BARRIERS AND DRIVERS TO THE IMPLEMENTATION OF GREEN HYDROGEN IN THE EUROPEAN STEEL INDUSTRY: A PESTLE Analysis

What are the barriers and drivers of green hydrogen uptake in the European steel industry?

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ABSTRACT

The European steel industry accounts for 5% of all European CO_2 emissions, emphasizing the urgent need to decarbonize the sector using cleaner energy carriers like green hydrogen. Despite increasing research on this issue, very few studies have sought to explain the barriers and drivers underlying this industry transition at the EU level. Hence, this research aims to fill this knowledge gap by identifying macro-level barriers and drivers associated with adopting green hydrogen in the European steel industry. Therefore this study utilizes the PESTLE framework and employs a cross-sectional qualitative research design, conducting six semi-structured interviews with key stakeholders in the European steel industry. Findings demonstrate the interconnected nature of PESTLE factors influencing the adoption of green hydrogen. As such, the availability and cost of green hydrogen are closely related to political, economic, and technological barriers. Findings suggest that overcoming these barriers, especially the economic ones, requires significant influence from the political & legal dimensions, including policy frameworks and incentives for adopting green hydrogen and transforming steel sites. The paper concludes by providing practical implications and recommendations for stakeholders such as international policymakers, steel manufacturers, and sustainable enterprises. These insights will guide efforts to achieve a more sustainable European steel industry.

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INTRODUCTION

The burning of fossil fuels in the last decades has caused climate change to a big extent (1). More than ever, we require cleaner energy carriers to decarbonize industries and achieve sustainable development (2). One fruitful alternative to fossil fuels displays hydrogen, which can be generated by renewable energies and then is widely known under the name green hydrogen (2). Technically, the most promising and mature way to produce green hydrogen displays water electrolysis, which splits chemically water into hydrogen and oxygen with direct current, resulting in zero CO2 emissions and high-purity hydrogen (3). Because of its many sources, high calorific value, good thermal conductivity, and increased reaction rate, hydrogen is regarded as the most favourable clean energy in the twenty-first century (4). Additionally, due to its ability to effectively store energy and enable the decoupling of energy creation from energy demand (5). By 2030, green hydrogen is predicted to be crucial to the energy transition by enhancing other renewable energy technologies, with some countries emerging as leaders in renewable energy development and hydrogen generation (6). The European Union and its member states aim to represent such a leadership role regarding the energy transition, as the plans of the European Green Deal imply (7). However, this only can be realized when energy-related sectors foster decarbonizing, considering that they account for more than 75% of EU greenhouse gas emissions (8). Achieving sustainable development and decarbonization in energy-intensive industries requires the support of innovative projects and activities by the private business sectors, acting as change agents in the new development paradigm (9). Here sustainable enterprises, a driving force for radical innovation and achieving sustainable development, could accelerate this transition (9). In particular due to their ability to create market opportunities by changing existing institutions to their favour (10).

Generally, replacing fossil fuels with green hydrogen represents a strategically important key in achieving the European climate goals because green hydrogen can decarbonize around 18% of energy-related sectors (11). However, scaling up green hydrogen is determined by various uncertainties encompassing demand, supply, and infrastructure coordination (12). Consequently, this leads to a three-sided "chicken-and-egg" problem: without supply, there is no demand; without demand, there is no supply; and without transportation infrastructure, distributed trade is impossible (12)**.** While some industrial sectors can be more effectively electrified and hence won't need green hydrogen, others will dependent more on green hydrogen. That applies especially to the steel industry, which can only partially benefit from direct electrification due to its high-temperature processes (13).

Moreover, the steel industry has to be given priority with green hydrogen as a radical innovation, because it has exhausted incremental innovations including increases in energy efficiency (14). Adopting this radical innovation infers a fundamental transformation of a whole industry's business model, where sustainable entrepreneurs might be necessary due to their ability to build a business case by favoring more environmentally friendly production methods (15). To conclude, deep decarbonization in steelmaking by replacing fossil fuels and avoiding C02 is pivotal when considering that the European steel sector contributes to 5% of European CO2 emissions and acknowledging the EU's estimated steel demand is expected to increase from 166 million tonnes currently to almost 200 million tonnes in 2050 (16) (17). Despite the foreseen increase in steel production in the coming years, technical research shows the possibility of cutting production emissions up to 95% compared to 1990 levels (16). To cut emissions drastically, the steel production process and the energy system must undergo fundamental modifications (18).

To achieve this, the steel sector needs assistance from governments, the energy sector, and other industries to succeed in this systematic change, adding further complexity to this process (16). To identify bottlenecks in the green hydrogen penetration by the steel sector and its underlying complex cross-sector nature, revealing influencing barriers and drivers is inevitable. Because literature so far has frequently examined barriers and drivers within the context of single players and countries, there is a need for more holistic studies incorporating macro-level factors by looking from an EU-Level (19,20). To address and respond to this particular knowledge gap, this study builds upon the following research question:

What are the barriers and drivers regarding the uptake of green hydrogen within the European steel industry?

The novelty and contribution of this study are at least two-fold. Firstly, this research is among the first to apply the chosen theoretical framework in this context, hence enriching literature and theory. Secondly, answering the research question reveals practical implications for a range of stakeholders, such as international policymakers, steelmakers, and sustainable entrepreneurs. The structure of this paper is as follows. In Chapter 2, a literature review will be conducted, while Chapter 3 continues to elaborate on the chosen research methods. The study proceeds in Chapter 4 by presenting the findings according to obtained primary data. In Chapter 5, the discussion critically reviews the findings by bringing them into context. The Chapter 6 draws a conclusion on this research, while Chapter 7 acknowledges limitations and proposes further research.

THEORY

The structure of the theory section is as follows. First, the European steel industry's unique characteristics and today's efforts in contributing to sustainable production are presented. Understanding the complex nature and link to the sustainable development of this sector is inevitable, before introducing and utilizing the PESTLE framework to present current barriers and drivers linked to green hydrogen steelmaking.

Characteristics of the European steel industry and its decarbonization efforts

With over 125 billion euros in yearly sales, 310,000 highly skilled individuals employed directly, and an average annual output of 153 million tons of steel, Europe's steel industry is a global leader in environmental sustainability and innovation (21). While this industry provides direct employment for 310,000 workers, millions more European citizens are working indirectly at over 500 steel production facilities spread throughout 22 EU Member States (21).

Only a small number of nations control the majority of the EU's steel production, while the top four EU steel producers in 2020 were Germany (26%), Italy (15%), France (8%), and Spain (8%) (17). EU's steel production and the underlying sector are characterized by large enterprises, substantial market entry barriers, and merger pressure (22). Low-profit margins and high fixed expenses are typical problems for this sector (22). Steel products are demanded by a variety of industries, with the construction sector contributing to 37% of the highest steel consumption, followed by Automotive (16%) and the mechanical engineering sector (15%) (23).

Coming to steel production, the process of making steel starts with mining iron ore, which is then reduced to iron by eliminating oxygen (24). Iron is further transformed into steel by lowering the carbon level, adding alloys, and removing impurities (24). In the European Union, reducing iron ore to iron and, consequently, the steel output is dominated by two production pathways, namely the blast furnace/basic oxygen furnace (BF/BOF) route and the scrap-based electric arc furnace (EAF) route (14). Because the conventional Blast furnace/basic oxygen furnace production route is highly polluting due to the dependency on coking coal as a reducing agent, finding an alternative cleaner production pathway is of priority (17).

