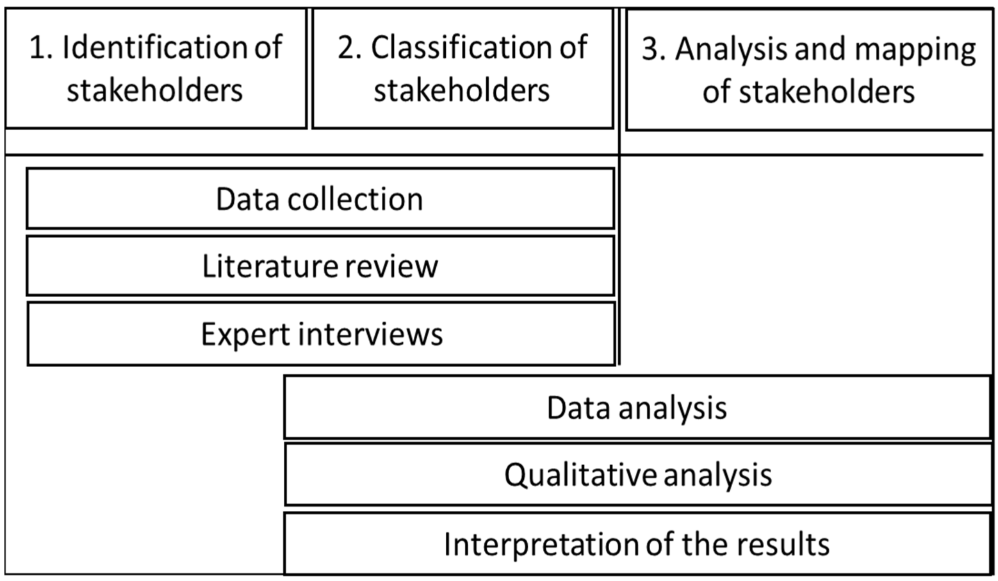

Figure 1. Methodology outline.

Our research approach refers to the TIS, which involves studying the set of actors and rules that influence the speed and direction of technological change in a specific technological area [13]. Here, an analysis of actors, networks, and institutions in the green hydrogen sector in Luxembourg is provided. The methodological process used to answer the question of which actors are active in the field of green hydrogen in Luxembourg consisted of three main phases:

1. Identification—Systematic identification of actors based on the literature and project documentation
2. Categorization—Classification of stakeholders into functional groups
3. Mapping—SNA of interconnections between stakeholder groups

Also, the stakeholders selected for interviews are based in Luxembourg but vary significantly in terms of geographical reach and operational scale. Some of them are involved in international projects or partnerships beyond Luxembourg, including activities in Belgium, the Netherlands, France, and Germany. Their reflections, therefore, often include insights derived from cross-border initiatives or regional experiences. The interview coding was carried out by the first author, following multiple readings of the transcripts and iterative refinement of themes. The analytical process was supported by regular discussions with the co-author to enhance thematic clarity and ensure interpretive coherence.

4.1. Stakeholder Identification

To identify relevant stakeholders in Luxembourg's green hydrogen sector, we conducted a structured mapping approach based on desk research and document analysis. This included national strategies, policy papers, media coverage, and official websites of public agencies and industrial consortia. From this material, we extracted organizations and actors mentioned in green hydrogen projects, planning, or public discourse, and then categorized them by type (e.g., government, industry, civil society). In detail, the stakeholder identification was carried out following the systematic categorization of [11] using a Google search, a review of academic (pre-reviewed journals, working papers, etc.) and the gray literature (reports, websites, news articles, etc.) for relevant stakeholders and projects in the hydrogen sector in Luxembourg in the period from April 2024 to October 2024. The goal was to obtain an initial overview of the topic and to identify the first actors. A table listing all stakeholder categories and subcategories was created. To gather additional information and deeper insights into stakeholders' motives, we use semi-structured interviews with experts as the primary data collection method. The identified participants from the literature review serve as a basis for selecting interview partners.

For the expert interviews, an interview guide was developed covering the topics of:

(a) contextual information about the company, projects, and activities;
(b) impressions and experiences on social acceptance, participation, and public perceptions and discourses of the green hydrogen development in Luxembourg;
(c) a reflection on (un)successful implementation.

The full interview guide is attached in Appendix A. The interviews were conducted as online meetings. In total, 10 individuals participated in the interview sessions. Interviews lasted 42.04 min on average, with a minimum and maximum duration of 27 and 57 min, respectively. Information on interview duration and the number of interviewed individuals is summarized in Table 1. For reasons of privacy and data protection, names of companies, organizations, and persons are anonymized. Each interview was recorded, fully transcribed, and evaluated using MAXQDA Analytics Pro 2020 software.

Table 1. Overview of interviews.

Number	Type of Stakeholder	Duration (min)
1	Electricity (distribution and transmission)	57:24
2	Transport sector	31:08
3	Transport sector (buses)	36:40
4	Transport sector (refilling station operators)	31:47
5	Industrial sector	39:04
6	Industrial sector (steel industry)	27:30
7	Public companies	57:24
8	Consultants	43:11
9	Energy cooperatives	50:19
10	Electricity utilities	43:42

4.2. Stakeholder Classification in Luxembourg

The stakeholder categorization aimed to create an overview of the actors using a category system made by [11]. The categorization consists of several interconnected main category blocks (see Figure 2). Subcategories are introduced to prevent information loss and guarantee a detailed overview of the rather general categories.

