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France's Green Horizon: Supply-Side Drivers for a Competitive Transition in Export Markets

Cristina Peñasco[1]

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Abstract

France's green transition offers a unique lens into the interplay between decarbonisation strategies and industrial competitiveness within the context of a high-income economy. As a major European economy, France stands at a critical moment in balancing its reliance on nuclear power with the acceleration of renewable energy adoption and fostering green industrial innovation. This is relevant as the country faces increasing pressure to align with the EU's 2050 carbon-neutrality goals while addressing domestic challenges, including fiscal constraints. This study employs a descriptive methodology based on a comparative analysis of indicators. By analysing indicators such as R&D spending, patenting trends, renewable energy costs, and green export shares, the paper assesses France's green goods export competitiveness, industrial strengths, energy transition inputs, and transition risks relative to other G7 nations, China, and Spain. The findings reveal that while France benefits from strong nuclear infrastructure and high Green Complexity Potential, its share in global green exports has declined—from 4.7% in 2000 to 2.5% in 2022. Furthermore, lagging renewable energy deployment, limited fiscal support, and gaps in green innovation suggest that France risks falling behind some European counterparts, such as Germany or Italy, in achieving leadership in the green transition. However, opportunities exist in high-complexity sectors such as hydrogen, environmental monitoring, and carbon capture technologies, where France's existing capabilities can drive competitiveness and export growth. Its participation in a single European green good export market is a key strategy to strengthen a competitive transition in France and Europe more widely.

Keywords: Green Transition, Industrial Competitiveness, Exports, Decarbonization, Green Innovation

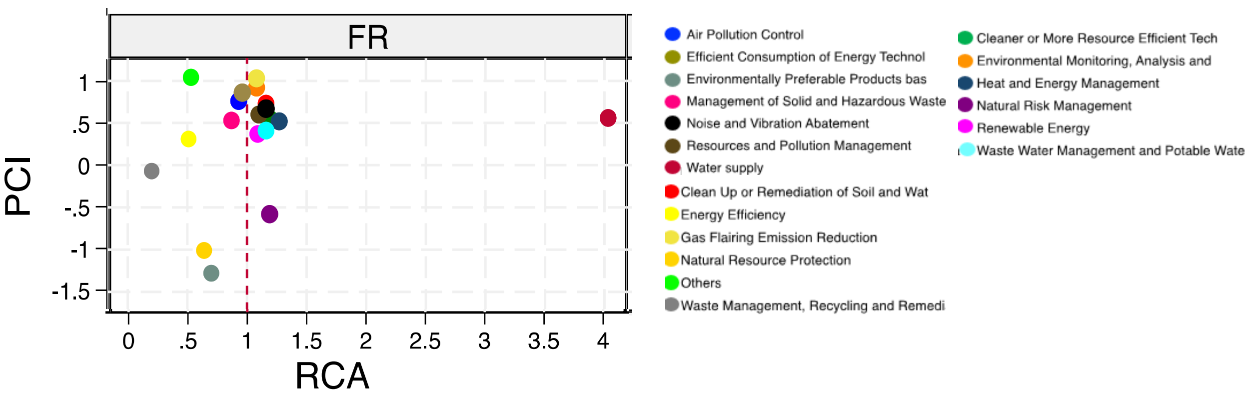
JEL classification: G28, G21

[1] Centre for Climate and Nature (CCN), DGSO – DSF, Banque de France, cristina.penascopaton@banque-france.fr.

NON-TECHNICAL SUMMARY

France's transition to a low-carbon economy offers insight into the complex balance between reducing carbon emissions and maintaining industrial competitiveness in a high-income economy. As a major EU economy, France must align its reliance on nuclear power with the need to expand renewable energy and foster green innovation. These efforts are crucial for meeting the EU's 2050 carbon-neutrality goals while addressing domestic challenges, such as fiscal limitations and slow renewable energy deployment. This paper focuses on how France can enhance its competitiveness in green manufactured goods export markets as part of its broader transition. Using a descriptive comparative methodology, it examines key indicators like R&D investments, patenting trends, renewable energy costs, and manufactured green goods export shares assessing France's performance, from a supply-side perspective, relative to other G7 nations, China, and Spain. The study highlights risks if France fails to close gaps in renewable and innovation, while identifying sectors with high growth potential from a green good exports angle. The recent Draghi report underscores urgency of evaluating European competitiveness amid global sustainability shifts. This paper complements the report by examining France's position in the European green economy and its ability to contribute to and benefit from this transition. France's declining green manufacture goods export share reflect broader challenges and stress the need for coordinated policy and industrial efforts. A key contribution is the exploration of France's role in a potential unified European green export market, highlighting the benefits of economic integration.

France maintains a low-carbon electricity system, with 65% of its electricity generated from nuclear energy. However, its adoption of renewable energy remains limited. Despite fiscal constraints, France aims to expand its renewable energy capacity by 2030. Targets include 54-60 gigawatts (GW) of solar photovoltaic capacity and 34.7 GW of onshore wind power. Achieving these goals requires improved infrastructure, streamlined permitting, and advanced energy storage. France's strengths lie in its nuclear infrastructure and high Green Complexity Potential", which measures its ability to diversify into advanced green industries. The country has shown strong capabilities in sectors like hydrogen and environmental monitoring, supported by consistent R&D investments. Still, its global green good export share fell from 4.7% in 2000 to 2.5% in 2022, revealing a gap between innovation and market performance. Greater participation in an integrated European green goods market could amplify France's efforts and competitiveness in global value chains. France faces significant opportunities in green technology sectors, including: hydrogen technologies, environmental monitoring. Areas like carbon capture and renewable energy systems offer also opportunities for growth but require stronger policy and industrial support. The country's fiscal challenges could hinder progress. Addressing these challenges will require targeted investments, policy reforms, and a focus on translating innovation into industrial and export strengths. With clear strengths in innovation and industry, the country must now close gaps in deployment and export competitiveness. By leveraging its high-complexity sectors and improving frameworks, France can reinforce its role in the European and global green economy.



L’horizon vert de la France : les moteurs d’offre pour une transition compétitive dans les marchés d’exportation

RÉSUMÉ

La transition écologique de la France offre une perspective unique sur l'interaction entre les stratégies de décarbonation et la compétitivité industrielle dans une économie à haut revenu. En tant que grande économie européenne, la France se trouve à un moment crucial, devant concilier sa dépendance à l’énergie nucléaire avec l’accélération de l’adoption des énergies renouvelables et la promotion de l’innovation industrielle verte. Cela est d’autant plus pertinent que le pays subit une pression croissante pour s’aligner sur les objectifs de neutralité carbone de l’UE à l’horizon 2050, tout en faisant face à des défis internes, notamment des contraintes budgétaires. En analysant des indicateurs tels que les dépenses en R&D, les tendances en matière de dépôts de brevets, les coûts des énergies renouvelables et la part des exportations de biens verts, cette étude évalue la compétitivité des exportations françaises de biens verts, les atouts industriels du pays, les intrants de la transition énergétique et les risques associés, en comparaison avec les autres pays du G7, la Chine et l’Espagne. Les résultats montrent que, bien que la France bénéficie d’une infrastructure nucléaire solide et d’un fort potentiel de complexité verte, sa part dans les exportations mondiales de biens verts a diminué, passant de 4,7 % en 2000 à 2,5 % en 2022. En outre, le retard dans le déploiement des énergies renouvelables, le soutien budgétaire limité et les lacunes en matière d’innovation verte indiquent que la France risque d’être dépassée par certains de ses homologues européens, comme l’Allemagne ou l’Italie, en matière de leadership dans la transition écologique. Cependant, des opportunités existent dans des secteurs à forte complexité, tels que l’hydrogène, la surveillance environnementale et les technologies de captage du carbone, où les capacités existantes de la France peuvent stimuler sa compétitivité et la croissance de ses exportations. Sa participation à un marché unique européen des biens verts constitue une stratégie clé pour renforcer une transition compétitive en France et à l’échelle européenne.

Mots-clés : transition verte, compétitivité industrielle, exportation, décarbonation, innovation verte

1. Introduction

In recent years, the global economy has seen a shift towards sustainability, urged by the need to address climate change and environmental degradation. As the European Union embarks on its ambitious journey towards becoming carbon-neutral by 2050 outlined in the European Green Deal (European Commission, 2019), the role of member states becomes fundamental. This objective necessitates an important move towards clean and renewable energy sources, increased energy efficiency, and innovative technologies across all sectors of the economy. To successfully navigate this transition, a simultaneous focus on competitiveness, green innovation and technological change is needed. This balanced approach aligns with the recent Draghi report's emphasis on boosting Europe's competitiveness and productivity to ensure that the region can lead in innovation and sustainability, and securing a resilient economic future in the face of global challenges (Draghi, 2024). The aforementioned shift goes beyond the environmental urgency, presenting a tangible and necessary potential for economic benefit.

The modern concept of "green growth" (Bowen and Hepburn, 2014; Fouquet, 2019; among others) and before that, the Porter Hypothesis (Porter and Linde, 1995) in its strong version, embraced the possibility of wealth, competitiveness and well-being without ignoring the limits set by our environment (Stoknes and Rockström 2018; Zenghelis et al. 2022). Citing Buiter et al. (2020), Zenghelis et al. (2022) conclude that when public funds are allocated to enhance the efficacy of public infrastructure or to augment the productivity of private assets, this can propel economic growth and increase tax revenue. Therefore, it is key to direct investments toward assets that not only boost productivity but also hold substantial promise in the emerging markets shaped by carbon constrains, ensuring their value is not diminished over time (Aghion et al. 2016).

In this context, the transition to a greener economy presents both economic opportunities and structural challenges for advanced economies (Zenghelis et al. 2024). France, as one of Europe's leading industrial nations, is at a crossroads, seeking to balance competitiveness, industrial transformation, and sustainability goals. Despite a high debt-to-GDP ratio, France with its unique potential strengths i.e. technological innovation, decarbonised energy, a strong welfare state, and a privileged access to EU markets (Filer and Peñasco, 2024); provides a compelling case study for examining the dynamics of this transition in a context of fiscal and budgetary contraints. The austerity measures introduced in the 2025 budget have led to decreased funding for various ecological initiatives. The 2025 Finance Act introduces significant cuts to France's green funding, notably, the Green Fund, which supports local authority projects for ecological transition. Additionally, aid for the electric vehicle fleet conversion has been reduced by €800 million over two years, further limiting resources for sustainable mobility (Gouvernment France, 2024). These budgetary constraints may jeopardize the progress of local climate initiatives and underline the tension between fiscal prudence and ecological ambitions.

With the European Union's target of achieving carbon neutrality by 2050, France must not only decarbonise its energy system but also maintain export competitiveness in manufactured goods—a critical component of its economic resilience. To understand how France can transition effectively to a competitive green economy while fostering innovation and reducing emissions and reliance on fossil fuels, this paper uses a descriptive methodology in two steps. First, it analyses the current transition landscape of France with a focus on supply-side indicators of different phases of the innovation process including research and development (R&D) investment, patents and decarbonised energy supply. Second, it evaluates France's export competitiveness in manufacturing by analysing supply-side factors related to industrial policy, and complexity potential, comparing its trajectory with other G7 nations, China, and Spain.

Exports play a central role in France's economy, contributing approximately 34.28% of its Gross Domestic Product (GDP) in 2023 (World Bank, 2025). Specifically, exports of goods alone accounted for about 23% of GDP. The composition of these exports is dominated by manufactured products, with transport equipment (23%), mechanical equipment, electronic and computer equipment (19%), and chemicals, perfumes, and cosmetics (12%) leading the sectors. In this context, understanding how France can leverage its existing industrial strengths while navigating transition risks is essential. Specifically, following the methodology and data on green products/categories collected by Andres and Mealy (2023) in the Green Transition Navigator, this study aims to explore the productive capabilities, export competitiveness and diversification-potential of France within the framework of a green economy. Using the classification of Andres and Mealy (2023), we identify the green categories of products that are best placed to become competitive in the export market of France. Then, we provide (industrial) policy guidelines that may help the country to transform its manufactured goods export markets in the context of the transition to decarbonised economies while at the same time fostering economic competitiveness (See e.g. Rodrik, 2014; Draghi, 2024). By examining the composition of France's manufactured exports, we aim to assess whether and where, in a context of fiscal constraints where choices may need to be made (Anadon et al., 2022); the country is well-positioned to capitalize on the global shift towards sustainable production and trade.

This document is structure as follows. First, it includes an overview of the current decarbonisation targets and transition strategy in France. Section 3 includes the main data and methods used to analyse both supply-side factors and green competitiveness potential of France. The reamaining sections show first, the main results of a comparative analysis of the energy transition landscape for France considering the main inputs for a successful transition as e.g. R&D expenditures, patents or cost reductions in green technology and deployment; and second, the green competitiveness outlook of the country in comparison to other G7 economies plus China and Spain. Finally, section 6 concludes with a short discussion.

2. Overview of decarbonisation targets and transition strategy in France

France’s energy transition is embedded within a regulatory and institutional landscape, shaped by both domestic policies and European Union directives. As a leading EU economy, France plays a crucial role in meeting the European Green Deal’s objective of achieving carbon neutrality by 2050 (European Commission, 2019). The National Energy and Climate Plans (NECPs) serve as a principal framework for EU Member States to define their climate and energy ambitions, strategies, and specific actions for the decade spanning 2021 to 2030. These plans, that were required to be finalized by the end of 2019, are important for providing a clear and comprehensive understanding of how the EU intends to achieve its climate and energy goals by 2030, including the collective target of a 32% share for renewable energy[1]. As such, the NECPs are a crucial tool in offering transparency and predictability to the green and renewable energy industry throughout the upcoming years. Their role is instrumental in fostering investment and catalysing economic activity and job creation within the sector.

France's pathway to decarbonizing its economy needs to balance its longstanding leadership in nuclear energy[2] with the growing commitments to renewable resources and innovation in sustainable technologies. Recognizing nuclear power as a cornerstone of its low-carbon energy supply, France continues to invest in this sector, with almost 65% of the electricity produced in

[1] This target has been updated to 42.5% of renewable energies (with an additional indicative target of 2.5% to reach 45%) in gross final energy consumption by 2030 (European Commission, 2023)

[2] France has been a leader in nuclear technology, which is considered a low-carbon energy source, although the green credentials of nuclear energy can be debated (Ferguson et al. 2010; CAN, 2024).

the country from nuclear sources in 2023, while also exploring advancements such as small modular reactors (SMRs) to address future energy needs and safety concerns (Elysee, 2021). Indeed, traditionally the amount of R&D dedicated to nuclear energy has been high in the country, representing more than half of the public R&D energy expenditure until 2021 (See section 4). In parallel, France is ramping up its renewable energy portfolio, with significant investments aimed at expanding solar and wind energy capacities, reflecting a broader European ambition towards a sustainable and resilient energy framework (Ministere de la Transition Ecologique, 2020). The most up to date targets to reduce greenhouse gas emissions and enhance renewable energy capacity are set also by the French Government on the NECP. The country aims for a 50% reduction in greenhouse gas emissions (excluding land use, land-use change, and forestry) by 2030, striving for carbon neutrality by 2050. There is a target to decrease final energy consumption by 30% in 2030 compared to 2012 levels, and to reach a primary energy consumption of 158.6 million tonnes of oil equivalent (Mtoe) in 2030, which is a reduction from 212 Mtoe in 2022. The strategy includes a significant decline in fossil fuel consumption with a 70% decrease in coal-based primary energy consumption by 2030, a 50% reduction in petroleum products, and a 40% decrease in gas-based consumption by the same year (France, 2024).