Currently, the most radical decarbonization pathway is the so-called carbon-avoidance pathway (16). This pathway is achieved by switching from an integrated BF to an electric arc furnace steel production route with increasing use of green hydrogen, where emissions could be incrementally reduced to water than CO2 (16,25). Promoting this specific production route is crucial because the steel industry accounts for 5% of all C02 emissions in the EU (17). Therefore, several industry members have started various decarbonization projects in the steel industry (4). Accordingly, EAF and hydrogen direct-reduction plants will gradually replace current integrated sites, as stated in the step-by-step plans of the German SALCOS initiative and the Swedish HYBRIT project (22).

Barriers and drivers of green hydrogen penetration in the European steel industry - A PESTLE Analysis approach

PESTLE – Framework. Responding to a call for testing the empirical validity of the PESTLE framework, this research utilizes the PESTLE framework to discern barriers and drivers from literature and interviews (26). The chosen framework is regularly used in strategic management to investigate the environment in which a business or industry functions (27). While the PESTLE analysis might be helpful for strategic management in conventional businesses, this is especially true of sustainable enterprises due to their stakeholder-oriented business models.

Also, for academic research, as in sustainable entrepreneurship, using the PESTLE framework represents a fruitful method for analyzing the larger context in which sustainable entrepreneurship occurs. Coming to the proposed factors of the PESTLE framework distinguishes between the Political, Economic, Social, Technological, Legal, and Environmental dimension (28). By selecting the PESTLE analysis for this research, it is possible to get into further detail about the macro-level factors impacting European steelmakers' adoption of green hydrogen. Below, each PESTLE factor will be addressed on its own, according to recent literature.

Political & Legal. Deploying the most sophisticated technologies won't alone be sufficient for decarbonizing the steel industry, instead, this industry transformation requires a well-suited policy framework (14). More particular, foreign rivalry, technological risks, and the need for new infrastructure all indicate the need for significant public participation (22). To ensure green hydrogen for industries such as the steel industry, the European Commission published in July 2020 the EU Hydrogen Strategy (29). The EU's Hydrogen Strategy aims to prioritize green hydrogen in the EU's energy and environment policy. In particular, the EU committed to meeting specified targets for electrolyzers of 6 GW and 40 GW by 2024 and 2030, respectively (29). Meeting these targets requires extensive support from governments, particularly in coordination, exploring business models, and providing financing for low-emission electricity and hydrogen infrastructure (30). Simultaneously to scaling up the green hydrogen production, as EUROFER stresses, it is highly relevant that politics grant priority access to hydrogen supply and existing grids for sectors such as the steel industry (21).

Distribution efforts by the EU require active collaboration with neighbouring nations and areas because, for instance, some countries have more capacity for renewable energy due to favourable geographical conditions, which is obligatory for green hydrogen generation (31). Here collaboration should include everything from research and development to regulatory policy, direct investments, and fair commerce in hydrogen and associated technologies and services (31). To conclude, the risks and benefits of this industry transformation must be shared between private and public parties in a transparent and accountable manner (24). Continuing with the legal dimension, European steel production emissions are primarily regulated via the Emission Trading System (ETS) (24). The ETS operates under the "cap and trade" premise and is placed on the total amount of specific greenhouse gasses that the system's operators can emit, while the cap is gradually reduced in order to reduce total emissions (32). Regardless of the incentive offered by the EU ETS, studies suggest that this instrument only creates marginal pressure for the transition to lower emission-intensity technology by energy-intensive industries (33).

Less affected by this legal instrument is particularly the European steel industry, with their exclusive right of having a free allocation of emission allowances and low carbon prices (33). The trigger to introduce a free allocation of emission allowances by the EU was primarily the concern of carbon leakage, or to express differently, the migration of the European steel industry into countries with lower carbon prices (22). Due to the adverse side effects of the free allocation rule, the European Parliament and Council recently announced a new legal instrument to address the issue of carbon leakage (34). As the plans of the Fit for 55 package reveal, the so-called carbon border adjustment mechanism (CBAM) is foreseen to gradually replace the free allocation rule (34). The CBAM guarantees that higher emissions beyond the EU's boundaries, either through manufacturing relocation to non-EU nations or higher imports of carbon-intensive items, do not compensate for the EU's emissions reduction efforts (34).

Economical. From an economic point of view, the literature indicates the high capital intensity and further low margins of the steel industry as a barrier to green hydrogen uptake (22). Accordingly, these characteristics led to an industry with quite durable structures and processes, where new technologies are rather integrated into existing infrastructure than accommodated by new infrastructure. These industry-specific barriers are particularly a bottleneck when considering that green hydrogen is currently not yet cost-competitive and thus drives costs for hydrogen-based steelmaking higher than those production pathways with fossil fuels (35).

However, as studies point out, by 2050, the costs of green hydrogen-based steelmaking could be competitive with those of conventional steelmaking, given there is a significant decline in the cost of green hydrogen and an increase in the price of CO2 emissions (17). As long as prices for green hydrogen may not have reached economic feasibility, revenue streams from hydrogen storage and synergies with other industries could mitigate the cost disadvantage borne by steel producers (36). Furthermore, financial assistance alternatives, including Horizon Europe, Partnerships, Significant Projects of Common European Interest, and the ETS Innovation Fund could aid (16). In particular, pre-competitive innovation stage financing presents an attractive solution to incentivize the steel industry to initiate demonstration projects to go from proof of concept to full-scale demonstration of a new process while keeping financial uncertainties under control (22).

Social. Considering the influence of social aspects by an industry transformation is vital to avoid creating new social inequalities. Starting with the impact on local employment, labor intensity for green hydrogen steelmaking is predicted to increase by around 40% (5). Besides creating new jobs, this industry transformation might also negatively affect local communities. Because the public partly perceives hydrogen storage as unsafe, neighbors at the production site could be significantly worried and display a social barrier (5). Furthermore, the legitimacy of this industry transformation might be vulnerable, considering that steelmakers might need financial support beyond project funding due to the aforementioned economic barriers (33).

Aside from public acceptance, it is still being determined if steel produced with green hydrogen gets endorsed by end-consumers and larger customers. In particular, because green hydrogen steel provides no additional functionality compared to its less environmentally-friendly counterpart, it is questionable if higher production costs, in the beginning, can be transferred to customers by paying a green premium (24,37). Nevertheless, since steel materials only make up a small portion of the costs of finished goods, a green premium would likely not negatively affect the buying power of consumers and thus only affect larger industrial customers (24).

Technological. Switching to green hydrogen steelmaking requires a variety of technological changes. Firstly the coking plant, the blast furnace, and the basic oxygen furnace would all need to be replaced, switching from BF/BOF to H-DR (Hydrogen-Direct Reduction) with an EAF (24). H-DR requires a direct reduction shaft, an electric arc furnace, an electrolyzer and hydrogen storage (24). Steel manufacturers must ensure a substantial grid connection when acquiring electric arc furnaces to satisfy the increased power demand since transmission grids are a critical complementary infrastructure, as research stresses (33).

