Institut européen
European Institute

Executive Master
in EU Studies

Industrial policy and the European Green Deal: the EU's bet on hydrogen and carbon capture

Supervised by Dr. Tamás Szigetvári

Jean BUFFIERE

2024

Table of Contents

Abstract

The European Union (EU) strives to become the first carbon neutral continent by 2050. Through its European Green Deal (EGD) strategic direction and policy package, the EU and its Member States have shown a renewed desire to shape future European industry and make the energy transition to a low-carbon economy a cornerstone of their climate ambitions. Among the key levers to deliver on the EGD objectives, renewable hydrogen and carbon capture and storage are two technologies in need of maturity and scaling up before they can effectively contribute to a low-carbon economy. Since 2020, the EU has gradually asserted its wish to speed up the deployment of these technologies, driving change from a European level. In other words, there is now a European industrial policy for so-called net-zero technologies, including hydrogen and carbon capture and storage.

Shaping industrial production in manufacturing sectors is the premise of industrial policy. Industrial policy remains a somewhat controversial field due to its apparent contradiction with a free-market-based economy. Interventionist policies have gradually fallen out of favor among industrialized economies and increasingly replaced by market dynamics. That said, research has shown the merits of well-designed industrial policies in fostering the domestic development of emerging technologies and markets. This paper aims to take a critical look at recent EU policy developments surrounding hydrogen and carbon capture and storage. We zoom into the EU's explicit strategies and specific policy development in support of building European hydrogen and carbon management industries. We build our analysis on concepts drawn from literature on industrial policy, an analysis of policy effectiveness and alignment, and case studies regarding the initial effect of these policies on industrial deployment of low-carbon hydrogen and carbon capture and storage projects.

We will argue that despite large efforts by the EU, the current policy package is unlikely to enable EU-based renewable hydrogen and to reach the desired contribution to climate goals by 2030. A first reason is that new regulation has tied hydrogen developments with that of other renewables and energy-based industries, which have found themselves in difficulty due to inflation-related cost increases and increased interest rates. A second reason is the current lack of the needed infrastructure and manufacturing capacity which, due to technical maturity and cost constraints, will take time and effort to reach maturity. A third reason is that, as

comprehensive as it has become, the current policy mix falls short of enabling the industry to bridge the cost and risk gaps that are inherent to such technological and engineering endeavors. In this context, both expectations and policy tools need to be revised and market development must be phased in. Low-carbon hydrogen production combined with carbon capture and storage could emerge as in-between solution to enable key long-term infrastructure to be build and shorter-term climate benefits to be realized, while renewable hydrogen value chain is being built. Current EU policies under the EGD will need to evolve to accommodate additional flexibility in this regard.

1. Introduction

1.1. The European Green Deal

The European Union (EU) ambitions to become the first net-zero continent by 2050. The European Climate Law is a binding commitment that requires EU Member States to become carbon neutral by 2050. The European Green Deal (subsequently referred to as EGD or Green Deal) was unveiled in March 2020 on the eve of the Covid-19 pandemic. It not only announced a comprehensive EU-wide regulatory package. The Green Deal also marked the release of a new overarching long-term strategy of the EU. The EGD aims for the "*transformation of the EU into a fair and prosperous society living in a modern, resource-efficient and competitive economy*", including "*net zero greenhouse gas emissions*" and "*decoupling economic growth from the use of natural resources*"[1]. As such the EGD replaces the Lisbon and Europe 2020 Strategies and serves a comparable purpose as multiannual development strategy, albeit now spanning over three entire decades.[2]

With the EGD as strategic direction towards 2050, the European Commission has further devised shorter term goals with regards climate and energy transition targets. The *Fit for 55* legislative package was proposed by the Commission in 2021 and targets a legally binding intermediate step of 55% reduction of carbon dioxide (CO2) emissions to be achieved by Member States by 2030.[3] A second step of reducing emissions by 90% by 2040 has been

---

[1] European Commission 2020a

[2] Becker et al. 2020 and Widuto et al. 2023

[3] Council of the EU 2024a

proposed by the Commission and is currently under preparation.[4] **Figure 1** shows an overview of the scale of the effort needed to reach climate neutrality. To reach these targets, the EU economy must undergo a dramatic reduction in its carbon intensity and achieve a 7-fold acceleration in its decarbonization efforts in the period until 2030.[5] As fossil fuels represent 80% of all emissions across transportation, industry, buildings, and agriculture, decoupling economic growth from the use of fossil fuels while maintaining or improving the bloc's competitiveness to ensure continued economic development is a massive challenge.

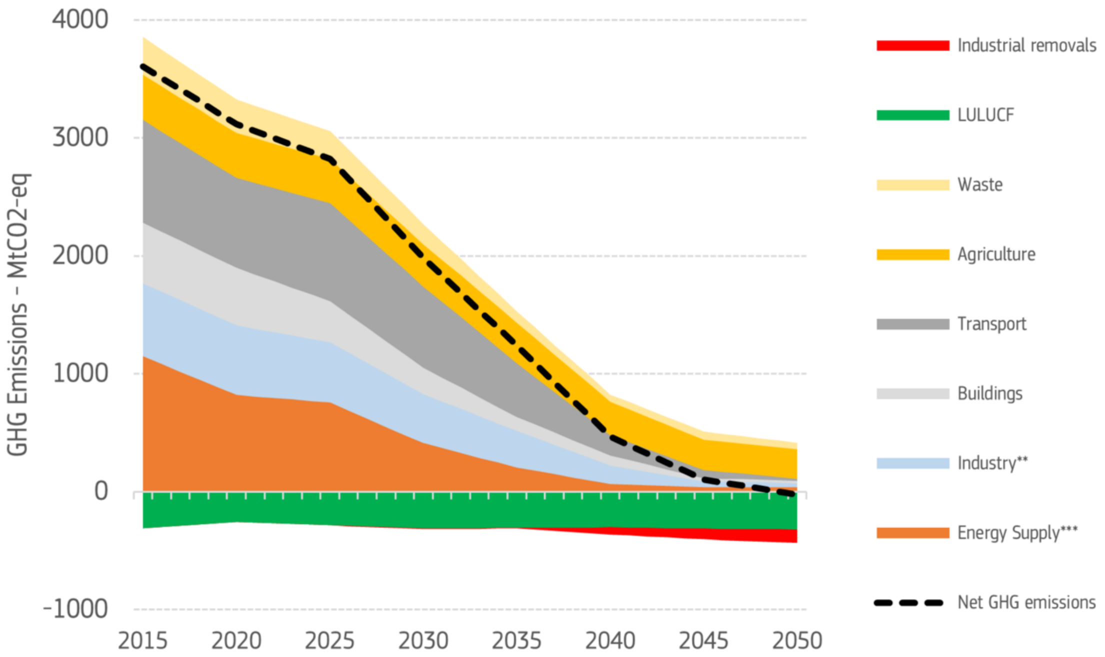


Figure 1. Greenhouse gas emissions trajectory in the period 2015-2050 as projected by the European Commission in order to reach climate neutrality by 2050.[6]

Abating greenhouse gases (GHG) emissions entails replacing fossil-based resources by renewable sources of energy and materials. This constitutes the main pathway to reaching a net-zero economy. The challenge for established, developed economies is to achieve this without compromising economic growth or the competitiveness of European industry. From an industrial perspective, net-zero can be achieved through four main types of industrial developments: 1) the deployment of renewable energy production capacity, 2) the electrification of industrial processes, 3) the use of low carbon fuels, 4) and the management

---

[4] COM/2024/63 final

[5] McKinsey 2020

[6] European Commission 2024a, citing PRIMES, GAINS, GLOBIOM data

of residual CO2 emissions.[7] Arguably, renewable energy production and electrification are readily available technologies that have been developed over the past few decades and have today reached a more mature state. The cost of renewable energy has been constantly decreasing over the past two decades, mainly due to technological advances and economies of scales, such that some technologies are already competitive with fossil-based processes, as shown in **Figure 2**. It is important to note that this context was taken as starting point by the EGD and subsequent EU legislation, including regarding hydrogen.

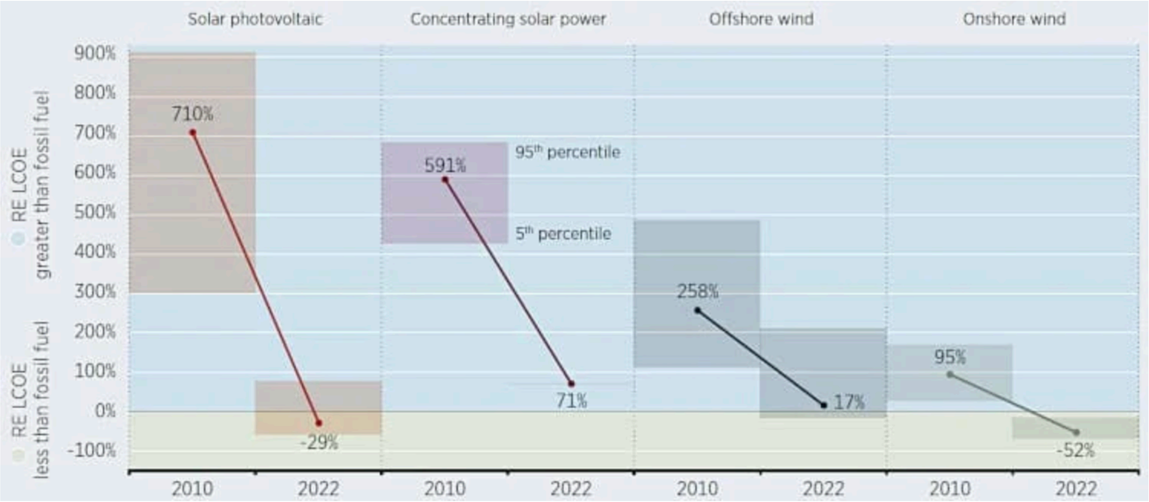


Figure 2. Levelized costs of renewable energy production in 2010 and 2022 in comparison with levelized costs of fossil-based processes.[8]

This means that economically efficient conversions have already taken place or are currently ongoing. By contrast, low-carbon fuels and carbon management are relatively new techniques not yet proven at scale. Their deployment and scaling up incur additional development costs, as well as financial and operational risks for the private sector.[9] Indeed, decarbonization represents a major hurdle for the European manufacturing industry. This is for three reasons. First, additional capital investments are needed to comply with increasingly stringent environmental regulations. These investments aim at reducing negative externalities and do not generally command a direct price premium or a competitive advantage in the markets. Thus, from a purely financial standpoint the corresponding

---

[7] Fries 2023

[8] IRENA 2023

[9] Fries 2023

investments represent hurdles that are generally not justified on their own. Here, regulatory incentives, such as a carbon tax or tax rebates on energy-efficient investments, aim to steer industry towards favoring more environmentally friendly operations.

Second, decarbonization requires using technologies and infrastructure which are not yet available in a mature state. This increases the business risk for companies who are involved in developing them, or for those who are required to use them. In capitalist economies, higher risk would command higher return expectations, further increasing the cost of debt and equity, and thus of decarbonization. Third, any capital-intensive industry is constrained by a certain path dependency. The lifetime of large capital investments often reaches several decades. Today's GHG emissions are resulting from investment decisions made sometimes a generation or two ago. Climate urgency requires additional investment decisions to be made well in advance of expected end-of-life of existing assets. From a resource utilization standpoint, early decommissioning production assets is inefficient and incurs additional effort, resources, and costs. Moreover, the risk of production assets becoming stranded by additional regulatory constraints is another fear for the industry.

For reasons cited above, the decarbonization of industry as required by the European Green Deal represents a significant challenge from a policymaker's perspective. First, industry needs a comprehensive and stable policy framework. This framework must be composed not only of clear and appropriate incentives to reduce GHG emissions, but also of support in the development of new technologies and trigger capital investment in new low-carbon processes and infrastructure. In a market economy in which firms are free to direct their investment decisions as they see fit, firms choose the path of least resistance to achieve their financial goals. Facing stringent regulations there is a real risk that companies would scale down domestic production capacity and shift it to more accommodating regulatory environments. This would result in no overall emissions reduction, a phenomenon commonly referred to as *Carbon Leakage*, which must be avoided. This is because the EU still relies on industry for a large share of its Gross Domestic Product. Carbon leakage defeats the objective of reducing overall (that is, global) carbon emissions and leads to further deindustrialization. The risk is that of deindustrialization, whereby firms would shift their manufacturing operations to more lenient environments, creates additional geopolitical dependencies and potential major social disruptions. Thus, we make the assumption that there exists a general European interest in preserving some industrial capacity within the EU, not least as lever to deliver on the objectives of the EGD itself. This is where industrial policy comes into play.

1.2. The New Industrial Strategy for Europe and the Net-Zero Plan

Over the past few years, the idea of a European industrial policy has undergone somewhat of a revival. The Council of the EU has drawn a timeline of its industrial policy actions dating back from 2017, when the European Council gave the European Commission the mandate to formulate a new industrial policy agenda. Over the past almost 8 years, the Council of the EU has listed more than 30 events of special significance for the European Council and the Council of the EU with regards the EU's own industrial policy.[10] However, arguably the most important event regarding EU industrial policy occurred in 2019 and 2020, just as the European Green Deal was being conceived. This change initiative takes its roots in longstanding factors and challenges such as climate change, globalization and a changed geopolitical environment, but also the internal contradictions of existing EU policies.[11]

In March 2020, in parallel to the EGD, the European Commission unveiled its *New Industrial Strategy*.[12] The Strategy was explicitly called for one year earlier by the European Council and as such received explicit sponsorship by EU Heads of States.[13] The document unveils eight strategic axes, including general measures as well as sector-specific measures (heavy industry, energy efficiency, critical raw materials, pharmaceuticals) in support of European industry. Hydrogen stands out as the only molecule (like oil and natural gas), or technology, to have its own dedicated initiative. In this Communication, the Commission clearly states the EU's ambition to actively drive industrial change within its Member States.[14] The New Industrial Strategy lays the ground for a renewed industrial policy in the *Green* and *Digital* spheres with a particular attention on competitiveness in the global arena. Through this Strategy, the EU defines a will to shape industrial development through policy,

---

[10] Council of the EU 2024d

[11] Zuuleg 2017

[12] European Commission 2020b

[13] European Council 2019

[14] COM/2020/102 final

albeit in respect with its social norms, with the rules of the single market, and in compliance with the EU's international commitments. The Strategy presents an agenda based on support of its industry mainly based on horizontal, i.e., non-sectorial, policies. This includes a review of intellectual property, competition, and trade rules, as well as public procurement, in service of the EGD objectives. However, the strategy also allows for provisions related to sectorial or thematic policies, such as carbon-intensive industries, critical raw materials, pharmaceutical products, and industrial ecosystems.

Subsequently, the EU has adapted its industrial policy ambitions to the reality of events and crises it had to face. This notably included the Covid-19 pandemic and its aftermath on the global economy. The NextGenerationEU (NGEU) program was adopted in late 2020 and aims to serve as "*a groundbreaking temporary recovery instrument to support Europe's economic recovery from the coronavirus pandemic and build a greener, more digital and more resilient future*"[15]. With its large financial support and innovative common borrowing scheme, NGEU was presented by the EU itself as an update of the New Industrial Strategy. The Strategy was updated in 2021 through a second Communication to include additional crisis mechanisms and support for Small and Medium Enterprises (SMEs) in its scope, in alignment with the NGEU program.[16] This indicate that the EU sees its industrial policy as key to not only serve the EGD goals, but also in the broader scope of challenges and crises.

With industrial policy identified as lever for delivering the EGD, the EU released in February 2023 *a Green Deal Industrial Plan*, also referred to as the Net Zero Plan. The Net Zero Plan concretizes the ambitions stated under the New Industrial Strategy in support of a green European industry. The Plan encompasses four pillars, themselves announcing a broad and ambitious policy agenda. Below are some of the axes of policy developments covered by the Net Zero plan. First, the EU sees the need for a predictable and simplified regulatory environment. This is covered through a Net-Zero Industry Act, a Critical Raw Materials Act, and a reform of electricity market design.

Second, the EU wishes to enable faster access to funding for private and public actors. This is achieved via a Temporary State Aid Crisis and Transition Framework, the General Block

---

[15] European Commission 2024b

[16] COM/2021/350 final

Exemption Regulation, the REPowerEU and InvestEU programs, as well as the Innovation Fund instrument. Third, the EU sees the need to enhance EGD-related skills. This is supported by Net-Zero Industry Academies, by combining a *skills-first* approach with existing approaches based on qualifications, by facilitating access of third country nationals to EU labor markets in priority sectors, and by fostering and aligning public and private funding for skills development. Fourth, the EU foresees the need to support open trade for resilient supply chains, for renewed engagements with the EU's partners and the World Trade Organization (WTO), the further development of Free Trade Agreements, and to defend the Single Market from unfair trade practices.

The Green Deal Industrial Plan also introduces, arguably for the first time at such scale and in such an explicit manner, dedicated technology-specific ambitions. The EU intends to take an active role in supporting the development of specific technologies, among others hydrogen and carbon capture and storage. Hydrogen and carbon capture and storage technologies under the framework of the EGD and Net-Zero Plan are the subsequent focus of this paper. The Net-Zero Plan makes 18 citations of hydrogen and two mentions of carbon capture and storage. While stating as a footnote the intention to remain technology neutral, the Communication foresees a "*massive switch to fossil-free hydrogen as a storage medium, fuel and feedstock*"[17]. Importantly, the Communication foresees the preparation of a Net-Zero Industry Act (NZIA) Regulation "*to underpin industrial manufacturing capacity of key technologies*". In its quest to gear up for climate neutrality, the EU now ambitions to steer not only technological development, but also directly the factors of industrial production.

As announced in the Net Zero Plan, the Net-Zero Industry Act (NZIA) Regulation was agreed on a provisional basis in February 2024 by the European Parliament and the Council.[18] NZIA comes in support of the Fit for 55 targets to be reached as part of the EGD's first 2030 milestone. The stated objectives of the NZIA are to streamline the corresponding regulatory and permitting framework, to stimulate demand and access to market including via public procurement, to enhance skills, and to facilitate the sharing of best practices. The Act aims to promote investments in domestic production capacity with the introduction of a

---

[17] European Commission 2023

[18] European Commission 2024c

minimum share of at least 40% of domestic manufacturing in related development projects. The Act also intends to position domestic European industries favorably in the global market for low-carbon technologies, which is expected to reach 600 billion euros by 2030.[19] Moreover, NZIA further introduces technology-specific production targets in support of the Net Zero Plan, namely related to carbon capture and storage, with a target of 50 million tons of annual injection by 2030.

One major innovation of NZIA is the formulation of a list of eligible *Net-Zero Technologies* based on criteria of maturity, expected contribution to decarbonization, and security of supply considerations. Being labelled as net-zero technology makes related developments eligible to a simplified regulatory framework and to dedicated financial support, including by relaxing the EU's traditionally stringent State aid rules. The Act lists the selected technologies including renewable hydrogen, with a stated potential up to 20% energy mix in industry and up to 50% in transport. The Act also selects carbon capture and storage, with a stated potential up to 80 million tons of annual CO2 abated by 2030. Arguably the most ambitious but also contentious provision in the NZIA in relation to these technologies is the minimum share of domestic origin for production assets of 40%, which is akin a *local contents* provision used in traditional industrial policy. In the provisional text, the term *hydrogen* is mentioned 15 times and the term *capture* 37 times, marking the growing importance of these two technologies in the EU's strategy to deliver on the EGD objectives.[20]

1.3. Hydrogen and carbon capture

Hydrogen and carbon capture and storage are relatively recent technologies that are seen as enablers of transition to net-zero under the EGD. Hydrogen is an energy-dense molecule that can be used as an energy carrier and as a fuel. Much like natural gas, hydrogen is a gas that can be compressed and liquefied, stored in tanks and underground storages, and transported via pipelines or trucks. The molecule is not naturally present on Earth although it is the main combustible in stars, including or own sun, and is the main fuel involved in nuclear fusion. On Earth it must be manufactured from conversion from another energy source. Hydrogen possesses the advantage of being easily converted from (via electrolysis) and into (via fuel

---

[19] Council of the EU 2024b

[20] Council of the EU 2024c

cells) electricity, as well as from (via reforming) and into (via methanation) natural gas. Often labelled the *Swiss Army Knife* of energy, hydrogen integrates relatively easily within the existing energy systems and can complement both electricity-based and natural gas-based supply chains.

Once produced, hydrogen can be injected as a fuel for combustion as replacement of natural gas in power plant and metallurgic processes, used as reducing agent in various chemical processes, or stored onboard vehicles, where it enjoys higher volume density than batteries. Once stored, it can be easily converted into electricity to power electric powertrains in virtually all transport applications. The two-way convertibility also provides potential benefits in buffering the intermittence of renewable power sources such as solar and wind, thus improving efficiency and grid balancing. As hydrogen can be produced from either natural gas or from electricity, it can act as a bridge between current fossil-based and future renewable-based societies. However, the efficiency losses during conversion make it a higher-cost energy carrier than electricity or natural gas. Moreover, not all hydrogen molecules are created equal and are often labelled with a so-called *Color*. Fossil-based hydrogen is commonly referred to as *Grey Hydrogen* or as *Fossil-based Hydrogen*. The conversion from fossil natural gas into hydrogen releases CO2 into the atmosphere unless used in combination with carbon capture and storage, in which case the result is *Blue Hydrogen* or as *Low-Carbon Hydrogen*. By contrast, hydrogen obtained from electrolysis powered using renewable power has no embedded CO2 emissions, in which case the product is commonly labelled *Green Hydrogen* or as *Renewable Hydrogen*. More colors have been devised depending on other factors, such as the source of energy used during electrolysis. **Figure 3** summarizes the main colors of hydrogen depending on the production pathway.

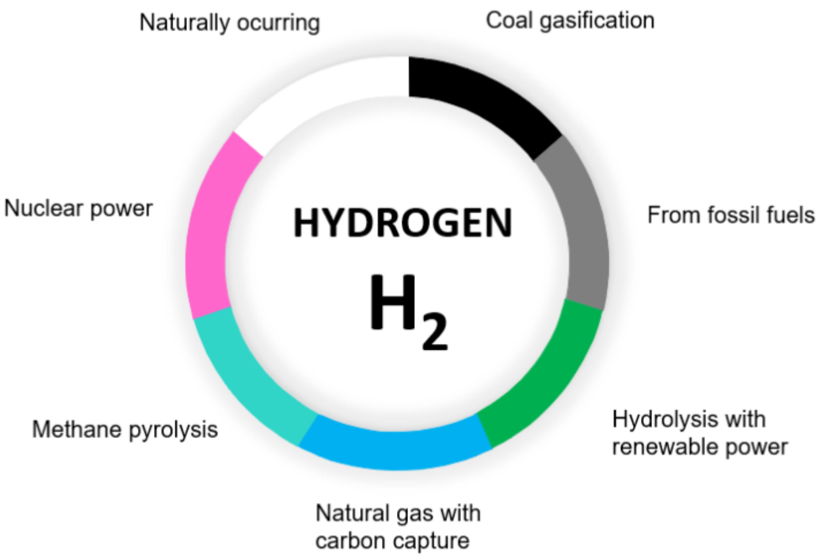


Figure 3. The Colors of hydrogen as relevant to the EU regulatory framework.[21] Most hydrogen is produced today from natural gas and labelled as grey, turned into blue with carbon capture, while hydrogen is green when renewable power is used as energy input.