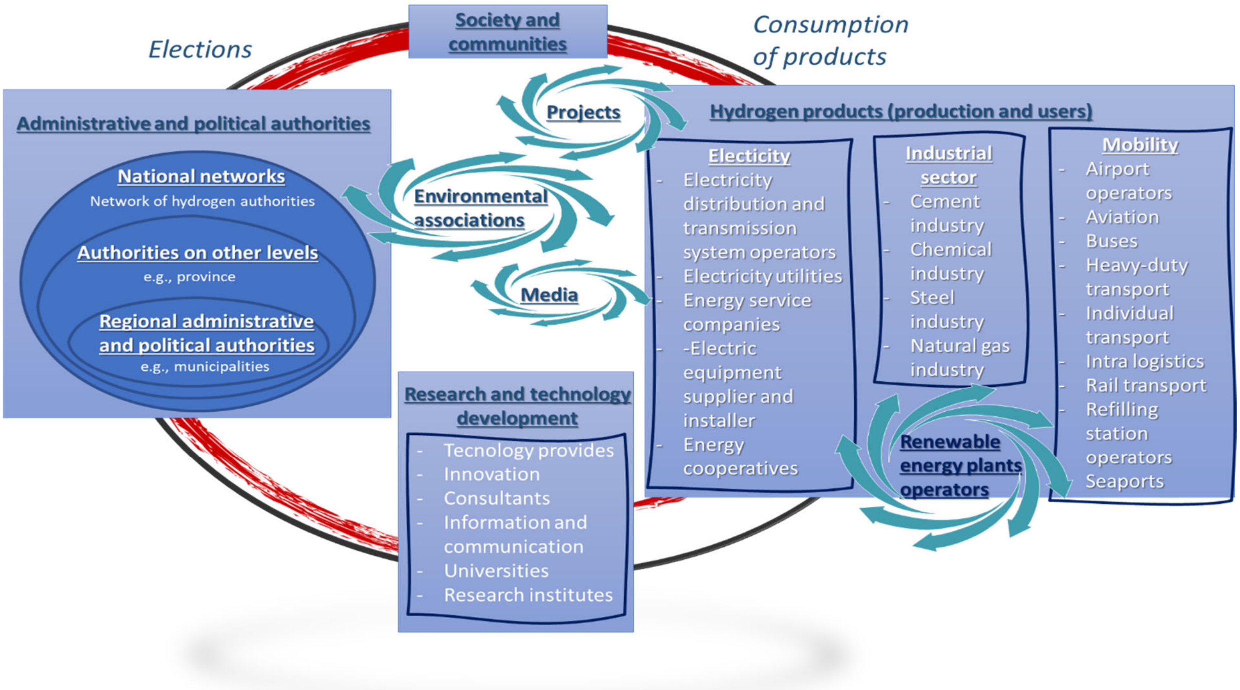

Figure 2. Categorization and relationship of stakeholders. The arrows illustrate the directions of influence and interaction among stakeholder groups. A detailed explanation of these dynamics is provided in the paragraph above "4.2. Stakeholder Classification in Luxembourg".

In detail, the dynamics among stakeholders in Luxembourg are organized as follows: society and communities influence both product consumption and the election of political authorities. Hydrogen products are categorized into production and users, which are further divided into three subcategories:

(a) Electricity covers electricity distribution and transmission system operators; electricity utilities with different activity focuses along the electricity value chain; energy service companies, which provide a wide range of energy solutions like planning power generation and energy supply; electric equipment suppliers and installers; and energy cooperatives.
(b) Mobility involves airport operators, aviation, buses, heavy-duty transport, individual transport, intra-logistics, rail transport, refilling station operators, and seaports.
(c) The industrial sector consists of the cement, chemical, steel, and natural gas industries.

Operators of renewable energy installations remain a separate category that affects all three listed sectors. Research and technology development, instead, includes: technology providers which are manufacturers and providers of special equipment for hydrogen technologies (e.g., fuel cells, electrolysers, storage tanks, pipelines, compressors, and liquefaction plants); innovation and consultants which contain scientific, political, technical, and economic consulting as a service; companies in the information and communication technology sector (e.g., service providers or data center operators); universities and research institutes. Administrative and political authorities are divided into national networks (a network of hydrogen authorities), authorities at other levels (e.g., provinces), and regional administrative and political authorities (e.g., municipalities). Projects, environmental associations, renewable energy plant operators, and media are separate categories that influence all the others listed above.

4.3. Stakeholder Analysis and Mapping

From a quantitative perspective, stakeholder groups in the transport sector have the highest number in the hydrogen sector in Luxembourg, followed by projects and consultants (see Figure 3). Therefore, there is a major push towards using green hydrogen in the mobility sector. Indeed, numerous projects and action plans are underway in this direction. The interviews provide additional information on existing or potential new collaborations or partnerships between stakeholders and the identification of risks/opportunities within the different stakeholder groups. The results of the interviews are reported in Section 5.

