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Environmental Policy Stringency and European Innovation Scoreboard: a study on the effectiveness of European cleantech policies on innovation performance

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Abstract

Over the last few years, climate change has become one of the most critical challenges humanity has to face. The impacts it is having on the environment are now becoming extreme and irreversible. Urgent action is needed to guarantee the Earth's survival and this responsibility cannot be dodged further.

International institutions and national governments are expected to work in close cooperation so as to achieve concrete results in the shortest time. The European Union, throughout the years, has been taking a leading role, with the aim of coordinating and driving Member States' operations towards a modern society and a sustainable economy.

The European Green Deal, issued in December 2019, clearly states the goal of outlining a growth strategy that will support the EU during the transition towards a net-zero greenhouse gas emissions economy by 2050. To achieve this ambitious target, several measures are being implemented, and the commitment and participation of Member States is imperative.

Still, Governments are struggling to find the best policy mix that fosters both citizens and firms to undertake greener activities. A wide variety of instruments exist that differ according to the stringency they convey. Stricter environmental policies can have either a positive or a negative effect on firms' activities. Specifically, studies show that more stringent environmental policies lead to more innovative outcomes, ultimately having a positive effect on society. By contrast, others suggest that stricter regulations only drive companies to relocate abroad.

The goal of this paper is to investigate the correlation between the environmental policy stringency and the innovation activities, aiming to prove that stricter policies foster innovation. Specifically, under a methodological point of view, this paper will start by building a dataset containing a list of policies and regulations implemented by Member States in the last years. Further, two indexes are introduced and four analyses are undertaken, in order to investigate evidence of the correlation under several points of view.

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1 Introduction

Earth's climate has experienced, throughout history, huge changes. As the atmosphere gets warmer, long-term alterations affect temperatures, ecosystems and weather conditions. These changes, which are mainly due to natural causes, build up slowly throughout the centuries, and stimulate species to continuously look for new equilibria. Still, in the most recent years of the Earth's life, human activity has altered these equilibria, and changes have become increasingly extreme, resulting in unpredictable weather events and violent natural phenomena. Forests are being destroyed, oceans polluted, and species are at high risk of extinction: climate change has definitely become the most critical threat to the Earth's and humans' survival and urgent action is required to face all these environmental-related challenges.

It is mandatory that international institutions and national governments work in close cooperation to define solid strategies and action-plans that can mitigate negative effects and ensure future prosperity. To this end, several agreements have been submitted at international level to formulate a climate-resilient pathway.

In December 2015, 196 countries taking part to the United Nations (UN) Change Conference (COP21) signed a legally binding international treaty on climate change, defining a milestone of net-zero emissions path. The Paris Agreement [1] was aimed at defining a global response to climate change by "*Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."* (UNFCCC, 2015, *Paris Agreements*, United Nations)

To achieve these ambitious goals, strong efforts are required by governments, that need to take the lead and define the most efficient and effective policy structures. In this regard, the European Union (EU) is playing a key role by coordinating Member State's efforts towards the objective of being the first continent having a net-zero greenhouse gas (GHG) emissions economy by 2050.

To this end, in December 2019, the EU issued the European Green Deal [2]. "*It is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of* *greenhouse gases in 2050 and where economic growth is decoupled from resource use*." (European Commission, 2019, *The European Green Deal*, COM(2019) 640 final)

Among several measures adopted by international organizations to tackle climate change, the European Green Deal has played a pivotal role in Europe long-term strategy. The document addresses several topics, with the aim of turning environmental challenges into opportunities and ultimately lead to a sustainable economy [3].

In July 2021, an entire set of proposals was adopted by the European Commission. The package was composed of policies fit for reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels [4]. This package is known as *Fit for 55* [5], and comprises three of the most impactful legislative proposals. The EU Emission Trading System (EU ETS) [6] sets a cap to emissions that companies are allowed to produce and creates a system of allowance trading which enhances competitiveness to stimulate emissions reduction. The Carbon Border Adjustment Mechanism (CBAM) [7] ensures that firms are not pushed to relocate carbon-intensive production outside Europe, by putting a carbon price on imports of selected products. Last, the Renewable Energy Directive (RED) [8] sets the target to produce 42.5% of energy from renewable sources by 2030.

To comply with the parameters set by the agreements, European Member States must rely on legislative bodies that are capable of driving the economy towards sustainable paths. Hence, it is pivotal for them to understand how legislative measures will affect both the business and the environment and to choose the best policy mix to ensure that a green growth is pursued.

Within the academic literature, quite a few researchers investigated the correlation between environmental policies and the cleantech sector, mainly focusing their efforts in assessing how the climate policy framework can stimulate clean innovation while mitigating climate change.

Within this perspective, studies emerged that delved into the measurement of the stringency of environmental policies, aimed at defining a quantitative indicator. In 2014, Botta and Kozluk [9] developed the Environmental Policy Stringency Indicator, a policy-based composite indicator which quantitatively expresses how strict environmental regulations are on a scale of 0 to 6.

The findings made by OECD researchers gave birth to a flourishing literature aimed at investigating the correlation of the new index with a huge set of country-related variables. Specifically, the relationship between environmental policy stringency and clean innovation was tested by multiple articles, resulting in different outcomes. The vast majority of scholars supports the Porter Hypothesis (Porter and Van der Linde, 1995 [10]) and argues that properly developed restrictive environmental policies promote innovation activities ("weak" version of the Porter Hypothesis) and boost firms' competitiveness ("strong" version of the Porter Hypothesis). Conversely, other researchers claim that stricter environmental standards lead firms to relocate abroad, following the Pollution Haven Hypothesis.

The present work comes under the broad category of papers aimed at investigating the weak version of the Porter Hypothesis. Although the topic is extremely discussed, this study brings about aspects of novelty, by choosing the European Innovation Scoreboard [11] as a proxy of innovation activities. This variable is developed by the European Commission on a yearly basis and comprises a set of measures related to financial, societal and environmental aspects.

In conclusion, the goal of this thesis is to assess how European Member States are taking actions against the threat of climate change, by looking for evidence of the weak version of the Porter Hypothesis.

The work is structured in two parts, further divided into several chapters. The first part of the document is aimed at creating a dataset containing a list of national implementations of some Directives and Regulations published by EU to comply with the Green Deal indications. This part is composed of a first chapter fully dedicated to the Green Deal, followed by a *Data and Methodology* section describing the procedure that led to the creation of the dataset. To conclude, a chapter will be dedicated to showing some analyses derived from the data.

The second half of the thesis is devoted to the analyses. The Environmental Policy Stringency (EPS) Index is first introduced, reporting the most relevant findings that led to its creation. Before diving into the description of data and methodologies used for the analyses, a short paragraph outlines the research question. An entire chapter follows, presenting the four analyses that will be discussed. Finally, the last chapters illustrate, respectively, conclusions driven by the results obtained and limitations and further development of the present studies.

2 The European Green Deal

The first chapter of this thesis is fully devoted to the study of the European Green Deal [2]. As already mentioned, this document has assumed a key role in defining Europe long-term strategy, acting as a reference for further legislations. Moreover, within this publication, the EU strongly affirms its leading position towards a more sustainable economy.

The European Green Deal is aimed at defining the transition towards a sustainable economy, by acting on two main levers. First of all, transition needs financing. Additionally, transition must be fair, and no one can be left behind. Therefore, the European Commission structured the document upon eight pillars, each of them addressing a specific area involved in the transition (Figure 1). The detailed descriptions of such pillars are reported in the following chapters.

Figure 1. The structure of the European Green Deal.

2.1 Increasing EU's climate ambition for 2030 and 2050

The first chapter of the Green Deal focuses on setting ambitious targets and defining key milestones of the transition. To this end, the years 2030 and 2050 are taken as a reference, and policies are created to drive Member State actions. The following paragraphs are aimed at outlining the most relevant initiatives set by the EU.

The European Climate Law [12] was issued in June 2021. This document is intended to transpose into law the goal set out in the European Green Deal of making economy and society climate-neutral by 2050. To this end, the Regulation includes a legal objective for Member States to achieve net zero GHG emissions by 2050, either by cutting emissions, investing in green technologies and protecting the environment. Furthermore, a more ambitious target is set: by 2030, a 55% reduction in net emissions of GHG as compared to 1990 is to be achieved [13].

Second, the Just Transition Mechanism (JTM) [14] was created. This tool is aimed at ensuring that transition towards a climate-neutral economy happens in a fair way. In order to mitigate the socio-economic impact of the transition, the EU has adopted this mechanism to provide support to regions and workers that face the greatest challenges. In the period 2021-2027, the JTM is expected to mobilize € 55 billion across these regions.

Last, the "Fit for 55" package [5] was approved in 2021. As already described, it is composed of a set of proposals covering several economic areas. Among them, the EU ETS [6], the CBAM [7] and the RED [8] were the most impactful ones.

2.2 Supplying clean, affordable and secure energy

To achieve the climate objectives set out in the first paragraph, the EU states that it is mandatory to act on the Energy sector. Therefore, in the second chapter of the Green Deal, indications are set for Member States to present climate plans by the end of 2019. Renewable energy sources are at the core of the transition, and the need for them has recently increased due to Russia's invasion of Ukraine.

In May 2022, the European Commission adopted the REPowerEU Plan [15], aimed at reducing the dependence on Russian fossil fuels as rapidly as possible (Figure 2). As of today, this plan resulted in almost 20% saving of energy demand, an increase in the deployment of renewables and ultimately a strong reduction in the dependency on Russian fossil fuels [16] (Figure 3).

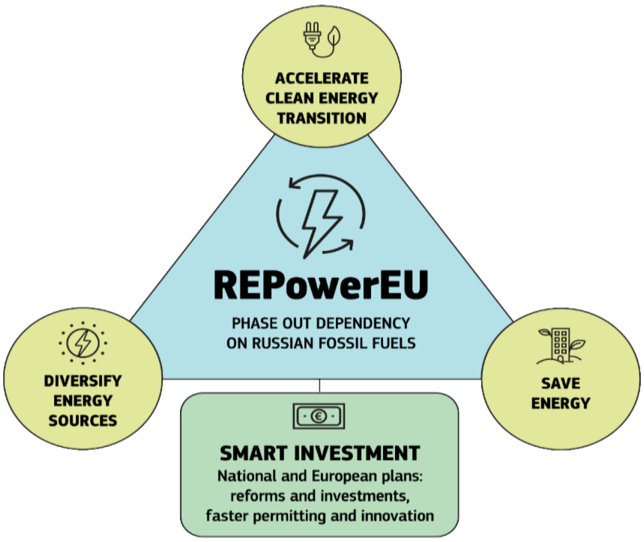

Figure 2. The structure of the REPowerEU.

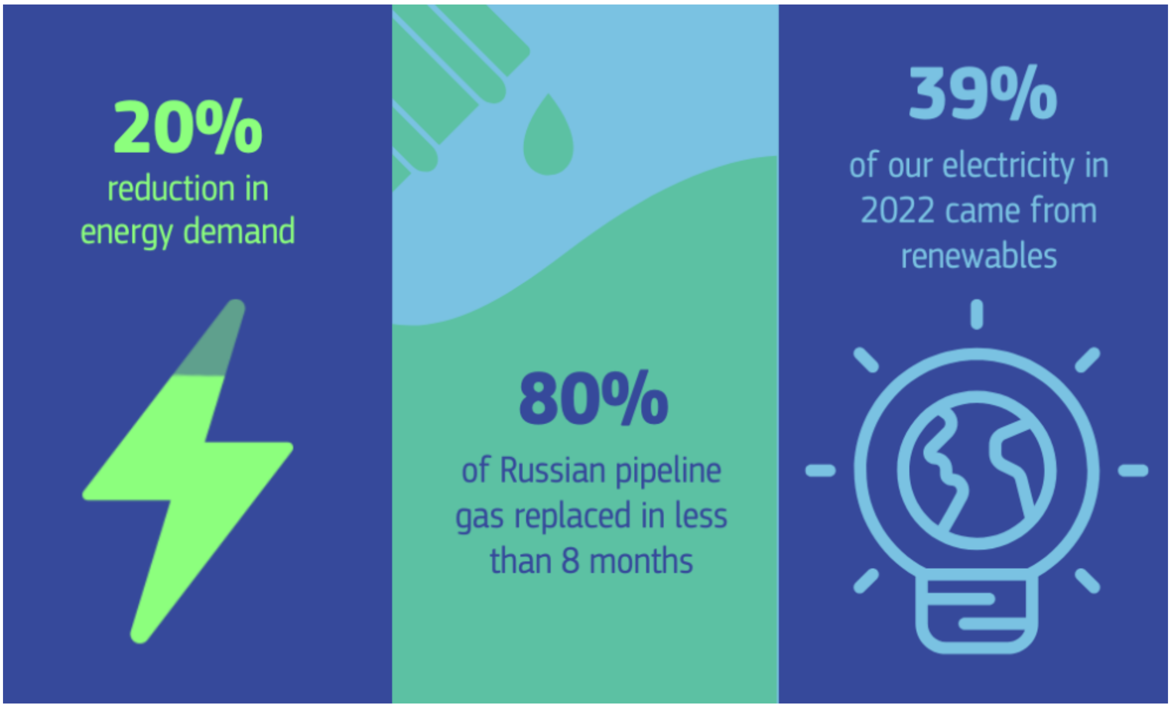

Figure 3. Figures describing the results obtained through the implementation of REPowerEU.

2.3 Mobilizing industry for a clean and circular economy

The shift of an industrial sector usually takes about 25 years, so it's crucial to take action now in order to achieve 2050 goals. Realizing a fully circular economy requires the mobilization of industry, thus a specific action plan needs to be defined.

The current "take-make-dispose" model is to be changed soon, as it damages both the environment and the economy. Unnecessary resource wastage does indeed lead to scarcity of materials and unstable raw material prices, which are to be added to the impacts it generates to natural environment. It is intuitive that this model is no-longer sustainable and the circular economy approach, based on recycling and waste reduction must be adopted immediately.

To this end, EU has developed the Circular Economy Action Plan (CEAP) [17], which announces initiatives along the entire life cycle of products. In the last couple of years, several policies have been published to address waste reduction. In March 2022, the Sustainable Products Initiative outlined a proposal for the Ecodesign for Sustainable Products Regulation [18]. In November 2022, European Commission revised the EU rules on Packaging and Packaging Waste [19] and set a framework for biodegradable and compostable plastics. In 2023, the monitoring framework [20] was revised and measures were set to reduce the impact of microplastic pollution on the environment [21].

2.4 Building and renovating in an energy and resource efficient way

The impact of buildings on the environment is huge, as not only take they part in the generation of waste and pollution, but also, they cause high energy consumption. As claimed by Santamouris (2016) [22], the building sector accounts for around 40% of worldwide energy consumption and 36% of energy-related GHG emissions. Moreover, requirement of raw materials for buildings is around 3 billion tons, equal to half the global annual material use. In addition, construction accounts for the 25% share of air pollutants.

The figures outlined by Santamouris show the huge negative impact buildings are having on the environment, but, at the same time, they highlight that a renovation of this sector can lead to huge positive effects. As it is written in the Green Deal, "*While increasing renovation rates is a challenge, renovation lowers energy bills, and can reduce energy poverty. It can also boost the construction sector and is an opportunity to support SMEs and local jobs*" (*The EU Green Deal*, ch. 2.1.4, p. 9).

It is not surprising, therefore, to get to know that European Commission launched the Renovation Wave Strategy [23] in 2020, aimed to convert all buildings into zero-emission structures by 2050. The path outlined by the initiative is built on three main pillars (Figure 4), them being the decarbonization of heating and cooling, the eradication of energy poverty, and the renovation of public buildings and social infrastructure. Specific ambitious targets are set: GHG emissions from buildings shall be reduced by 60% and final energy consumption must decrease by 14%, both by 2030, compared to 2015 levels. Also, a doubling of the annual renovation rate (currently at 1%) should be pursued [24].

Figure 4. The 3 main pillars the Renovation Wave Priorities is built on.

2.5 Accelerating the shift to sustainable and smart mobility

Transportation is one of the main pillars of modern societies, as it has a strong impact on quality of life and economy boost. As a matter of fact, these positive connotations are counterbalanced by negative externalities transports generate. As of today, a quarter of GHG emissions are due to transportation sector (EEA (2023) [25]). Therefore, urgent action and strict targets are required. The 82 initiatives described in the Sustainable and Smart Mobility Strategy [26] issued by the Commission in 2020 all lead to a 90% reduction of GHG emissions by 2050, which will involve significant changes to the whole industry. The foundations of this document rely on three main aspects [27].

The first pillar is to be sustainable. In practice, it consists in a strong boost to multimodal transport. A huge share of freight carried by road is to be shifted onto rail and water, which requires an increase in the capacity of railways and waterways.

Second, the Commission states that transportation must be smart. Therefore, the automated and connected multimodal mobility (Smart Mobility), together with smart traffic management systems, should rapidly enter the current framework of transportation infrastructures and lead it to strong reduction in congestion and pollution of urban areas.

Third, the transportation sector must be resilient. Indeed, as already pointed out, the European Green Deal is aimed to ensure a fair transition that makes transportation affordable and accessible in all regions and for all passengers. Also, transport safety and security must be set up across all models, with the target of bringing the death toll close to zero by 2050.

According to the most recent updates, the European Environment Association (EEA) claims that emissions due to domestic transport will only drop below their 1990 level in 2029. Also, indicators show that transport GHG emissions have rebounded after the decrease due to Covid-19 Pandemic, resulting in a +7.7% in 2021. The share of energy from renewable sources used for transport, which Directive 2018/2001 [28] imposes to be no lower than 14% by 2030, reached 10.2% in 2021. The number of electric vehicles is steadily growing and has registered a +23% in 2022. This result is enhanced by Regulation 2023/851 [29], which states that by January 1st, 2035, a 100% reduction in average emissions must be achieved, with respect to 2021 [30].

2.6 From "Farm to Fork": designing a fair, healthy and environmentally-friendly food system

The European Commission's Farm to Fork Strategy [31] represents EU's firm dedication to transform the existing food system into an environmentally sustainable, socially equitable and health oriented one. As a matter of fact, the food system is currently unsustainable, as it leads to resource depletion, biodiversity loss, increased food waste and it accounts for about one third of the global GHG emissions.

The transition will involve the entire food chain and will address both operators and machinery and technologies (Figure 5). At least 40% of agricultural policy's budget and 30% of Maritime Fisheries Fund will indeed contribute to climate action. Moreover, precision agriculture and organic farming are to be fostered (by 2030, 25% of total farmland should be under organic farming). Switching to more concrete numerical targets set by EU, the use of chemical pesticides is to be reduced by 50% by 2030, and fertilizers will be cut by 20% [32].

Figure 5. The "Farm to Fork" strategy will involve the whole food chain.