By contrast and as its name indicates, carbon capture and storage is an abatement technique that consists in capturing CO2 in a concentrated and purified form at the point of emission, followed by transportation (via pipelines in gaseous form, via trucks or ships in liquid form) and sequestration in a medium that will prevent its future release into the atmosphere. This technique, when used at scale can provide a pathway to decarbonize the so-called *Hard-to-Abate* heavy stationary industrial sectors including steelmaking, cement, oil refining, and chemicals. Thanks to this technology, existing fossil-based processes, once fitted with additional carbon and capture technology and infrastructure, could become near-carbon neutral without their substantive modification or replacement. Furthermore, when applied to a source of CO2 which is itself of renewable origin, such as the combustion of sustainably sourced biomass, carbon capture and storage could in theory achieve negative emissions, i.e., a net decrease in the overall carbon present in the atmosphere. Given the massive potential climate benefits offered by this technology, it has been suggested that carbon storage be offered as a public service.[22] In addition to the large-scale storage concept described above, other carbon capture and utilization (CCU) as well as direct air capture (DAC) pathways are under development. Both CCU and DAC rely on different

---

[21] Sen et al. 2022

[22] Sekera and Lichtenberger 2020

technological and conceptual assumptions but share the same outcome of long-term CO2 removal and sequestration. For simplicity, the various carbon capture technologies described above are referred to as either carbon capture and storage or as carbon capture in this paper.

While carbon capture does not help to solve challenges related to security of supply in energy procurement, from a technology standpoint carbon capture and storage is a relatively straightforward, through capital-intensive way to achieve emissions reduction. A prerequisite for efficient operation is that the corresponding industrial process readily emits concentrated streams of CO2. This requires adapting or creating new industrial processes in addition to creating a dedicated carbon management infrastructure. Large-scale carbon capture and storage is also conditioned to the availability of transport infrastructure as well as of an appropriate medium for the sequestration of the captured CO2, for instance in underground storage caverns or in depleted oil and gas fields. This makes the feasibility of carbon capture dependent on location and on ability to repurpose existing infrastructure to reduce costs. **Figure 4** the foreseen integration and synergies between electrical, hydrogen, and carbon capture and storage networks within a net-zero energy system. **Annex 1** includes a technical note on H2 and carbon CCS technologies and investment efficiency.

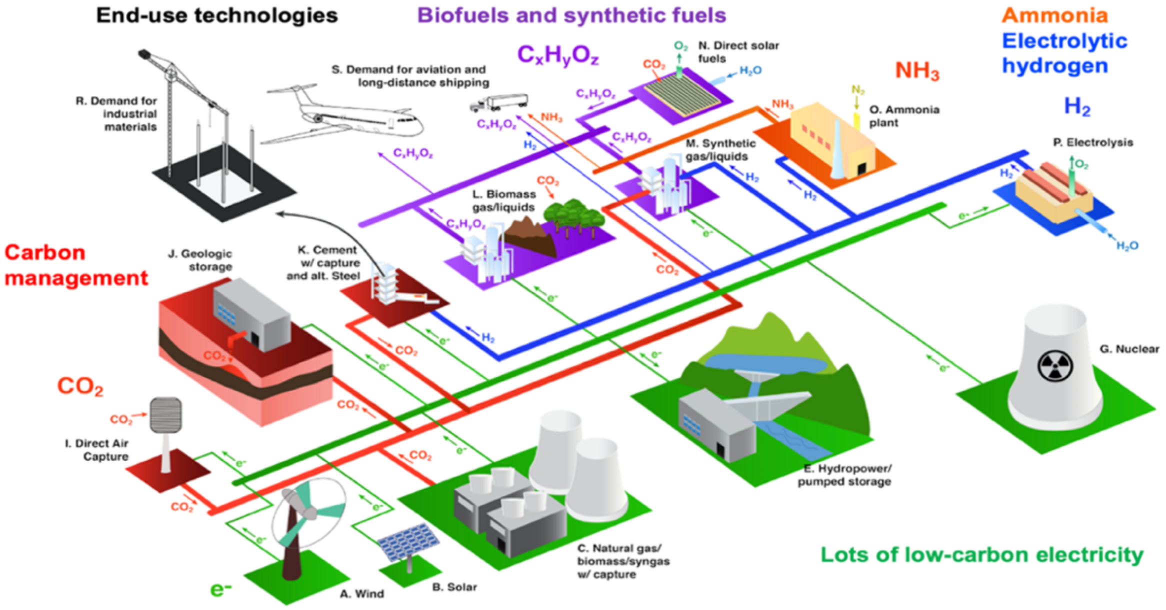


Figure 4. Hydrogen (in blue) and carbon management (in red) infrastructure within a net-zero energy system centered around renewable and low-carbon energy sources (in green).[23]

---

[23] Davis et al. 2018

Hydrogen and carbon capture and storage share a commonality in that the associated technological development, production capacity, and infrastructure are of limited maturity. For hydrogen, most electricity-based hydrogen conversion technologies, including fuel cells and electrolyzers, are still under development, lack mass-market manufacturing facilities, and require sub-technologies which are themselves at various stages of technological readiness. Further research and development (R&D) effort is expected to gradually improve the currently limited conversion efficiency over time, though this will remain constrained by physical limitations. Moreover, a main reason is that the infrastructure needed to reach a so-called *hydrogen economy* is specialized and highly capital intensive, with limited opportunities to repurpose existing assets for hydrogen service. For carbon capture and storage, the challenge is of a financial nature, but also of regulatory and public acceptance ones. Flagship carbon capture projects, even when transport uses existing assets and when injection is foreseen to occur offshore, have triggered environmental and social concerns which are addressed through lengthily risk assessment and approval procedures[24][In addition, the largest projects require financial resources beyond those available to even the largest individual companies, with investments amounting to hundreds of millions of euros to develop a single project.

Therefore, in either case the technology is either falling short of the efficiency required to justify itself in comparison to alternatives (for hydrogen) or has not yet been realized at meaningful scale (for hydrogen and carbon capture). These challenges are reflected in current production values and state of technological development. Globally, hydrogen production is responsible for 900 million tons of CO2 emitted annually, which is more than the entire GHG footprint of Germany. Of the approximately 100 million tons of hydrogen produced annually around the world, only around 0.1 million tons or 0.1% is renewable (green) while 0.5% is low-carbon (blue).[25] For carbon capture, some projects have been in discussion for years and most announced projects are still in development phase, with only a single large-scale site operational within the European Economic Area (EEA). This site, in Norway, sequestrated 19 million tons of CO2 since its inception in 1996, thus proving the viability of carbon capture technology at scale though in a single project.[26]

---

[24] NautaDutilh 2023

[25] EIA 2023

[26] Equinor 2024

1.4. Research questions and methodology

In summary, the energy transition to net-zero is a technological challenge as well as an industrial and a policymaking one. Two emerging technologies in particular, hydrogen and carbon capture and storage are gradually emerging as pillars of the EU's decarbonization strategy under the European Green Deal, acting in parallel with, or in complement of, the scaling up of renewable energy production and use, as well as the development of other CO2 abatement technologies and pathways. In this context, the EU has gradually integrated both technologies into plans to support and steer industrial production towards a net-zero society. Arguably, there is a pre-EGD and a post-EGD period in EU green industrial policy.

The energy crisis of late 2021 aggravated the need to switch to domestic energy production. The outbreak of Russia's war in Ukraine in early 2022 and weaponization of natural gas supplies has added an energy security component to the already complex goal of driving the EU towards carbon neutrality. Through its New Industrial Strategy, NZIA but also RePowerEU plans, the EU has decided to take an active role in shaping future energy systems and carbon-intensive industries. Actively steering private industrial decisions to develop and maintain domestic manufacturing capacity is the core tenet of industrial policy. From this introduction, we can thus infer that the EU has the stated intention to adopt an industrial policy in support of the Green Deal objectives.

This leads us to wonder what kind of industrial policy the EU intends to develop, what mandate is given to it to do so, what kinds of tools it is choosing to apply, and importantly, whether early market developments allow us to draw a conclusion on its likely success. This paper aims at providing an analysis of the industrial policy output generated at EU level in support of the European Green Deal specifically targeted at the deployment of hydrogen and carbon capture and storage technologies at scale. The main research question is twofold and summarized as follows: what kind of industrial policy is the EU pursuing and does it appear appropriate considering the objectives of the EGD and the opportunities and constraints inherent to hydrogen and carbon capture and storage; and what do current market developments inform on the industry's early reaction to the policy instruments tools it is developing?

The main research question can be further subdivided into three research axes. First, this paper explores some of the insights academic industrial policy research brings about technology development, market creation, and (re)industrialization. Taking a theoretical approach is instrumental in addressing the research question. This is because, although hydrogen and carbon capture and storage are new technologies, the process of industrial policy, that is, the attempt by governments to shape manufacturing in relation to stated national objectives, is not. Throughout modern industrial history, nearly all national governments have played an influential role, albeit to various degrees, and devised some kind of industrial strategy, albeit with various degrees of effectiveness. By understanding some of the opportunities and pitfalls of industrial policy, we are better able to judge which approaches and policy instruments may be better suited to the specific contexts and circumstances of the European Green Deal.

Second, this paper assesses the current state of development of the hydrogen and carbon capture technologies in relation to early EU strategies and industrial policy actions in support of the hydrogen and carbon capture and storage sectors. We especially analyze the objectives that the EU has set, as this informs on the kind of role the EU intends to play in shaping its industry. We also review some of the main policy instruments that have been applied until today or that are currently under preparation by European legislators. In addition, because industrial policy involves the necessary interaction between public and private actors, we also assess the degree of understanding and alignment between policymakers and industry in the selected sectors as an assumed prerequisite to a successful industrial policy. We will also attempt to qualify the effectiveness of the policies in deploying the corresponding technologies at industrial scale.

Third, building on the previous two, we will attempt to provide a forward-looking assessment regarding potential future policy directions. Assuming that devising a policy mix is an empirical exercise which, by definition, is never perfect and must constantly evolve in a changing market environment, we will explore what adjustments may lead to higher alignment between industry needs and the EU's own capabilities, in turn enabling the prospect of increases policy effectiveness, while at the same time managing expectations regarding what a realistic contribution of hydrogen and carbon capture technologies and markets in support of the European Green Deal objectives could look like going forward.

The paper follows a three-section structure according to the axes described above. We start by reflecting on the theoretical motivations behind industrial policies in general, including some of the major implications in relation to the European Green Deal. We then take a closer look at the existing current framework around hydrogen and carbon capture, drawing several conclusions in relation to the kind of policy approach the EU has chosen with regards these two technologies. We then turn to the private sectors and the current state of hydrogen and carbon capture markets, as seen by the position of its private actors and of the state of selected current industrial projects and attempt to draw a causal link between the EU's policy objectives and recent market developments. We close by drawing several conclusions regarding potential policy gaps and possible avenues for further developments.

This analysis is supported by the following research methodology. The first section is supported by a classical literature review mainly drawing on the works of various specialists on the matter and compiled by Oqubay in its excellent volume, the *Oxford Handbook of Industrial Policy*.[27] More targeted literature, also based on empirical evidence including from *OECD* studies, is also included.[28] The second section draws on a mix of qualitative elements found in primary and secondary EU legislation, as well as a quantitative representation of the EU's policy output through a targeted keyword searched conducted across the open access *EU-Lex* database.[29] The third section includes a press review of hydrogen-related developments in the period from the second half of 2023 until May 2024, taken mainly from articles, interviews, and analyses published in the specialized news outlet *Hydrogen Insight*.[30] This section also draws some conclusions from a selection, comparison, and analysis of the market performance of public companies operating in the hydrogen sector since the European Green Deal was announced.

---

[27] Oqubay 2020a

[28] Cammeraat, Dechezleprêtre and Lalanne 2022

[29] https://eur-lex.europa.eu/homepage.html

[30] https://www.hydrogeninsight.com

2. Industrial policy

2.1. What is industrial policy

Industrial policy is a broad field of study that does not have a single agreed definition. At an abstract level, industrial policy describes *"some form of government intervention that selectively promotes certain industries"*[31]. This definition tends to be selective of certain instruments and excludes de facto most horizontal measures that affect all firms and several sectors in similar ways, such as R&D schemes or training support.[32] A more actionable definition with regards the end goal of industrial policy is employed by Zuleeg as "*the strategic effort by the state to encourage the development and growth of a sector of the economy*"[33]. This wider perspective potentially includes any government measures that aim at influencing industry, including in areas such as manufacturing, trade, technology, and innovation. This also potentially covers regional, labor, fiscal, and even monetary policy. As per this definition, industrial policy research is the study of the effect of targeted or non-targeted government interventions or policy instruments aimed at influencing industrial production at the sectorial or firm level.

A third definition focuses on the impact of such interventions: "*Industrial policy is a type of selective government intervention or policy that attempts to alter the structure of production in favor of sectors that are expected to offer better prospects for economic growth in a way that would not occur in the absence of such intervention in the market equilibrium.*"[34] This opposes industrial policy with market-based dynamics and market failures in particular, the areas of an economy where markets fail to provide an efficient outcome. Alternatively, in some situations the market equilibrium is not desirable, for instance, due to issues of fairness, leading to the need for resource distribution. For this study, we adopt a fourth definition proposed by Oqubay which describes industrial policy as *"a strategy that includes a range of implicit or explicit policy actions and instruments selectively focused on specific industrial sectors and new activities for the purpose of shaping structural change and promoting catch-*

---

[31] Djafar and Milberg 2020

[32] Bianchi and Labory 2020

[33] Zuleeg 2017

[34] Pack and Saggi 2006

up in line with a broader national vision and development strategy"[35]. Here, industrial policy pursues specific sector-related objectives and uses a potentially wide range of policy tools designed by governments to achieve these objectives by influencing, directly or indirectly, firms operating in the target sector. In this view, the starting point of industrial policy is to formulate a coherent strategy.

Given the broad influence public authorities can have on the private sector, industrial policies are mainly microeconomic but can also be macroeconomic by nature. Indeed, monetary and fiscal policy also influence firm behavior. For instance, monetary policy in support of a stable and competitive exchange rate, as well as balance of payment considerations, have traditionally been part of the industrial policy toolbox. However, such policies are assumed too broad and indirect to be considered in the scope of this paper. This paper voluntarily focuses on microeconomic tools, such as regulations and subsidies, as well as other EU-wide actions from EU institutions and the European Commission in particular, explicitly hydrogen and carbon capture and storage sectors. In the present case, given the situation as described in the previous section, it is assumed that such industrial policy will be targeted at overcoming the inherent technological risks and cost hurdles of the nascent hydrogen and carbon capture and storage industries.

Recently, industrial policy fell out of favor, being negatively associated with a *Protectionist* or *Dirigiste* view of the political economy. This is because governments tend to become tempted to *Pick and protect winners*, or *Safeguard and help losers*. Governments are tempted to selectively support certain technologies, sectors, or firms on a discretionary basis, often for interests other than purely economic ones. Economic theory predicts that the outcome of such protectionism is likely suboptimal due to information imbalance, vested interests, and uncontrolled rent seeking behaviors.[36] In this context, industrial policy should not support struggling industries and protect *National Champions* but should aim to increase national (or European) competitiveness through the creation of a global level playing field, and to encourage the adaptation and transformation of its domestic industry over time. By contrast, neoclassical economics advocate the efficient allocation of resources through price

---

[35] Oqubay 2020b

[36] Mazzucato et al. 2015

adjustment in well-functioning markets for factors of production. This is to be achieved with minimum public action targeted at shaping industrial production. The neoclassical current has been particularly prominent in western economies since the neo-liberal turn of the 1970s and 1980s in Western economies, commonly referred to as the *Washington consensus*. Industrial policy under the neoclassical approach is restricted to a minimalist form of government intervention.[37]

The Washington consensus prescribes an initial push towards the liberalization, deregulation, and privatization of sectors which previously enjoyed (public) monopolistic-type protection, such as transport, utilities (e.g., electricity, water, waste disposal), and healthcare. This push is generally followed by a government withdrawal whereby market dynamics take over. Public intervention is generally limited to correcting market failures, such as providing public goods and managing some externalities. That is not to say that industrial policy is incompatible with neoclassical economics. Only, the narrow, sectorial and targeted interventions of the past tend to be replaced by broad, horizontal and non-discriminatory measures. These measures typically aimed to generate a favorable business environment, a national innovation system, efficient critical infrastructure, a general education system, and a sound regulatory framework – measures deemed respectful of prevailing market competition rules.[38]

Industrial policy is also relevant from the point of view of cohesion and redistribution. Macroeconomic models developed by Krugman show that trade favors producers of goods in industries which enjoy increasing returns to scale.[39] There, increasing returns leads to comparative advantage and trade specialization. However, if trade involves nations with different levels of availability of capital, the result is a capital-rich core and a capital-poor periphery. This situation may naturally lead to national government intervention aimed at altering market dynamics by allowing domestic industry to develop and upgrade itself by ensuring some level of protection from international trade dynamics. This insight is for instance relevant for regionally integrated entities such as the EU, where individual Member States enjoy various levels of economic and industrial development.

---

[37] Weiss 2020

[38] Bailey and De Propris 2020

[39] Reiner 2020 and Ocampo 2020, citing Krugman 1981

2.2. Three classical phases and a modern shift

From a historical standpoint, industrial policy has been largely concerned with developments in manufacturing industries used as lever to improve a country's position in international trade. In short, industrial policy is about *Industrialization*. Indeed, mainstream economics foresees that exports are desirable because they generate domestic economic growth and a more favorable balance of payments. In this context, scholars of industrial policy have identified three broad phases of industrial policy development. These were devised by studying historical cases, ranging from the first industrial revolution in 18th century Britain to the emergence of East Asian economic powers in the second half of the 20th century. The first historical phase of industrial development policy has been characterized as *Import-substitution Industrialization*.[40] This phase entails economic development via the progressive replacement of imported goods by domestically produced alternatives. In this phase, the country seeks to incentivize local companies to manufacture identical or replacement goods domestically. This creates a substitution effect which promotes economic growth. This stage of industrial development typically involves using trade protection as policy tool, either seeking to reduce (via import tariffs or quotas) or create additional hurdles (via for instance local content requirements) to imports. In addition, targeted subsidies or tax rebates, can be given to local companies as incentives to create or shift production capacity.

The second phase of industrial policy has been characterized as *Export-substitution Industrialization*. In this phase, the country attempts to upgrade its existing manufacturing base to produce higher value-added products and leverage local comparative advantage. Export-substitution can be combined with import-substitution to optimize manufacturing output. The overall industrial policy strategy under this phase has been summarized by Storm as follows: "*a country should reorient its exports as much as is possible to fast-growing markets and plan for import substitution in those imports for which the income elasticity of demand is high*"[41]. If successful, the country moves away from exporting global commodities to gradually more specialized products. By contrast, the third phase of industrial development has been characterized as the *Integration* into *Global Value Chains*. In this

---

[40] Oqubay 2020b

[41] Storm 2020

phase, demonstrated in practice by the growth of ASEAN countries throughout the second half of the 21st century, growth is achieved through further upgrading of production in targeted sectors, focusing on high-value-added goods, to the point of achieving competitive advantage in global niches.[42] In this phase, governments are encouraged to promote network clusters which create efficiencies and generate additional positive externalities as well as spillover effects.[43]

Any industrial policy requires a national government having the desire and capacity to shape and influence industrial production. At the most basic level, many governments of developed or developing economies have throughout modern economic history applied some form of industrial policy, not least to protect their strategic interests such as defense and military sectors. In this context, two different intensities of intervention have been identified in which governments take a different role with regard industrialization. A less active form of government is one from which actions are limited to ensuring the well-functioning of markets, limiting their scope of intervention to that of a *Facilitating State* focused on correcting market failures. By contrast, a most proactive form of intervention requires the state having the ambition to act as *Developmental State* which requires an entrepreneurial mindset but also well-functioning bureaucratic and political institutions.[44]

The mainstream, and largely still relevant today, neoliberal turn marked by the Washington consensus has been challenged by economists, including by Hausmann and Rodrik in relation to industrial policy.[45] These authors emphasize the importance of entrepreneurship in securing economic growth and in the role public institutions can take in promoting it.
In this framework, governments may want to intervene beyond market dynamics to promote trade and economic development through so-called *Mission-Oriented* policies.[46] A taxonomy of policies, distinguishing between supply-push and demand-pull instruments, has been devised by Criscuolo et al. and depicted in **Figure 5**. This modern view of industrial policy revolves around direct or indirect public-private incentives as well as various support

---

[42] Bailey and De Propris 2020

[43] Djafar and Bilberg 2020

[44] Oqubay 2020b

[45] Hausmann and Rodrik 2003

[46] Mazzucato and Kattel 2020

(such as subsidies) and protection (such as import barriers) measures to promote and protect entrepreneurship. In turn, entrepreneurship creates externalities which makes the case for governments taking some level of risk, for instance by providing loan guarantees, risk capital, or through development banks.[47] In more extreme situations of market failure, the state is called upon to act as E*ntrepreneur of Last Resort*.[48]

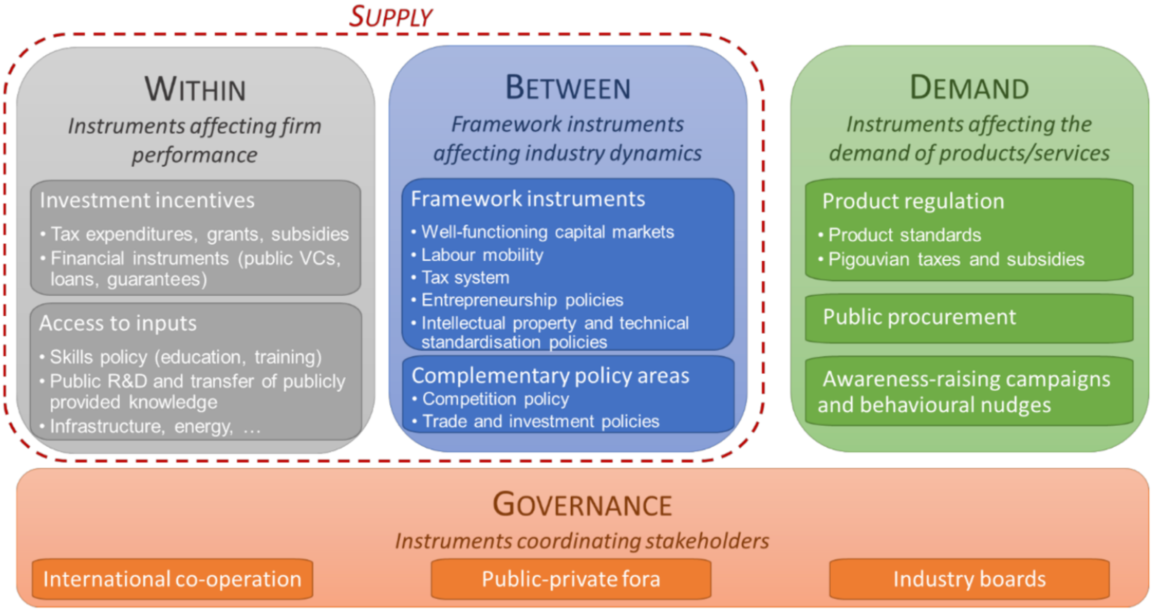


Figure 5. Taxonomy of industrial policy instruments available across modern market-based economies, and classified according to their supply-push and demand-pull characteristics.[49]

2.3. Policy tools for new technologies and markets

No matter the theoretical foundation and chosen governmental role, two cases have been identified that typically justify most industrial policy interventions. The first case is the need to protect and nurture emerging technologies, markets, and firms. This is referred to as *Infant Industry*.[50] Early market intervention can appear at odds with the objective of maintaining a strong competition policy, which aims to remove rents (additional profits) accumulated through imperfect competition. However, the argument in favor of government action is that perfect competition prevents an infant industry from developing itself because no individual firm is strong enough to bear the risk of innovation or investment. Particularly in capital

---

[47] Weiss 2020

[48] Cimoli et al. 2020

[49] Criscuolo et al. 2022

[50] Reinert 2020, citing Mill 1848

intensive industries, it is not uncommon for new projects and ventures to require upfront investments in R&D or in capital assets. These projects require significant resources as well as a certain risk tolerance. The venture capital industry, as well as the consolidation of firms into larger, diversified entities that can afford temporary and singular losses among a portfolio of profitable, longer-term projects, are some of the ways markets have developed to mitigate the risk inherent to entrepreneurship. However, such market-based support is not always available or accessible to all, for instance small enterprises or firms in less developed economies and markets. As a result, a developmental state may be tempted to intervene.

