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A Global Production Network and Multi-Level Perspective analysis

Master's thesis in Globalisation and Sustainable Development
Supervisor: Markus Steen
May 2024

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Abstract

In the broader context of the necessity of a sustainable transition, particularly in the field of energy production, this work focuses on the role of European Oil & Gas companies in the development of a newly growing hydrogen market.

In doing so, two main theoretical frameworks have been used. From one side, a Global Production Network derived perspective will focus on the role of big hydrocarbon companies in this newly established market, mainly by identifying them as lead firms. As a consequence, the relational bargaining of these companies *vis-à-vis* external actors, including the public sector, will be studied. Furthermore, strategies of risk management, as well as the geographical embeddedness of physical infrastructures and natural resources controlled by such companies, will be taken into consideration. In addition, a Multi-Level Perspective has been utilised, to better understand the ambivalent relationship between Oil & Gas incumbents, technological niche configurations, challenging the mainstream market of energy, with the implementation of new hydrogen technologies (such as blue and green).

This work relies on the utilization of qualitative data. More specifically, the main sources are secondary data derived from corporate reports, sustainability reports, media press releases, and other forms of information. In addition, primary data derived from semi-structured interviews will complement the data set.

Overall, this study concluded that the development of hydrogen is far from reaching viable economic solutions. Consequently, Oil & Gas firms are strategically boosting research and collaboration with niches and academy. This translates in a strategical diversification, useful to lower the economic risks derived from the sustainable transition in act. In addition, these companies have an active (and seldomly conflictual) relationship with the European legislation, particularly concerning the main typology of hydrogen to use to boost the market.

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A mamma e papà, i miei più grandi sostenitori, e a mia sorella, la mia migliore amica, mando un forte abbraccio e un profondo ringraziamento.

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Riccardo Frediani, 15.05.2024

Table of contents

Figures

Tables

Abbreviations

H_2: hydrogen

O&G: Oil & Gas

CCS: Carbon Capture and Storage

CCUS: Carbon Capture, Utilisation and Storage

MLP: Multi-Level Perspective

GPN: Global Production Network

CO_2e: CO_2 equivalent

1. Introduction

This thesis aims to research the socio-economic behaviour of European O&G companies, in the context of assessing the future of the hydrogen molecule as an energy carrier, with respect to a sustainability framework, which more and more interests the worldwide socio-political and economic spheres. This research will be conducted utilising a Global Production Network (GPN) inspired theoretical approach, together with a Multi-Level Perspective (MLP), to understand the role of these firms in the development of a hydrogen economy in the broader scenario of energy production, which includes both fossil and non-fossil supply. In the context of this thesis, the utilisation of both frameworks appears complementary. On one side, GPN offers the possibility to understand O&G companies as major actors in this transformation, therefore allowing for research in the assets, infrastructures, and expertise of such companies in the newly forming world of hydrogen, and the consequences of their approach on the future of the technology. In addition, GPN will allow to explore the contradictions, as well as the common grounds between these major companies, and the surrounding institutions, such as states, supra-national entities, society, and technological R&D. Nonetheless, in the complexities of the creation of a new market for an innovative energy source, it is reductive to focus the sight only on the role of major O&G companies. As a matter of fact, a plenitude of actors is involved in the development (and in the specific routing of such development) of H_2. In the participation of this energy evolution, political actors are surely involved, as previously mentioned. Consequently, society is part of this process, both by electing political leaders, as well as by demanding sustainable transitions in the energy field. Furthermore, other actors are giving their contribution. Since hydrogen represents a new technology, new innovative inputs are required, to create those apparatuses necessary in reshaping the mainstream market for energy. Therefore, by broadening the point of view, GPN alone cannot offer a proper answer to the questions posed by this research. MLP can offer a meso-level framing, adding to the analysis the agency power of wider socio-political policymakers, as well as the reforming strength of new technologies in the development of the mainstream energy industry.

Precedent research has acknowledged the usefulness of GPN and MLP approaches in the analysis of sustainable transitions. For a comprehensive analysis of the convergence between sustainability studies and MLP, see for example Vähäkari et al. (2020). While there exists precedent research on the intertwining between the O&G sector and the newborn hydrogen market, it mainly utilises a GPN perspective to understand such mechanics (see, for example, Vezzoni, 2024). Other instances can be found in which GPN theory was effectively implemented to study hydrocarbon player transformations (Dodge, 2020). Nonetheless, the implementation of an ulterior layer of analysis, represented by the addition of MLP to the theoretical framework might play a functional role in the broader and more specific definition of the forces in play in this energy transition. Attempts to use hybrid approaches, including MLP, in the study of the hydrogen implementation are already available. An example is brought by Damman et al. (2021), whose study (grounded in Norway) shows a certain degree of uncertainty in the present political framework surrounding this resource, thus translating in a difficult interpretation of the potential of H_2 in the energy sector. The research concludes that quite likely hydrogen will show its potential mainly in a scenario in which the oil sector will not be shut down completely, but rather reinvented as a natural gas provider.

1.1 Introduction to the field

Despite its recent popularisation, the history of hydrogen started centuries ago, when scientist Henry Cavendish was able to extract the molecule by reacting zinc metal with hydrochloric acid in 1766 (Jonas, 2009). From that first discovery, hydrogen saw a multitude of purposes, due to its versatility and chemical properties, such as for aerial transportations and for electrical production. Nonetheless, of the plentiful ideas involving hydrogen, in recent decades the most debated and groundbreaking one is its utilisation as an energy carrier, which would allegedly be able to substitute partially, or completely, the over-abuse of fossil fuels that the world is experiencing nowadays.

Hydrogen reserves huge potential as an alternative fuel, since its final consumption does not lead to carbon emissions. Nonetheless, nowadays main modalities of production of H_2 molecules are polluting processes. Indeed, as of today, most hydrogen is produced from hydrocarbons such as natural gas and oil, which are composed of a mutable amount of carbon and hydrogen atoms. However, when the extraction is over, the excess carbon mixes with oxygen, producing polluting residual gases, which are typically emitted in the environment. Despite non-polluting, industrial grade technologies to produce clean hydrogen are known and available, the vast majority of H_2 derives from polluting, and often cheaper, processes. Despite hydrogen is characterised by a high energy density (Cai et al., 2013), the exploitation of this new resource presents some challenges, representing a fundamental problem in a generalised adoption of such carrier for the future of the energy transition. These limitations stem from the fact that hydrogen is not naturally available, and, despite being an incredibly abundant resource, it is possible to obtain only by extraction from other compounds. Secondly, the H_2 molecule is of an extremely small size, meaning that the containment of it, for storage or transportation purposes, appears tumultuous (Ishaq et al., 2022).

1.2 Significance of the study

As previously stated, hydrogen must be produced from other substances, and therefore it cannot be considered a source of energy, but rather an energy carrier. Still, this does not affect the importance of hydrogen in the decades to come, as it can play a fundamental role in the reduction of pollution from the transportation industry, as well as serve fundamental purposes in the so-called hard-to-abate industries, (i.e. those productive sectors which are highly energy-consuming, and therefore highly polluting). The most common (and cheap) resource containing hydrogen is water (H_2O), and the extraction process from it is well known and perfectioned (Rama Uttam Pandit, 2022). Nonetheless, as mentioned, nowadays the most used system for hydrogen production consists of its separation from oil and natural gas (typically methane) molecules. In 2020, this methodology accounted for 95% of worldwide production of H_2, which was later utilised for ammonia and fertiliser production, rather than as an energy carrier. Only 5% of H_2 production in 2020 derived from other methodologies of extraction (Jadhav et al., 2020).

As a matter of fact, this poses a fundamental question. As previously mentioned, hydrogen can play a fundamental role in a sustainability transition operation. Nonetheless, its production from fossil fuels harasses the pivotal condition for hydrogen to be green. Therefore, a new categorisation was made, and the so-called hydrogen rainbow theory began to develop (The Colors of Hydrogen: An Overview, 2023). Hydrogen production can be differentiated, depending on the starting base of production. As such, it is possible to retrieve black hydrogen, using coal and/or oil as a starter, grey hydrogen utilising methane gas, blue hydrogen involving methane gas and the use of carbon capture and storage systems (or CCS) to reduce the pollution of the process. Other minor technologies in experimentation can be found, such as pink hydrogen, exploiting nuclear energy surpluses to electrolyse the water, or yellow hydrogen which exploits excesses in grid electricity. Of all the spectrum, the most important colours blue hydrogen, and green hydrogen (exploiting surpluses of renewable energy to electrolyse water to produce H_2). The figure below schematises the colour spectrum:

	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind | Solar | Hydro Geothermal | Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas | coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

Figure 1: the colours of hydrogen, feedstock and pollution levels. Adapted from Cheng & Lee (2022).

As the World Bank (2023) and the Hydrogen Council (2022) underline, since hydrogen production is founded on chemical processes, it is likely to require a high level of expertise, investments, and infrastructures to be scaled up and achieve a worldwide transition. Therefore, the conditions for hydrogen production leave a handful of actors which could afford the significant investments required. On top of states, few other actors can intervene in such markets. Big corporations are one of these (Zingales, 2017). Of such companies, the most prone to act are O&G ones, as they can feel threatened by potential transitions, as well as because they aim for a repositioning of the industry on a blue hydrogen level, due to of the vast amount of natural gas owned by such companies. Indeed, precedent studies confirm how O&G companies are prone to move towards more sustainable solutions, albeit it must be argued that one of the main incentives to act in such direction is the economical volatility of oil prices (Morgunova & Shaton, 2022).

On this matter, forecasts on the production of low-impact hydrogen for the near future do not appear extremely positive. Indeed, the IEA, in their Global Hydrogen Review (2023) states that low-emission production will rise, from less than 1Mt of H_2 in 2022, to probably 20Mt of green and blue hydrogen (combined) generated in 2030. Nonetheless, despite the significant increase, low-emission hydrogen will not be sufficient to reach the Net Zero 2050 policy. Of the major geographies of hydrogen production, IEA (2023a) identifies Europe as the most proficient, accounting for around a third of the expected low-emission production of hydrogen. Of this, IEA (2023b) estimates that the majority of H_2 will be extracted by the means of electrolysers; nonetheless, also blue hydrogen will play an important role. On the other hand, China is the biggest polluter on this field. Despite its intention to diffuse electrolyser technology in the next years, it appears that its hydrogen production (which, as of 2023, is the biggest in the world), is still mainly relying on coal and oil. The figure below shows more in detail the expected production of blue and green hydrogen, per geographical area.

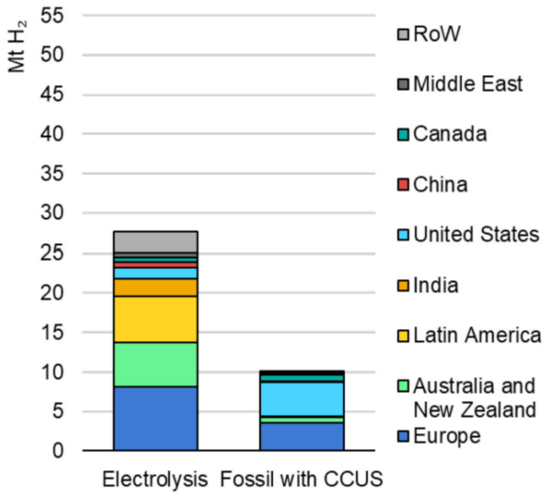

Figure 2: green and blue hydrogen production, per geographical area. Source IEA, Global Hydrogen Review (2023).

Despite a European leading role in the production of more sustainable hydrogen, the expected outcomes for 2030 raise some questions. Indeed, EU's main policy goals advocate to produce 10Mt of clean hydrogen, and the import of other 10Mt by 2030 (European Commission, 2020b). Note that in 2020, when this agenda has been approved, blue hydrogen was not categorised as "clean", and therefore must be excluded by European targets. By watching at the prospects elaborated by the IEA (2023a), it appears unlikely for the EU to reach such goals.

1.3 Defining the research question

Europe is trying to implement hydrogen as a new energy carrier. As such, the engagement of O&G companies is utterly important. Nonetheless, as these companies are also agents in this radical green shift, they have the power to shape it, thanks to their prominent infrastructure and capital oligopoly, and their eventual ability of dialogue with public institutions. Therefore, the main goal of this research can be questioned as follows: *what is the engagement of the main European Oil & Gas companies concerning the adoption of hydrogen? Furthermore, which types of pressures and relationship are involved in the generation of this new market? What role are O&G firms enacting in it?*

1.4 Thesis structure

This thesis will comprise various chapters. After the delineation of the introduction, a second chapter will follow, presenting the state of nowadays hydrogen industry. Subsequently, a theoretical section will be introduced, in which the main theory utilised in the creation of this paper will be elucidated. A fourth chapter about the methodology and data collection will follow. Afterwards, chapter five will focus on the presentation of the collected information. In the first part, the findings from secondary data will be presented, extrapolating the main information from sustainability reports, strategies, media statements and other sources from Oil & Gas firms. The second part will focus mainly on the findings derived from the interviews conducted with sector experts. Lastly, a discussion and a conclusion will terminate the elaborate.

2. Hydrogen

This chapter will focus on a brief presentation of the industrial reality around the production of hydrogen. A short history of the technology will be summarised. Subsequently, the main protagonist of the industry will be introduced, together with the main focal points of the needed infrastructures and innovations.

2.1 Industrial history and future prospects

The first input in the creation of an energy sector based on hydrogen is retrievable in 1968, when the hypothesis of carrying it through pipelines, to exploit it as an energy carrier was suggested in a scientific gathering in Stockholm (Bockris, 2013). Just four years later, in 1972, a paper, the first of its kind, was published, suggesting a complete dismantling of oil infrastructures, in favour of hydrogen (Bockris, 1972), *de facto* suggesting for a complete hydrogen economy to be installed. In more recent terms, a hydrogen economy can be defined as *"a proposed system, in which, hydrogen is produced from carbon-dioxide-free sources and is used as an alternative fuel"* (Liu et al., 2012). Despite the remarkable long-term vision of such papers, the achievement of such an economy appears to be still far from reach.

Indeed, several challenges still appear incumbent. Firstly, the definition proposed by Liu et al. (2012) suggests that the creation of hydrogen molecules must happen via carbon-dioxide-free sources, therefore eliminating from the value chain any form of grey or blue hydrogen. Nonetheless, as of today, that does not seem likely to happen, since, as the International Energy Agency points out (Global Hydrogen Review, 2023), around 75% of hydrogen production in 2022 was conducted via fossil fuels, without CCUS (that is CCS technology, plus the Utilisation of the collected CO_2) systems (therefore, in a high-polluting manner). As previously explained, to take advantage of the low carbon emission footprint of hydrogen, this must be produced via the exploitation of renewable resources electricity. The figure below explicates such production:

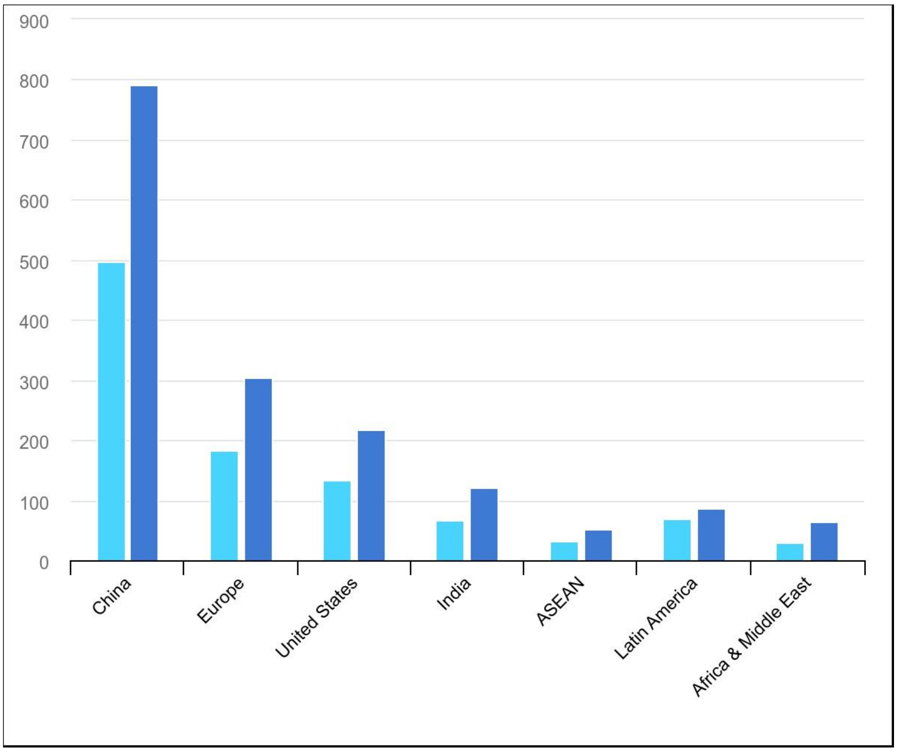

Figure 3: renewable energy capacity for selected world regions, in GW. Light blue: capacity between 2015-2020; blue expected capacity between 2021-2026. Adapted from IEA (2021).

Focusing on Europe, despite it being one of the highest producers of renewable energy, it is not yet sufficient to have residuals to be used for green hydrogen production. The increase in green energy would require big investments and new infrastructure, and by this time, despite the graph foresees an increment in renewable energy capacity, it does not appear to be enough to compensate for the whole European demand. Indeed, in 2021 renewables represented only 11.8% of the gross final consumption of energy in the continent (Eurostat, 2023): it is therefore clear that the rise in production forecasted for the next years will not compensate for the whole remaining demand.

Secondly, an ulterior problem is represented by the costs that the hydrogen supply chain displays. Costs will likely drop, once a scalar economy is properly in place, but nowadays the production, and even more the distribution of the resource, is expensive (Dou et al., 2017). As Dou et al. (2017) explain in their publication, plenty of adaptations can be taken, to reduce such constraints. On top of scaling up as a price-reduction strategy, further technological advancements will lead to cheaper transportation pipelines for the gas. On top of that, they suggest cooperation between public and private sectors to address the initial investment concerns. As a matter of fact, the hydrogen supply chain is constellated by public-private partnerships, as better enunciated in the next section.

2.2 The supply chain

The hydrogen supply chain is complex, as it comprises a high number of steps from production to the final distribution. The figure below tries to summarize and exemplify it.