For renewable energy, France was the only Member State to miss the 2020 renewable energy target established under the EU's renewable energy directive. To correct this, France's updated NECP includes an aim to reach 54-60 gigawatts (GW) of photovoltaic (PV) capacity by 2030, with the potential to expand this to 75-100GW by 2035. For wind energy, the target is up to 34.7GW of onshore wind capacity by 2028 and increased offshore wind ambitions of 5.2-6.2GW by the same year. Yet, while the French NCEP includes particular provisions for wind and solar energy by 2030-2035, it does not include a percentage range for renewable energies, contradicting the EU’s Renewable Energy Directive (Messad, 2023). The updated version of the French NCEP (France, 2024), fails to mention a final renewable energy consumption objective for 2030, referring instead to a decarbonised energy target incorporating nuclear power. Also, to support the shift to cleaner transportation, France is promoting zero-emission vehicles with all new vehicles to be zero-emission by 2040 and estimates the deployment of 6.8 million heating and cooling units in individual homes and 2.2 million units in collective buildings by 2028.

More recently, the country has identified as an opportunity the hydrogen sector. As can be seen in Section 4 (See figure 3), substantial funding for R&D has been allocated in the last year to the hydrogen economy. Also, important funding is being allocated through the National Strategies to developing green hydrogen production and utilization across industrial and transportation sectors, marking a strategic move towards reducing greenhouse gas emissions and enhancing energy independence. France is taking significant steps toward building a carbon-neutral economy with a considerable emphasis on the role of hydrogen, particularly for sectors where reducing carbon emissions is challenging. Announced in September 2020, France's hydrogen plan aims to fast-track hydrogen development and application with an allocation of 7 billion euros from the government budget up until 2030. The focus is primarily on advancing electrolytic hydrogen production. The initiative sets an ambitious target to create a robust hydrogen ecosystem capable of generating 6.5 GW of green hydrogen within the next decade. Integral to this plan are initiatives to create regional hydrogen ecosystems, provision of financial incentives for eco-friendly hydrogen projects, and participation in global partnerships like the Clean Energy Ministerial Hydrogen Initiative. These efforts are geared towards enhancing knowledge sharing, improving best practices, and bolstering the global expansion of environmentally friendly hydrogen solutions (IEA, 2021).

Measures were further bolstered by the ‘France 2030’ Investment Plans approved by the French National Assembly in 2022. This plan includes: €8 billion allocated to the energy sector to develop small nuclear reactors (€1 billion), develop green hydrogen projects (€1.9 billion), and to decarbonise the industry (€5.6 billion). It also includes €4 billion for the transport sector to produce nearly two million electric and hybrid vehicles (€2.5 billion) and low-carbon airplanes (€1.2 billion). Additional provisions of €1 billion have also being approved to tenfold renewable power installed capacity by 2050 up to 100GW. Tax credit for research and development (R&D) were also approved in 2023. Yet, the approval of the Budget for 2025 reduces the number and type of expenses eligible for the R&D tax credits in firms, reduces the budget allocated to the green transition and includes a strong cut in the research budgets of higher education institutions (Le Monde, 2025).

3. Data and methods

3.1. Data to evaluate national level green transition input, output and outcomes in France

The analysis in this document is divided into two main set of results. First, we aim at summarizing the current transition landscape in France, in a comparative way, with a focus on the energy sector. This sector is critical as more than 70% of the global GHG emissions come from energy use, in particular, in buildings, transport and industry (Ritchie, 2020). Second, we explore France's export strengths in green products to elaborate on policy implications associated to the degree to which the country might face difficulties transitioning away from specific brown products export markets, and to the green industrial growth opportunities in export markets that align with the country's existing productive capabilities. Considering these two types of analysis, we can have an accurate overview of the transition risks and competitive advantages of France in comparison to other relevant economies around the world e.g. the other G7 countries, China or Spain[3], in its transition to become a decarbonised and cleaner economy.

For the first analysis, the data used to evaluate the current transition landscape in France was collected from a variety of sources. Indicators were obtained from Eurostat, the OECD statistic databases, the International Energy Agency, IRENA datasets, the 2024 EU Industrial R&D Investment Scoreboard and Our World in Data.

For the second part of the analysis, we rely on the comprehensive dataset of green products provided by the Green Transition Navigator (Andres and Mealy, 2023). This dataset showcases novel metrics of green competitiveness, transition risks and future green diversification potential across multiple countries and territories. Using this dataset, we are able to explore France's export strengths in green products to elaborate on policy implications associated to the degree to which the country might face difficulties transitioning away from specific brown products, and to the green industrial growth opportunities that align with its existing productive capabilities.

First, we follow the definition of the OECD (1999) that considers that "the environmental goods and services industry consists of activities which produce goods and services to measure, prevent, limit, minimise or correct environmental damage to water, air and soil, as well as problems related to waste, noise and eco-systems. This includes cleaner technologies, products and services that reduce environmental risk and minimise pollution and resource use" (OECD, 1999, p9). This definition is in line with later attempts to go further and define the concept of eco-innovation as any innovations in products and processes that diminish negative environmental impacts, regardless of whether their primary purpose is ecological (Carrillo-Hermosilla et al. 2009).

As aforementioned, we analyse the open access data and lists created by Mealy and Tyetelboym (2022). These authors developed two main green product lists. The first is a list of 295 green

[3] We add Spain to the group of countries for comparison due to the proximity with France and the cooperation needed between the two countries in regards to the energy system.

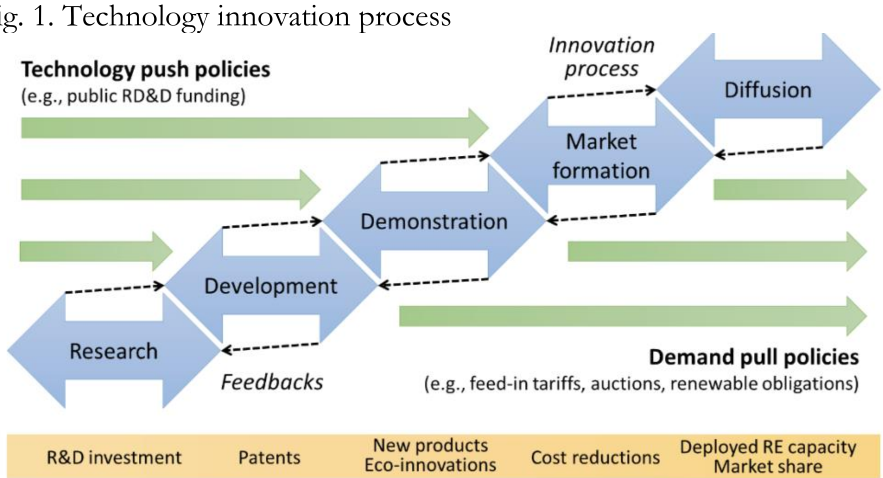
products, obtained by taking the union of the WTO Core list, OECD lists, and the APEC list. This list represents a range of environmental categories (see section 3.2), including air pollution, wastewater management, and recycling among many others. The authors also developed a smaller list of 62 renewable energy products including all products falling under the WTO Renewable Energy Products category, under the OECD's Renewable Energy Plant categories, as well as two additional APEC renewable energy products (solar heliostats and parts for solar heliostats) that were not included on either the WTO or OECD lists. The renewable energy product list focuses on low-carbon technologies that are key for addressing climate change. Using these lists, we can highlight the environmental goods and services prioritised by France[4].

3.2. Methods

To understand the extent to which the policy and regulatory landscape has been effective until now in transforming slowly the energy sector of France, we rely, as aforementioned, on an analysis of indicators and certain criteria. In particular here, and for a first historical analysis, we are focusing on indicators associated to technological effectiveness, cost-related outcomes and innovation outcomes (For a detailed definition see Peñasco and Anadon, 2018 or Peñasco et al., 2021a). For our analysis, technological effectiveness, cost saving impacts and innovation are intricately related and part of the same narrative (See Fig 1 below). To understand the extent to which innovation to foster an effective transition to decarbonise economies is needed, it is necessary to examine a range of indicators that span the entire innovation process. Focusing on just one indicator might lead to an incomplete understanding.

For the second part and more general analysis, we rely on indicators of future competitiveness, and in particular on a set of indicators that allow us to understand the opportunities for industry creation in a context of transition in France. In this study, we include a comparative analysis of three main indicators, i.e. a product complexity index (PCI) designed to measure the technological sophistication of a product or a category of products; a proximity index that measures the product's similarity to the country's productive capabilities and is correlated with the probability of developing future competitiveness in a product; and lastly a Revealed Comparative Advantage (RCA) indicator that measures if a country exports a product competitively.

Fig. 1. Technology innovation process



Source: Peñasco et al. 2021b (This figure was originally adapted from Grubler et al. 2012)

[4] The number of total products is extracted from the sector and product information section of the green transition navigator.

With these three indicators we are able to draw the Green competitive strengths of France, represented by the products or, in this case, category of green products that France already exports competitively (RCA > 1), but also the future Green opportunities that represents those categories of green products that France does not exports yet competitively (RCA <1), but could develop competitiveness due to the proximity with products and categories in which the country shows an comparative advantage. In particular, we focus on 19 green categories homogenised in the *Green Transition Navigator* (Andres and Mealy, 2023):

1. Air Pollution Control
2. Clean Up or Remediation of Soil and Water
3. Cleaner or More Resource Efficient Technologies and Products
4. Efficient Consumption of Energy Technologies and Carbon Capture and Storage
5. Energy Efficiency
6. Environmental Monitoring, Analysis and Assessment Equipment
7. Environmentally Preferable Products based on End-Use or Disposal Characteristics
8. Gas Flaring Emission Reduction
9. Heat and Energy Management
10. Management of Solid and Hazardous Waste and Recycling Systems
11. Natural Resource Protection
12. Natural Risk Management
13. Noise and Vibration Abatement
14. Others
15. Renewable Energy
16. Resources and Pollution Management
17. Waste Management, Recycling and Remediation
18. Waste Water Management and Potable Water Treatment
19. Water supply

This complexity approach is a supply-side story. While nowadays, attention is being driven towards demand, a supply-side perspective remains essential in the green transition, as it ensures that economies have the technological and productive capabilities to meet growing demand for sustainable solutions. Without supply-side investment, demand-driven shifts risk bottlenecks, inflation, or dependence on foreign producers (Semieniuk & Mazzucato, 2019). The complexity-based approach, as seen in the Green Transition Navigator, helps identify key technological capabilities for sustainable growth (Mealy & Teytelboym, 2022).

4. Energy transition landscape in France

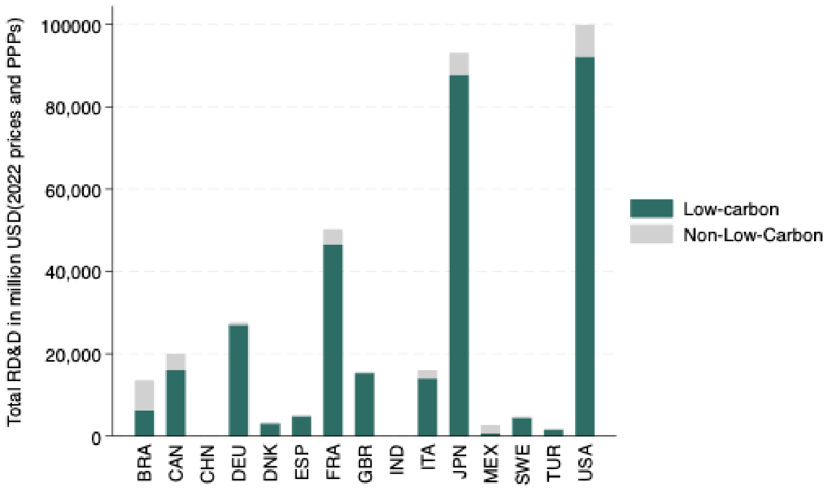
France already poses a highly decarbonised electricity sector mainly due to the large proportion of electricity generated with nuclear energy. While the reduction in emissions of France has been, as aforementioned, steadier, the new emission reduction target of 47.5% in 2030 in comparison to the 2005 levels will force the country to quickly decarbonise other sectors like transport or buildings (Gouvernment France, 2023).

4.1. R&D investments and patents (R&D&d)

To achieve a successful transition to decarbonized economies, a long-term commitment to public support and funding for green R&D is necessary (Lee & Kim, 2021). This commitment is crucial for promoting the development and deployment of technologies essential for transitioning to cleaner energy sources. Cleaner technological change supported through R&D can enhance the productivity of capital and labour, contributing to environmental sustainability and economic growth (Rubio et al., 2009). Additionally, R&D investment in renewable energy technologies has been shown to impact energy productivity (Eid et al., 2024) and total or multifactor productivity positively in empirical ex-post studies (see Garces & Daim, 2010 for the US; Lin and Xie, 2024 for renewable energy enterprises).

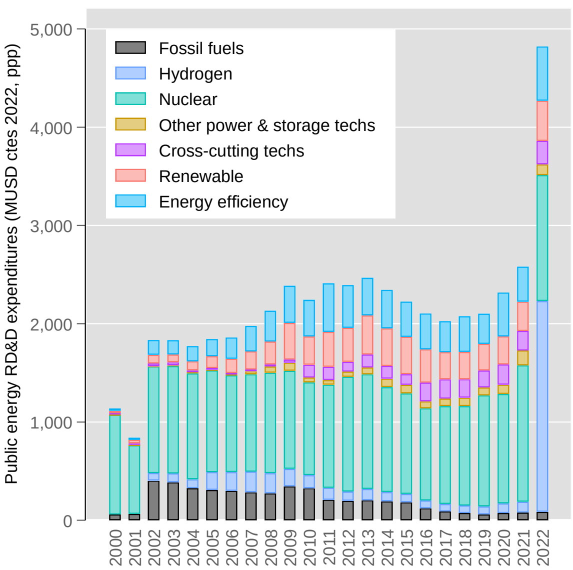
The following figures show the total public energy RD&D expenditures by France in comparison to other economies worldwide. As can be seen, the proportion of RD&D expenditures dedicated to low carbon energy sources surpass greatly that of non-low-carbon sources providing a clear signal of the innovation pathways that we will see in the years to come (Fig. 2)

Fig. 2. Total public energy RD&D expenditures (MUSD ctes 2022, ppp) by country 2000-2022.



Source: Own elaboration with data from the IEA Energy RD&D budgets. Data from 2000 until 2022, except: BRA (2013-2020), MEX (2013-2021), ESP (2000-2021), USA (2000-2015). No data availability for CHN and IND. This is Public RD&D as private is only available for AUT, ITA, CZQ and POR from 2013 onwards with an unstable pattern. Low carbon includes: energy efficiency, carbon capture and storage (CCS), renewable energy sources, nuclear, hydrogen and fuel cells, other power and storage, and other cross-cutting technologies and research. Non-low carbon includes: coal, gas, oil and other fossil fuel RD&D with the exception of CCS.

Fig. 3. Total public energy RD&D expenditures (MUSD ctes 2022, ppp) France 2000-2022.