2.7 Preserving and restoring ecosystems and biodiversity

The effects of climate change on nature are easily recognizable in the degradation of ecosystems. Sea-level and temperature increase led to the alteration of natural habitats, which ultimately affects species survival. In order to face these challenges, the EU developed a Biodiversity Strategy [33] that also collaborated to support a green recovery from the Pandemic. This strategy is composed of three main actions.

First, Natura 2000 [34], the EU network of protected areas on land and at sea, must be enlarged. Currently, it covers 18% of EU land and 8% of EU water.

Second, the Nature Restoration Law was issued, which set a broad restoration goal for long-term recovery of nature in EU. 30% of EU land and marine regions must be covered by these policies by 2030.

Third, specific measures are to be introduced to tackle global biodiversity challenge and to ensure good implementation.

2.8 A zero-pollution ambition for a toxic-free environment

To fight pollution emission, the European Green Deal states that measures are required both to prevent pollution generation and to clean and remedy to it. Keeping this aim in mind, on May 12th, 2021, the European Commission adopted the EU Action Plan: “Towards Zero Pollution for Air, Water and Soil” [35], which depicts a zero-pollution vision for 2050. Such a vision is made more concrete through the definition of some stringent targets. These targets include the reduction of the number of premature deaths caused by air pollution by 55%, the reduction of plastic litter at sea by 50% and microplastics released into the environment by 30%, a significant cut of the waste generation by 50% [36].

Additionally, the Chemical’s Strategy for a Toxic-Free Environment [37] was released in 2020. It is aimed at protecting both citizens and the environment by keeping under control the effect of chemicals and boosting investments in production and use of sustainable and safe substances.

Finally, to remove CO_2 from the atmosphere, the EU structured a plan to capture it in soil and forests. In June 2022, the Land, Land Use Change and Forestry (LULUCF) Regulation was issued, lastly revised in March 2023. Following a two-phase approach, the revised regulation establishes new binding targets for Member States. Until 2025, the current system holds, with the obligation to balance emissions and removals (as of 2019, EU-level of net removals was equal to 249Mt, with a binding target of 225 Mt). From 2026 to 2030, an increased target for net removals of 310 Mt.

3 Creating a dataset listing all European cleantech policies: a methodological overview

The first chapters have carried out the hard task of introducing the reader to the topic this thesis has the aim to address. While they have outlined the theoretical basics standing behind the study, the following section will rather describe the practical operations that have been performed when started dealing with the research focus.

3.1 Research objective

As previously mentioned, the first part of this work was devoted to the creation of a dataset listing and classifying policies and regulatory initiatives issued by the 27 EU Member States when asked to implement Directives and Regulations set by the Commission. Once completed, this dataset will allow for insights and analyses that may be useful for further studies.

Hence, it is not surprising that this chapter will describe the phases of research, analysis and categorization of policies across EU Member States.

It is worth mentioning that these very first steps were performed by a group of five students, under the coordination and supervision of three professors: Elisa Ughetto from Politecnico di Torino, Laura Toschi and Sara Zanni from Università degli Studi di Bologna.

3.2 Identification of Green Deal topic

The starting point of the research is the Green Deal, which the previous chapter has described in detail. Having read the original paper, each member of the team decided the topic he or she preferred to deepen. Personally, given my work experience in the field of logistics and transportation, the choice fell on the sub-chapter "Accelerating the shift towards a sustainable and smart mobility”. This section mainly focuses on the strategy the EU wants to put in place in order to reduce the GHG emissions and finally reach a zero-emission mobility.

Moreover, the topic has been further detailed by the Fit for 55 package – which introduces new sophisticated measures to achieve the 55% reduction of GHG by 2030 – and is currently being addressed by lots of European countries. For instance, the EU Emissions Trading System [6], known as EU ETS, has been modified in April 2023 so as to meet the targets that were set.

3.3 Definition of the keywords

After the choice of the topic, a list of keywords was to be defined. This list should contain words defining the topics addressed by the Green Deal and it is aimed at helping to narrow the research field.

At this stage, the approach was to follow a hierarchical structure, meaning to create categories in which to group different keywords. To do so, the research began by reading the whole Green Deal paper and highlighting the words that recur the most across it and thus best summarize it.

Still, it emerged that the list derived from this first approach was composed of keywords that were not specific to one topic only, rather they addressed the whole document in a holistic way. By mutual consent with the whole team, it was agreed to define these keywords as “transversal”. They are listed in Table 1 below.

Table 1. List of the "transversal" keywords.

Climate neutrality • Greenhouse gas emissions reduction • Renewable sources • Clean energy transition
Modernize and transform the economy • Digital transformation • Digital technologies

• Energy efficiency • Energy performance • Energy flexibility • Performance monitoring • Data accessibility
Taxation aligned with climate objectives
Citizen awareness and education

Being this first list too broad, a second, more detailed analysis of the Green Deal topic was undergone. By following precious advice of supervisors, a set of peculiar keywords emerged. They were clustered into several groups, and finally listed in Table 2 shown below.

Table 2. List of the keywords related to the topic "Accelerating the shift towards a sustainable and smart mobility".

Sustainable and smart mobility • Multimodal transport • Combined Transport Directive • Single European Sky • Smart traffic management systems • Recharging and refueling points • Sustainable alternative fuels
Air quality • Air pollutant emission standards
International Civil Aviation Organization
International Maritime Organization

3.4 Definition of the dataset fields

In order to create a consistent dataset, it was mandatory to establish the fields required for the analysis and the type of data each field will contain.

Following a structure proposed by the supervisors, 29 fields were identified, which are listed in the following Table 3.

Table 3. List of the 29 fields of the dataset.

Item	**Format**	**Values**
COD	Alphanumeric code: CountryCode_DirectiveYear_DirectiveNumber_PolicyYear_PolicyNumber_TopicNumber	CountryCode: 2-letters country code defined by international organization; DirectiveYear: year of creation of the Directive; DirectiveNumber: number of the Directive; PolicyYear: year of creation of the policy; PolicyNumber: number of the policy; TopicNumber: number of EU Green Deal chapter (see *Topic*)
Country	Text	2-letters country code
Level	Alphanumeric Code	Level of the policy: Europe; Country; Region
Year	Alphanumeric Code	Year of creation of the policy
Topic	Text	Number of the chapter of EU Green Deal
Policy Name	Text	Official name of the policy (in original language)
Policy reference	Text	Official policy reference (usually composed by year of creation and number)
Overlapping	Alphanumeric Code	This field contains the code of other policies or directives which create an overlap
Instrument	Text	EU Commission’s strategy; EU Commission’s strategy / Standard definition / Incentives-taxes; EU Commission’s strategy / Targets for all MS; Standards and obligations; Administrative arrangement;

		Binding targets; Infrastructure design; R&D; Long-term strategy; National regulation
Superordinate Law	Text	Name of the Directive that the policy implements
Policy level	Text	Code of the policy level: EU for Europe, CO for country, RE for region
Mechanism	Text	Market -Based; Non-Market-Based
Type_Botta	Text	Classification of the policy according to the paper of Botta (N/A if the classification is not applicable to the specific policy)
Type_De_Serres	Text	Classification of the policy according to the paper of De Serres (N/A if the classification is not applicable to the specific policy)
Type_Kruse	Text	Classification of the policy according to the paper of Kruse (N/A if the classification is not applicable to the specific policy)
Type_An_Economic_Analysis_of_Biodiversity	Text	Classification of the policy according to the paper "An economic Analysis of Biodiversity" (N/A if the classification is not applicable to the specific policy)
Type_From_Farm_to_Fork: Sustainability_Goals_and_Policy_Instruments	Text	Classification of the policy according to the paper "From Farm to Fork" (N/A if the classification is not applicable to the specific policy)
Category	Text	Regulatory Policy; Financial Incentives; Banning Regulation
Perimeter of application	Text	Subjects affected by the policy
Technology	Text	Technology impacted by the policy
Created on	Date	Creation date
Expired on	Date	Expiration date (whether the policy is expired)

Transposition Deadline	Date	Date by which a Member State should implement a Directive
Adoption (days)	Number	Difference between the date of creation of a policy and the deadline imposed by the EU Directive, in days (if positive: delay in the implementation; if negative: advance)
Adoption (year)	Number	Difference between the date of creation of a policy and the deadline imposed by the EU Directive, in years (if positive: delay in the implementation; if negative: advance)
Late	Binary	Analysis of implementation date in relationship to the transposition deadline: Late; Early
Last amended	Date	Date of last amendment
Indicator	Text	Description of the performance indicators listed in the policy, if present
Stringency	Number	Number defined by OECD indicating how the policy-mix of a given country in a given year addresses climate externalities *(See Chapter 4)*
Notes	Text	Notes and comments

3.5 Research phase

Once the dataset fields were agreed, the research phase could begin. However, by simply typing some of the keywords and browsing the internet, a huge number of results was generated. Then, a solid research methodology was to be structured in order to make a differentiation between reliable and non-reliable sources and limit the waste of time.

It's worth mentioning that, as it usually happens in similar works, not only this phase was the toughest one, but also it took quite a few times to be completed.

By comparing evidence resulted from team members' experience and following a trial-and-error approach, after about one month, the following steps were agreed:

1. First, the set of Directives and Regulations specifically related to one topic was to be defined;
2. Second, for each Directive and Regulation identified, the whole set of policies issued by a Member State in order to transpose those EU documents into national legislation was to be defined;
3. Last, each of the national transpositions was to be studied and categorized into the dataset.

To address the first problem, the keywords listed above were searched on the EU official website [38]. Also, by browsing the website, it is easy to find some sections related to each of the Green Deal topics, reporting the latest news and updates.

Once the list of Directives and Regulation was set, the focus should shift to one Directive only, which should drive the following steps of the research. To perform this further step, the EurLex portal [39], where all the EU legislative acts are saved and categorized, was extremely useful. Here, users have the possibility to access the EU documents translated in most of the Member States languages and they are also allowed to see, for each EU law, a list of some documents transposing that law.

So, to find all the national transpositions of a specific Directive, the EurLex portal was just a starting point. Two were the steps to be performed:

1. The first operation consisted in opening all the links related to the national transpositions already present on the EurLex;
2. Second, to increase the completeness of the search, some queries were written on Google by translating the keywords of the Directive into different languages; results generated from this search were added to the laws already registered in step 1.

Little by little, confidence with the methodology grew up, and so did the familiarization with some of the most-visited national websites. The following Table 4 contains a list of links that have been identified as the most reliable sources for each Member State.

Table 4. List of the most common websites used in the policy research phase.

Member State	Code	Website
Austria	AT	https://www.ris.bka.gv.at/
Belgium	BE	https://etaamb.openjustice.be/fr/index.html
Bulgaria	BG	https://iisda.government.bg/
Cyprus	CY	https://www.nomoplatform.cy/
Czech Republic	CZ	https://www.zakonyprolidi.cz/
Germany	DE	https://bmdv.bund.de/DE/Home/home.html
Denmark	DK	https://www.retsinformation.dk/
Estonia	EE	https://www.riigiteataja.ee/en/
Greece	EL	https://www.taxheaven.gr/
Spain	ES	https://www.boe.es/
Finland	FI	https://www.finlex.fi/fi/
France	FR	https://www.legifrance.gouv.fr/
Great Britain	GB	https://www.legislation.gov.uk/
Croatia	HR	https://narodne-novine.nn.hr/
Hungary	HU	https://net.jogtar.hu/
Ireland	IE	https://www.irishstatutebook.ie/
Italy	IT	https://www.gazzettaufficiale.it/home
Lithuania	LT	https://e-seimas.lrs.lt/portal/documentSearch/lt
Luxembourg	LU	https://legilux.public.lu/
Latvia	LV	https://likumi.lv/
Malta	MT	https://legislation.mt/
Netherlands	NL	https://zoek.officielebekendmakingen.nl/uitgebreidzoeken
Poland	PL	https://isap.sejm.gov.pl/
Portugal	PT	https://diariodarepublica.pt/dr/home
Romania	RO	https://anap.gov.ro/web/
Sweden	SE	https://svenskforfattningssamling.se/
Slovenia	SI	https://www.uradni-list.si/
Slovakia	SK	https://www.slov-lex.sk/domov

3.6 Categorization of the policies

The categorization action was the last step to be performed. Although the previous ones were for sure the most time-consuming ones, especially at the very beginning, the action of categorization and registration of each policy into the dataset was not free from issues.

First, each Member State has its own legislation code, thus not all countries implement the Directives by using the same acts. By way of example, Italy implements each European Directive by issuing a "Decreto Legislativo", a proposal of a law, which is explicitly denominated as "Implementation of EU Directive" and contains all the elements described in the Directive. France, by contrast, follows a completely different approach, as the French President usually approves several laws known as "Décrets" and "Arretés", in different times, to implement just one single Directive. As a consequence, the operations of categorization and uniformization of the dataset were much more complex than planned.

Another topic that emerged as an issue in categorizing policies from different countries was the way to identify the most relevant aspects within the different laws. This happens mainly because not all the Member States follow the structure of the Directive and most of them often create documents full of annexes where key tables and numbers are stored.

In addition, a problem was represented by the difference between languages. Some automatic translators played a crucial role in deciphering the content of the most complex laws, but still they could not help to translate files which were realized in pdf format, and thus not accessible.

3.6.1 Market-Based and Non-Market-Based policies

As described above, one of the fields to be completed for the classification of the policies was defined as "Mechanism". Its aim was indeed to address the mechanism chosen by the governments when creating a policy, either Market-Based or Non-Market-Based.

The classification of instruments into these categories has been discussed by several authors within the literature, with specific regards to the effects that Market- and Non-Market-Based instruments may have on climate change.

As De Serres et al. (2010) [40] clearly explain, environmental policy instruments can be broadly classified under two categories, depending on how they address social and climate issues.

A first possible approach to face externalities is to take direct action against the market activities undertaken by private actors. This can be done by following two main paths: either governments introduce environmentally related taxes and charges, or they create a system of tradeable pollution permits or quotas. Given that these actions have an impact on the market and put a price on pollution, they can be grouped into the so-called Market-Based instruments. Some examples of sub-categories of the Market-Based group can be found in Kruse et al. (2022) [41]:

- *CO_2 Trading Schemes*
  They define a maximum quantity of CO_2 emissions that can be emitted, by leveraging a system of allowances;
- *Renewable Energy Trading Scheme*
  A system that is based on the trade of certificates based on obligation to source electricity from green sources;
- *CO_2 Taxes*
  Taxes on the rate of CO_2 emissions;
- *Nitrogen Oxide (NO_x) Tax*
  Taxes on the rate of NO_x emissions;
- *Sulphur Oxides (SO_x) Tax*
  Taxes on the rate of SO_x emissions.

All instruments that do not comply with this categorization are defined as Non-Market-Based. Botta and Kozluk (2014) [9] proposed the following subgroups:

- *Command-and-control regulations*
  They impose decisions on operations by fixing some technology standards or performance standards and targets (for instance, limits on CO_2 emissions);
- *Technology-support policies*

They act on the supply by incentivizing greener production modes and investing in environment-related R&D;

- *Voluntary approaches*

  These are activities aiming at increasing customer awareness and sensitivity to environmental impacts of products.

To complete the dataset, a decision was taken to create three columns that could further detail the classification of Market- and Non-Market-Based policies according to the above-mentioned scientific papers, De Serres et al. (2010) [40], Botta and Kozluk (2014) [9] and Kruse et al. (2022) [41]. These columns were appropriately named in the dataset with the name of the papers' authors.

4 Statistics of the dataset

Once all the policies were registered, downloaded and categorized in the dataset, several descriptive statistics could be computed in order to identify the most common phenomena highlighted by the data.

To do so, some cleaning operations were performed, so as to obtain consistent data in the final dataset.

4.1 Number of policies

The dataset consisted of 934 lines, each of them containing a single policy. More specifically, 315 were categorized as Market-Based policies, while the remaining 619 as Non-Market-Based.

From Figure 6 below, a clear trend emerges that highlights how countries located in Northern Europe are those that tend to create the highest number of policies to implement the EU instructions. Indeed, Lithuania, Sweden, Finland, Latvia and Estonia register a total of 246 policies, which accounts for more than 26% of the total number of policies in the whole dataset. By contrast, Mediterranean countries like Spain, Italy, Greece, Malta and Cyprus show much lower values.

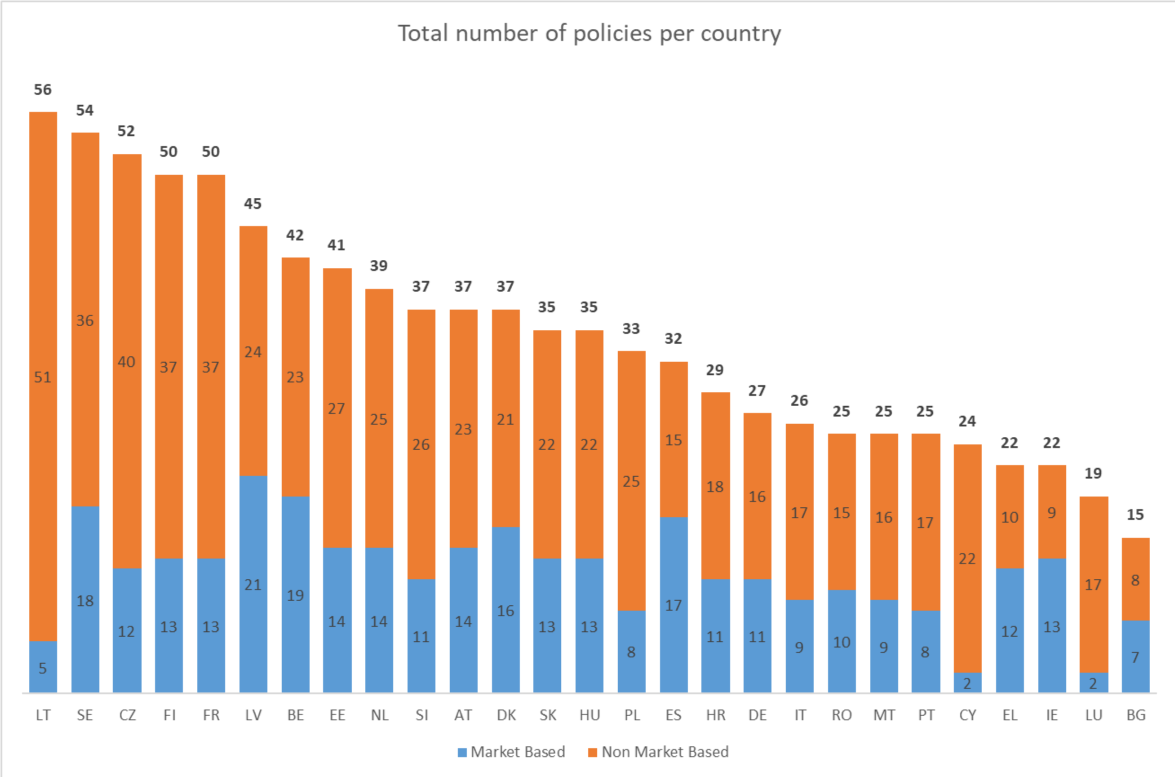

Figure 6. Total number of policies implemented per country, divided by Market- and Non-Market-Based.