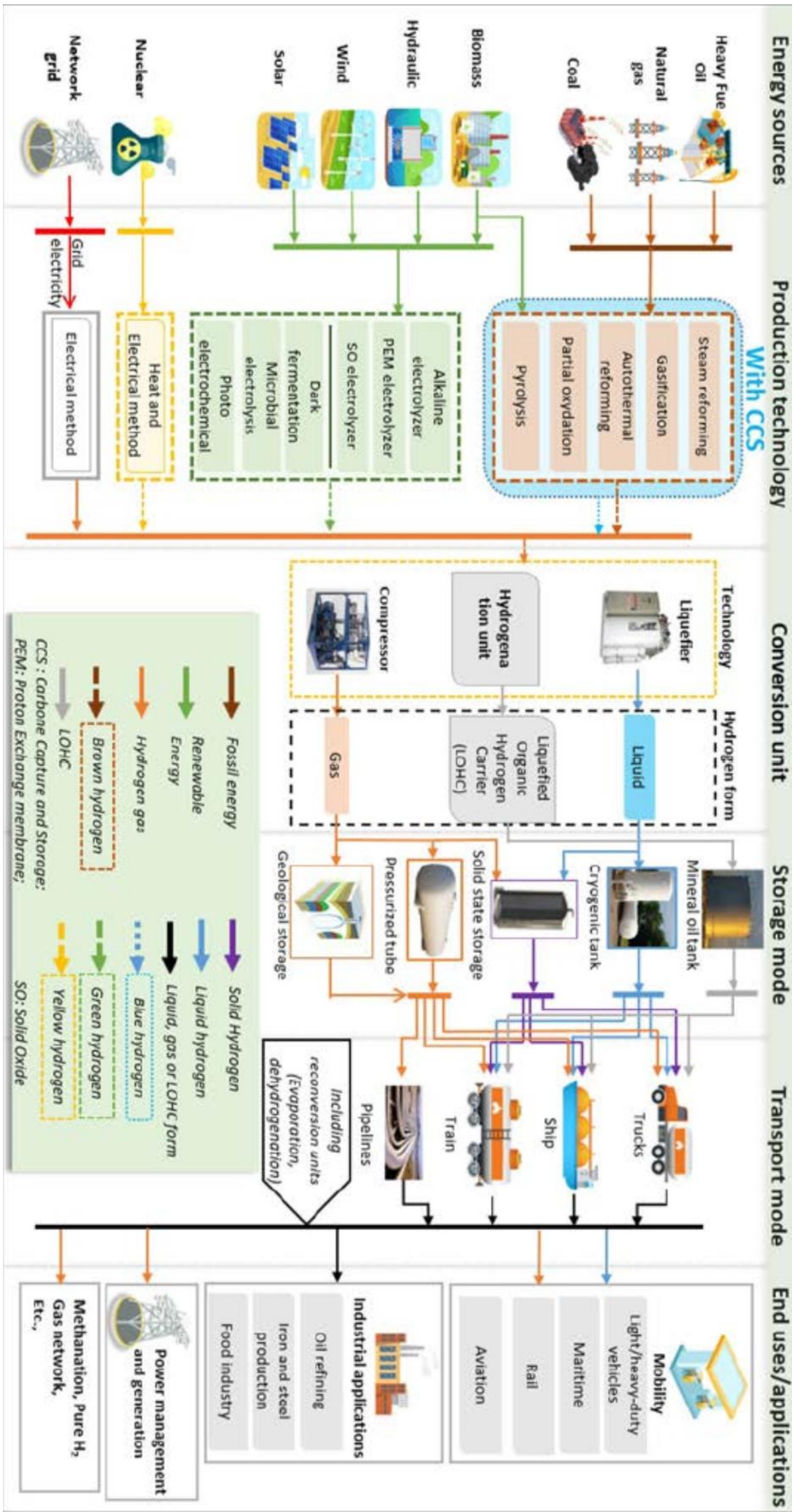

Figure 4: a schematic exemplification of hydrogen value chain. Adapted from Moustapha et al. (2023)

As shown, the hydrogen supply chain is composed of molecule production, storage (which is dependent on the modality of conversion in liquid or gaseous hydrogen), transportation and final use.

Considering the production, the technology utilised depends on the energetical source utilised in the process. Nonetheless, as previously stated, the utilisation of only sustainable resources to produce hydrogen appears nowadays impossible, due to the high relative costs of it, *vis-à-vis* blue or grey hydrogen. A barrier of 2$/kg has been theorised, for green hydrogen to become economically competitive (Garcia-Navarro et al., 2023). Other studies consider this eventuality possible starting from 2030 (see Moustapha et al., 2023). It appears evident, therefore, that the owners of energy resources carry a consistent power over the whole value chain: in GPN theory these are the lead firms; conversely, in an MLP, these are the energy regime incumbents.

The second step is represented by the storage and transportation of the resource. These two steps are interdependent since the most suited transportation system depends on the material state of hydrogen. As of today, gaseous storage represents the largest utilised method, despite others being under experimentation (Moustapha et al., 2023). As of today, transportation is mixed. While nowadays most of it takes place via maritime transport, or road, for larger hydrogen economies a pipeline grid is expected to be the best solution, as it can grant the fastest transport for higher volumes of gas, with low maintenance costs (Moustapha et al., 2023); nonetheless, high levels of initial investments will be required.

Lastly, the final distribution is at the moment limited to specific scopes. Indeed, hydrogen will play useful roles in limited industries, such as the transportation sector and heavy industry.

2.3 Future prospects on hydrocarbons and hydrogen

As hydrogen acquires a more interesting role in the energy diversification strategy, it is important to notice how hydrocarbons are and will play a significant role in the prospected future, therefore affecting the overall creation of alternative solutions.

Indeed, despite international commitment towards a reduction in CO_2 emissions - see, for example, the Paris Agreement (2015) - or more geographically enclosed strategies such as the EU's commitment on pollution reduction (European Green Deal, 2021), the global trend shows significantly different outcomes, as the control of O&G reserves still is a powerful propellent of geopolitical power. As an example, the Russian invasion of Ukraine started a European energy emergency, due to the reduction in hydrocarbon acquisitions of the EU from Russia's reservoirs; in the meantime, this sparked a new possibility for developing countries, such as India, which was conversely able to buy cheaper products (Warren & Ganguly, 2022). Indeed, as an IEA (2023c) study confirms, global oil consumption is set to increase at least until the end of the 2020s, especially due to an increased demand for petrochemical applications. This trend is highly relatable for developing giants, such as India and China, which are seeking a more dominant position in the production, importation, and consumption of hydrocarbon-related assets. Nonetheless, as strategic papers evidence (Rech & Duterne, 2021), also the EU, despite its body of regulations, is still set to consume high amounts of crude oil in the foreseeable future, despite a slight reduction expected at the beginning of the 2030s.

Nevertheless, despite the foreseeable energy strategies seem to doomily point toward an increased interest towards polluting energy solutions, it is also true that renewables will play a role in the future. As a matter of fact, experts, both in industrial settings, as well as in academia, are noticing a shift in policies, as new materials and expertise are becoming of strategic importance. As Yergin (2020) explains, new actors will be able to gain increased importance due to sustainable shifts, while countries stuck in the production of just O&G might risk losing their geopolitical hold. Similarly, also the industrial world is acknowledging the importance of such a shift. As an example, corporate advising company KPMG underlines the importance of renewables as a third global energy revolution, marking the strategic significance in acquiring and investing in these new assets (KPMG, 2023).

In conclusion, despite the petroleum economy playing a large role in the energy sector, it is also true that there is space for innovation. In this sense, hydrogen is of fundamental importance, also for countries outside the EU. As an example, China owns the largest hydrogen electrolyser fleet in the world. Similarly, also the European Union appears to take such investments seriously, as the first hydrogen Important Project of Common European Interest, *Hy2Tech*, has received 5,4bn$ funding (European Commission, 2022).

2.4 New actors

Apart from O&G companies, other private actors are involved in the enhancement of hydrogen. The hydrogen market is abundant in new start-up companies, trying to emerge in the growing market (Hydrogen Europe, 2024). Of the various applications affected by the introduction of hydrogen in the energy market, niche environments are more prone to stimulate the development of technologies for fuel cells, electrolysers, and storage. In general, niche companies are focusing on technological advancements concerning the methodology of production, storage, or utilization of H_2, therefore confirming the notion of which niches can be technical challengers for the big players. However, the relationship of new niche players *vis-à-vis* bigger firms is complex and variegated. As such, the correlations between these new players and broader companies will be further explained in the discussion of this study.

2.5 European socio-political background

In the delineation of the hydrogen system, institutions are playing an important role. As GPN theory evidences (Coe, 2021), their role can be of facilitators, as well as antagonists of economic transformations. This section will investigate the main policy directives, to better clarify what the role of European institutions is.

Among the most active in terms of policy delineation is the European Union, which is trying to create a homogenised market. As a matter of fact, hydrogen is valued as a fundamental resource to decarbonize its productive processes, as well as reducing the dependence on the import of fossil fuels. The latter is more and more a pressing issue, due to the realisation that several European countries are not self-sufficient in terms of energy security, and are therefore relying on supplies coming, in some cases, to hostile countries. Therefore, the European Union is planning on producing 10 million tonnes of “renewable” hydrogen, in addition to an importation equal to the same amount by 2030 (European Commission, 2020a). As the EU is setting the goal to accept solely renewable H_2 for its industrial decarbonisation, the term “renewable” itself has been strictly legislated, to ensure clarity both for citizens and investors. The 20 June 2023, the European Commission approved two delegated acts, which provide clear information on this matter. In short, the Commission evaluates as “renewable” only the hydrogen which is produced via electrolyser (i.e. green), and that can reduce, throughout its whole lifecycle, greenhouse emissions by at least 70%, compared to mainstream fuel molecules. Despite the strict regulations, they will be implemented gradually to allow investors to slowly redirect their assets. These rules are valid also for imported hydrogen. As greenhouse emissions are not required to be completely cancelled, the role of blue hydrogen is questionable. It might not violate the 70% rule, but the Commission specifically requires electrolyser-produced H_2.

Hydrogen is part of the *REPowerEU* plan, which ultimately aims to exclude Russian dependency in terms of energy policies. More specifically, H_2 is viewed as fundamental for Europe’s energy security for a variety of reasons: it can be used as a vector for renewable energy storage, it will be fundamental for transportation, and for the decarbonization of those implants which cannot rely on a complete electrification of the production chain (such as steel and chemical sectors). Consequently, the EU is actively working in support of five pillars: investment, production and demand, creation of a hydrogen market and infrastructure, research and cooperation, and international cooperation (European Commission, 2020b). This is due to the awareness of the EU that scaling up hydrogen is at the moment a task that no private company, nor any single member state would be able to address alone. In other words, the exploitation of the advantages brought by the single market becomes fundamental in the creation of a properly functioning international value chain.

More in detail, the EU is planning to enhance investments through the creation of the European Clean Hydrogen Alliance, a discussion arena, covering the whole hydrogen value chain, and active in the creation of workshops, publications, conferences, and production standard alignments (ECHA, 2023). In addition, the Commission is supporting strategic investments through the European recovery plan. An example is the inscription of green hydrogen projects in the IPCEI configuration.

Production and demand are boosted via different schemes, each aiming at a specific sector. The Sustainable and Smart Mobility Strategy (European Commission, 2021) will facilitate the implementation of hydrogen for the transport sector. Carbon Contracts (European Commission, 2024) will be created to support the production of low-carbon steel and chemicals. Additional support measures, including the creation of comprehensive, European-wide criteria for the certification of renewable hydrogen will be implemented (European Commission, 2020b).

The creation of a unified market and infrastructure for H_2 will start with the planning of a comprehensive European transportation network, to be further expanded in a network of fuelling stations (European Commission, 2020b). This infrastructure will likely stem from pre-existing ones, to give the opportunity to stakeholders to repurpose the already operating infrastructures. This action will more likely affect the owners of gas pipelines, as they will be able to give new scope to the pipes, as they can ensure the transportation of liquid or gaseous hydrogen. The repurposing of these infrastructures will be policy driven, via the adoption of new gas legislation.

Innovation will be promoted via the Clean Hydrogen Partnership (European Commission, 2020b), an optimization chamber for R&I funding. In addition, the EU has launched various partnerships, including a call for cohesive interregional innovation. Another call made by the EU regards Green Airports and Ports. Moreover, the EU is proposing to facilitate the presentation and implementation of potential new green technologies.

Internationally, the EU has the ambition of strengthening its soft power position in discussion arenas over technical standards and regulations. The leading role of Europe will also regard its geographical neighbours, particularly southern and eastern European countries, in addition to implementing cooperation with the African Union.

European regulations surely are the main root and landscape of hydrogen development. Nonetheless, it is dutiful to underline that on top of it, every Member State has its regulations in place, which might facilitate the adoption of hydrogen. In total, 15 nations in Europe, representing 34% of the Continent have in-law regulations to target net-zero emissions; other 13 countries (30%) generated in policy document; 2 states proposed some regulation; other 2 have pledged the adoption of similar policies. Lastly, 12 nations (27%) have no net zero targets, nor they have proposed or pledged one (Net Zero Tracker, 2024). In addition, European regulations have the soft power to affect also external countries, which see the EU as a prerogative market to invest in. It was the case for Russia, before the worsening of diplomatic relations; it still is the case for Norway, as Equinor clearly states the intention to capture 10% of Europe's hydrogen market by 2030 (Equinor Sustainability Report, 2023).

Lastly, an ulterior stratum is given by international energy institutions, advocating for a hydrogen transition. The two main agencies are the IEA (International Energy Agency), and IRENA (International Renewable Energy Agency). The first one was founded in 1974, as a response to the major oil crisis. Nowadays, it comprises more than 30 countries, consuming 80% of worldwide energy, and producing 62% of it. As energy security challenges evolve, also the role of the IEA did, and they are now deeply involved in the policy structure of renewables, as a direct consequence of the Paris Agreement, signed by all member states of the IEA. Concerning hydrogen, the IEA produces international analysis, overviews, predictions on production, utilization, and pollution of H_2, charts, and lastly, they gather policy decisions. In total, 323 policy white papers are available on the website. IRENA, on the other hand, comprises 168 countries (in addition to the EU), and provides international cooperation and support to all member states concerning renewable energy, its accessibility, security, and production. In general, their mission to achieve by 2027 is to "*take the leading role in accelerating the global, renewables-based energy transition to fight climate change, enhance human welfare and drive an urgent and systemic shift for increased energy access, reduced inequalities, improved energy security, and prosperous and resilient economies and societies*" (IRENA, 2023). Nonetheless, it must be noted that both these agencies are intergovernmental organisations, which therefore rely on the willingness of their members to commit to specific agendas, and therefore have no initial decisional power.

3. Theoretical frameworks

As previously mentioned, the theoretical frameworks used in the development of this work will be variegated. Firstly, it will comprise a derived GPN approach. Not all the theoretical knowledge connected with GPN literature will be used in this thesis, hence the decision to imprint it as a GPN-derived approach. In addition, MLP theory will be employed, to better understand the relationship between O&G lead firms and other sociopolitical and technical systems. Ultimately, the analysis of such correlation will lead to a comprehensive view of the approach that O&G companies are taking concerning hydrogen. Both are inserted in a broader energy transition framework. In the following sections, all three will be analysed more in-depth, clarifying their role in the definition of the thesis and its conclusions.

3.1 Energy transition framework

As for a broader framework, it is important to remark on some key theoretical notions. Firstly, it is dutiful to clarify the meaning of the terms utilised. The shift in some sectors from the consumption of hydrocarbons to hydrogen represents an energy transition, in the sense that the energy carrier will differ, but more broadly it is frameable as a sustainable transition event, as it will assure a lower CO_2 level emission. Indeed, sustainable transitions "*refer to systemic changes needed in societies in response to the environmental crisis we are facing*" (Huttunen et al., 2022). Nonetheless, the complexity of such systemic changes crosses transversally a multitude of factors. Indeed, to achieve a complete shift, it is dutiful to create a consensus among various strata of public opinion. However, this relationality is doomed to clash against the complex repartition of power and knowledge between different social groups (Lawhon & Murphy, 2011). Especially in recent decades, the balance of power tends more and more often to shift in favour of corporations, as they can gather a high number of investments, infrastructures and social agency. Usually, state institutions play an important role as mediators and innovators in transitory times (Blohm, 2021). In the hydrogen case, it appears that leading O&G firms are keeping a discrete amount of decisional power, as better explained in the next sections. Nonetheless, statal roles still is of fundamental importance to incentivise mutational processes, as well as stimulating legislation on the matter. This is specifically true in the case of O&G companies since the majority of them are at least partially controlled by national entities. Research (Bradshaw, 2009; Bompard et al., 2017) draws a clear line between energy management and state influence, as energy security is a fundamental prerogative for economic and social development.

Particularly, the ability to create strategic energy differentiation and innovation is a focal point in the development of a secure market (Fita et al., 2022).

From a more technical standpoint, the transition requires the presence of new technologies to uprise (Seeliger & Turok, 2013). Notwithstanding, the previous analysis underlines how transitions also necessitate the intervention of societal practices in order to spark radical change. Therefore, transitions can be understood as socio-technical changes, and literature, indeed accepts this same conclusion (see, for example, Geels, 2007). As extensively explained in the next sections of this chapter, transition theory utilises a multi-layered approach to understand the different levels in which such transformations take place (Geels, 2019).

In conclusion, it is possible to argue that transition studies require a broader socio-technical analysis which takes into consideration broader segments, as the complexity of the transformation involves the participation of multiple levels of agency. This will be supervised by the utilisation of an MLP approach. On top of that, literature suggests the integration of geographical perspective in transition studies (Markard et al., 2012). GPN will therefore be a useful tool since it is able to explore the geographies of value chain creation and risk management.

3.2 GPN derived approach

As a broad definition, Global Production Networks can be defined as "*an organizational arrangement, comprising interconnected economic and non-economic actors, coordinated by a global lead firm, and producing goods or services across multiple geographical locations for worldwide markets"* (Coe & Yeung, 2015). In other words, GPN is a natural development of the Global Value Chain theory, based on the concept that, due to modernisation transformations, the production of goods and services is now intrinsically modelled around global functional arrangements. Consequently, the global special configuration of GPNs translates, from a micro-level point of view to specific, socially constructed and locally integrated clusters, fundamental for the macro functioning of the supply chain. (Gereffi & Korzeniewicz, 1994).

In practical terms, thanks to this perspective, it is possible to identify Oil and Gas companies as the lead firms in the energy sector. The emergence of a new, competitive sector such as hydrogen provokes a reaction from lead firms, as they can utilise their knowledge, expertise, capital and infrastructure to permeate this new market, with the ultimate goal of emerging as lead firms of a renovated, and more variegated energy market. Previous GPN research has been produced on transformative changes in the energy regime (see, for example, Afewerki & Steen, 2022), with positive results in terms of further comprehension of future strategies put in place by the analysed companies.

A focal point in shaping the future of an ongoing transformative market is the division of decisional power between lead firms, public institutions, and other eventual actors. Especially while researching energy transition regimes, the redistribution of decisional power appears asymmetrical yet uncertain, as the conditions for the creation of power disparities appear unclear and dependent on the case (van der Ven, 2018). Consequently, GPNs are not anymore mere economic collaboration schemes, but rather arenas of socio-political contestation (Levy, 2008). Nonetheless, the high amount of dispersion generated by high-investment and long-reach value chains requires top-class coordination, which is usually obtainable only by lead firms (Levy, 2008). Therefore, the intent of this thesis remains to draw an analysis which is mainly based on a firm-centred point of view. Indeed, it appears that the economic complexities of a globalised world have reduced the importance of state-driven social analysis, in favour of more firm-driven approaches (Henderson et al., 2002). Despite some literature on transition theory portrays the state as a positive facilitator and collaborator to such shifts (Lawhon & Murphy, 2011), it appears dutiful to utilise the strength points of a GPN-derived approach to analyse firm's positions in the hydrogen market. Furthermore, as previously mentioned, public institutions must be taken into consideration. Therefore, GPN plays a pivotal role in the explanation of the bargaining relationship between public and private sectors, as well as in the definition of the balance of decisional power among these two groups.