Being constrained to new complementary infrastructure comes with increasing reliance on these novel complementing systems, which can be perceived as a barrier (33). Complementary infrastructure also infers sophisticated storage possibilities for green hydrogen. In this regard, high-pressure gaseous storage and cryogenic liquefied storage are currently the most practicable technologies in the industry for large-scale storage and transfer of hydrogen energy (38). The technical possibility of storing green hydrogen is precious because it allows for decoupling electricity demand and ongoing production, granting high production flexibility with cost benefits (5). To conclude, according to the literature, there are no critical technological obstacles that could hinder the uptake of green hydrogen in the steel industry as technologies are available and mature. However, technical hurdles exist, which are rather linked to the required green hydrogen infrastructure than the green hydrogen steelmaking processes itself.

Environmental. From an environmental perspective, adapting to green hydrogen steelmaking has high leverage to tackle human-made climate change by mitigating significant amounts of emissions (39). Additionally, human health could be positively affected directly by the improvement of local air quality (39). Regarding emission mitigation, it is to note that if all energy input is electricity on a steel site, the grid's emission intensity determines to a large extent, how much CO2 is released (24). More precisely, if energy input consists mainly of renewable energy, a significant portion of the CO2 emissions from BF/BOF steelmaking can be avoided in the H-DR route (35). Zero-emission energy alone, however, is insufficient to produce steel by a green hydrogen production pathway. For instance, the mining and production of iron ore and limestone, the calcination of lime, and the addition of carbon as a necessary component of steel all still include the release of CO2 (35).

METHODS

Research Design

Due to the novelty of the particular research topic, an exploratory qualitative research design was chosen to gain an in-depth understanding of the complex topic at hand (40). While therefore, primary data was obtained cross-sectional from relevant stakeholders with semi-structured interviews, academic journals and websites served as secondary data for this SEP project. Adhering to a cross-sectional design was suited for answering the research question since it allows for obtaining data from a diverse sample of stakeholders and subsequently drawing general findings (41).

Data collection

For the data collection, a purposive sampling method was necessary to identify relevant participants who could best contribute to the study's aim (42). Moreover, a heterogeneous sampling technique was followed to catch various perspectives on this industry transformation. The search for a heterogeneous sample was triggered by a value chain analysis provided by EGEN, the collaboration company of this SEP-Project. The value chain analysis (Appendix A) revealed 1st-level, 2nd level and 3rd-level relevant stakeholders of an ongoing European project dealing with green hydrogen uptake in the steel and aluminium industry. After getting an understanding of the relevant stakeholder groups for the research, there was intensive desk research started to find potential interviewees. Here again EGEN provided assistance, particularly by giving access to an innovation patent and project search engine. In the following, this particular tool was utilized to identify relevant active or closed European projects dealing with the research topic. Analysis of these projects led to contact details of potential interviewees. However, ideally they had to fulfil specific selection criteria before contacting them. These were being a high-level employee of a relevant identified stakeholder group, having a higher academic education background, and, more importantly, experience in a project dealing with green hydrogen steelmaking. Although over 25 interviewees were contacted through phone and/or email during this process, only six agreed to be interviewed. Finally, six representative stakeholders on an EU level were interviewed, such as research institutes, steel technology providers, and green hydrogen producers. Table 1 provides an overview of the interviewees participated in this study.

Interviewees	Position	Industry	Firms location
I1	Head of Department Efficiency of Ressources and R&D Coordination	Steel manufacturers research institute	Germany
I2	Process Engineer	Steel technology provider	Luxembug
I3	Technical Research Manager	Research university	Italy
I4	Head of Large Systems Product Developmemt	Electrolyzer producer	Germany
I5	Researcher Energy Transition	Research institute	Netherlands
I6	Business Line Manager Research Affairs	Engineering consultancy	Italy

Table 1 - Overview of Interviewees

An interview guide was developed to obtain comparable data from the interviews (see Appendix B). The PESTLE factors heavily determined the questions embedded in the interview guide. Questions were designed to be open-ended and not dependent on each other so that all six interview questions could be addressed in any order, allowing flexibility to the researcher and interviewee. Moreover, thanks to choosing semi-structured interviews, respondents could deviate from the interview guide as needed to address answering the research question (41). Regarding conducting interviews, all were held online between April-May 2023 and lasted, on average, 20-45 mins. They took place online and were recorded via Microsoft Teams, since most interviewees were not located in the Netherlands. Before interviews were carried out, all interviewees were sent a consent form (Appendix C). Furthermore, due to secrecy and ethical concerns, collected data sets and interviewees were anonymized to avoid any information revealing the subjects' identities. While the majority of interviewees were held in the English language, a couple were completed in German.

Data analysis

The process of analyzing primary data was initiated by transcribing the interviews. Here the software otter.ai aided this process. In a first step, the transcripts were checked for accuracy and corrected if necessary. Afterwards, the coding stage began, which was pre-determined by the PESTLE framework. In particular, categories such as Political, Economical, Social, Technological, Legal, and Environmental drawn from the PESTLE framework built the base of the coding tree in the form of themes while further levels of sub-categories were added later on in the process (28). Creating sub-categories included assigning “codes” to phrases that provided common information (41). Finally, after aligning codes and representative quotes to the pre-set PESTLE themes, a final coding tree resulted, as depicted in Appendix D.

RESULTS

In this chapter, results derived from the six conducted semi-structured interviews are presented. Findings encompass barriers and drivers and are categorized according to the PESTLE factors. First, this chapter will elaborate on barriers from a Political & Legal, Economical, Social, Technological, and Environmental dimension, followed by corresponding drivers. A visualization of the findings embedded in the PESTLE framework is provided in Appendix E.

Barriers

Political & Legal. Interviews reveal that overregulation seems to be an issue. According to the interviewees I1 and I4, overregulation encompasses mainly the green hydrogen market and its technical requirements. This overregulation doesn't come without costs, as I1 stresses, *"It is simply a very complicated issue in Europe that we always regulate in great detail. And that causes great costs on the part of the applicants, the industry. But of course also in the area of politics and regulation."*

From the standpoint of an electrolyzer manufacturer, Interviewee I4 adds further:

> *"The regulations that exist in the technical area. So the technical norms and standards, the supply chain law or the regulation of how to produce electrolytic hydrogen so that it is considered green hydrogen. It's all very complicated and certainly a challenge to figure out what is economically viable or not."* (I4)

Although creating regulations and definitions according to I1 is a necessity as *"They set criteria[...] If we didn't have this regulation now, it would mean that we could use existing wind power plants to produce green hydrogen."* simultaneously they can inhibit the ramp-up of green hydrogen for the steel industry. I1 believes *"[...] it is very difficult to achieve this ramp-up, I think it would be better if we set up simpler mechanisms, simpler regimes".* Despite this perceived overregulation, surprisingly, respondents claim there is no definition of green hydrogen and green steel out there yet. Accordingly, I2 says, *"[...] there is the question, what counts as green steel?"* while I4 contents *"[...] It is not yet clearly regulated what green hydrogen is. That's not good either. There are different approaches. But in any case, that is still a difficulty.''*. Another reported barrier resulting from the overregulation is the lengthy process of receiving subsidies for green hydrogen steel projects. Despite I4 claims there is *"[…] a great deal of support and that it is also politically desirable for hydrogen to be used in all sectors."*, the interviewee further acknowledges:

> *"But the structures with which this is to be supported, i.e. the incentives and funding structures, are ultra complicated. There are thousands of programs, which start at the state level, go up to the federal level and up to the EU. It's super difficult to see through all that. And to find the right programs for yourself or to understand what incentives there are across the board." (I4)*

Aside from finding and applying for the proper funding, receiving financial support has to occur in a timely manner, considering the vast amounts of investments needed. However, receiving the funding quickly might not be the norm like I1 notes: *"We are waiting here for our funding of our investment, as I said over 2 billion euros. We are waiting now also already over 1 year. That were a very lengthy process, which had been delayed more and more, with quite a lot of inquiry rounds."*. While providing funding is crucial to mitigate the investment costs and risks by European steel producers switching to green hydrogen, politics also have to ensure industry competitiveness within and outside of the EU.