This difference could be related to the way each country approaches their obligation to create laws to implement EU Directives. As already mentioned above, some countries usually create just one law to implement the whole content of a Directive, while others tend to create more documents, each of them focusing on a specific topic described in the Directive. Then, it is pivotal to understand that the graph highlights a tendency to use just one law common to the Mediterranean countries, opposed to the attitude of Northern countries to address each chapter of the Directive separately.

Another insight that could be noted is Bulgaria negligence to implement EU laws (only 15 policies created to reach EU targets), which is confirmed by the frequent Commissions' decisions on infringements [42].

As far as the mechanism is concerned, it is straightforward to notice that Non-Market-Based policies overcome Market-Based ones. More specifically, the former category accounts for 619 policies, almost doubling the 315 contained in the latter. What emerges from this huge difference is that very few countries show an equilibrium in the choices of the mechanism of the policies. It is intuitive to notice that only Greece, Ireland, Bulgaria, Spain, Latvia and Belgium split almost equally their policies in the two categories.

As explained in the previous chapters, the choice between Market- and Non-Market-Based instruments can determine the impacts of regulations on citizens' lives, thus it's not to be overlooked. Generally, from the dataset emerges that countries prefer choosing Non-Market-Based policies, with the exceptions of Spain, Greece and Ireland, which seem to believe in the power of Market-Based instruments to better fit the guidelines given by the EU.

Moreover, Figure 7, that is presented below, shows the distribution of the policies across the different topics of the Green Deal. At first sight, it is immediately visible that Topic 8, "A zero pollution ambition for a toxic-free environment", and Topic 3, "Mobilizing industry for a clean and circular economy", collect the highest number of policies, accounting, together, for 50.2% of the whole dataset. On the other hand, Topics 6 and 7, whose focus is on food, ecosystems and biodiversity, are the less-represented ones (less than 10% of the dataset).

The reasons for this huge discrepancy could be found in the different timing of the policies. Regulations and Directives related to those last chapters have been created in the most recent years: the vast majority of them are dated in the range 2018-2022, which explains why many countries have not worked on these topics yet.

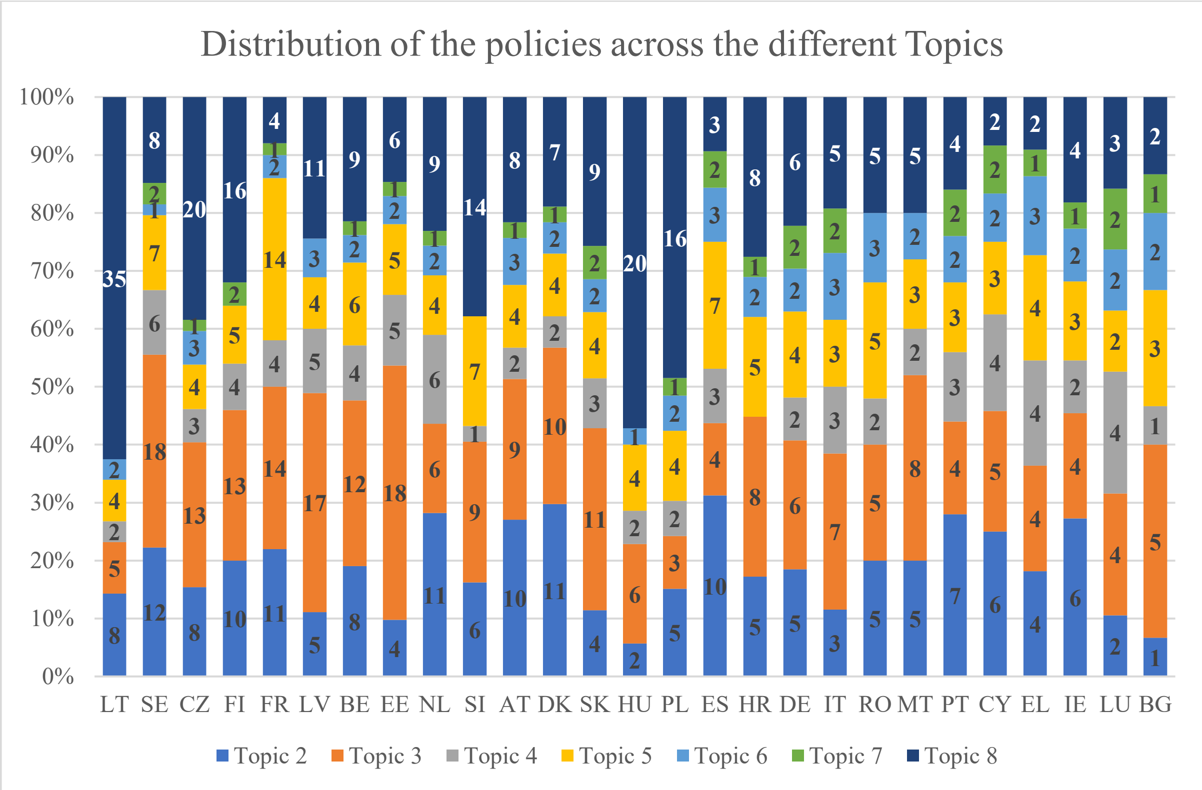

Figure 7. Distribution of policies across the different topics of the Green Deal.

By studying the distribution of policies across the years, national governments choices can be analyzed. This insight is presented in Figure 8 below. The most relevant efforts were made by Member States in 2020 and 2021 (116 and 222 policies registered, respectively), while in 2022 the results are lower.

The reason for this distribution is that most of the deadlines imposed by the EU Directives created after the European Green Deal were concentrated in 2020 and 2021. This shows that the real effects of a Directive cannot be seen immediately, rather they will be evident only after some years. More specifically, Member States tend to implement the Directive really close to the deadline imposed.

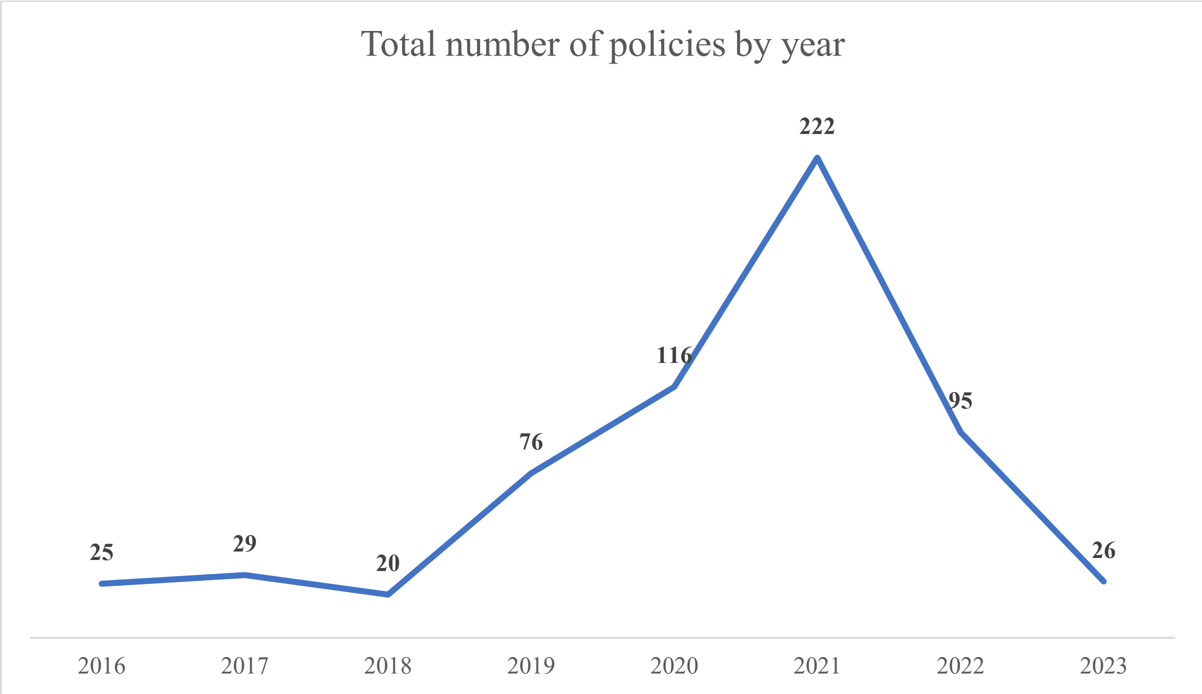

Figure 8. Total number of policies implemented from 2016 to 2023.

4.2 Implementation time

A further analysis can be conducted about the relationship between the implementation date and the deadlines imposed by the EU.

Figure 9 shows the number of policies implemented before and after the deadlines imposed by EU Directives.

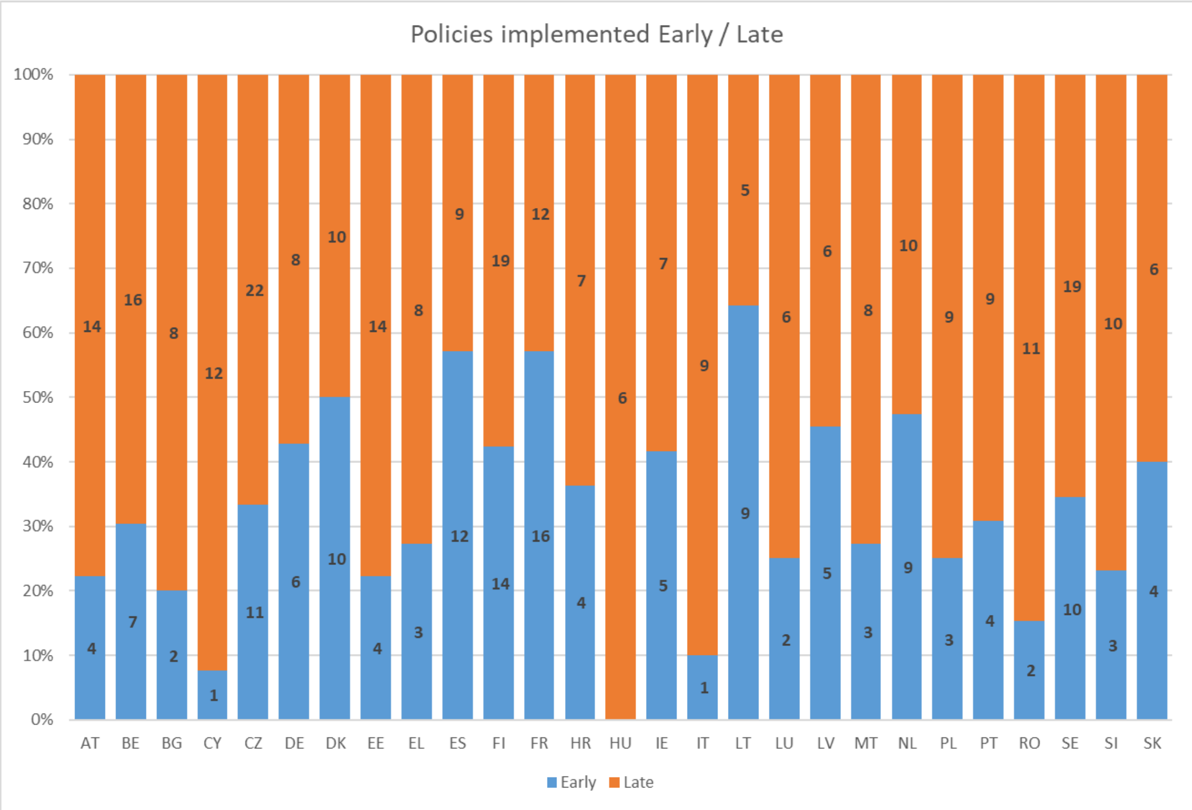

Figure 9. Distribution of policies implemented earlier or later than the mandatory deadline imposed by the relative Directive.

Data clearly show that Member States tend to implement Directives later than stated by the EU: only Lithuania is able to be on-time in more than the 60% of the cases.

Moreover, by studying the average time to implement a Directive, results show that, at a global level, governments create laws, on average, about 3 to 4 months later than the deadline. More in details, this value is computed as a global average, as it does not take into account the differences between Directives.

To deepen the analysis, in Figure 10 below, this information is depicted. The evidence emerging from the figure is that almost all the Directives contained in the dataset were implemented with delay by Member States. This is probably due to the heavy investments required by the EU to reach the goals stated in the Green Deal and the Fit For 55 package.

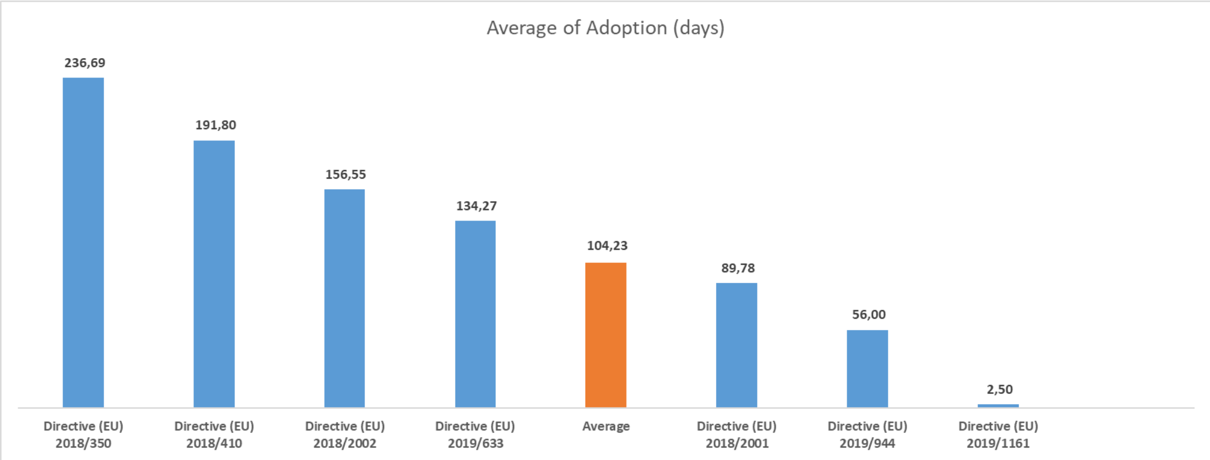

Figure 10. Average days of adoption with respect to the deadline, divided by Directive.

By breaking down the global averages into countries' averages, the following chart, presented in Figure 11, emerges.

Although the average value computed before shows that countries tend to be late when implementing Directives, here some exceptions show up: Lithuania, Finland, France and Czech Republic are indeed the readiest countries to adapt to EU instructions, and they're used to create laws much earlier than the imposed deadline.

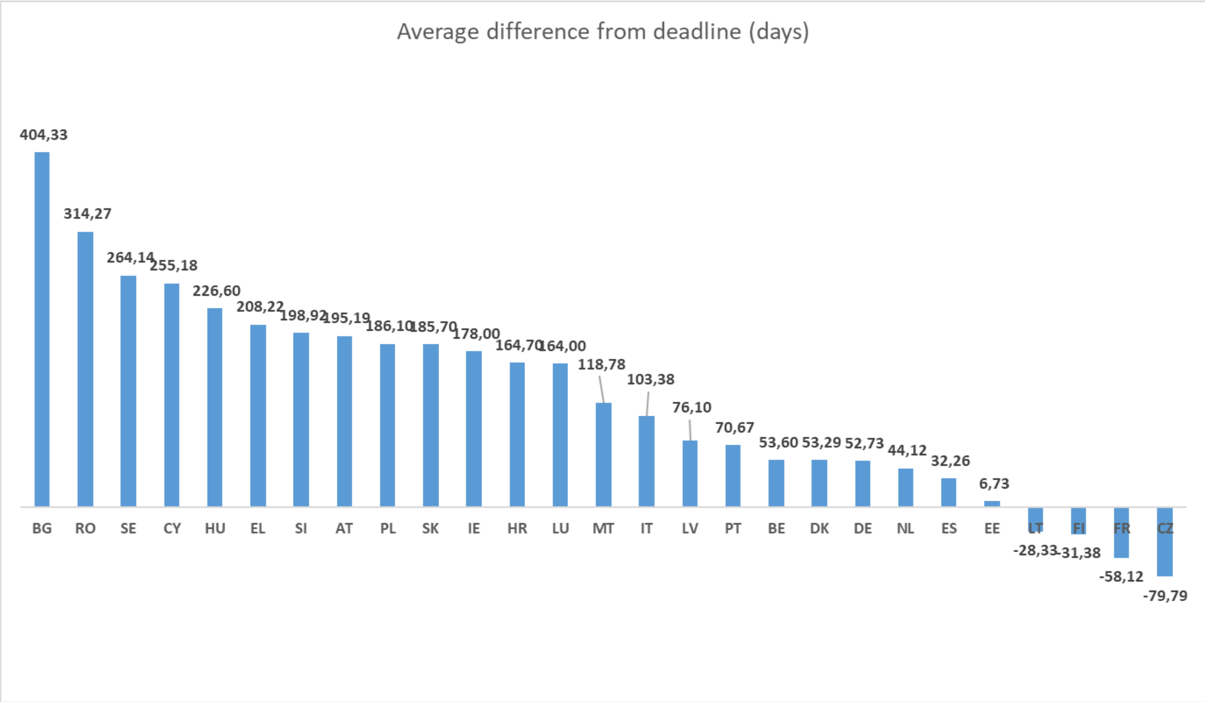

Figure 11. Average days of adoption with respect to the deadlines, divided by country.

5 Environmental Policy Stringency Indicator

This chapter is dedicated to the Environmental Policy Stringency (EPS) Index, which aims to quantify how strict environmental regulations are. Quite a few studies exist that propose different methodologies to compute stringency indicators: in this chapter, the most relevant ones will be reported.

5.1 Literature related to EPS

To face climate change, strong effort is asked to Member States by the EU. As a consequence, a tool to measure, compare and evaluate the impacts of their policy instruments is required. As Kruse et al. (2022) [41] explain, there are three main reasons that state the importance of having a common indicator across countries and time. First, it's essential to evaluate the progress made by each country and to compare this result with other countries. Second, it allows to create a benchmark, thus stimulating countries to adopt ever more ambitious policies. Last but not least, an index works as a mean to quantitatively evaluate the impact of environmental policies on economic and social outcomes.

Although these reasons are of common knowledge, a unified European Policy Stringency Index was created only in 2014, thanks to the work of Botta and Koźluk [9]. Before their studies, several approaches were followed, coming up with extremely different and partial results.

Indeed, research in several fields has been limited by the fact that no one indicator was defined as a common value of policy stringency. Thus, the majority of papers give advice about this, but surprisingly just a few papers have actually addressed the problem and worked on the construction of such indexes. In one of these papers, Knill et al. (2012) [43] state that the way to assess the environmental policy stringency is mainly driven by data availability, and thus a theoretical approach could be misleading.

Several indicators have been proposed, which could be grouped into four groups: survey indicators, monetary indicators, policy specific indicators and performance indicators.