As understandable, such bargaining relationships, together with the mutability in firms' alliances, force lead firms to engage with a multitude of actors, including other firms and public institutions. Therefore, lead firms necessitate holding on to a high amount of corporate power, defined as the capacity to influence decisions and resource allocations *vis-à-vis* other firms and institutions in the network (Henderson et al., 2002). This specificity of lead firms generates a variegated selection of strategies. When the bargaining is produced *vis-à-vis* a public institution, it is possible to identify extra-firm strategies, as the lead firm is engaged in a dialogue with a structure which is not entirely economical. On the other hand, when the strategy is aimed against or towards another company the strategies are considered intra- or inter-firm, depending on the case (Coe & Yeung, 2015).

A second important aspect of GPN theory which is needful for the analysis of the research question, is the comprehension of O&G companies as risk-takers. Management of risk implicitly becomes the stemming root of a GPN, as it has the potential to mitigate three main typologies of risks, derived from cost-capability ratios, market imperatives and financialization (Coe and Yeung, 2015). Therefore, risk management analysis becomes fundamental to grasp the more profound reasons behind long-term market strategies (Billing & Bryson, 2019). Nonetheless, it is dutiful to remember how risk can also be socially constructed, therefore stemming from societal or institutional concerns, therefore augmenting Coe and Yeung categorisations, and as a result, complicating the analysis (Völlers et al., 2023). Indeed, it appears that, as Guo et al. (2023) pointed out, risk management does not originate only from the internal decision-making layer but is also affected by the agency power of external actors. Therefore, this GPN-related framework must be integrated with further instruments of analysis.

Considering the findings reported in section 2.2 concerning the hydrogen value chain, it is dutiful to underline how the macro-cosmos of hydrogen GPN can be decomposed in minor subsections. Indeed, every step in the value chain can be vertically analysed. Therefore, it is possible to retrieve that any step (production, storage, distribution and consumption) is in fact a GPN per se. Nonetheless, this does not exclude the possibility of having the same actors playing significant roles in more than one of these GPNs.

The utilisation of GPN for the study of industrial decoupling from CO_2 is well established, especially in the analysis of the energy sector and its resources, both financial and political (Coe & Gibson, 2023). The academic utilisation of such a framework has developed greatly. Indeed, the first suggestions on exploiting GPN theory for hydrocarbon value chain analysis (Bridge, 2008) stemmed from the realisation that O&G sectors cannot be perceived only as an exploitative industry, in which statal decisions are reigning. On the contrary, O&G is also embedded in different geographies, and in different economic situations, which are dictated by the research of profit by the lead firms in such sector. Nonetheless, the discourse has been evolving, society-wise, and therefore the embedded geographies of production of such value chains have been modified. In Europe, the major change is due to the pressing request for a less polluting sector. Indeed, studies have shown how the restructuring process dictated by a demand for a more sustainable energy sector has proven challenging for O&G GPNs, leading to profound modifications of their assets and investments. In the case of the UK's Oil market, this led to divestments or strategic repositioning (Bridge & Dodge, 2022). While network modifications appear to be frequent as a worldwide solution, adopted also in developing economies, divestment strategies appear proper only for small portions of the market (Bridge & Bradshaw, 2017; Dodge, 2020), mainly those affected by high socio-political demands for sustainable change.

In general, it is possible to argue that, on the basis of the theory beforehand explicated, it is likely to retrieve O&G companies as proficient actors in the hydrogen world, as it appears the best option for long-term economic survival; on the other hand, however, the transition will be based on the capital, infrastructure and expertise pre-emptively possessed by such entities, since it appears as the best risk-management decision. In other words, GPN theory suggests a positive approach of O&G companies towards hydrogen, especially blue.

Some recent theory (Coe & Gibson, 2023) poses the utilisation of Global Production Network theory in climate change studies as a challenge. Indeed, it appears that GPN approaches have lost contact with the geographical reality, as it can misrepresent the geographies in which such decarbonisation processes happen. Nonetheless, it can also be an efficient tool in the theorisation of new decarbonised value chains. Indeed, GPN can be resourceful in understanding how the fragmentation of capitalistic investments is part of the problem (Coe & Gibson, 2023); in addition, it can answer questions concerning where and how decarbonisation industries appear, and the meaning of new investments or divestments on the general climate balance (Devine-Wright, 2022).

As a final note, it appears dutiful to underline that not every aspect of GPN theory will be used in this assessment, while other theoretical basis will be drawn from a different perspective. Thus, it appeared more dutiful to claim this first approach merely as GPN-derived.

3.3 Multi-Level Perspective

As previously stated, risk management and transformative solutions for O&G companies have the potential to arise not only from the inside but also from outside pressures. Thus, the idea of involving an ulterior framework of analysis appears to be appealing. Concerning MLP appropriateness on sustainability transition, the theoretical framework is specifically designed to analyse such issues, as the theory confirms (Geels, 2011; Geels, 2019; El Bilali, 2019). The Multi-Level Perspective (or MLP) can compromise this need. MLP theory stems from the idea that *"the stability of established sociotechnical configurations results from the linkages between heterogeneous elements"* (Geels, 2002). In other words, MLP adds in its framework the ability to look beyond the singular sociotechnical regime (i.e. in this case the O&G lead firms and their socio-economic connections), to consolidate a broader view, which takes into consideration extra-network elements. The figure presented below will clarify the general idea more in detail:

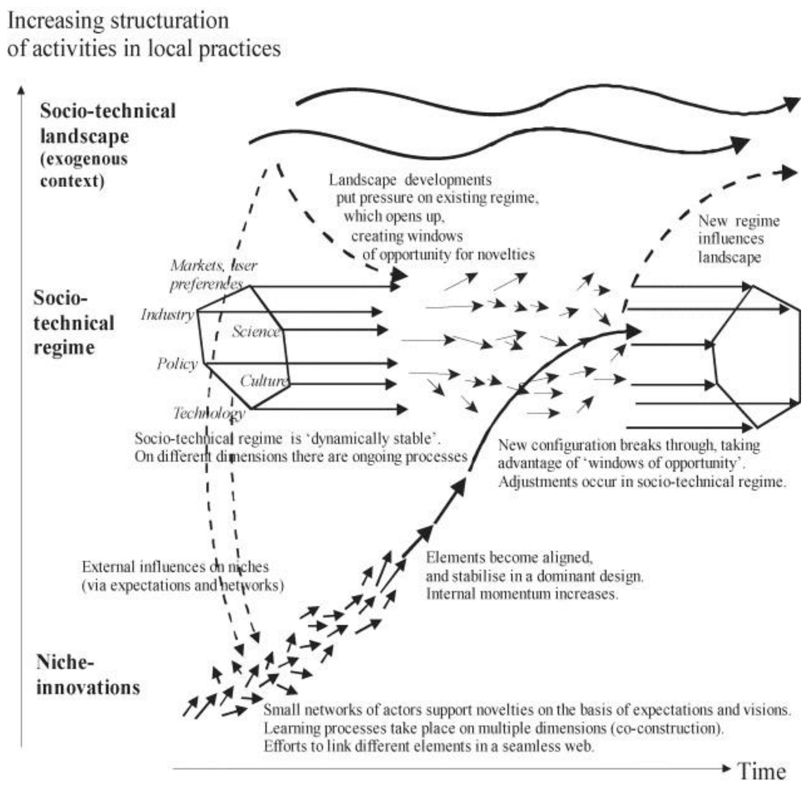

Figure 5: MLP structure. From Geels & Schot (2007).

As the schema explicates, MLP is primarily composed of three, interacting layers. The central one is defined as the socio-technical regime. This is definable as a technological regime, that is a *"shared cognitive routine in an engineering community and explained patterned development along 'technological trajectories'"* (Geels & Schot, 2007), together with the inclusion of the contribution of other social parts, such as scientists, policymakers, and special-interest groups, which have the power to shape the development of technological shifts (Geels & Schot, 2007). In the case in exam, this allows to widen the perspective of lead firms' decisions, as the classic GPN risk management strategy reasoning must now go through a more complex lens, in which it is not only the oligopoly of O&G firms to detain the vast majority of decisional power, but rather we can assist to mediated decisions among a vast amount of interest groups.

More in-depth, the socio-technical regime comprises all those so-called incumbent actors, defined as *"established prominent actors with a lifelong history […] large both in terms of personnel and revenue, have political power, but are often black-boxed and labelled as homogeneous industry structures with predefined roles and relations"* (Ramanauskaitė, 2021). The role of incumbents in shaping MLP theory has been the object of prolific literature. Indeed, while in past theory they were evaluated as unmoveable, and rooted in the conviction of the maintenance of the status quo, against the transformative push offered by the other layers of the model (see, for example, Geels & Schot, 2007). As a critique to MLP theory, incumbents were seen as standardised entities, focusing only on a few, mainstream, technologies. Nonetheless, more modern configurations of the MLP theory have re-evaluated the role of incumbents in transitory periods. Indeed, numerous papers (see Ampe et al., 2021; Hockerts & Wüstenhagen, 2010) can be found indulging in new, fundamental roles which incumbents can interpret during socio-technical reconfigurations. Incumbents, especially in socio-technical transitions involving energy and sustainability sectors, are becoming more and more participants in such transformations, instead of being plain antagonists of regime revolutions. In short, incumbents' participation has widened, and have now a plethora of participatory options: they can be promoters of new technologies and change, they can keep a "traditionalist" position as opposers of the transition, or they can be implicated as hybrid actors (Ramanauskaitė, 2021). In other words, they are enacting a re-orientation leading to a less dogmatic and more proactive role in the energy transformation (Abadzhiev et al., 2023). Basing the statement on GPN theory, in the specific case of the hydrogen revolution, it can be argued that O&G companies will want to participate in the way that can generate the most proficient risk-management practices. Strategically, this also implies that O&G firms will be able to leverage their resources and capabilities to capture value in new niche energy sectors (Steen & Weaver, 2017). It will be a central part of this thesis to discuss which incumbent practice suits best such a definition.

Regime stability is usually granted by lock-in mechanisms, such as investments, competencies, and broader commitments (Geels et al., 2017). Nonetheless, it is not unmoveable, but it is on the other hand susceptible to change. This is possible because of the two ulterior strata depicted by the MLP framework. Above the socio-technical regime, it is possible to identify a larger landscape, identified as an exogenous context. This landscape comprises bigger aspects of macro-economy, cultural patterns and major political shifts (Geels & Schot, 2007). In other words, the societal opinion on sustainability and a green shift promoted a pressurisation of the oil and gas industry, therefore engaging it in a mutation. Indeed, societal and experts' negative reviews brought against O&G giants are easy to find in recent years, as accusations of "greenwashing" appear to be supported by data (Li et al., 2022). Furthermore, the role of the state and political institutions in general is of implicit importance but has nevertheless been disregarded by part of the academic research. A call for a higher level of integration on this side is needed (Johnstone & Newell, 2018).

The implications of the socio-political opinion are even more profound once the niche-innovation layer is added to the equation. Niches are micro-level incubator rooms, where expertise outside of the mainstream regime gathers, to form a new protected field (Kemp et al., 1998). Nonetheless, while the niche is usually seen as a counterpart of the mainstream economic regime, the fluctuations brought on the ladder by the changing socio-political conditions refuelled the aspirations of such niches. As such, a straightforward connection between the first and third layers can be drawn, as can be seen in Figure 5. Therefore, the capabilities of niches to impact broader energy transition frameworks become predominant, giving the stage to transformative technologies in the field of energy. In this specific case, hydrogen niche started its expansion. As a result, the surfacing of new energy technologies impacts once more on O&G risk management strategies. In simpler terms, the decision between fighting against the application of hydrogen as a new energy carrier, or the assimilation of it as a new investment opportunity becomes the fundamental question for the O&G world. Nonetheless, as already clarified in the introduction, the above socio-political pressure seemed to have eased the choice for many O&G majors. This seems to confirm the theoretical expectations retrieved with the application of a GPN standpoint: O&G companies appear interested in the conservation of the economic status quo, regardless of the technological or social transition that this implies. In other words, as soon as the transformation happens through their means, Oil and Gas companies will work as niche facilitators, encouraging technological investments and investing capital in the transformation.

In conclusion, MLP acts as a meso-level structure (Geels, 2004), capable therefore of grasping those elements properly of the sustainability transition, drawing a powerful theoretical line between transition studies and MLP theory.

3.4 Summary

In conclusion, this chapter was meant to draw some theoretical basis for the delineation of the thesis project. At first, some perspectives on transition theory have been traced. Secondly, the analysis reached more in-depth by exploring the positives of the utilisation of a mixed theoretical system. In particular, a GPN-derived approach will create opportunities for the evaluation of the value chain of hydrogen lead firms. On top of that, a firm-centric view will help to understand the strategies of such companies, which are quite often dictated by their network geographies, in addition to the management of economic and social risks. Nonetheless, the comprehension that sustainable transitions are not only dictated by economic or technological shifts calls for the improvement of the theoretical background. By adding an MLP analysis, it is possible to have a more comprehensive view of the situation, as the transition becomes not only technical, but also social. MLP, therefore, gives back power of agency to the public opinion, on top of institutions. Furthermore, it helps improve the model by adding an ulterior element of technical niches, challenging the mainstream economic regime. In summary, this conjunction between a GPN-based approach and MLP comprises what Markard et al. (2012) suggest for the future of transition studies.

Lastly, it is possible to summarise the theoretical expectations of this research. GPN's theoretical standpoint suggests that O&G companies, as lead firms in the energy sector, will try to maintain such position also in new competitive niches that are being created, including hydrogen. This is derivable, as it is the best risk-management strategy. Nonetheless, in the calculation of best convenience, O&G firms will try to influence the transformative process, to render it near to the pre-existing infrastructures, expertise and resources owned by such companies. As such, in a meso-level view derived from an MLP perspective, these companies will likely work in favour of the socio-technical transformation. This is due to the aforementioned GPN considerations, on top of the landscape pressures on the regime. The relationship with the pre-existing niches still requires clarification.

In conclusion, a visual schematization is provided, to identify the prompts provided by both theoretical frameworks, and their importance in the analysis of the data:

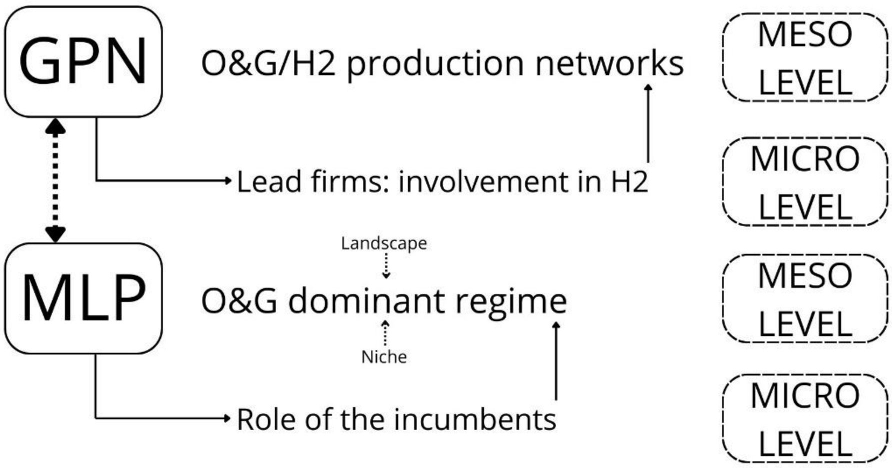

Figure 6: schematization of the theoretical framework. Own elaboration.

It appears evident how the two frameworks are both able to provide information concerning a broader, meso-level, which stems from the understanding of O&G majors as lead firms in the value chain of hydrogen, as well as incumbents in the mainstream energy sector. Additionally, the two methods of analysis can cooperate complementarily, as the integration of both is able to provide ulterior information and revitalise the analysis. The study of coping strategies adopted by lead firms is an enhancer for a better understanding of how the regime works, and how external pressures are coping with it. Vice versa, the knowledge of the landscape and the niches the incumbents are operating can explain the economic strategies adopted by the lead firms.

4. Research methodology

In this chapter, the methodology utilized in the data collection and analysis will be explained. The chapter is divided as follows: firstly, the research design will be addressed; secondly, a section about data collection will follow; thirdly, the methodologies of analysis will be presented; lastly, the quality of research, eventual limitations, and ethical considerations will be elucidated.

4.1 Research design

This research is based on a qualitative method of analysis. The final purpose of this thesis is to produce new knowledge in this field, while giving a possible expectation for the next development of the hydrogen market, possibly underlining similarities and differences of approach between various actors and suggesting strategies to correct eventual flaws in the current address of the hydrogen value chain. Indeed, qualitative methods are potent tools when the aim is to understand the particularities of a phenomenon and its development processes (Steen, 2016), as qualitative research has the potential to provide a rich picture, underlining connections relationships, causes, effects, and dynamic processes within the case in analysis (Mohajan, 2018).

Nonetheless, the steps performed during the completion of this work were not linear. At the beginning of this work, the ideas concerning theories and methodologies to utilise were not precise. Rather, the starting point was to respond to some empirical questions, concerning the role of O&G conglomerates in the creation of a hydrogen economy. Therefore, the decision to utilise GPN and MLP theory, combined with qualitative research emerged as a response to answer these empirical questions. Albeit it not being the first intention, overall, the writing of this thesis relied on the utilisation of an abductive method. As the delineation of the theory to utilise became clearer, the practical application of it to the case in analysis was able to stem some hypotheses on the research. Afterwards, data collection took place. Nonetheless, instead of leaving methodological heuristics aside, the researcher focused on challenging the methodological knowledge base during the coding and analysis of the data. In such a sense, the research design approaches what Timmermans & Tavory (2012) describe. This approach allowed to engage in a recursive process of double-fitting data and theories. This enhanced the depth and difficulty of analysis, rendering a process of back-and-forth between data analysis and methodology development. Thus, this resulted in new theories being promoted, creating, as retrievable in subchapter 6.3, a more dynamic presentation of the framework.

Nonetheless, the decision to adopt this method, as forementioned, was not intentional. Rather, it was due to the necessity of the case, as the analysis of the hydrogen market required constantly drawing new methodological lines, since, as better explained in the next chapters, the detailed study of it added more layers to the theoretical definitions used, thus requiring for more review of GPN and MLP literature. This proved challenging, especially considering the time constraints requested for the delivery of this elaborate. In addition, despite this methodology proved to be effective in providing answers to the research question, it is dutiful to notice that it was far from a perfected, and schematic methodology, like the one presented by Falcone (2014), but rather it was a discursive and cyclical methodology.