I1 notes accordingly:

> *"And as far as I know, there is still no adequate instrument to protect us from non-European competition. There are currently these activities in the area of carbon border adjustment mechanisms, which are aimed at protecting the basic materials industry from this, but this has not yet been defined and adapted."(I1)*

As long as no adequate legal instruments are set in place to protect the European steel industries, this further bears the risk of carbon leakage like I1 says, *"[...] this must not lead to the European steel industry going under. And that we will be supplied by non-European sources in the future, because of the increased CO2 price in the EU."*

Economical. For the interviewees I1, I2, I3, and I5 one of the biggest economic barriers is the high costs related to green hydrogen. Interviewee I5 notes here: *"*[…] *It's the cost of green hydrogen, they are still quite high. I mean, there's barely any production yet."* Aside from the costs of green hydrogen, high upfront investments required for new infrastructure such as furnaces, electrolyzers, and distribution infrastructure are perceived as an economic hurdle. Like I3, a specialist from academia contends:

> *"[...] the biggest, let's say the most important barriers which I perceive as a technician, as a scientist, and as a that's a member of the steel community is the investment required for having hydrogen, human hydrogen producing units inside steel works and hydrogen compliant distribution network and hydrogen producing facilities." (I3)*

These are not just some incremental investments to be done like I1 points out *"We have to invest billions of euros to convert our steel production to low-C02 steel production"*. To be more transparent, I1 adds: *"For us, Salzgitter, Germany's second largest steel producer, this means that we are now investing between 2.2 and 2.4 billion euros in the first stage of converting our production to create a basis for low-C02 production."* While the findings mentioned above indicate that the green hydrogen steelmaking pathway is challenged with significant upfront investment and energy costs, I1 & I2, and I5 also believe that low costs of fossil fuels and free allocation of emission certificates are barriers to changing the status quo. I5 adds to this issue: *"I mean, the whole position the steel industry still has in there with free allocation of rights makes it a bit less strong than it could be, […]".* From the steel producers' point of view (I1) this affects costs as follows: *"And for each of these CO2 quantities that are emitted, we have to buy certificates […] Honestly, here has been toned down a bit, currently we pay only for 30% of the emission then CO2 costs."*

Social. The rise in the workforce may reveal a societal barrier, according to I1, I3, and I5. This has implications for steel-makers, as I5 claims *"Labor force, especially technical personnel expertise on more novel and complex topics, such as green hydrogen electrolysis[…]"* has to be arranged. Aside from finding new expertise, another hurdle is to reskill a big percentage of the existing workforce, mainly because change often triggers resistance in humans. I5 adds in this regard:

> *"[…] I mean, people that have been working in the sector that know the trade the current way things go. And that may not, you know, want to switch quite quickly. So you need to re-educate part of the workforce, things like that. I think labor could be a challenge here." (I5)*

According to I1, one of the biggest German steel producers, this task is already up on their agenda as he says: *"Of course, we then have to look at the extent to which we need other qualifications. Of course, we are already working on training new personnel."*

Another important point that emerged from the interviewees concerning the social dimension is the topic of customer acceptance regarding green hydrogen steel. Here one can differentiate between the acceptance of end-consumers and industrial customers, such as car manufacturers. Interviewees disclose that industrial customer acceptance for green hydrogen steel might be more predictable as I4 contends that there is *"[...] a certain drive that currently comes more from the manufacturers who would like to go green there."* On the other side I1, I2 and I4 stress the uncertainty to what extent green steel is accepted by the end-consumers. Like I4 believes there is the issue that *" [...] Ultimately, of course,it doesn't matter to the customer whether he has green steel. In the application, it makes no difference."* Looking from the steel producer's perspective, I1 remarks:

> *" [...] but the difficulty is that we produce the same product in the future, quality steel with less CO2. But you can not see the product, just a feature that less CO2 was emitted during production." (I1)*

For industrial customers and end-consumers, buying green steel as a consumer does not come without additional costs, since *"CO2 reduction always costs money"* as I2 admits. In the end according to I1 "*[...] we need the customer to be willing to pay the majority*". However, additional costs, for instance, borne by end-consumers for a car consisting of green steel, could be manageable, as I1 illustrates:

> *"I always like to quote this study by Agora Energiewende, which assumes additional costs of about 120-140 euros per ton of steel at a steel price of 400 euros. If we put that into perspective, a car contains about one ton of steel, then we're talking about additional costs of around 200 euros. And as end customers, we have*

to ask ourselves at some point whether we are prepared to pay this amount. In the end, it is also a social question." (I1)

Technological. Coming to the technological dimension and corresponding hurdles, I2, I3 & I4 all agreed on green hydrogen availability and the linked renewable energy demand as one of the main barriers. According to I3, a research expert in this particular domain, *"The problem is hydrogen availability. […] "* and moreover if *"[…] in the end will we have enough hydrogen or will we discover that we have to turn to keep our blast furnace running for much more time than expected because we don't have hydrogen."* Interviewee I5 elaborated on the issue of hydrogen availability as well. He says: *"So, I mean, there is no large-scale production of hydrogen that can easily be used in the steel industry. So I think that is a big barrier at the moment as well. "(I5).* It is noted that the lack of green hydrogen supply has its roots mostly in the vast amounts of renewable energy needed for producing green hydrogen via electrolysis. This bears consequently a challenge for steel sites, as I2 states:

"[…] Conventional steelplants needs about 1.5-5.0GW electrical power for green hydrogen generation, for reference, mean capacity of windmills in operation in 2020(USA) is 2.75MW. Newer windmills can reach 8-12MW offshore, 3-4 onshore, while mean capacity for nuclear power plant is 1GW. " (I2)

Green hydrogen supply is also influenced by the technological efficiency of green hydrogen production via electrolyzer as I2 claims, *"[…] hydrogen production has efficiency losses during* *electrolysis using electricity."* Therefore I3 stresses that *"[…] technologies still need to progress, I think the yield of the hydrogen producing facilities need to be improved […] "*