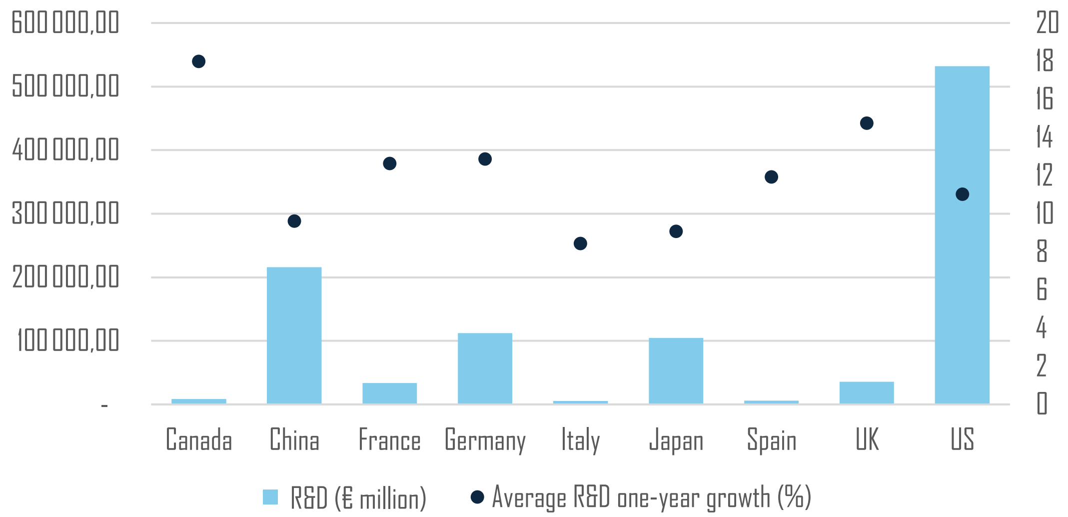
Source: Own elaboration with data from IEA (2023).

France seems to have slow down its general R&D contributions as they fell from 2.23% in 2012 to 2.18% in 2022 (See. Fig. A1 in appendix) (Eurostat, 2024). Yet, France has increased the proportion of their GDP dedicated to RD&D in energy during the last two years, reaching in 2022 a 1.3% of the GDP (IEA, 2023). As per Fig. 3, public energy RD&D expenditure reflects evolving priorities, with significant growth in funding for energy efficiency and hydrogen, particularly after 2020, while funding for renewables and nuclear remains relatively steady, with a slight decline from 2012 to 2017. This steadiness and reduction can be attributed to several factors, including economic constraints following the 2008 global financial crisis, which led to tighter public budgets, and the increasing maturity and cost-competitiveness of renewables like wind and solar. However, the significant increase in overall funding post-2017 reflects renewed urgency in addressing energy transition challenges, with an emphasis on innovation across all energy sectors to meet climate and sustainability goals.

While countries like Germany prioritized early on investments in renewable energy technologies, —mainly as a result of a greater dependency on gas imports, but also of nuclear accidents and political debates around the credentials of the technology; — countries such France with a long tradition of nuclear energy started later to redirect their RD&D expenditures towards renewable energy (Bonnet et al. 2019). Still today nuclear technologies represent more than 30% of the public energy RD&D expenditure of the country in 2022, having represented historically around 50% of the total budget. In France, the prioritization of non-emitting energy technologies in R&D policies is clear as only around 2% of the budget for RD&D energy technologies is dedicated now to fossil fuels (IEA, 2021).

Yet, public investments on their own will be insufficient to transform the whole system and studies have highlighted the major role played by both public and private R&D (OECD, 2023). A combination of public and private R&D investments, with appropriate incentives and collaboration frameworks, is important for driving innovation, sustainability, and economic growth in the context of decarbonisation. However, information on R&D spending in the private sector is limited (Pasimeni et al., 2019). Fig. 4 shows the R&D investments made by the world's top 2000 R&D investors[5] in the G7 countries, China and Spain (JRC et al. 2024).

Fig. 4. World's top 2000 R&D industrial investors expenditure in R&D



Source: Own elaboration based on 2024 EU Industrial R&D Investment Scoreboard.
Note: Number of firms per country – Canada (24), China (524), France (50), Germany (106), Italy (17), Japan (185), Spain (11), UK (63), US (681). Left – hand axe in € million and right-hand axe (%).

[5] These 2000 investors are responsible of approximately 75% of the R&D performed by the business sector globally

France appears in the Top – 10 list of R&D spenders in 2024 in the 8th position after US, China, Germany, Japan, South Korea, Switzerland and the UK. However, the information shown in Fig. 4 correspond to global R&D expenditures without specifying how 'green' they are. Some authors have tried to build up estimates of R&D expenditure in the private sector for climate change mitigation technologies[6] in Europe through a patent-based method under the assumption that inventive activity is financed by the applicants of the invention (see Pasimeni et al. 2019). Using this method, Pasimeni et al. (2019) concluded that the private sector devoted almost 4 billion € to R&D in mitigation technologies, in comparison to over 12 billion € from Germany, 2 billion € from the UK and less than that in Italy and/or Spain in the period 2012-2014. This would situate France as the second country in the context of the European Union in terms of corporate mitigation R&D investments.

Intimately connected to R&D expenditures, we find one of the most used innovation indicators i.e. patents (See Fig. 4). In the context of energy transition and decarbonisation, patents are instrumental in driving innovation and technology transfer for climate change solutions (Kim, 2011). They stimulate innovation by providing a framework for protecting intellectual property rights, which in turn encourages investment in green technologies. The transition to a green economy necessitates the decarbonisation of major sectors such as power, transport, and industry, where patents play an important role in facilitating this shift (Stern and Valero, 2021). Patents not only incentivize innovation but also contribute to the development of a conducive environment for entrepreneurship, thereby enhancing productivity and economic growth. According to some authors, European countries show a statistically significant positive relationship between the number of environmental patents and real GDP growth (See, e.g. Ferreira et al. 2020). Yet, patents are not solely important as a driver of GDP growth, its exchange —and other forms of technological transfer— can become an instrument for the promotion of economic competitiveness at the national level (Peñasco et al. 2016). In particular, a good patent environment may be an indicator of future competitive areas for particular economies (See analysis in the following section). It can help increase the diffusion of technology, facilitate vertical specialization and the division of labour between companies, and prevent duplication of R&D efforts at both micro and macro levels (Green and Scotchmer 1995, Gambardella, 2005).

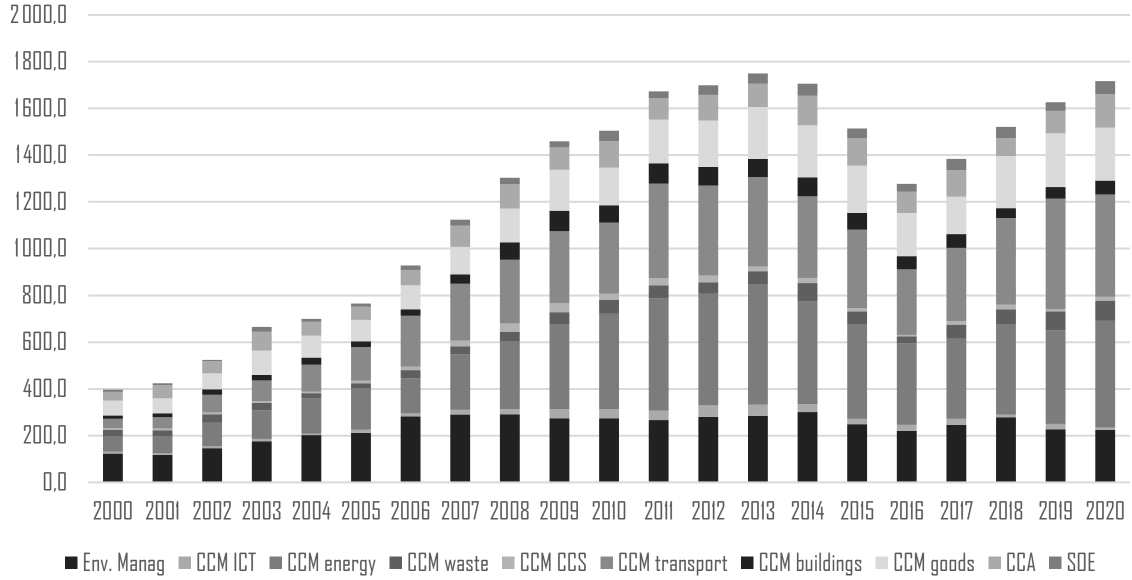
The number of patents related to environmental and low carbon technologies were on the rise in France during the first years of the century and right after the economic with a strong decrease between 2013 and 2016 (See Fig. 5). Currently, it represent 16% of the total number of French applications[7]. As can be seen from the figure below, France seems to be on a stronger position than other European Countries in the G7 e.g. Italy and the UK, in terms of patenting in environmental-related technologies (Fig. 6). This might not be surprising given the scale and output of both in relation to the research and development (R&D) sector. Specifically, France invests more in R&D than these two countries, both in absolute terms and as a percentage of GDP. This higher investment level is crucial as it directly influences the number and quality of innovations that can lead to patents (Dechezleprêtre et al., 2015). Additionally, France has a more substantial industrial base than other counterparts in the EU, particularly in sectors such as energy, automotive, and aerospace, which are central in environmental technology. This robust industrial base not only generates more patentable innovations but also has the capacity to commercialize them effectively (Johnstone et al., 2010). Lastly, the ecosystem for innovation in France, including collaboration between universities, research institutions, and industry, is more developed

[6] These patents on Climate Mitigation Technologies include the following groups Y02A – Adaptation, Y02B – Buildings, Y02C – CCS, Y02D – ICT, Y02E – energy, Y02P – goods, Y02T – Transportation, Y02W – Waste and Y04S – Smart-systems.

[7] Data available at OECD (2024) Patent Database.

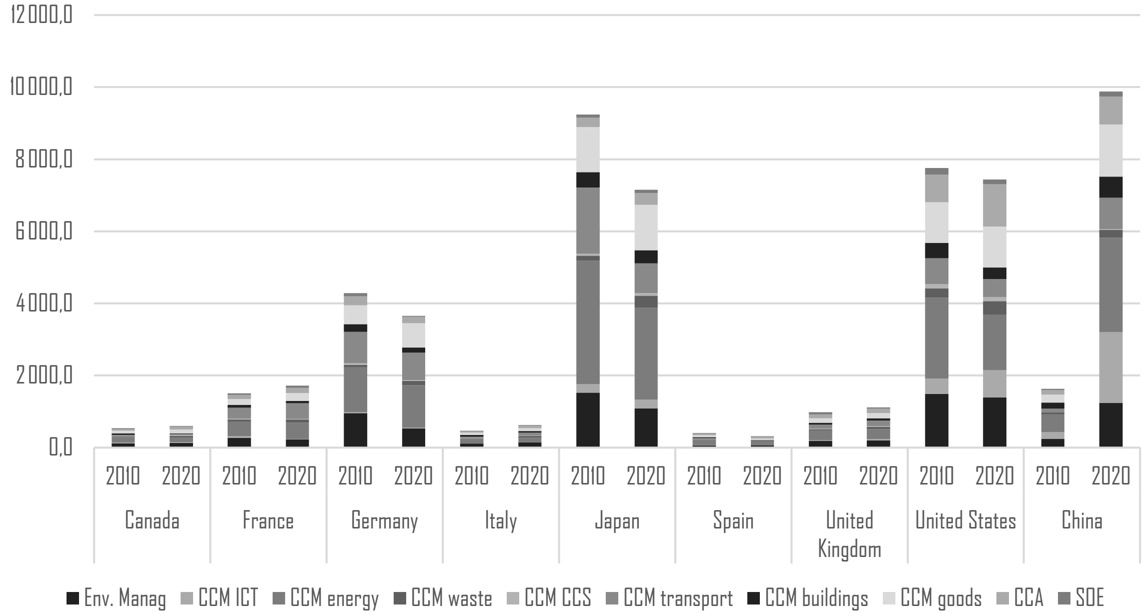
compared to other G7 economies. Indeed, in terms of environmental patents, in 2015, a large majority of patent applications in green technologies were made by the private sector (see, Haggmark and Elofsson, 2022). Interestingly, France appears as the country with a highest number of patent applications in green technologies made by the public sector (33%) vs. the private sector (67%). For other economies in the G7, the private sector applied for more than 83% of the patents in this field. This network fosters an environment where scientific findings are more likely to be transformed into marketable technologies, subsequently leading to patents (Costantini et al., 2017).

Fig. 5. Number of environmental-related technology patent applications (WIPO)



Source: Own elaboration with data from OECD. Note: Number of environmental patent applications WIPO by Applicant(s)'s country of residence and priority date. CCM: Climate change mitigation. CCS: Carbon, capture, and storage, CCA: Climate Change Adaptation, SOE: Sustainable Ocean economy.

Fig. 6. Number of environmental-related technology patent applications by G7 countries, China and Spain in 2010 and 2020



Source: Own elaboration with data from OECD. Note: Number of environmental patent applications WIPO by Applicant(s)'s country of residence and priority date. CCM: Climate change mitigation. CCS: Carbon, capture, and storage, CCA: Climate Change Adaptation, SOE: Sustainable Ocean economy.

4.2. Deployed RE capacity and generation and cost reductions (Market formation and Diffusion)

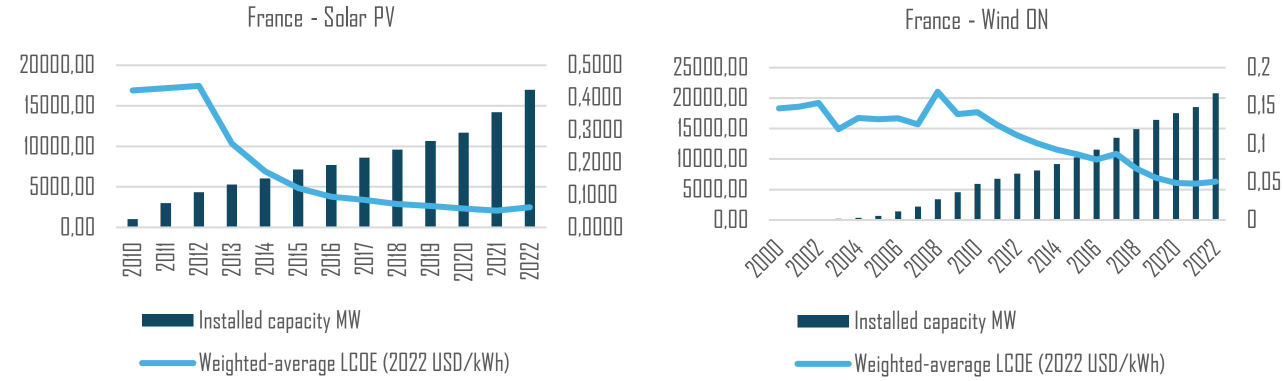
One of the main differences between France and other leaders in renewable energy installed capacity in Europe, like Spain, is the proportion of renewable electricity generation over the total production. Until 2021 only 22% of the electricity was generated with renewable energy in France, far away from the almost 60% reached in Spain during the last term of 2024 or even the average at the EU level that represented almost 37% in 2021 (IRENA, 2024a). Yet, as mentioned in previous sections, still the electricity system is pretty decarbonised in France due to the nuclear capacity that reaches more than 65GW. Indeed, France is the country in the world producing more nuclear power per capita (Plackett, 2022). While among the targets set by French government, we find a reduction of the share of electricity production with nuclear energy from approximately 70% to less than 50% by 2035; President Macron announced in 2022 the construction of 6 new reactors at an estimated cost of €50 billion, with the first coming online by 2035 (Placket, 2022). Yet, the French state-owned utility EDF has raised its initial estimates for the cost of construction of the six new nuclear reactors to 67.4 billion euros (Reuters, 2024a). Different voices affirm that this strategy may be fallible (Ferguson et al. 2010) due to the high costs of nuclear power[8].