By enlarging the view, it is possible to categorise this study as a case study. As Steen (2016) explains, a case study might vary and incorporate research on less concrete entities as soon as they are enclosed by specific characteristics. In this case, the analysis concerns specific O&G companies, operating in a specific geography (Europe), and a specific market (H_2). Also, it can be argued that, since hydrogen represents a novelty in the energy sector, case study is a fitting alternative as it becomes highly useful in less developed or newer areas of research (Darke et al., 1998). Furthermore, viewing this study as a particular type of case study has allowed for a circular dynamic of theory development and testing (Yin, 2018), based on the adherence to the observed data. As aforementioned, the retrofitting of theory and data allowed for dynamic research, which ultimately led to the proposition of a specific MLP model for the case in analysis. Nonetheless, the ability of these findings to "*have implications going well beyond the same kind of case and extend to a whole host of other unlike situations*" (Yin, 2018) – i.e. their analytical generalisation – was questioned. More details will follow in the discussion in subchapter 6.3, as well as in the conclusions.

In this research, two main data collection methodologies have been used. At first, the main intention was to utilise secondary data to draw a general overview of the status of hydrogen in Europe. Subsequently, primary interviews would have been conducted to delve more in-depth into ENI's and Equinor's strategies concerning hydrogen. Nonetheless, while drawing data from the interviews, it was noted to be impossible to utilise the collected information in the wanted way, since retrieving experts from the two specific companies proved to be difficult, particularly due to the time constraints in the finalisation of this work. Furthermore, due to the aforementioned time constraints in the delivery, it resulted impossible to conduct new interviews. Consequently, the approach to the thesis changed, and interviews have been used to complement the general view given by secondary data, ultimately leading to a general case study on the role of European O&G firms in the newborn hydrogen market. Nonetheless, it is important to underline how the utilisation of mixed methods of data collection allows to strengthen the findings and discussion of the thesis, particularly by combining them in a process of data triangulation (Karmilla Kaman & Othman, 2016). A broader discussion on triangulation will follow in subchapter 4.4.

4.2 Data collection

This research includes both primary and secondary data. The first has been collected through semi-structured interviews. The informants are managerial representatives of O&G companies, as well as one representative from the public sector involved in the sustainable development of energy, therefore qualifying them as experts in the subject treated. Despite the ongoing academic struggle to define an expert (Döringer, 2020), in this instance, they will be defined as persons knowledgeable of a particular subject, identified by virtue of their specific knowledge, their community position, or their status (Kaiser, 2014). Due to the managerial position of the interviewees, it can be argued that they are effectively experts in this field of knowledge, thanks to their position and status inside the investigated companies.

The secondary data has been extrapolated from a variety of sources, including company reports, published future strategies, sustainability reports, academic and scientific literature. For a comprehensive review of the material analysed refer to Appendix I. Data from secondary sources have been confronted with key findings drawn from the interviews. In this way, through a triangulation of data, it was possible to underline eventual discrepancies or confirm the convergence of main findings from the secondary data (Flick, 2004). Indeed, the utilisation of primary data, in addition to the already acquired secondary information, was able to spark a more in-depth analysis, thanks to the broad replies given by the interviewees. Nonetheless, it is dutiful to underline that, since the research is based on qualitative data, particularly for what concerns the interview data, the results might not be replicable, which appears as an important weakness of the approach taken.

The interviews have been conducted by following a semi-structured layout, leading to broad replies by the interviewees. As a first step in the creation of the interview guideline, an empirical research question was drawn from a more abstract and theoretical perspective (Knott et al., 2022). More specifically, this meant translating this thesis research question (i.e. the exploration of Oil and Gas companies' present and future attitudes towards hydrogen) into pragmatic inquiry for the interviewees. A specific regard has been held for the theoretical frameworks during the creation of the interview guide. Hence, multiple questions concern the value chain and value creation of the hydrogen market, as well as the institutional landscape and the niche unsettlement of the mainstream energy sociotechnical regime. For a more comprehensive overview on the interview guide, refer to Appendix II.

The selected modality of questioning is a one-to-one, non-standardized, open interview (Hofisi et al., 2014). The choice was dictated by the opportunity to give the respondents the possibility to express broader answers. This was reasoned as fundamental in the dissertation of a broad research question, which touches upon vast socio-political themes. Nonetheless, it is dutiful to underline how, especially in open-question interviews the respondent can be biased in the answers provided. Simultaneously, also the data analyst can be subjected to personal biases in the reconstruction of the data from the answers received (Hofisi et al., 2014).

The geography of study in this research is ample, spacing through Europe, in the context of comparison data between interviewees. This translates to an enhanced importance of the theoretical frameworks applied to the analysis of the interviews, as they possess the capabilities to capture the geographical embeddedness and differences between different special economies. Due to the difficulty in accessing the targeted experts, the recruitment of interviewees happened through the utilisation of different methodologies. Stemming from my own, and my supervisor's networking abilities, the process continued via the utilisation of a snowball methodology (Naderifar et al., 2017). In other words, the primary experts to be contacted became part of a networking chain, which allowed them to obtain ulterior contacts. The method totalled 5 interviews, with an average length of ca. 45 minutes.

4.2.1 Interview conduction and transcription

As aforementioned, during the preparation of the interview guideline, some major topics of interest have been found and discussed, in accordance with the theoretical framework utilised for the research. In short, the main themes can be summarised as follows:

1. General insights on the companies activities concerning sustainable transition as a whole;
2. The interviewees' perspective on the hydrogen value chain: fundamental form a GPN perspective to understand the actual state of the hydrogen market;
3. Insight information on green and blue hydrogen: as the market evolves it is of utmost importance to clarify which technology will likely be predominant in the future;
4. The role of institutions in the market: as hydrogen economic perspectives evolve, institutions are deeply involved in future development. Therefore, it becomes preponderant to analyse their role, and their relationship with O&G companies. Additionally, this data will allow to investigate further the socio-technical transformation in progress through MLP;
5. Further development in O&G companies' investments: particularly in regard to niche investments, as this will allow the completion of the data collection for MLP analysis.

The interview guide, together with the consent form (see Appendix III) has been delivered to the respondent beforehand, following Sikt compliance regulations. All interviews have been recorded, in compliance with privacy regulations, and with pre-emptive authorization from the interviewee. Subsequently, the interviews have been transcribed. The transcription process underwent a double check, both human and with the support of an AI tool (Microsoft Teams Transcription tool), to guarantee the highest quality possible.

All the interviews have been coded utilising an intelligent transcription modality. Therefore, a verbatim transcription was not used, as pauses and filler words have been omitted. In addition, the grammar has been reformulated in some instances, to give more fluidity to the final transcription. As (Bailey, 2008) explains, this decision has been taken by evaluating the context of the research. As the interest is to extract the precise information, explained by trained experts, related to the research question in exam, it has been evaluated as superficial to analyse the emotions, pauses, and filler utilised by the interviewees.

4.2.2 Informants

The informants are mainly representatives of major O&G companies in Europe. In addition, a representative of public institutions has been interviewed. The choice of these specific respondents is due to comply with specific criteria. Firstly, the respondents were selected to be experts in the field with is being investigated. In this case, the belongingness of the respondents to high-responsibility positions inside such companies marks them as experts in their fields. Secondly, interviews will be utilised in this research to inquire more in-depth about the roles of O&G firms, as well as their involvement with the public sector. The informants have been recruited through my and my supervisor's networks; subsequently, a snowball methodology has been used to ample the set of interviewees.

The interviews have been held in English. Since the respondents originate from different countries, the utilisation of a common language for all responses became fundamental to guarantee a fair starting base. The interviewees will not be identifiable throughout this research, in compliance with the restrictions and authorisations this research has received from Sikt. Additionally, all interviewees have been alerted and agreed on the treatment of their personal data.

4.3 Analysis method

As previously stated, the two main theoretical frameworks utilized in this research are compatible with the topic in examination. In the analysis of both primary and secondary data, both have been highly regarded, to prepare a data analysis suitable with the theoretical and academic frameworks exposed. Therefore, the first part of the work was to undergo an in-depth analysis of the main structures of GPN and MLP theory. In this way, it was possible to extrapolate the most suited ideas to perform the data analysis. A more accurate review on the theory methodology can be found in chapter 3.2.

The interviews were set to obtain specific information concerning topics which are relevant to the definition of the research question. By concentrating the questions on the resources, infrastructures, and expertise of the companies in question it is possible to assert their role as lead firms. Furthermore, questioning the interviewees about a broader upper landscape, comprising institutions and public opinion, as well as bottom challengers and the relationship among these actors allows to get insights from an MLP perspective, therefore broadening the conclusions that can be drawn from this research. Similarly, also the analysis of secondary data has undergone an analysis stemming from the academic background. Indeed, the analysis of these sources was focused on finding focal data for a GPN and MLP approach. More specifically, the main aspects were represented by:

- Finding data on the infrastructures, expertise and assets owned by O&G companies, both in their mainstream field, as well as in hydrogen;
- Finding data concerning the strategic direction of such companies concerning hydrogen as a potential innovative energy carrier solution. In addition, emphasis has been put on understanding whether these companies are investing in developing blue or green hydrogen
- Finding data concerning the relationship between political institutions and O&G companies. More particularly, it was investigated whether these entities are creating a participatory relationship or rather a conflictual opposition of interests;
- Finding proofs of commitment in the active participation of O&G companies in their reshaping, within a sustainability perspective.

4.4 Quality of the research design

The quality of research is usually evaluated by underlining its validity, reflexivity and generalisation (Kvale, 1995). As validity might refer to "*the truth and correctness of a statement*", it is dutiful to underline how, especially in qualitative research, there are multiple ways to question a subject, and therefore multiple truths, while validity only underlines the fundamental threshold between a truth and an untruth (Kvale, 1995). In this case, the validity of the research has been granted by a meticulous triangulation of the secondary data findings and the interviews. Indeed, often the secondary data guaranteed a confirmation of what the experts acknowledged during the data gatherings. Nonetheless, it has happened that contradictions have been noted. However, this did not affect the validity of the study but rather encouraged a vivacious discussion, reflecting on the dissimilarities which have been found.

It must be noted, as Honeycutt & Jussim (2020) underline, that these reflections might have been biased by the researcher's positionality. Since some socio-political topics are discussed, particularly on the power of private corporations *vis-à-vis* public institutions, some reading keys might likely have stemmed from some personal convictions. The awareness of the researcher's reflexivity in the analysis of the data is of fundamental importance. It is also noticeable that the interviewees themselves are part of a dynamic socio-political environment, which influences the production of information. The development of this thesis with the aid of an external supervisor has surely tackled the double-fronted biases brought by the researcher's and interviewee's biases.

Reliability refers to the replicability of the research (Steen, 2016), and since the hydrogen market is a continuously mutating subject, it is likely that in the near future the interviewees' and companies' positionalities on some matters might experience profound changes. While this study has been conducted by relying on strict data collection, as previously explained, the mutability in the subject has the potential to outdate this study. Nonetheless, at the time of writing, other publications have drawn similar conclusions to the one found by this research (see, for example, Vezzoni, 2024, or Moncreiff et al., 2024), allowing for some reassurance concerning the reliability of this thesis.

Lastly, the generalisation of the findings in this thesis is doubtful and will receive particular attention in subchapter 6.3. While generalisation in the case study itself (i.e. among the different O&G firms analysed) is quite achieved throughout this thesis, thanks to the presentation of a generalised model describing their relationship with the hydrogen market, it is unlikely that such a model can be representative of broader theory, usable in different contexts.

4.5 Limitations

Some limitations in the data analysis must be noted. Firstly, as stated before the transcription of the interviews might have generated some data loss. As aforementioned, the problem has been tackled by the utilization of an AI tool (Microsoft Teams transcription tool), as a double check. Nonetheless, it still is possible that some information has been lost in the process. Secondly, it is important to note that all interviews have been held in English, to ensure a common language base. Nonetheless, despite the proficiency of the interviewees in the language, it is possible that some mistakes or errors in carrying the information may have happened, as English is not the mother tongue of any of the informants, nor of the interviewer.

Concerning the secondary data analysis, it is dutiful to notice that some documents are not accessible, probably deliberately or might have been cut off of relevant information. In either case, this has complicated the analysis (Bowen, 2009). Furthermore, the researcher’s cultural and informational biases might have played a distorted role in the interpretation of the data selected from secondary sources.

Lastly, it is dutiful to underline some important downsides of this methodological approach. In particular, as Mohajan (2018) points out, it appears difficult to prove the scientific reliability of the data used for the research. Consequently, the repetition of the same findings appears to prove difficult to obtain. Particularly in the research at hand since it is based on a fast-evolving subject, it is likely that further research might bring to different conclusions. Also, it must be added that there is no statistical inference, as the interviews are not representative of a broad segment of the population, but rather only of a small portion of experts. As such, this thesis represents an analytical generalisation, contributing to the pool of knowledge about these kinds of firms and their role in the energy system.

4.6 Ethical considerations

In line with Sikt guidelines, data has been handled following privacy regulations (Sikt, 2024). The listing of personal data in this research, which includes the names of the interviewees, and their professional roles has been handled in accordance with Sikt guidelines, and after explicit permission, both from Sikt and the interviewees. Consensus from the respondents has been collected both on paper, via Consent Form, retrievable in Appendix III, and orally at the beginning of the interview, to assess that all terms and conditions have been clearly understood. Per Sikt rules, all the participants were given the possibility to withdraw from the interview or subsequently from the research at any moment, without specifying any reason. One interviewee decided not to take part in the study and is therefore excluded from the final count of informants.

5. Data presentation

5.1 Empirical context

In the presentation of the hydrogen economy, a first aspect appears clear. In the creation of an initial value chain, this new technology suffers from a chicken-and-egg problem. In other words, a vicious circle is created, in which no demand generates no supply, and conversely, no supply produces no demand. In addition, to complicate this problem a third factor must be added, as no transportation and storage of the resource produces an unequal spatial-economical geography, leading to unbalanced value capture in the overall production network (Schlund et al., 2022). Indeed, the energy transition of incumbent actors towards hydrogen will not happen from zero, as it will stem from pre-existing forms of infrastructure. This solution seems to tackle the three-sided chicken and egg issue that arose before. As Vezzoni (2024) clearly explicates, the re-proposition of already in-use infrastructures and investments is a strategy of non-differentiation - and therefore of risk management - of long-term investments operated by O&G majors.

Nonetheless, literature (Lamb et al., 2020) underlines the prominent role of O&G industries in the development of hydrogen, and therefore it appears complicated to break the relationship between the adoption of H_2 as a new energy carrier and the re-purposing of existing infrastructures. Similarly, the utilisation of CCUS technologies seems to answer to a similar perspective, as it generates competitive possibilities for the repurposing of natural gas reserves (Vezzoni, 2024).

Therefore, it appears that the overall restructuring of global capitalism is playing a fundamental role in the definition of the future of the technology. In other words, the liberalisation of fundamental parts of the economic strata has affected sectors which were once predominantly state-controlled. Among these, energy security is retrievable. With the spread of the Washington Consensus, a large wave of privatisations pervaded the energy sector (Stevens, 1997), creating contrasting interests, between states, preoccupied with maintaining secure energy positions, and private companies, with the prerogative to generate the highest amount of revenue possible. In this sense, the relationship between state and private organizations becomes of fundamental importance to understand the progression and the geographical capitalist differences amidst different transition realities (Newell, 2019). Corporative role surely changes depending on the type of relationship and the grade of control that statal institutions have on O&G majors. Nevertheless, it is safe to say that generally O&G companies appear to invest in hydrogen as a strategy to reiterate the already established energy technical regimes. As IEA's global hydrogen report (2023a) outlines, in 2022, of the 95 Mt of H_2 produced globally, around 40 Mt have been utilized in petrochemical refineries, accounting for 42% of global production; of this big portion, only 1% was produced with sustainable practices (i.e. blue or green hydrogen).

As with previous literature, this research draws its root from a GPN analysis of hydrogen policies. Nonetheless, it will differ from previous articles in the sense that it will draw its conclusions based on the analysis of different publications (such as reports, press releases, strategies, and media articles), taking into account the differences between the infrastructures, capital and expertise owned by these different companies. In addition, MLP will offer a broader dynamic of analysis.

5.2 Company data analysis

In this section, the collected secondary data from the companies in analysis will be exposed. The companies researched were selected on two bases: firstly, they all represent O&G companies with legal basis in Europe (for this criterion, Russia has been considered as a European country, due to its influence and importance in the petroleum market in this region); secondly, they all represent major players in such market, due to their level of revenue. For a complete list of the documents analysed, please refer to Appendix I. A summarizing table will conclude this section.

5.2.1 Lukoil

Lukoil is the second biggest Russian oil company. The company is public, and the State-owned shares represent only a small fraction. In terms of sustainability, reaching for certain information was demanding, as it is impossible to access recent data. The last available company report is about 2022, and the details draw a negative scenario, as scope 1 and scope 2 emissions of the company are on the rise. In terms of hydrogen, the word has been used very little throughout the report, and vaguely. Indeed, no concrete project is presented, but on the contrary, an unclear interest towards investments in green hydrogen implants outside of Russian borders is expressed. Moreover, the intent to build “CO2-neutral hydrogen technologies” in Russia is explicated (Lukoil, 2022). This call for blue hydrogen production is with all probability due to the richness of natural gas in Russian geography. Nevertheless, for the moment referred by the report (i.e. 2022) no technology appeared to be in function, and therefore the actual production of hydrogen amounted to zero. Taking a further look into planned projects, it appears that at the end of 2022, Lukoil completed the modernization of the Nizhny Novgorod Refinery, located in Russia, and “hydrogen production units” have been added (Lukoil, 2022). The colour, amount, and final utilisation of the hydrogen are not specified. Nonetheless, it is likely that, considering the refinery location, the hydrogen produced is blue, and that it would be used to power up the refinery itself. Lastly, a memorandum of intent was signed by Lukoil and ROSATOM group for the creation of a green hydrogen facility in Romania, with the purpose of supplying Lukoil's refinery located in the country (Mrchub.com, 2022). Despite the intention being expressed 3 years ago, and being also remarked in the company's sustainability report, it was impossible to retrieve more information concerning the status of construction of the infrastructure, leading to think that it has possibly never started.