Environmental. One environmental barrier reported by interviewees is the land use intensity of renewable energy production, which poses a risk for local ecosystems. Like I2 remarks, *"Then there is the renewable electricity supply infrastructure which needs huge land for wind, solar parks. All has the potential to destroy and harm ecosystems."* Apart from the wind and solar parks, I5 adds,*"[…] electrolysis will also require space, you know, for your, your installations, your stacks, all of that. So I think the space required would be one that I would see as a negative environmental impact, which could create issues with, you know, what's possible, what's accepted by society."* When asked about environmental barriers, I2 mentioned an environmental risk linked to the manufacturing of iron ore pellets, as *"For the usage of hydrogen in DRI shaft type technology one requires iron ore pellets […]"*. The dilemma is that these manufacturing plants*"[…] use huge amounts of water and further produce large amount of toxic sludge waste. […] As a consequence local people and environment suffer from the pollution as it happens for example in Brazil. Worst case, dam breaks can occur which lead to flooding and destruction of entire villages and risking human lives significantly." (I2)*

Drivers

Political & Legal. As one of the previous chapters highlighted European overregulation as a political & legal barrier, I1 and I4 also gave an outlook on which specific policies could serve as a driver instead. I1 accordingly:

> *"We now also have to make sure that we don't regulate ourselves to death during the ramp-up in Europe […] In comparison, in the U.S. this Inflation Reduction Act (IRA) where they have said quite flatly. Whoever builds a plant for renewable hydrogen in our country will get the corresponding tax subsidies. Everything is much more simply regulated." (I1)*

Interestingly, interviewee I4 also addresses the IRA and remarks: *"If you compare this with the IRA in the USA, it's super simple. They just say you produce green hydrogen. Okay, then you get so many dollars per kilo. Everybody can calculate with a pocket calculator whether he can build his own plant or not.*" Besides crafting less bureaucratic policies, a policy framework should also stimulate green hydrogen production as I5 states: *"So what policy probably can do to help the steel industry […] is to drive their investment toward, let's say, plants, that produce hydrogen and then can distribute the hydrogen among the industrial […]".* While increasing the availability of green hydrogen through regulations is essential, political institutions must also play a role in promoting demand for green steel. According to I1, this can be realized by creating a lead market:

> *"[…] the regulator should create mechanisms so that there are some lead markets, i.e. markets where the regulator says, okay, if we do public buildings like bridges, then we require that steel is used there that is produced on the basis of a high hydrogen content. That could be another driver." (I1)*

Economical. Coming to economical drivers, Interviewees I1, I4, and I5 argue that green steel could serve as a business case for the European steel industry. As I5 notes:

> *"And in the final industry, so some customers, especially if they're trying to, you know, go for a green and environmentally friendly, co2 neutral kind of product, I think there is room for customers do want to buy the product, even if the product is a bit more expensive. So I think that's not necessarily a barrier and could even create opportunities for green steel to accelerate."* (I5)

Moving from the end-consumers standpoint to an industrial customer perspective, some interviewers reported manufacturers' growing interest in green steel. For instance, as I4 shares, *"I only know from Salzgitter that VW is already asking for green steel […] So there is also a certain drive that is currently coming from the manufacturers, who would like to go green."* Hence among other industries, particularly the automotive industry, could represent one of the first large industrial customer groups for green hydrogen steel. According to I1, this sector is of special interest considering that *"[…] sustainability is becoming more and more important in the supply chains of automotive production."*

Social. From the social point of view, most interviewees acknowledge that a significant percentage of society is supporting this industry transition, thus serving as a driver. I3 supports this view and believes that behind this industry transformation, *"[…] the driver is, is clear, the social factor. I think society is also willing to see the industry reducing their co2 emission. […] ."* Another recognized driver is the potential improvement in industry reputation from choosing green hydrogen steelmaking over conventional production processes and the overall legitimacy of deep decarbonization activities. In this regard, I3 illustrates *"Steel is produced since many, many centuries and peoples can can think that there is nothing new in this entity that this industry is old and outdated […]"*. This thinking is nowadays observable when looking at how the steel sector is perceived by employees, as I2 points out that *"[…] the Iron and steel sector lacks the attractiveness as an employer for younger talents due to its economic downturn since decades."* Nevertheless, by the integration of green hydrogen in steel making, I3 is confident that this barrier could be turned into a driver and reputation of the whole steel sector could increase since *"[…] novell and advanced technologie inside the production path that is so consolidated can also help people to understand how which let's say technological and scientific value is behind this kind of industry"*.

Technological. Looking at the technological dimension, the most important driver reported by Interviewees I1, I3, and I4 is the maturity of the underlying technology in green hydrogen steelmaking. Interviewee I1 in this regard:

> *"So, for the time being, I don't see any technical problems on the whole. The technology is available, and we are currently investing and building a plant." (I1)*

I4 is of similar opinion and comments *"I know that there are established technologies in the steel industry for producing green pig iron from iron ore and processing it into steel."* and since the technology is available, *"There are also plants that already do this on an industrial scale."* Interviewee I1 and I3 elaborated on drivers linked to green hydrogen infrastructure. While I1 addresses the topic of green hydrogen distribution via pipelines and claims that *"The natural gas network is also suitable for hydrogen transport, at least in terms of pipelines"*, I3 further stresses the technological feasibility and advantage of storing hydrogen, because *"[…]it's more difficult to store energy than to store hydrogen. So when you have energy that no one's consumed, so you can produce hydrogen and then use the hydrogen when you need it."*

Environmental. Concerning environmental drivers, interviewees I1, I3, I4, and I5 all have the opinion that from a macro level, this industry decarbonization is largely driven by climate change, while from a micro level, by local pollution. Accordingly, I1 says:

> *"An important topic that we now want to address with this low-CO2 steel production based on green hydrogen is, of course, the issue of climate change." (I1)*

Besides climate change as a major driver, the energy transition expert I5 adds: *"So there's a very much a push for green hydrogen in steelmaking […] to limit, other environmental effects, the local environmental effects."*. In particular because,*"[…] there are harmful substances that are also released in the air and that go and land in the area of the of the steel plant. And this is from the coke factory, and that can be closed when you're moving to hydrogen use."(I5)*

I1 concludes on this particular topic by noting:

> *"[…] when we rebuild our steel mill, the overall impact on the environment will be low. In the future, we will no longer have coal, which will also contain by-elements such as sulfur-containing compounds. And with hydrogen and natural gas, there will of course be fewer emissions in the future, and noise emissions will also be addressed." (I1)*

DISCUSSION

As a best-case example for transdisciplinary research, this study demonstrates the difficulty and interconnectedness underlying a sustainable development challenge facing a cross-sector industry. More specifically, findings reveal the interdependence of macro-level barriers and drivers linked to green hydrogen adoption in the European steel industry. As such is, the technological barrier of green hydrogen availability and high renewable energy demand closely related and further linked to the economic barrier of green hydrogen costs. Applying the law of supply and demand, one can infer that there is currently a higher demand for green hydrogen than supply allows, which drives cost and consequently creates an economic barrier. That brings implications for politics and sustainable entrepreneurs. First, politics must support scaling renewable energy capacities and green hydrogen production facilities. As interviewees refer to in this study, European politics can take the Inflation Reduction Act of 2022 (IRA) and its clean hydrogen production tax credit as a policy template to stimulate a flourishing green hydrogen economy (43). Particularly because the IRA's tax incentives can cut the cost of producing green hydrogen in half (44).