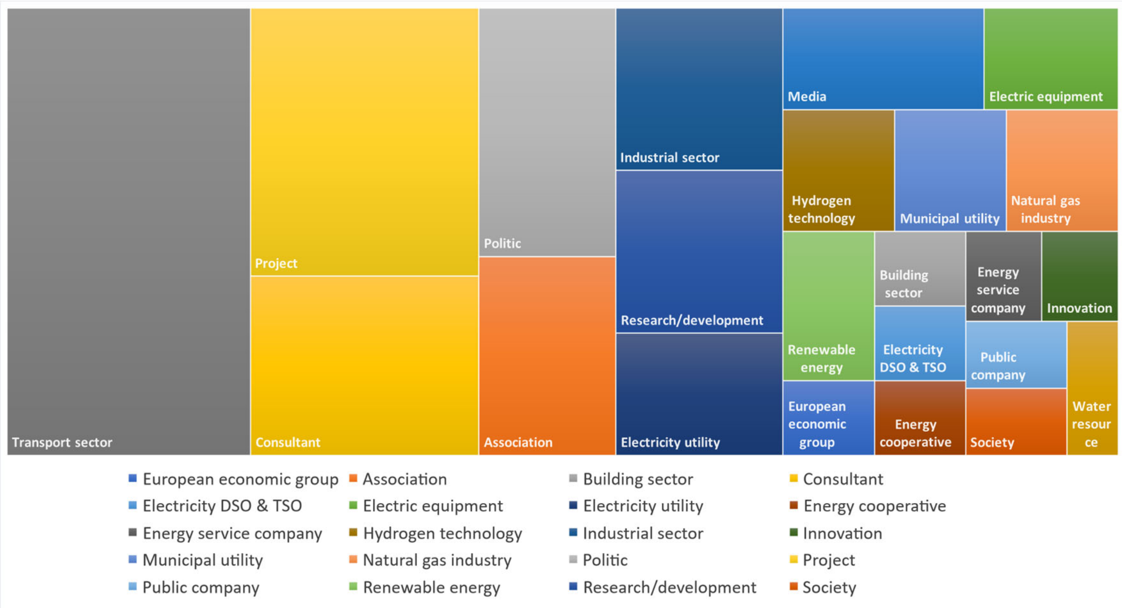

Figure 3. Hydrogen sector coverage in Luxembourg. The map illustrates the distribution of stakeholders across different categories in the Luxembourg hydrogen sector. The size of each square represents the relative presence and weight of that stakeholder group within the national context: larger squares indicate higher representation. Colors are used only to visually distinguish categories and do not carry additional analytical meaning.

For the analysis of the interaction between stakeholders, a social network analysis (SNA) is conducted. This analysis allows the graphical illustration of connections or collaborative ties. For the visualization of social networks and calculation of indicators, the Social Network Visualizer version 3.1. (SocNetV) [38] tool is applied. For our analysis, we chose the metric density and the centrality indicators degree and betweenness, which are considered the most important indicators [41]. The degree of centrality is the total number of ties the respective node has. In terms of stakeholder groups, the degree of centrality is equal to the number of connections to other groups. The degree of centrality measures the number of ties a node has to other nodes in the network. In social network theory, this index is often considered a measure of actor activity [42]. It can be computed in both undirected and directed networks/relations, but is usually best suited for undirected ones. Each stakeholder group is represented as a node. Figure 4 shows the network in which 40 stakeholder groups are presented.

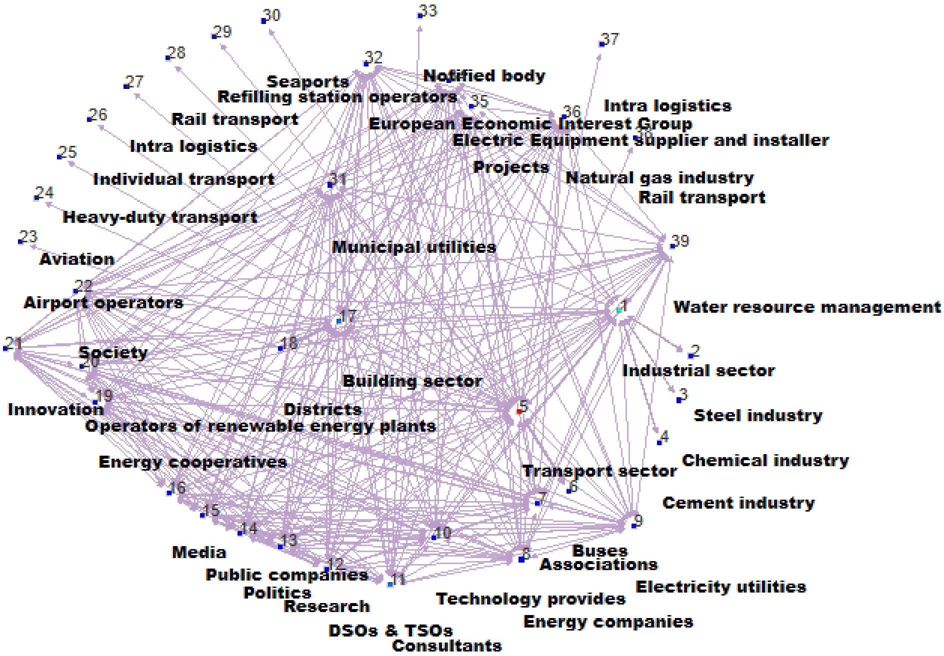

Figure 4. Network of stakeholder groups in Luxembourg in the green hydrogen sector.

The network shown in Figure 4 is drawn with a degree of centrality index and radial type. The density of the graph is 0.32. This value means that over a third of all possible connections between stakeholders are present. Thus, only some stakeholder groups have few or only a single connection to other groups.