5.2.2 Rosneft

Rosneft is the biggest Russian oil company. It has been a publicly owned company since 2006 when the first IPO was announced. Due to the currently ongoing Russian invasion of Ukraine, the company has experienced major divestments initiated by its European partners, such as BP's decision to sell its shares of the company (Bousso & Zhdannikov, 2022). At the moment of writing, it was impossible to access fundamental information concerning their assets, particularly concerning hydrogen. In fact, the company's website, and its related documents, are inaccessible, therefore complicating the gathering of useful data. Consequently, the only available data has been retrieved from external sources, such as other O&G companies, as well as media resources. From these sources, it appears that Rosneft has engaged in memorandums of intent with a broad variety of other O&G companies, such as Equinor and BP, to enhance their production of hydrogen (mainly blue), and their carbon capture technologies (Equinor, 2021; BP, 2021). Nonetheless, it is dutiful to notice that all such press releases are dated 2021, and no other more recent news is available. It is therefore safe to assume that the beginning of the war has stopped these newborn cooperations. Nonetheless, some media articles (Griffin & Dmitrieva, 2022) state the willingness of Russia to develop a hydrogen market, to transform their economy in H_2 suppliers for Europe in the near future. It is likely that Rosneft would be partaking in such plan. However, it is dutiful to notice how it was impossible to find recent information concerning the development of these ambitions. Furthermore, Russian production would likely be entirely, or in a vast majority, based on methane reforming, due to the country's richness in this resource. In the eventuality of a geopolitical distention between Russia and Europe, which would re-ignite commerce between the two parties, this might create some tensions, as the European general prerogative is to rely on green hydrogen.

5.2.3 TotalEnergies

TotalEnergies (previously *Total*) is a French company and one of the biggest worldwide firms in the energy sector. Their approach towards sustainability has been taken by following a precise and strict route, consisting in massive divestments from polluting production, and a complete recalibration of the company. Indeed, the company's name change itself is a clear indicator of the repurposing of the firm in the energy market, from a strictly O&G company to a "multi-energy" industry (TotalEnergies, 2024). Their sustainability report sets the goal to achieve this transformation by 2050, remarking how TotalEnergies risk management main strategy is to diversify their assets and to comply with what they evaluate as the socio-political needs of the future. In this perspective, in the documents analysed it is evident how TotalEnergies wants to underline their connection with society, and their willingness to cooperate with it. Despite the commitment might appear bland, and only reported as a strategical de-responsabilisation of the practices which are endangering the planet and the communities where TotalEnergies operates, the company can brag about being one of the most sustainable O&G businesses to date, as shown in their sustainability report by independent studies (TotalEnergies, 2024).

Concerning the hydrogen business, TotalEnergies is engaged in the enhancement of their production, storage, transportation, and reselling of the resource. The main commitment for the company is to completely terminate the production of grey H_2 by 2030 and substitute it only with blue and green (Hydrogeninsight, 2023). Of the energy mixture that the company intends to provide, sustainable hydrogen will represent 25% of the whole, and at the moment the investments in such technology represent 1/3 of the whole assets. Initially, the company is planning on exploiting hydrogen to lower the emissions of their oil refineries (TotalEnergies, 2024). Nevertheless, TotalEnergies plans on expanding the adoption of H_2 in the world of transportation. The choice appears reasonable, considering their already established value chain, and more specifically their important presence in the market of gas stations. In practical terms, their total output of H_2 in 2022 amounted to 22,000 tonnes/year.

TotalEnergies is also engaged in the development of its technologies, especially through a participative relationship with sectorial niches. An example of this is brought by their partial acquisition of AirLiquide, a company specialising in the development of sustainable hydrogen production machineries (TotalEnergies, 2024).

5.2.4 Shell

Shell is a British private oil company and one of the biggest in the world. Similarly to TotalEnergies, Shell's approach towards sustainability has become increasingly concrete in recent years, as their investments towards renewables is steadily increasing. For comparison, the company invested around 4,3bn$ in green technologies in 2022, with an +89% increase, compared to the monetary assets invested the previous year (Shell, 2023).

In the investments done towards a green shift, hydrogen appears to have an important role. While the company states that its goal is to implement a fully green hydrogen economy in the future, at the moment they are highly reliant on blue hydrogen and investing plenty in CCUS technology. Nonetheless, the company is preparing to fulfil their commitment, as they recently approved the final investment decision on an electrolyser facility, which will be built in the Netherlands, and will have a capacity of 200MW. Furthermore, Shell is in partnership to build the offshore wind farm which will furnish energy to the complex (Shell, 2024).

Apart from this infrastructure, Shell is embedded globally in the production of hydrogen. The company states to have electrolyser projects in the Netherlands, Germany, China, and Australia. Nonetheless, none of these appears to be built and operational yet. It is therefore questionable to grasp what level of H_2 production will the company be able to achieve in the next years. Concerning the final distribution of the resource, Shell is active in the reselling for privates in the form of gas stations, retrievable in Europe, North America, and Japan (Shell, 2024). At the moment, however, the market for private hydrogen cars is almost non-existent, apart from some minor development in Japan. Consequently, Shell's plan to resell H_2 for private use appears to be far from an economically sustainable market. In addition, at the moment it appears that hydrogen will be mostly used for supporting the energy consumption of the company's petrochemical refineries.

5.2.5 BP

BP (or British Petroleum) is one of the four biggest Oil and Gas companies in the world, with its main headquarters located in the United Kingdom. The company appears to be highly attentive to hydrogen developments, as their analysis suggests that H_2 market will correspond to the gas' one nowadays (BP, 2024). As BP states the importance of hydrogen for the future, it is a prerogative for the company to reach a big market share in the future decades. To achieve such a goal, BP is trying to implement both its green and blue hydrogen production, with the ultimate stated goal to produce a mixture, based on 70% green and 30% blue by 2050. At the moment, the company controls various hydrogen projects in Europe (BP, 2023).

As BP works toward a hydrogen transition, their belief is that the new energy carrier will be of fundamental importance in 3 main sectors: feedstocks, industry, and transport. Nonetheless, some clarifications must be made. Indeed, BP thinks that it will be mainly heavy industry that will take advantage of the implementation of hydrogen, as it can be a solution for those "hard-to-abate" sectors. Conversely, the transport sector will be only partially interested in the transition. While private road cars will be the least affected, H_2 will be a fundamental energy vector for road heavy transportation, the maritime sector and aviation (Hydrogeninsight, 2023). In BP's foreshadowing, all three will be fully based on hydrogen-derived fuels. Nonetheless, in this initial state, BP's plans, similarly to other O&G companies here analysed, intend to utilise their H_2 solely to boost their own refineries.

From their perspective, this initial decision stems from a fundamental lack of market at the time of writing. Indeed, as previously analysed, this appears to be a fundamental curse in the hydrogen market. Nonetheless, BP states to be actively engaged on a political level, to pose a more solid basis for the development of this value chain. More in general, the company affirms to be engaged in sustaining every practice that will lead to net-zero emissions. Despite the valuable commitment, it must be noted that this decision poses the basis for the creation of lobbyist interests, which are meant to be understood in the forthcoming eventuality of an economically important progression of sustainable market. In other words, while BP is doing the "right thing", they are also developing their future economic strategies, by advocating radical changes in the mainstream energy sector. These strategies are clear in the pressures that BP was able to put on various governments, including the United States, the United Kingdom, and Australia. In monetary terms, BP plans on investing between 7 to 9 billion $ in transition technologies, before 2030 (BP, 2023).

It is likely that BP is actively working on the expansion of hydrogen to a global commodity, as the company is preparing for the creation of international exchange hubs. Furthermore, they plan on creating a supranational transportation system, which would be based on refurbished gas pipelines. That would attract the company's enthusiasm, as it would be a great opportunity to re-align their assets, pre-existing infrastructures, and expertise. In their plans, BP states an ongoing process of creation of such structures, which would be able to transport 2,8 million tonnes of hydrogen per year (BP, 2023).

Lastly, BP is also busy in the creation of strategic partnerships, both with other big sectorial players, as well as with emerging niches. On one side, BP has an ongoing partnership with Equinor, as they are developing an initial interest in the utilisation of British exhausted gas fields for CCUS. On the other, BP has started investing in new technologies which could be able to cut the prices of green hydrogen. It is the case of their interest in *Advanced Ionics*, a start-up whose new products might be able to deliver green hydrogen for a fraction of the cost (Reuters, 2023).

5.2.6 Repsol

Repsol is the biggest Spanish-based O&G company. Despite their activities in the hydrocarbon energy market, the company, similarly to TotalEnergies, is enacting a profound rebranding, defining itself as a “global energy company” (Repsol, 2023). In their strategy, it is clear the full commitment to transition to a broader variety of energy supply.

Among the various investments, hydrogen has an important role, as the company explicitly states their “firm commitment to hydrogen” (Repsol, 2023). This position assesses Repsol’s decision not only from an economic standpoint but also from a socio-political one. One of the first practical decisions taken by the company, appears the creation of *SHYNE*, a Spanish hydrogen consortium, comprising 35 different firms, and led by Repsol. The intent is to create a uniform value chain and to bring together the different hydrogen initiatives now in development in the Iberic region. The planned investment in the consortium amounts to more than 2,500 million € (Repsol, 2023).

In addition, Repsol is actively working in close contact with European guidelines, as the company was granted part of the 5,200 million € in financial aid offered by the European Commission in the *Hy2Use* project. The amount won by Repsol will be used for the creation of 2 electrolysers, in Cartagena and Petronor. A third electrolyser, with a capacity of 150MW, is expected to be built, as a combined effort of different Spanish companies, in Tarragona (European Commission, 2022). From Repsol’s perspective, the already planned infrastructures will be able to fully satisfy the national set target (1.9 GW) by 2030. In addition, Repsol is seeking further possibilities of hydrogen development in the Iberian Peninsula. To reach these goals, Repsol has created a new technological branch, with the intention of stimulating internal technological innovation. At the same time, the company is actively talent scouting for hydrogen expertise (Repsol, 2024).

The projected utilisation of the resource will involve hard-to-abate industries, which are a focal point, from Repsol’s perspective, to stimulate the initial growth of the hydrogen market. Contrarily to other analyses, the company believes that by 2050 hydrogen will be a pivotal resource also in the transportation market. In addition, Repsol believes also that hydrogen will be largely utilised by other markets, such as hard-to-abate sectors, and internally for fostering the utilisation of their refineries.

Overall, Repsol’s plans include the control of the entire value chain of hydrogen, starting from the investments for green electricity production, the storage of such energy, the exploitation of it for the ramp-up of electrolysers, and the production, storage and transportation of hydrogen. Nonetheless, despite these ambitious plans, Repsol recently has interrupted some investments in this direction, due to regulatory concerns. It appears, in fact, that the company is afraid about the uncertainty of the market, and the little protection given by regulatory institutions (Hydrogeninsight, 2023).

5.2.7 Equinor

Equinor is one of the biggest European Oil and Gas companies, and its main headquarters are in Norway. The company was founded to manage the raw material riches of the Norwegian continental shelf. Throughout the years, the company developed their international relevance and is now a worldwide company.

Concerning sustainability, Equinor is actively engaged in a variety of operations, from the construction of offshore wind farms to the development of hydrogen utilisation. Particularly concerning H_2, Equinor claims to have the medium-term ambitious goal of controlling at least 10% of the whole European market (Equinor, 2022). Nonetheless, the company claims that the extraction of natural gas and oil will not cease to exist, but it will be exploited to produce low-carbon fuels, such as blue hydrogen. This strategy seems in line with the company's risk management, and assets restructuring. Indeed, Equinor owns big assets in terms of methane gas. Furthermore, the company is a leader in the construction of CCUS solutions, which they are trying to expand to further markets (Equinor, 2023). Examples include the building of the Northern Lights project, which will start operations in 2024 and will represent one of the biggest projects of its kind in the world. Equinor is discussing the construction of CCUS technology also in the UK, as well as with hard-to-abate private companies in the USA.

In terms of decarbonisation, Equinor's strategy is divided into 4 main sectors. Every sector has increasing levels of complexity to decarbonise. The first one is represented by transportation. The easier solution is represented by battery + hydrogen transportation for heavy duties; a more long-term solution is represented by hydrogen fuel cell trains, and lastly by the creation of hydrogen long haul ships. The second sector is power. While the first steps do not require hydrogen, in Equinor's vision, the third, and more complex, will require the use of hydrogen-fired combined cycle power plants, as a backup source of power to avoid large-scale electrical intermittencies. The third sector of decarbonization is industry. In this case, Equinor sees it as fundamental blue hydrogen to ramp up heavy industries. Lastly, the fourth sector that requires decarbonization is heat. In a more complex view, Equinor imagines hydrogen as an efficient energy carrier, to transfer energy from producers to end-users. In addition, hydrogen might be used for large-scale seasonal energy storage (Equinor, 2023).

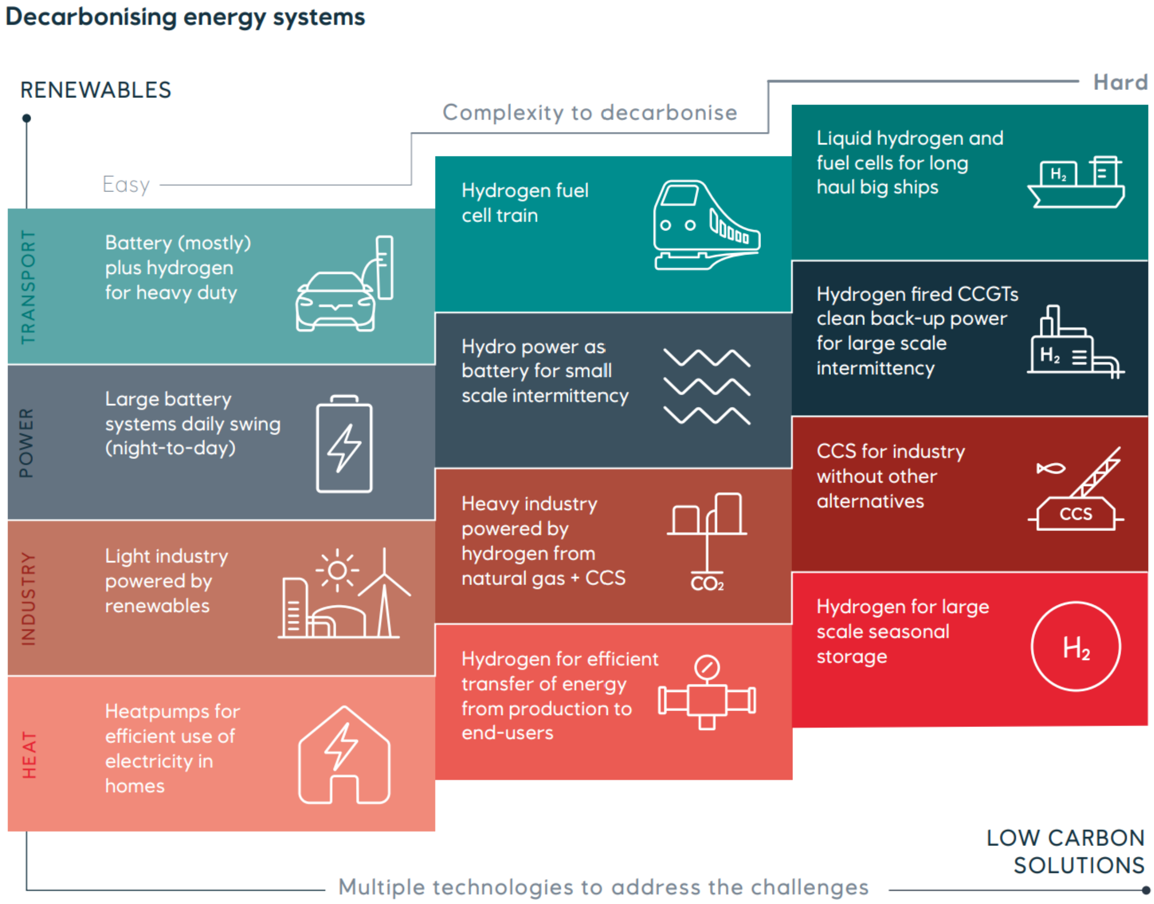

Figure 7: Equinor's decarbonization strategy. Adapted from Equinor Integrated Annual Report (2023)

Equinor is involved in a multitude of hydrogen projects, especially in Norway, Continental Europe, the UK, and the USA (Equinor, 2024). Of these, all are examples of blue, except for one project, NorthH2, which will represent Europe's biggest green hydrogen project, and will serve hard-to-abate industries in Belgium, the Netherlands and Germany, thanks to an increasing capacity production provided by a partnership of a multitude of companies, including Equinor and Shell. Nonetheless, the prevalence of blue hydrogen prospects is unquestionable, as all the other significant investments are done in such direction. Speaking of direct investments made by the company, Equinor claims to have invested around 12 billion $ in renewables in 2023 and 2024, and that the number will increase to 23 billion by 2030 (Equinor, 2023).

5.2.8 ENI

ENI is Italy's biggest O&G company. The company was founded as a public, state-owned firm, and still nowadays 30% of the company's action value is owned by the Italian government. As most of the previously discussed companies, also ENI is involved in a business model change, as renewables are becoming more and more part of the firm's portfolio. Indeed, the company has been undergoing a rebranding process, as a new subsidiary, named ENI Plenitude was founded in 2021, to manage the development and selling of sustainable energy, mainly solar. Nonetheless, the development of hydrogen is still in the hands of the main company, ENI (ENI, 2024).

The company declared 14 million € in hydrogen investments in 2022 alone (ENI, 2023). Similarly to other O&G industrial realities, ENI at the moment intends to use H_2 as feedstock for traditional refining processes, as well as in two biorefineries in Venice and Gela, where it will be a fundamental ingredient in the production of HVO biofuels (i.e. treated vegetable oils, which can therefore be transformed in sustainable fuels). Apart from the utilisation in their own refineries, ENI is active in the development of other projects, most of which are in Italy. Most of such projects are blue, and some will comprise the experimentation of new methodologies of H_2 production. An example is “Waste to Hydrogen”, a new generation process, that promises to transform plastics and secondary solid fuels into hydrogen, with a reduction of 90% in greenhouse emissions, compared to the mainstream blue hydrogen methodologies. Generally speaking, it appears that ENI’s first goal is to use hydrogen as a mean to decarbonise hard-to-abate sectors (ENI, 2023).

Some examples of green hydrogen production are retrievable. In South Italy, two projects have been awarded by the IPCEI *Hy2use* commission and will receive European funding for the installation of electrolysers, which will be utilized to decarbonize the heavy industries in the south of the country (European Commission, 2023). This project will be developed in collaboration with the Italian State, and SNAM, a third-party company, once integrated into ENI, which deals with gas transportation and the pipeline grid (ENI, 2022). Other collaborations will happen in the north of the country, where ENI intends to build the first hydrogen valley, together with the state-owned rail transport firm, Trenitalia (ENI, 2024). In this case, the hydrogen utilised will be partially blue and partially green.

In general, ENI puts plenty of emphasis on the creation of partnerships to deliver prompt decarbonization. On top of the already mentioned strong collaboration with SNAM, the company is part of the Alliance for Industry Decarbonization, co-founded by ENI, and meant to be a multisectoral collaborative platform with the goal of accelerating such process. The Alliance held its first meeting during COP27 and agreed on the importance of developing green hydrogen, CCUS and renewables. In addition, ENI has been one of the five O&G founding companies of the Oil and Gas Climate Initiative (OGCI), which today includes 12 companies, representing a third of global hydrocarbon extractions (ENI, 2023). Lastly, ENI is also engaged at the academic level, with local universities, to grow new expertise in the field of hydrogen. Together with SNAM, the power company Edison and the Milan Polytechnic Foundation, the Hydrogen Joint Research Platform was created, to stimulate the development of new technologies (ENI, 2023).