Moreover, private actors like sustainable enterprises should exploit the massive business opportunity of supplying green hydrogen to industrial users such as steelmakers (45). Lastly, the green hydrogen distribution must be coordinated if steelmakers have no large-scale electrolysis installed at their sites. As findings discern the technological feasibility of utilizing existing gas pipelines for green hydrogen transportation, the steel sector could exploit existing infrastructure. Nonetheless, if using pipelines is not possible, green hydrogen must be transported using specialized vehicles or ships that shouldn't be driven by fossil fuels to preserve the environmental advantages of green hydrogen usage (13). Besides distribution, the possibility of storing green hydrogen and the flexible green hydrogen production possibilities with electrolyzers might reduce the economic barrier of green hydrogen cost. For instance, if large amounts of green hydrogen are predominantly produced when renewable electricity costs are low, considering that electricity cost is the single most crucial factor in the cost of producing green hydrogen (43).

Switching to green hydrogen in energy-intensive industries such as the steel industry also brings considerations for energy security. In particular, replacing green hydrogen by coke might boost Europe's independence from foreign coking coal markets (24). Conversely, regional disparities in renewable energy resources between EU and non-EU countries will likely require green hydrogen and renewable energy imports by member states, creating new geopolitical dependencies, as with fossil fuels, bears a danger. In order to reduce these dangers, EU member states' politics should promote domestic green hydrogen generation and/or sophisticated international cooperation. Nevertheless, as long as green hydrogen production is not scaled sufficiently and affordable supply to European steelmakers is not ensured, political institutions have to subsidize the price of green hydrogen paid by steel producers. The same applies to the vast investments needed to transform steel sites. Importantly, to avoid transaction costs, governments' financial aid must be carried out as unbureaucratic as possible so that applicants receive funds quickly.

Another recommendation for international policymakers, derived from this study, is to work out clear definitions for green hydrogen and green steel, as a recent study has already stressed (37). Accordingly, interviewees remarked that definitions and certifications of green hydrogen and green steel are not widely available. However, having a clearly defined methodology is essential to avoid greenwashing by steel manufacturers and to strengthen trust on the customer side for sustainability claims made (46). In particular, because steelmakers could take advantage of a missing green hydrogen methodology by using instead of green hydrogen, the more abundant and affordable grey hydrogen, to produce steel, which is generated by fossil fuels and emits CO2 (13). Generally, study findings affirm a clear need for a supportive policy framework, as it has already been underlined by a recent study (14). Supportive in this sense means particularly mitigating economic risks of the steel industry, which further presents a necessary precondition to initiate the green hydrogen uptake. If this precondition is not fulfilled, traditional production pathways would likely be kept in place longer, risking reaching the legally binding climate goals set by the green deal and Paris Agreement.

Besides reaching climate goals and mitigating climate change, political support should also be reasoned by the benefits for local communities of transitioning to more environmentally friendly steel sites. As residential areas near steel factories could benefit from increased health through less noise pollution and particularly polluted air since air quality near steel factories may have an impact on cardiovascular physiology (47). Also, the effect on local employment is a point of discussion, considering that new expertise is required (5). That is expected to happen with resistance because some percentage of the workforce has to be reskilled fundamentally or even replaced. In this regard, it is important that worries and resistance by workers have to be heard and handled wisely by farsighted leadership. Further, acquiring new employees with special technological knowledge from the labor market will be unavoidable due to new production units. Here European institutions could stimulate the abundance of these new professionals by increasing the amount of domain-specific educational programs. Findings also have implications for single entities like steel manufacturers when seen from the firm-level perspective rather than an industry perspective. While the political and legal dimension, as discussed, is obligated to incentivize steel industry members to invest and act, more than just political intervention is required. Especially steel producers must proactively lead this transformation, which further calls for specific organizational capabilities. Here firms equipped with dynamic capabilities could have an advantage in switching to green hydrogen steelmaking because they allow them to respond quickly to market changes and to take risks (48). Also, the leadership style and managerial capabilities might determine the degree to which firms are willing to institute fundamental change and redesign existing business models. For example, having transformational leaders on board is probably a supporting factor because they aren't afraid to depart from the status quo (49).

CONCLUSION

As steel is a crucial component in the circular economy and for a sustainable future, this SEP-Project contributes to sustainability literature by providing evidence for the decarbonization challenges of the European steel sector with green hydrogen (16). Therefore, the research question "What are the barriers and drivers regarding green hydrogen uptake in the European steel industry?" was answered by identifying multiple drivers and barriers from six semi-structured interviews, according to the PESTLE factors (Appendix E). Utilizing the PESTLE framework in this research context displays a novelty to the best of the author's knowledge, hence adding empirical validity to the theoretical framework. Findings revealed most barriers and drivers are located within the political & legal, technical, and economic spheres and influence each other. As emerged in the interviews, currently, the most critical barrier is the lack of green hydrogen and correspondingly high costs. Here the latter, paired with high upfront investments for new infrastructure, leads to the issue of cost disadvantages by switching to green hydrogen steelmaking. Thus as long as green hydrogen steelmaking is not cost-comparative to traditional steel manufacturing, the political & legal dimension is called to support the European steel industry by providing the necessary resources for this change process. According to the interviewees, political & legal support on the EU level for this industry transition is existing and is expected to be intensified. However, speaking in practical terms, so far, policy and regulatory efforts are rather perceived as counterproductive by research participants. More particularly, legal constraints, such as overregulation and corresponding bureaucracy, represent a hurdle. On the contrary, the social and environmental dimensions could be identified as the most influential driver. In detail, legitimacy and climate change are key factors in the EU supporting the implementation of green hydrogen for steel makers.

LIMITATIONS & FUTURE RESEARCH

As with every research, this study does not come without limitations. Firstly due to the qualitative nature of this research paired with a small sample size, findings can only be generalized in a theoretical setting (41). Another disadvantage of the qualitative setting is that interview bias could have occurred from both the interviewer and the interviewee during the research. From an interviewer's point of view, there was the risk of respondent bias, such as the social desirability bias, especially since the interview guide was sent prior to the interview. Also, the researcher's actions in leading the interviews, coding, and analyzing primary data might lead to biases due to the heavily subjective nature of this process. Hence future research could address these issues, for instance, by replicating the study with a quantitative research design, thus ensuring more reliability. Besides the limitations concerning the qualitative approach, the time and word limit of this SEP Project has displayed a boundary. By having more resources, future researchers could use other study designs to increase validity. For example, by choosing a longitudinal instead of a cross-sectional research design, scientists could investigate associations and causal relationships of barriers and drivers in this particular dynamic setting (41). Also, the exclusive focus on the PESTLE factors displays a limitation. Hence, future studies could consider internal factors, such as by adopting a firm-level perspective. In particular, scholars can investigate the influence of the so-called dynamic capabilities on the uptake of green hydrogen by steel manufacturers with a case study approach.