The data presented are relevant for identifying stakeholder relationship outcomes. According to empirical studies in the literature, the ability to engage stakeholders facilitates the development of new knowledge and fosters the innovations needed for proactive growth in a specific area (e.g., [43]). Wolff [44] emphasized as early as 1998 that to address changes, especially in the environmental scenario (e.g., to include other technologies, new approaches, and attitudes), collaboration with a wide range of stakeholders is required. Moreover, trust is considered particularly crucial in both organizations and projects. It is essential for maintaining stable relationships, sustaining cooperation, and facilitating exchanges, even in routine interactions [45]. Therefore, establishing strong connections between stakeholders in Luxembourg is an essential first step in creating market and business opportunities for the country and its companies. These collaborations can lead to new regional value creation and help reorganize national and international development policy. While many stakeholders were described as open to collaboration, some tensions emerged—particularly between public sector actors demanding transparency and economic users seeking efficiency. Additionally, the relative absence of grassroots or environmental justice groups in the stakeholder network points to a risk of social blind spots in the hydrogen agenda. This echo calls for more deliberative and inclusive governance in clean energy transitions [22].

We then calculated centrality indicators to determine the most central stakeholder groups (see Table 2).

Table 2. Centrality values.

Stakeholder Groups	Centrality	Centrality′	%
Transport sector	704.745489	0.451760	45.175993
Industrial sector	216.495489	0.138779	13.877916

Table 2. *Cont.*

Stakeholder Groups	Centrality	Centrality′	%
Building sector	74.745489	0.047914	4.791377
Consultants	74.545489	0.047786	4.778557
Hydrogen technology	0.745489	0.000478	0.047788
Electricity DSOs and TSOs	0.745489	0.000478	0.047788
Research and development	0.745489	0.000478	0.047788
Media	0.745489	0.000478	0.047788
Society	0.745489	0.000478	0.047788
Municipal utility	0.745489	0.000478	0.047788
Electric equipment supplier and installer	0.745489	0.000478	0.047788
Energy service companies	0.697870	0.000447	0.044735
Public companies	0.697870	0.000447	0.044735
Innovation	0.650251	0.000417	0.041683
Water resource m	0.650251	0.000417	0.041683
Operators of renewable energy plants	0.642857	0.000412	0.041209
European economic interest group	0.642857	0.000412	0.041209
Associations	0.592857	0.000380	0.038004
Politics	0.592857	0.000380	0.038004
Electricity utility	0.545489	0.000350	0.034967
Energy cooperatives	0.545489	0.000350	0.034967
Projects	0.495489	0.000318	0.031762
Natural gas industry	0.495489	0.000318	0.031762

The transport sector is the most critical stakeholder group that connects the others. Since the mobility sector is one of the most likely to develop in Luxembourg in the green hydrogen sector, it is not surprising that it represents the most important bridge. The industrial and building sectors occupy places two and three. A higher number of connections is attributed to a greater extent of information exchange. The SNA shows that a few central stakeholder groups participate in many different hydrogen-related activities. As much as stakeholder analysis is essential for an overall view of an area, on the other hand, it can be static and fail to provide deeper information related to the dynamics among stakeholders, possible conflicts, or cooperation. The high centrality of the transport sector suggests its role as a narrative and logistical anchor in Luxembourg's green hydrogen strategy. This reflects broader debates on energy justice and participation in sustainability transitions (see [46]). Interview analysis allows us to have a clearer overview of these issues. The social network analysis shows that actors in the transport sector hold central positions. Combined with interview insights, this supports the assumption that network centrality and trust are positively linked to stakeholders' willingness to collaborate and coordinate actions across sectors.

Overall, the findings are consistent with the exploratory assumptions formulated at the outset. Stakeholders highlighted economic and safety risks, but also pointed to trust, centrality, and collaboration as critical components of a successful transition. These insights reinforce the need to address perceived barriers while leveraging existing social and institutional dynamics.

5. Interview Analysis and Discussion

Building on the stakeholder mapping, the following section presents the results of the expert interviews, which offer deeper insights into social perceptions, sectoral expectations, and perceived risks.

A qualitative thematic analysis has been used to systematically identify and organize the patterns of themes for 10 interviews. The thematic analysis approach includes both the descriptive and interpretive approaches and contains six main steps: becoming familiar with the data, generating initial codes, searching for themes, reviewing potential themes, defining and naming themes, and finally producing the report [47]. The analysis software MAXQDA was used for the systematic literature review, transcribing interviews, coding the data, and identifying the frequencies. The interview guideline also provides the basis for the analytical framework used to interpret the accumulated data.

5.1. General Stakeholder Perceptions on Green Hydrogen

This section explores how stakeholders perceive green hydrogen at a general level. It highlights a general openness toward the technology, balanced by concerns over regulatory uncertainty and knowledge gaps. Literature insights are integrated to frame these perceptions in a broader European context.

Overall, the experts underlined a large degree of openness from local communities and stakeholders towards green hydrogen and its local use and production, along with high expectations regarding environmental and climate protection. On the other hand, the potential for using hydrogen in Luxembourg remains unclear due to a lack of knowledge, regulation, and legislation. Experts highlighted insights from various European contexts regarding green hydrogen pilot projects. While Luxembourg was generally perceived as having favorable conditions for such initiatives, some limitations were also identified. Stakeholders noted that the small size of the national market and the limited industrial base posed challenges for large-scale deployment. In contrast, countries like Germany and France were often described as having more mature infrastructures, broader funding programs, and a greater number of industrial participants. Despite these challenges, Luxembourg was seen as a promising coordination platform and innovation hub.