Survey indicators

Survey indicators were created by analyzing results coming up from reports containing information provided by people identified as "experts". For instance, Dasgupta et al. (2001) [44] based their analysis on self-reported information from country officials, subsequently complemented by responses from NGOs to reduce the biases due to self-reporting. Other, more recent, papers, like Kalamova and Johnstone (2011) [45] and Timmins and Wagner (2009) [46] rely on the indicator developed by the World Economic Forum (WEF) by asking "business leaders" to assess the stringency of the policies of various countries. It's straightforward to notice that those indicators are affected by the huge bias of being based on the individual perceptions of respondents, rather than on data.

Monetary indicators

Other indicators mainly rely on monetary expenditures. Pearce and Palmer (2001) [47] and Magnani (2000) [48] evaluate expenditure-based policy instruments only and use public expenditures for environmental protection as a measure of environmental policy stringency. List and Co (2000) [49] use instead pollution abatement cost as indicator.

Policy specific indicators

An example of indicator belonging to this category can be found in Smarzynska and Shang-Jin (2003) [50]. They based their analyses on the ratification of four international treaties in environmental politics and then adjusted the measure by multiplying it with the number of environmental NGOs per million people. Nakada (2006) [51] follows a similar approach and uses a dummy variable to model whether a country has ratified the Kyoto protocol by 2003. However, both are highly specific indicators.

Performance indicators

Different groups can be identified within this category. First, several researchers (Damania (2001) [52], Broner et al. (2012) [53], Grether et al. (2012) [54]) focus on the lead content in gasoline, thus addressing one of the most important environmental issues. Another group of researchers use the total emissions of a country as indicator (Xing and Koldstad (2002) [55] evaluate SO_2 emissions, Smarzynska and Shang-Jin (2003) overall CO_2 emissions). Last, Emerson et al. (2012) [56] rely on the Environmental Performance Index (EPI), created by the Yale Center for Environmental Law and Policy (YCELP), although the aim of the index was not to assess the environmental policy stringency.

It's to be noted that all those approaches are performance indicators, as they quantify the problem environmental policies try to solve rather than the stringency itself.

Sauter and Caspar (2014) [57] highlight that all the indicators previously discussed share a common problem, meaning none of them is based on an explicitly stated methodological framework. This ignores one of the most fundamental rules of the index construction, stated by Nardo et al. (2008) [58]: every index needs to be based on a strong theoretical framework describing the phenomenon it aims to measure.

De Serres et al. (2010) [40] contribute significantly to the index creation process, by developing an analytical framework for policies that would ensure both economic efficiency and environmental integrity. Their paper outlines that the best choice of instruments to address climate externalities is related to both the predominant market failures and the differences in institutional capacities of the countries. Thus, the most appropriate policy response will consist of more than one single instrument. When defining the strategy, governments cannot avoid taking into consideration the environmental side-effects of policies, whether they're related to economic inefficiency or environmental damage.

A key finding of De Serres' studies is the categorization of the policies in market- and non-market-based instruments, depending on their mechanism. According to their results, putting a price on pollution through taxes or tradable permit systems plays a central role in increasing the incentives to citizens. The use of command-and-control regulation and voluntary approaches, moreover, is to be leveraged if pollution emissions cannot be monitored and thus a tax upon them cannot be properly defined.

Starting by the classification proposed by De Serres et al. (Table 5), Botta and Koźluk (2014) were able to fill the gap in the literature by creating the EPS Indicator, which allowed, for the first time, to compare policies across time and countries. The approach they followed relied on the construction of a measure that could turn quantitative and qualitative information contained in the policy instruments adopted by governments into a common and comparable index of environmental policy stringency, specific to each country.

Table 5. List of Market- and Non-Market-Based instruments, as per De Serres et al. (2010).

Name	**Example**
Market-Based Instruments	
Taxes and charges directly applied to pollution source	Tax on emissions of NO_x
Taxes and charges applied on input / output of a production process	Diesel tax
Trading scheme	Emissions Trading Scheme for CO_2
Subsidy for environmentally-friendly activities	Feed-In Tariffs
Deposit-refund systems	Deposit-Refund Scheme for beverages
Non-Market-Based Instruments	
Command-and-control regulations	Emission Limit Value for NO_x
Technology-support policies	Government R&D expenditures (%GDP)
Voluntary approaches	Not covered

To do so, Botta and Koźluk decided to work on a composite indicator, which results from the aggregation of individual indicators into a single measure, based on an underlying analytical model. Such a model was based on the idea that environmental policy stringency is defined as the cost (either explicit or implicit) of polluting or of an environmentally harmful behavior. This definition is straightforward for market-based instruments, such as taxes or emission limits: the higher the price to pay or the lower the limits imposed, the higher the stringency of the measure. Also, in the case of subsidies to R&D, the higher the subsidy, the higher the opportunity cost of polluting, and ultimately the higher the stringency. However, this reasoning is not easily adaptable to non-market-based policies: Botta and Koźluk state that these parameters must be accurately analyzed before being chosen.

Based on this structure, an index was computed for the Energy Sector only and later extended to an Economic-Wide Indicator. The structure relies on the aggregation of market-based and non-market-based instruments, both the categories accounting for half of the total indicator (see Figure 12 below).

The results were evaluated on a scale from 0 to 6, although the range of values taken by the indicators across countries was, of course, narrower.

In the most recent years, as mentioned above, Botta and Koźluk's model has been extensively used (more than 300 citations on Google Scholar as of 2022), before being lastly updated by Kruse et al. in 2022 [41].

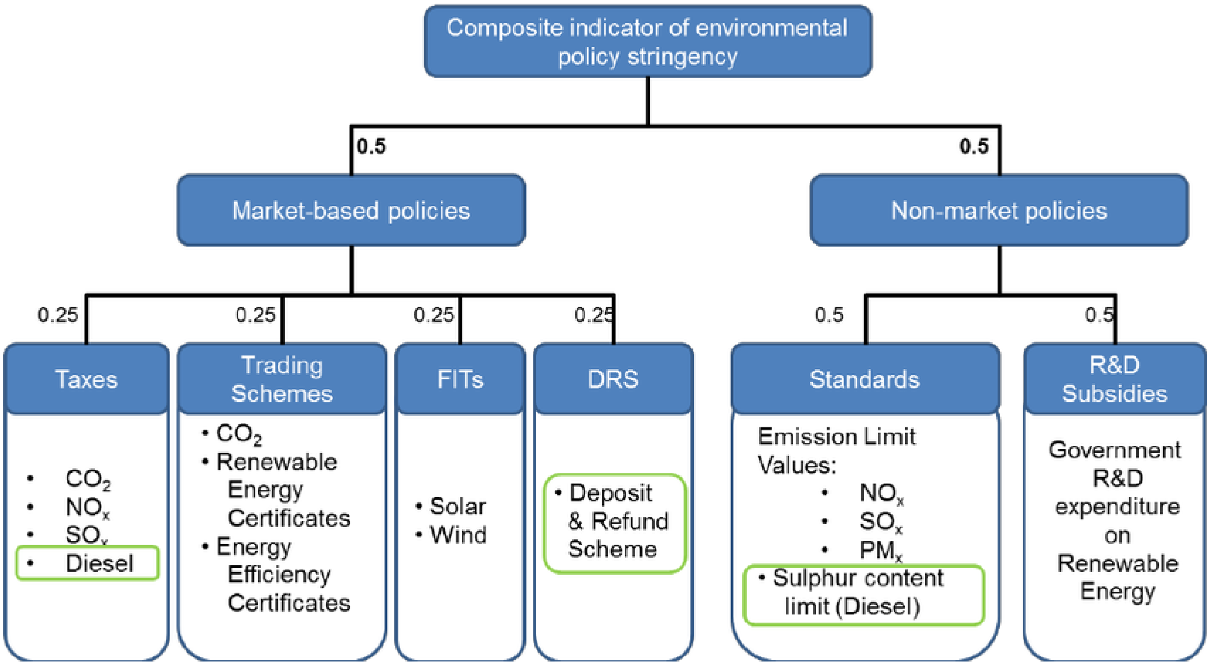

Figure 12. Structure of the Environmental Policy Stringency Index, as defined by Botta and Kozluk (2014).

The revised EPS index (known as EPS21) extends Botta and Koźluk's studies by adding a third sub-category, so as to group market-based, non-market based and technology support policies. The following Table 6 describes each of them more in detail.

Table 6. Description of the categorization of policies, as described by Kruse et al. (2022).

Name	Description
Market-Based Instruments (MBI)	*This category groups policies that put a price on pollution.*
CO_2 Trading Schemes	Regulate CO_2 emissions that can be emitted by structuring an allowance-trading system. The higher the price, the more stringent the policy.
Renewable Energy Trading Scheme	They establish a system for trade in renewable energy certificates, based on the obligation to source a specific percentage of electricity from green sources. The higher the percentage, the more stringent the policy.
CO_2 Taxes	Tax rate for CO_2 emissions. The higher the rate, the higher the stringency.
Nitrogen Oxides (NO_x) Tax	Tax rate for NO_x emissions. The higher the rate, the higher the stringency.
Sulphur Oxides (SO_x) Tax	Tax rate for SO_x emissions. The higher the rate, the higher the stringency.
Fuel Tax (Diesel)	Tax rate for a liter of diesel fuel. The higher the rate, the higher the stringency.
Non-Market-Based Instruments (NMBI)	*This category groups policies that regulate emission limits and standards.*
Emission Limit Value (ELV) for Nitrogen Oxides (NO_x)	Maximum concentration of nitrogen oxides emissions. The lower the value, the more stringent the policy.
Emission Limit Value (ELV) for Sulphur Oxides (SO_x)	Maximum concentration of Sulphur oxides emissions. The lower the value, the more stringent the policy.
Emission Limit Value (ELV) for Particulate Matter (PM)	Maximum concentration of particulate matter emissions. The lower the value, the more stringent the policy.
Sulphur content limit for diesel	Maximum concentration of sulphur permitted in diesel for automobiles. The lower the value, the more stringent the policy.
Technology-support policies	*This category groups policies that support innovation in clean technology and their adoption.*

Public research and development expenditures (R&D)	Amount spent by the government on R&D on low-carbon energy technologies divided by the country's nominal GDP. The higher the ratio, the more stringent the policy.
Renewable energy support for Solar and Wind	Average awarded price from a wind or solar auction. The higher this value, the more stringent the policy.

The reason that drove Kruse, Dechezleprêtre, Saffar and Robert to adopt this third group of policies is that they operate differently from market- and non-market-based policies. Indeed, technology support elements do not target negative externalities, rather they act on positive externalities, thus they have to be considered separately. The structure of the revised EPS index is shown below in Figure 13.

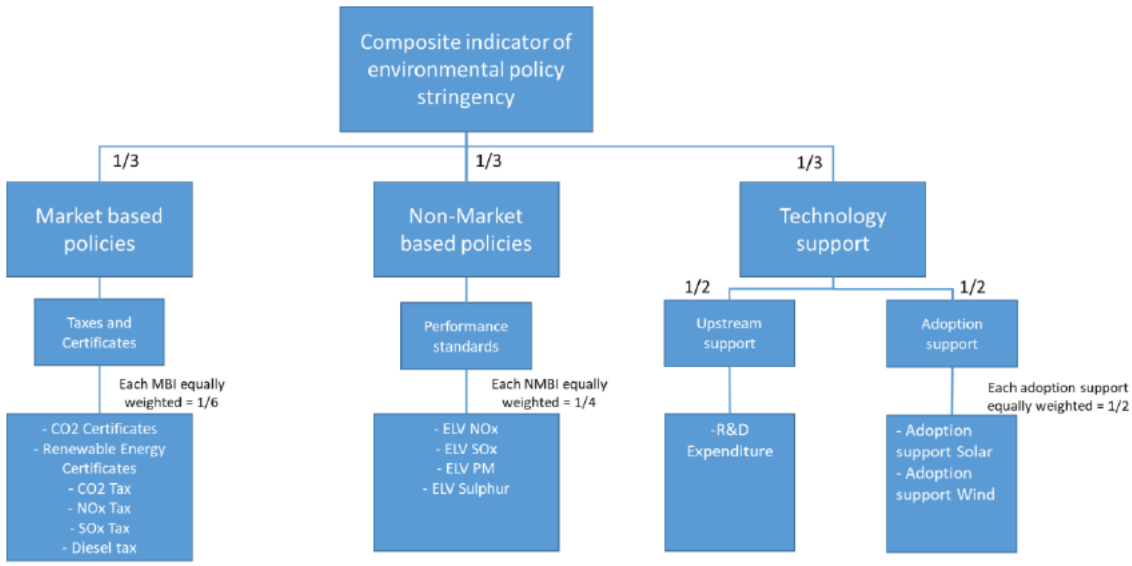

Figure 13. The structure of the Environmental Policy Stringency Index, as revised by Kruse et al. (2022).

The main limitation of this index is related to all those policies that still fall outside its coverage. For instance, those instruments that regulate emissions derived from agricultural production are not represented in Kruse's work (although it has to be noted that these instruments are not yet commonly developed across Europe). Kruse states that "*Future work […] could expand the index to cover additional policy instruments*" (Kruse et al. (2022), *Measuring Environmental Policy Stringency in OECD countries: an update of the OECD composite EPS Indicator,* p. 9) [41].

5.2 EPS Statistics

To complete the analysis of the EPS index, some statistics are reported below. First, the average annual growth rate is computed. It is depicted in Table 7 and it shows that, on average, the index has increased substantially since 1990. Specifically, over the last two decades, the average value of EPS has moved from 1.3 to 3.1, meaning it has more than doubled (+138%) in about 20 years. However, the growth was substantial during the first decade of 2000s, while in the most recent years the average annual growth rate slowed down to 1.1%.

Table 7. Average annual growth rate of EPS, by decades.

Decades	Average annual growth rate
1990 – 2000	6.8%
2000 – 2010	8.0%
2010 – 2020	1.1%

Moving beyond the average of the index, it is possible to break down the analysis and study country-specific changes across the years.

Figure 14 outlines the variations of the EPS across the last two decades: blue bars represent the EPS values in 2020, while diamonds state the 2000 levels.

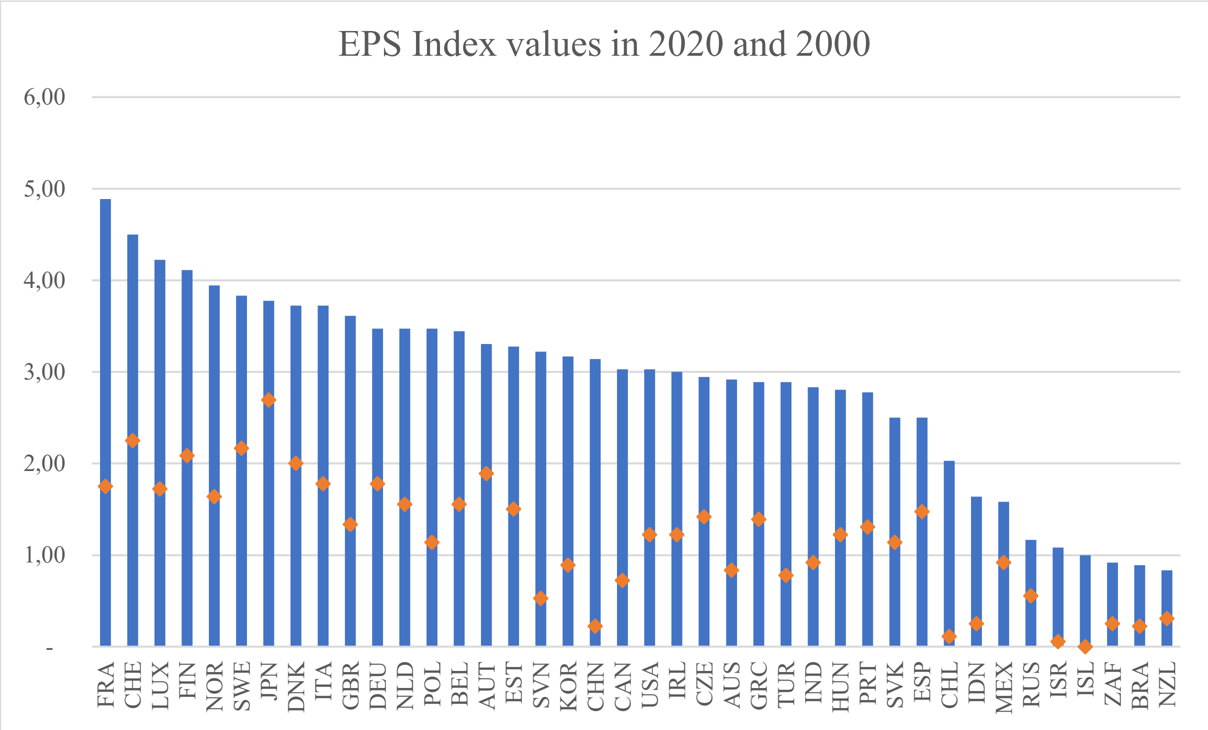

Figure 14. EPS index in 2000 (orange diamonds) and in 2020 (blue bars).

It is straightforward to notice that no country has worsen its stringency value within the last 20 years. France, Switzerland, Luxembourg and Finland were known, in 2020, as those countries applying the most stringent environmental measures.

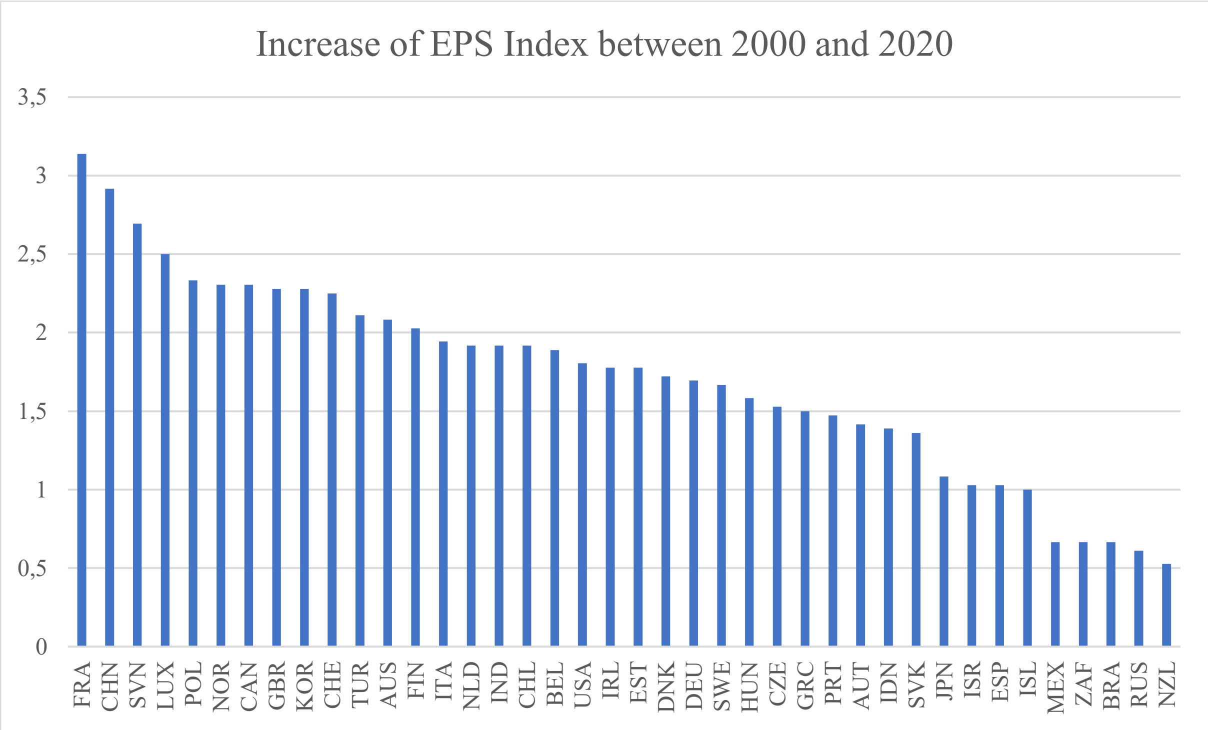

Figure 15. Absolute increase in the EPS between 2000 and 2020.