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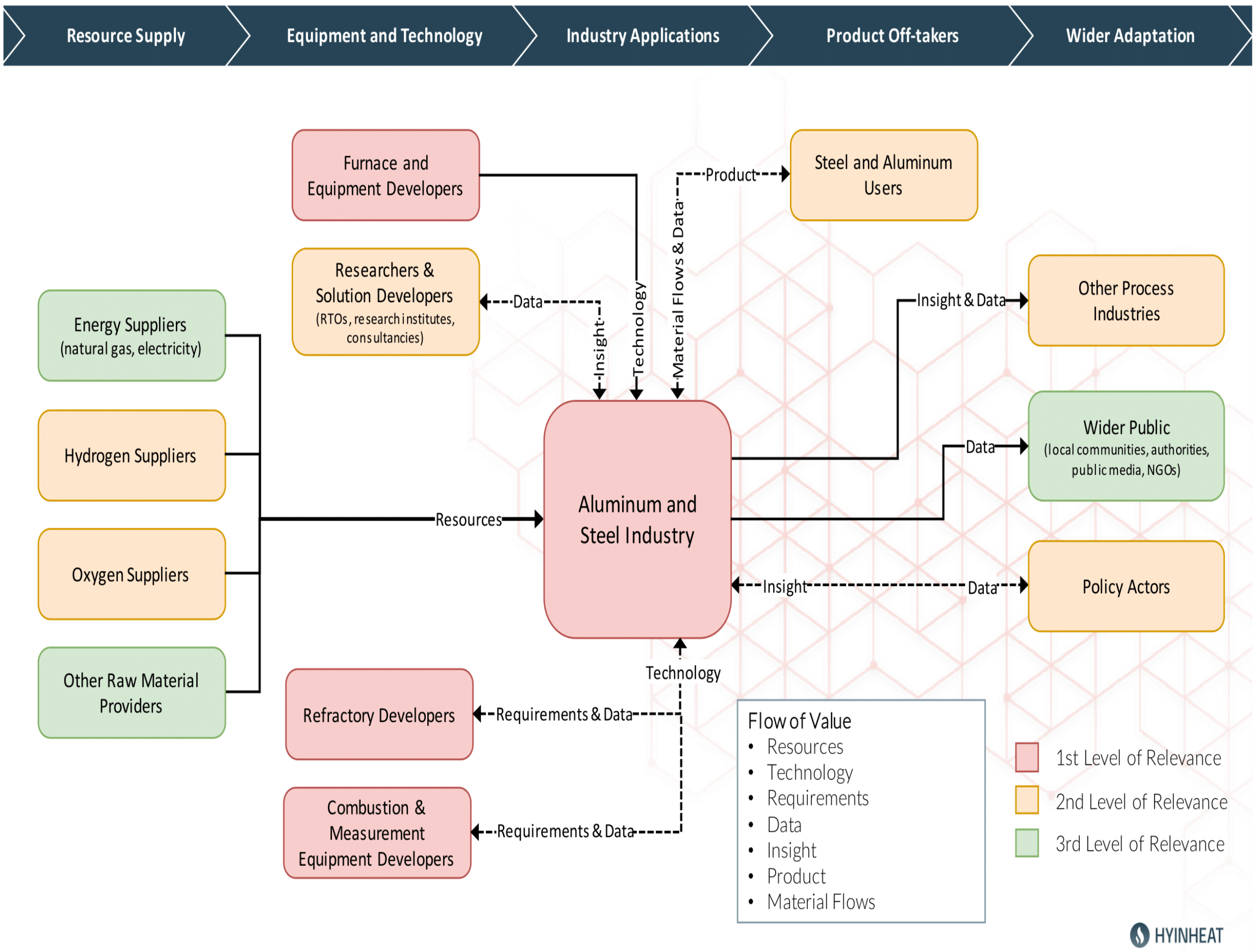
APPENDICES

Appendix A - Value Chain Analysis



Appendix B - Interview Guide

Introduction

Good morning/afternoon; nice to meet you, and thank you so much for agreeing to do this interview with me. My name is Viktor Schultz-Zehden, and I am a Master's student at Campus Fryslan/University of Groningen in Sustainable Entrepreneurship. I am currently conducting research on the barriers and drivers of the uptake of green hydrogen in the European steel industry as part of my Master's Thesis.
The interview and the corresponding questions are guided by my methodology and theoretical framework, the PESTLE Analysis, which includes six factors: Political, Economical, Social, Technological, Legal, and Environmental.
The interview consists of 6 open-ended questions. It will take around 30-60 min. If possible, I would like to record the interview and further on to transcribe the data with the help of otter.ai, a transcribing software. In case you want to remain anonymous, anything you share with me in this interview remains confidential, and your name or the name of the company will never appear on any public record.

Do you have any questions about this? If not, let us start.

Q1: According to your expertise, what are barriers and driver of the green hydrogen uptake in the European steel industry from a political and legal point of view? Like policies, directives, laws, and regulations e.g.

Q2: Regarding economic factors, what are you considering the most critical barriers and drivers?

Q3: Coming to social factors, which are determined by customers, labour force and target market, for instance. What do you think are the barriers and drivers of this industry transformation with green hydrogen?

Q4: Continuing with the technical dimension, what technical issues do you recognize in the uptake of green hydrogen in the steel industry?

Q5: Lastly, the uptake of green hydrogen in the steel industry is strongly linked to environmental or ecological factors such as consumer health, climate change e.g.
Can you think of any environmental barriers in this regard by considering the whole value chain?

Q6: To conclude, what, according to your expertise, is the most critical barrier currently, and do you have an idea how to overcome it?

Appendix C - Consent form

university of groningen / campus fryslân

Research Consent Form

Participant:

Interviewer: Viktor Schultz-Zehden

The purpose of the research is to understand the drivers and barriers towards the uptake of green hydrogen in the European steel industry. Participation in the research is voluntary. The interviews will be recorded and further transcribed with help of software. In case of any discomfort, the participant has the right to not answer any of our questions or terminate the interview at any point without consequences.

I want to keep my name anonymous.

- □ Yes
- □ No

I Would like to get the results of the research:

- □ Yes
- □ No

By signing this form I give my informed consent to participating in the interview.