In contrast to pessimistic forecasts from almost all analysts (See Meng et al. 2021), policies supportive of research into, and development and deployment of new technologies have already driven remarkable and unexpectedly large cost reductions in renewable and other energy technologies. Over the past decade, the cost of both solar photovoltaic (PV) generation, and battery storage necessary to address intermittency of supply, have fallen nearly tenfold across the world, while offshore wind costs have fallen by more than half (See also Grubb et al., 2021a; and Way et al., 2022). This opposes the trend in nuclear costs that increased about 26% from 2009 to 2019[9]. Fig. 7. below shows the trend in cost reductions and increases in installed capacity of the two main renewable energy sources in France, i.e. onshore wind and solar PV.

[8] Just from a rough and very simple calculation, the French Flamanville 3 reactor situated in Normandy, with a total expected capacity when finished of 1.65GW, is estimated to cost around €19 billion. While the cost of renewable energy projects can vary widely depending on technology, location, scale, and other factors, using average costs for renewable capacity, e.g. Solar PV capacity at an average cost of €0.8 million per MW, onshore wind capacity at an average cost of €1.5 million per MW, and Offshore wind capacity at an average cost of €3.25 million per MW; with a budget of €19 billion, France could installed about 23 GW of solar PV, 12 GW of onshore wind, or alternatively approximately 6 GW of offshore wind.

[9] Data extracted from https://ourworldindata.org/cheap-renewables-growth

Fig. 7. Evolution installed capacity (MW) and the weighted-average LCOE[10] (2022 USD/kWh)



Source: Own elaboration with data from IRENA (2024) and IRENA (2023). Note: Installed capacity in MW in the left y-axe and Weighted average LCOE (2022 USD/kWh) in the right y-axe.

Onshore wind costs have significantly decreased in recent years. France has demonstrated remarkable progress, with installed costs (€/MW) in onshore wind reducing by 56% between 1990 and 2023, as reported by IRENA (2024b). Although this reduction is slightly behind countries like Sweden and Spain, it represents a substantial achievement for the country. Regarding the levelized cost of electricity (LCOE), from 2010 to 2023, France achieved a 67% decrease in LCOE for onshore wind, which is comparable to the leaders in renewable technology across Europe like Germany with reductions of 65% during the same period, Italy (66%), Spain (72%), the UK (72%), the US (65%) or China (71%). In terms of capacity factors, a key indicator of technological improvement, France has shown a stronger increase than other G7 European economies since 2010, reaching approximately 33% by 2022 (IRENA, 2024b).

For solar energy, France has made steady advancements despite facing challenges in the past. Unlike Spain, which experienced a stagnation in solar development from 2012 to 2017 due to regulatory uncertainties, France maintained a more stable trajectory. Since 2010, the total installed cost of utility-scale solar PV in France has fallen by 81%, slightly below Spain's 85% reduction but ahead of Germany (76%) and at the level of e.g. China (82%). A similar trend can be observed in the LCOE, which decreased by 87% in France compared to 88% in Spain, 85% in Germany or 87% in Italy —in the context of the EU—, and in comparison to 90% in China, 87% in the UK or 74% in the US during the same period. France's achievements in deploying solar capacity highlight its commitment to renewable energy, driven by consistent national policies and growing investments in low-carbon technologies (IRENA, 2024b).

Yet, as more intermittent renewables enter in the energy and electricity mix, more investments will be needed also in improving the grids, the general infrastructure and the batteries that allow to avoid risks associated to climatic events like e.g. droughts or extreme temperatures[11]. Indeed, droughts have significant impacts on hydroelectric power generation[12]. Rising temperatures are expected to extend summer lengths and increase the number of heatwave days, which could escalate electricity demand for air conditioning. This can put stress on hydropower and thermal power plants due to lower precipitation and runoff, though less cloud cover might increase solar

[10] While the LCOE does not consider the need for back up flexible energy and/or storage here we add for comparison, the last calculation of the LCOE of PV-utility scale plants with Battery 3:2 in Germany. It oscilates approximately between 6€cent/kWh to 11€cent/kWh (Kost et al. 2024)

[11] These additional infrastructure investments are not considered under the LCOE of renewable technologies mentioned earlier

[12] While nuclear power may be less flexible than required to accommodate the intermittency of an increasing generation with renewable energy, it provides a paired reliable baseload for variable sources.

power generation. In 2016-2017, a severe drought already demonstrated its impact by halving hydropower output in Spain, highlighting the vulnerabilities of the energy sector to such extreme weather conditions (IEA, 2022). In particular, geopolitical risks can affect also renewable energy asset prices, potentially impacting sustainable development (Dutta & Dutta, 2022). For example, in 2022, the performance of the solar photovoltaic (PV) sector showed divergent trends across global markets. The reduction in the Levelized Cost of Electricity (LCOE) during this period was not as pronounced as the 13% annual reduction witnessed in the preceding year. According to IRENA's datasets for the largest 20 utility-scale solar PV markets, more than half recorded a real-term rise in their total installation expenses. Notably, France and Germany experienced a 34% surge in costs, and Greece's expenses soared by an estimated 51%, influenced by elevated prices for PV modules and raw materials in late 2021 and continuing into 2022. While fluctuations in project costs are to be expected, the overarching trend suggested that the inflationary pressures on commodities and labour had a pronounced effect on certain markets (IRENA, 2023). Yet, the panorama on 2023 was more optimistic with total installed costs declines for solar PV in all major markets mostly due to supply chain easing and a reduction in inflation trends. European countries registered large reductions in installed costs, with Greece seeing a decline of 48% or 29% in Germany. China, saw a decline of 10% and the United States of 4%. Onshore and offshore wind also experienced global weighted average LCOE reduction of 3% and 7 % respectively.
The dynamics of cost reductions and penetration of renewable energy in the electricity system is relevant as some early analysis have concluded for the case of Spain that the greater the share of renewables in the energy mix, the greater the decoupling of wholesale electricity prices from traditional determinants based on natural gas and emission allowance prices. According to the results of this study, in Spain average electricity prices were 10%-15% lower in the period 2017-2019 due to the contribution of wind and solar energy reaching almost 50% lower prices in 2024 (Quintana, 2024). This is especially important when, one of the main issues faced by the industry in Europe is the high energy costs in comparison to other economies worldwide.

5. Comparative transition and future green export trends in France

In his report on the future of European competitiveness, Mario Draghi emphasizes the critical role of exports in enhancing the EU's economic standing. He notes that Europe is the most open major economy, with a trade-to-GDP ratio exceeding 50%, compared to 37% in China and 27% in the United States (European Parliament, 2024). This openness underscores the importance of exports for the EU's economic health. Draghi also highlights that Europe's share of world trade has declined since the early 2000s in both goods and services (Institute of Export & International Trade, 2024). This trend indicates a need for the EU to bolster its export performance to maintain and enhance its global competitiveness mainly in those high-value goods and services that will boost the green transition. Yet, in the context of trade fragmentation, exports alone will not fix all challenges and strengthening domestic investments or supply chains is essential (Terzi, 2022).

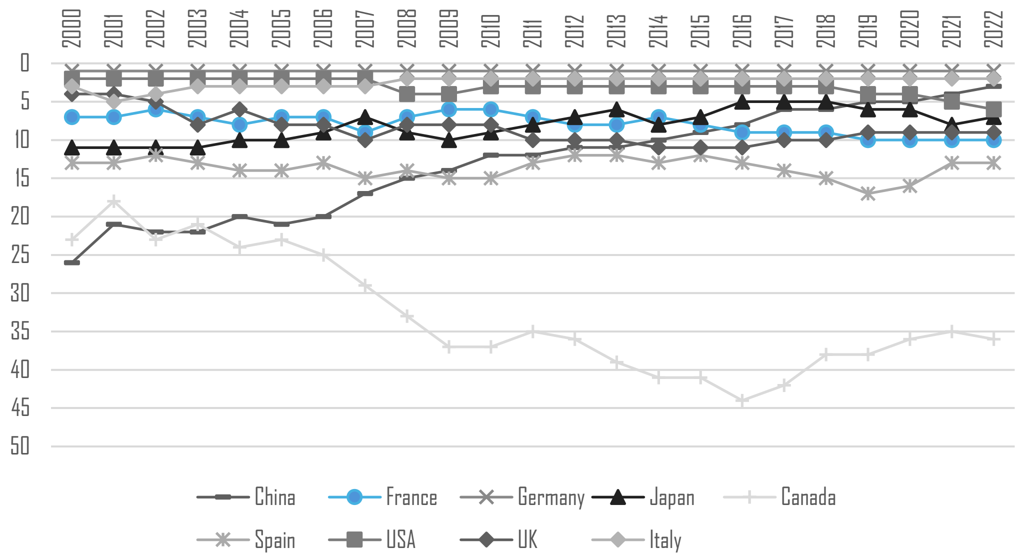
5.1. Green complexity index and green export analysis

The Green Complexity Index (GCI) is a measure that combines a country's ability to produce technologically sophisticated green products with its overall capability to export these goods competitively (See Mealy and Teytelboym, 2022 for a description of the calculation of the index). By comparing the GCI for the G7 countries plus China and Spain[13], we can draw insights into the French position in the green technology market and its contributions to global sustainability efforts in comparison to the major economies worldwide. France traditionally has a strong industrial base

[13] We add Spain to the group of countries for comparison due to the proximity with France and the cooperation needed between the two countries in regards to the energy system.

and significant investments in technology and research, which contributes positively to its GCI. France has been, also, a leader in nuclear technology, which is considered a low-carbon energy source, although as aforementioned, the green character of nuclear energy can be debated (Ferguson et al. 2010; CAN, 2024). Additionally, France has been increasing its capabilities in other renewable energies and sustainable technologies. The French government's commitment to reducing carbon emissions and transitioning to a greener economy also supports the development of complex green technologies (IEA, 2021). Considering Germany as the bastion of green innovation and the engine for the transition to low carbon economies in Europe, we add it here for comparison. Germany is often seen as a leader in both the complexity of its industries and its commitment to green technologies. It ranks highly in global indexes for innovation, including green technologies such as renewable energy equipment, energy-efficient technologies, and sustainable automotive technologies (like electric vehicles). Germany's strong engineering sector, substantial investments in research and development, and robust government policies supporting sustainability contribute to its high GCI and therefore to be the first economy in the ranking (Fig. 8). Unlike Spain, which has shown a positive trend and moved up a couple of places, France has lost some positions. This shift highlights challenges France faces in the transition to decarbonise its economy, signalling the need for stronger efforts to capitalize on opportunities and address weaknesses in its decarbonisation strategy (Fig. 8).

Fig. 8. Green complexity index ranking



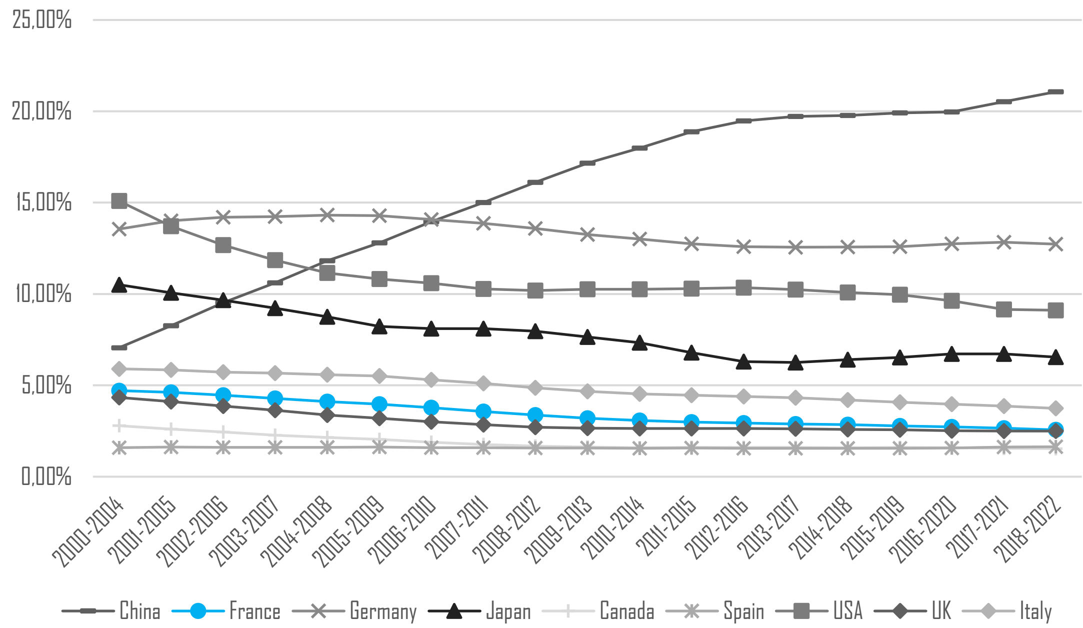
Source: Own elaboration with data from Andres and Mealy (2023).
Note: The figure shows the ranking occupied by the G7 economies plus China and Spain in terms of the GCI overtime. The ranking is calculated for 231 economies around the world. Years refer to the end of each 5-year period (e.g. 2005 is based on average trade values over the period 2001-2005).

Looking more specifically at the figures behind the GCI (See Fig. 8 and 9) and the aforementioned ranking, i.e., the country share in global exports of green products; the data reveals a significant decline in France's share in the global market of green product exports, dropping from 4.71% to 2.56% between 2000 and 2022. This declining trend is mirrored in France's renewable energy exports, which decreased from 3.95% to 2.24% during the same period. In contrast, Germany, while experiencing a slight reduction in green product exports (from 13.55% to 12.73%), has demonstrated growth in renewable energy exports, rising from 11.10% to 12.38%. Similarly, Italy's performance has weakened, with green product exports falling from 5.9% to 3.74% and renewable energy exports declining from 4.51% to 2.74%.

While Spain has shown a modest increase in its green product exports, moving from 1.58% to 1.64%, and a more significant rise in renewable energy exports (from 1.11% to 1.75%), it remains far below France's historical figures. France's declining share in green exports may reflect broader structural changes in its economy and shifts in global demand for green products, as suggested by academic literature (Fankhauser & Jotzo, 2018). France's energy system, while benefiting from a significant share of nuclear power, remains reliant on imported fossil fuels, particularly natural gas. In 2020, France's energy import dependency was 44.7%, with natural gas imports accounting for 94.7% of its consumption (European Commission, 2022). This dependency exposes France to fluctuations in global energy markets and potential supply chain disruptions. In the digital sector, France has experienced substantial growth, with the market size estimated at €66 billion in 2023 and projected to reach €70.5 billion in 2024. This expansion is driven by increased demand for digital services, software publishing, and engineering and technology consulting (ITA, 2024).