Among a common trend of stringency increase, some countries have shown stronger performances than others in the last decade. It is the case of France, which applied much stricter policies, achieving an absolute increase of 3.2, China, that registered a +2.9, and Slovenia, +2.8 (Figure 15).

5.3 Correlation between EPS and Number of Policies

By merging data related to the EPS index and those obtained by performing the preliminary research, a correlation between the EPS and the number of policies issued by a country can be studied.

Interesting enough, what emerges by plotting the data is that a nonlinear correlation links the variables. More in details, Figure 16 and Figure 17 depict on two scatter-plots the distribution of the cumulated number of policies as related to the EPS values considered with a

1-year lag and a 5-years lag, respectively. From these visual representations, it is straightforward to notice that the relationship between the variables is, in both cases, quadratic.

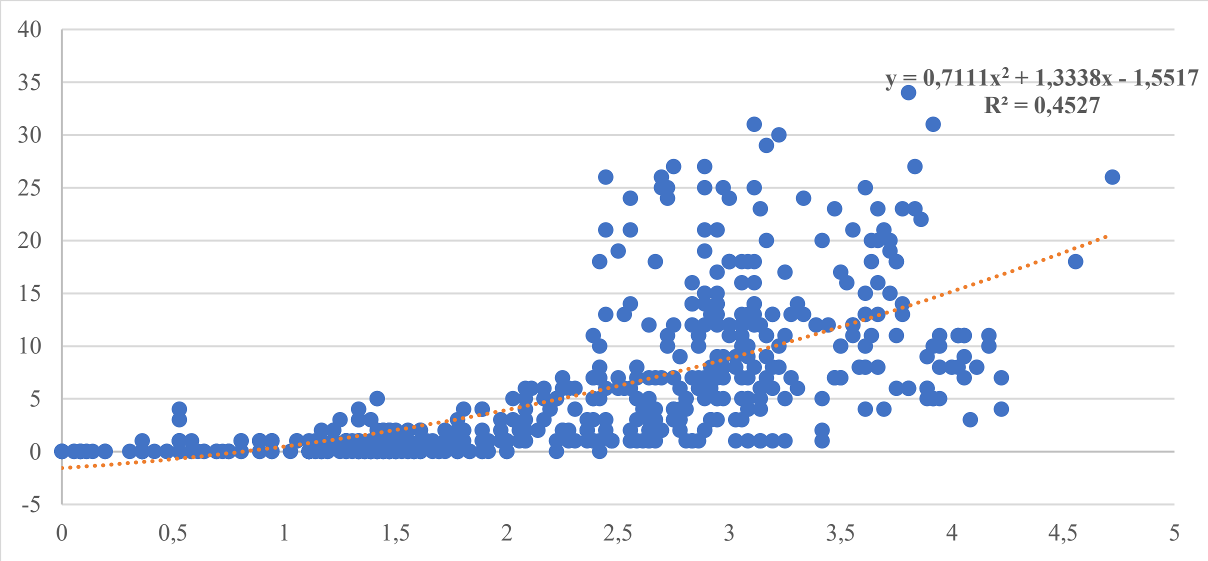

Figure 16. Scatter plot of 1-year-lagged EPS (on the x-axis) and cumulated number of policies per country (on the y-axis).

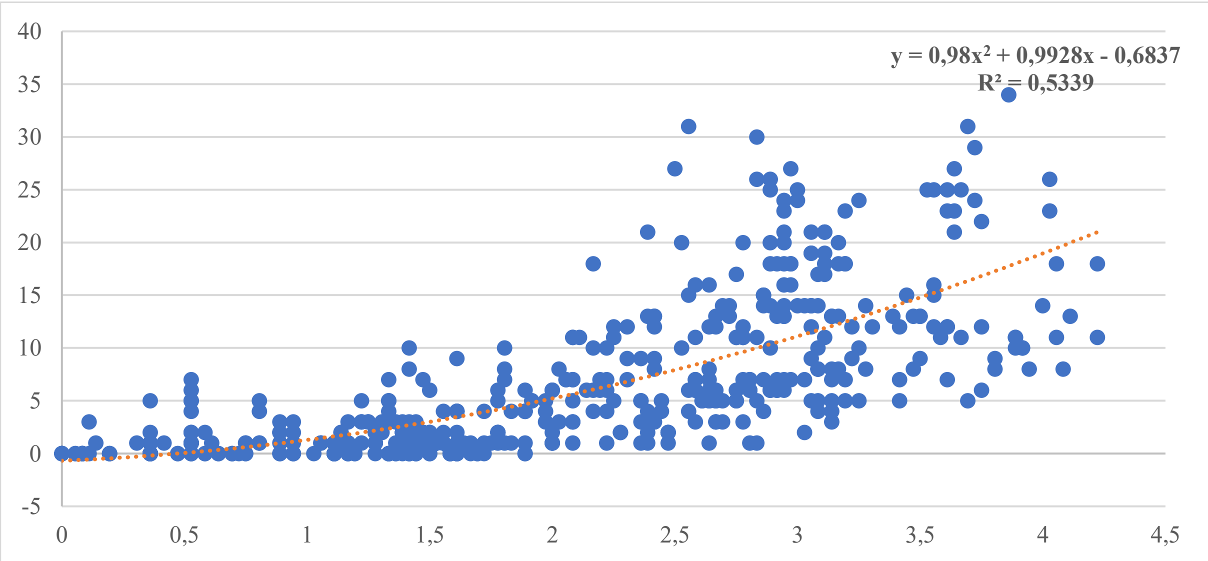

Figure 17. Scatter plot of 5-year-lagged EPS (on the x-axis) and cumulated number of policies per country (on the y-axis).

The main conclusion that can be drawn from this study is that more stringent policies somehow affect in a positive way the generation of other environmental policies, stimulating countries' legislative actions.

However, this result has two main limitations to be pointed out. First, it takes into account two variables that refer to the same topic, meaning they both aim to quantitatively explain some qualitative aspects included in the same policies. Second, the number of policies is subject to some biases, since – as already mentioned before – the legislative structure is different across the countries. In other words, there are structural differences between countries when deciding how to implement EU Directives. For instance, France is used to issue a higher number of laws to implement the same Directive that Italy transposes into one document only.

In conclusion, the evidence drawn from these charts is extremely weak and should not be considered as a substantial result of this study. Still, the figures are reported here with the aim to show the distribution of the variables.

6 Literature review

A crucial theme frequently discussed in literature is related to the impact that environmental policies have on innovation. In this regard, this chapter's aim is to make an overview of the most relevant findings that analyze the correlation between environmental policies stringency and clean innovation, in order to introduce the reader to the study discussed in this paper.

6.1 Two polarized positions: The Porter Hypothesis and the Pollution Heaven Hypothesis

The link that correlates the stringency of the instruments adopted by governments to address climate change and the effective results these instruments have on stimulating innovation activity has been polarized, in literature, in two opposite positions.

On the one hand, some researchers state that stricter environmental standards will drive polluting firms to move their businesses to countries having lower environmental pressure. This will have negative effects on the welfare of citizens of countries with more stringent regulations, who will see the majority of companies relocating abroad. Tobey (1990) [59], Cole and Elliot (2003) [60], Levinson and Taylor (2004) [61] share this point of view, commonly known as the Pollution Haven Hypothesis. Within their studies, they show how competitiveness is likely to be harmed by excessively stringent policies.

On the other hand, lots of researchers (Jaffe and Palmer (1997) [62], Albrizio et al. (2017) [63], Dechezleprêtre and Sato (2017) [64] to name just some of them), support the Porter Hypothesis (Porter and van der Linde (1995) [65]). Porter and van der Linde, in their paper, state that well-crafted environmental policies do not harm competitiveness, rather they benefit both the environment and the firm, by increasing innovation activity. Jaffe et al. (1995) [66] argue that by increasing the stringency of environmental policy, not only can be pursued economic growth, but also competitiveness will be enhanced.

6.2 “Weak” and “strong” version of the Porter Hypothesis

Analyzing Porter’s work, Jaffe and Palmer (1997) [62] stated that the Porter Hypothesis can assume two different forms, depending on the strength of the regulations.

The “weak” version highlights the link between environmental policy instruments and innovation activities, stating that stricter regulations foster innovation. However, in this first version the relationship between environmental policy stringency and economic performance of a firm is not mentioned. It is indeed studied by the “strong” version of the Porter Hypothesis, which states that regulations stimulate firms to create new products or process that will ultimately increase their profits (see also Lanoie et al. (2011) [67]).

After the first critics of the Porter Hypothesis in the mid-1990s argued that the theoretical background was lacking (Palmer et al. (1995) [68]) and that there was no evidence that showed how direct costs caused by environmental regulations could be compensated (Walley and Whitehead (1994) [69]), studied began in order to find empirical evidence.

A relatively large literature focuses on testing the “weak” version of the Porter Hypothesis, while few papers exist that properly study the “strong” version.

Figure 18. Causal links involved in the Porter Hypothesis, as described by Kruse and Dechezleprêtre (2022).

Jaffe and Palmer (1997) [62] constructed an econometric model which was then tested on data from the manufacturing industry in the US. Their goal was to study the relationship between pollution control expenditures and innovation activity, measured as R&D expenditure and number of patents. Their findings showed that pollution abatement costs and expenditures (PACE) have a positive effect on R&D, thus verifying the weak version of Porter Hypothesis. Still, they found little evidence that the number of successful patent applications was related to the cost of compliance.

In 1996, Lanjouw and Mody [70] had already worked on the weak version of the hypothesis, concluding that expenditures in pollution reductions enhance the creation of environmental-technology patents with a 1- or 2-years delay.

De Vries and Withagen (2005) [71] investigated the impact of environmental regulations on innovation reducing SO_2 emissions in 13 OECD countries, finding support for the weak version (although their results are not robust to changes in model's specifications)

Popp (2006) [72] followed a similar approach and measured innovation by the number of patents. He studied data from firms in Japan, Germany and the US, ultimately concluding that innovation is stimulated by the increase of stringency inside a company's country but it is not related to legislative changes of other countries.

By studying R&D expenditure, Kneller and Manderson (2012) [73] claimed that an increased pressure to reduce emissions leads companies to invest in R&D in environmental capital.

Carrion-Flores and Innes (2010) [74] analyzed a panel of 127 manufacturing industries between 1989 and 2004 and concluded that innovation influenced by environmental policies contributes to a reduction in emissions, while Johnstone et al. (2010) [75] confirmed the weak version of Porter Hypothesis studying green patents only (i.e. patents in the renewable energy sector).

A specific study on patents in emission control technology was performed by Lee et al. (2011) [76], who proved that environmental regulations encourage business to innovate in the American automotive sector.

Lanoie et al. (2011) [67] worked on data derived from a survey of business managers and found that an increase in regulation stringency led to an increase in R&D expenditures, thus significantly supporting the weak version. Still, business managers' data were not enough to find evidence of the strong version.

Rubashkina et al. (2015) [77] studied a panel of data from European countries and found evidence for the weak version only.

Albrizio et al. (2017) [63] studied the strong version of the Porter Hypothesis across 23 OECD countries, but did only achieve satisfying results on the short run. Other researchers analyzed this version, but their data panel was related to one country only (Berman and Bui (2001) [78], Alpay et al. (2002) [79], Murty and Kumar (2003) [80], Zhao et al. (2018) [81]).

More recently, Martinez-Zarzoso et al. (2019) [82] extended the model initially proposed by Jaffe and Palmer (1997) and later refined by Rubashkina et al. (2015), to test both the weak and the strong version. They included in their work several variables as a measure of innovation (R&D expenditure, number of patents and Total Factor Productivity), and were the first to introduce the EPS index as an indicator of the stringency of environmental regulations. Their model was based on quantile regression and was applied to 14 OECD countries in the period 1990-2011. Results showed that EPS has a positive effect on R&D, especially when 5-year lags are considered. Also, in the long-term, stringency is affecting R&D, patents and TFP, hence the stricter the policies implemented by a country, the higher the incentives to promote clean production processes.

Another study that is worth mentioning is the paper of Kruse and Dechezleprêtre (2022) [83]. The researchers' approach was to use both firm- and sector-level data to evaluate innovation activity and economic performance. The choice of combining several panels of data is to be found in the fact that it's extremely important for policymakers to take into account the impacts of environmental regulation on competitiveness between firms. Results of the study show that clean innovation is driven by environmental regulation (measured by EPS) in directly regulated sectors only. This implies that direct regulations are required to induce clean innovation in those sectors being the most carbon intensive. Indirect regulations, by contrast, seem to be less effective, as they appear unlikely to induce sufficient clean innovation to decarbonize the economy rapidly.

Last, Li and Shao (2023) [84] extended the study to a more complex model, including financial market development as a cause to renewable energy innovation. The conceptual framework of their study is outlined in Figure 19 below.

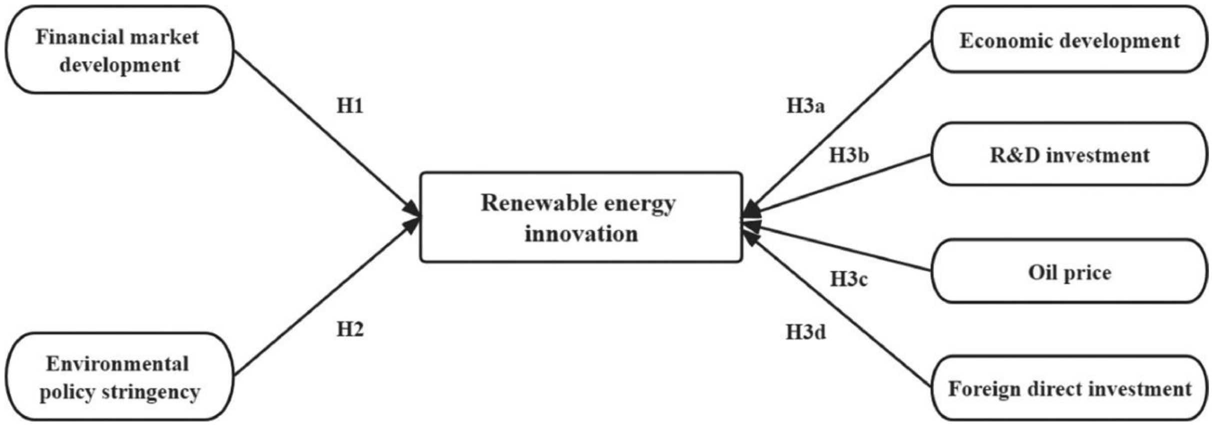

Figure 19. Conceptual framework of the study made by Li and Shao (2023).

By applying a nonlinear model to the 37 OECD countries in the range 1990-2019, they obtained results showing that the increase of financial development leads to a lower impact and that, oppositely, the increase of policy stringency drives the impact to rapidly increase. Such findings imply that OECD countries should adopt stricter environmental policies to match their desire of increasing renewable innovation.

7 Research question

Starting from the extensive literature review described in the previous chapter, this study aims to test the weak version of Porter Hypothesis. In other words, the question to be investigated in this paper is whether a correlation exists between the stringency of environmental regulations categorized in our dataset and the innovation activity performed by each country: does implementing more stringent policies lead to higher innovation performance?

8 Data and methodology

To test the validity of the weak version of the Porter Hypothesis, several studies have been conducted in literature, all of them differentiating because of the variables chosen to model the stringency of environmental policy regulation and the innovation activity, and because of the panel data used to test the model. This chapter is aimed at describing the choices made within this work.

8.1 How to measure stringency: the choice of the EPS variable

As already discussed in the previous part of the paper, the definition of a variable to measure the stringency of environmental policies is not trivial, as quite a few challenges emerge when dealing with the construction of an indicator.

As Botta and Koźluk [9] explain in their study, three aspects are to be considered when choosing this index.

First, multi-dimensionality is a key topic to be addressed. It is determined by the intersection of the environmental multi-dimensionality (i.e. various plans of environmental regulations) with the policy design multi-dimensionality (i.e. all the possible instruments currently at governments' disposal to create a policy).

A second issue is related to sampling. For example, the share of polluting industries in a country adopting stringent environmental policies may be lower than the share of polluting industries in a country adopting less stringent policies precisely because such policies lead to specific industrial structures. Hence, it could be that policies themselves drive the sample of industries subject to those policies.

Lastly, identification is a main concern. Indeed, it is not straightforward to assess whether the consequences of more stringent policies are to be attributed to environmental policy stringency or to other factors. Several features are involved in determining the consequences of stricter regulations, and identifying which of them are related to the stringency is not a trivial task.

Galeotti et al. (2020) [85] highlight how the literature presents conflicting results when analyzing the impact of environmental policy stringency on several variables. They argue this is due to the fact that the proxies used to model stringency of environmental policies are computed in extremely different ways.

Kruse and Dechezleprêtre (2022) [83], in this regard, criticize the literature that used measures such as PACE (the already discussed studies of Lanjouw and Mody (1996) [70], Jaffe and Palmer (1997) [62], Carrion-Flores and Innes (2010) [74], to cite some) or emissions (Rubashkina et al. (2015) [77]). They suggest that such variables can result in confounding factors that affect both innovation and the measure of regulatory stringency, thus being endogenous. More exogenous measures such as the Environmental Policy Stringency Indicator are to be preferred. The lag structure of this indicator allows to mitigate the concerns arising from political adjustments to environmental policies. Moreover, the EPS is the only index able to combine hard, market-based measures and soft, non-market-based instruments into one quantitative indicator, thus allowing a comprehensive and consistent analysis.

As a consequence of this dissertation, the choice of this study is to use the EPS index as a measure of environmental policy stringency.