Providing some development rent, otherwise known as growth-enhancing rent, is one key objective of industrial policy. Corresponding policies typically take the form of subsidies or tax rebates which enable companies to retain additional profits. In turn, this gives companies and entrepreneurs some financial room to invest in additional production capacity, or to develop their own innovation capacities.[51] Subsidies can be designed to operate on a performance-related, non-discriminatory (e.g., technology neutral) basis. However, it is key for public actors to actively manage rents. That is, the government must have the capacity to counterbalance private sector interests and to keep firms accountable for certain performance targets, through reciprocal conditionality in conjunction with the developmental and innovation aspects of the rent. This is also to prevent players from exerting market power and create barriers to entry, and to not fall prey to vested interests which blur the line between public and private responsibilities.

Beyond providing rent, governments have additional tools at their disposal to influence the behavior of firms operating in a market economy. Examples of push-like policies aim to provide an incentive for companies to enter a particular market or adopt a particular strategy (such as export orientation or product upgrading) or technology. Within the classical industrial policy toolbox such so-called *Hard* policies may include public ownership of companies, selective credit extension, favorable tax treatments, public procurement, public infrastructure projects, restrictions on foreign investment, or the promotion of domestic firms, for instance through local content requirements.[52] In addition, wider-ranging pull-like

---

[51] Roberts 2020

[52] Cimoli et al. 2020

policies, also labelled as *Soft* policies, may include incubators, training, and financial incentives for entrepreneurs.[53] Other specific instruments designed to influence certain sectors of the economy include guaranteed markets, feed-in tariffs (including reverse competitive auctions), cap-and-trade systems, efficiency standards, specialty bonds, temporary and conditional trade protection, favorable credit terms, as well as various forms of informal pressure.[54] In the realm of industrial policy, governments routinely get creative depending on the objective at hand.

The second case is the creation of positive externalities, for instance through technological innovation. Positive externalities are associated with the idea of public good. Private innovation is driven by the prospect of rent gained by establishing a temporary market advantage, which serve as incentive to take a business risk. In cases where externalities are high and the possibilities for private protection (e.g., patent, trademark, contract) are limited, no market advantage is drawn from the effort and the firm will not pursue it. This hinders innovation and thus may justify government intervention. General education and fundamental research are two such examples of such cases which may be handled by public agents. In a Developmental State the government as a stakeholder has the ability to pool risk and bear long-term investments in a way that no individual private actor or sector can. In addition, some endeavors are so inherently risky and long term (e.g., space program) that they cannot be borne by a single company. Regarding public goods, some developments are favorable to a (public) monopolistic status considering the economies of scales that they generate (e.g., critical national infrastructure). Seeking economies of scales serves as justification for governments to conduct ambitious industrial programs in what has been called *Big Push Industrialization*.[55]

On industrial policy, the experience from other geographies and industries can be informative as to the potential of industrial policy to spearhead new industries, technologies, and markets. Brazil provides a good success story, having shaped a bioethanol market in the 1970s through a targeted industrial policy.[56] The program was triggered by the Brazilian

---

[53] Kozul-Wright and Fortunato 2020

[54] Storm 2020

[55] Storm 2020

[56] Mingo and Khanna 2013

government in response to an exogenous shock (oil crisis) in an overarching attempt to reduce the country's reliance in imported goods and to rely instead more on domestically produced fuels. This was achieved through policies which supported new production facilities. Facilities built under the industrial policy program turned out to be more productive than prior existing plants. However, in the neoclassical economic context, industrial policy is intended to be applied during a defined period of early market development. A task for the government is to shift the sector from a supported state to a market-based competition through a "*competitive post-industrial policy business landscape*"[57]. This has been identified as a particularly delicate task, though one for which little empirical evidence of key success factors has been documented.

2.4. The Single Market and competition rules

This sub-section turns to some of the legal principles surrounding any EU-wide industrial policy. The Single Market remains a cornerstone of the EU and its scope and application have been evolving over time. From a legal perspective, within the EU legal system there exists two axes of tension. First, a tension exists between internal market rules and sectorial policies Second, a tension exists between enabling free market competition and allowing public intervention, either at EU or Member State level. By design, Single Market rules have been conceived such that they leave limited room for national governments to intervene. The legal basis for the protection of fair competition is twofold. Art. 101 and 102 of the Treaty on the Functioning of the EU (TFEU) forbids concerted practices of companies that restrict competition and the abuse of a company's dominant position. Moreover, Art. 107 TFEU prohibits State aid from Member States to companies operating within the Single Market. However, exceptions exist when such aid is justified by, for example, for services of general economic interest, including in situation of crisis. This is conditioned to the fact that such State aid does not distort competition in such a way as to be contrary to the public interest and, regarding crises, is supposed to be temporary. Art. 108 TFEU empowers the European Commission to monitor, review, and request that any illegal State aid be abolished, though the Council of the EU possess the power to overrule the Commission's decision under exceptional circumstances.

---

[57] Ibid.

Restrictions to the free movement of goods are, however, relatively commonplace. Policies often have an impact on the free trade of related goods, and potentially on the level playing field of competition within impacted fields, within and outside the Single Market. Restrictions on free movement of goods either on the basis of Art. 36 TFEU, regarding public interest or public health, or for *Mandatory Requirements,*[58] could be justified under the objective of environmental protection in certain cases where the EU has not yet regulated. The ECJ has in the past approved a variety of environmental measures on the basis of mandatory requirements of general interest. A prime example of policy field where certain regulation and subsidies are generally accepted is environmental protection. This includes, for instance, restricting the validity of green certificates to limited geographic areas.[59] In its broad meaning, environmental protection has been elevated as an overarching issue for the EU and extension to its Member States.[60] As such, environmental protection must be integrated horizontally into all EU policy areas, whereby the target is to reach and maintain a high level of protection.[61] Different policies can be adopted on the basis of Art. 191-193 TFEU on the level of protection, harmonization, and differentiation; also, in light of Art. 114 TFEU on ensuring a common playing field.

Exceptions to the EU's prohibition of State aid have as prerequisite that they shall not impair the well-functioning of the Single Market. The Council can decide on allowing for exceptions, for instance in cases related to the security of supply of energy in the EU and to the energy transition to renewables. As far as the Commission is concerned, it has since 2005 through its *State Aid Action Plan* put an increased emphasis on correcting market failures. Specific criteria were set up including, among others: 1) the contribution to a well-defined objective of common interest; 2) the need for state intervention to solve a situation that will not be solved by market forces alone, or address equity or cohesion concerns; 3) that such aid provides an incentive for additional action which would either not be undertaken, or not in an appropriate way, without the aid; and 4) that the instrument must be appropriate and

---

[58] ECJ Case C-120/78 - Rewe-Zentral AG

[59] ECJ Case C-573/12 - Ålands Vindkraft AB

[60] Art. 11 TFEU

[61] Art. 114(3) TFEU

proportionate to address the objective of common interest, including in its effect in relation to a potential negative impact on competition, such that the balance must remain positive.[62]

This view has especially applied to the market failure corresponding to the idea of *Carbon Leakage* mentioned in the previous section. This is the basis for some exemptions under the general Emissions Trading Scheme (ETS) and the rationale for the newly formulated and complementary and upcoming Carbon Border Adjustment Mechanism (CBAM). This is to ensure that domestic manufacturing remains competitive in a globalized business environment while gradually improving its environmental performance. Art. 107 TFEU forms the basis for the prevention of illegal State aid, though barring several categories of exceptions. These range from considerations of (non-discriminatory) social, economic development, and cultural considerations, to disaster relief and economic disturbances, to designated Important Projects of Common European Interest (IPCEI). As such, the fields of exemption are not fixed over time and can change in mutual agreement between the Commission and the Council. The pursuit of C*ommon Interest* is a major consideration in selecting additional fields of exception. As such, the existence of ETS and CBAM indicates that the discretionary powers of the Commission under Art. 107(3) TFEU are significant.

2.5. Industrial policy and the WTO

In the age of global supply chains of the twenty-first century, the Single Market does not, operate in a vacuum. Arguably one of the basic assumptions of the EU as an economic power is that its internal market gives it leverage in the international trade arena. The legal basis for the EU's Common Commercial Policy (CCP) finds its source in the TFEU. Art. 207 and 218, which give the Commission exclusive competence to conduct the CCP. This includes the initiative and mandate to conclude Preferential Trade Agreements (PTAs), either bilateral or multilateral. Modern PTAs are comprehensive and may touch on areas of non-exclusive competence of the EU. In such cases, legally each chapter needs to be reviewed individually and unanimity secured by all Member States where necessary.[63] However, the scope of the EU's commercial policy as well as its ability to exert external influence through PTAs are framed by its adherence to the World Trade Organization (WTO).

---

[62] Hettne 2020

[63] ECJ 2017

The General Agreements on Tariffs and Trade (GATT) under the hospice of the WTO has since 1947 served as guideline for the global liberalization of trade among an increasingly large number of sovereign states. The basic purpose of the GATT is to constrain governments from imposing measures that may distort international trade. The following two paragraphs summarize, in essence, the scope of GATT. Article 1 provides for the so-called *Most Favored Nation* clause which prevents discrimination between trade partners. Notable exceptions to this include free trade areas and customs unions. Article 3 introduces the *National Treatment* clause, according to which a member shall not discriminate between its own and *Like* foreign products after they enter the Single Market, for example through unfavorable tax treatments applied to the benefit of the domestically produced goods.

Article 11 bans all forms of import restraints (e.g., quotas) other than tariffs (i.e., duties, taxes, and other charges). Tariffs are not per se forbidden but the possible range of applicable tariffs is regulated under GATT rules. Tariff barriers are preferred to non-tariff barriers by the WTO because they are more obvious forms of protectionism and are thus easier to recognize and control. By contrast, non-tariff barriers can be used as a more sophisticated form of protectionism. Finally, Article 20 contains some general exceptions, which could be relevant to restrictions justified for the protection of the environment. Two categories of policies are generally accepted: to reduce consumption or risks, or to conserve certain resources. However, there is a general concern that such measures may constitute disguised restrictions on international trade.

In 1994, the dispute settlement mechanism was introduced as annex to GATT. It is composed of rules of proceedings and of an appellate body. For the ECJ, the appellate body and its decisions retain a diplomatic nature, which prevent EU law to see its compatibility judged against WTO rules.[64] However, the compatibility of EU policies related to the energy transition and environmental protection under GATT remains a relevant issue. One clear example is the EU's CBAM which is bound to apply to imports from non-EU countries, including import of hydrogen from third countries. This extension of the ETS scheme is meant to provide a non-discriminatory regulatory environment for EU producers. As such,

---

[64] ECJ, case C-377/02 - Léon Van Parys NV

a possible conflict with WTO rules compatibility is possible. Here, initial legal review has indicated that in principle, CBAM could be made compatible with GATT rules.[65]

As part of the WTO rules, the EU and in particular its CCP is also bound to the Agreement on Subsidies and Countervailing Measures (SCM) Agreement which regulates State aid, such as public subsidies. The SCM forbids a range of State aid measures akin some of the most traditional forms of industrial policy, which relate to State aid and export subsidies. The SCM agreement distinguishes between two basic categories of subsidies: those that are prohibited, and those that are actionable, i.e., subject to challenge in the WTO or to countervailing measures. Under Article 3 of the SCM Agreement, prohibited subsidies consist of two sub-categories. The first category consists of subsidies contingent, directly or indirectly, on export performance (*Export Subsidies*). The second category consists of subsidies contingent, directly or indirectly, upon the use of domestic over imported goods (*Local Content Subsidies*). These two categories of subsidies are prohibited because they are designed to directly affect trade and thus are most likely to have adverse effects on the interests of other WTO members.[66] Thus, GATT rules greatly limit the use of such policies to promote domestic manufacturing. Moreover, imposing conditionality in foreign direct investments are also generally forbidden except for least developed countries. By contrast, financial incentives, public procurement, and support of state-owned companies are in many instances acceptable.

Subsidies and local content policies are part of the classical industrial toolbox. According to Isabelle Ramdoo at ECDPM, Local Content Policy (LCPs) "*measures can be put in place to stimulate downstream linkages, notably through local value addition or beneficiation. In this case, LCPs attempt to meet two main objectives, through (i) export-oriented strategies, to develop local manufacturing capabilities and add value to unprocessed minerals and (ii) import-substitution strategies, to respond to growing local demands for processed products. Market restriction instruments include domestic sales requirements; various forms of export restrictions; licensing requirements; trade- balancing measures; and domestic and international market reserve policies*".[67] LCPs aim to distort trade and may be perceived as

---

[65] Le Blanc 2023

[66] WTO

[67] Ramdoo 2016

too discriminatory considering GATT rules. Interestingly, the SCM Agreement originally included in Article 8 a list of subsidies to be deemed *Non-Actionable,* that is, subsidies that could not be challenges in front of the WTO by third countries. This list included certain subsidies for research, environmental protection, as well as regional development. However, this provision only applied provisionally for the first five years of the SCM Agreement. It has since expired, and has not been replaced, such that today no subsidy programs are explicitly protected as non-actionable and thus in theory all targeted subsidy schemes akin to State aid could be challenged in from of the WTO.[68]

2.6. The EU and recent industrial policy developments

In summary, we can see that through its New Industrial Strategy, the EU states the clear ambition to act as developmental state in relation to its industry. This seems especially apparent since 2020 and the release of the European Green Deal, which has spearheaded a drive to actively shape domestic technological development and manufacturing. That said, EU Institutions and Member States operate in a rules-based environment which in many ways restricts the scope of the industrial policy it can conduct. This is due to internal factors (the rules of the Single Market, the interests of its Member States and other stakeholders) as well as external factors (its internal commitments, including GATT and SCM rules). Financial support schemes such as EU subsidies and State aid are major instruments of industrial policy in support of new technologies and markets. These are precisely the kinds of instruments that are regulated, when not plainly forbidden, at EU and global level. The tension is likely to be apparent when we will look closer at specific policies in support of hydrogen and carbon capture technologies in the next section.

The EU has on multiple occasions reiterated its commitment to comply with Single Market rules, WTO rules, and with the multilateral rules-based trade order. Arguably the former is fully within Member States' control, which makes it likely that some flexibility exists there. That said, the SCM Agreement is being challenged by the European Parliament and deemed obsolete, especially regarding the objectives of environmental protection and climate action.[69] The compatibility of the new waves of subsidy support for green technologies, such

---

[68] Howse 2010

[69] European Parliament 2024

as the Inflation Reduction Act (IRA) in the USA and the NZIA and other schemes in the EU, could in principle be challenged in front of the WTO. It has been shown that ETS and CBAM could be made compatible with existing rules, so in practice, there seems to be a degree of flexibility in designing compatible instruments. Here, the NZIA target of 40% is a non-binding intention that appears more as a stated ambition than a true LCP. The blocking of the appellate body since December 2019 has caused speculation about the future of the WTO as a regulating body. However, a dispute would be a source of uncertainty. Although non-binding, the 40% domestic manufacturing target in the EU's NZIA recalls a similar provision in the USA's IRA.[70] When enacted in 2022, this provision has been decried by the EU as distorting trade competition.[71] This development has raised concerns over a global race for green subsidies with the goal to attract businesses, create jobs, and gain a technological edge in the energy transition.

In recent years, a few events of significance also reinforced the role of trade as an instrument of industrial policy. Former USA President Trump introduced tariffs on steel and aluminum, which his successor President Biden kept in place. In early 2024 President Biden announced new tariffs on imported electrical vehicles from China. Meanwhile, the EU has launched a series of probes into allected anti-competitive behavior by Chinese manufacturers. This includes imports of electric vehicles and wind turbines, products which are deemed essential to the EU's energy transition to net-zero under the EGD. Depending on the outcome of the investigation, the EU could follow a similar path to the US and impose trade barriers to those imports under the form of import duties. It has been argued that these developments are symptoms of a willingness to reintroduce *Managed Trade*, i.e., using trade restrictions as a tool for industrial policy under the CCP, rather than plain political protectionism.[72]

---

[70] Allenbach-Ammann 2023

[71] European Parliament 2023

[72] Sapir 2024

3. EU strategies, rules, and instruments in support of H2 and CCS

3.1. Renewable hydrogen rules under the EGD

This section looks closely at strategies and support for hydrogen and carbon capture and storage at EU level. The *Hydrogen Strategy for a climate-neutral Europe* (Hydrogen Strategy) was unveiled in July 2020.[73] The Communication recognizes the key role of hydrogen in the energy transition and includes 20 concrete initiatives in support of hydrogen technology. The major impact of the text, as far as being a comprehensive strategy is concerned, is to see hydrogen integrated into other, existing developments and initiatives at EU level. For instance, hydrogen is to be added as dedicated fuel to the framework of Trans-European Energy Infrastructure (TEN-E) and Trans-European Transport Network (TEN-T), related to hydrogen transport infrastructure and refueling stations, respectively. The text also introduces the possibility for Member States to include hydrogen to their national Recovery and Resilience Plans under NGEU, for a total of 9.3 billion Euros. Hydrogen is also considered in the EU's Sustainable and Smart Mobility Strategy and the third recast of the Renewable Energy Directive (REDIII). All 20 action points were completed by early 2022. Arguably, the merit of this Communication was to elevate the status of hydrogen and to give it a role of primary importance across numerous fields of application of secondary EU law.

Following the 2020 Strategy, The Commission sought to clarify its ambitions and bring regulatory clarity around the concept of renewable hydrogen. First, the RePowerEU Plan was released in March 2022 against the backdrop of Russia's war in Ukraine and its weaponization of energy supplies.[74] The Plan sets a target of 10 million tons of renewable hydrogen produced within the EU by 2030. The Plan also proposes that an additional 10 million tons of renewable hydrogen be imported into the EU from third countries.

Regulatory clarity was brought for the industry by REDIII. Through a Directive and a Regulation, the Commission proposed in 2021 a definition of renewable hydrogen which is aligned with the 70% GHG reduction threshold for other renewable fuels under REDIII.[75] The texts also proposed that hydrogen network and infrastructure be governed by market-

---

[73] COM/2020/301 final

[74] COM/2022/230 final

[75] COM/2021/803 final

based regulators, much like the natural gas networks. This includes non-discrimination rules applicable for wholesale natural gas and hydrogen markets, market-based pricing and mechanisms, and regulated tariffs.[76] The two proposals are made on legal basis of Art. 194(2) as well as 114(1) TFEU, with energy being a shared competency of the EU. In essence, the EU's approach is to align rules around hydrogen to that existing for comparable substitutes, mainly for natural gas.

REDIII was enacted in late 2023 and, besides clarifying the GHG threshold for renewable hydrogen, recognizes its potential for the decarbonization of fuels and energy systems.[77] In REDIII, renewable energy projects are considered to serve "*imperative reasons of overriding public interest*". This statement encompasses climate objectives but also security of energy supply considerations. In REDIII the main target shifts from the amount of renewable fuel or energy, to the emission reduction potential of the fuel or energy. Being in the scope of REDIII means renewable hydrogen now gets its own related GHG reduction targets, through it is only applicable to the (industrial) sectors in the scope of REDIII, that is, excluding transport fuels which are covered under different regulations.

Through its Delegated Acts, REDIII also set a binding target of 42% of hydrogen (and its derivatives) used in European industry to qualify as renewable fuel of non-biological origin (RFNBO) by 2030, and 60% by 2035. This means that 42% of all hydrogen used in industry by 2030 will need to comply with the corresponding GHG reduction target and be produced from renewable energy source. The first draft REDIII released in late 2021 initially proposed a share of 50% for industry. This target was judged "*highly ambitious*" by the scientific community, even before the strict rules surrounding renewable hydrogen (e.g., additionality, temporality) were announced and considering costs of renewable hydrogen of 2-5 euros/kg, which is now seen as very optimistic.[78]

As non-binding supplements to REDIII, two delegated acts on renewable hydrogen introduced the non-legally binding definition of renewable hydrogen produced by electrolysis. The first Delegated Act confirmed the definition of renewable hydrogen as

---

[76] COM/2021/804 final

[77] EU Directive 2023/2413

[78] CE Delft 2022

meeting a threshold for emissions reduction of at least 70% compared with conventionally produced hydrogen. The definition is not a mandatory requirement but will be used as one of the criteria for obtaining public support and granting subsidies across the EU. As such, RFNBO marks the de-facto standard for renewable hydrogen within the EU. Initially the Commission proposed a higher threshold of 80%.

In addition to the GHG reduction threshold, the EU set additional requirements for the qualification of renewable hydrogen. First, there is a requirement of additionality. Renewable hydrogen needs to be produced from newly installed, rather than already existing, renewable power sources. This is to ensure that the required electricity is not simply displaced from other uses. The second criterion is that of temporal and geographic correlation. To qualify as renewable, the power required to produce hydrogen must come from a nearby region and correspond to a real-time generation of renewable electricity. This is to ensure that the hydrogen is produced from an at least equivalent amount of renewable electricity. The second Delegated Act provides a precise quantitative method for calculating the CO2 equivalent emissions embedded into RFNBOs. Emissions to be considered include direct and somewhat indirect emissions over the full life cycle of the fuel, including related to processing and transport. Certification of renewable hydrogen will be done by the so-called voluntary scheme, through third-party certification that are often already established and recognized by the Commission. There is a transitional period until 2028 before these rules will become applicable.