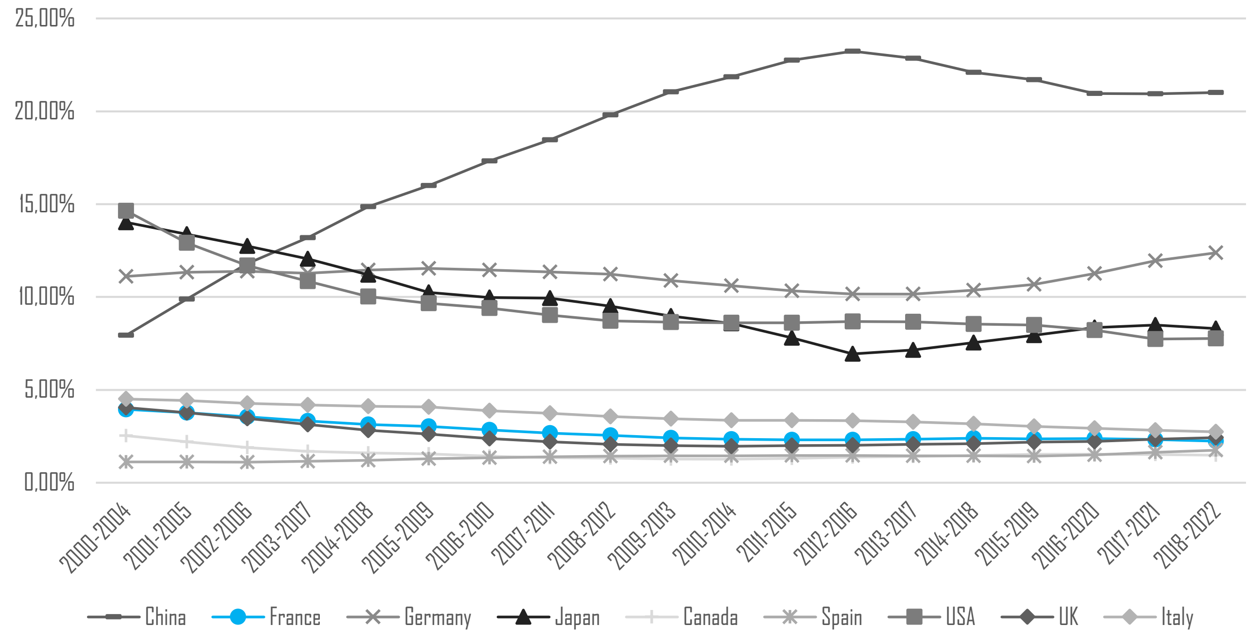
All in all, challenges persist for France in maintaining its competitiveness in green exports. While Germany's stable performance reflects its robust industrial base and leadership in high-value manufacturing sectors, including renewable technologies (See Fig. 9 and 10), France appears to be losing ground. Addressing these trends will require France to strengthen its industrial strategy and adapt to shifts in global markets for renewable energy and green products.

Fig. 9. Country share in global exports of green products



Source: Own elaboration with data from Andres and Mealy (2023).
Note: Years refer to the end of each 5-year period (e.g. 2005 is based on average trade values over the period 2001-2005).

Fig. 10. Country shares in global exports of Renewable Energy



Source: Own elaboration with data from Andres and Mealy (2023).
Note: Years refer to the end of each 5-year period (e.g. 2005 is based on average trade values over the period 2001-2005).

5.2. *Relative comparative advantage and transition risks outlook*

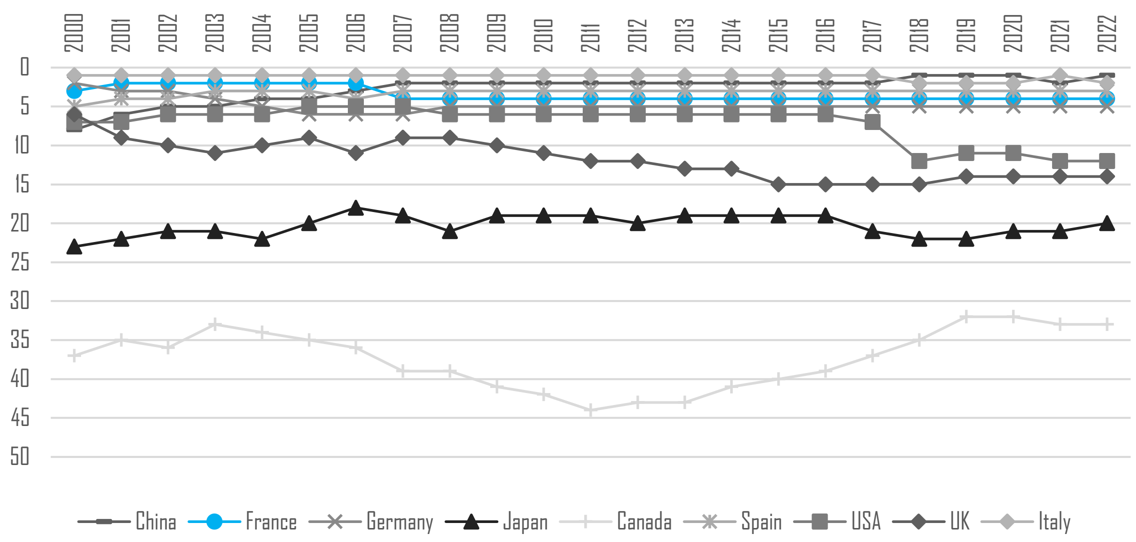
Andres et al. (2023) created a measure of country lock-in to low-complexity and brown exports called the Brown Lock-in Index (BLI)[14]. In a nutshell, the BLI measures the share of brown exports in a country's export volume, weighted by the inverse of a product complexity index (PCI) that proxies the technological sophistication of a product; such that less technologically sophisticated products (which tend to be associated with lower income and growth compared to more complex ones, and open up fewer diversification paths) carry a larger weight. We analyse below the Green Complexity Potential, i.e. the potential of a country to diversify into green, complex products in the future based on its existing competitive strengths; and the Brown Lock-in Index, i.e. that proxies a country's transition risk, based on the share of low-complexity brown products in its export basket; to accurately assess each country's environmental positioning in terms of lower transition risks. To facilitate the analysis, we are focusing here on the ranking of France in comparison to G7 countries, China and Spain, for these two indicators, among a group of more than 200 countries.

In regards to its Green Complexity Potential (GCP), France shows a relative stable position with minor fluctuations, ranging in the ranking from 3 in 2000 to 4 in the later years (2006-2022). This stability indicates that France has maintained a consistent capability to innovate and diversify in green technologies, keeping the country as one of those with the highest potential around the world to succeed in the transition to greener economies. Ranked fourth in the world in terms of GCP, France has productive capabilities that enable it to diversify more easily into a wide range of

[14] The BLI, measures the share in exports and gives a greater weight to less complex brown products. $BLI_c = \sum_b \frac{exports_b}{\sum_b Exports_p} * (1 - \widetilde{PCI})$ where $\frac{exports_b}{\sum_b Exports_p}$ is the share of each brown product in overall export values and PCI the product complexity index normalized to take a value between 0 and 1 (See Andres et al. 2023)

green, complex products (See Andres and Mealy, 2021 and analysis below). Yet, its potential seems to stand behind that of other European economies like Italy or Spain. While Germany stands as the leader on green complex products based on its GCI, its GCP starts at 2, increases to 6 around the mid-2000s, and then stabilizes at 5. This suggests a substantial enhancement in Germany's potential to develop and expand into complex green products, reflecting strong policy and industrial support for green technology sectors. Yet, given its historical engagement with the green economy, its potential seems behind that of France. France's steadiness highlights its consistent and balanced approach to green industrial development. Spain, on the other hand, while making strides in GCP by rising from sixth in 1999 to stabilizing at third in later years, still trails behind France's historically higher position and productive complexity. Italy stands as a notable leader in GCP rankings, occupying first or second position consistently since 2000. However, this leadership highlights the competitive nature of green product diversification in Europe, with France closely following as a major global player (Fig. 11).

Fig. 11. Green Complexity Potential (GCP) ranking



Source: Own elaboration with data from Andres and Mealy (2023).

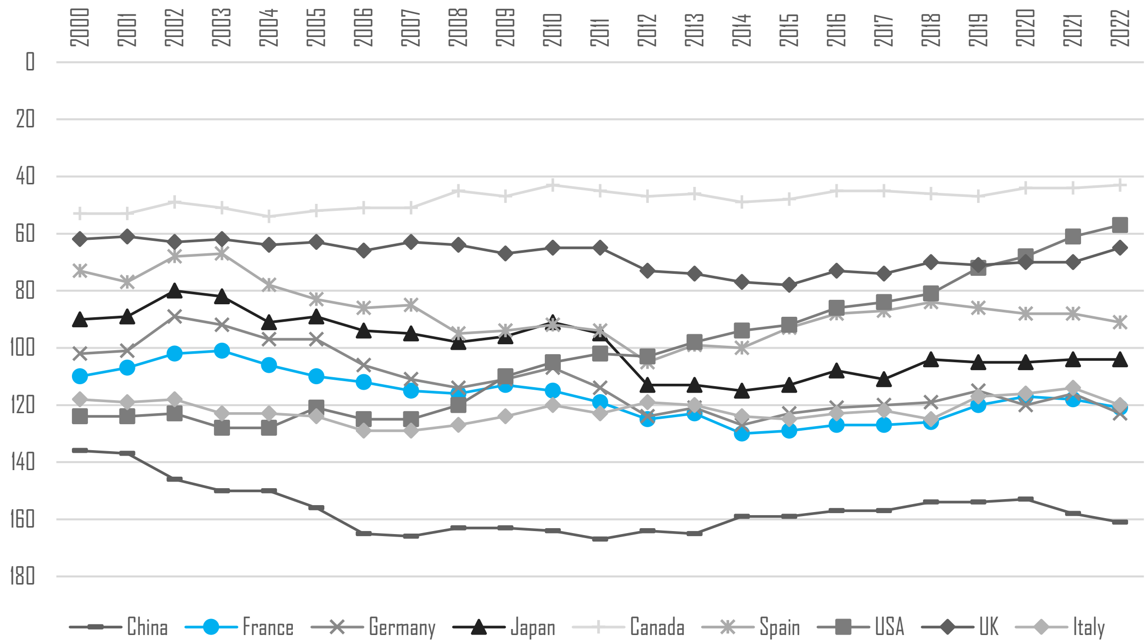
An analysis of the Brown Locking Index (BLI), as a proxy for a country's transition risk based on the share of low-complexity, environmentally harmful products in its export basket, reveals France's relative stability and gradual progress in reducing its environmental risks i.e. reducing its BLI. France's BLI ranking improved from 110 in 2000 to 121 in 2022, reflecting a slow but consistent effort to lower its dependence on brown products[15]. This trajectory indicates that France is enhancing its environmental positioning and reducing transition risks while maintaining a relatively stable and mature export profile. Compared to France, Spain faces a higher transition risk, with a significant proportion of brown exports still present in its export basket. However, Spain has shown notable improvement, moving from a BLI rank of 73 in 2000 to 91 in 2022. While this represents a positive trend, Spain remains behind France, as well as other EU G7 representatives such as Germany and Italy. Germany and Italy exhibit stability at higher BLI rankings, reinforcing their established positions as leaders in reducing transition risks. However, the figure demonstrates that France, while slightly behind Germany, is effectively maintaining its

[15] Unlike for the GCP, in the BLI ranking, the lower the position in the ranking the lower the transition risks and the better the environmental strengths of the industrial landscape in the country.

progress, aligning with its role as a global leader in green innovation and sustainable industrial practices (Fig. 12).

Overall, France's steady improvement and mature capabilities in managing transition risks underline its commitment to a sustainable export profile. As France continues to balance stability with gradual progress, it reinforces its standing among the leading EU nations in reducing reliance on low-complexity brown products.

Fig. 12. Brown Lock-in index ranking



Source: Own elaboration with data from Andres and Mealy (2023).

The table below (Table 1) is an adaptation of a broader one from Andres et al. (2023) showing the Brown complexity index, as a measure of the dependence of a country on brown activities which, in the context of the transition to low carbon economies will provide fewer economic and competitiveness opportunities; and some additional important variables in relation to competitiveness in a green transition context for the G7 economies plus China and Spain. Andres et al. (2023) developed this index that counts the number of competitive brown exports, weighted by each product's complexity. It would be expected that even if in brown technologies, those countries with more sophisticated export capabilities, will be able to adapt more easily to a greener production system. The BCI correlates positively with the GCI, showing that countries exporting competitively complex products, even if they are classified as 'brown', also tend to have strong capabilities to export other complex green products.

France demonstrates strong positioning in the transition to a green economy. The Brown Complexity Index (BCI) score of 3.24 highlights France's ability to manage its dependency on complex brown products effectively, placing it ahead of countries like Spain (2.39) and Canada (1.62). Moreover, France has a relatively low brown export share at 8.99%, significantly below other industrialized nations like the UK (19.29%) and Japan (18.67%), indicating a more environmentally balanced export profile. France's Green Transition Outlook (0.75) further underlines its readiness to diversify into green and technologically advanced sectors. This figure reflects a positive trajectory compared to other European partner countries like Spain who has worsen its Green transition outlook during the last 6 years moving from 0.45 to a negative outlook of -0.04 in 2022. This French comparative advantage shows the country can pull its complex industrial capabilities to enhance its competitiveness in green technologies. Yet, the challenge lies in balancing fiscal constraints with the need to maintain competitiveness in emerging green export markets. Critics argue that large-scale green investments may crowd out other forms of public and private spending, particularly when fiscal consolidation limits government budgets, forcing cuts in infrastructure and innovation programs crucial for industrial competitiveness (Pisani-Ferry, 2021). Under austerity pressures, public investment in green technologies and industrial innovation risk being underfunded, potentially slowing the development of domestic capabilities in sectors like renewable energy, electric vehicles, and hydrogen production (Semieniuk & Mazzucato 2019). This could put French firms at a disadvantage compared to countries with more aggressive industrial policies, such as the U.S. and China's state-backed green investments (Mealy & Teytelboym, 2022). Moreover, higher production costs from carbon pricing and regulatory shifts could weaken France's export competitiveness if firms face rising costs without sufficient technological upgrades (Acemoglu et al., 2012). However, failing to invest now could lead to long-term market share losses, particularly in high-value green technologies where France has strategic potential.

As highlighted in Andres et al. (2023), nations with high economic complexity, such as France, are better positioned to swing toward green exports due to their existing industrial diversity and sophistication. France's consistent performance in green and brown transition indices underscores its ability to sustain economic growth while reducing dependence on brown exports. This aligns with the findings that export diversity and complexity are critical in mitigating transition risks. While Italy leads the Green Transition Outlook with 0.94 and demonstrates stable performance in both BCI and green exports, France is positioned closely behind and ahead of Germany, reflecting a stable yet ambitious trajectory. The higher GDP per capita of France in comparison to Italy, though, suggests that France has more robust economic levers to sustain long-term growth.