8.2 Dependent variable: the European Innovation Scoreboard

The second question this paper has to face before dealing with the analysis, is related to the dependent variable which is going to be chosen in order to model the innovation activity of each country.

As extensively discussed above, the measure of innovation activity is not a trivial task. Research exist that use R&D expenditures as a proxy of innovation activity of a country (Jaffe and Palmer (1997) [62], Kneller and Manderson (2012) [73], Rubashkina et al. (2015) [77]). The vast majority of studies, however, rely on the number of patents as indicator, either focusing on green patents only (Brunnermeier and Cohen (2003) [86], Popp (2006) [72], De Vries and Withagen (2005) [71], Carrion-Flores and Innes (2010) [74], Johnstone et al. (2010) [75], Lee et al. (2011) [76]), or extending their studies to the number of patents in general (Lanoie et al. (2011) [67], Lanjouw and Mody (1996) [70]).

Oppositely to what the literature suggests, this paper aims to investigate the correlation between environmental regulations and innovation activity by using the European Innovation Scoreboard as dependent variable.

The annual European Innovation Scoreboard (EIS) [87] is an index developed by the European Commission that allows a comparative assessment of the research and innovation performance of EU Member States and selected third countries. It's to be used by countries when evaluating areas where stronger efforts are required to boost their innovation performance.

The EIS 2023 represents the third edition of the index; it analyses data from all EU Member States, 11 other European countries, and, at a less detailed level, 11 global competitors.

A first analysis of Member States' innovation performance, compared to the EU average, leads to a classification in four different groups. This division is represented in Figure 20 below.

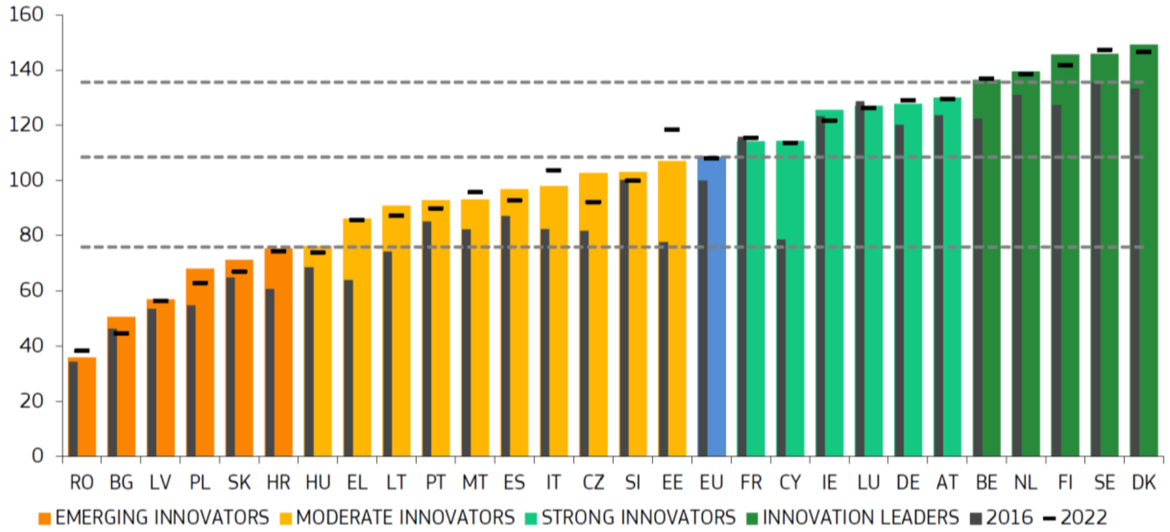

Figure 20. The EIS 2023 values per country, colored depending on their performance relative to that of the EU in 2016. The horizontal hyphens represent values of EIS 2022. Grey bars show values of EIS 2016. Dashed lines highlight the threshold values between performance groups.

As it is intuitive to notice, the four categories are represented in different colors, and the height of the bars corresponds to the EIS 2023. A description of the four groups is reported below.

1. *Innovation Leaders*

   Belgium, Denmark, Finland, the Netherlands and Sweden are part of this group as the values of their indexes are larger than 125% of the EU average, thus indicating strong innovation performance.

2. *Strong Innovators*

   Good results are achieved by Austria, Cyprus, France, Germany, Ireland and Luxembourg, whose EIS is above the EU average.

3. *Moderate Innovators*

   The largest group contains 10 countries (Czech Republic, Estonia, Greece, Hungary, Italy, Lithuania, Malta, Portugal, Slovenia and Spain) and is dedicated to innovators showing results slightly below the EU average.

4. *Emerging Innovators*

   The last group is composed of those countries showing EIS lower than 70% of the EU average, namely Bulgaria, Croatia, Latvia, Poland, Romania and Slovakia.

Analyzing the trend of the EU innovation performance, it is possible to notice that it has increased, on average, by 8.5 percentage points since 2016, as it is described in Figure 21.

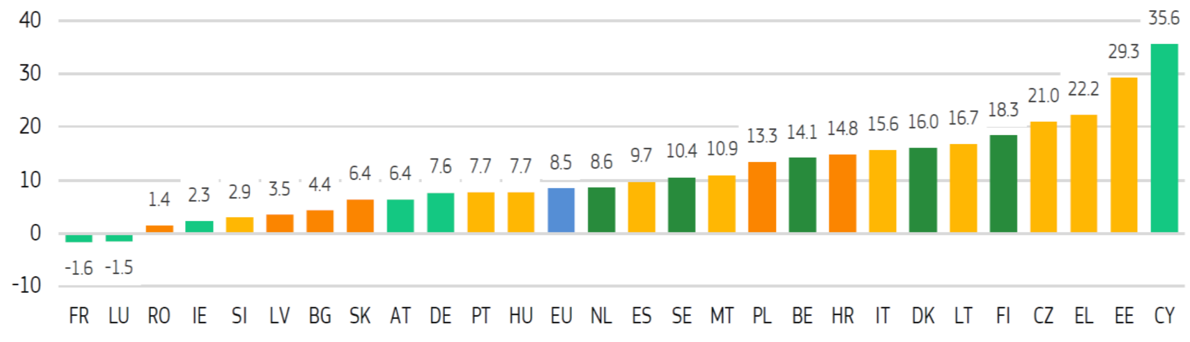

Figure 21. Performance changes in EIS between 2016 and 2023. Bars' colors refer to EIS 2023 performance.

More specifically, innovation performance has increased in 25 EU Member States, mostly in Cyprus, Estonia, Greece, and Czechia, countries whose performance has grown by more than 20 percentage points.

For Finland, Lithuania, Denmark, and Italy, performance improved between 15 and 20 percentage points, while Croatia, Belgium, Poland, Malta and Sweden increase their EIS by 10 to 15 percentage points. Spain and the Netherlands achieved an increase in innovation performance by less than 10 but more than 8.5 percentage points, which allows them to be ranked above the EU average.

Lastly, 12 Member States whose performance has grown slower than the EU average are shown. Among them, Hungary, Portugal, Germany, Austria, and Slovakia improved their innovation activities, showing an EIS increase by more than 5 percentage points, while Bulgaria, Latvia, Slovenia, Ireland, and Romania did not manage to achieve the 5% threshold. Last, Luxembourg and France's performance resulted in negative values, although both the countries are still part of the Strong Innovators category.

It is extremely interesting to notice that France and Luxembourg are precisely those countries that occupy the highest positions in the EPS country ranking in 2020 (see previous chapters). Furthermore, they also belong to the list of States that have strongly increased their policy stringency within the last decade.

The growth trend in innovation performance can also be analyzed separately for each of the four groups presented above.

Starting with Innovation Leaders, it is noticeable that their performance improved from 2016 onwards, with an acceleration since 2021. When comparing performance in 2023 to 2016, its growth sets to 13.5 percentage points, above the average of the EU, as it is shown in Figure 22 below.

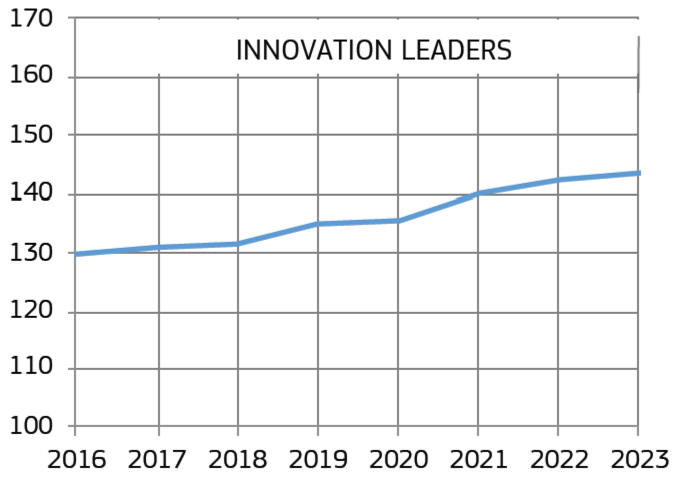

Figure 22. EIS performance growth of Innovation Leaders.

As far as the group of Strong Innovators is concerned, between 2016 and 2023, innovation performance increased less than that of the EU and that of the Innovation Leaders. This growth sets at 8.1 percentage points, as shown in Figure 23 below.

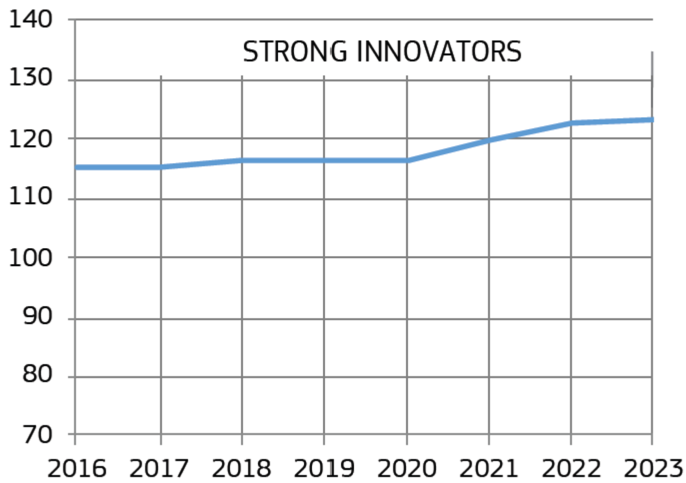

Figure 23. EIS performance growth of Strong Leaders.

Analyzing the Moderate Innovators' results, it is possible to notice that performance has been increasing since 2016, with an acceleration since 2018, as presented in Figure 24 below.

Average performance has improved by 14.4 percentage points, compared to 2016, meaning it's grown at a higher rate than the Strong Innovators and the Innovation Leaders.

In this group, only three Member States, Hungary, Portugal and Slovenia, show a growth rate that is lower than the EU.

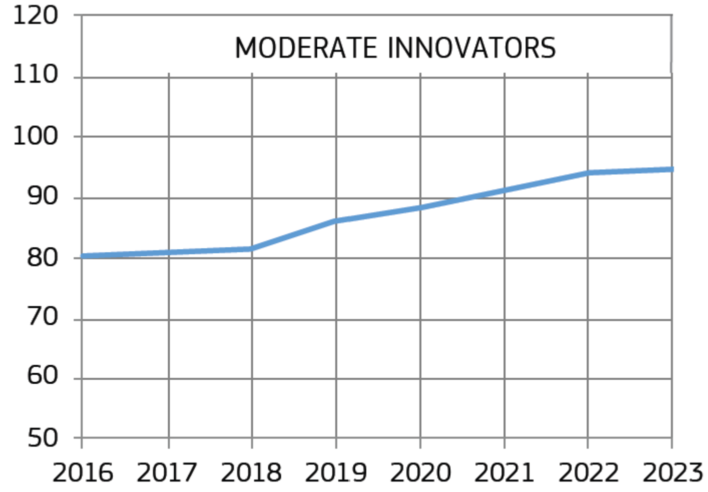

Figure 24. EIS performance growth of Moderate Innovators.

At last, the group of the Emerging Innovators shows over time an improvement in their overall performance that sets to 7.3 percentage points, as it is presented in Figure 25 below. This value sets below the average rate of increase for the EU and below that for the other performance groups. This group has therefore widened the gap that separates their performance from the Moderate Innovators' one.

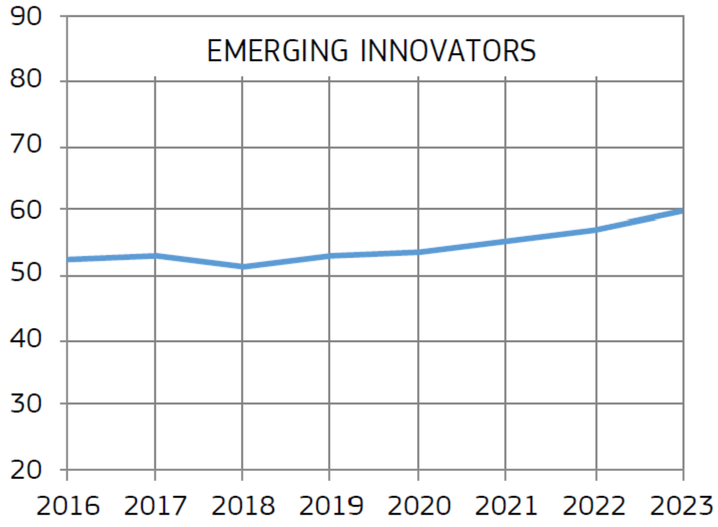

Figure 25. EIS performance growth of Emerging Innovators.

By making an aggregated analysis, it is straightforward to notice that the differences between the average values of the four groups have globally decreased since 2016. Specifically, the gap between Moderate Innovators and Strong Innovators has narrowed by more than 6 percentage points.

The only group that hasn't shown this trend is the group of the Emerging Innovators: the performance differences within this set of countries have not narrowed and they are not catching up to the next group of Moderate Innovators.

Additionally, as it is shown on the map in Figure 26, there is an evident geographical distribution of innovation performance: countries that belong to the group of the Innovation Leaders and most of the countries that belong to the group of the Strong Innovators are located in Northern and Western Europe. By contrast, Moderate and Emerging Innovators groups are mainly composed of Southern and Eastern Europe Member States.

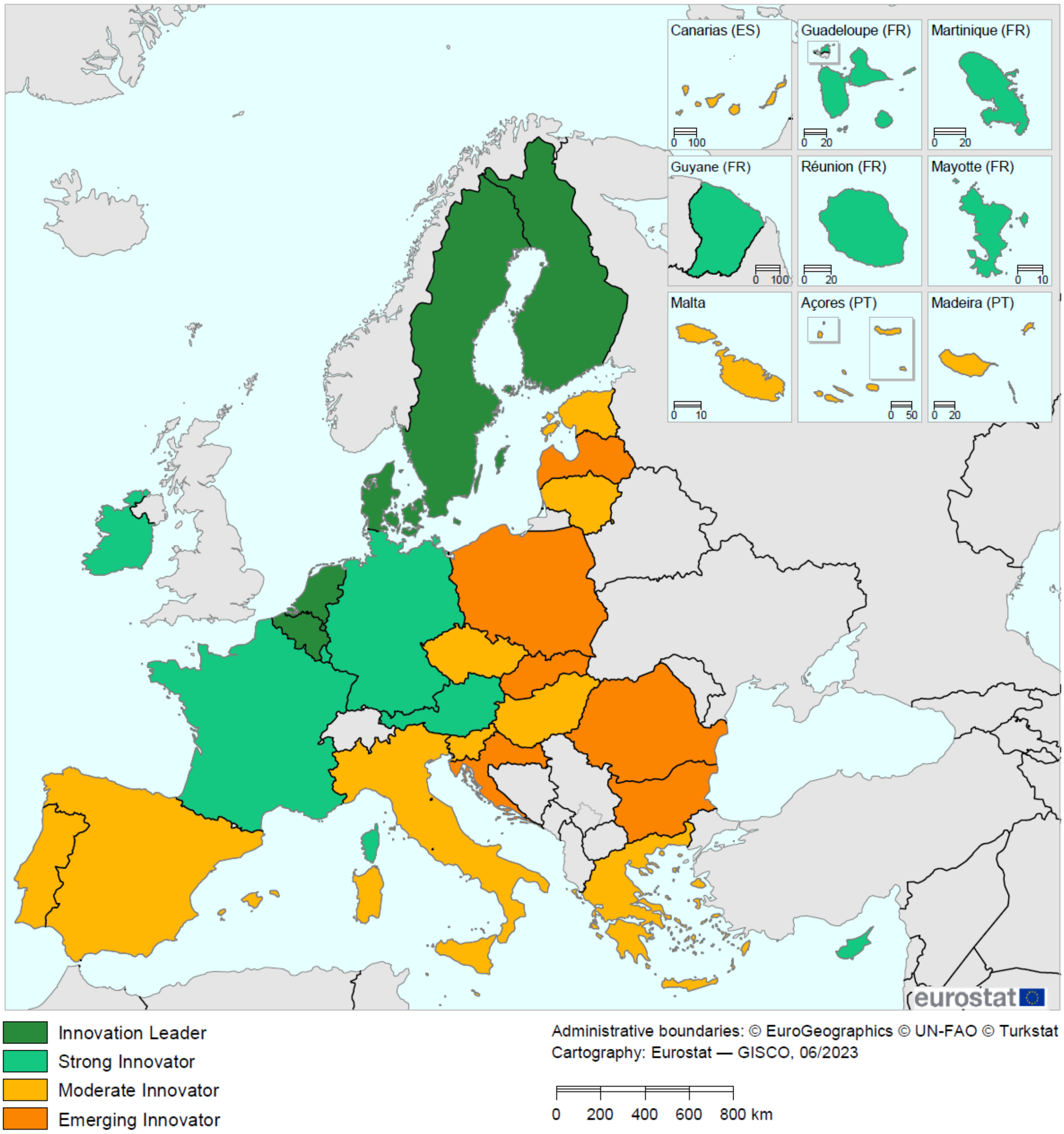

Figure 26. Map showing the performance of EU Member States' innovation system.

8.2.1 Structure of the European Innovation Scoreboard

The EIS is computed by aggregating 32 indicators, divided into 4 main types of activities.

The structure of the index is outlined below, where all the sub-indicators are listed.