Signature

Researcher   Participant

Appendix D - Coding Tree

Themes (PESTLE)	Barriers	
	Codes	*Representative quotes*
Political&Legal	*Overregulation*	"The regulations that exist in the technical area. So the technical norms and standards, the supply chain law or the regulation of how to produce electrolitic hydrogen so that it is considered green hydrogen. It's all very complicated and certainly a challenge to figure out what is economically viable or not." (I4)
		"It is simply a very complicated issue in Europe that we always regulate in great detail. And that causes great costs on the part of the applicants, the industry. But of course also in the area of politics and regulation." (I1)
	No clear definition of green hydrogen	"Than there is the question, what counts as green steel? product certification, definition." (I2)
		"It is not yet clearly regulated what green hydrogen is. That's not good either. There are different approaches. But in any case, that is still a difficulty." (I4)
	Lenghty process of receiving subsidies	"[…] there is a great deal of support and that it is also politically desirable for hydrogen to be used in all sectors. But the structures with which this is to be supported, i.e. the incentives and funding structures, are ultra complicated. There are thousands of programs, which start at the state level, go up to the federal level and up to the EU. It's super difficult to see through all that. And to find the right programs for yourself or to understand what incentives there are across the board." (I4)
		"We are waiting here for our funding of our investment, as I said over 2 billion euros. We are waiting now also already over 1 year. That were a very lengthy process, which had been delayed more and more, with quite a lot of inquiry rounds." (I1)
	Carbon leakage	"But we also have to look at the economic costs of competition outside Europe. In my opinion, this must not lead to the European steel industry going under. And that we will be supplied by non-European sources in the future, because of the increased CO2 price in the EU." (I1)
	International competitiveness	"And as far as I know, there is still no adequate instrument to protect us from non-European competition. There are currently these activities in the area of carbon border adjustment mechanisms, which are aimed at protecting the basic materials industry from this, but this has not yet been defined and adapted." (I1)
Economical	*Cost of green hydrogen*	"It's the cost of green hydrogen, they are still quite high. I mean, there's barely any production yet." (I5)
	High investments for new infrastructure	"[…]the biggest, let's say the most important barriers which I perceive as a technician, as a scientist, and as a that's a member of the steel community is the investment required for having hydrogen, human hydrogen producing units inside steel works and hydrogen compliant distribution network and hydrogen producing facilities" (I3)
		"We have to invest billions of euros to convert our steel production to low-C02 steel production." (I1)
	Low cost and free allocation of C02 certificates	"And for each of these CO2 quantities that are emitted, we have to buy certificates. […] Honestly, here has been toned down a bit, currently we pay only for 30% of the emission then CO2 costs." (I1)
		"I mean, the whole position, the steel industry still has in there with free allocation of rights makes it a bit less strong than it could be […] " (I5)
Social	*Reskilling of workforce*	"Labor force, especially technical personnel expertise on more novel and complex topics, such as green hydrogen electrolysis, […]. I mean, people that have been working in the sector that know the trade the current way things go. And that may not, you know, want to switch quite quickly. So you need to re-educate part of the workforce, things like that. I think labor could be a challenge here." (I5)
		"Of course, we then have to look at the extent to which we need other qualifications. Of course, we are already working on training new personnel." (I1)
	Customer acceptance	" […] but the difficulty is that we produce the same product in the future, quality steel with less CO2. But you can not see the product, just a feature that less CO2 was emitted during production." (I1)
		"So there's also a certain drive that currently comes more from the manufacturers who would like to go green there. Ultimately, of course, it doesn't matter to the customer whether he has green steel. In the application, it makes no difference." (I4)
Technological	*Availability of green hydrogen*	"The problem is hydrogen availability. But in the end will we have enough hydrogen or will we discover that we have to turn to keep our blast furnace running for much more time than expected because we don't have hydrogen." (I3)
		"So, I mean, there is no large scale production of hydrogen that can easily be used in of green hydrogen, can easily be used in the steel industry. So I think that is that is a big barrier at the moment as well" (I5)
	Renewable energy demand for green hydrogen generation	"Conventional steelplant needs about 1.5-5.0GW electrical power for hydrogen generation (for reference, mean capacity of windmills in operation in 2020(USA) is 2.75MW (newer windmills can reach 8-12MW offshore, 3-4 onshore), mean capacity for nuclear power plant is 1GW)" (I2)
	Efficiency in green hydrogen production	"[…] Then there is the point that hydrogen production has efficiency losses during electrolysis using electricity." (I2)
		"And in this sense the technologies still needs to progress I think because for sure there is not the yield of the electric let's say the yield of the hydrogen producing facilities need to be improved" (I3)
Environmental	*Land use intensity of renewable electricity production*	"Then there is the renewable electricity supply infrastructure which needs huge land for wind, solar parks. All has the potential to destroy and harm ecosystems." (I2)
	Usage of iron pellots	"For the usage of hydrogen in DRI shaft type technology one requires iron ore pellets. […] These plants of producing iron ore pellets use huge amounts of water and further produce large amount of toxic sludge waste. What makes it worse, it that sludge waste is often dumped into dams in extracting developing countries with corrupt local officials. As a consequence local people and environment suffer from the pollution as it happens for example in Brazil. Worst case, dam breaks can occur which lead to flooding and destruction of entire villages and risking human lives significantly." (I2)

Themes (PESTLE)	Drivers	
	Codes	*Representative quotes*
Political&Legal	*Approach of US policies*	"If you compare this with the IRA in the USA, it's super simple. They just say you produce green hydrogen. Okay, then you get so many dollars per kilo. Everybody can calculate with a pocket calculator whether he can build his own plant or not." (I4)
		"We now also have to make sure that we don't regulate ourselves to death during the ramp-up in Europe [...] In comparison, in the U.S. this Inflation Reduction Act (IRA) where they have said quite flatly. Whoever builds a plant for renewable hydrogen in our country will get the corresponding tax subsidies. Everything is much more simply regulated." (I1)
	Creating lead market for green hydrogen steel	"I also think that the regulator should create mechanisms so that there are some lead markets, i.e. markets where the regulator says, okay, if we do public buildings like bridges, then we require that steel is used there that is produced on the basis of a high hydrogen content. That could be another driver." (I1)
	Stimulating green hydrogen production	"So what policy probably can do to help the steel industry. And not only the steel industry is to drive their investment toward, let's say, plants, that produce hydrogen and then can distribute the hydrogen among the industrial [...]" (I5)
Economical	*Business case for steel industry*	"I only know from Salzgitter that VW is already asking for green steel [...] So there is also a certain drive that is currently coming from the manufacturers, who would like to go green." (I4)
		"And in the final industry, so some customers, especially if they're trying to, you know, go for a green and environmentally friendly, co2 neutral kind of product, I think there is room for customers do want to buy the product, even if the product is a bit more expensive. So I think that's not necessarily a barrier and could even create opportunities for for green steel to accelerate." (I5)
Social	*Society*	"So, the driver is, is clear, the social factor, I think society is also willing to see all these industry reducing their co2 emission." (I3)
	Reputation of the steel industry	"Firstly, one general problem is that the Iron and steel sector lacks the attractiveness as an employer for younger talents due to its economic downturn since decades [...]" (I2)
		"Also, such novell and advanced technologies inside the production path that is so consolidated can also help people to understand how which let's say technological and scientific value is behind this kind of industry. Steel is produced since many, many centuries and peoples can can think that there is nothing new in this entity that this industry is old and outdated, which is not the case, I know, is not the case, even before it was not the case even before hydrogen, and probably the uptake of the new technologies can make this more visible." (I3)
Technological	*Mature green hydrogen steelmaking technology*	"So, for the time being, I don't see any technical problems on the whole. The technology is available, and we are currently investing and building a plant. It will go into operation in 2025 so that we can also use hydrocarbons." (I1)
		"I know that there are established technologies in the steel industry for producing green pig iron from iron ore and processing it into steel. There are also plants that already do this on an industrial scale." (I4)
	Transport of hydrogen via gas pipelines	"The natural gas network is also suitable for hydrogen transport, at least in terms of pipelines." (I1)
	Storage of hydrogen	"One good thing of hydrogen is that you can store it and you can use excess energy to produce hydrogen, for instance, it's more difficult to store energy than to store hydrogen. So when you have energy that no one's consumed, so you can produce hydrogen and then use the hydrogen when you need it." (I3)
Environmental	*Climate Change*	"An important topic that we now want to address with this low-CO2 steel production based on green hydrogen is, of course, the issue of climate change." (I1)
	Local pollutions of steel site	"So there are harmful substances that are also released in the air and that go and land in the area of the of the steel plant. And this is from the coke factory, and that can be closed when you're moving to hydrogen use. So there's a very much a push for green hydrogen in steelmaking, in general, in direct reduction of iron, whether it's natural gas or, or hydrogen, to limit, other environmental effects, the local environmental effects." (I5)

Appendix E – PESTLE framework