Table 1. Indicators of the brown economy in selected countries

Country	BCI	Brown exports (1M USD)	Brown Export Share (%)	GDP per capita 2023 (USD)(*)	Transition outlook (*) 2022	Green Transition outlook (*) 2022
USA	4.93	2462.74	17.11	81,695	-0.55	-0.14
Japan	4.27	1257.50	18.67	34,017	-0.13	0.35
Germany	3.95	1824.49	13.21	52,746	0.14	0.64
France	3.24	468.56	8.99	44,461	0.36	0.75
UK	3.03	802.01	19.29	48,867	0.03	0.72
Spain	2.39	534.73	17.27	32,677	0.21	-0.04
Italy	2.22	434.85	8.74	38,373	0.95	0.94
China	1.91	652.10	2.60	12,614	0.9	-0.49
Canada	1.62	1269.66	31.52	53,372	-0.56	0.1

Source: Reproduced and updated (*) from Andres et al. 2023. GDP per capita updates for 2023 are extracted from Macrotrends. The transition outlook and the green transition outlook indexes have been updated with the last available data (2018-2022) from the Green Transition Navigator. Note: The BCI forms a direct counterpart to the GCI and measures the number and complexity of brown products a country is competitive in. It is computed as $BCI_c = \sum_b \rho_b^c * \widetilde{PCI}$. Export capabilities in more technologically sophisticated activities may take longer to develop and bring greater benefits to the economy. However, by opening up a greater number of diversification paths they are likely associated with easier transition pathways. Both transition outlook and green transition outlook are standardized indexes with a mean of 0 and a standard deviation of 1. The transition outlook measures the proximity of brown products in a country's export basket to climate compatible exports while the green transition outlook measures the proximity of brown products in a country's export basket to green exports.

The former analysis leads to consider what are the revealed competitive advantages (RCA) of France in the process of transitioning to greener economies for various sectors. This exercise is useful as it allows to showcase the specific green categories in which a country is currently competitive, as well as potential green industrial opportunities. This analysis is especially relevant for policy makers trying to decide on their technology choices (Anadon et al. 2022)

We map below the current green competitive advantages and opportunities for France. Fig. 13 below shows the relationship between an indicator of RCA specifying if a country exports a product competitively and a Product Complexity Index that shows the level of sophistication of a particular product. The figure below compares therefore the panorama of competitive green strengths and opportunities of France in comparison to the other G7 economies, China and Spain.

Specifically, in terms of green competitive strength i.e. categories of products with RCA>1, France is well situated in 11 categories of products which reflect its technological capabilities and established industries. The country exhibits strong export capabilities in sectors like Water Supply (RCA 4.03, PCI 0.56), indicating a significant competitive advantage and sophistication in water-related technologies. The high RCA in this sector suggests a well-established industry that France can capitalise on to lead in global water management solutions leveraging this strength for sustainability and international market leadership. Other sectors where France is competitive now include Heat and Energy Management (RCA 1.27, PCI 0.52) or Cleaner or More Resource Efficient Technologies and Products (RCA 1.19, PCI 0.55). Under the later, we find many of the components associated to the transition of the automobile sector one of the European strategic concerns. This category of green products seem especially important in the green products export markets as the four EU economies in the analysis lead in terms of comparative advantage. Something similar happens in regards to Heat and Energy Management where the four EU economies are only surpassed by China. Yet, these industries continue to grow and face increased competition globally. Therefore, maintaining productivity growth will be key to preserving and enhancing France's position in these markets. Particularly promising are exports of products under the categories of Gas Flaring Emission Reduction (RCA 1.08, PCI 1.03) and Environmental Monitoring (RCA 1.08, PCI 0.92). These sectors not only have a reasonably high RCAs but also the two highest PCIs, indicating advanced technological capabilities which are crucial for addressing environmental challenges effectively and with close proximity to the available capabilities at the country level. While these areas have comparatively moderate RCAs, their high PCIs signal advanced technological sophistication. Such capabilities suggest that France is well-positioned to further expand and innovate in these domains.

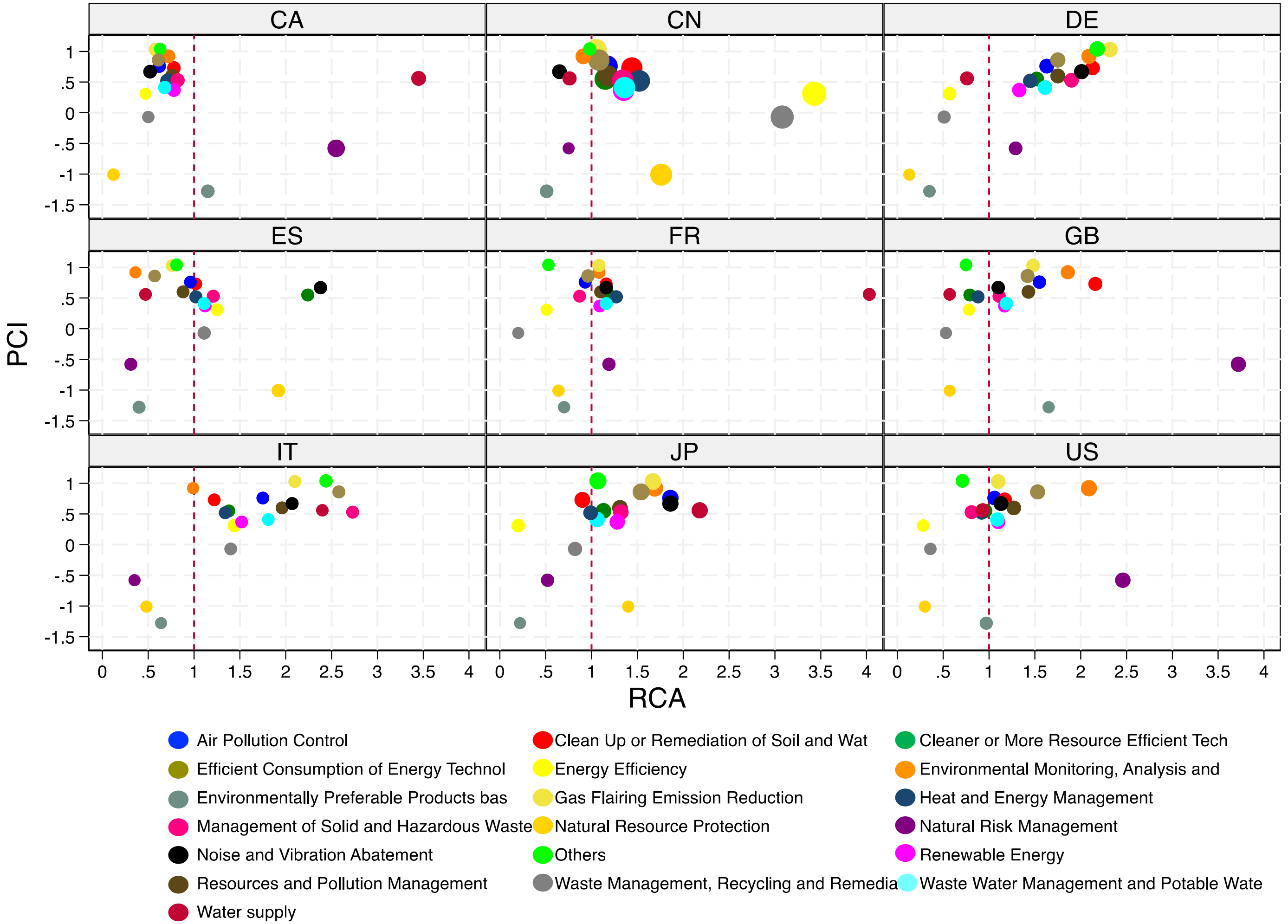
However, France's future productivity growth in these sectors may depend on its ability to integrate cutting-edge technologies like artificial intelligence and data analytics into production and monitoring processes. Investments in R&D and workforce upskilling will also be crucial to maintaining France's competitive edge in these high-tech industries. Renewable Energy represents a key strength for France, reflecting its advanced industrial base and policies focused on sustainability. With a high PCI and competitive RCA, France can compete with Germany, a leader in renewable technologies, while positioning itself as a key player in Europe's energy transition. Unlike Spain, which focuses on domestic deployment, France's export-oriented capacity gives it an edge in this high-growth sector. Yet there is fierce competition in this segment with all countries in the analysis, except Canada exhibiting high RCA in the category of renewable energy. Despite the global emphasis on renewable energies and efficiency, France's current capabilities in these areas are underdeveloped, representing significant potential for growth. In 2023, France imported approximately 479 terawatt-hours of natural gas, a decrease of about 100 terawatt-hours compared to the previous year. This reliance on external sources exposes the country to price volatility and supply chain risks. Industrial electricity prices in France are also a concern. In 2023, the average industrial electricity price amounted to approximately 205 euros per megawatt-hour, with supply costs representing almost 85% of the electricity bill. This pricing structure can hamper competitiveness, particularly for energy-intensive sectors such as manufacturing. To address these challenges, expanding renewable energy infrastructure and reducing energy costs for industry are essential. Investments in grid modernization and cross-border interconnections could enable France to better integrate its renewable resources. Also, France's robust nuclear capacity can provide grid stability as renewables scale up. Advocating for an EU-wide approach to energy procurement and market integration could help reduce price volatility, lower costs, and build a more resilient energy framework.

Additionally, France is competitive in Environmental Monitoring and Analysis Equipment, where it almost matches Germany, US and United Kingdom capabilities and surpasses Canada, Italy, Japan, Spain or China in export competitiveness. Similarly, Cleaner or More Resource-Efficient Technologies present an opportunity for France to build competitiveness. While Spain dominates this category, France's high proximity suggests it could catch up by focusing on innovation and scaling exports.

However, France also faces significant opportunities in sectors where it has not yet developed export competitiveness (RCA < 1), signalling readiness for growth. For instance, France shows strong potential in Efficient Consumption of Energy Technologies and Carbon Capture, categories where Italy, Japan, Germany, the UK or the United States currently lead. By integrating carbon capture systems into its nuclear and industrial processes, France can bridge the gap in this area. Among other areas of potential growth, Resources and Pollution Management (RCA 0.93, PCI 0.76) together with Air pollution control products (RCA 0.93, PCI 0.76) are notable areas where France has the opportunity to improve competitiveness in highly sophisticated products. Although France is currently close to achieving a competitive edge in these sectors, further investment in technological development and policy support could enable it to become a leader in these critical areas. Enhancing productivity through innovations in these sectors will allow France to improve cost-efficiency and scale these solutions both domestically and internationally.

Environmentally Preferable Products (RCA 0.7, PCI -1.28) shows a negative PCI, indicating a need for technological improvement and innovation in products designed for better environmental performance. These products lack technological sophistication, requiring substantial innovation to improve their environmental performance and align with global standards. Low productivity in this category, as indicated by the lower complexity of the products, suggests inefficiencies that need to be addressed. By focusing on improving the design and manufacturing processes for these products, France can close the gap and better compete in this growing global market (See Fig. 13 and Table A1 in the Appendix).

Fig. 13. Green competitive strengths and opportunities in France in comparison to other G7 countries, China and Spain



Source: Own elaboration with data from Andres and Mealy (2023). Note: The y-axis shows each category of product's complexity as measured by the PCI. Categories with higher PCI tend to be more technologically sophisticated. The x-axis shows the RCA at the category of products level. RCA > 1 indicates sectors where each country is competitively exporting, whereas RCA < 1 points to potential areas for development. The size of the bubbles (categories) represents the proximity between each category and the country. The higher the proximity i.e. the bigger the bubble, the more likely a country will develop competitiveness in it in the future. The proximity has been rescaled to move from 1 to 10 (Andres and Mealy, 2021; Hidalgo et al., 2007; Neffke et al., 2011; Hidalgo et al., 2018

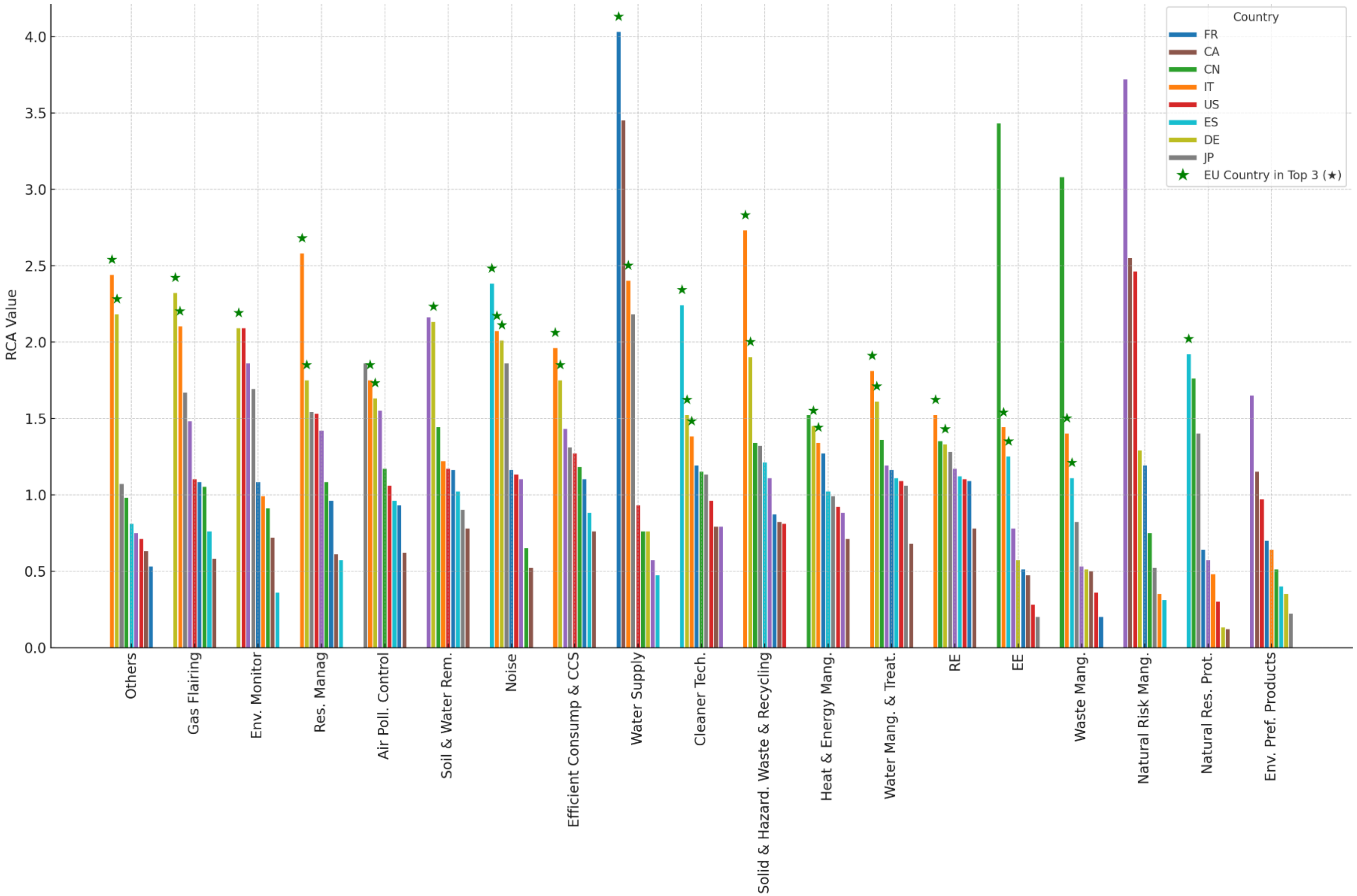
5.3. Relative comparative advantage of a single European goods export market

The analysis in Section 5.2. considered France as an independent open economy, but the particularities of the European Union make it logical to assess European countries as a single European goods export market. The high degree of economic integration, shared regulatory frameworks, and coordinated trade policies among member states suggest that their collective performance in green technology sectors offers a more comprehensive perspective on Europe's competitive standing in global markets (European Commission, 2023b).