In the literature, several studies (e.g., [6]) confirm that hydrogen technologies have generally been assessed as neutral to positive on a general abstract level. This means that *the idea* of using green hydrogen is widely supported. However, some authors have pointed out that there is some local resistance to the development of green hydrogen projects. For example, Ref. [48] found that while the Dutch population supports the establishment of hydrogen fuel stations, this positive attitude is moderated by a NIMBY (Not In My Back Yard) effect. Even though some social scientists have critically examined the NIMBY concept over the years (e.g., [49]), due to its simplistic and generalized assumptions, we argue that people-place bonds should be further explored within the context of Luxembourg. Currently, experts perceive a positive social attitude toward green hydrogen; however, this does not rule out the possibility that implementing a specific local project could lead to different opinions. Recent literature underscores the role of procedural justice in shaping public acceptance of low-carbon technologies, including green hydrogen. Resistance may stem not only from spatial proximity (as in NIMBY dynamics), but also from a perceived lack of fairness, transparency, and inclusiveness in decision-making [50,51]. Studies [52,53] show that early community engagement, access to information, and the perception of being included are crucial in shaping trust and legitimacy in energy transitions. These procedural aspects can be as decisive as technical performance or environmental impact in determining local support. While experts in our study perceived a generally positive social attitude toward green hydrogen, this does not rule out the possibility of local resistance, particularly if stakeholders feel excluded from governance processes, experience limited procedural transparency, or perceive a lack of fairness and responsiveness in how decisions are made and justified.

A key difference emerged between industry actors, who viewed hydrogen as a compliance and decarbonization tool, and mobility stakeholders, who emphasized visibility, user experience, and public perception. This divide reflects differing logics of value (economic vs. communicative) in the sector's development. Thus, the interviewed industry experts stated that significant decarbonization would require green hydrogen in various local industries, despite Luxembourg's industry being smaller and less international compared to its neighboring countries. The main national industries are focused on glass, cement, steel, and metal, but the production is not as extensive as in other close industrial countries like the Netherlands, France, and Germany. On the other hand, industries have rules to follow to be greener and avoid sanctions or subsidies to pay (CO_2 taxes). In this case, the use of green hydrogen would be not only an environmental matter but also an economic one. Nevertheless, the use of green hydrogen brings with it an excessive expense, considering the expense of machinery, which involves economic risks. In the future, the experts suggest that the industry groups should develop partnerships with hydrogen producers to organize the production that could be used for several projects. This will require the development of some cooperation between consumers and producers, but also between consumers and authorities.

To summarize, local stakeholders see the development of green hydrogen in the industrial sector as essential, particularly to avoid fines. However, this development requires a careful process to mitigate excessive economic risks. Establishing a new branch in the energy sector demands significant investments, which inherently carry various economic risks. In fact, during the initial ramp-up of the hydrogen market, stakeholders may face market ramp-up risks, including slow market dynamics or a less favorable learning curve and cost reduction than expected. Therefore, stakeholders need to grasp the dynamics of market ramp-up. It is relevant not to underestimate the temporal ramp-up risk because the process can take longer than anticipated. For example, solar photovoltaic technology took a considerable amount of time to achieve even a small percentage of market coverage [54]. Once that milestone was reached, growth accelerated rapidly. In conclusion, during the ramp-up phase, stakeholders interviewed expect low-carbon hydrogen to be in short supply, and production costs are likely to remain high.

5.2. Key Factors Influencing Acceptance: Costs, Risk, and Values

This part examines the key elements that shape stakeholder acceptance, with a particular focus on economic costs, risk perception, and environmental values. It shows how both practical and normative considerations influence attitudes toward green hydrogen adoption.

A key concern, raised by 90% of interviewees, was the high cost of green hydrogen, particularly related to infrastructure, transport, and maintenance. In fact, the interviewees expressed doubt that such projects could materialize without increased financial support at local, national, and EU levels. These cost-related concerns were often linked to broader regulatory uncertainties, especially regarding safety and technical standards. Long-term commitments associated with infrastructure development were also viewed as a barrier, due to uncertainty and limited available information.

Moreover, 40% of interviewees emphasized that the type of hydrogen (green vs. gray) should be the real focus, rather than the sector in which it is used. From an interview: "*There is a lot of talk about* industry vs. mobility, *but the important thing is that green hydrogen is used. We should also remember that hydrogen is only one of the possible solutions to protect the environment.*" Our findings underscore the relevance of personal beliefs and problem awareness in shaping stakeholder evaluations. This aligns with existing research [55], which found that environmental values and personal norms strongly predict both support for and opposition to hydrogen development.

In addition to economic issues, health and safety risk perceptions emerged as a concern mentioned by all participants. While recent studies indicate that positive feelings toward hydrogen often outweigh fears [56], interviewees stressed the power of local concerns to shift public sentiment. As one interviewee underlined it: *"We have all also been informed about the risks. And the risk can be very scary. There are these unknown risks. What happens, for example, if there is a leak? What if an accident happens?"* Such concerns reflect broader research indicating that hydrogen safety is a multidimensional concept, influenced by emotional responses, perceived severity, and uncertainty [57,58]. For example, Slovic et al. [59] noted that perceived fear is a particularly powerful predictor of technology rejection. Likewise, Hildebrand et al. [60] found that risk perceptions manifest at different levels (micro, meso, and macro) across the hydrogen value chain, influencing both public and stakeholder acceptance. Trust emerged as a crucial factor in influencing uncertainty. Following Luhmann's [18] notion of trust as a mechanism for reducing complexity, and Putnam's [61] concept of social capital, trust can enhance public engagement and acceptance. This was underlined in several interviews, where respondents emphasized the need for clear, visual, and relatable communication strategies.