1. **Framework conditions**

   This first category, Framework Conditions, captures drivers of innovation performance that are external to the firm. It is made upon three dimensions:

   1.1. Human resources

   This class evaluates the skills and education of the workforce. The three indicators chosen to make the evaluation are as follows:

   1.1.1. New doctorate graduates in STEM (Science, Technology, Engineering, Mathematics).

   1.1.2. Population aged 25-34 with completed tertiary education.

   1.1.3. Population aged 25-64 involved in lifelong learning activities.

   1.2. Attractive research systems

   This class measures the competitiveness of the science base at international level. It is composed by:

   1.2.1. International scientific co-publications.

   1.2.2. Most cited publications.

   1.2.3. Foreign doctorate students.

   1.3. Digitalization

   This is a measure of the technological advancement of a country, and it is further detailed into:

   1.3.1. Broadband penetration among enterprises.

   1.3.2. Individuals with above basic overall digital skills.

2. **Investments**

   Secondly, the category of Investments analyzes the investments made in both public and private sector and is structured as follows:

   2.1. Finance and support

   This group studies the financial investments made by a country, and it is computed on the basis of the following indicators:

   2.1.1. Venture capital investments.

2.1.2. R&D expenditures.

2.1.3. Direct government funding and government tax support for business.

2.2. Firm investments

This details the investments made by firms and is composed by 3 indicators:

2.2.1. Business R&D expenditures.

2.2.2. Non-R&D innovation expenditures.

2.2.3. Innovation expenditures per person employed.

2.3. Use of information technologies

This segment is related to detail whether citizens are used to leverage information technology in their day-to-day activities. The indicators used to evaluate this measure are:

2.3.1. Enterprises actively increasing the ICT skills of their personnel.

2.3.2. Employed ICT specialists.

3. Innovation Activities

The third macro-category aggregated into the EIS is defined Innovation Activities and investigates different aspects of innovation by acting on three dimensions:

3.1. Innovators

This class measures how SMEs have introduced innovation both within the organization and on the market. It is numerically evaluated by the following indexes:

3.1.1. SMEs with product innovations.

3.1.2. SMEs with business process innovations.

3.2. Linkages

This includes measures that express innovation capabilities given by research and collaboration:

3.2.1. Collaboration efforts between innovating firms.

3.2.2. Research collaboration between the private and public sector.

3.2.3. Job-to-job mobility of Human Resources in Science & Technology (HRST).

3.3. Intellectual assets

The third dimension captures several forms of Intellectual Property Rights (IPR). It is composed of the following indicators:

3.3.1. PCT patent applications

3.3.2. Trademark applications

3.3.3. Design applications

4. **Impact**

The last area included in the computation of the European Innovation Scoreboard, Impacts, is related to the effects of innovation activities and is measured throughout the following dimensions:

4.1. Employment impacts

This category investigates the impact of innovation on employment practices, and is defined by:

4.1.1. Employment in knowledge-intensive activities.

4.1.2. Employment in innovative activities.

4.2. Sales impacts

The class studies the impact of innovation on sales results by analyzing the following indicators:

4.2.1. Exports of medium- and high-tech products.

4.2.2. Exports of knowledge-intensive services.

4.2.3. Sales resulting from innovative products.

4.3. Environmental sustainability

The last group takes into account the improvements related to the environment, and is evaluated through:

4.3.1. Resource productivity.

4.3.2. Exposure to Air pollution by fine particulates PM2.5.

4.3.3. Development of environment-related technologies.

8.2.2 Computation methodology

The 32 indicators outlined above are taken from several sources, such as Eurostat databases [88], Scopus database [89], PATSTAT database [90], EUIPO database [91]. The following section will summarize the calculation methodology that leads to the final value of the EIS, as revised in 2023.

Once verified the data availability, the overall performance is computed for each country in every year, by computing a composite indicator, the Summary Innovation Index (SII). A specific procedure is followed to compute this value, as described below.

According to the original text [87], the first step to be performed is the setting of the reference years. For each indicator, a reference year is identified according to the data availability. In the most recent version of the report, the average year presenting complete data availability is 2021.

Second, the missing values have to be fixed. The methodology states that any missing value is replaced with the values corresponding to the previous year.

A third and really important operation is related to the identification and elimination of outliers, so as to obtain a set of values that is consistent for the analysis. Also, data that have highly skewed distributions across countries are transformed by using a square root transformation (i.e. the square root of a value was registered instead of the value itself).

The fourth activity to be done is the re-scaling of the indicators. Indeed, without performing this action the values could not be aggregated. The re-scaling is done following a normalization procedure, thus leading to values belonging to a [0;1] range (minimum scores converted to 0, maximum ones to 1).

By acting on these values, the SII is then computed. It is the unweighted average of the re-scaled scores, each indicator receiving the same weight, equal to 1/32.

Last, performance scores relative to the EU are calculated by dividing the SII of each country by the SII of the EU multiplied by 100. These values are computed taking as a reference point the performance of the EU in 2016, it being the first year available in the dataset.

8.3 Data availability: definition of the dataset

Given the structure of the indexes this paper aims to consider in the analysis, a set of common data was to be created.

On the one hand, the first dataset, constructed with the objective of classifying policies related to European Green Deal and containing the values of EPS index as per the study made by Kruse et al. (2022) [41], collects values of EPS in the range 1990-2020 for 18 countries only.

On the other hand, the dataset released by the European Commission showing the values of the EIS contains data of 49 countries (27 EU Member States, 11 other European countries, 11 non-European countries) in the range 2016-2023.

As a consequence, a merge of the two datasets results in a database consisting of 20 countries in the range 2016-2020. This database will be the starting point of the analyses conducted in this study.

The structure of the dataset is described in the following Table 8.

Table 8. Structure of the dataset used to perform the final analyses.

Column	**Description**	**Example**
Code	This column contains a code composed by "Country Name _ Year"	Italy_2020
Year	The year the values refer to	2020
Zone	Here it's specified whether the country is part of the EU	EU
Country	Code of the country	IT
Country Name	Full name of the country	Italy
Indicator	Description of the indicator	Summary Innovation Index
Value	Value of the corresponding indicator	0,4693
EIS Perf	Innovation performance category of a country, according to EIS Report	Moderate

9 Final analyses: 3 ways to address the problem

The following chapter is aimed at describing the analyses made to show evidence of the weak version of the Porter Hypothesis. three different approaches will be proposed in the following, in order to address the topic from various perspectives.

9.1 Analysis (1): Recomputing EIS by including EPS

The first study reported in this paper focuses on recalculating the value of the EIS by adding, as a sub-indicator, the value of the EPS.

9.1.1 Data and methodology: Multiple t-tests

Starting by the dataset containing the values of EPS and EIS described above (8.3), an analysis has been performed by listing all the values of the 33 selected indicators across the years 2016-2020.

Table 9 below shows, as an example, data related to Italy.

Table 9. List of values of the 32 indicators used to compute the EIS, divided by year, for country Italy.

Indicators	**2016**	**2017**	**2018**	**2019**	**2020**
1.1.1 New doctorate graduates	77,12	77,12	77,12	77,12	77,12
1.1.2 Population with tertiary education	21,56	21,56	21,56	21,56	21,56
1.1.3 Population involved in lifelong learning	90,11	90,11	90,11	90,11	90,11
1.2.1 International scientific co-publications	79,03	84,05	88,70	95,58	102,10
1.2.2 Scientific publications among the top 10% most cited	101,80	105,30	107,88	108,11	108,09
1.2.3 Foreign doctorate students as a % of all doctorate students	74,80	79,45	80,15	86,18	90,93
1.3.1 Broadband penetration	60,77	60,77	60,77	60,77	60,77
1.3.2 Individuals with above basic overall digital skills	82,45	82,45	82,45	82,45	82,45

2.1.1 R&D expenditure in the public sector	67,74	64,52	61,29	59,68	61,29
2.1.2 Venture capital expenditures	77,82	82,47	75,86	77,23	79,75
2.1.3 Direct and indirect government support of business R&D	32,48	30,57	61,91	78,24	140,34
2.2.1 R&D expenditure in the business sector	60,00	60,00	60,00	61,54	65,39
2.2.2 Non-R&D innovation expenditures	83,62	83,62	83,62	93,31	93,31
2.2.3 Innovation expenditures per person employed	59,68	59,68	59,68	78,10	78,10
2.3.1 Enterprises providing ICT training	46,50	43,31	50,32	75,80	91,72
2.3.2 Employed ICT specialists	75,86	75,86	75,86	75,86	75,86
3.1.1 SMEs introducing product innovations	109,72	109,72	109,72	147,68	147,68
3.1.2 SMEs introducing business process innovations	118,36	118,36	118,36	147,49	147,49
3.2.1 Innovative SMEs collaborating with others	65,25	65,25	65,25	53,21	53,21
3.2.2 Public-private co-publications	120,69	124,33	128,49	142,08	151,98
3.2.3 Job-to-job mobility of HRST	52,94	52,94	52,94	58,82	70,59
3.3.1 PCT patent applications	70,11	72,59	73,00	73,66	72,03
3.3.2 Trademark applications	99,06	104,66	106,49	108,00	110,94
3.3.3 Design applications	128,56	141,15	134,23	122,24	124,55
4.1.1 Employment in knowledge-intensive activities	101,21	101,21	101,21	101,21	101,21
4.1.2 Employment in innovative enterprises	109,51	109,51	109,51	126,60	126,60
4.2.1 Exports of medium and high technology products	79,64	80,88	80,37	80,18	77,98
4.2.2 Knowledge-intensive services exports	68,64	67,26	68,30	68,34	65,23
4.2.3 Sales of new-to-market and new-to-firm innovations	81,91	81,91	81,91	102,44	102,44
4.3.1 Resource productivity	190,97	204,04	214,07	223,07	224,92
4.3.2 Air emissions by fine particulates	106,27	107,30	107,83	109,80	110,37
4.3.3 Environment-related technologies	75,02	72,17	64,21	63,99	64,82

Once this table was outlined, the re-scaled values were to be calculated. As suggested by the EIS report [87], this operation can be done by dividing each value by 100 and multiplying it by the re-scaling factor, 0.505. In the case of Italy, results are shown in the following Table 10.

Table 10. Re-scaled indicators, from 2016 to 2023, for country Italy.

Indicators	2016	2017	2018	2019	2020
1.1.1 New doctorate graduates	0,389	0,389	0,389	0,389	0,389
1.1.2 Population with tertiary education	0,109	0,109	0,109	0,109	0,109
1.1.3 Population involved in lifelong learning	0,455	0,455	0,455	0,455	0,455
1.2.1 International scientific co-publications	0,399	0,424	0,448	0,483	0,516
1.2.2 Scientific publications among the top 10% most cited	0,514	0,532	0,545	0,546	0,546
1.2.3 Foreign doctorate students as a % of all doctorate students	0,378	0,401	0,405	0,435	0,459
1.3.1 Broadband penetration	0,307	0,307	0,307	0,307	0,307
1.3.2 Individuals with above basic overall digital skills	0,416	0,416	0,416	0,416	0,416
2.1.1 R&D expenditure in the public sector	0,342	0,326	0,31	0,301	0,31
2.1.2 Venture capital expenditures	0,393	0,416	0,383	0,39	0,403
2.1.3 Direct and indirect government support of business R&D	0,164	0,154	0,313	0,395	0,709
2.2.1 R&D expenditure in the business sector	0,303	0,303	0,303	0,311	0,33
2.2.2 Non-R&D innovation expenditures	0,422	0,422	0,422	0,471	0,471
2.2.3 Innovation expenditures per person employed	0,301	0,301	0,301	0,394	0,394
2.3.1 Enterprises providing ICT training	0,235	0,219	0,254	0,383	0,463
2.3.2 Employed ICT specialists	0,383	0,383	0,383	0,383	0,383
3.1.1 SMEs introducing product innovations	0,554	0,554	0,554	0,746	0,746
3.1.2 SMEs introducing business process innovations	0,598	0,598	0,598	0,745	0,745
3.2.1 Innovative SMEs collaborating with others	0,33	0,33	0,33	0,269	0,269
3.2.2 Public-private co-publications	0,609	0,628	0,649	0,718	0,767
3.2.3 Job-to-job mobility of HRST	0,267	0,267	0,267	0,297	0,356
3.3.1 PCT patent applications	0,354	0,367	0,369	0,372	0,364
3.3.2 Trademark applications	0,5	0,529	0,538	0,545	0,56
3.3.3 Design applications	0,649	0,713	0,678	0,617	0,629
4.1.1 Employment in knowledge-intensive activities	0,511	0,511	0,511	0,511	0,511
4.1.2 Employment in innovative enterprises	0,553	0,553	0,553	0,639	0,639
4.2.1 Exports of medium and high technology products	0,402	0,408	0,406	0,405	0,394
4.2.2 Knowledge-intensive services exports	0,347	0,34	0,345	0,345	0,329

4.2.3 Sales of new-to-market and new-to-firm innovations	0,414	0,414	0,414	0,517	0,517
4.3.1 Resource productivity	0,964	1,03	1,081	1,126	1,136
4.3.2 Air emissions by fine particulates	0,537	0,542	0,545	0,554	0,557
4.3.3 Environment-related technologies	0,379	0,364	0,324	0,323	0,327

As a result, all the values will belong to the [0;1] range, the highest ones getting the values of 1, and the lowest ones scoring 0.

Then, the stringency values are added to the dataset and normalized as described above. In the case of Italy, results are shown below in Table 11 and in Table 12.

Table 11. Values of the EPS indicator, for Italy, in the timeframe 2016-2020.

Indicator	2016	2017	2018	2019	2020
5. EPS	4,06	4,06	3,78	3,75	3,72

Table 12. Re-scaled values of the EPS indicator, for Italy, in the timeframe 2016-200..

Indicator	2016	2017	2018	2019	2020
5. EPS	0,02	0,02	0,19	0,19	0,19

Starting with these values, the new SII' (i.e. SII considering the EPS value) is easily computed as the unweighted average of the 33 indicators. In the example of Italy, results are shown below (Table 13).

Table 13. Table showing results of the SII' (considering the EPS), the standard deviation and the number of observations collected for Italy in the timeframe 2016-2020.

	2016	2017	2018	2019	2020
SII'	0,409	0,416	0,422	0,452	0,470
Standard dev	0,169	0,181	0,181	0,197	0,203
n	33	33	33	33	33

Now, this value is to be compared with the value originally computed not considering the EPS among the indicators. Table 14 below shows the SII values for Italy as per the dataset publicly available.

Table 14. Summary Innovation Index (SII) values computed without adding the EPS. Data related to Italy, in the timeframe 2016-2020.

	2016	**2017**	**2018**	**2019**	**2020**
SII (without EPS)	0,416	0,422	0,426	0,454	0,469

To evaluate the differences between the values computed without the EPS and those computed by considering it in the calculation, a t-test is required. More specifically, it was decided to test the differences between the means both at a significance level of 95% and 99%.

The multiple tests performed were structured upon the following hypotheses:

$$H_0: SII_{c,t} = SII'_{c,t}$$

$$H_a: H_0 \; is \; false$$

where the indexes c and t indicate that SII values must be tested for a given country, at a given year, respectively.

The table below shows results computed in the case of Italy (Table 15).

Table 15. Results of the calculation of the Student's t statistic. Data related to Italy in the timeframe 2016-2020.

	2016	**2017**	**2018**	**2019**	**2020**
t-Stat	0,238	0,193	0,129	0,058	0,041
p-value	0,8137	0,8479	0,8982	0,9539	0,9675

It is straightforward to notice that all the *p-values* computed are much higher than the chosen confidence level of 0.01 and 0.05. Consequently, all the *t-Stat* values fall within the acceptance region, thus the null hypothesis cannot be rejected. As a matter of fact, no test results in a significant difference between the means, neither at 95% nor at 99% confidence levels.

9.1.2 Results and discussion

A table summarizing all the results across the 18 countries was then created, which is reported below (Table 16). At first glance, it is easily visible that there's no significance difference between the means in the whole dataset, both at 95% and 99% confidence level. Hence, the final result of SII does not change significantly, although a new variable is added in the computation.

Table 16. Summary of the results of the multiple t-tests.

Country Name	Conf. Level	2016	2017	2018	2019	2020
Austria	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Belgium	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Czech Rep.	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Denmark	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Finland	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
France	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Germany	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Greece	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Hungary	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Ireland	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Italy	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant

Netherlands	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Poland	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Portugal	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Slovakia	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Slovenia	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Spain	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Sweden	95%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Austria	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Belgium	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Czech Rep.	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Denmark	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Finland	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
France	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Germany	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Greece	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Hungary	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Ireland	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant

Italy	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Netherlands	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Poland	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Portugal	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Slovakia	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Slovenia	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Spain	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Sweden	99%	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant

Some insights could be derived from this study. First, the fact that no significance difference between the means arises leads to think that a possible correlation exists between the variables. Indeed, whether EPS and EIS had completely different distributions, the values of SII' computed right above should be affected by EPS significantly, thus resulting as significantly different from SII.

However, it's to be noted that EPS may also affect the computation of SII in a lighter way. Indeed, one single parameter added to the computation is unlikely to have a strong impact on the final outcome, as it weighs only 1 over 33. So, it is not illogical to think that, although EPS values are not correlated with EIS, the differences in the means are not significant, as EPS only accounts for 1/33.

Still, the fact that no observation results as significant could lead to think that a relationship may exist between EPS and EIS. Indeed, although EPS represents only 1/33 of the value of SII', the probability of all the results being not significant is still low.

To summarize, this first analysis shows that the reasons explaining why the value of SII' does not change significantly from that of SII are to be attributed partly to the low impact of EPS values on the index computation, partly to a possible trend the variables share.

9.2 Analysis (2): Different innovation categories show different values of EPS

To go deeper into the analysis and look for confirmation on the existence of a relationship between EPS and EIS, the approach of an Analysis of Variance (ANOVA) has been chosen.

9.2.1 Data and methodology: ANOVA

Data is derived from the dataset described above, obtained by merging the values of EPS computed by Kruse et al. (2022) [41] and those of EIS resulting from the European Innovation Scoreboard Report (2023) [87].

Specifically, countries are grouped into 4 categories according to their level of innovation performance, as described in the Report [87]. By analyzing the data, a trend emerged in the average stringency values of the groups, which is highlighted by Table 17 below.

Table 17. Average values of EPS computed for the 4 innation performance groups, divided by year.

Innovation Performance	**EPS average values**					
	2016	**2017**	**2018**	**2019**	**2020**	**Total average**
Leader	3.53	3.51	3.57	3.56	3.72	3.58
Strong	3.28	3.29	3.47	3.58	3.78	3.48
Moderate	2.96	3.02	2.92	2.99	3.02	2.98
Emerging	2.94	2.65	2.81	2.93	2.99	2.86

Strong evidence can be noted from the table. Indeed, a trend associating EPS and EIS emerges: the higher the stringency of the policies applied by a country, the higher its innovation performance.

This assumption seems to hold for the whole dataset, although, on average, the difference between the Moderate and Emerging groups are very small.

To test whether a hidden relationship exists behind the numbers shown in the table, a test was to be performed, which allowed to evaluate the differences of 4 means. To this purpose, the ANOVA model was chosen.

ANOVA is the acronym of Analysis of Variance, and it is a statistical method commonly used to evaluate the difference between the means of several groups and assess whether they're due to causal links between the variables or to variability.

Hence, the hypothesis H_0 that this study was aimed to test was whether the means of the four groups were equal at a significance level $\alpha = 0.05$:

$$H_0: \mu_{leader} = \mu_{strong} = \mu_{moderate} = \mu_{emerging}$$

$$H_a: H_0\ is\ false$$

The ANOVA was performed by using the Excel *Data Analysis* extension, which summarizes the results in tabular forms.