The analysis of the relative comparative advantage (RCA) of European countries within the green technology sectors highlights specific strengths in key environmental and sustainable industries. Based on the data provided by the Green Transition Navigator (See Table A1 in appendix), European countries consistently rank among the top three countries in the G7 (plus China and Spain) in several categories demonstrating Europe's established leadership in green exports. Fig. 14 summarises the ranking of countries in the analysis based on RCA for each green technology category. We find European countries with relative comparative advantage in all categories except in two, low-complexity, categories i.e. waste management, recycling and remediation and environmentally preferable products based on end-use or disposal characteristics. In 14 out of 19 green categories, at least two European countries are in the top 3. Categories like noise and vibration abatement, and cleaner or more resource efficient technologies and products stand out with 3 of the 4 European countries in the analysis in the top 3. The latter is important, as many of the green products included in that category are part of the supply chain for electric vehicles in the automobile sector. Also, gas flairing emission reductions, resource and pollution management, efficient consumption of energy technologies, water supply or waste water management stand out as fields where European expertise has led to a strong competitive advantage. Renewable energy is another major strength, with Europe excelling in wind, solar, and hydropower solutions. Energy efficiency is another area where Europe demonstrates a strong comparative advantage. However, the export market is, by far, led by China, like waste management.

The RCA raking in Fig. 14 suggests that a unified European goods export market would benefit from an enhanced global competitiveness in environmental products. By capitalizing on these established strengths, Europe can consolidate its leadership in sustainable industries, reinforce its export strategy, and expand its influence in the global market for green goods. The integration of these advantages into a single European trade policy could create synergies in research, development, and production, further cementing Europe's role as in the transition to a sustainable economy.

Fig. 14. Ranking of countries in the analysis based on RCA for each green technology category



Source: Own elaboration using AI tools with data from the Green transition navigator (see appendix. Table A1). Note: The name of the categories has been shorten to facilitate the reading of the figure. For the full names, see Table A1

6. Discussion and conclusions

This manuscript has reviewed the current state of France's green transition, focusing on the role of supply-side factors exploring the productive capabilities, export competitiveness and diversification- potential of France within the framework of a green economy. The French energy transition, underpinned by its strong reliance on nuclear energy and expanding renewable portfolio, presents a nuanced scenario with important achievements and unresolved challenges. France's nuclear sector has historically allowed it to maintain a low-carbon electricity profile, with nearly 65% of its electricity coming from nuclear energy in 2023. However, the country's renewable energy adoption lags behind peers like Germany and Spain, which have achieved a much larger share of renewables in their electricity mix. This situation underscores the need for a recalibrated policy framework that bridges the gap between its nuclear dominance and its renewable energy aspirations. France's heavy reliance on nuclear energy ensures a relatively low-carbon energy system but raises concerns about the high costs and inflexibility associated with nuclear infrastructure. While the government continues investing in nuclear advancements, such as small modular reactors, these efforts must be complemented by an accelerated expansion of renewable energy sources. Recent targets for solar and wind capacity by 2030 are ambitious but require significant improvements in permitting processes, grid enhancements, and storage solutions to avoid reliance on energy imports during periods of high demand or climatic stress. For instance, France's lagging renewable energy share of just 22% in electricity generation in 2021, compared to Spain's 60% and Germany's 41%, illustrates the urgency of policy reform to catch up with EU frontrunners (IRENA, 2024a). Furthermore, the government should prioritize investments in grid modernization and storage solutions, critical for integrating intermittent renewable energy sources. Expanding interconnections with neighbouring countries would also enhance energy security and reduce reliance on imported fossil fuels, which accounted for 44.7% of France's energy consumption in 2020 (European Commission, 2022).

France's R&D investments highlight its potential to lead in green innovation, particularly in hydrogen technologies, which have received substantial funding under the France 2030 investment plan. However, the decline in patent applications for green technologies over the last decade, as compared to other leading G7 economies like Germany, points to challenges in translating R&D spending into scalable industrial applications maybe connected to the fact that France had the lowest share of private-sector green technology patent applications vs. public sector appliactions among G7 countries (67%), whereas in other G7 economies, private-sector applications exceeded 83% (Haggmark and Elofsson, 2022).France's trajectory in green industrial competitiveness reveals a dual reality i.e. it has a significant potential rooted in advanced industrial capabilities but there is also a need for targeted interventions to exploit this potential fully. The Green Complexity Potential (GCP) metric places France among global leaders, reflecting its ability to diversify into technologically sophisticated green sectors. However, the decline in its share of global green exports, dropping from 4.7% in 2000 to 2.5% in 2022, stresses challenges in translating these capabilities into market dominance. Addressing this disconnect is key, especially as France seeks to strengthen its role in the global green economy amid intensifying competition from other advanced economies.

France could address its declining position in green exports by fostering competitiveness in high-complexity sectors where it already demonstrates strong potential. For instance, targeted support for industries like gas flaring emission reduction technologies and environmental monitoring equipment can exploit existing capabilities. These technologies are increasingly essential in addressing global environmental challenges, from air and water quality monitoring to climate resilience. To profit from this, France should encourage cross-sector collaboration, integrating digital technologies such as artificial intelligence and IoT into environmental solutions. This would not only enhance product sophistication but also create new export opportunities in high-value markets. Moreover, enhancing policies to support nascent opportunities, such as efficient consumption of energy technologies and carbon capture and storage is essential. Targeted support for these sectors, such as R&D tax credits, pilot projects, and scaling programs, could enable France to establish leadership positions in these markets. Also, France's relatively low dependency on environmentally harmful, low-complexity products (Brown Lock-In Index rank of 121 in 2022) compared to some of its neighbours like Spain and the UK provides a unique competitive edge. This lower dependency reduces transition risks, enabling France to turn more effectively towards green industrial development. However, this advantage must be consolidated through proactive policies that foster green industrial diversification.

France's ambition to develop 6.5 GW of green hydrogen capacity is complemented by its existing industrial expertise in chemicals and energy, sectors that can benefit from hydrogen integration. However, to translate this investment into global market leadership, France must focus on the entire hydrogen value chain, from electrolyzer manufacturing to the deployment of hydrogen-powered transport solutions. Strengthening international partnerships, particularly within the EU, could further bolster France's position by fostering collaborative innovation and market access (European Commission, 2020). As an example, GRTgaz and Terega, two of France's prominent energy infrastructure operators, are actively collaborating on the H2MED hydrogen pipeline, which aims to connect France with Spain and other EU nations. This ambitious project highlights France's role in fostering regional cooperation to advance hydrogen infrastructure (Reuters, 2024b). The recent focus on hydrogen technologies should be complemented by strong incentives for related technologies. Establishing export hubs for green technologies and relying on France's leadership in water management systems, where it has a significant Revealed Comparative Advantage (RCA 4.03), could open new markets and strengthen its green export position (Andres and Mealy, 2023).

Bringing diversification and cooperation to this discussion, the high degree of economic integration within the EU makes assessing European countries as a single goods export market, a more accurate picture of their collective competitiveness in green technologies. Shared regulatory frameworks and coordinated trade policies create synergies that enhance Europe's global position in sustainable industries. Leveraging these advantages through deeper cooperation in innovation and industrial strategy could further consolidate Europe's leadership in the green economy.

Yet, France must realign its fiscal strategies to ensure sufficient funding for all green initiatives. France is facing fiscal constraints, exemplified by recent austerity measures that have reduced funding for environmental and climate related initiatives, such as halving the Green Fund budget from €2.5 billion in 2023 to €1.2 billion in 2025. While fiscal prudence is desirable, this reduction risks undermining the progress of local climate actions. Restoring funding levels for these programs, potentially in combination with EU financing mechanisms, could provide part of the resources to maintain progress without exacerbating national debt. Strengthening its export competitiveness and green industrial base, increasing fiscal and policy support, and investing in human capital and innovation ecosystems are essential steps to ensure a robust and sustainable transition. However, limitations arise from this supply-side focus, as it overlooks demand-side factors such as evolving consumer preferences, global market trends, and international trade policies or fragmentation. These elements significantly influence France's competitiveness in the green goods sector, and neglecting them can present an incomplete understanding of its market position. Nonetheless, analyzing the supply side remains essential, as it ensures France has the technological and productive capacity to meet global demand for sustainable products.

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Appendix

Table A1. List of competitive strengths and opportunities per country

Country	Category	RCA	PCI	Proximity	Anchor proximity
	Green competitive strengths				
CA	Water supply	3.45	0.56	0.20372715	1.64673541
CA	Natural Risk Management	2.55	-0.58	0.23991977	2.41215432
CA	Environmentally Preferable Products based on End-Use or Disposal Characteristics	1.15	-1.28	0.18975678	1.35128341
	Green opportunities				
CA	Management of Solid and Hazardous Waste and Recycling Systems	0.82	0.53	0.19541148	1.47087169
CA	Cleaner or More Resource Efficient Technologies and Products	0.79	0.55	0.19213985	1.40168164
CA	Clean Up or Remediation of Soil and Water	0.78	0.73	0.18871632	1.3292794
CA	Renewable Energy	0.78	0.37	0.19041448	1.36519274
CA	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	0.76	0.6	0.19396357	1.44025075
CA	Environmental Monitoring, Analysis and Assessment Equipment	0.72	0.92	0.19235116	1.40615064
CA	Heat and Energy Management	0.71	0.52	0.19901044	1.54698434
CA	Waste Water Management and Potable Water Treatment	0.68	0.41	0.18719591	1.29712487
CA	Others	0.63	1.04	0.17685798	1.07849352
CA	Air Pollution Control	0.62	0.76	0.18822809	1.31895388
CA	Resources and Pollution Management	0.61	0.86	0.18352834	1.21956152
CA	Gas Flairing Emission Reduction	0.58	1.03	0.18844761	1.32359647
CA	Noise and Vibration Abatement	0.52	0.67	0.19060429	1.36920689
CA	Waste Management, Recycling and Remediation	0.5	-0.07	0.17610387	1.06254528
CA	Energy Efficiency	0.47	0.31	0.17314644	1
CA	Natural Resource Protection	0.12	-1.01	0.17766878	1.09564077
	Green competitive strengths				
CN	Energy Efficiency	3.43	0.31	0.59870903	10
CN	Waste Management, Recycling and Remediation	3.08	-0.07	0.55882272	9.15646543
CN	Natural Resource Protection	1.76	-1.01	0.51048649	8.13422792
CN	Heat and Energy Management	1.52	0.52	0.4988692	7.88853981
CN	Clean Up or Remediation of Soil and Water	1.44	0.73	0.4850526	7.59633992
CN	Waste Water Management and Potable Water Treatment	1.36	0.41	0.4916559	7.73598953
CN	Renewable Energy	1.35	0.37	0.49661849	7.84094079
CN	Management of Solid and Hazardous Waste and Recycling Systems	1.34	0.53	0.49117421	7.72580258
CN	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	1.18	0.6	0.48024127	7.49458749
CN	Air Pollution Control	1.17	0.76	0.48576318	7.61136753
CN	Cleaner or More Resource Efficient Technologies and Products	1.15	0.55	0.49253916	7.75466923
CN	Resources and Pollution Management	1.08	0.86	0.48700251	7.63757742
CN	Gas Flairing Emission Reduction	1.05	1.03	0.48083693	7.50718475
	Green opportunities				
CN	Others	0.98	1.04	0.24714157	2.56488435
CN	Environmental Monitoring, Analysis and Assessment Equipment	0.91	0.92	0.30910267	3.87526715
CN	Water supply	0.76	0.56	0.26933221	3.03418256
CN	Natural Risk Management	0.75	-0.58	0.22291442	2.05251703
CN	Noise and Vibration Abatement	0.65	0.67	0.28099972	3.28093252
CN	Environmentally Preferable Products based on End-Use or Disposal Characteristics	0.51	-1.28	0.25585544	2.74916925
	Green competitive strengths				