5.2.9 Summary and key findings

In the table below, the key findings are summarised. It is possible a schematic view on the landscape pressures and the involvement of these companies with H_2 niches is given.

Company	**Lukoil**	**Rosneft**	**TotalEnergies**	**Shell**
Interest in sustainability	Low	Unknown, probably low	High	High
Interest in hydrogen	Yes, low	Unknown, probably interrupted	Yes, high	Yes, high
Main H_2 colour	Blue	Probably blue	Blue and Green	Blue, planned switch to green
Hydrogen production	Yes	Unknown	Yes	Yes
Hydrogen storage	Unknown	Unknown	Yes	Yes
Hydrogen distribution	Unknown	Unknown	Yes	Yes
Hydrogen utilisation	Probably internal	Unknown	Yes, internal and external	Yes, internal and external
Hydrogen reselling	Unknown	Unknown	Planned	Planned
Firm partnership	Some intents signed	Agreements probably stopped	Yes, with other O&G majors	Yes, with other O&G majors
Socio-political partnership	Unknown	Unknown	Yes	Yes
Innovative technological interest	Unknown	Unknown	Yes, collaboration with niches	Yes, collaboration with niches
Landscape pressure	Low	Unknown, probably low	High	High

Company	**BP**	**Repsol**	**Equinor**	**ENI**
Interest in sustainability	High	High	High	High
Interest in hydrogen	Yes, high	Yes, high	Yes, high	Yes, high
Main H_2 colour	Green and blue (70%/30%)	Mainly green	Green and blue (mainly blue)	Green and blue
Hydrogen production	Yes	Yes	Yes	Yes
Hydrogen storage	Yes	Yes	No	Planned
Hydrogen distribution	Yes	Yes	Yes	Planned in collaboration with external source
Hydrogen utilisation	Yes, only internal at the moment	Yes, mainly internal	Yes, mainly internal	Yes, only internal at the moment
Hydrogen reselling	Planned	Planned	Yes, 10% of EU market planned	Planned
Firm partnership	Yes	Yes	Yes, with other O&G majors	Yes, with other O&G majors
Socio-political partnership	Yes, macro-planning of international transportation	Yes, active bargaining	Yes, tight connection with the state	Yes, several discussion arenas. Partially state controlled.
Innovative technological interest	Yes, collaboration with niche	Yes, active collaboration through consortium	Yes, collaboration with niche	Yes, academic and niche collaboration
Landscape pressure	High	High	High	High

Table 1: summarization of O&G firms' peculiarities. Own elaboration.

In conclusion, it is possible to retrieve some clear patterns. Firstly, it appears that the lead firms experiencing the highest levels of landscape pressure are the ones which must operate in highly democratic settlements. It is likely that democracy, in a broader sense also considering the freedom of information and knowledge as a mean to practice popular sovereignty (Dahrendorf, 2014), is impacting the long-lasting changes in the landscape view. As a result, different levels of pressure can be identified acting on the energy incumbents.

Furthermore, energy incumbents appear highly interested in technological niches, and the ability these possess to challenge their predominant role. Consequently, it appears that O&G incumbents are trying to start long-lasting collaborations and think tanks, to gather high levels of control concerning the development of fundamental innovation in the hydrogen field. Generally, this translates into big cohesion in the creation of hydrogen projects, as well as in the generation of academic development arenas, usually in-house financed, or companies' consortiums where deep control from O&G incumbents is retrievable. In general, these actions can be included in a broader risk management strategy, as the diversification of production, as well as the renewed interest in knowledge production are fundamental in a long-term planning process. Or, in other words, it appears that energy incumbents are participating as proactive investors in the generation of new niche knowledge, rather than having a more "classical" and conservative view (Ampe et al., 2021).

5.3 Interviews

In addition to secondary data, interviews have produced interesting data. The key points will be exposed by thematic areas, and eventually triangulated with secondary data findings. The data retrieved will be grouped by theory relevance, underlining the main information useful to construct a discussion based on the previously exposed theoretical framework.

5.3.1 Infrastructure, expertise and assets

All the interviewees were able to list plenty of infrastructures, expertise and assets which are nowadays owned by big O&G firms and can be repurposed in a future change of scenario in the energy sector. In general, this signals a commitment from big O&G companies to shift towards a more sustainable perspective. This choice is surely forced by international policies pointing towards this specific direction, as interviewees 1, 2, 3 and 5 point out, but is also retrievable in the willingness of the companies themselves. As interviewee 3 states: "*the decisional branch of my firm decided to urge even more pressing pollution policies, involving also scope 3 emissions*"; actively seeking emission reductions appears to play a fundamental risk management strategy. In addition, numerous Sustainability Reports (such as TotalEnergies, ENI and Equinor) explicitly talk about the social responsibility these companies need to undertake.

This commitment translates into a long list of expertise and infrastructures which will come in handy in the future years. Firstly, most interviewees (1, 2, 3, and 5) recognise the significance of dealing with big projects of strategic importance. Indeed, hydrogen will be required to scale up and lead firms in O&G will have to construct broader future scenarios and start long-term investment plans. This will likely generate a more integrated system (interviewee 1), therefore complicating the overall landscape of energy. Consequently, high levels of expertise will be required. In addition, interviewees 2 and 3 underline how the ability to manage and deliver a high quantity of energy molecules will be an important strength. While the electrification process will not require any gas or liquid transportation, the adoption of hydrogen will. In this scenario, the long-lasting ability of mainstream energy companies to deal with these transportation systems will come in handy. Indeed, interviewee 4 agreed: "*we are more prepared, and therefore we would rather deal in molecules, than in electricity*". The repurposing of expertise and infrastructure already possessed by these companies is fundamental in the risk management of the future transition. Lastly, interviewee 1 underlines how in all probability hydrogen will be a highly regulated market, and therefore "*high levels of knowledge and experience will be needed in dealing with the legislative norms*". This finding is confirmed by secondary data, as many big O&G players are explicitly willing to collaborate with the EU's apparatus. Furthermore, interviewee 5 acknowledges how it will likely be important to create geostrategic connections with Africa, as "*it will allow for the import of cheaper green hydrogen*".

The experts agree that a substantial part of the existing infrastructures will be repurposed. This will play two key roles: on one hand, it will allow for a faster adoption of hydrogen; on the other hand, it will enable a cheaper and more efficient transition. Among the infrastructures which can be repurposed, it is possible to retrieve pipeline connections, as one of the main ideas for upscale transportation regards pipelines, rather than maritime shipping. In addition, interviewees 1, 2 and 3 confirm the intention to continue refining petrochemical products, but with the auxilium of hydrogen-powered plants. Concerning new investments, interviewees 2 and 3 underline how the ability of O&G companies to repurpose hydrocarbon revenues into renewables and low-carbon solutions will likely be a fundamental factor: "*hydrogen will likely not be as profitable as the commerce of oil or gas. So, reaching high levels of efficiency becomes fundamental*".

Overall, it appears that plenty of the aforementioned skillsets and assets will play an active gatekeeping role. While for smaller, start-up companies, it will be complicated to gather investors, expertise and planning infrastructures, it appears that the O&G world already has well-established and lubricated mechanisms of investments, as well as consolidated assets already at its disposal to start this process. Therefore, niche environments will likely struggle to emerge, *vis-à-vis* the incumbents' power. In addition, from a GPN perspective, it appears that O&G companies are expecting to use the expansion of hydrogen's market as a strategic drive to diversify the range of their available products. As interviewee 3 stated, "*either the O&G world collapses economically before 2050, or we learn to strategize a diversification*".

5.3.2 Blue vs. green: strategical direction

From the interviews, it appears that the stronger push is towards blue hydrogen. While for interviewee 1 it is too early to identify a real winner between the two options, as a proper real market is still not well-established, for other experts the clear direction is to pursue blue, at least in the short term. A multitude of Sustainability Reports from O&G firms (e.g. Equinor, Shell, ENI) confirm this view. The reasons given relied on similar points. Interviewees 2 and 3 talked about the easier access to a scaled-up blue market, for various reasons. For one thing, blue hydrogen presents cheaper costs, as nowadays Europe does not have enough renewable energy abundance to fully commit only to green. On this topic, interviewee 3 stated "*the European commitment towards green hydrogen* - which will be analysed more in-depth in the next sub-chapter - *is now being questioned, as the first projections on costs are now being proven wrong*". The public role, in this case, appears to be conflictual, *vis-à-vis* the private sector. In addition, blue hydrogen is perceived as more reliable, as energy security is more and more an incumbent issue to be addressed, and customers who will commit to hydrogen expect a safe refurbishment of energy at any time. Therefore, "*relying only on weather conditions, such as wind and sun*" is not a viable option. Despite not being directly mentioned, it is also likely that this strategical direction is also playing a fundamental role in the market repositioning of O&G conglomerates: indeed, these companies possess big reserves of natural gas, and its continuous exploitation surely would represent an economic benefit and a strategic decision in the restructuring of their economic positions. Furthermore, despite the diversification of O&G companies is also touching the world of renewables, such as offshore wind, which will likely be used for the production of green H_2, it is also true that they possess peak knowledge in the world of CCUS. Consequently, as interviewee 3 stated, "*blue hydrogen respects the so-called energy trilemma: security, affordability, and sustainability*".

Nonetheless, the interviewees did not show a completely pessimistic attitude towards green hydrogen. Indeed, many experts agree that green H_2 will be a fundamental factor in the primordial stages, as it is easier to develop on a smaller scale, compared to blue. Subsequently, blue hydrogen will gain the upper hand, as it is easier to upscale, as discussed. Lastly, in a longer-term analysis, green will again play a major role, when the availability of renewable energy will be sufficient to cover a bigger part of the demand. Nonetheless, blue will still be part of the colour mix, as it is an efficient counterpart in case of a lack of green supplies. Different view concerns the import of hydrogen, which is also one of the pillars of the European Commission strategy. Both interviewees 3 and 4 foresee the possibility of importing directly green hydrogen from North Africa, through pipelines or maritime connections with Southern Europe, achievable due to the solar energy density in the territory, generating cheaper green H_2, remarking the strategical decisions to opt for the more economically convenient GPN approach.

In conclusion, the decision to aim mainly towards blue hydrogen, at least from a short-term perspective, appears to be a choice dictated by a strategic willingness to keep lower costs and repurpose the raw material and expertise already possessed by the O&G industry. Nevertheless, it must be argued that some perplexities expressed against an immediate wide adoption of green hydrogen are indeed correct. As of today, the issues concerning the high costs (and therefore the lower commitment of customers towards this technology) and the uncertain reliability of distribution are concerning. As interviewee 3 clearly explained, "*low-carbon solutions, such as blue hydrogen, are not zeroing emissions, but are nonetheless effective in contrasting CO_2e pollution*". Since a large-scale adoption of green appears today of difficult realisation, blue might represent a viable alternative.

5.3.3 The role of political institutions

The role of political institutions has been broadly discussed. Firstly, most interviewees agreed on the incisive inputs that policymakers were able to give to the formation of a hydrogen market. Nonetheless, interviewee 4 gave a different perspective, acknowledging the leading role of the private sector. In this expert's opinion (the only one working for a public settlement), the policy framework is forced to move along with the necessity of the market, as "*it is private firms which will ultimately develop innovative technologies and make a profit out of this*". Consequently, public institutions have the role of enforcing these processes, as the goal is to see a complete realisation of a more sustainable energy sector and are therefore obliged to comply and bargain with the request of the private sector.

As foreshadowed, for all the other experts, employed in the private sector, the main transformative driver is to be found in public political institutions. As interviewee 1 explains, in a simplified view Europe is "*a democracy, where people are able to express their opinions through the elections of new leaders*"; therefore, the shift in decision-making exemplified by the new European political class, which is demanding lower emissions, a transformative energy sector and an amplified responsibility towards nature preservation is a depiction of people's power of agency. In other words, the slowly mutating landscape is now exerting a considerable amount of pressure *vis-à-vis* the mainstream energy sector. The other interviewees agree to some extent that the energy transformation is derived from a change in policies, which is therefore requiring an appropriate answer. Nonetheless, it is also true that the relationship between the private and public sectors is not as simple, nor as clear. Experts confirmed certain degrees of bargaining and lobbyism happening from both fronts. The mutual relationship between public and private is also confirmed by multiple documents. Among the most important, is the authorisation by the European Commission to fund some fundamental hydrogen projects, under the Hy2Use framework, some of which regard the collaboration of major O&G firms - ENI, Respol, TotalEnergies, Shell (State Aid: Commission Approves up to €5.2 Billion of Public Support by Thirteen Member States for the Second Important Project of Common European Interest in the Hydrogen Value Chain, 2022).

Particularly, the experts underlined an ambivalence in the role of public institutions. On one hand, policy frameworks are propellers of technological innovation and are actively working in favour of the transition, with the auxilium of public funding, as well as the creation of discussion arenas. On the other hand, the European framework is predominantly focused on the adoption of specific technologies, mainly green, while leaving a reduced margin of operation for the implementation of blue hydrogen. This goes directly against the main prerogatives of O&G companies, which, as previously explained, would prefer to develop blue on a larger scale. Consequently, public actors become market enhancers on one side, while maintaining a coercive position on the other. On this issue, interviewee 3 underlined the focal role that lobbyism and bargaining is playing. In his opinion, it is possible to retrieve a specific policy decision to focus technological and economic efforts on a specific development (i.e. green H_2). Nonetheless, this commitment is the fruit of "*a convincement stemming from political elites, specific stakeholders and part of the academic community, which has not been challenged enough*". Therefore, this political address appears to be a top-down decision, in deep contrast with what emerged beforehand. The full commitment to green has nowadays started to be contested, as this generates new possibilities, particularly for the O&G world. Indeed, the strong conviction of some companies, which decided to bet mainly on blue, has now gained popularity, giving increased bargaining and agency power to some lead firms. Consequently, their political strength appears to be engorged, as they can now challenge the mainstream political framework. As interviewees 2 and 3 remark, even though blue hydrogen is not capable (as of today) of guaranteeing a 100% clean source of energy, the effectiveness of CCUS reaches levels of 95% capture. Since green is not doable on a large scale, and the mainstream alternative is to keep a business-as-usual situation, blue hydrogen emerges as the best option. This is confirmed by lower-level decision-makers, particularly at a state level. Indeed, many European countries, such as Germany, Belgium, Norway, the Netherlands, and in a smaller way also southern

Europe, for example Italy, are trying to keep an open interpretation of European directives and are at the same time allowing for an open dialogue with O&G representatives.

5.3.4 Drivers and barriers in the hydrogen market

From the analysis stemming from the data collected throughout the interviews, a main, fundamental, information emerges. As of today, all interviewees agree that no hydrogen market is operational and functioning. Conversely, interviewees 3 and 4 remarked how plenty of announced projects do not reach an FDI status, but are rather pre-emptively blocked; therefore, "*a high number of big firms are "chickening out" of the game*" (interviewee 5). The consequences are plenty.

For starters, many experts lament a too-weak political framework. As of today, many firms are reluctant to start big investment cycles, which could last up to 10/15 years, due to political uncertainty, mainly derived from the race between green and blue hydrogen, and that can therefore affect a broad adoption of hydrogen in the near future. Paradoxically, European political institutions, which are on paper hydrogen enhancers, are blocking the formation of specific H_2 markets. It is therefore questionable, especially in these first phases, if their operations will benefit or rather slow down the broad adoption of hydrogen. Secondly, hydrogen is facing a pessimistic phase. Indeed, while the broad adoption of green hydrogen has been scaled back, it is also true that many promising fields of application for the new energy carrier have been deemed as unapplicable for the time being. As an example, plenty of the applications publicised by Equinor in their report (see figure 7), from public rail transport to house heating, will not become a concrete reality, at least not before 2050. Consequently, the adoption of hydrogen will concern only a few industries: high-pollutant factories (i.e. fertilisers, steel, chemicals), oil refineries (which are already owned by O&G companies), and rocket fuel. Even the adoption of hydrogen as a practical solution for zero-emissions plane flights has been reconsidered. The reasons are plentiful. From one side, electrification appears as a more convenient, efficient, and easy solution, and therefore H_2 will appear as a viable solution only for those industrial apparatuses which cannot rely on electricity only. Secondly, hydrogen is a dangerous substance to handle, and therefore only a few industries possess the knowledge to utilise it safely. Thirdly, hydrogen is still not attractive to most possible customers. Consequently, due to the high prices, no customers desire to commit as an early adopter to this technology: a chicken-and-egg game dominates the adoption of hydrogen, as no demand produces no supply, and conversely, no supply generates no demand. In general, the experts confirmed that even a broad adoption of hydrogen will not generate a profitable market, comparable to the revenues in the O&G market.

In summary, hydrogen adoption is constellated by big barriers, which can lead to a predominant role for O&G companies, as well as other big companies, leaving little room for start-ups and other niche environments. This is due to the high levels of commitment and investments which are required to scale up the hydrogen market. Nonetheless, some interviewees confirmed how on a small scale it is easier to develop green H_2 technologies, therefore giving some possibilities of development for small industrial realities. In addition, the European Commission has approved high levels of liquidity for the generation of financial aid for these projects. However, it appears that O&G companies are acting as active gatekeepers, trying to not allow for a high number of competitors to enter the market. This point will be better discussed in the next subchapter.

While big O&G companies are forced to partake in the creation of hydrogen, as the incumbent energy transition is lawfully forced, the drivers for new actors to stem in this newcoming market appear to be few. For once, the political framework, in its ambivalent role, is playing the part of an enhancer, via the adoption of public funding and public discussion arenas. However, as the experts underline, it is quite likely that it is not enough to generate the broad response the EU is expecting for. Ultimately, this can play in favour of the O&G world, which can repurpose the high amount of revenue derived from hydrocarbons into greener technologies. As this financial adjustment can be done fully in-house, it gives strong leverage, compared with companies relying entirely on public funding.

5.3.5 Niche involvement

As said, hydrogen adoption can be interpreted as a niche technology, which is trying to challenge the mainstream energy sector. Consequently, for MLP, the adoption of new systems of energy production is affecting the incumbent sector. This role requires a broad involvement of new sectors in the production of energy. This is particularly true in the case of hydrogen, as the value chain is extremely complex. In fact, since H_2 will be mainly produced in two distinct ways, both modalities call for the adoption of different systems, and therefore for the involvement of variegated industries.

The inclusion of hydrogen niches has attracted the attention of both the public and private sectors, which are operating in different ways, as they follow different ideologies. On one side, the public sector is allowing for fair competitiveness, by allowing start-ups and industrial niches to participate in the allocation of public funds. Nonetheless, as mentioned, IPCEI *Hy2Use* also attract the participation of major O&G companies, as well as other big conglomerates from other industries. In addition, the EU is trying to stimulate networking and technological innovation through the adoption of broad arenas of discussion and participation.