Finally, as proposed by the Commission in 2021, the decarbonized gas package foresees the development of a dedicated hydrogen transport infrastructure and of a competitive wholesale hydrogen market. Quantified targets include a 75% reduction in cross-border tariffs and allowing blending of natural gas pipelines with up to 5% hydrogen, thus blurring the divide between natural gas and hydrogen infrastructure. The EU also set a limit for traditional fossil-based long-term natural gas contracts to 2049. A political agreement was reached in December 2023 between The European Parliament and the Council on updated rules to decarbonize the gas market and to create a European hydrogen market. This will require new EU-wide rules and the creation of a European Network of Network Operators for Hydrogen, with a split between Transmission System Operators (TSOs) and Distribution System Operators (DSOs). This will also require the EU to clarify the definition of low-carbon hydrogen. As of the time of writing in May 2024, the legal acts are in preparation[79] and are unlikely to be finalized until the new legislative cycle is in place after the 2024 European elections. It is currently expected that an additional Delegated Act will adopt a dedicated definition for low-carbon hydrogen, also considering a 70% GHG reduction threshold.

3.2. EU-wide financial support for hydrogen

Hydrogen R&D and commercialization have enjoyed longstanding financial support from the EU under various support schemes. Hydrogen-related funding dates back from 2004 with the 5th Framework Programme (FP) for Research and Technological Development committing 145 million euros to R&D support. Funding increased to 315 million euros in the 6th FP, though funds were until then not distributed under a common program. In 2007 the European Hydrogen and Fuel Cell Technology platform was created, replaced in 2008 by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), a long-term public-private partnership (PPP). The principle of the PPP is co-participation between the EU and the private sector of at least 50%, thus creating a multiplier effect. Between 2007 and 2013, hydrogen enjoyed 470 million euros of EU funding under the 7th FP. The FCH JU PPP was extended in 2014 under Horizon 2020 with 665 million euros in funding, distributed between industrial and research initiatives. This corresponded to a shift from R&D support to commercialization support, as the EU took the initiative to co-finance several major electrolyzer projects within the Member States under the Horizon2020 framework. This is to ensure the scaling up and feasibility of hydrogen projects from lab to pilot, to full commercial scale can be demonstrated, and their learnings captured and reinvested into future projects. In 2021, FCH JU was replaced by the Clean Hydrogen Partnership, with total allocated funding of 1 billion euros for the period until 2027. In total the EU has allocated 2.6 billion euros in direct R&D funding for hydrogen technologies over nearly two decades, gradually increasing the allocated funds and making use of the co-financing lever to increase the effects of those investments. **Figure 6** shows the ramping up of EU-wide R&D funding support for hydrogen over time.

---

[79] Updates of the Gas Directive 2009/73/EC and Gas Regulation (EC) No 715/2009

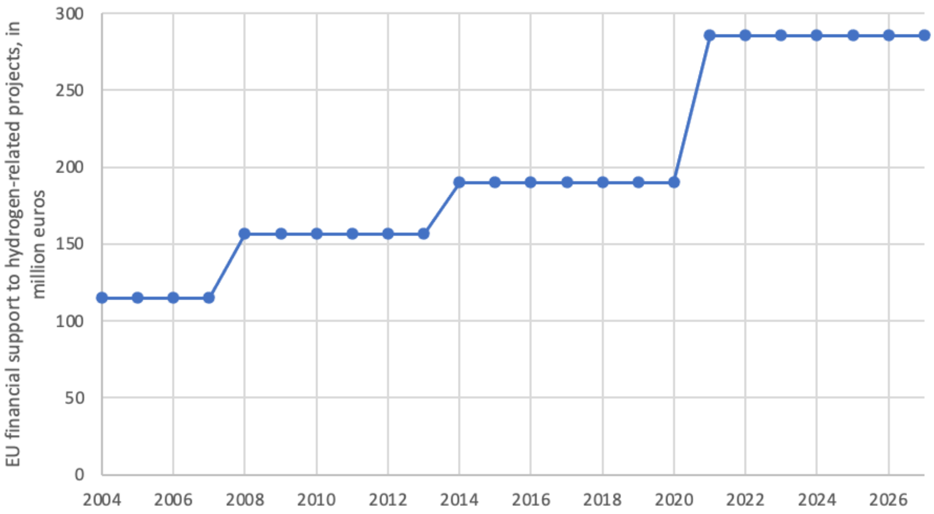


Figure 6. EU hydrogen-related funding for the period 2004-2027, including co-financing. Source: author compilation of figures made available by the Clear Hydrogen Partnership.[80]

The above shows that despite the seemingly recent momentum created by the European Green Deal, hydrogen has enjoyed continued and increasing development support for more than two decades. In addition, hydrogen was included in the scope of the more recent *Innovation Fund* scheme, with 12 out of 39 selected projects (30%) out of its first call for proposals related to hydrogen technologies. Launched in 2020, the Innovation Fund is a technology neutral scheme which aims to support the deployment of large decarbonization projects.[81] The Fund is financed from the proceeds of the ETS, the EU's carbon tax. Most recently, its third call for proposal in 2023 totaled requests for financing of 18 billion euros, corresponding to an abatement potential of 2.4 billion tons of CO2 equivalent over the lifetime of these projects, or 85% of total annual CO2 emissions inside the EU. 71 projects out of 239 submitted were linked to electrification of energy sources, to hydrogen, or a combination of both. With an annual budget of 3 billion euros which is dependent on the amount of ETS tax collected, the selection process is stringent and so are the administrative eligibility criteria set by the EU.

In 2020, The Hydrogen Strategy announced a pilot carbon contracts for difference (CCFD) program specifically to support the production of renewable hydrogen. The EU has since introduced its own dedicated reversed auction funding mechanism, dubbed the *Hydrogen*

---

[80] Clean Hydrogen Partnership

[81] https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/what-innovation-fund_en

Bank. The Bank aims to cover increased operational costs of renewable hydrogen. In April 2024, the European Commission awarded nearly €720 million to seven renewable hydrogen projects in Europe, selected through the first competitive bidding process under the European Hydrogen Bank. Subsidy rules under the Hydrogen Bank remain to be fully clarified, regarding for instance stacking rules, that is, the possibility for projects to cumulate EU as well as State aid support (covered in more details in the next section). Moreover, in case of renewable hydrogen production using intermittent renewable power, the subsidy would only cover the share of hydrogen effectively produced during intermittence, consistent with the temporal correlation rule for renewable hydrogen under the Delegated Act.[82]

As a final remark, it is important to note that support for hydrogen has also been increasingly considered as part of the EU's regional and cohesion policy. For instance, the EU launched its Hydrogen Valley initiative, promoting interregional cooperation in the development of hydrogen infrastructure and networks. The initiative supported two rounds of Hydrogen Valley partnerships encouraging cross-regional cooperation. Hydrogen was also included as part of the Eastern Partnership with European neighbors. The EU is also directly active in various international fora in an effort to harmonize the definitions and standards applicable to hydrogen and trigger developments at global scale.

3.3. Carbon capture and storage

Carbon capture and storage is presented as an intermediate step in the EU's overall push to a net-zero society. Carbon capture technology is seen as particularly suitable to decarbonize cement, steel, and power plants, for which no renewable alternative is currently available at scale or foreseen to be technologically ready in the near future. Like for hydrogen support, carbon capture is not a new topic of discussion at EU level and some legal basis was already available prior to the EGD. The 2009 CCS Directive provides a legal framework for the transport and geological storage of CO2.[83] When combined with the ETS Directive, the CCS Directive provides an incentive for the exploration of carbon capture and storage as industrial solution by putting a price on industrial CO2 emissions. Interestingly, the entire EEA is covered which includes Norway, the territory of many geological structures able to

---

[82] Hydrogen Insight 2023a

[83] Directive 2009/31/EC

sequestrate CO2 in the North Sea area. Brexit certainly prevented the EU from easily accessing the geological storage sites that are under UK jurisdiction, thus increasing reliance on Norway for large-scale CCS projects in North-western Europe.

In parallel to carbon capture and storage, carbon capture and utilization is regulated by a 2018 Directive which aims to promote synthetic fuels made from captured CO2.[84] In addition, a Delegated Act establishes a minimum threshold for GHG emissions savings of recycled carbon fuels, and specifies a methodology for assessing emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels.[85] As such, carbon capture represents a technological step towards producing other types of synthetic fuels, commonly referred to as *E-fuels*.

Following the publication of the EGD, the Commission published three communications relevant to carbon capture and storage. The *Communication on Sustainable Carbon Cycles* was released in 2021.[86] The text makes 15 mentions of CCS and includes actions to support industrial carbon capture for deployment until 2030. The document also recognizes the role of alternatives technologies such as DAC and the potentially negative emissions from capture of biogenic CO2. An emissions and accounting reporting scheme is to be completed by 2028. The Directive also sets the target of 5 million tons of CO2 removed annually via CCS technologies in flagship projects, and unveils other actions, such as the creation of a CCUS forum, the continued inclusion of carbon capture technologies in the Horizon Europe and Innovation Fund subsidy frameworks.

In 2022, a second Communication unveiled a proposal for a voluntary framework for the certification of carbon removals, under the form of a Regulation.[87] The legal basis is Art. 192(1) TFEU on environmental policy. The text, as proposed by the Commission, would set a certification framework on the basis of four criteria: 1) quantification, 2) additionality and baselines, 3) long-term storage, and 4) sustainability. This is to prevent the risk of either multiple count of the same carbon emissions, as well as the count of emissions whose

---

[84] Directive 2018/2001

[85] Delegated Regulation 2023/1185

[86] COM/2021/800 final

[87] COM/2022/672 final

removal does not in fact contribute to fighting climate change, for example because their storage cannot be considered *Permanent* or because their removal does not reduce the absolute amount of CO2 in the atmosphere (e.g., if they come additionally from new projects). A provisional agreement on the text was reached on 20 February 2024.

Finally, the *Industrial Carbon Management Strategy* was published by the Commission in February 2024.[88] The Communication recognizes the gap between the expected availability of renewable energy and the total demand for energy in the EU. The gap to reach the EU's climate objectives is 280 million tons of CO2 by 2040 and 450 million tons by 2050. In the EU's own words, carbon capture and storage projects will play a major role to close that gap, with the ambition to have 50 million tons CO2 annual capture and storage capacity by 2030. This is a ten-fold increase over the 2021 target. The document also acknowledges the role of DAC and biogenic CCS as resulting in negative emissions. These would need to account for half of the total CO2 removal effort. According to the Commission's forecast, already 10 million tons of carbon capture and storage capacity are on track to being installed by 2027, thanks to support from the Innovation Fund. Moreover, National energy and climate plans (NECPs) already pledge more than 30 million tons worth of capture capacity by 2030. By 2025 the Commission expects that some segments (such as cement) would become "*mature enough and sufficient competition may be expected to move from project-based grant support to market-based funding mechanisms*"[89]. The Commission foresees national support from the Innovation Fund through auctions, which would select the most competitive projects throughout the entire EEA area, similar to what is being done as support for hydrogen with the Hydrogen Bank.

3.4. Two Separate yet interdependent development paths

The EU's current ambition regarding carbon capture and storage is summarized as follows: "*Achieving this vision of a well-functioning and competitive market for captured CO2 requires partnership with industry and Member States, and resources to develop a coherent policy framework that provides regulatory certainty and incentives for investments in carbon capture, storage, use and carbon removals. They are technologies indispensable to achieve*

---

[88] COM/2024/62 final

[89] Ibid.

climate neutrality and to underpin efficient infrastructure investments in transport and storage infrastructure."[90] It appears the EU is set to go beyond the existing ETS and upcoming CBAM, and intends for European actors to build a market for CO2 accompanied with dedicated physical transport and handling infrastructure.

Here, the Communication also recognizes the following four difficulties, from an industrial standpoint, which it hopes to address in order to enable the scaling up of CCS. First, private sector business cases for carbon capture are dependent on future CO2 prices, require significant upfront investments, and are dependent on market supply and demand. Second, there is a lack of comprehensive regulatory framework for carbon removals and certain CO2 uses. Third, the sector suffers from insufficient cross-border coordination and planning which limits the potential of CCS to serve as large-scale industrial carbon management solution. Fourth, the sector lacks sufficient incentives for early investments proving the soundness of carbon capture in a commercial setting.

The Strategy foresees a stepwise deployment of dedicated infrastructure, initially starting with lowest cost solutions in terms of capture of the CO2, transport to shore, and shipping to offshore geological storages. The Commission also foresees some CCU applications for the captured CO2, for instance reused to make synthetic fuels (E-fuels) that could replace fossil-based fuels in the aviation, maritime, and heavy-duty sectors. In a second stage, the infrastructure would expand to less favorable locations and processes, as economies of scale lower costs, and, hypothetically, as the price of CO2 under the ETS is expected to increase. The Commission recognizes the scale of investments necessary to build a well-functioning physical CO2 removal market, with capital investment needs of over 12 billion euros and 7000 km of pipelines in place by 2030, rising to 16 billion euros and 19000 km by 2040. Actions for 2024 include a potential CO2 transport regulatory package, a coordinated infrastructure planning including public and private actors, adapt the ETS to consider CO2 transport. Further actions by early 2026 would include a platform matching supply and demand, a mapping of potential CCS sites, a knowledge sharing platform, guidance for perm The EU acknowledges that several member states (Denmark and the Netherlands) already have national subsidy schemes in place for industrial, large-scale CCS. They also included

---

[90] Ibid.

CCS technology in their national Recovery and Resilience plans. The EU aims to learn from these pioneering member states and for Member States to include CCS in their own NECPs.

Furthermore, the Commission wishes to establish an *Enabling Environment* for industrial carbon management. On the state of development, projects amounting to more than 100 million tons of transported CO2 are already planned by firms in the EU within the cross-border TEN-E energy network framework. However, the CCUS forum brought forward an estimated additional investment need of around 10 billion euros by 2030, which would compensate the absence of a well-functioning carbon removal market. Looking back, the Innovation Fund has already contributed 3.3 billion in grants for CCS and CCU projects. The Connecting Europe Facility (CEF) has itself granted a further 0.7 billion euros. Looking forward, the European Investment Bank (EIB) has 45 billion euros available in loans in support of the Net-Zero Plan, including for CCS. Specifically for CCS, the ETS scheme will also serve as incentive to justify the industry's individual business cases and commercial setup.

In terms of support, in addition to Horizon Europe and the Innovation Fund, the CEF funds cross-border infrastructure projects including CCS transport capacity in both the TEN-E and TEN-T plans. To close the gap, carbon contracts for differences (CCFDs) enabled and financed at national are seen as a viable option. They de-risk the financial aspect of projects by covering for additional costs of a new technology versus established alternatives. Finally, a future IPCEI on carbon capture is envisaged depending on the outcome of the dedicated process to select IPCEIs, the Joint European Forum. In short, the EU is now replicating for carbon capture and storage the approach it has also taken in parallel for hydrogen.

Regarding low-carbon hydrogen, which is essentially fossil-based hydrogen by which the CO2 emitted during reforming has been captured and sequestrated, the Commission's 2021 proposal for a Directive on common rules for the internal markets in renewable and natural gases and in hydrogen recognizes that "*renewable hydrogen production is not likely to scale fast enough to meet the expected growth in demand for hydrogen in the Union. Therefore, low-carbon fuels ('LCFs'), such as low-carbon hydrogen ('LCH'), may play a role in the energy transition in line with the Union's climate targets, particularly in the short and medium term to rapidly reduce emissions of existing fuels, and support the transition of the Union's customers in hard-to-decarbonise sectors in which more energy or cost-efficient* *options are not available*".[91] Moreover, the 2024 Communication on Industrial Carbon Management makes 7 mentions of the word hydrogen. In that Communication, the Commission recognizes the potential *Interactions* and S*ynergies* between CCS and low-carbon hydrogen. However, the document, while recognizing the interdependency between the two technologies, falls short of adopting a joint approach or linking (renewable and/or low-carbon) hydrogen and carbon capture and storage from a more strategic standpoint.

3.5. The growing importance of State aid support

As we have seen, specifically regarding hydrogen and carbon capture and storage, the EU has gradually scaled up its investment subsidies, such that today the EU has dedicated large funds to supports the additional costs both for H2-related capital investments (e.g., through the ETS-funded Innovation Fund) and operational expenditures (e.g., through the reversed auction Hydrogen Bank).[92] In addition, in March 2023 the European Commission also unveiled the State aid Temporary Crisis and Transition Framework, giving way for Member States to provide additional national support measures in sectors which are key for the transition to a net-zero economy, in line with the Green Deal Industrial Plan.

Before that, the EU already strengthened its proactive use of State aid to enhance domestic competitiveness and shaping infrastructure and innovation projects through the criteria defined in its Important Projects of Common European Interest (IPCEI) Communication in 2021, though IPCEIs were initially launched in 2018. Calls for Projects of Common Interests (PCIs) have been launched every two years since 2013.[93] A criterion for the selection of PCIs is that they must improve the EU's security of energy supply, which has been a longstanding challenge even prior 2022. PCIs benefit from faster and more efficient permit granting procedures, improved regulatory treatment and possible access to financial support under the CEF. In 2020 the regulation regarding TEN-E was overhauled, introducing a new set of criteria.

---

[91] COM/2021/803 final

[92] Norton Rose Fulbright 2024

[93] European Commission 2024d

As seen in the previous section, carbon capture has enjoyed longstanding status as technological hope for decarbonization. Early PCIs related to carbon capture and storage date back before the European Green Deal. Between 2018 and 2021 eight cross-border CCS-related PCIs on cross-border energy infrastructure (Porthos, Athos, Aramis, Northern Lights, etc.) were proposed for funding under the CEF. These projects are designed in already oversized forms in order to enable long-term growth, anticipating a full-fledged CO2 transport infrastructure in the future.[94] Of these PCIs, three received funding from the CEF, for a total amount of around 120 million euros. Between 2014 and 2020, 107 projects have benefited from the CEF, for a total of 4.7 billion euros in total. In 2023, 14 CCS projects were again selected for the 6th round of PCIs, some repeating from the previous call (also from the 4th call). Upon proposal by the Commission, the European Parliament and the Council are tasked with adopting or rejecting the call. The sixth round also includes 65 hydrogen projects out of the 179 hydrogen projects submitted, and out of the 166 projects selected in total, a share of 39%.

PCI support for hydrogen tends to be more recent. Since 2020, hydrogen is supported by three separate IPCEIs, an unprecedented number for a single technology. Combined, these IPCEIs allow for direct state support of up to 17 billion euros and are expected to trigger 21 billion euros additional investments from the private sector. As of May 2024, a fourth IPCEI covering hydrogen has been unveiled. Among Member States, Germany is leading the way with a comprehensive support plan announced in February 2024. The plan involves replacing or converting fossil-fired power plants with hydrogen technology, with up to of 16 billion euros in financial support to achieve it. For Germany this serves a double objective of helping the country meet its climate commitments (through the decommissioning of coal-fired plants) but also of strengthening the country's energy autonomy (through the replacement of natural gas by a combination of renewables and hydrogen).

Finally, recognizing that renewable hydrogen incurs additional costs and technological risk for the industry, the 2020 Hydrogen Strategy foresaw additional financial needs and related instruments to support the shift from fossil-based to renewable-based hydrogen for industrial uses, such as and chemicals and steel. The 2023 revision of the ETS now includes the option

---

[94] European Commission 2021

to introduce national CCFD schemes under national State aid rules. The rationale is that "*carbon contracts for difference for renewable and low-carbon hydrogen could provide initial support for early deployment in various sectors until they have become sufficiently mature and cost-competitive in their own right. For renewable hydrogen, direct market-based support schemes and quotas could also be considered. This should allow to kick-start a hydrogen ecosystem of significant scale throughout the EU in the coming decade and towards full commercial deployment afterwards*"[95]. Here, the Commission recognizes that a stepwise approach with low-carbon hydrogen may be needed to reach full-fledged technological development, and that covering cost increases via Member State-driven CCFDs, are an important part of the support needed to achieve this. This demonstrates a willingness to have Member States cover a complementary part of the support for these technologies.

3.6. The EU as a developmental actor shaping new markets

The EU has placed an increasing amount of resources and policy focus on renewable hydrogen especially since the release of the European Green Deal. In the span of four years, multiple strategies have been formulated and the EU has provided not only for a general direction on strategic development, but also for the broad conditions enabling new hydrogen and CO2 markets to be formed. In less than five years, a complete regulatory framework around the production of renewable hydrogen and the transport of hydrogen has been designed and is being implemented. It appears the same will follow regarding industrial carbon management and low-carbon hydrogen. Regarding the overall approach, the EU has adopted a balanced mix of political announcements, adaptation and creation of a regulatory environment, and expansion of a wide range of financial support schemes. Some of the announced targets, such as yearly hydrogen production and CO2 capture, do not form a part of the traditional industrial policy toolbox, in the sense that they are neither *per se* export-oriented targets nor equivalent to import or export quotas. As such, the strategies regarding production of hydrogen and sequestration of CO2 do not fall directly under the classical trade-oriented industrial policy framework.

---

[95] COM/2020/301 final

The effect of these announcements on industry are debatable and will be looked into more details in the next section. They do, however, have the merit to provide a strong message of support for the scaling up of technologies. Besides climate objectives under the European Green Deal, there is a clear concern over energy security which doubly justifies the sense of urgency shared by the EU. In this area of technological development, there is no doubt that the EU does not want to wait for markets to form organically, and intends to act as Developmental State. In addition to this, increasingly large financial support, both from the EU budget and through relaxing State aid rules, is being made available in support of hydrogen and carbon capture. Most of these schemes are not new but have enjoyed renewed support, while new schemes such as the Hydrogen Bank have been introduced in order to address specific aspects of this technological context. In the latter case, the intention is to de-risk the financials of the more ambitious projects and to provide support for the early adoption of more costly technical solutions. Far from acting as full-fledged Entrepreneur of last resort, there is a clearly stated intention to support industry in early phases of technological scale up and market formation.

The EU's hydrogen strategy appears to be the correct one, insofar as it aims to gradually scale supply and demand for renewable hydrogen and carbon capture and storage into fully functioning markets where Single Market competition rules and EU-wide harmonization and regulation approaches would eventually apply. This is done in a tailored step-wise manner. First, the EU supports pilot projects to test technical feasibility and facilitate learnings. When the technology is proven commercially feasible, flagship initiatives are co-financed. This is done in a competitive grant support based on merit. The necessary market-based regulatory framework is established in parallel. Finally, when the market has reached beyond infant state, the EU gradually move away from grant-based support, both from EU budget and from Member State aid, then to market-based mechanisms operating under harmonized EU rules.

Through ambitious public initiatives, it appears that both the EU and Member States go beyond the setting of objectives to be reached and are increasingly adopting technology-specific policies. This is akin the traditional dilemma of *Picking Winners* through vertical, firm-level industrial policy. On the one hand, such policy is intended to bring clarity and speed because it allows the rapid scaling up of infrastructure (e.g., pipeline network for hydrogen transport, large-scale electrolyzer manufacturing) and the enjoyment of the economies of scale. On the other hand, this is a risky strategy that may result an inefficient use of resources (public funds) to meet targets that could have been achieved through different technologies, or worse, fail to deliver on the expected technological improvements which are a prerequisite to the EU maintaining its competitive position as a guarantor of future economic growth. The EU's various financial support programs have through various instruments supported numerous research or pilot projects over the past twenty years. With the advent of the EGD, the EU's approach has shifted from technological support of early-stage technologies to an industrial policy attempt at wide-scale market creation. As such, we can speak about both a paradigm shifts in the role the EU sees hydrogen in the energy transition, but also how the EU sees itself as a developmental actor in shaping new technologies and markets.