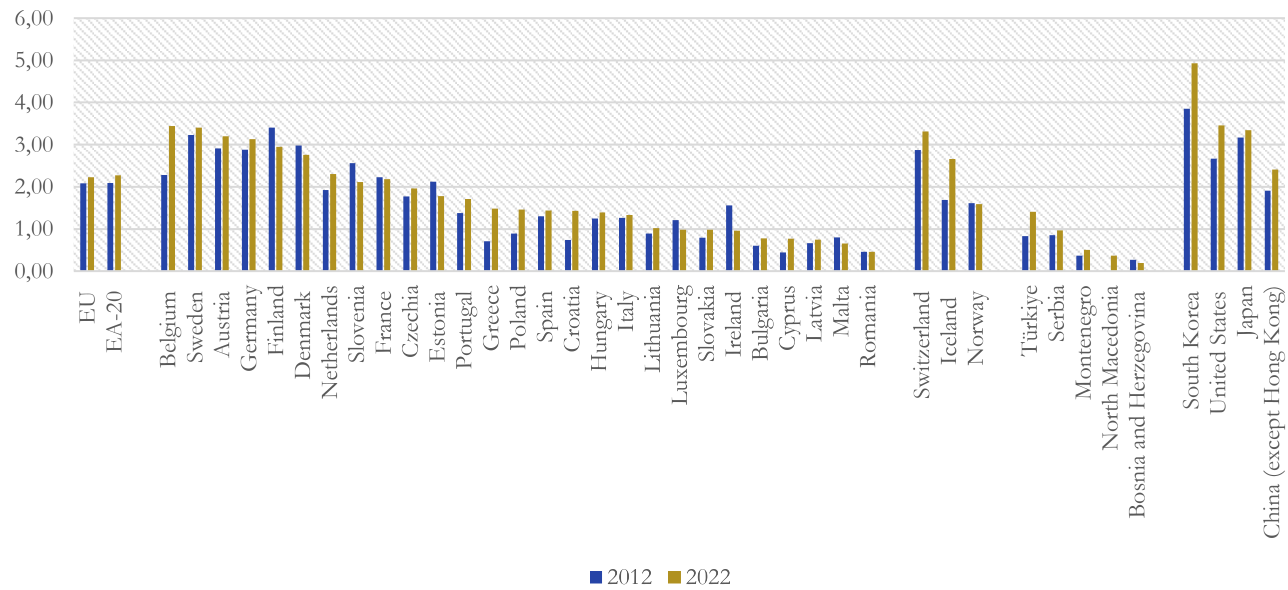
DE	Gas Flairing Emission Reduction	2.32	1.03	0.52284964	8.39568954
DE	Others	2.18	1.04	0.53324847	8.61560906
DE	Clean Up or Remediation of Soil and Water	2.13	0.73	0.47944833	7.47781816
DE	Environmental Monitoring, Analysis and Assessment Equipment	2.09	0.92	0.5121425	8.16924995
DE	Noise and Vibration Abatement	2.01	0.67	0.50839906	8.0900819
DE	Management of Solid and Hazardous Waste and Recycling Systems	1.9	0.53	0.48614245	7.61938846
DE	Resources and Pollution Management	1.75	0.86	0.51394192	8.20730499
DE	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	1.75	0.6	0.49314438	7.76746865
DE	Air Pollution Control	1.63	0.76	0.49482585	7.80302913
DE	Waste Water Management and Potable Water Treatment	1.61	0.41	0.47823212	7.45209709
DE	Cleaner or More Resource Efficient Technologies and Products	1.52	0.55	0.4885432	7.67016071
DE	Heat and Energy Management	1.45	0.52	0.47314571	7.34452728
DE	Renewable Energy	1.33	0.37	0.47121256	7.30364408
DE	Natural Risk Management	1.29	-0.58	0.43277758	6.49080279
	Green opportunities				
DE	Water supply	0.76	0.56	0.4460054	6.77055106
DE	Energy Efficiency	0.57	0.31	0.42157606	6.2539078
DE	Waste Management, Recycling and Remediation	0.51	-0.07	0.4000724	5.79913808
DE	Environmentally Preferable Products based on End-Use or Disposal Characteristics	0.35	-1.28	0.37344115	5.2359278
DE	Natural Resource Protection	0.13	-1.01	0.35027495	4.74599812
	Green competitive strengths				
ES	Noise and Vibration Abatement	2.38	0.67	0.44524196	6.75440557
ES	Cleaner or More Resource Efficient Technologies and Products	2.24	0.55	0.42452582	6.3162908
ES	Natural Resource Protection	1.92	-1.01	0.45458788	6.95205756
ES	Energy Efficiency	1.25	0.31	0.42127076	6.24745109
ES	Management of Solid and Hazardous Waste and Recycling Systems	1.21	0.53	0.42989563	6.42985395
ES	Renewable Energy	1.12	0.37	0.42307103	6.28552423
ES	Waste Water Management and Potable Water Treatment	1.11	0.41	0.42295054	6.28297594
ES	Waste Management, Recycling and Remediation	1.11	-0.07	0.44170354	6.67957334
ES	Clean Up or Remediation of Soil and Water	1.02	0.73	0.40853869	5.97818721
ES	Heat and Energy Management	1.02	0.52	0.43430362	6.52307636
	Green opportunities				
ES	Air Pollution Control	0.96	0.76	0.41754439	6.16864408
ES	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	0.88	0.6	0.42006027	6.22185105
ES	Others	0.81	1.04	0.42220072	6.26711838
ES	Gas Flairing Emission Reduction	0.76	1.03	0.40920472	5.99227288
ES	Resources and Pollution Management	0.57	0.86	0.40678192	5.94103423
ES	Water supply	0.47	0.56	0.41161059	6.04315325
ES	Environmentally Preferable Products based on End-Use or Disposal Characteristics	0.4	-1.28	0.42517221	6.32996083
ES	Environmental Monitoring, Analysis and Assessment Equipment	0.36	0.92	0.37837504	5.34027205
ES	Natural Risk Management	0.31	-0.58	0.4267698	6.36374755
	Green competitive strengths				
FR	Water supply	4.03	0.56	0.40103616	5.81952022
FR	Heat and Energy Management	1.27	0.52	0.41312914	6.07526838
FR	Cleaner or More Resource Efficient Technologies and Products	1.19	0.55	0.40336644	5.86880219
FR	Natural Risk Management	1.19	-0.58	0.42115666	6.24503802
FR	Clean Up or Remediation of Soil and Water	1.16	0.73	0.39947225	5.786446
FR	Noise and Vibration Abatement	1.16	0.67	0.43475503	6.53262292
FR	Waste Water Management and Potable Water Treatment	1.16	0.41	0.40407907	5.88387318
FR	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	1.1	0.6	0.41033107	6.01609331
FR	Renewable Energy	1.09	0.37	0.3995751	5.78862111
FR	Gas Flairing Emission Reduction	1.08	1.03	0.41096062	6.02940744
FR	Environmental Monitoring, Analysis and Assessment Equipment	1.08	0.92	0.41269596	6.06610728
	Green opportunities				
FR	Resources and Pollution Management	0.96	0.86	0.4226886	6.27743635
FR	Air Pollution Control	0.93	0.76	0.40271682	5.8550636
FR	Management of Solid and Hazardous Waste and Recycling Systems	0.87	0.53	0.39371993	5.66479314
FR	Environmentally Preferable Products based on End-Use or Disposal Characteristics	0.7	-1.28	0.37160717	5.19714189
FR	Natural Resource Protection	0.64	-1.01	0.36942273	5.15094445
FR	Others	0.53	1.04	0.38142214	5.4047135
FR	Energy Efficiency	0.51	0.31	0.36001965	4.95208366
FR	Waste Management, Recycling and Remediation	0.2	-0.07	0.3579987	4.90934352

	Green competitive strengths				
GB	Natural Risk Management	3.72	-0.58	0.39157094	5.61934521
GB	Clean Up or Remediation of Soil and Water	2.16	0.73	0.34643087	4.66470168
GB	Environmental Monitoring, Analysis and Assessment Equipment	1.86	0.92	0.35466507	4.83884241
GB	Environmentally Preferable Products based on End-Use or Disposal Characteristics	1.65	-1.28	0.28476177	3.36049404
GB	Air Pollution Control	1.55	0.76	0.32577243	4.22780701
GB	Gas Flairing Emission Reduction	1.48	1.03	0.33246277	4.36929767
GB	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	1.43	0.6	0.33319526	4.38478869
GB	Resources and Pollution Management	1.42	0.86	0.34319037	4.59616988
GB	Waste Water Management and Potable Water Treatment	1.19	0.41	0.32197012	4.14739398
GB	Renewable Energy	1.17	0.37	0.31540224	4.00849339
GB	Management of Solid and Hazardous Waste and Recycling Systems	1.11	0.53	0.31791606	4.06165675
GB	Noise and Vibration Abatement	1.1	0.67	0.3289435	4.2948703
	Green opportunities				
GB	Heat and Energy Management	0.88	0.52	0.31155795	3.92719252
GB	Cleaner or More Resource Efficient Technologies and Products	0.79	0.55	0.30605969	3.8109126
GB	Energy Efficiency	0.78	0.31	0.28316369	3.3266972
GB	Others	0.75	1.04	0.30049127	3.69314903
GB	Water supply	0.57	0.56	0.29716792	3.62286536
GB	Natural Resource Protection	0.57	-1.01	0.27943134	3.24776365
GB	Waste Management, Recycling and Remediation	0.53	-0.07	0.28436492	3.35210147
	Green competitive strengths				
IT	Management of Solid and Hazardous Waste and Recycling Systems	2.73	0.53	0.53421508	8.63605129
IT	Resources and Pollution Management	2.58	0.86	0.53625679	8.67923048
IT	Others	2.44	1.04	0.5596304	9.17354651
IT	Water supply	2.4	0.56	0.48898562	7.67951725
IT	Gas Flairing Emission Reduction	2.1	1.03	0.52601621	8.46265765
IT	Noise and Vibration Abatement	2.07	0.67	0.53576478	8.66882505
IT	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	1.96	0.6	0.52266485	8.39178153
IT	Waste Water Management and Potable Water Treatment	1.81	0.41	0.51164558	8.15874082
IT	Air Pollution Control	1.75	0.76	0.51776889	8.28823943
IT	Renewable Energy	1.52	0.37	0.51192735	8.16469984
IT	Energy Efficiency	1.44	0.31	0.56142037	9.21140174
IT	Waste Management, Recycling and Remediation	1.4	-0.07	0.51507862	8.2313443
IT	Cleaner or More Resource Efficient Technologies and Products	1.38	0.55	0.51152111	8.1561085
IT	Heat and Energy Management	1.34	0.52	0.52298574	8.39856791
IT	Clean Up or Remediation of Soil and Water	1.22	0.73	0.52169947	8.37136528
	Green opportunities				
IT	Environmental Monitoring, Analysis and Assessment Equipment	0.99	0.92	0.48096663	7.50992781
IT	Environmentally Preferable Products based on End-Use or Disposal Characteristics	0.64	-1.28	0.4628728	7.12727091
IT	Natural Resource Protection	0.48	-1.01	0.47459138	7.37510089
IT	Natural Risk Management	0.35	-0.58	0.46844894	7.24519771
	Green competitive strengths				
JP	Water supply	2.18	0.56	0.31856644	4.07541129
JP	Air Pollution Control	1.86	0.76	0.32543232	4.22061422
JP	Noise and Vibration Abatement	1.86	0.67	0.31962754	4.09785204
JP	Environmental Monitoring, Analysis and Assessment Equipment	1.69	0.92	0.33572396	4.43826677
JP	Gas Flairing Emission Reduction	1.67	1.03	0.33255389	4.37122462
JP	Resources and Pollution Management	1.54	0.86	0.33804172	4.48728378
JP	Natural Resource Protection	1.4	-1.01	0.2221189	2.03569305
JP	Management of Solid and Hazardous Waste and Recycling Systems	1.32	0.53	0.30133506	3.71099396
JP	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	1.31	0.6	0.3053482	3.79586585
JP	Renewable Energy	1.28	0.37	0.29715936	3.62268423
JP	Cleaner or More Resource Efficient Technologies and Products	1.13	0.55	0.30594134	3.80840981
JP	Others	1.07	1.04	0.34252392	4.58207552
JP	Waste Water Management and Potable Water Treatment	1.06	0.41	0.30125599	3.70932184
	Green opportunities				
JP	Heat and Energy Management	0.99	0.52	0.28099972	3.28093252
JP	Clean Up or Remediation of Soil and Water	0.9	0.73	0.30910267	3.87526715
JP	Waste Management, Recycling and Remediation	0.82	-0.07	0.26933221	3.03418256
JP	Natural Risk Management	0.52	-0.58	0.24714157	2.56488435
JP	Environmentally Preferable Products based on End-Use or Disposal Characteristics	0.22	-1.28	0.22291442	2.05251703

JP	Energy Efficiency	0.2	0.31	0.25585544	2.74916925
	Green competitive strengths				
US	Natural Risk Management	2.46	-0.58	0.38764898	5.53640178
US	Environmental Monitoring, Analysis and Assessment Equipment	2.09	0.92	0.41750499	6.16781078
US	Resources and Pollution Management	1.53	0.86	0.37678684	5.30668417
US	Efficient Consumption of Energy Technologies and Carbon Capture and Storage	1.27	0.6	0.35854681	4.9209352
US	Clean Up or Remediation of Soil and Water	1.17	0.73	0.36373894	5.0307409
US	Noise and Vibration Abatement	1.13	0.67	0.36735049	5.10711976
US	Gas Flairing Emission Reduction	1.1	1.03	0.35843993	4.918675
US	Renewable Energy	1.1	0.37	0.3433897	4.60038553
US	Waste Water Management and Potable Water Treatment	1.09	0.41	0.34602371	4.65609085
US	Air Pollution Control	1.06	0.76	0.35363808	4.81712309
	Green opportunities				
US	Environmentally Preferable Products based on End-Use or Disposal Characteristics	0.97	-1.28	0.3048181	3.78465505
US	Cleaner or More Resource Efficient Technologies and Products	0.96	0.55	0.34022117	4.53337581
US	Water supply	0.93	0.56	0.34274269	4.58670214
US	Heat and Energy Management	0.92	0.52	0.32818747	4.27888145
US	Management of Solid and Hazardous Waste and Recycling Systems	0.81	0.53	0.33336669	4.38841401
US	Others	0.71	1.04	0.32382873	4.18670088
US	Waste Management, Recycling and Remediation	0.36	-0.07	0.28366353	3.33726795
US	Natural Resource Protection	0.3	-1.01	0.27219907	3.09481212
US	Energy Efficiency	0.28	0.31	0.28827882	3.43487438

Source: Andres and Mealy (2023) – Green transition navigator.

Fig. A1. Gross domestic expenditure on R&D in 2012 and 2022 (% GDP)



Source: Own elaboration with data from Eurostat. Note: The majority of 2022 values are estimated. When data on 2022 is not available, the last available date is chosen. 2022: Belgium, Austria, Germany, Netherlands, Slovenia, France, Czechia, Estonia, Portugal, Greece, Poland, Spain, Croatia, Hungary, Italy, Lithuania, Luxembourg, Slovakia, Ireland, Bulgaria, Cyprus, Latvia, Malta, Norway, Serbia, 2021: Denmark, Switzerland, Turkey, Bosnia and Herzegovina, South Korea, US, Japan, 2020: North Macedonia; China; 2018: Montenegro. 2013 is used instead of 2012 for Iceland and Montenegro

Box A1. Summary of regulatory green framework in France.

In regards to renewable energy, France arrived later than other countries when it comes to the use of feed-in-tariffs (FITs) for the support or renewable energy like solar energy. Very low levels of support existed in the country up to 2005, yet rapidly the Government understood the need of supporting this type of energy through demand-pull policy instruments. While the legal basis for energy auctions is set with the Decree n°2002-1434 of 4 December 2002 on the procedures of calls for offers for electricity producing installations and the Decree n°2004-90 on compensation for the additional costs arising from public electricity services, France did not put in place the first renewable energy auction until 2011 with tenders for wind installed capacity in particular areas. Yet, it was not until 2016 that the tendering support scheme was settled with the publication of two decrees (n°2016-682 and n°2016-691) for different types of renewable installed capacity (IEA, 2021a). France has financed renewable energy deployment through general taxation paid by all citizens, rather than imposing non-tax levies or passing costs to end users through electricity bills like e.g. Spain. The country has the highest environmental policy stringency among OECD countries largely due to a more stringent and robust emissions taxation system. However, some analysts argue that France's environmental taxation system is driven less by ecological objectives and more by traditional revenue generation goals (Chiroleu-Assouline, 2015).

Based on the Law on Energy Transition for Green Growth (LTECV) of 2015, France has established itself as an early proponent of the energy transition through a comprehensive planning system. This act built upon the foundations laid by the 2005 POPE Law and the 2007-2010 Grenelle Environment Laws, aiming to steer a greener economic growth by 2030. As complementary strategies, France presented in 2016 its National Strategy for Energy Research, setting out the main objectives for research and development (R&D) in energy transition, highlighting the need for multidisciplinary R&D and the strengthening of international collaborations and networks[16] (IEA, 2021a).

The starting point of the Law on Energy Transition for Green Growth (LTECV) was the result of the National Debate on the Energy Transition held in 2013. The debate considered four potential transition pathways to achieve a 75% reduction in greenhouse gas emissions by 2050 compared to 1990 levels: decarbonisation through electrification, diversification and moderate energy efficiency efforts, strong efforts for energy efficiency and diversification, and strong efforts for energy efficiency with a focus on sobriety and nuclear phase-out. No single pathway achieved consensus, but there was general agreement on the need for the energy transition to be economically beneficial for France, significantly cutting the final energy demand and fossil fuel consumption.

The LTECV established ambitious targets, including a 40% emissions reduction by 2030 in comparison to the 1990 levels and a 75% by 2050; a reduction in the final energy consumption of 20% by 2030 and of 50% by 2050 with respect 2012; a reduction in the nuclear energy share in electricity production down to 50% by 2025 and additional renewable energy targets of 23% by 2020 and 32% by 2030 of the gross final consumption[17]. The 2019 Energy and Climate Law updated some of the previous targets to align them with the aim of achieving climate neutrality by 2050, which includes an 85% reduction in greenhouse gas emissions. New targets were also introduced, such as the deployment of 1 GW of offshore wind per year by 2024. However, France did not meet its initial target of 23% renewable energy in its gross final energy consumption by

[16] Additional information on the timeline of policies can be extracted from the IEA Policy Database (https://www.iea.org/policies)
[17] Ibid

2020. The actual figure reached was 19.1%, falling short of the target by 3.9 percentage points (Rudinger, 2022).

Partly in response to this shortfall, France adopted in 2020 the National Low-Carbon Strategy (SNBC) (Ministere de la Transition Ecologique et Solidaire, 2018), which provides sector-specific emissions reduction targets and outlines the pathway across successive five-year carbon budgets.