On the other hand, the private sector is operating in a more diversified way. On one side, Oil and Gas companies are positively accepting to team up or joint venture with external companies. All experts agreed that the uncertainties derived by the little adoption of hydrogen, combined with the complexity of its eventual value chain, require partnering up, especially in these first stages. Nonetheless, Oil and Gas companies are also acting antagonistically *vis-à-vis* niche environments. As briefly mentioned beforehand, the O&G world is required to transition to greener solutions, as the consequence would be to bankrupt. Therefore, the obliged choice to repurpose towards greener and low-carbon solutions creates the need for O&G incumbents to gatekeep the access of possible new competitors. This is confirmed by the broadly adopted decision of most O&G companies to acquire niche realities or to create their own academic arenas, financed directly and therefore giving high abilities to control and acquire ulterior knowledge.

6. Discussion

6.1 The role of incumbents in the hydrogen economy

The starting point of this thesis is the identification of O&G companies as lead firms in the hydrogen market. In this way, the analysis of their policies and tendencies would fall under the well-established array of risk-management strategies, typical of consolidated GPNs (Coe, 2021). The retrieved long lists of projects, in active, waiting for FDI, or planned, concerning the development of hydrogen are symbols of a growing, established market, which forcefully becomes global and well-structured, due to the vastness of investments, expertise and materials needed for its functioning. Despite finding confirmation in many secondary sources, this point of view has been subsequently disrupted by the extension of the data with interview collection. Indeed, all interviewees agreed that now there is no functioning and economically viable hydrogen market in place. Many future planned projects are being postponed, or not approved, while stakeholders and firms are becoming increasingly sceptical in approving long-term investments in this technology. In addition, the momentaneous non-profitability of hydrogen translates into increasing difficulties for start-ups and smaller companies to access big opportunities, together with the confirmation of the experts that the public subsidies are still not sufficient. This theoretically leaves a bigger place for established companies, which can produce their revenue from different sources, as in the case of O&G companies. In this case, the territorial embeddedness (Coe, 2021) of O&G firms to specific natural resources explains their resolution to continue the exploitation of such riches. In addition, this might explain the high level of participation of O&G companies in R&D development concerning hydrogen, especially regarding the investments or purchase of niche firms in the market, as evidenced by the secondary sources examined: as better explained in the next subchapters, it is likely that O&G firms are playing a proactive role in the development of such niches (Geels, 2011). Furthermore, this strategy is conforming to a broader diversification aim, with the final goal to repurpose the assets owned by these big corporations, with the clear idea that the role of hydrocarbons will slowly decrease, as foreseen by the IEA (2023c) and IRENA (2023).

Despite the lack of a well-established market, it is possible to retrieve some key points. Firstly, O&G companies seem to act as lead firms in the emerging market of H_2. Despite the impossibility, as of today, of identifying real network winners, as confirmed by all the interviews, O&G companies are strategically positioning themselves as future lead producers and providers of hydrogen, while at the same time not detaining the entirety of the value chain, but rather offshoring to secondary companies, or the customers, as confirmed by most interviewees (nr. 1, 2, 3 and 4). This seems evident in the case of the transport infrastructures, storage, and seldomly even in the production of hydrogen. In the near future which appears to be challenged by the dominant presence of blue hydrogen, it is certain that O&G companies own the necessary raw material (i.e. natural gas), as well as the expertise and capital assets to coordinate a new-emerging value chain. Furthermore, hydrogen appears to represent a strategic risk management operation (Völlers et al., 2023). As evidenced by interviewee 3, O&G companies have the agency to transform hydrocarbon revenues into diversified assets, usually utilised to ramp up renewables (such as wind turbines and solar energy), and low-carbon solutions. The ability to structure this diversification internally might play in favour of the incumbent O&G world in retaining their leading power in the energy sector, as it enhances O&G's cost-capabilities ratios (Yeung & Coe, 2014). As said, this diversification will also include the construction and amplification of renewables power plants, which could lead to a prominent role for O&G companies also in the production of green H_2. In a legislative framework which is dominated by uncertainty and contrast, the incumbents are transversely investing in the production value chain of both blue and green hydrogen. In other words, the political uncertainty is contrasted with a broader strategy of diversification, quite likely with the goal not to disrupt shareholder's trust, and therefore to maintain a fundamental financial discipline (Yeung & Coe, 2014). Nonetheless, the size and impact of hydrogen as a production network might have been overexaggerated. The first perspective on hydrogen introduced the idea of a broader utilisation of the energy carrier, which was spacing from house-heating to transportation, to heavy industries. Some reports (such as Equinor's) still confirm the point of view. Nonetheless, the reality, at least for the short term, is much more limited to a few industries which have expertise in safely handling hydrogen. In addition, some heavy industries, like refineries, chemical producers and steel factories might exploit hydrogen. Consequently, H_2 is not en route to become a full substitute for hydrocarbons, as the interviewees suggest that the most efficient transition is brought by electrification. Therefore, the implementation of hydrogen will translate into a smaller, and probably less profitable, market. As interviewee 3 clearly stated, the bubble surrounding hydrogen is bursting.

Lastly, the bargaining relationship of O&G companies *vis-à-vis* political institutions is complex. While secondary sources confirm the intention for the O&G world to partake in the transition with a focus on societal needs, primary data intricated the drawing of this relationship. While on one side most interviewees working for the O&G world (nr. 1, 2 and 3) confirm that the political framework is a fundamental driver for the definition and the development of hydrogen formation, the correlation between the private and public sectors is conflictual. On one hand, the European legislator is clearly aiming for a predominantly green transition (see, for example, the

Renewable Energy Directive 3, 2020), while many O&G firms are not ready to fully commit to it. The evanescence of the veil of hope surrounding the adoption of hydrogen might become a fundamental factor. As multiple interviewees affirm, the economic numbers surrounding green hydrogen are being revised, and the prospects are not roseous. Indeed, as the prospected price to produce green hydrogen is steadily increasing, it is possible that this will open spaces for dialogue between the legislator and the private sector.

6.2 Energy transition and policymakers

In the delineation of this thesis' discussion, it is dutiful, in the first place, to underline how all the actors and documents analysed understand and confirm the necessity of a transformation in the energy production systems. Nonetheless, this is not superficial or obvious. From a mere economic standpoint, the most efficient means to sustain energy production and industry are still based on hydrocarbons, as interviewees 1 and 3 underline. Notwithstanding, other factors concur in changing the perspective of development, as societal concerns impose to renovate the incumbent energy systems. It seems confirmed, therefore, that to ignite massive transitions a broader consensus is needed. This must engage with public opinion, stakeholders, private companies, and any other entity with a significant power of agency *vis-à-vis* the incumbent energy sector. As Armstrong (2021) points out, the involvement of public opinion, grassroot innovation, NGOs and public engagement is an instrument of agency, which typically corroborates the scientific standpoint on the necessity of a greener transition, empowering it with an even stronger sense of agency. This is retrievable in the public press releases and reports of major Oil and Gas companies: while only some describe their transition as human-based (such as TotalEnergies, ENI, Equinor) and made to incentivise the potentiality of the employees and society in general, the vast majority of them (with the non-insignificant exclusion of the two Russian companies) explicitly gives details on their commitment to lower carbon emissions, not only due to legal bindings but also because of a strong belief that it is a necessity. This convincement is confirmed by interviews 1, 2 and 3.

The need for a systemic change (Huttunen et al., 2022) appears to be understood also from a political perspective, as all the interviewees agree on the fundamental aspect of policy frameworks. Nonetheless, a multifaceted issue emerges. Understood that European policymakers are indeed working towards the adoption of alternative energy systems, from where does this willingness stem from? In addition, is the policy framework detaining the ultimate power of guidance in the commitment towards hydrogen, or is this balance of power mainly shifted in favour of private firms? In other words, a clarification concerning the role of the incumbents and of the landscape in the hydrogen energy market is needed. While the latter question will find a more appropriate space for discussion subsequently, it is dutiful to clarify the first issue. From a linear standpoint, it is easy to assume that in a democratic settlement, as is the European legislator, actively producing market regulations, the choice to engage with H_2 represents a bottom-up transition: the electors have the power to influence future choice through the mechanisms, checks and balances of representative democracy. The same thesis is confirmed by interviewee 1. Nonetheless, a more complex picture can be drawn. It is possible to enlarge the power of agency to strategic stakeholders, representatives of green lobbyism, which root for specific transitions to happen. This would not come as a surprise: sustainable energy lobbyism has already shown its influential potentiality in Japan (Li et al., 2019), as well as in Germany, creating a profound policy network (Sühlsen & Hisschemöller, 2014). Consequently, the bottom-up assumption surrounding the adoption of sustainable energy transition would be challenged. On this matter, interviewee 3 referred to a top-down indication being given to the hydrogen market, by undisputed elites, consisting of green politicians, academics, and other stakeholders. Questioning the decision-making process is fundamental to understanding the trajectories which are shaping the adoption of hydrogen in Europe.

6.3 Landscape, niche pressure and private sector

As outlined beforehand, the relationship between the broader landscape, technological niches and the private sector is complex. The dominant regime of energy production has been challenged in a multifaceted way. The main pressures arose from the societal concerns about climate change, and the scientific proofs confirming this theory. Therefore, as evidenced by Huttunen et al. (2022), the systemic changes translated into the societal power of agency, which consequently caused an insurgent socio-political movement which imposed new legal frameworks to be implemented at a European and frequently at a national level. This meso-level pressure has been determinant in enhancing a profound restructuring of the incumbent's role in society, forcing them to acknowledge more responsibility in the CO_2 emissions, as evidenced by the new regulations concerning sustainability report publications, and the commitment to emission reduction retrievable in almost every O&G company analysed. Nonetheless, while the meso-level pressure has been certainly determinant in influencing big hydrocarbon firms, it is also true that a recursive relationship is in the act. Indeed, the role of the incumbents is influencing the dominant regime. As they are forced to green their activities, new investment strategies are being implemented. An example is given by interviewee 3, who states that a strong power of the company is the ability to reinvest hydrocarbon revenues in new markets, often involving green technology, and therefore starting a transformative process in the dominant energy regime, which the IEA foresee to be far greener in the next decades. It appears therefore that the schematisation presented in chapter 3.4 is respected, as while the meso-level is challenged by the social landscape, it is also interacting with the micro-level of the incumbents, which in a dynamic process are influenced and influence the dominant socio-technical regime.

In addition, MLP is adding a layer of analysis in the development of a hydrogen GPN. Indeed, the landscape pressures on the regime are forcing the introduction of new energy production systems, which are consequently impacting the formation of a new market for hydrogen. Nonetheless, as previously described, no functional hydrogen market is still in place, and this is therefore generating return feedback on the regime, and the landscape pressures to which it is subject. As the hopes for a fully green hydrogen market before 2050 are disappearing, due to a lack of technology, renewable energy, and high costs, this impacts the legislator, which is likely to modify the actual regulations, at least from a national level. Indeed, various interviewees affirm how European countries, such as Germany, Belgium, and the Netherlands, are seeking different ways to transpose European directives to incorporate more blue hydrogen intakes.

Lastly, then, it is dutiful to understand, in this game of counterparts and reciprocal influences, who is detaining broader decisional power. The essence of the debate between the public and private sectors takes the form of a chicken-and-egg game inside a chicken-and-egg game. Ascertained that, at the moment, there is no demand nor offer in the hydrogen market, it is questionable to understand who the major propeller of this market formation is. In other words, in a situation where it is uncertain whether it will be the creation of demand or of supply to enhance hydrogen as a hydrocarbon substitute, it is also uncertain who will be the principal actor to incentivise such transformation. On one side, all experts agree on the importance of legislative frameworks, for multiple reasons. It is representation of democratic agency, but more pragmatically, it is also instrumental for furnishing solid investment bases for private companies, which aim to produce profit out of this energy supply revolution. Nonetheless, on the other side, as interviewee 4 points out, innovative drives will be mainly operated by private firms: this is also retrievable in the important interest of O&G companies in creating, investing, or acquiring niche environments, which are incubators of technological innovation (Geels, 2011). Similarly, the creation, stimulated by O&G incumbents, of strategic alliances with stakeholders, universities and other experimental environments aims in this same direction. It is unlikely that incumbents will invest in R&D without the expectation of a return on the investment, which is likely supported also by political institutions. Nonetheless, the risk is to fall once again in a vicious circle in which no one wants to take the biggest parts of economic risks. Consequently, it is likely that the most certain scenario is one in which a bargaining dialogue between public and private will continue: on one hand, the political arena will try to focus resources and incentives in the development of hydrogen, addressing a precise route to follow (which at the moment appears to be towards green), lobbying the O&G to further invest in this field; on the other the incumbents will bargain more funds and resources out of the public sphere, underlining the non-sufficiency of what has been proposed, while trying to impose a different strategic view of the development of hydrogen, which has to include also blue H_2. In other words, an antagonistic extra-firm relationship (Coe & Yeung, 2015) might risk escalating.

In summary, the adoption of hydrogen presents a situation which is far more fluid and complex than the schematisation presented in chapter 3.3. As a matter of fact, it appears that the three elements (niche, socio-technical regime and landscape) play a less rigid and mixed role. On one side, contrary to traditional MLP theory (Geels & Schot, 2007), the landscape showed the ability to change and progress in short time: indeed, the amount of environmental goals reached in recent years have skyrocketed exponentially, and some events (such as the approval of the Paris Agreement) generated a landscape shock, which inextricably called for a new social representation of these dynamics (Upham et al., 2020). Consequently, identifying policymaking as simply part of the socio-technical regime is a wrongful simplification. Plenty of minority policies saw their entrance into the mainstream discourse, and their influence was undoubtedly incorporated in recent legislation. Similarly, the influence of the private sector was not immune to an imposed dialogue with society as a whole, and therefore with the political and stakeholder world.

Furthermore, the role of niches also needs to be rediscussed. Instead of a rigid structure dictated by classical MLP theory, where niches are separate entities *vis-à-vis* the regime, in this case, it appears that a more intricate connection is taking place. Similarly to classical theory (Geels & Schot, 2007), also in this case niche technology had to prove itself to become a challenger for the socio-technical regime. In this case, the characteristics required by niches to evolve into challengers are represented by the energy trilemma, as interviewee 3 stated: new technologies need to be sustainable, affordable, and they need to grant energy security. Nonetheless, a large issue remains unexplained. Who is the just, impartial decider which can verify the presence of these fundamental characteristics? On one side, there is the public legislator, which has clearly opted for green hydrogen, excluding blue, as not enough sustainable. On the other side, O&G companies mainly state the opposite, as green appears unsecure and unaffordable. Despite it not being directly mentioned by the interviewees, it is likely that blue hydrogen is supported also due to ulterior structural motives, such as the abundance of natural gas, and the strategic repurposing of the raw material, already owned by O&G incumbents. In addition, incumbents might also benefit from the opportunity to provide CO_2 storage. Consequently, the political discussion around the adoption of specific typologies of H_2

assumes a different weight, as the victor will likely become the economic and political “referee” for what concerns hydrogen development, at least for the near future.

Changing perspective, therefore, the relationship between incumbents and niches modifies deeply. Starting from the acknowledgement that new perspectives will be needed from the O&G world, niches are not any more challengers to fight, but rather facilitators to attract in their zone of influence. As the change will be done, the O&G world seeks the ability to obtain, at least partially, the power to influence how the transition will occur. Therefore, the relationship between niches and incumbents is constructive and dialogued, rather than conflictual. The gatekeeping role of O&G firms in the energy transition requires, then, to adapt to the need for a transformation, and consequently niches become enhancers of this process. Ultimately, it is possible to summarise these findings in a more dynamic scheme, which shall therefore substitute the classic MLP structure presented in chapter 3.3:

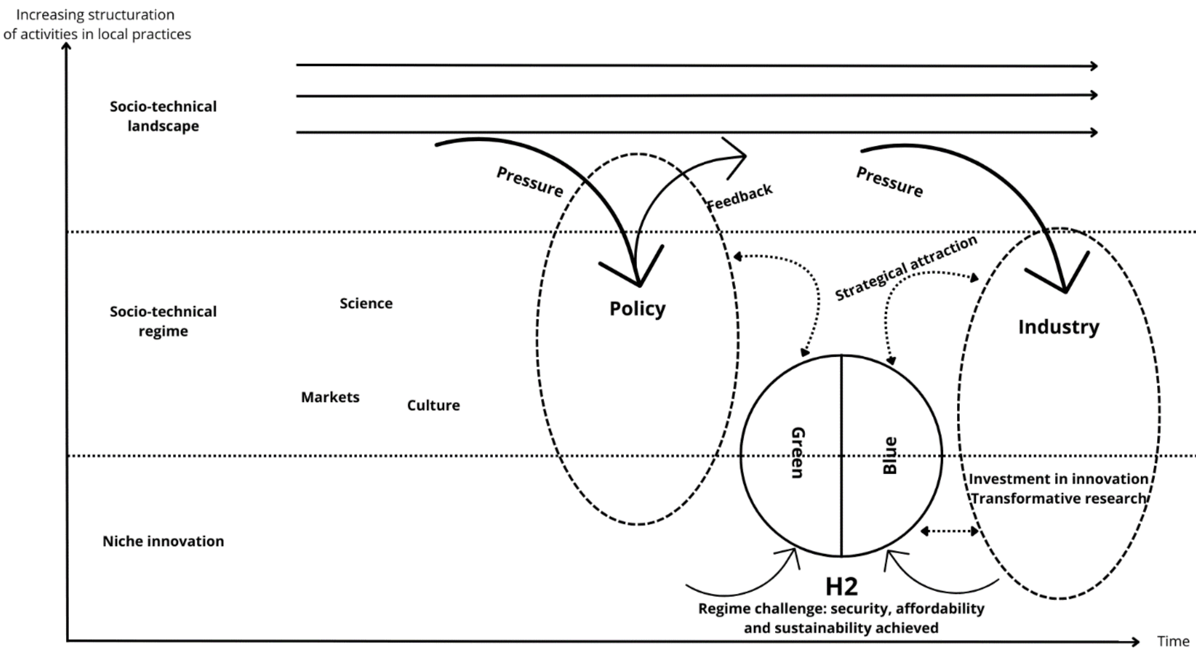

Figure 8: MLP schematisation in the hydrogen transition. Own elaboration.

As evincible, the distinction between niche and socio-technical regime is more blurred than in classical MLP theory. This point has been already analysed in more modern MLP theorisation, such as in Geels (2011) and Ampe et al. (2021), and more specifically applied in sustainable transitions in Stalmokaitė & Hassler (2020), as well as in Moncreiff et al. (2024). Also in this issue, mainstream industry not only actively participates in niche innovation, but it is also trying to influence the direction taken by technical expertise. Similarly, the policy world is influencing, and is influenced, by a specific typology of niche (i.e. green). Therefore, niche innovation cannot be seen as an external agent, whose main goal is to challenge and substitute the mainstream, but rather as a blurred threshold in which a multitude of interests converge and mix.