4. The European H2 and CCS industry today

4.1. The legal and regulatory momentum of the EGD

This section aims to analyze the industry's reaction to the EU's policy output under the European Green Deal. We start with putting EGD regulations, as described in the previous section, in their chronological context. We have seen that hydrogen and carbon capture technologies have enjoyed longstanding financial support. Regarding carbon capture, the regulatory framework dates back from the 2009 CCS Directive, together with other pieces of legislation, such as the Environmental Impact Assessment Directive or the Industrial Emissions Directive. Hydrogen R&D has been supported for two decades and the EU has gradually increased efforts to promote the technology at scale, first through demonstration projects, later through value-chain-based initiatives such as Hydrogen Valleys.

However, the acceleration of policy outlook since 2020 must be acknowledged and emphasized. In just four years – one legislative cycle – between the release of the EGD and the time of writing of this paper, hydrogen has been promoted to the status of Net-Zero technology. The regulatory framework surrounding hydrogen has been clarified, from definitions to the harmonization of European infrastructure, to market-based transactions. Opportunities to receive funding support have also flourished, with the introduction of new support schemes such as the Hydrogen Bank. All this activity must be visible as far as the place of hydrogen and carbon capture in the EU's policy output. **Figure 7** gives an overview of the quantitative policy output related to hydrogen and carbon as expressed as a share of all EU-produced documents, and looking specifically at EU legal acts. Moreover, **Annex 2** provides additional figures specifically related to sub-categories of hydrogen, such as the occurrence of “renewable hydrogen” across all EU legal acts over time.

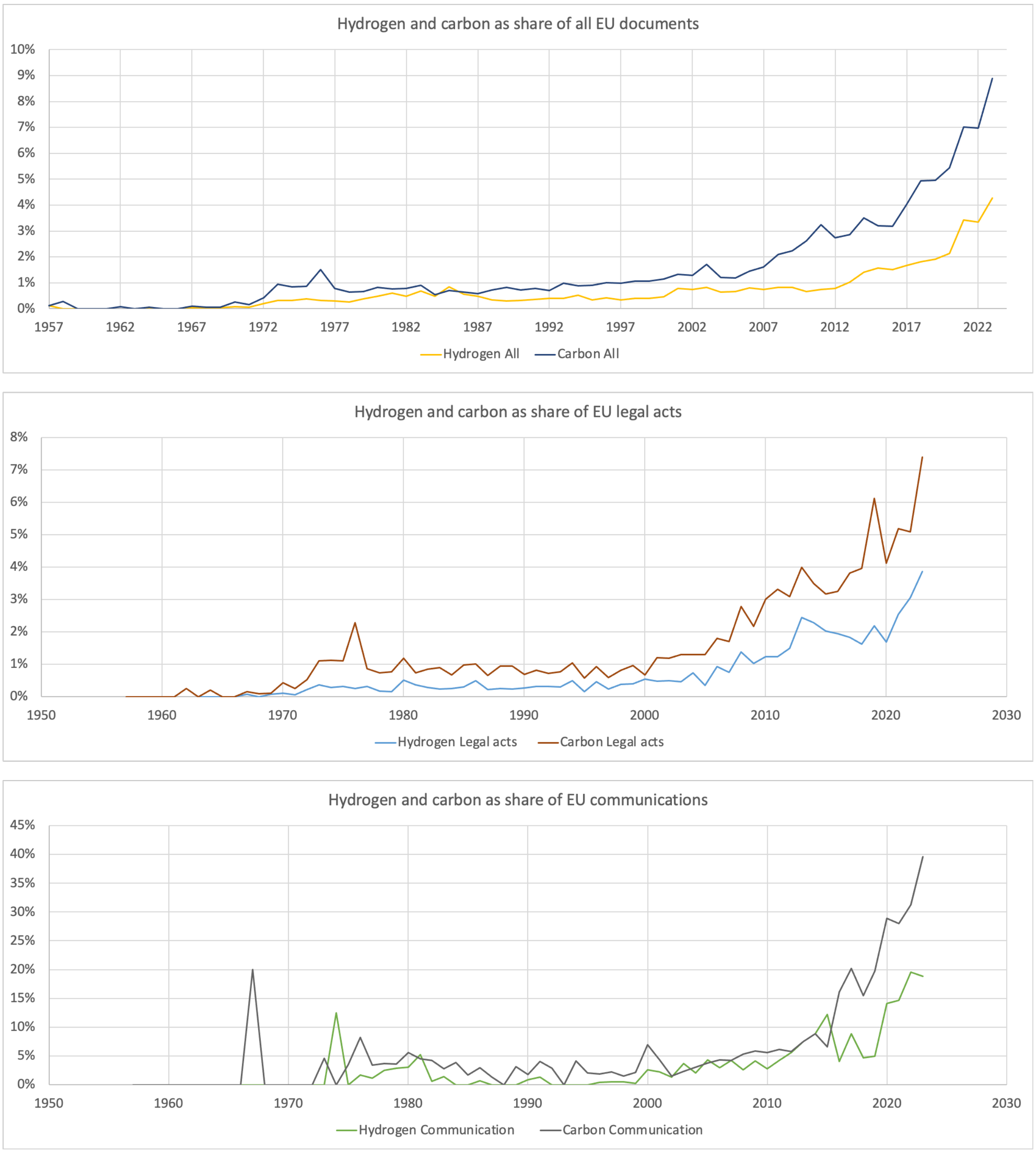


Figure 7. Occurrence of “hydrogen” and “carbon” terms as a share of all EU documents, EU legal acts, and EU communications. Source: compiled by the author from EUR-Lex.

The data shows that “hydrogen” was referenced in nearly 9% of all documents generated by the EU in 2023, up from 5% in 2019 and from around 1% in the period until 2005. The term “carbon” follows a similar pattern, albeit at a level around half of that of hydrogen.

Regarding communications, it is startling to see that 2023 saw a record 40% of all published communications contain the term hydrogen, twice the rate of for carbon. Overall, the past 18 years has seen a dramatic yet gradual increase in the reference to hydrogen across a range of EU documents. Of course, this includes all hydrogen-related references including, for instance, hydrogenation in foods, which is not related to the fight against climate change. Here, data found in **Annex 2** provides a more granular view, which overwhelmingly confirms the acceleration in pace after 2020. That said, an uptick around the year 2005, as well as further acceleration over the past two legislative cycles over the periods 2014-2019 and 2019-2024, must also be recognized as enabling efforts predating the EGD.

Despite having gained an all-star status under the European Green Deal, there is confirmation that recent policy developments around hydrogen have been the product of a longstanding effort to promote the two technologies, culminating in a large number of legal acts to be enacted in the period after 2020. However, there is no doubt that the recent policy momentum around hydrogen is unprecedented. For the first time, a large share of the policy output is under the form of secondary EU legislation. The term search also reveals that different sub-technologies or labels (such as renewable hydrogen or low-carbon hydrogen) move at somewhat different paces. While is too early to draw conclusions whether one label will outpace the other, the trend around recent EU policy activity appears to encompass multiple policy areas related to hydrogen and carbon capture.

Data on the importance of hydrogen for the EU clearly shows a change of position and pace since the EGD was announced in early 2020. There is clearly a *Before-EGD* and *After-EGD* momentum for hydrogen although it can be argued from the chronological trend that hydrogen-related regulation was several years in the making at the time the EGD was unveiled. This is consistent with the gradual ramp up of hydrogen subsidies as shown in the previous section. For the European hydrogen industry and from a policymaker's perspective, though efforts to promote hydrogen existed before that. This is for instance visible through the FCH-JU partnership which dates back from the formation of a *High-Level Group on Hydrogen* as early as 2002 and gradually grew in importance over the years. Nevertheless, the European Green Deal has brought hydrogen technologies and to a smaller extent carbon capture on a different level of ambition.

4.2. The state of European renewable hydrogen industry

With all the political declarations and EU policy instruments, one would expect the actors of renewable hydrogen production to thrive under the European Green Deal. After all, there has never been as much regulatory certainty and funding support around hydrogen and carbon capture than today. This is certainly true for hydrogen where continued support as well as key pieces of legislation (e.g., definition of renewable hydrogen as RFNBO, REDIII targets, CBAM covering hydrogen, Hydrogen Bank) aim to provide a clear outlook for the industry to invest. Moreover, as NZIA will require that 40% of hydrogen production assets be manufactured in the EU by 2030, we would expect a clear ramping up of domestic renewables production capacity including hydrogen, mainly under the form of electrolysis plants. This should trigger new technology-focused electrolyzer companies to emerge, existing players to find themselves in a strong position, final investment decisions regarding electrolyzer to be made, and new projects to be announced. Industrial policy seeks a certain degree of alignment between policymakers and private actors.

Select data in **Figure 7** and **Figure 8** show a somewhat more contrasted picture. The data does not aim to provide a complete overview of the competitive environment and current state of hydrogen-related technology manufacturing within the EU. That said, we take the market capital (number of shares time traded share price) of public listed companies involved in the energy transition as a basis for evaluating their health and the strength of their business. According to the net present value model, the market capitalization of a company is related (after removing the effect of any liabilities on the enterprise value) to the sum of its expected future earnings. The sum of future earnings, in turn, is a testament to the dynamism of the business activity that these companies are involved in, as evaluated by investors trading in the stock market. As seen in the section on industrial policy, rent seeking under the form of (expected) profits is often a prerequisite to, and enabler of, capital investments in manufacturing capacity. For this exercise, we considered a selection of companies further described in **Annex 4** and split into three core operating segments: oil and gas, renewables, and renewable hydrogen. The *Oil and Gas* segment represents conventional oil and gas majors who see in the energy transition a threat in their core business models of fossil energy extraction, refining, and distribution. The *Renewable Energy* segment represents large companies whose core business is related to the production of renewable energy, such as solar and wind. The *Pure Hydrogen* segment represents specialized companies, typically

SMEs, whose primary focus is to develop technology and manufacturing of renewable hydrogen-related production assets (electrolyzers). For these hydrogen players, a distinction is made between actors based inside and outside the EEA.

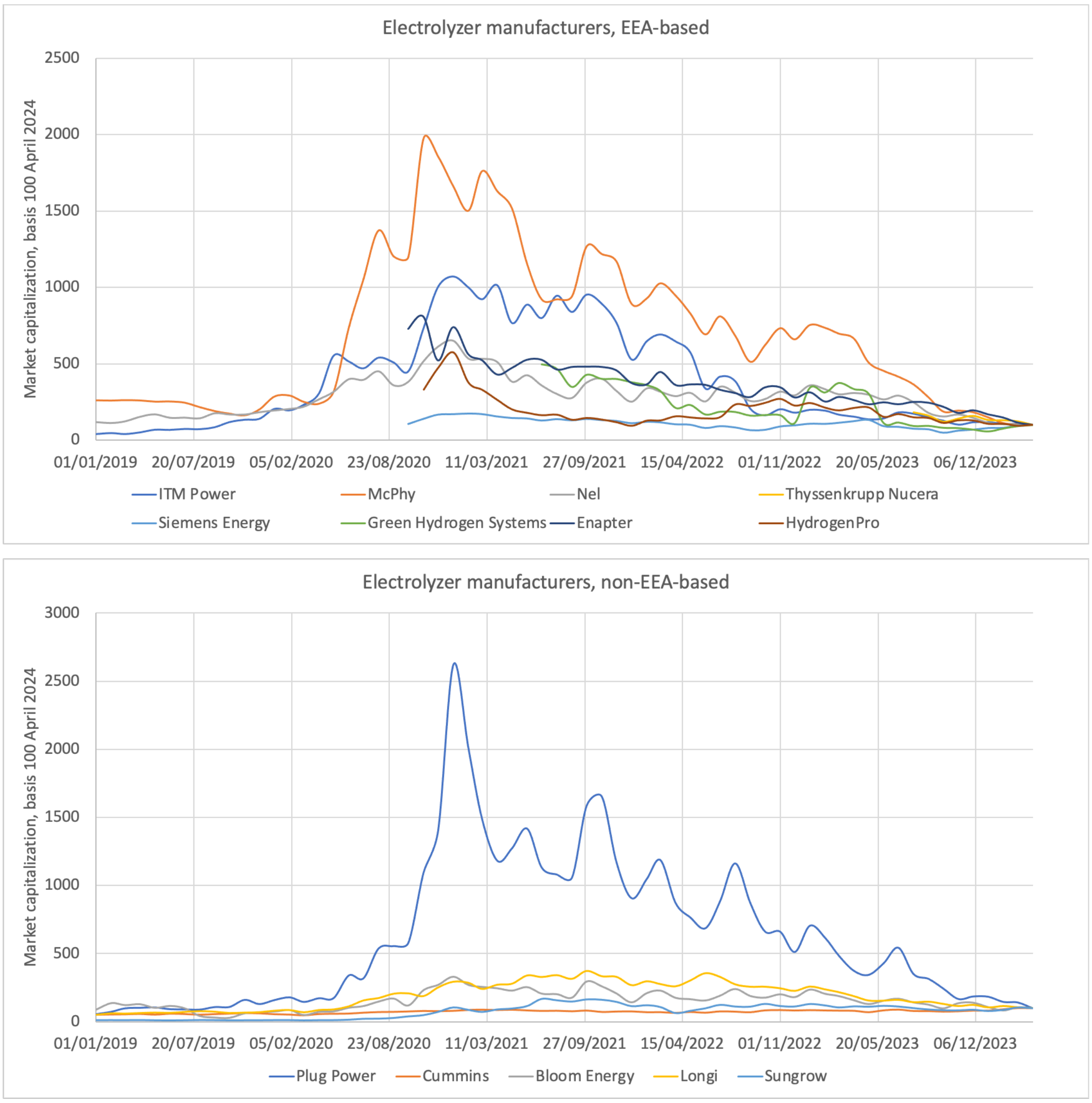


Figure 7. Market capitalization of European and non-European electrolyzer manufacturers. These represent the *Pure Hydrogen* actors among selected companies involved in the energy transition.

As **Figure 7** shows, market momentum around renewable hydrogen (as shown by increases in market capitalization of Pure Hydrogen players) started around mid-2020, with a peak in early 2021. Among public listed electrolyzer manufacturers, those with longstanding presence on the stock exchange saw their share price soar throughout 2020. Moreover, several Initial Public Offerings (IPOs) took place in 2021. Of the SMEs undergoing IPO during the period following the announcement of the EGD, early 2021 seems to have been the best moment to get listed. The reality, however, is that after reaching a peak in early 2021, the share price of most European electrolyzer manufacturers has fallen by more than 80% over the past three years.

This observation on the apparent congruence between the release of the EGD and of the New Industrial Strategy in early 2020, and the market reaction regarding EEA-based electrolyzer manufacturers bears the question of causality. To assess such causality, we also take a look at non-EEA-based electrolyzer manufacturers. One assumption is that the New Industrial Strategy and the EGD would strengthen the position of European electrolyzer manufacturers comparative to that of non-European electrolyzer manufacturers. This is because industrial policy under the form of financial support and other incentives to scale up domestic manufacturing should favor companies with an overall presence in that geography thanks to comparative advantage (existing manufacturing capacity, better access to funding, etc.). The data does not generally validate this hypothesis. Both EEA-based and non-EEA-based electrolyzer manufacturers underwent a similar share price drop from around 2021, though the majority of non-EEA companies tended to fare better. That said, we notice that individual companies, both inside and outside Europe, saw their share price soar up to 200 times their April 2024 level. It can be questioned whether this level of sensitivity has a concrete microeconomic rationale, or whether this is the sign of a *Hype* or a *Bubble* among investors and financial analysts.

The release of the Green Deal Industrial Plan in February 2023, with its explicit support of domestic manufacturing of hydrogen technologies, should have provided a boost of confidence for European manufacturers. Similarly, the announcement of the IRA in August 2022 in the USA should have had a similar effect. This assumption is also not evidenced by market data of public listed companies. As of April 2024, and despite multiple support schemes announced in the EU and the USA (and, presumably, other advanced economies as well) over the past four years, market capitalizations were back at similar or below the levels they were prior to the announcement of the EGD, the New Industrial Strategy, and the IRA.

Figure 8. Market capitalization of European oil and gas and renewable energy companies. These represent the *Oil and Gas* and *Renewable Energy* actors among selected companies involved in the energy transition, respectively.

Figure 8 shows that some *Renewable Energy* companies underwent a somewhat similar, albeit muted, trend, of increase followed by a decrease, though not all actors were sensitive to this. By contrast, Oil and Gas majors show a markedly different patterns, with a through in late 2020 followed by a steady recovery up until now. In short, most renewable energy companies and oil and gas majors are doing as well or better than they did prior to the announcement of the European Green Deal. For these companies, one explanation for the trend of the past four years is that market expectations, especially around oil and gas, are related to the state of the global economy. As the Covid-19 pandemic kicked in early 2020, economic activity slowed down and so did the overall demand for (fossil) energy. From 2021 onwards, as the global economy picked up, oil and gas majors recovered at the same time as the price of oil soared. It is interesting to note that for several of these companies, the recovery of the past three years brought their valuation at or slightly above their 2019 levels. For Renewable Energy companies, one factor that significantly affected their operations, at least in Europe, is the supply chain limitations and inflation that followed the recovery from the Covid-19 pandemic. This, more than any investor hype, could be due to the factors that significantly affected the operations of manufacturing companies post Covid-19 recovery, namely supply chain limitations, inflation, and higher interest rates. Interestingly, the European energy crisis of 2022 and 2023 did not seem to durably affect the upward trend in market valuation for any of these segments.

Indeed, following the pandemic, increases in input material costs had a dramatic effect on the capital costs needed to build renewable energy assets such as windmills and solar panels. Renewable energy projects and hydrogen projects are especially sensitive to interest rates.[96] For companies, higher interest rates increase the cost of debt which causes an additional financial hurdle for projects whose returns are already uncertain. For investors, higher interest rates put these projects in competition with other sources of returns, such as risk-free government debt. As a result, private projects need to show increased returns in order to attract capital, and less capital is available for the private sector as a whole. As the cost of manufacturing and construction soared, these became less competitive and triggered markets to revise their expectations. However, it is relevant to note that several of the selected Renewable Energy companies have diversified operations which includes operating fossil-based production assets. They also often have geographically diversified operations. Thus, it is difficult to pinpoint a single effect other than noticing that the Renewable Energy players did not experience volatility at the scale seen for companies operating in the sphere of renewable hydrogen.

4.3. Status of flagship renewable hydrogen projects

This section builds upon the previous one and zooms in closer at the status of individual renewable hydrogen projects. Over the past years a flurry of large projects has been

---

[96] Martin et al. 2024

announced within the EU. As part of the Hydrogen Strategy as well as the New European Industrial Strategy, a *Clean Hydrogen Alliance* was lunched in 2020. The Alliance gathers various stakeholder from public and private sectors across the entire hydrogen value chain. Among other initiatives, the Alliance reported a pipeline of more than 800 active hydrogen-related projects spread across the EEA.

Despite this dynamism, as of 2022, the pipeline of announced projects would only fulfil around 30% of EU production targets.[97] Projects range from small demonstration projects regarding a specific technology, to large, multi-million projects involving years of engineering and construction. This section does not aim to be complete as far as the status of individual projects is concerned, as this would be a study on its own. However, there is value in summarizing some of the announcements that were made in press releases around the year leading to the first quarter of 2024, in the period since hydrogen regulations and support schemes were unveiled or confirmed by the EU. These announcements give a taste of some of the challenges that the industry faces, and of some of the claims the industry makes in relation to hydrogen and carbon capture. The focus is on the largest projects, as these are of a *Flagship*-type nature, more communicated upon and often the visible signs of wider underlying trends.

An interesting case study is that of Uniper. In April 2024, Uniper, a leading power producing company, announced that its 500 MW electrolyzer project in the Rotterdam harbor (H2Maasvlakte), probably one of the largest electrolyzer project ever announced inside the EU, would be delayed until the end of the decade. Uniper's initial plan was for a gradual scale up in steps of 100 MW. The project was initially on track to see the first 100 MW piece commissioned by end of 2026. Now, as announced in April 2024, full production is only envisaged by 2030. As a matter of significance, the company is also returning the already awarded EU funds.

Uniper cites several reasons behind the decision to delay their flagship electrolyzer project and scaling down of their renewable hydrogen ambitions.[98] Among the cited reasons for the delay is that Uniper failed to secure a long-term Power Purchase Agreement (PPA) for

---

[97] Deloitte 2022

[98] Hydrogen Insight 2024i

renewable energy. The company claims that there is not enough offshore wind available until 2028 at earliest. As per new EU regulation, the produced hydrogen would not be renewable without temporal and geographic correlations with renewable energy production, nor would it fulfil the criterion of additionality regarding new installed renewable power production capacity. According to the EU definition for renewable hydrogen, power needs to be generated in the same bidding zone within a 3-year timeframe. As it stands today in the Netherlands where the project will be built, offshore wind projects are delayed due to the recent hurdles facing that industry because of inflation and global supply chain disruptions. As a result, the timelines for securing a renewable PPA and for building hydrogen production plants, even subsidized, must match. Today, according to Uniper, they do not.

As a second case study, the state of the last Innovation Fund and IPCEI funding rounds also gives clues as to the current state of the industry. From the 15 renewable hydrogen projects that were awarded EU funding in December 2023, for a total of 1.25 billion euros coming from the Innovation Fund, six projects were missing from the original list.[99] In practice, these projects failed to secure grant agreements with the Commission. These include projects driven by energy majors, such as Total, Shell, Engie, EDP, Repsol, which have a large strategic interest to step into renewable hydrogen as a replacement for their traditional, fossil-based businesses. As one example, a 250 MW project driven by BP (H2-Fifty), initially selected as IPCEI in December 2022, has been silent about the project timeline, with no recent announcements despite the good news of having been awarded significant funding.

Shell appears to be an exception. The company took Final Investment Decision (FID) on its flagship 200 MW electrolyzer project (Holland Hydrogen 1) in Rotterdam in July 2022. The plant is due to be commissioned in 2025, and will be powered with offshore wind power, coming from a wind park project in which Shell itself has a stake. While Shell presses ahead with their 200 MW electrolyzer, another liquid renewable hydrogen project (H2Sines.Rdam) in a cooperation between Portugal and the Netherlands and with other partners such as Engie, was scrapped, despite being selected for a grant from the Innovation Fund. The project aimed to supply heavy duty mobility with liquid hydrogen as early as 2028. Lack of regulations, market maturity, and lack of economic viability are cited as reasons for the abandonment.