In conclusion, while interviewees expressed optimism about hydrogen's potential for decarbonisation and regional coordination, concerns about safety, technological risks, and public trust emerged as salient themes. Although no local incidents have occurred in Luxembourg, several international events have shaped the perception of hydrogen risk. For example, a hydrogen refueling station explosion in Norway in June 2019 led to the temporary closure of multiple stations and halting of hydrogen vehicle sales by Toyota and Hyundai [62]. Recent research shows that public risk perception varies significantly depending on the type of hydrogen infrastructure, highlighting how technological context and familiarity shape societal responses [60]. On the other hand, studies show that even isolated incidents can influence public discourse, amplifying fear, despite advances in technological safeguards [56]. Media content in Germany, for instance, showed that while accident risks are rarely mentioned directly, historic incidents or station explosions significantly influence public sentiment [63]. Survey-based research also highlights a dissonance between perceived and actual risk. For instance, a comparative study across Norway, Spain, and Japan found that people tend to overestimate the likelihood and severity of hydrogen accidents, especially at fuelling stations, even when objective risk measures are low [64]. These findings underscore the importance of integrating transparent risk communication, clear safety standards, and trust-building measures as hydrogen strategies advance, particularly in emerging contexts like Luxembourg, where public familiarity remains limited and local stakeholder exposure is high. As the sector matures, it will be valuable to track how safety perceptions evolve and how effective risk mitigation strategies can shape acceptance. Future research should focus on aligning messaging with actual safety outcomes and integrating public education into the planning of policy and infrastructure rollouts. To address current limitations, future studies could employ longitudinal methods to capture changing perceptions over time, organize participatory workshops for stakeholders to enhance mutual understanding and trust, or conduct cross-country comparisons to distinguish between context-specific patterns and those that are more generalizable regarding acceptance and resistance. In addition, as recent debates on energy security and policy have shown, questions of supply chain resilience, technological control, and geopolitical dependence are as relevant for hydrogen as they are for any other energy carrier. To develop strong and sustainable hydrogen strategies in the coming years, it will be essential to incorporate these factors alongside environmental, economic, and social considerations.

5.3. Sectoral Preferences and Use Cases: Mobility, Industry, Heating

This section outlines the different expectations and acceptance levels across sectors. Stakeholders assess the potential of hydrogen in mobility, industry, and heating, revealing varied socio-technical barriers and opportunities based on visibility, control, and perceived impact.

A majority of interviewees (60%) identified the transport sector, particularly long-distance trucking, as the most promising application area for green hydrogen in Luxembourg. They cited its advantages over electric mobility, including greater power, shorter refueling times, and better suitability for long-haul travel. Luxembourg's geographic position in the heart of Europe was also seen as an asset, potentially serving as a strategic hub for refueling corridors. These views align with findings by Caponi et al. [65], who reported average hydrogen refueling metrics of 14.62 kg per bus and 10.28 min per refuel. Moreover, stakeholders suggested that mobility offers higher visibility and thus a greater potential to enhance public acceptance, as citizens can directly observe hydrogen-powered vehicles in action. By contrast, fostering acceptance in the industrial sector appears to be more challenging. Several interviewees noted that since many industrial actors are privately owned and their processes are less visible to the public, it is harder to communicate the benefits of switching from natural gas to green hydrogen. While the sector has high decarbonization potential, the lack of public exposure and transparency may limit societal engagement.

Heating was perceived as the most challenging sector for hydrogen integration, with 40% of stakeholders pointing to both infrastructural and social barriers. Interviewees mentioned limited public acceptance due to the close connection between energy systems and private households. Additionally, retrofitting existing infrastructure was seen as complex and costly. This view is supported by recent EU assessments. For instance, the European Commission's Joint Research Center (JRC) notes that using hydrogen for residential heating is far less efficient and more expensive compared to electric heat pumps or district heating solutions [66]. Similarly, the International Energy Agency reports that the conversion of homes to hydrogen heating would lead to significantly higher infrastructure costs and energy losses compared to electrification scenarios [67]. Luxembourg's own National Energy and Climate Plan (NECP) [68] emphasizes electrification and efficiency as key pathways for decarbonizing buildings, with hydrogen playing a limited role in specific industrial or off-grid use cases. These assessments align with stakeholders' concerns regarding acceptance, feasibility, and public readiness for hydrogen-based heating solutions in domestic settings.

Scholars [69,70] argue that hydrogen-based heating is less cost-effective than alternatives like heat pumps, solar thermal, or district heating. Although future cost developments remain uncertain, evidence indicates that hydrogen heating is likely to be more expensive for consumers. Furthermore, the domestic use of hydrogen is embedded in a broader socio-technical system shaped by multiple interdependent factors. Despite growing attention to hydrogen's role in residential heating, there remains a notable knowledge gap regarding how acceptance varies across communities and households. These variations merit further investigation, particularly given their potential influence on national and local implementation pathways.