In other words, a more modern rearrangement can be given to MLP theory, by implementing a notion of hybrid actors. They can act as a bridging connection between regime and niches, as suggested by Bünger & Schiller (2022) and McCauley & Stephens (2012), bringing a deeper layer of complexity to the analysis. In such a view, incumbents are collaborative agents. Indeed, the cooperation between the two distinct groups is sparked by a certain degree of compatibility (Bünger & Schiller, 2022) in their respective interests, as they both pursue technical innovation on similar topics. Thus, the concurrency between incumbents and niches transforms into mutual interest, which in Figure 8 is represented by the strategic attraction on one side, as well as the incumbents' investments in transformative research. As clearly understandable, the mutual interest stems from different perspectives. From one side, O&G majors are focusing on maintaining a certain degree of control and power in the energy sector, therefore incorporating potential new competitors in their sphere of interest. On the other side, niches are often incapable of penetrating the regime gatekeeping, due to lack of funding or resources. When state control is not enough, it is likely that niche environments are prone to accept subsidies from regime players. As more dynamic instances of MLP theory have been generalised and used in multiple fields (Bünger & Schiller, 2022; Kallio et al., 2020; Diaz et al., 2013), it is complicated to acknowledge that the specific configuration presented in figure 8 can be utilised in different settlement.

To conclude, by layering together multiple pieces which emerge from this discussion, it is possible to retrieve a situation similar to what Moncreiff et al. (2024) describe in their research. In the context of a sustainable transition, O&G firms are subject to recursive dynamics caused by their territorial embeddedness, represented by the social pressure for change, the translation of such pressures in the political world and the exploitation of natural resources; furthermore their internal dynamics (see for example the choice of aiming for blue hydrogen), represent an ulterior element in the generation of their response; lastly, their response is feedbacked by the relationship with niche environments:

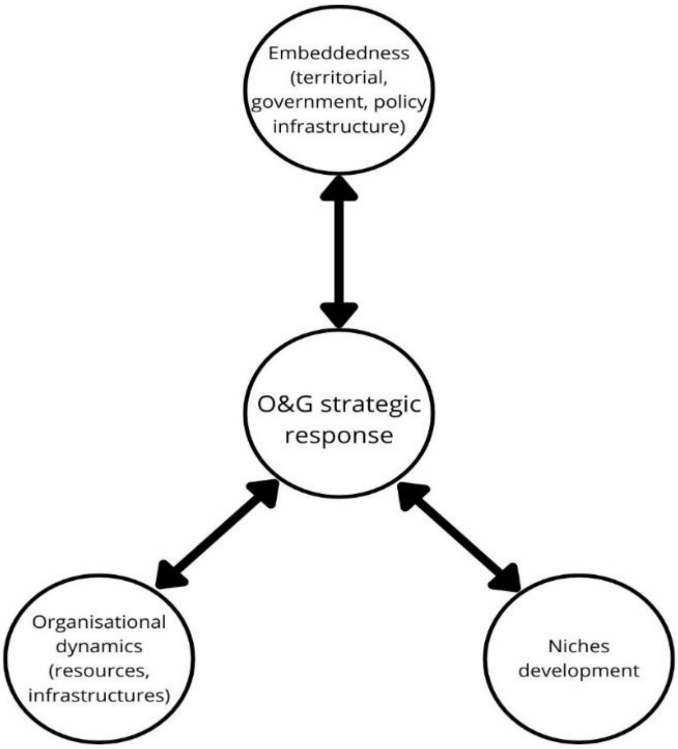

Figure 9: strategic response of O&G firms. Adapted from Moncreiff et al. (2024).

7. Conclusions

7.1 Key Findings

Concerning the role of O&G companies in the development of the hydrogen's market, some firm points can be drawn. For starters, it is undoubted that a well-established and explicit interest from these companies in the creation of an H_2 value chain is happening. Stemming from a landscape pressure which imposed a radical change in the mainstream delivery of energy, the incumbent socio-technical regime had to dynamize, enhancing a process of transformative reallocation of resources. As previously explained, this ongoing process is not a rigid contraposition of different actors, but rather a fluid dynamic. As such, hydrogen represents one of the multitudes of new solutions that have been brought to the table of discussion, to reach a full decarbonization by 2050. In this complex landscape, therefore, the diversification of assets, as well as the dialogued relationship between the O&G world and many stakeholders (such as politicians, representatives of NGOs, start-ups, etc…) represent long-term, well-though strategic processes of diversification, which, from a GPN perspective, are required for the economic survival of these firms in the next decades. Consequently, the dialogue and the desire to acquire decisional power in the selection of which hydrogen colour will eventually dominate the European supply becomes a strategic asset, as it could grant higher levels of control, reduced amounts of competitors, and allow for a repurposing of raw resources otherwise valueless.

The resulting consequences of these strategical decisions converge in the definition of a highly dynamic MLP structure, where the niche environment is con-participative in the redefinition of a new energy regime; simultaneously, the incumbents in the regime are acting as facilitators in this progression, as the landscape pressure, the dialogue and obligations drawn by the policy world (and to a broader extent by civil society), and the strategical diversification in act suggest that this course of action is the most effective to guarantee a profitable future in the energy revolution which will take place.

7.2 Implications

The implications of a broader interest of O&G companies in the adoption of hydrogen are multifaceted. Firstly, the ability to influence the development of the hydrogen market formation might be exemplificative of the swift and enhanced power that the private sector is assuming *vis-à-vis* the public sector. Nonetheless, in this specific case, it still needs to be proven which of the two visions are bringing higher benefits, since, as explained beforehand, both green and blue hydrogen present pros and cons. Consequently, the definition of a precise strategy still appears blurred, especially in recent months, as the limitations imposed by the European legislator are being rediscussed due to major faults, both economical and of practical realisation, being noticed in the green H_2 implementation.

Nonetheless, a fundamental point remains. Regardless of the political and social connotations brought by the specific typology of hydrogen which will be adopted, and regardless of the leveraging power that this decision will ultimately develop, it rests assured that a deep societal need for change in regard to broad energy consumption is needed. The desire for change stems from the exogenous pressure brought by the progressive landscape changing point of view. Consequently, it cannot be affected by endogenous decisions, but it can only be satisfied by allowing a transformative process to take place. Therefore, the focal point should be put on the actual realisation of such decarbonisation intervention, regardless of the main actors involved or the hydrogen colour. Indeed, the beginning of this process will surely produce positive effects on climate change and CO_2e pollution. Even though blue hydrogen combined with the most modern CCUS systems can guarantee a maximum capture of 95% of pollutant gases (as interviewee 3 explained), and therefore it is not as clean as the green solution, it is still effective in drastically reducing air contamination.

In conclusion, the starting point of the change in this socio-technical regime is not due to a lack of resources, or because of changing economic conditions, which require some eventual distancing from the utilisation of hydrocarbons. On the contrary, it grows from a dynamic societal landscape which was able to undergo a fast mutation in the general thinking point. Therefore, the condition to satisfy by undergoing a process of shift in the energy system is to allow for more accepted technology to dominate in the regime, and hydrogen, to some extent and for specific industries, represents a more than valid alternative. Therefore, to summarize, it is important to remark that the change has to happen, as it has already started to take place, and therefore every connotation of it is to be supported.

7.3 Limitations

To conclude this elaborate, it is dutiful to underline some limitations which might have affected its realisation. In the first place, some temporal limitations have been noticed in the drafting of this thesis, as the limited amount of time given for the completion of it might have affected the outcome. In addition, this limitation has been aggravated by the difficulty and time-consuming operation of finding experts to interview. Indeed, since the interviewees are often competent employees, with high levels of responsibility, it was convoluted to organise an appointment to perform the interview. Furthermore, it must be noted that all the interviewees who kindly accepted to be part of this research are highly trained experts, as said, and therefore it is likely that the data gathered from their interview might be subject to certain degrees of biases, as they all represent important corporations, and they all are trained in giving interviews and share data. Lastly, it must be taken into consideration that the interviewing sample was quite limited. Despite the data set has been enlarged with the utilisation of a broad selection of secondary data, it is important to remark on such limitation, as the interviewing sample might not be representative of the whole O&G macrocosm.

7.4 Further research

This research identified some issues regarding the utilization of MLP theory in modern contexts, where the dynamics between different actors are more fluid and interchangeable. As Berkhouth et al. (2004) explain, MLP approaches tend to underline the power of niches to start a process of radical transformation, which therefore might substitute the ongoing regime. Nonetheless, it is dutiful to underline how the regime is taking more and more of a predominant position in the definition, control and involvement in niche protected environment, as therefore the distinction between the two groups become more blurred, and therefore more complex to analyse.

In addition, it appears that this research has been focusing on specific segments comprising the socio-technical regime, particularly the industrial sector and the policymaker. Nonetheless, the regime ensemble is composed of a multifaceted and more complex environment, including other aspects such as culture and technology, which are undoubtedly playing a solid role in the consolidation of the regime, and therefore are likely to act and influence the adoption of hydrogen as a new energy carrier.

In conclusion, further studies are needed to better understand the future of this newborn market. As the adoption of hydrogen is nowadays just in the early stages, it is dutiful to keep track and produce new academic literature on the topic. In addition, more flexibility in the frameworks used has to be called for, since the combination of private and public sectors, together with the niche environment are more and more reciprocally participative in the generation of a new sociotechnical regime, and therefore must be understood in a more dialogued modality. Especially in the short-term future, with the development of more complex forms of market participation in hydrogen, it is important to draw a more realistic picture, also from a GPN standpoint, to better comprehend the market flow, and ultimately help the legislator and the private sector to take more concrete and effective decisions. Lastly, new elements must be brought into the analysis. As said, MLP approach can be based on the interconnection of a multitude of elements which co-participate in the creation of the regime. In general, further research on different sustainable transitions would be of fundamental importance to confirm or reject the generalisation of the model presented in Figure 8. Indeed, the novelty brought by the model could also be of potential benefit for different markets.

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Appendix

Appendix I: review of analysed documents

Document type	Document name	Publisher	Year of publication
Report	Hydrogen	IEA	2023
Report	Renewable electricity capacity growth by region/country, main case 2015-2020 and 2021-2026	IEA	2021
Media article	Hydrogen Supply Chains: a Detailed Look at How They Work	AST	2022
Corporate release	Our Sustainability approach	TotalEnergies	2024
Report	Sustainability & Climate 2023 Progress Report	TotalEnergies	2024
Media article	TotalEnergies to switch from grey to green hydrogen at German refinery by 2030	Hydrogeninsight	2023
Corporate release	Shell sustainability – our climate target	Shell	2024
Report	Shell Sustainability Report 2022	Shell	2023
Scientific paper	Pathways to a more sustainable production of energy: sustainable hydrogen—a research objective for Shell	Gosselink, J.W.	2002
Corporate release	What do we do – Hydrogen	Shell	2024
Report	BP sustainability report 2022	BP	2023
Corporate release	Gas & low carbon energy	BP	2024
Corporate release	Hydrogen Europe – what we do	HydrogenEurope	2024
Media article	BP: Clean hydrogen will play a minimal role in the decarbonisation of cars and space heating	Hydrogeninsight	2023

Media article	BP backs green hydrogen start-up aiming to cut fuel's costs	Reuters	2023
Media article	Repsol freezes millions of euros of investment in 100MW Basque country green hydrogen project: report	Hydrogeninsight	2023
Corporate release	Management report 2023 – Repsol Group	Repsol	2023
Report	Integrated Management Report	Repsol	2023
Corporate release	Our contribution to the SDGs	Repsol	2024
Report	ENI for 2022 – A just transition	ENI	2023
Corporate release	ENI e SNAM formano una jv per il primo progetto di CCS in Italia	ENI	2022
Corporate release	Idrogeno, il potenziale di un vettore energetico	ENI	2024
Corporate release	Equinor presents its first energy transition plan	Equinor	2022
Report	2022 Energy transition plan	Equinor	2022
Report	2022 Integrated annual report	Equinor	2023
Corporate release	Our organisation	Equinor	2024
Corporate release	Hydrogen in Equinor	Equinor	2024
Media article	Carbon Capture and Storage pros and cons	Treehugger	2021
Report	Hydrogen	IRENA	2022
Strategy report	The future of oil supply in the European Union	The Shift Project	2021
Press release	Commission welcomes provisional agreement on modernising management of industrial emissions	European Commission	2023
Media article	Cheap Russian oil cuts OPEC's share of India imports to record-low 50%	Reuters	2024

Report	Oil analysis and forecast to 2028	IEA	2023
Press release	State Aid: Commission approves up to €5.4 billion of public support by fifteen Member States for an Important Project of Common European Interest in the hydrogen value chain	European Commission	2022
Report	Lukoil sustainability report	Lukoil	2023
Media article	LUKOIL and ROSATOM Overseas plan a green hydrogen production unit in Romania	CEEnergy News	2022
Corporate release	Oil refining	Lukoil	2024
Press release	Lukoil and Rusatom overseas reach agreement to study project of green hydrogen production for romanian petrotel-lukoil s.a. refinery	Lukoil	2021
Media article	Lukoil, a Russian Oil Company, Calls for an End to the Ukraine War	The New York Times	2022
Media article	Lukoil completes reconstruction of several units at Volgograd refinery	MRC	2022
Report	Global Hydrogen Review 2023	IEA	2024
Strategy	A hydrogen strategy for a climate-neutral Europe	European Commission	2020
Press release	Equinor and Rosneft agree to cooperate on carbon management	Equinor	2021
Media article	Insight from Moscow: Russia aiming to take major role in global hydrogen markets	S&P Global commodity insights	2022
Strategy	EU hydrogen strategy	European Commission	2023
Strategy	EU strategy on energy system integration	European Commission	2023

Strategy	European Clean Hydrogen Alliance	European Commission	2023
Strategy	European Partnership for Hydrogen Technologies	European Commission	2024
Strategy report	Report of the Director-General Medium-Term Strategy 2023-2027	IRENA	2023
Media article	Data explorer – net zero tracker	Net Zero Tracker	2024
Media article	Hydrogen Valleys strategic for the autonomy of the EU	European Commission	2023
Report	Global Hydrogen Companies Database	Enerdata	2024
Media article	Insight from Moscow: Russia aiming to take major role in global hydrogen markets	S&P Global	2022

Appendix II: interview guideline

O&G companies are important for the world, as they provide energy and fundamental products. Nonetheless, it appears evident how the environment and the public opinion require a change in energy policies. This calls for an adaptation of Oil & Gas actions, in order to reach net zero targets, and a better balance with the environment. The purpose of this study is to understand better how O&G companies envisage being part of the transition to net zero, and what strategies and activities they have in place. Specifically, the study focuses on hydrogen, both green and blue.

1) What are the actions that your company can undertake in order to be part of the sustainable transition?

2) In general, from a long-term projection, which infrastructures and expertise do you think your company can rely on in the transformation of its assets and products?

3) Concerning hydrogen, is your company convinced it will be one of the major assets/investments in a short term (5 years or less) or long term view (+5 years)?

4) In a short term view, how would you describe the value chain of hydrogen, and its related market?

5) What are your economic perspective as an evolving energy company in the hydrogen market? In other words, what do you think will the source of revenue be in the hydrogen market? Are there parts of the value chain that you think will be more profitable to control?

6) From your perspective, how will the hydrogen market evolve in the near future?

7) Where do you think your company will position itself vis-à-vis blue and green hydrogen?

   (as a backup) Do you think blue or green hydrogen will take the lead in the market?

8) Do you think that institutional apparatus (including law, regulations, and the position of national and international political institutions) are influencing the adoption of hydrogen as a new energy carrier?

9) What is your position concerning the dialogue between your company and institutional regulations? In other words, what is your company's position vis-à-vis institutional influence concerning the development of hydrogen market?

10) What does your company see as a fundamental driver for the development of a hydrogen market? Do you think institutions are playing a role in this?

11) Concerning informal institutions, such as norms, good practices and social acceptance, do you think they have a role in your company's positioning?

12) How is your company's hydrogen activities structured? Are they all inhouse, or are you seeking further collaborations with external corporations?

Appendix III: consent form

Are you interested in taking part in the research project

“Master’s thesis, Oil & Gas companies and their role in the future of the hydrogen value chain”?

Purpose of the project
You are invited to participate in a research project where the main purpose is to assess the importance of Oil & Gas companies in the definition of a new energy market, represented by hydrogen. Particularly during this historical time, where actions are requested to tackle the climate crisis, Oil & Gas lead firms are diversifying their energy portfolio. One of the new and promising technologies is represented by hydrogen, as a potential low-emission energy carrier. Therefore, getting more in-depth with the potential projects, infrastructures and expertise owned by such companies concerning hydrogen is of focal importance. In addition, the relationship between Oil & Gas companies and socio-political institutions regarding the implementation of an hydrogen infrastructure will be discussed. The project is a master’s thesis.

Which institution is responsible for the research project?

NTNU is responsible for the project (data controller).

Why are you being asked to participate?

Due to your undisputable expertise concerning Oil & Gas, and the green transition that such companies are undertaking, you participation to this project is of fundamental importance. Furthermore, you contribution as an employee of one of the biggest Oil & Gas companies in Europe increases the importance of your interview. Your contact has been found by utilising my own or my supervisor’s networking capabilities.

What does participation involve for you?

If you chose to take part in the project, this will involve that you will take part in a semi-structured, open interview. It will take approx. 45 to 60 minutes. The interview includes questions about the future of the hydrogen technology and value chain, the interests of your company in it, and the dialogue between your company, socio-political institutions and other private expertise in the hydrogen sector. Your answers will be recorded.

Participation is voluntary
Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw.

Your personal privacy – how we will store and use your personal data
We will only use your personal data for the purpose(s) specified here and we will process your personal data in accordance with data protection legislation (the GDPR). Only me and my thesis supervisor will have access to your data. The data will be stored in password protected computers. The list of names, contact details and respective codes will be stored separately from the other collected data.

What will happen to your personal data at the end of the research project?

The planned end date of the project is May, 2024. At the end of the project, all data will be anonymized.

Your rights
So long as you can be identified in the collected data, you have the right to:
- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and
- send a complaint to the Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?
We will process your personal data based on your consent.

Based on an agreement with *NTNU*, The Data Protection Services of Sikt – Norwegian Agency for Shared Services in Education and Research has assessed that the processing of personal data in this project meets requirements in data protection legislation.

Where can I find out more?
If you have questions about the project, or want to exercise your rights, contact:
- NTNU, Riccardo Frediani riccarfr@stud.ntnu.no, +393458415105, or thesis supervisor, Markus Steen, Markus.steen@sintef.no, +47 90 64 54 96

If you have questions about how data protection has been assessed in this project by Sikt, contact:
- email: (personverntjenester@sikt.no) or by telephone: +47 73 98 40 40.

Yours sincerely,

Project Leader

Student

Markus Steen

Riccardo Frediani

Consent form

I have received and understood information about the project "Master's thesis, Oil & Gas companies and their role in the future of the hydrogen value chain" and have been given the opportunity to ask questions. I give consent:

- ☐ to participate in an interview

I give consent for my personal data to be processed until the end of the project.

(Signed by participant, date)

NTNU
Norwegian University of
Science and Technology