---

[99] Hydrogen Insight 2023b

The state of technological development is also an often-cited reason, touching electrolyzers but also the rest of the hydrogen value chain. Both ships and vehicles capable of storing and using liquid hydrogen, deemed critical to a hydrogen economy, are yet to be unveiled.[100]

The state of infrastructure development is also mentioned as a key hurdle for the industry. The scaling up of hydrogen infrastructure is relevant to ensure connection with producers (in areas where renewable energy is available) and consumers (in industrial areas where hydrogen is needed) of hydrogen. To overcome this, the manufacturing of hydrogen production systems and infrastructure must be scaled up and supported by industrial policy.[101] The conversion of existing natural gas grids for hydrogen service will incur an additional cost increase for the final consumer, which was estimated for Germany to be almost double the cost to transport natural gas today (+87%).[102] For mobility, the Chief executive Officer of European carmaker Stellantis stated in April 2024 that the technology remains twice more expensive than electrical vehicles, which themselves are already more expensive than conventional vehicles.[103]

Given the scale of required investments public or regulated actors, the industry faces a typical *Chicken-and-Egg*-type problem. Germany recently announced a delay in their future *Backbone* hydrogen pipeline, which is to comprise 9700 kilometers of mainly converted natural gas pipelines, by five years, from 2032 to 2037. The delay was justified by other delays in the construction of renewable hydrogen projects. Investments would be borne by private investors who would recoup their investments through grid fees. In case the market would not pick up in a way that will allow companies to make a fixed return on their investments, the German government would reimburse 76% of the costs.[104] The scaling up of infrastructure in parallel to production projects is a tough problem for network operators and public governments to solve. Denmark is a good example of country with large hydrogen ambitions, with 7 GW of new offshore wind projects already been announced for renewable

---

[100] Hydrogen Insight 2024a

[101] EPRS 2021

[102] Hydrogen Insight 2024d

[103] Hydrogen Insight 2024h

[104] Hydrogen Insight 2024e

hydrogen production.[105] Denmark set conditions prior to the construction of its own hydrogen pipeline, such that the transport capacity should be booked by at least 44% before construction can start. Another condition is that all hydrogen transiting through the pipeline should be renewable as per the EU definition. Another condition is that the pipeline must connect with Germany, thus adding a cross border element to an already complex endeavor.

Moreover, especially relevant in countries with dense industrial clusters like the Netherlands, industry faces issues of grid congestion. Past underinvestment caused the electrical network to operate at full capacity. Congestion requires reinvestments, also due to the ageing of the network, and already caused grid fees to triple in the last three years alone. In the face of hurdles to build up renewable hydrogen production capacity, the EU has had to regulate in other areas, such as the production of renewable electricity. RePowerEU already foresees an increase in the scaling up of wind and solar, with growth rates in installed capacity up to double their recent historical values. For renewable hydrogen the hurdle is of another scale, with compound growth rate of nearly 100% every year needed until 2030 to meet the 10 million tons of annual renewable hydrogen production. In short, electrolyzer capacity would need to double every year for ten consecutive years for EU targets to be met. Should that occur, there may still be a shortage of new renewable power capacity to produce the hydrogen.[106]

What these reports show is that the peak hype of early 2021 seems to have gradually faded and replaced by cautious pragmatism and realism in face of the technical maturity challenges and higher than anticipated cost increases. Among the factors contributing to the hype, momentum around the European Green Deal could certainly have played its part. The EGD itself came to inception at a time when various optimistic reports were released, either by consultants or trade associations.[107] While it is difficult to establish causality, it is reasonable to argue that European policymakers took ambitious assumptions as basis to formulate EGD-derived policies. Here, it is significant that the energy crisis at the end of 2021, and the weaponization of natural gas supplies by Russia in 2022 appear to have done little to slow down or revert the downfall of the renewable hydrogen hype.

---

[105] Hydrogen Insight 2024f

[106] Boigontier et al. 2023

[107] McKinsey, 2020 and Hydrogen Council 2020

4.4. Sources of regulatory (un)certainty

Beyond costs and technical challenges, the regulatory environment is also cited as reason for project delays. The reality is that only small projects have received FID in recent months.[108] The EU, meanwhile, continues to support hydrogen projects, with 65 new projects awarded support for PCI (cross-border Member States) or PMI (Member State - third party states) schemes in April 2024. These projects can benefit in addition to funding under the Connecting Europe Facility instrument.[109] However, subsidies do not seem to have the desired effect. This seems to be for several policy-related reasons.

First, the long and arduous process to get awarded subsidies is often cited as additional reasons for delays in investment decisions. Some of the complaints are directed to the fact it can take between one and two years between funding application and project selection. After funding has been awarded, 60% of the total amount is only granted after project has met its objectives, in a classic attempt for the EU to impose performance-based funding, a kind of conditionality. By contrast, the funding process is perceived as faster in the USA, where subsidies come as soon as the application is approved. Moreover, the industry cites strict rules and a large administrative burden compared with subsidy processes in other geographies. European companies show a preference for tax credits, such as the ones awarded by the USA under the IRA. That is not to say that the IRA is achieving better results in practice. In the USA, public administrations are now considering switching from tax rebates to EU-like subsidies, after the initial round of incentives failed to attract sufficient hydrogen consumers for the production tax credit under the IRA. Recently, energy giant Engie announced delaying 4 GW worth of worldwide projects by five years, citing lack of industry progress. Reasons included, for the USA-based projects, public discussions about the rules for the IRA-unveiled production subsidy of up to $3/kg for renewable hydrogen. Similarly, the first 800 million euros of the awarded subsidies under the Hydrogen Bank were initially delayed by one year until the end of 2024.

---

[108] Hydrogen Insight, 2024b

[109] Hydrogen Insight 2024c

Second, according to industry, operational costs through feed-in tariffs-like support such as CCFDs are also needed to complement investment subsidies. Such CCFD schemes are possible but have not been unveiled in many Member States. The EU-driven Hydrogen Bank is so far seen as too uncertain by many industry players. National CCFD schemes are gradually taking shape, but the process is not unified yet. Germany unveiled one billion euros in additional funding, adding to an already existing four-billion-euro scheme, under the H2Global platform, in support of renewable hydrogen, even proposing to merge the national scheme with the EU-wide Hydrogen Bank.[110] The Netherlands has announced it would use the German platform to offer its own 300 million euros in financial support. The plan has been approved by the EU in relation to the EU's State aid rules. However, one year after the announcement, no confirmation has been announced.[111] Spain has also stepped up its support for hydrogen projects, applying on its companies' behalf for IPCEI support to complement the Recovery and Resilience Facility scheme. However, failure for funding to materialize within the expected timeframe (more than two years between IPCEI award and materialization of the funding) has resulted in final investment decisions being delayed. Inflation has not helped, as cost level has increased over the past two years, creating an additional hurdle for the private sector. In addition, companies face electoral uncertainty, as governments may change position over time.[112]

The lack of progress on the ground across the industry, along with downward revision of future production and offtake forecasts despite multiple earlier announcements, has been dubbed a *Reality check*, with only 5% of announced projects considered credible enough to ever materialize.[113] A range of reasons are given for this, from long lead times to lengthy permitting, to the unclear granting of subsidies. Furthermore, now that harmonizing EU legislation has been passed, Member States will need to transpose and implement the new rules. They will also decide how far and fast they want to give State aid support according to national context and capabilities. This phase may also become a source of delay and uncertainty. The delay experienced to transpose the newly enacted REDIII into Member State law is also cited as a source of regulatory uncertainty. The industry appears to drag

---

[110] Hydrogen Insight 2023c

[111] Hydrogen Insight, 2023d

[112] Hydrogen Insight 2023e

[113] Hydrogen Insight 2023h

their feet because of technological risk, additional costs and funding requirements, but also in an attempt to push the EU to revise the Delegated Acts setting rules for renewable hydrogen. Looser rules (e.g., additionality) would lower the cost of renewable hydrogen. A report by the Commission is expected by 2028 while the Delegated Acts setting the strict requirements for renewable hydrogen could be revised as late as 2030.[114] This may trigger a delay in some projects and for the industry to adopt a *Wait-and-See* approach and heavy advocacy with the view to trigger a future relaxation of these rules.

Beyond subsidies and regulations, it appears necessary for European industry to de-risk some of the larger hydrogen projects. Only a select few companies – including the energy majors cited above - possess balance sheets that enable them to engage in large projects on their own. Additional instruments are being considered to offer loan support for projects or companies which traditional commercial banks would see too big a risk. The European Investment Bank (EIB) has stated its eagerness to support hydrogen projects. However, as per today's rules, the EIB only offers co-financing alongside other commercial banks. Meanwhile, renewable projects based on somewhat unproven technology, and for which there is no mature market yet are proving too risky for commercial banks.

4.5. The need for a transitional step

Consultants such as Deloitte had initially modelled possible future scenarios, predicting an optimistic ramping up of hydrogen production and use, even claiming that the European low-carbon hydrogen (derivative) market would be sustaining itself as early as 2030 for ammonia and 2035 for hydrogen.[115] As seen in the previous section, as of today most large-scale such project are yet to have received FID. As it stands, the deployment of renewable hydrogen infrastructure and market is being delayed, and the 2030 targets will most likely not be met. A reason for this is the fact that in setting the current rules, "*The Commission is being heavily influenced in its approach by its experience in trying to liberalise natural gas markets over the last quarter century, including the issue of unbundling networks from gas production and supply*"[116]. The revision and potential relaxing of current EU policies is not expected by

---

[114] Hydrogen Insight 2023g

[115] Hydrogen Insight 2023f

[116] Barnes 2023

the end of the decade. For hydrogen, this means the current regulatory hurdles will not easily be alleviated. Yet, despite these hurdles, the direction taken by the EU is, from industrial policy and technological development perspectives, the correct one. Industry needs support and guidelines in order to break the inertia and path dependency of fossil-based energy supply. That said, from the industry's point of view the tendency for the EU to enact the perfect policy mix results in unnecessary administrative red tape and regulatory burden.

Looking at scenarios, the EU will need to support industry to remove the main bottlenecks that are the lack of sufficient renewables production and the lack of manufacturing capacity by companies who can bear the risk of technological scale-up and of conducting large-scale, complex development projects. Support for electrification and incentives (e.g., through Member State-level tax rebates) to install domestic production capacity should, therefore, be the focus on the next cycle for European legislators. State aid will enhance competition across Member States that are willing and financially able to bear some of the costs associated with early market development. Simplifying the portfolio of subsidies and access for smaller companies without expansive administrative resources, is currently on the agenda and could be beneficial. That is not to say that the simplest schemes are always desirable. As the initial feedback from the IRA shows, the USA are spending a lot more money under the IRA than the EU under its various support schemes. The USA's approach is less efficient, partly because the US does not have a unified set price on carbon. The EU should aim to maintain a balance of the most efficient, yet leanest, policy mix possible.

Electrification and renewable hydrogen are, among other technologies and solutions, the end-goal of the energy transition for replacing fossil fuels. This will decrease emissions for a significant share of the industrial decarbonization effort (for e.g., chemicals, fuels, metals). We can expect that carbon capture and storage, as well as other carbon management techniques currently under development, will cover the remaining hard-to-abate sectors (for e.g., cement, glass). However, bottlenecks occurs because electrification, net decongestion, and the building of massive transport infrastructure are prerequisite to scaling up the renewable hydrogen economy. In times of supply chain bottlenecks, inflation, and high interest rates, the deployment of new renewable energy production capacity risks stalling the entire buildup of national and transnational hydrogen supply networks. Here, industry and governments alike face a classical *Chicken-and-Egg*-type problem. No renewable hydrogen network will be built until hydrogen production capacity is available at scale. No production capacity will be built at scale until there is a demand for renewable hydrogen at competitive price. And no renewable hydrogen will be competitively priced until a full-scale renewable hydrogen network has been built and is available to transport it.

Additional domestic production of renewable (or low-carbon) energy is doubly beneficial because it will also reduce the EU's dependency on foreign energy imports. That is, provided that the materials needed for electrification do not create additional dependencies, something the EU has been working on in parallel with battery alliance and critical raw materials initiatives. Energy security has become even more important since the energy crisis of late 2021, aggravated by Russia's war in Ukraine since 2022 and the threat of weaponization of natural gas and oil exports towards Europe. With geopolitical tensions in the Middle East on the rise since late 2023, we can expect that the reliable and economical supply of energy will remain one of Europe's major challenges for years to come.

The joint action of policymakers and industrials is thus key to jointly addressing solving this issue through a stepwise development. It is quite clear that since the EGD, there will be little political support for building new fossil-based hydrogen infrastructure inside the EU. National governments and EU institutions are only eager to fund projects that reduce both the EU's carbon footprint and its energy dependency. But if both can't be achieved at the same time, a two-step approach is possible, with an in-between step using a combination of low-carbon hydrogen, produced from fossil sources with carbon capture technologies, and the gradual scaling up of renewable projects in parallel. That is because, in parallel to the stalling seen in the renewable hydrogen industry, meanwhile carbon capture and storage has been doing relatively well. Despite environmental concerns, the first large-scale European CCS project (the Porthos consortium in the Rotterdam harbor area) was finally allowed to make FID in late 2023.[117] As it stands, Porthos will come onstream in as early 2026 making it the first large-scale commercial industrial carbon management project in the EU. Moreover, other EEA-based oil majors such as Equinor have announced ambitious low-carbon hydrogen investments, the first of which kickstarted the first half of 2024 a detailed feasibility study for a 1 GW blue in northern Netherlands, with a target onstream date in 2029.[118] These recent developments are a testimony to the importance oil and gas majors

---

[117] Porthos 2023

[118] Equinor 2024

take in supporting the energy transition to renewables, with a first step controversial yet critical step towards low-carbon fuels.

Low-carbon hydrogen can be readily produced competitively at scale and contribute to climate goals thanks to carbon capture and storage. This solution is not a silver bullet mainly because a favorable location is needed for carbon capture and storage. Blue hydrogen projects favor geographical areas that are favorable for carbon capture, i.e., in the vicinity of depleted oil and gas fields. While CO2 storage is theoretically possible over long distance through rail or ship, the economics of such solution may require more incentives to be realized than for opportunities where the necessary infrastructure is nearby. Thus, from an economic efficiency standpoint, the more favorable locations should be developed first. Low-carbon hydrogen does not reduce the EU's dependency on fossil fuels such as natural gas but does provide heavy industry with large quantities of decarbonized hydrogen which enjoys the same properties as renewable hydrogen at more competitive cost for the industry. That way, current bottlenecks regarding renewable energy and the learning curve for electrolyzers no longer constitute a blocking point for setting a clear agenda for hydrogen infrastructure.

In parallel to developing large-scale infrastructure using low-carbon hydrogen, standalone renewable hydrogen projects should continue to be built. This is to ensure economies of scale are realized over time, which will gradually enable the EU to fully benefit from additionally installed renewable power generation. However, it is possible that as per current needs, most additional renewable power generation should be needed for the production of electricity rather than hydrogen. For reasons of efficiency and simplicity, electrification should be favored over renewable hydrogen whenever possible. In suitable cases, standalone renewable hydrogen projects can allow reduced time-to-market as such projects minimize the quantity of infrastructure (electrical grid, hydrogen pipelines) required to be in place before the hydrogen can be transported and used. This is also because like low-carbon hydrogen, renewable hydrogen needs a favorable environment (cheap renewable power; no readily available natural gas infrastructure) to become more competitive over fossil-based alternatives. At a later stage, low-carbon projects can be phased out at the end of their economic lifetimes and can replaced by renewable hydrogen projects, which hopefully by then will have reached technological maturity and for which manufacturing capacity will be available inside the EU. In that way, gradually the EU will achieve the expected security-of-energy-supply benefits of replacing foreign natural gas-based feedstocks by domestic renewables-based feedstocks. This will take two or three decades and will rather contribute to the goal of climate neutrality by 2050 rather than the initially formulated target of 2030.

4.6. Scenarios for future European industrial policy

The surge in hydrogen-related activity since the release of the EGD indicates that the European Commission is willing to go one step further in selecting and actively promoting specific technologies. One risk and inherent weakness of the EU's strategy is that it is developing market instruments that are betting on technology that is promising but not proven commercially at scale, or whose development could take longer than is hoped for. One point of debate remains whether being technology neutral is really desirable for climate technologies, in contrast to current EU policies that tend to support specific technologies. Here, the OECD recommends technological neutrality and horizontal policies such as R&D support where possible.[119] It has been shown that technology neutral approaches tend to be more risk-adverse and financially focused, mainly because they offer more support more mature technologies. In the Netherlands, subsidy support is focused on carbon reducing efficiency and is less targeted are more breakthrough technologies.[120]

From an energy security standpoint, the continued electrification using renewables is the natural and obvious way forward. This requires the upgrading of electrical infrastructure. This alone will create cost increases which the market and end consumers will need to bear. Except in exceptional cases, renewable hydrogen would alleviate some of the limitations of having a renewables-heavy grid (e.g., storage) at a considerable cost. To meet its climate objectives and ambitions to realize a net-zero society, the EU will need to accommodate and facilitate low-carbon hydrogen in combination with carbon capture through an appropriate regulatory framework. This transitional step will enable key infrastructure (namely, hydrogen and CO2 pipeline backbones as complements or replacement to natural gas networks) to be gradually built and used already before massive amounts of renewable hydrogen would be made available. In this regard, recent announcements that such hydrogen pipelines would only accept renewable hydrogen, and that a number of these national-

---

[119] Cammeraat, Dechezleprêtre and Lalanne 2022

[120] Criscuolo, Dechezleprêtre and Lalanne 2023

sponsored pipeline projects would be delayed, is a serious concern. The EU should mediate and harmonize the restrictions to pipeline transport, such that a gradual ramp up using low-carbon hydrogen would be possible until at least 2040 or 2050.

Another approach, which would constitute a *U-turn* for EU policymakers, would be to abandon the support of specific technologies and to adopt a more technology neutral approach. As discussed earlier in this paper, market-based technology neutral instruments (e.g., carbon tax) are generally preferred to technology specific (e.g., net-zero technologies) ones. This would partly de-risk the energy transition and ensure an economically efficient allocation of capital resources. However, given the strategic interest the EU has taken in shaping technological development since 2020, this scenario seems unlikely to materialize.

Beyond hydrogen and carbon capture technologies, what is at stake the reindustrialization of Europe for net-zero industries as set as objective under the NZIA. This will require increasing the bloc's overall competitiveness. From a macroeconomic policy and given the scale of required investments and performance catch-up required by European firms, prerequisites will include improving several key factors of competitiveness. As seen in the section on industrial policy, the EU is seriously constrained in the scale of industrial policy (e.g., export-oriented support) it can offer its industry because of the internal (Single Market) and external (GATT and SCM) limitations of the rules-based international liberal order.

That is not to say, however, that the EU is powerless in its search for industry competitiveness. The recent *Letta Report* on the future of EU competitiveness is instructive regarding future cross-industry policy avenues the EU could choose to embark on.[121] Similarly, drawing from the experience of the last four years, some authors have suggested various prerequisites for a successful green industrial policy.[122] Five axes of horizontal policy development could positively impact hydrogen and carbon capture industries. First, a well-functioning capitals market union to allocate funds readily available but today limited by national boundaries. Second, relaxed rules on market consolidation to reach scale required to compete on the global technological and industrial arena. Third, a favorable business environment allowing for risk-taking and risk-bearing. Fourth, an overall growing

---

[121] McWilliams et al. 2024

[122] Tagliapietra and Veugelers 2020

economy giving prospects of favorable returns on these investments over the required lifetimes of such projects. Finally, support for technological development including brain retention and attraction and best-in-class innovation facilities and infrastructure.

The next European electoral cycle for the period 2024-2029 will be likely marked by the continued threat of war. This context is likely to foster continued talks about setting a strong industrial policy but more targeted at defense and security industry. There, concentration and de-fragmentation of longstanding national industries will be key. It remains to be seen whether EU rules on competition and State aid will be bent or changed to accommodate the new geopolitical environment facing the EU and its Member States. For this as well as other reasons, such as the rise of right-wing extremism, the risk is that European Green Deal objectives will step back to second place in the order of priority is a real threat.

5. Conclusions and future research

Through the EGD package and subsequent activities, the EU has, within a single institutional term and in just four years, gradually developed and unveiled a full-fledged industrial policy. Long-term climate goals are a major justification for the EU's attempt to steer its industry. However, climate goals are only one of several overarching factors that justify this apparent change of course. Recent experiences also include the Covid-19 pandemic and disturbances in global supply chains; the threat of trade disputes and of a global race for subsidies; the Russian aggression in Ukraine and weaponization of energy supply. These events and trends served as a reality check for the EU, as various signs that globalization and market-based economy left uncheck lead to a suboptimal outcome in times of crisis.

After decades of being neglected or fraught upon as contrary to the liberal market economy ideal, industrial policy is back on the international policymaker's scene. Being taboo does not, however, mean that industrial policy was abandoned in the EU or even among western economies. A few key elements of recent history may have triggered the EU to revise its stance towards a market economy balanced with elements of industrial policy. Industrial policy has been one of the many EU responses to these threats, which also included the issuance of common debt, common procurement, renewed momentum for (or at least openness to discuss) future EU enlargement, among other developments. Looking ahead, the long-term implications of these disturbances in terms of EU adjustments remain to be seen.

For one, the common security and defense policy and the mutualization of military capabilities may be high on the agenda of the next legislative period starting end of 2024. In any case, the last four years have legitimized the EU as political entity and asset for its Member States as per the principle of subsidiarity, but especially in times of crisis.

Having an explicit industrial policy does not, however, means that the EU will neglect what constitute one of its founding principles. As an economic and commercial entity, the EU remains committed to a market-based approach to competition and regulated State aid within the single market, as well as to its international commitment to promoting a rules-based international order. That said, the scale of the challenges posed by its climate and security objectives have gradually required it to take a proactive stance in shaping industry, within but also outside the borders of the Single Market. As such, rather than a change of course, it is more an attempt at integrating and expanding the scope of previously existing policy instruments in order to make them effective in light of the current challenges to be tackled.

This need is particularly visible in the climate and energy security spheres. For European and national politicians, the gap between ambition and reality is too big for these to be left prey to market forces. That is where industrial policy, a practice as old as the industrial revolution itself, becomes most relevant. However, what constitutes the strength of a well-defined industrial policy is also the weakness of a poorly defined one. Here the EU walks a fine line, which it may or may not have crossed. Only time and experience will tell and the outcome is likely to be mixed and conclusions may be hard to draw. However, industrial policy research appears as relevant as ever to provide that feedback loop that policymakers will use to correct course or refine their tools.

The recent engouement around hydrogen and carbon capture, especially regarding renewable hydrogen, is the sign of a bet made by European policymakers, a kind of industrialization gamble made on the basis of less-than-solid assumptions by consultants and certain industrial players, who in many cases appear to have initially overplayed their hand. That is not to say that the chosen direction is inherently wrong. The two technologies have distinct histories, rationales, and pathways. Both technologies are inherently bound to work together in service of the EU's climate and security goals. Historically, hydrogen has long been hyped as the single solution to all problems while carbon capture was seen as second-rate solution.

In just a couple of years, it seems the tables are being turned. The rollercoaster will undoubtedly continue but the EU has undeniably seized the European Green Deal moment to set both technologies on stronger European footing. Ambitions may need to be recalibrated along the way, as they often do.

To its credit, the EU is exploring the entire range of tools available in the classical industrial policy toolbox. This includes a limited of import-substitution-type measures aimed at securing domestic production capacity, such as local content requirements, subsidies for scaling up production capacity, and a unified carbon tax now strengthened by the carbon-border adjustment mechanism. CBAM will be instrumental to address the risk of carbon leakage and deindustrialization described in the introduction. EU policies now also include a range of export-substitution-type measures aimed at upgrading domestic production through the funding of R&D and demonstration projects as well as public-private partnerships, with the aim to gain a technological edge, or at the very least catch up on its own capabilities. Finally, the EU is also somewhat proactive in promoting global value chains and entrepreneurship, not least by supporting human capital development. The result is an integrated and comprehensive framework, yet also a complex and bureaucratic one.