5.4. Collaboration, Governance, and the Role of Public Authorities

Here, the analysis focuses on the perceived importance of coordinated efforts between stakeholders, institutions, and policymakers. It stresses the need for long-term partnerships, continuous exchange, and stronger political commitment to support implementation. All the experts interviewed (100%) underlined the importance of a strong collaboration and exchange with a clear dialogue between all the stakeholders, including the future customers, authorities, and the ministry. Furthermore, it is relevant to establish follow-up and cohesion among partners involved in a project, rather than viewing each project as a separate entity that concludes once the project is over. From one of the interviews: *"It's really important to* *not only finish the project and then just leave it, but I think having these closed-loop philosophies or stakeholders to keep exchanging is important . . . for us to learn, to hear the experiences of the clients, to hear the questions and then be able to improve on the other projects".* This aligns with the assumption that collaboration and stakeholder dialogue are viewed as essential enablers for successful implementation. Nearly all interviewees stressed the importance of continuous exchange, especially between project developers, institutions, and end-users.

Furthermore, 70% of the interviewers explained the importance of having support from the government and politics: *"[. . .] it might be obvious when I think that the government has an important role in perception, but also the implementation of hydrogen projects in any country. If the government does not support the implementation of hydrogen, it will be really difficult to implement it"*. The support from the government is seen as essential for building a concrete green hydrogen system and transition. As well as a need for more pilot projects to make hydrogen more tangible and accessible, and to counter the degree of skepticism, especially in terms of efficiency. Also, this way, local companies can see how it works and also show the local chain (renewable energy infrastructures, hydrogen, etc.), and this could lead to the public perception of green hydrogen in different stakeholder groups.

5.5. Knowledge Gaps, Communication, Trust, and Stakeholder Engagement

The final part highlights challenges related to public understanding of hydrogen, underlining the role of effective communication and trust-building. It explores how informed engagement and participatory strategies can enhance social acceptance and support market development.

In our dataset, experts point out a lack of knowledge from the population about hydrogen-related topics such as production, storage, and distribution. There is also limited media coverage and minimal discussion surrounding it, and ongoing projects have yet to yield concrete advancements. Currently, the hydrogen sector is not well developed, making it seem abstract, especially for local communities, and this could cause some resistance from the population. Foremost, hydrogen awareness and knowledge levels remain low across most countries [71,72]. Scholars emphasized that awareness and knowledge (objective and subjective) can increase acceptance indirectly by increasing the perceived environmental benefits [73], positive affect, and perceived societal effects [55], lower perceived risk [74], and trust in the technology (e.g., safety) [75]. Thus, these findings suggest that awareness knowledge influences green hydrogen acceptance (mostly positively) but only via its influence on other variables. In conclusion, methodologically sound participatory processes can enhance public acceptance and foster active support, particularly through increased information and training across various sectors [76,77]. Our findings reinforce the relevance of relational and trust-based dynamics in shaping stakeholder behavior during the early phases of market ramp-up. This contributes to ongoing discussions in the sustainability transitions literature on the need for socially embedded governance. Policy-wise, our study recommends co-design processes, continuous dialog with end-users, and region-specific communication strategies.

While economic and safety concerns remain prominent, most interviewees also acknowledged clear opportunities associated with green hydrogen. Several experts emphasized the strong potential of hydrogen to support Luxembourg's climate targets, particularly in sectors where direct electrification is challenging. In terms of sectoral application, the mobility sector, specifically long-haul heavy-duty transport, was cited by 60% of respondents as a strategic use case. Stakeholders highlighted how hydrogen can enable fast refueling and longer ranges, providing advantages over battery electric vehicles. Thus, Luxembourg's central geographical position within Europe was also seen as a competitive advantage, potentially allowing it to become a key transit and refueling hub for international hydrogen-powered freight. Experts suggested that this role could enhance both economic resilience and environmental leadership at the EU level. Moreover, many interviewees viewed green hydrogen as a catalyst for regional value creation, including new market opportunities and green job creation, particularly in infrastructure, maintenance, and logistics. One participant noted: *"This is not just about decarbonization, it's a chance to reinvent parts of our economy."* These insights reveal that, despite tangible concerns, stakeholders show high levels of openness and expectation regarding hydrogen's role in the transition. They also express a desire to engage proactively, provided that the process is inclusive, visible, and supported by policy instruments.

Building on this knowledge and communication challenges, our findings suggest the need for a structured approach to stakeholder engagement. To this end, we propose a preliminary framework structured along three axes:

1. Transparency (clear communication on benefits/risks);
2. Reciprocity (structured feedback loops between stakeholders);
3. Visibility (showcasing working pilot projects).

This framework can guide both national strategies and EU-level collaborative initiatives aiming to foster socially robust green hydrogen deployment.

5.6. Limitations and Future Research

While we aimed for a rigorous research design, the triangulated approach that combines literature review, expert interviews, and social network analysis strengthens the robustness of the findings. However, certain limitations should be acknowledged. The stakeholder sample, though diverse, may not be fully representative of all relevant actors, particularly those from the policy and civil society domains, and it could be expanded. Given the exploratory nature of this study and the still-limited stakeholder landscape in Luxembourg's hydrogen sector, a purposive sampling strategy was applied to ensure coverage across key categories. While only one interview per sector was conducted, each participant was selected based on their strategic role or institutional relevance, ensuring an informed perspective on sectoral dynamics. This approach aimed to provide a first mapping of emerging narratives and concerns, which can serve as a basis for future research involving larger samples. Plus, while the sample size of ten interviews is consistent with qualitative standards for exploratory research, especially in a small national context like Luxembourg, we acknowledge certain limitations. The selection was influenced by accessibility and willingness to participate, which may have introduced selection bias. Stakeholders more actively involved in hydrogen initiatives may have been overrepresented, while more skeptical or peripheral voices may not have been equally captured. Therefore, the findings should not be interpreted as fully representative of all sectors or positions within Luxembourg's hydrogen landscape but rather as a first insight into key actors' perceptions and framing at an early implementation stage.