Net-zero technologies, chief among which hydrogen and to some extent carbon capture and storage among other, increasingly appear as two cases of Big-Push Industrialization. The regulatory progress since 2020 is proof of the EU's willingness to shape these infant markets. Politically and institutionally, this remains a sensitive area because of the (political) costs associated with the financial effort required to achieve the EU's ambitious decarbonization and climate objectives. Recent U-turns in several key policy areas of the EGD, most notably the phasing out of internal combustion engines and environmental regulations, are providing a taste of the political challenges to come.

The overarching goal is to ensure a level playing field in global competitiveness, which is highly dependent on the state of world Trade. Under President Trump, the US administration's protectionist tendencies were early signs of trade tensions and an increasing tendency to resort to retaliation. Moreover, industrial policy is clearly visible in China's planned market economy, which is already triggering concerns in western economies. The US and UK are concerned that Chinese technologies, such as in telecommunications, might compromise their national security. For its part, the EU is concerned that industrial support to export-oriented Chinese manufacturing firms might distort fair competition and undermine the single market. A second element is the tools necessary to support the energy transition. Since President Biden with its IRA championing *Made in America* provisions and strong investment and operations incentives, it seems neoclassical economics promoting market-based dynamics are not directly applicable to certain industrial sectors. Politics seem more and more entangled in business decisions or restrictions, also shown by the US's decision to prevent China from accessing certain technologies. The war in Ukraine has also seen Western governments preventing exports of military or dual-use equipment to Russia. Moreover, the public authorities' response to the Covid-19 pandemic showed the power of national governments to use public procurement to shape market behavior.

In this context, industrial policy research appears today more relevant than ever as the EU will need to apply the entire range of instruments at its disposal and may need to devise new responses to tackle these upcoming challenges. Only a thorough empirical analysis of the pros and cons of each of these policy avenues will provide the necessary feedback loop through trial and error, so appropriate learnings can be captured and implemented in future policy adjustment rounds. Today more than ever before, industrial policy design requires adopting and entrepreneurial mindset.

List of abbreviations

CBAM	Cross-border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCP	Common Commercial Policy
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture, Utilization and Storage
CEF	Connecting Europe Facility
CCFD	Carbon Contract for Difference
CO2	Carbon Dioxide
DAC	Direct Air Capture
EEA	European Economic Area
EGD	European Green Deal
ETS	Emissions Trading System
EU	European Union
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
FP	Framework Programme
GHG	Greenhouse Gases
GW	Gigawatt
H2	Hydrogen
HE	Horizon Europe (Previously Horizon 2020)
NZIA	Net-zero Industrial Act
IPO	Initial Public Offering
IRA	Inflation Reduction Act
IPCEI	Important Project of Common European Interest
LCH	Low Carbon Hydrogen
LCP	Local Content Policy
MW	Megawatt
NECP	National Energy and Climate Plan
NGEU	NextGenerationEU
PCI	Project of Common Interest
PPP	Public Private Partnership
PTA	Preferential Trade Agreement
R&D	Research and Development
RED	Renewable Energy Directive
RFNBO	Renewable Fuel of Non-Renewable Origin
SCM	Subsidies and Countervailing Measures
SME	Small and Medium Enterprises
TFEU	Treaty on the Functioning of the EU
WTO	World Trade Organization

List of tables and figures

Bibliography

Allenbach-Ammann, János (2023): The 'Buy European' clauses in the Net-Zero Industry Act, Euractiv, available online: https://www.euractiv.com/section/economy-jobs/news/the-buy-european-clauses-in-the-net-zero-industry-act/ (last accessed: 25 May 2024).

Bailey, David and **De Propris**, Lisa (2020): Technological Disruptions, GVCs, and Industrial Policy, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 485-504.

Barnes, Alex (2023): EU Hydrogen and Gas Decarbonisation Package: help or hindrance for the development of a European hydrogen market? Oxford Institute for Energy Studies, available online: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2023/03/The-EU-Hydrogen-and-Gas-Decarbonisation-Package-ET22.pdf (last accessed: 25 May 2024).

Becker, William, **Norlén**, Hedvig, **Dijkstra** Lewis and **Athanasoglou**, Stergios (2020): Wrapping up the Europe 2020 strategy: A multidimensional indicator analysis, in: Environmental and Sustainability Indicators, Volume 8, 100075, available online: https://www.sciencedirect.com/science/article/pii/S2665972720300593 (last accessed: 25 May 2024).

Boigontier, Thomas et al. (2023): Low-carbon hydrogen production in the EU: are 2030 targets achievable? Available online: https://hal.science/hal-04158824/document (last accessed: 25 May 2024).

Cammeraat, Emile, **Dechezleprêtre**, Antoine, and **Lalanne**, Guy (2022): Innovation and industrial policies for green hydrogen. 2022. OECD Science, Technology and Industry policy papers No. 125, available at: https://www.oecd.org/publications/innovation-and-industrial-policies-for-green-hydrogen-f0bb5d8c-en.htm (last accessed: 25 May 2024).

CE Delft (2022): 50% green hydrogen for Dutch industry, available online: https://cedelft.eu/wp-content/uploads/sites/2/2022/03/CE_Delft_210426_50_percent_green_hydrogen_for_Dutch_industry_FINAL.pdf (last accessed: 25 May 2024).

Cimoli, Mario (2020): Industrial Policies, Patterns of Learning, and Development: An Evolutionary Perspective, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 93-124.

Clean Hydrogen Partnership, Our Story, available online: https://www.clean-hydrogen.europa.eu/about-us/our-story_en (last accessed: 25 May 2024).

COM (2019) 640 final, The European Green Deal, 11 December 2019.

COM (2020) 102 final, A New Industrial Strategy for Europe, 10 March 2020.

COM (2020) 301 final, A hydrogen strategy for a climate-neutral Europe, 8 July 2020.

COM (2021) 350 final, Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe’s recovery, 5 May 2021.

COM (2021) 800 final, Sustainable Carbon Cycles, 15 December 2021.

COM (2021) 803 final, Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal markets in renewable and natural gases and in hydrogen, 15 December 2021.

COM (2021) 804 final, Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the internal markets for renewable and natural gases and for hydrogen (recast), 15 December 2021.

COM (2022) 230 final, REPowerEU Plan, 18 May 2022.

COM (2022) 672 final, Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for carbon removals, 30 November 2022.

COM (2023) 62 final, Green Deal Industrial Plan for the Net-Zero Age, 1 February 2023.

COM (2024) 62 final, Towards an ambitious Industrial Carbon Management for the EU, 6 February 2024.

COM (2024) 63 final, Securing our future, 6 February 2024.

Council of the EU (2024a): Fit for 55, available online: https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/ (last accessed: 25 May 2024).

Council of the EU (2024b): Infographic - Net-zero industry act: a benchmark for the manufacturing capacity of strategic net-zero technology products, available online: https://www.consilium.europa.eu/en/infographics/net-zero-industry-act/ (last accessed: 25 May 2024).

Council of the EU (2024c): Proposal for a Regulation of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe’s net-zero technology products manufacturing ecosystem (Net Zero Industry Act), 7613/23 + ADD 1, available online: https://data.consilium.europa.eu/doc/document/ST-6269-2024-INIT/en/pdf (last accessed: 25 May 2024).

Council of the EU (2024d): Timeline - EU industrial policy, available online: https://www.consilium.europa.eu/en/policies/eu-industrial-policy/timeline/ (last accessed: 25 May 2024).

Criscuolo, Chiara, **Lalanne**, Guy and **Diaz**, Luis (2022): Quantifying industrial strategies (QuIS): measuring industrial policy expenditures, OCED Science, Technology and Industry Working Paper 2022/05, available online: https://www.oecd-ilibrary.org/science-and-technology/quantifying-industrial-strategies-quis_ae351abf-en (last accessed: 25 May 2024).

Criscuolo, Chiara, **Dechezleprêtre**, Antoine and **Lalanne**, Guy (2023): Industrial strategies for the green transition. In: Tagliapietra and Veugelers, Sparking Europe’s new industrial revolution, A policy for net zero, growth and resilience, Bruegel Blueprint Series 33, available online: https://www.bruegel.org/sites/default/files/2023-07/Bruegel%20Blueprint%2033%20030723_0.pdf (last accessed: 25 May 2024).

Davis, Steven et al., (2018): Net-zero emissions energy systems. Science Vol 360, Issue 6396, available online: https://www.science.org/doi/10.1126/science.aas9793 (last accessed: 25 May 2024).

Delegated Regulation 2023/1185 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a minimum threshold for greenhouse gas emissions savings of recycled carbon fuels and by specifying a methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels, OJ L 157, 20.6.2023, p. 20–33.

Deloitte (2022): The European hydrogen economy – taking stock and looking ahead. An outlook until 2030. Deloitte Monitor, available online: https://www2.deloitte.com/content/dam/Deloitte/fr/Documents/financial-advisory/European_hydrogen_economy_FINAL.pdf (last accessed: 25 May 2024).

Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006, OJ L 140, 5.6.2009, p. 114–135.

Directive 2018/2001/EU of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast), OJ L 328, 21.12.2018, p. 82–209.

Djafar, Budi and **Milberg**, William (2020): Global Value Chains and Regionally Coordinated Industrial Policy: The Case of ASEAN, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 207-236.

ECJ, Opinion 2/15 of 16 May 2017, Singapore opinion, available online: https://curia.europa.eu/juris/document/document.jsf?text=&docid=190727&doclang=EN (last accessed: 25 May 2024).

EPRS (2021): The potential of hydrogen for decarbonizing EU industry, European Parliament Scientific Foresight Unit (STOA). PE 697.199, available online: https://www.europarl.europa.eu/RegData/etudes/STUD/2021/697199/EPRS_STU(2021)697199_EN.pdf (last accessed: 25 May 2024).

Equinor (2024): Sleipner area, available online: https://www.equinor.com/energy/sleipner (last accessed: 25 May 2024).

Equinor (2024): Equinor and Linde sign agreement on H2M Eemshaven hydrogen project, available online: https://www.equinor.com/where-we-are/the-netherlands#linde-announcement (last accessed: 25 May 2024).

European Commission (2020): Making Europe's businesses future-ready: A new Industrial Strategy for a globally competitive, green and digital Europe, available online: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_416 (last accessed: 25 May 2024).

European Commission (2021): Candidate PCI projects in cross-border carbon dioxide (CO2) transport networks in view of preparing the 5th PCI list, available online: https://energy.ec.europa.eu/system/files/2021-04/detailed_information_regarding_the_candidate_projects_in_co2_network_0.pdf (last accessed: 25 May 2024).

European Commission (2024a): 2040 climate target, Reducing net emissions by 90% by 2040, available online: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2040-climate-target_en#documents (last accessed: 25 May 2024).

European Commission (2024b): Next GenerationEU, available online: https://commission.europa.eu/strategy-and-policy/eu-budget/eu-borrower-investor-relations/nextgenerationeu_en# (last accessed: 25 May 2024).

European Commission (2024c): Commission welcomes political agreement to make clean technology manufacturing in the EU resilient and competitive, available online: https://ec.europa.eu/commission/presscorner/detail/en/ip_24_680 (last accessed: 25 May 2024).

European Commission (2024d): Key cross-border infrastructure projects, available online: https://energy.ec.europa.eu/topics/infrastructure/projects-common-interest/key-cross-border-infrastructure-projects_en#the-pci-list (last accessed: 25 May 2024).

European Council (2019): European Council meeting conclusions, 22 March 2019, available online: https://www.consilium.europa.eu/media/38789/22-euco-final-conclusions-en.pdf (last accessed: 25 May 2024).

European Parliament (2023): EU’s response to the US Inflation Reduction Act (IRA), Briefing, available online:

https://www.europarl.europa.eu/RegData/etudes/IDAN/2023/740087/IPOL_IDA(2023)740087_EN.pdf (last accessed: 25 May 2024).

European Parliament (2024): Key new factors likely to shape the EU's trade agenda in the next five-year term, April 2024, available online: https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/754448/EXPO_BRI(2024)754448_EN.pdf (last accessed: 25 May 2024).

Fries, Steven (2023): Macroeconomic implications of decarbonization, policy tradeoffs and sequences, Institute for New Economic Thinking at the Oxford Martin School, University of Oxford Peterson Institute for International Economics, available online: https://www.piie.com/sites/default/files/2023-06/2023-06-05-02fries.pdf (last accessed: 25 May 2024).

Hausmann, Ricardo and **Rodrik**, Dani (2003): Economic Development as Self-discovery, in: Journal of Development Economics 72: 603–33, available online: https://growthlab.hks.harvard.edu/files/growthlab/files/2002_econ_development_self_discovery_hausmann_rodrik.pdf (last accessed: 25 May 2024).

Hettne (2020): The EU state aid ban – a straitjacket for a successful European industrial policy? In: Andhov et al., EU Industrial Policy in a Globalised World – Effects on the Single Market, SIEPS, 2020, 1op, available online: https://lucris.lub.lu.se/ws/portalfiles/portal/81123674/Sieps_EU_Industrial_Policy_2020_1op_eng_web.pdf (last accessed: 25 May 2024).

Howse (2010): Climate Mitigation Subsidies and the WTO Legal Framework: A Policy Analysis, IISD, available online: https://www.iisd.org/system/files/publications/bali_2_copenhagen_subsidies_legal.pdf (last accessed: 25 May 2024).

Hydrogen Council (2020): Path to hydrogen competitiveness, A cost perspective, available online: https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf (last accessed: 25 May 2024).

Hydrogen Insight (2023a): EU clarifies subsidy stacking rules for upcoming hydrogen pilot auction, available online: https://www.hydrogeninsight.com/policy/eu-clarifies-subsidy-stacking-rules-for-upcoming-hydrogen-pilot-auction/2-1-1530403 (last accessed: 25 May 2024).

Hydrogen Insight (2023b): Fifteen hydrogen projects to receive €1.25bn of EU innovation funding after signing grant agreements, available online: https://www.hydrogeninsight.com/innovation/fifteen-hydrogen-projects-to-receive-1-25bn-of-eu-innovation-funding-after-signing-grant-agreements/2-1-1572279 (last accessed: 25 May 2024).

Hydrogen Insight (2023c): Germany extends flagship H2 Global green hydrogen purchasing scheme to all EU member states, available online: https://www.hydrogeninsight.com/policy/germany-extends-flagship-h2-global-green-hydrogen-purchasing-scheme-to-all-eu-member-states/2-1-1459130 (last accessed: 25 May 2024).

Hydrogen Insight (2023d): Netherlands plans green hydrogen import auction by early 2024, backed by €300m of subsidies, available online: https://www.hydrogeninsight.com/policy/netherlands-plans-green-hydrogen-import-auction-by-early-2024-backed-by-300m-of-subsidies/2-1-1435546 (last accessed: 25 May 2024).

Hydrogen Insight (2023e): EDP set to delay FIDs on green hydrogen projects as promised funding from Spanish government fails to materialize, available online: https://www.hydrogeninsight.com/production/edp-set-to-delay-fids-on-green-hydrogen-projects-as-promised-funding-from-spanish-government-fails-to-materialise/2-1-1481616 (last accessed: 25 May 2024).

Hydrogen Insight (2023f): Green and blue hydrogen producers can break free of subsidies as soon as 2030: Deloitte, available online: https://www.hydrogeninsight.com/production/green-and-blue-hydrogen-producers-can-break-free-of-subsidies-as-soon-as-2030-deloitte/2-1-1466872 (last accessed: 25 May 2024).

Hydrogen Insight (2023g): European green hydrogen projects are being delayed due to torturously slow EU subsidy processes, say developers, available online: https://www.hydrogeninsight.com/policy/european-green-hydrogen-projects-are-being-delayed-due-to-torturously-slow-eu-subsidy-processes-say-developers/2-1-1483308 (last accessed: 25 May 2024).

Hydrogen Insight (2023h): 'Reality check' Hydrogen developers walk back large-scale ambitions this decade, available online: https://www.hydrogeninsight.com/production/-reality-check-hydrogen-developers-walk-back-large-scale-ambitions-this-decade/2-1-1524707 (last accessed: 25 May 2024).

Hydrogen Insight (2024a): This Shell-backed project to ship vast volumes of liquid green hydrogen from Portugal to the Netherlands has been scrapped April 2024, available online: https://www.hydrogeninsight.com/production/exclusive-this-shell-backed-project-to-ship-vast-volumes-of-liquid-green-hydrogen-from-portugal-to-the-netherlands-has-been-scrapped/2-1-1621919 (last accessed: 25 May 2024).

Hydrogen Insight (2024b): Engie delays 4GW green hydrogen target by five years, due to slower-than-expected industry progress, available online:

https://www.hydrogeninsight.com/production/engie-delays-4gw-green-hydrogen-target-by-five-years-due-to-slower-than-expected-industry-progress/2-1-1605256 (last accessed: 25 May 2024).

Hydrogen Insight (2024c): EU to fast-track 65 hydrogen projects after signing energy infrastructure list into law, available online: https://www.hydrogeninsight.com/policy/eu-to-fast-track-65-hydrogen-projects-after-signing-energy-infrastructure-list-into-law/2-1-1623079 (last accessed: 25 May 2024).

Hydrogen Insight (2024d): Hydrogen pipeline network would cost customers 87% more to use than existing gas grid: study, available online: https://www.hydrogeninsight.com/policy/hydrogen-pipeline-network-would-cost-customers-87-more-to-use-than-existing-gas-grid-study/2-1-1623816 (last accessed: 25 May 2024).

Hydrogen Insight (2024e): Germany’s €20bn hydrogen pipeline network delayed until 2037 as coalition parties agree on financing structure, available online: https://www.hydrogeninsight.com/policy/germany-s-20bn-hydrogen-pipeline-network-delayed-until-2037-as-coalition-parties-agree-on-financing-structure/2-1-1623153 (last accessed: 25 May 2024).

Hydrogen Insight (2024f): Denmark agrees to finance hydrogen pipeline network — if sector meets five conditions, available online: https://www.hydrogeninsight.com/policy/denmark-agrees-to-finance-hydrogen-pipeline-network-if-sector-meets-five-conditions/2-1-1622183 (last accessed: 25 May 2024).

Hydrogen Insight (2024h): Cost of hydrogen mobility is 'sky high', says Stellantis CEO, two months after introducing eight new H2 van models, available online: https://www.hydrogeninsight.com/transport/cost-of-hydrogen-mobility-is-sky-high-says-stellantis-ceo-two-months-after-introducing-eight-new-h2-van-models/2-1-1621183 (last accessed: 25 May 2024).

Hydrogen Insight (2024i): Uniper delays major offshore-wind green hydrogen project to end of decade, hands back EU subsidies, available online: https://www.hydrogeninsight.com/production/exclusive-uniper-delays-major-offshore-wind-green-hydrogen-project-to-end-of-decade-hands-back-eu-subsidies/2-1-1620287 (last accessed: 25 May 2024).

IEA (2023): Global Hydrogen Review 2023, available online: https://iea.blob.core.windows.net/assets/cb9d5903-0df2-4c6c-afa1-4012f9ed45d2/GlobalHydrogenReview2023.pdf (last accessed: 25 May 2024).

IRENA (2023): Renewable power generation costs in 2022, available online: https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022 (last accessed: 25 May 2024).

Le Blanc, Bart (2023): Potential conflicts between the European CBAM and the WTO rules, Norton Rose Fulbright, available online: https://www.nortonrosefulbright.com/en/knowledge/publications/9c5d9ec6/potential-conflicts-between-the-european-cbam-and-the-wto-rules (last accessed: 25 May 2024).

Kozul-Wright, Richard and **Fortunato**, Piergiuseppe (2020): Managing Trade through Productive Integration: Industrial Policy in an Interdependent World, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 237-265.

Martin et al. (2024): Conflicts of interest: the cost of investing in the energy transition in a high interest-rate era, Wood Mackenzie, Horizons, available online: https://www.woodmac.com/horizons/energy-transition-investing-in-a-high-interest-rate-era/ (last accessed: 25 May 2024).

Mazzucao, Mariana and **Kattel**, Rainer (2020): Grand challenges, industrial policy, and public value, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 311-336.

Mazzucato, Mariana et al. (2015): Which industrial policy does Europe need?, Intereconomics, Vol. 50, Iss. 3, pp. 120-155, available online: https://www.intereconomics.eu/contents/year/2015/number/3/article/which-industrial-policy-does-europe-need.html (last accessed: 25 May 2024).

McKinsey (2020): How the European Union could achieve net-zero emissions at net-zero cost, Report, available online: https://www.mckinsey.com/capabilities/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost#/ (last accessed: 25 May 2024).

McWilliams et al. (2024): The Letta report: an assessment of the energy proposals, Bruegel, available online: https://www.bruegel.org/first-glance/letta-report-assessment-energy-proposals (last accessed: 25 May 2024).

Mingo, Santiago and **Khanna**, Tarun (2013): Industrial policy and the creation of new industries: evidence from Brazil’s bioethanol industry, Industrial and Corporate Change, pp. 1–32, available online: https://wcfia.harvard.edu/files/wcfia/files/ind_corp_change-2013-mingo-icc_dtt039.pdf (last accessed: 25 May 2024).

NautaDutilh (2023): Final ruling of the Dutch Council of State in Porthos nitrogen case, available online: https://www.nautadutilh.com/en/insights/final-ruling-of-the-dutch-council-of-state-in-porthos-nitrogen-case/ (last accessed: 25 May 2024).

Norton Rose Fulbright (2024): EU scales up green subsidies: How you can benefit from new support for clean investments, Publication, available online: https://www.nortonrosefulbright.com/en/knowledge/publications/b01d19d5/eu-scales-up-green-subsidies-how-you-can-benefit-from-new-support-for-clean-investments (last accessed: 25 May 2024).

Ocampo, José Antonio (2020): Industrial Policy, Macroeconomics, and Structural Change, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 62-92.

Oqubay, Arkebe (2020a): The Oxford Handbook of Industrial Policy, Oxford University Press.

Oqubay, Arkebe (2020b): The Theory and Practice of Industrial Policy, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 17-60.

Pack, Howard and **Saggi**, Kamal (2006): Is there a case for industrial policy? A critical survey, World Bank Research Observer, 21(2), 267–297, available online: https://documents1.worldbank.org/curated/en/288741468326136798/pdf/767620JRN0WBRO00Box374387B00PUBLIC0.pdf (last accessed: 25 May 2024).

Porthos (2023)**:** First CO2 storage project in the Netherlands is launched, available online: https://www.porthosco2.nl/en/first-co2-storage-project-in-the-netherlands-is-launched/ (last accessed: 25 May 2024).

Ramdoo, Isabelle (2016): Do international trade rules prevent local content policies? ECDPM, available online: https://ecdpm.org/work/shifts-in-trade-development-volume-5-issue-6-december-2016-january-2017/do-international-trade-rules-prevent-local-content-policies (last accessed: 25 May 2024).

Reinert, Erik (2020): Industrial Policy: A Long-term Perspective and Overview of Theoretical Arguments, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 506-554.

Roberts, Simon (2020): Enterprises and Industrial Policy: Firm-based Perspectives, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 150-177.

Sapir, André (2024): US tariffs on Chinese imports: managed trade is back, Bruegel, available online: https://www.bruegel.org/first-glance/us-tariffs-chinese-imports-managed-trade-back (last accessed: 25 May 2024).

Sekera, June, and **Lichtenberger**, Andreas (2020): Assessing Carbon Capture: Public Policy, Science, and Societal Need. A Review of the Literature on Industrial Carbon Removal, Biophysical Economics and Sustainability, 5:14, available online: https://link.springer.com/article/10.1007/s41247-020-00080-5 (last accessed: 25 May 2024).

Sen et al. (2022): The Color Palette of the Colorless Hydrogen, The Way Ahead, available online: https://jpt.spe.org/twa/the-color-palette-of-the-colorless-hydrogen (last accessed: 25 May 2024).

Storm, Servaas (2020): Macro-Policy, Labour Markets, and Industrial Policy, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 451-484.

Tagliapietra, Simone and **Veugelers** Reinhilde (2020): A green industrial policy for Europe, Bruegel Blueprint Series 31, available at: https://www.bruegel.org/sites/default/files/wp_attachments/Bruegel_Blueprint_31_Complete_151220.pdf (last accessed: 25 May 2024).

Weiss, John (2020): Neoclassical Economic Perspectives on Industrial Policy, in: Oqubay et al. (eds.): The Oxford Handbook of Industrial Policy, Oxford University Press, pp. 125-149.

Widuto, Agnieszka, **Evroux**, Clément and **Spinaci**, Stefano (2023): From growth to 'beyond growth': Concepts and challenges, EPRS Briefing, available online: https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2023)747107 (last accessed: 25 May 2024).

WTO, Agreement on Subsidies and Countervailing Measures (“SCM Agreement”), available online: https://www.wto.org/english/tratop_e/scm_e/subs_e.htm (last accessed: 25 May 2024).

Zuleeg, Fabian (2017): Why the EU will have an industrial policy – but not necessarily a good one. EPC Commentary, available at: https://www.epc.eu/en/Publications/Why-the-EU-will-have-an-industrial-policy--but-not-necessarily-a-good~1d82b0 (last accessed: 25 May 2024).

Annexes

Annex 1. Technical note on H2 and carbon CCS technologies and investment efficiency.

Hydrogen (H2). H2 shares many properties with electricity. H2 refers to a simple molecule composed of two hydrogen atoms bound together and having the potential to release energy (electricity or heat) through chemical reaction, much like electricity refers to the presence of electrons having the potential to release energy (electricity or heat) through their movement through a conductive material. H2 is thus a form of energy storage, able to release heat through combustion reaction or electricity through electrochemical reaction. In both cases, the basic reaction involves hydrogen (H_2) reacting with oxygen ($\frac{1}{2} O_2$) to form water (H_2O). Like electricity, H2 is thus an energy carrier. Much like electricity can be stored (in batteries), H2 can be stored (in compressed form) before it can be used. Both carriers have their limitations: storing electricity requires heavy batteries (high volume density; low mass density), while storing H2 requires space (high mass density; low volume density). Both storages tend to be costly: batteries are expensive due to the amount of material involved, while storing H2 is expensive because compression requires energy. Electricity is generally cheaper to produce and more expensive to store (especially for long term storage), while H2 is more expensive to produce and easier to store (especially for short term storage). This makes both energy carriers, in theory at least, somewhat complementary. Unlike electricity which is directly generated from physical motion using a generator, H2 needs to be converted from another energy form before it can be transported, stored, and used. Two conversion methods are commonly used to generate H2. The first method is through the thermochemical reforming of methane – typically natural gas – into hydrogen ($CH_4 + O_2 = 2H_2 + CO_2$) which emits one molecules of carbon dioxide per two molecules of hydrogen. The second method is through the application of electrical current to water molecules which results in their splitting into hydrogen and oxygen (H_2O + electricity = H2 + ½ O2). The first method is a direct conversion from one molecule (methane, typically of fossil origin, but also possible from biomethane of renewable origin) to another, while the second is the transfer of energy from electrons to an energy-dense molecule. A main issue with H2 especially is that each conversion from electricity into H2 (for storage and transport) and potentially from H2 back into electricity (for end use) causes a loss of efficiency. The efficiency of an electrolyzer is around 70-80% depending on the technology while that of a fuel cell is around 40-60%. In contrast, the efficiency storing electricity into batteries is around 80-90%. When used for transport for instance, the total *Well to Wheel* efficiency has been comparable to internal combustion engines (around 30%) and is well below what is achievable through battery electric vehicles (80%). This physical limitation means that 1) H2 use should be prioritized where fewer conversions to and from electricity are needed, and 2) R&D can raise the hopes that efficiency of electrolysis and fuel cell technologies be increased over time through technological improvements.

Carbon capture and storage (CCS). Anthropogenic CO2 is one of the major threats to climate change because of its effects as greenhouse gas when released in the atmosphere. Because of low concentrations in the atmosphere and the inert (non-reactive) nature of CO2, once released it is very difficult and costly to remove. As a justification for undertaking large-scale CCS projects in hard-to-abate stationary heavy industrial sectors (such as steelmaking, cement, oil refining and oil-based products), let us consider the case of CO2 emissions reduction by the switch from internal combustion to battery electric passenger vehicles. From an investment perspective, with a premium of around 10 thousand euros the purchase of a battery electric vehicle is expected to save around 20 tons of CO2 emissions over the vehicle's lifetime.[123] The efficiency of that investment is 2 kg of CO2 avoided per euro invested. Let us now consider a large-scale CCS project like Porthos in the Netherlands, which is expected to cost 1.3 billion euros and save 37 million tons of CO2 over the project's lifetime.[124] The efficiency of that investment is 28 kg of CO2 avoided per euro invested. Setting aside project risks including environmental concerns, the Porthos project represents a dramatically more efficient investment than subsidizing the cost difference between internal combustion and battery-electric vehicles. The simplistic analysis above is not to discard the need to decarbonize the passenger vehicle sector. Instead, when selecting projects purely from a CO2 abatement efficiency perspective (i.e., discarding any elements of security of supply or systems integration), large CCS projects as well as the development of alternative CCU and DAC technologies are justified as one of the cost-effective decarbonization levers for hard-to-abate industrial sectors which, by definition, are otherwise hard to decarbonize using electrification or low-carbon fuels.

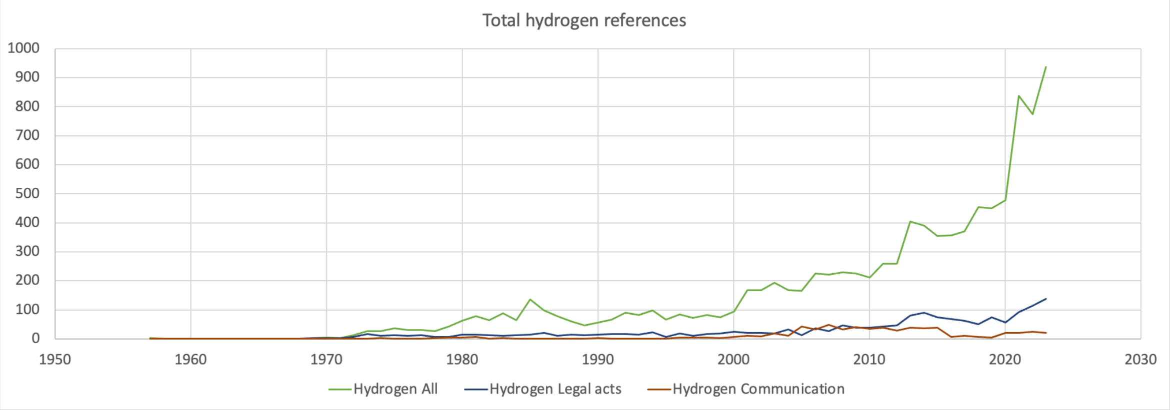
---

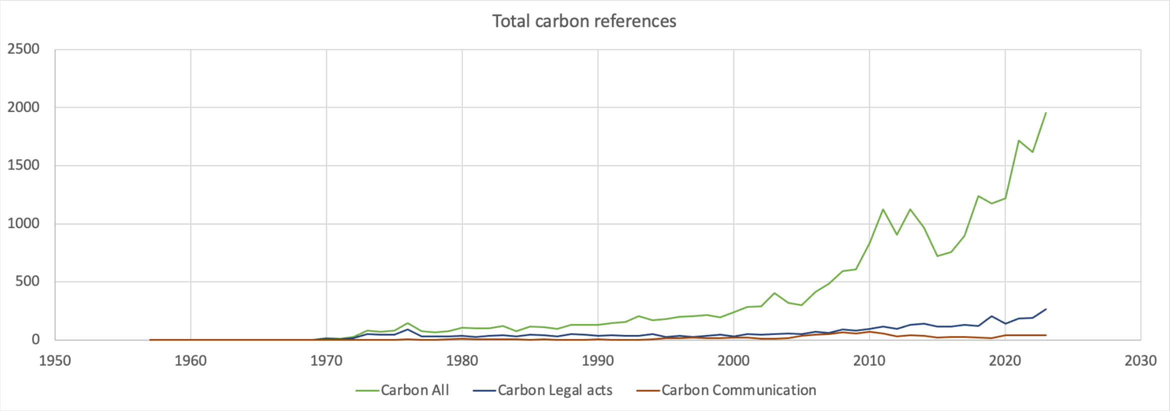
[123] EIA 2021: https://www.iea.org/data-and-statistics/charts/comparative-life-cycle-greenhouse-gas-emissions-of-a-mid-size-bev-and-ice-vehicle

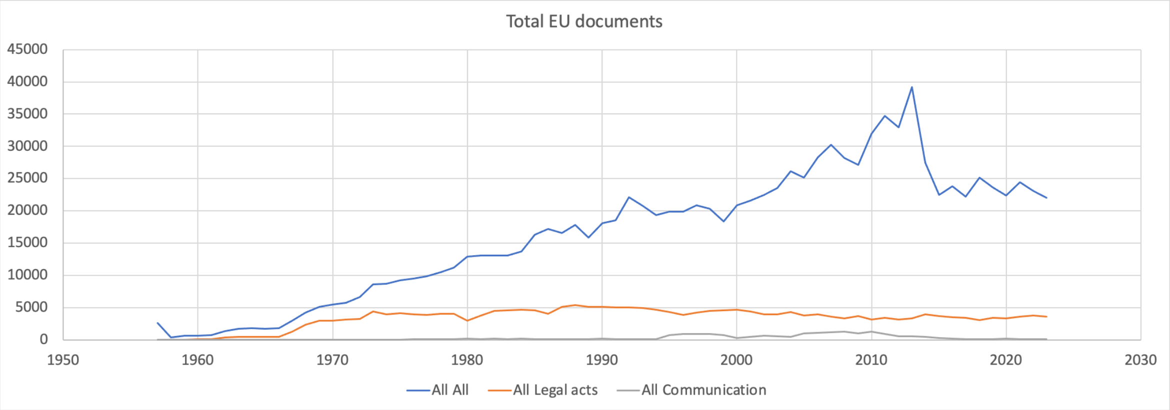
[124] Porthos CO2 Transport and Storage: https://www.porthosco2.nl/en/project/

Annex 2. Outcome of search performed on EUR-Lex related to the occurrence of hydrogen-related and carbon capture-related terms.

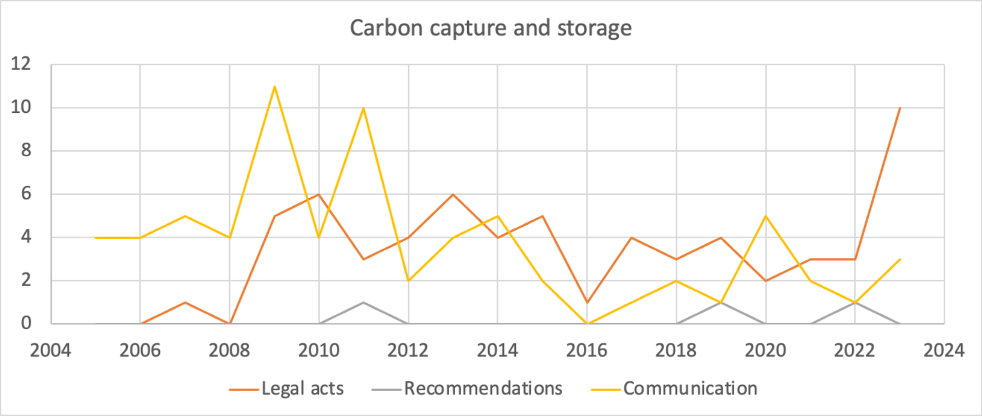
Hydrogen and carbon references:

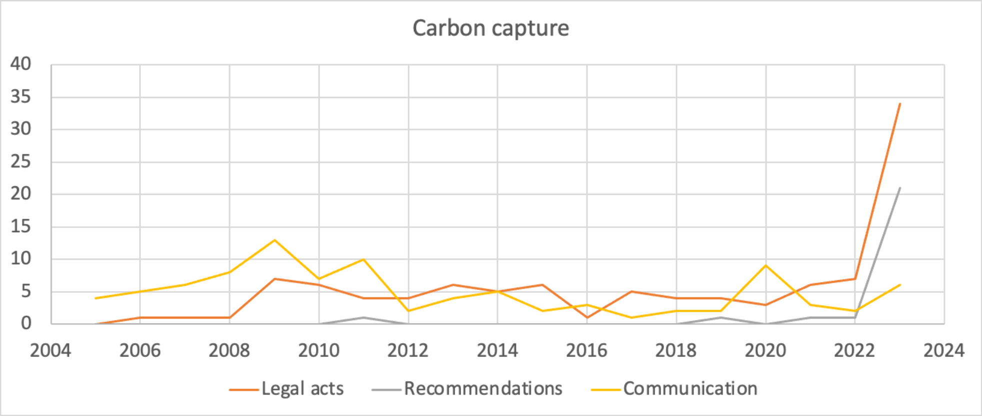


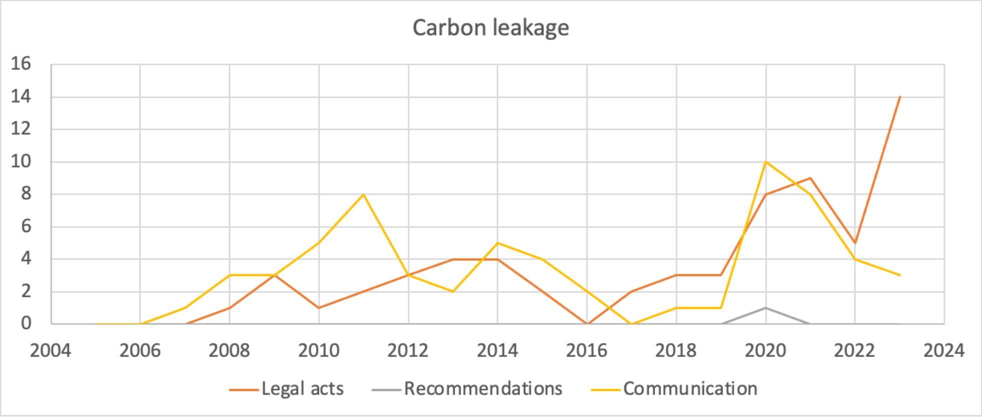




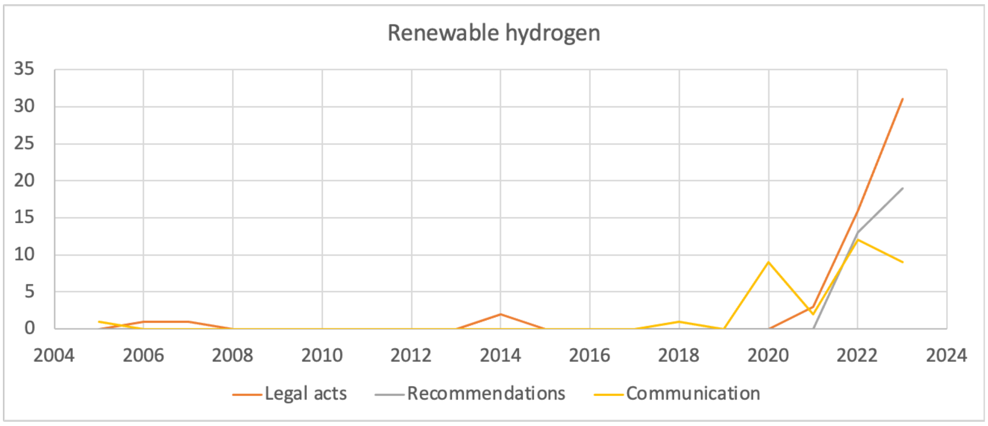
Carbon term:

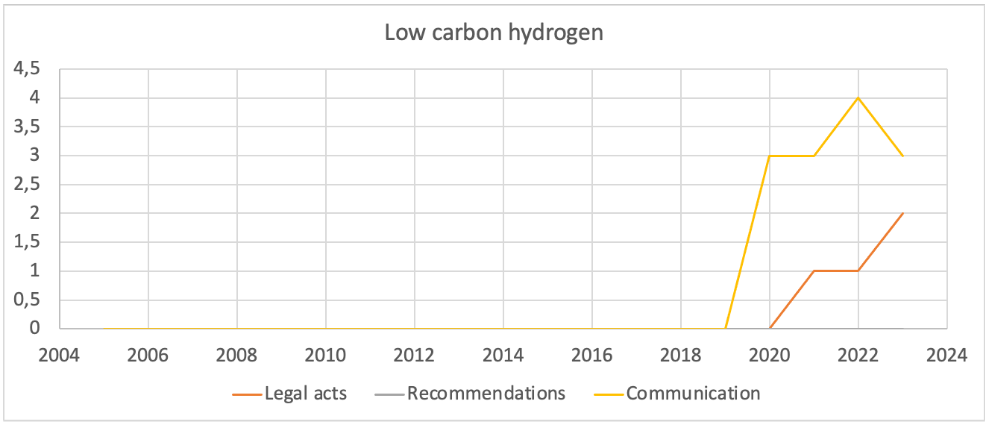

Carbon capture and storage
12
10
8
6
4
2
0
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Legal acts
Recommendations
Communication

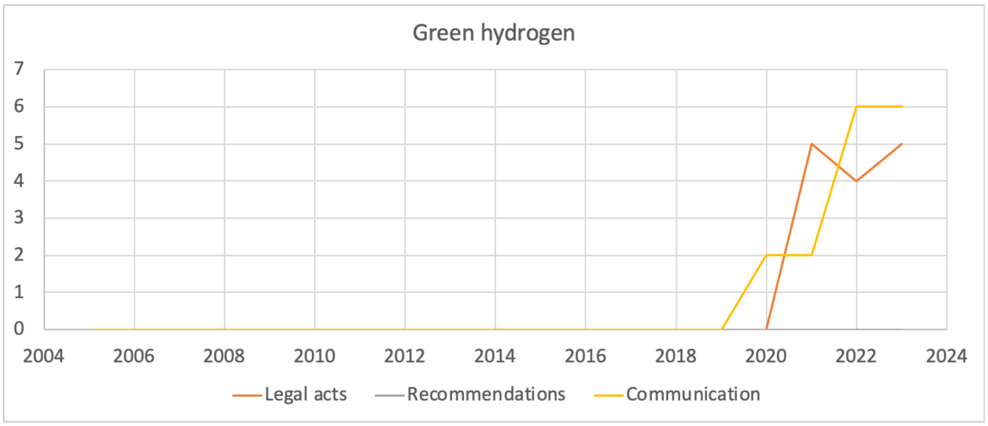

Carbon capture
40
35
30
25
20
15
10
5
0
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Legal acts
Recommendations
Communication

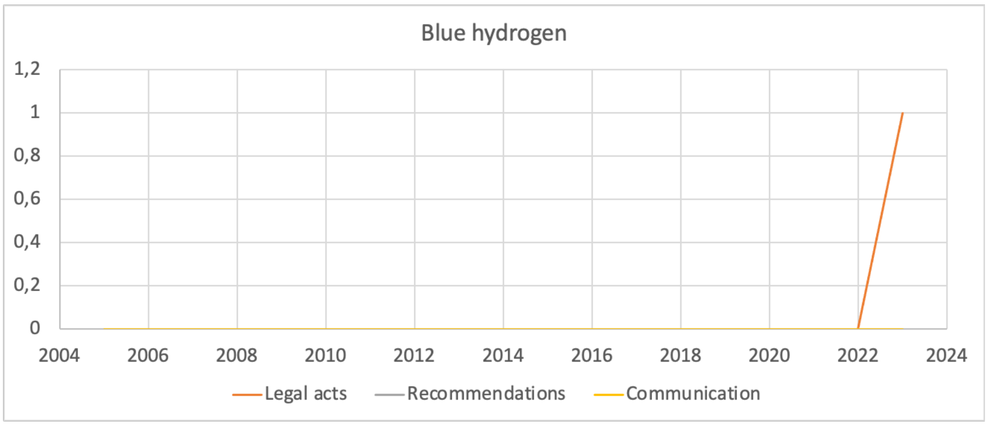

Carbon leakage
16
14
12
10
8
6
4
2
0
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Legal acts
Recommendations
Communication

Hydrogen term:









Annex 3. Market capitalization of selected companies

List of selected EEA-based *Pure Hydrogen* companies specialized in renewable hydrogen, including providers of electrolysis technology (1-16) and integrators (17-20).

#	Name	Origin	Fouding	Public	IPO in last 5 years	Market cap mid April 2024, mEUR	Technology
1	John Cockerill	Belgium	1817	No			Alkaline
2	Nel	Norway	1927	Yes	Yes	674	Alkaline, Proton electron membrane
3	Haldor Topsoe	Denmark	1940	No			Solid oxide
4	H-Tec Systems	Germany	1997	No			Proton electron membrane
5	ITM Power	UK	2001	Yes	No	368	Proton electron membrane
6	Green Hydrogen Systems	Denmark	2007	Yes	Yes	216	Alkaline
7	McPhy	France	2007	Yes	No	52	Proton electron membrane
8	Sunfire	Germany	2010	No			Alkaline, Solid oxide
9	HydrogenPro	Norway	2013	Yes	Yes	69	Alkaline
10	Thyssenkrupp Nucera	Germany	2015	Yes	Yes	1480	Alkaline
11	Stiesdal	Denmark	2016	No			Alkaline
12	Enapter	Italy	2017	Yes	Yes	142	Alkaline
13	Siemens Energy	Germany	2020	Yes	Yes	14140	Proton electron membrane
14	Genvia	France	2021	No			Solid oxide
15	Hystar	Norway	2020	No			Proton electron membrane
16	Stargate Hydrogen	Estonia	2021	No			Solid oxide
17	Ariema	Spain	2002	No			Integrator
18	H2B2	Spain	2016	No			Integrator
19	Lhyfe	France	2017	Yes	Yes	196	Integrator
20	Gen2 Energy	Norway	2019	No			Integrator

List of selected companies operating in other segments or from non-EEA locations:

Oil and Gas	1	BP
	2	ENI
	3	Equinor
	4	Total
	5	Shell
Renewable Energy	1	EDP
	2	EON
	3	Iberdrola
	4	Orsted
	5	RWE
	6	Vestas
Non-EEA Pure Hydrogen	1	Bloom Energy
	2	Cummins
	3	Longi
	4	Plug Power
	5	Sungrow