Additionally, while SNA provides a structural overview of stakeholder interactions, it does not capture the qualitative nature of these ties (e.g., cooperation vs. competition). Future research could enrich this analysis by including longitudinal data and deliberative participatory methods to explore evolving dynamics over time. Finally, recognizing that various public perception factors (procedural and distributive justice, social norms, emotional and cognitive evaluations, trust, etc.) are significant, it would be beneficial to explore these interdependencies and their relationships with different stakeholders in future studies in the context of concrete hydrogen projects on the local level. This exploration is relevant for further deployment of green hydrogen as it will provide a clearer understanding of the dynamics among different stakeholders. To conclude, the results of this stakeholder analysis helped to identify potential national and local conflicts at an early stage. This allowed us to establish criteria for a socially acceptable ramp-up of green hydrogen development. Plus, the analysis provided valuable insights into areas where there may still be a need for information and communication with the public. In addition to addressing perceived risks, future strategies should emphasize and leverage the positive expectations already present among stakeholders. Highlighting hydrogen's potential to support decarbonization, economic innovation, and regional leadership could increase engagement and accelerate acceptance.

6. Conclusions

This paper presents a comprehensive stakeholder analysis of the hydrogen market ramp-up in Luxembourg. Stakeholders are identified and categorized, and their relationships are analyzed using primary data from interviews, as well as secondary data from literature and assessments of real-life hydrogen projects shared during these interviews. The research design aims to ensure that the information is analyzed systematically and methodically.

The results indicate that the perceived impacts of green technologies, including economic costs and health risks, significantly influence perceptions of hydrogen energy technology. In the short term, the heating sector is not viewed as an important stakeholder group. The mobility sector is expected to experience the most significant market growth in Luxembourg, although it also raises the most concerns among the public. Interestingly, most of the interviewed stakeholders do not anticipate substantial conflicts among stakeholder groups during the market ramp-up. Instead, they advocate for increased collaboration that will benefit all parties involved. Additionally, they express a lack of support for project implementation at both local and national levels, as well as insufficient media communication regarding green hydrogen and its potential developments. This increased awareness could help address the existing knowledge gap. The economic aspect calls for government intervention to accelerate a politically desired market ramp-up. However, a long-term strategy that includes a hydrogen market target model should be defined.

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Appendix A. Interview Guideline

First cluster—Contextual information

- I would like to start by asking you to introduce the company you are working for and what your main tasks in the company are.
- What is your connection to the topic of energy/hydrogen?
    - What are your experiences in the hydrogen sector?
- Could you tell me more about the hydrogen projects and activities you are working on?
    - What is the aim of the projects/activities/experiences?
    - Who initiated the projects?
    - What is the status of the projects?
    - When and where did/will the projects start?
- What do you think are the advantages and disadvantages of the projects?
- In your opinion, what are the general advantages and disadvantages of the use of hydrogen in different sectors (mobility, industry, etc.)?
    - What could be the advantages and disadvantages of the use of hydrogen in Luxembourg?
    - What could be the application sectors for hydrogen in Luxembourg?
- In your opinion, what are the biggest chances and difficulties to the use of hydrogen in the industry in Luxembourg?
    - For which stakeholders could the development of hydrogen in industry pose risks/offer an opportunity?
- In your opinion, what are the biggest chances and difficulties to the use of hydrogen in the mobility sector in Luxembourg?
    - For which stakeholders could the development of hydrogen in the mobility sector pose risks/offer an opportunity?

Second cluster—Acceptance, participation, and public perceptions

- In your experience, what does the population think about the use of hydrogen?
- What do you think are the key factors for social acceptance of the use of hydrogen?
- What can negatively influence the social acceptance of hydrogen projects?
- Could you please share your experiences on what the needs of the communities in Luxembourg are to have a higher acceptance of the hydrogen sector? (e.g., What kind of information do they need? What kind of participation options do they prefer?)
    - Can you recommend communication strategies and tools that have helped you?
- How do you think the media can make a difference in the social acceptance of hydrogen use?
- Are there factors that may influence social acceptance differently in the different hydrogen sectors (e.g., industry, mobility, heating, etc.)?
    - What could be the reason for this difference?
- Are there factors that may influence social acceptance differently in the different stakeholder groups (e.g., residents, municipalities, authorities, politics, economic users, customers, etc.)?
- How did you make the community learn about your activities?
    - How did you involve the community in these activities?
    - What was the population's reaction to these projects?
    - Were there initiatives or opposition groups that formed against these projects?

Third cluster—Reflection on (un)successful implementation

- Can you imagine new collaborations or partnerships between stakeholders?
- What could be done better in the future?
    - What are the future goals?
- Are there any aspects we have not mentioned yet that are important?
- Is there anybody whom you think we should talk to who plays a key role in the hydrogen sector?

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