Initially, five different scenarios were computed, each of them dedicated to evaluating the difference between the means of the four groups of a specific year of the dataset, from 2016 to 2020. However, this analysis relied on weak foundations. Indeed, the total number of observations included in the dataset is very low (100), and working on even smaller subsets (5 years, each of them divided into 4 groups) leads to non-reliable groups of data.

As shown by the following Figure 27, which summarizes the values of 2016, the category of Emerging countries consists of 2 observations only, which are not enough to perform a structured analysis.

Anova: Single Factor

SUMMARY - Year:2016

Groups	Count	Sum	Average	Variance
Emerging	2	5,889	2,944	0,025
Moderate	8	23,694	2,962	0,386
Strong	5	16,389	3,278	0,402
Leader	5	17,667	3,533	0,183

Figure 27. Output of the Summary of data for 2016 made in Excel.

9.2.2 Results and discussion

Hence, the solution adopted was to use as input the mean values resulting from the whole dataset. The Excel output is reported below in Figure 28.

ANOVA one factor

SUMMARY

Groups	Count	Sum	Average	Variance
Emerging	10	28,638889	2,8638889	0,150454405
Moderate	40	119,3055546	2,982638865	0,233131023
Strong	25	86,9722214	3,478888856	0,515385768
Leader	25	89,416667	3,57666668	0,113765434

Analysis of Variance

Origin of Variance	SS	df	MS	F	Significance	F crit
Between Groups	8,323183119	3	2,774394373	10,42604122	5,31554E-06	2,699393
Within Groups	25,54582838	96	0,266102379			
Total	33,8690115	99				

Figure 28. Output of the ANOVA, made in Excel.

As the table shows, data were split irregularly across the groups. Emerging countries were only 10, while Moderate, the vast majority of the dataset, accounted for 40 values. Strong and Leaders had 25 observations each.

The means show the trend that was already visible in the table above, although variances are strongly unequal. Countries categorized as Leaders show very similar values of stringency (variance of 0.1138), while those belonging to the Strong category seem to have a wide range of EPS values (variance of 0.5154).

Overall, the table describing the ANOVA shows a *p-value* of $75.3155 \cdot 10^{-6}$, which is much lower than the assumed threshold $\alpha = 0.05$. Therefore, the null hypothesis can be rejected at a significance level of 95%, thus concluding that the difference between the means of the four groups is significant.

This result allows to bring some more light to the evidence that this paper is discussing, the weak version of the Porter Hypothesis.

Still, the analyses conducted so far are not enough to show strong evidence of the relationship between the variables, as they only state that the means of the 4 groups are not equal. Rather, to go deeper, studies should focus on analyzing whether some means are significantly lower than others.

9.3 Analysis (3): EPS average values of Faster Innovators are higher than those of Slower Innovators

In order to support the results obtained by the analysis of variances across groups, the means of those groups should be separately compared. T-tests will therefore be performed to assess whether the mean of a group is significantly higher than that of another group.

9.3.1 Data and methodology: t-tests

The dataset used to make this study is the same as above.

As already described in the methodology adopted to perform the ANOVA, an issue related to the low number of observations contained in the databases arises. Indeed, when dividing the observations into the 4 groups across the 5 different years, the reliability of the data gets lower and lower. Thus, a solution was to be found, that did not affect the reliability of results, still allowing at the same time not to lose the differentiation across the years and across the groups.

To meet these needs, the proposed solution was to merge the groups as follows:

- Emerging and Moderate are aggregated into a category called *Slow Innovators*;
- Strong and Leader are grouped into a set defined as *Fast Innovators*.

The averages of the new groups are described in the following Table 18.

Table 18. Average values of EPS for Slow and Fast Innovators.

Innovation Performance Groups	**2016**	**2017**	**2018**	**2019**	**2020**	**Average**
Slow Innovators	2.96	2.95	2.90	2.98	3.01	2.96
Fast Innovators	3.41	3.40	3.52	3.57	3.75	3.53

It is straightforward to notice that the differences between the means are even more polarized than those of the four groups, thus suggesting an evident difference between the subgroups.

To test whether these differences are significant, the confidence level was set to 95%, and multiple t-tests were built upon the following hypotheses:

$$H_0: \mu_{slow} \geq \mu_{fast}$$

$$H_a: \mu_{slow} < \mu_{fast}$$

Before choosing whether to go for an equal-variances-t-test or an unequal-variances-t-test, F-tests were performed to evaluate the differences between the variances. The hypotheses at the basis of the F-tests were the following:

$$H_0: \sigma^2_{slow} = \sigma^2_{fast}$$

$$H_0: \sigma^2_{slow} \neq \sigma^2_{fast}$$

The significance level α was set, as usual, to 5%.

Both the analyses were performed by leveraging the Excel extension *Data Analysis*.

9.3.2 Results and discussion

The output of the Excel solver is shown in tabular forms. As an example, only the computations for year 2020 are reported below in Figure 29 (results for other years are available in the Appendix).

F-Test Two-Sample for Variances
2020

	Slow Innovators	*Fast Innovators*
Mean	3,01111111	3,74722225
Variance	0,163614565	0,29620197
Observations	10	10
df	9	9
F	0,552375006	
P(F<=f) one-tail	0,194922088	
F Critical one-tail	0,314574906	

Figure 29. Output of F-test made on Excel to test the differences between variances of the groups. Data relate to year 2020.

t_test: Two-Sample Assuming Unequal Variances
2020

	Slow Innovators	*Fast Innovators*
Mean	3,01111111	3,74722225
Variance	0,163614565	0,29620197
Observations	10	10
Total Variance	0,229908267	
Hypothesized Mean Difference	0	
df	18	
t Stat	-3,432820524	
P(T<=t) one-tail	0,001483829	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,002967657	
t Critical two-tail	2,10092204	

Figure 30. Output of the t-test performed on Excel to test the differences between the means of the groups. Data relate to year 2016.

Figure 29 outlines the results obtained when testing the differences between the variances of the subgroups. As per data of 2020, the computed variances are 0.1636 and 0.2962 for Slow and Fast Innovators, respectively. The F-test states that, with a confidence level of 95%, the difference between variances is not significant, as the *p-value* is much higher than the threshold of 0.05, leading to reject the null hypothesis of equal variances.

This first result allows to structure an equal-variances-t-test, whose output is depicted in Figure 30. The *t-Stat* value of -3.4328 is lower than the *t Critical one-tail* value of -1.7341, thus falling into the rejection area. As confirmed by the *p-value* of 0.0015, the null hypothesis is to be rejected. In other words, the statement that the mean of the Slow Innovators is larger or equal than the mean of Fast Innovators is to be discarded, as it finds no statistical evidence.

The results of the tests performed across all years are summarized in the following Table 19.

Table 19. Summary of the p-values related to F-test and t-test performed to assess the significance of the differences between variances and means of the two groups, respectively.

	2016	**2017**	**2018**	**2019**	**2020**	**Average**
F-Test Two-Sample for Variances	0.4493	0.4583	0.1780	0.1656	0.1949	0.1021
t-test: Two-Sample Assuming Equal Variances	0.0400	0.0499	0.0071	0.0097	0.0015	0.0000

It's easy to notice that, once again, all the results show values that are lower than the threshold $\alpha = 0.05$, thus leading to reject the null hypothesis. Moreover, the last column of the table shows the output computed over the whole dataset, which corresponds to the lowest *p-value* of the sample (i.e. $1.24 \cdot 10^{-7}$).

As a final overview, this analysis has proven that, by aggregating countries into different innovation performance categories, a difference emerges in the average values of the EPS. More specifically, this difference highlights that countries that implement the most stringent policies are recognized as the fastest innovators.

10 Econometric model

The previous chapter focuses on the study of the relationship between a quantitative variable, EPS, and a qualitative variable, the innovation-performance categories created by EIS Report.

Still, as extensively discussed above, this index is computed by following a rigorous structure, which results in a quantitative measure. There is, therefore, wide space for further studies that involve both the quantitative measures of EPS and EIS.

Several mathematical methods exist that could be applied to this topic, but listing them all is far from the purpose of this paper. Nevertheless, for the sake of completeness, it was decided to address one of them, so as to have a wider perspective of the topic and avoid supporting wrong statements.

This conclusive chapter will be therefore devoted to investigating whether a linear regression model is able to explain the correlation between the values of EPS and those of EIS.

10.1 Model specifications

The model was developed by following the structure mostly used in the literature, and lastly described in 2019 by Martinez-Zarzoso et al. [82]. They used three different dependent variables, namely Research and Development Expenditures, Patent Applications and Total Factor Productivity, as a measure of innovation activity and tested how they were affected by EPS. Specifically, they followed intuition by Rubashkina et al. (2015) [77] and involved in the model 1- and 5-years lags to study the delayed reactions of firms to changes in regulations.

Following the methodological structure of these studies, the empirical model used within this paper takes the following form:

$$\ln{(EIS)_{i,t}} = \beta_0 + \beta_1 \ln{(EPS)_{i,t-k}} + \beta_2 \ln(GDPPC)_{i,t} + \beta_3 NOP_{i,t} + \epsilon_{i,t}$$

$EIS_{i,t}$ indicates the value of EIS for a given country, i, in a given year, t. The model is aimed at explaining the relationship, either positive or negative, that correlates this variable with the dependent variables $EPS_{i,t}$, indicating the value of the EPS computed for a country i and lagged of k years with respect to year t, with $k = 1{,}5$, and $GDPPC_{i,t}$, representing the per capita Gross Domestic Product of country i at year t, and $NOP_{i,t}$, indicating the number of policies issued by country i at year t. The error term $\epsilon_{i,t}$ is added in order to consider hidden and unknown relationships and the impact of variability [92].

10.2 Data and Variables

The sample used to conduct this analysis is a panel data derived from the reduction of the dataset described in the previous chapters, obtained by merging the database of EPS and data originated from the EIS Report [87]. As a consequence, data include 20 European Countries – Austria, Belgium, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Sweden, Slovenia and Slovakia – across a timeframe of 5 years, ranging from 2016 to 2020.

Data related to the per capita GDP was obtained from *OECD* database, while the total number of policies issued by a country was derived from the database created during the first phase of the work.

The variables are described in the following Table 20.

Table 20. Structure of the dataset used to perform the linear regression.

Variable	Definition	Source
EIS	Score of the EIS	*EIS Report*
EPS	Score of EPS	*OECD*
GDPPC	Gross Domestic Product per Capita, in US $ (2015)	*OECD*
NOP	Total Number of Policies issued by a country	*Database*

10.2.1 Descriptive Statistics

In order to have a first overview of the variables included in the model, some descriptive statistics were computed, which are reported in the following Table 21.

Table 21. Descriptive statistics of the variables.

	Ln(GDPPC)	***Ln(EPS)***	***NOP***	***Ln(EIS)***
Mean	4,6631	0,5041	2,13	1,9977
Standard Error	0,0150	0,0078	0,2329	0,0121
Median	4,6467	0,4948	1	2,0293
Standard Deviation	0,1500	0,0777	2,3297	0,1212
Min	4,4395	0,3575	0	1,7387
Max	5,0770	0,6892	10	2,1463
Count	466,3139	100	100	100

For each variable, the mean value, the standard error, the median, the standard deviation, the minimum and maximum values, and the number of observations were recorded. Still, when studying these numbers, few insights can be derived about the distribution of the variables country by country and year by year. Therefore, some figures related to the evolution of the variables over time and regions are presented below.

Regarding the number of policies, EPS and EIS, considerations made in chapters 3, 5 and 8, respectively, apply.

Moving on to GDP per capita, Figure 31 depicts the trend over time, describing values registered in 2000, 2010, 2016 and 2020. It is intuitive to notice that, for almost the totality of the countries included in the dataset, an increase in GDP per capita was registered. Specifically, Luxembourg and Ireland represent the peaks in 2020 values, far above the average of about $ 40 000.

Furthermore, it can be seen that Ireland, Estonia and Poland stands out as those countries that showed the highest growth within the last 20 years. By contrast, countries that showed the lowest increase in GDP per capita are Greece, Portugal, Spain and Italy, whose results are very low.

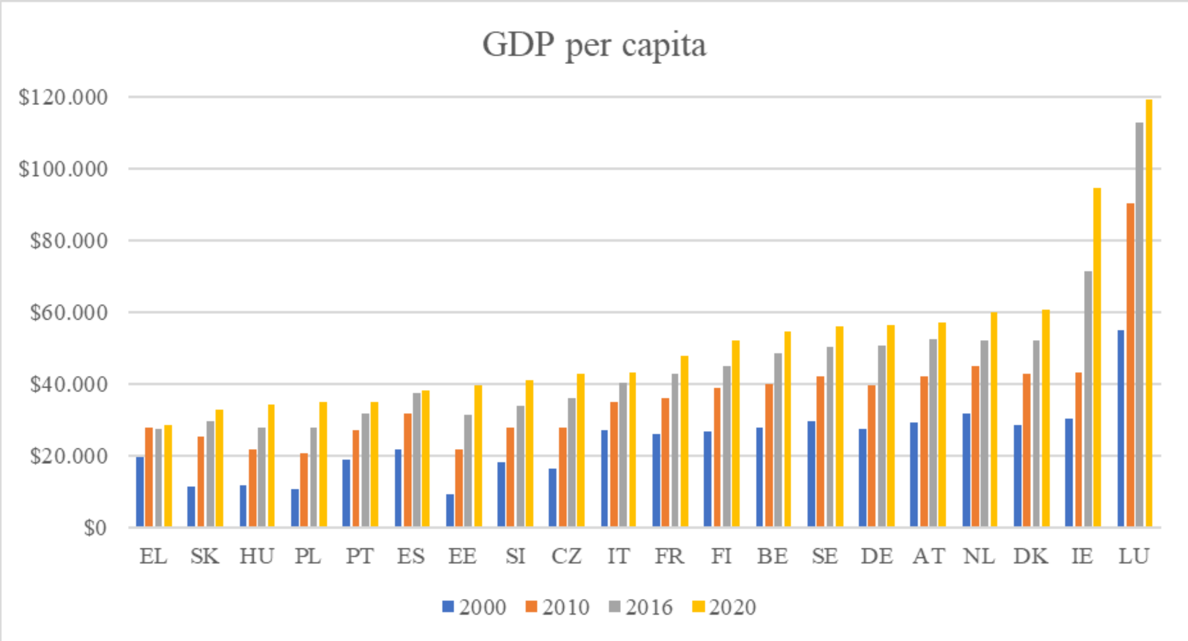

Figure 31. GDP per capita in 2000, 2010, 2016 and 2020, by country.

10.2.2 Correlation matrix

To complete the analysis of the key variables used in the model, a correlation matrix was computed, which is described in the following Figure 32.

	ln(EIS)	*ln(EPS)*	*ln(GDPPC)*	*NOP*
ln(EIS)	1			
ln(EPS)	0,4578	1		
ln(GDPPC)	0,7882	0,3929	1	
NOP	0,1295	0,1866	0,0511	1

Figure 32. Correlation matrix.

The Pearson coefficient between *ln(EIS)* and *ln(EPS)* shows a significant positive correlation, being equal to 0.4578. This suggests that an increase in EPS is associated with an increase in EIS, meaning the adoption of stricter environmental policies leads to higher innovation activity. Although this result brings some more light on the research under investigation, it is pivotal to emphasize that correlation does not imply causation.

A strong positive correlation can be noticed between *ln(EIS)* and *ln(GDPPC)* (r = 0.7882), indicating that higher GDP per capita is correlated with higher EIS score. This could mean that countries showing higher GDP per capita tend to invest heavily in innovative technologies.

Conversely, the correlation between *ln(EIS)* and the number of policies is weak, but still positive (r = 0.1295).

Furthermore, it is worthwhile to mention that a positive correlation exists between *ln(GDPPC)* and *ln(EPS)*. This shows that countries with higher GDP per capita usually implement the most stringent environmental policies. Yet, the value of the Pearson coefficient is other than high (r = 0.3929).

The number of policies shows weak positive correlation with both the GDP per capita and the EPS, showing that the influence of the number of policies does not have a strong impact within the model.

As already mentioned, it is essential to underline that, although the correlation matrix offers initial insights about the correlation between the variables, these insights do not necessarily imply causal links. The following regression analysis is indeed performed with the aim of finally assessing the influence of the independent variables over the dependent variable.

10.3 Regression Analysis

To perform the analysis, the Ordinary Least Squares (OLS) model is applied. It allows to estimate the relationship between a dependent variable (EIS) and one or more independent variables (EPS and per capita GDP), by performing a linear regression which minimizes the sum of squared differences between observed and predicted values.

In order to minimize the impact of extreme values and ensure comparability across economically diverse countries, values have been scaled by introducing natural logarithms.

The regression was performed using the Excel solver, whose outputs are reported in tabular form in the following.

10.4 Results and discussion

The first regression was related to the analysis of the effects of EPS on EIS considering a 1-year delay. Results are summarized in Figure 33.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,805657554
R Square	0,649084094
Adjusted R Square	0,638117971
Standard Error	0,072894326
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0,943531904	0,314510635	59,1899387	9,4345E-22
Residual	96	0,51010394	0,005313583		
Total	99	1,453635844			

	Coefficients	*Standard Error*	*t Stat*	*p-value*	*Lower 95%*	*Upper 95%*
Intercept	-0,88171336	0,23071409	-3,82167107	0,000235331	-1,339677213	-0,423749514
ln(GDPPC)	0,590494606	0,052222812	11,30721588	2,39232E-19	0,486833144	0,694156068
ln(EPSlag1)	0,236062143	0,101310324	2,330089705	0,02189595	0,034962739	0,437161547
NOP	0,003779598	0,003171018	1,191919651	0,236230921	-0,002514822	0,010074018

Figure 33. Output of the regression considering EPS lagged-1-year

It is straightforward to notice that the values of R square and Adjusted R square are rather satisfying, indicating that the model explains approximately 64% of the total variability. Moreover, it can be noted that the F-statistics is 59.19 and shows a *p-value* extremely close to 0, thus stating that the model is statistically significant.

Moving to the analysis of the significance of the variables, it is easy to notice that the per capita GDP is statistically significant at 1% level and shows a coefficient of 0.5905. This confirms the insight derived from the correlation matrix above, stating that a 1% increase in the GDP per capita leads to a 0.59% increase in the EIS score.

The 1-year-lagged EPS is statistically significant at 5%, showing a *p-value* of 0.0219 and a coefficient of 0.2361. It is intuitive to notice that this result allows to state that the weak version of the Porter Hypothesis holds, as a 1% increase in EPS leads to a 0.24% increase in the EIS value.

The number of policies issued by a country in a given year is the only non-significant variable, showing a *p-value* of 0.2362. Last, the coefficient of the intercept is highly significant.

The main conclusion that can be derived from this first model is that, considering a 1-year lagged effect of EPS, the weak version of the Porter Hypothesis holds, meaning that implementing more stringent regulations leads firms to increase their innovation activity in the subsequent year.

The second model to be tested involves the study of the effects of EPS with a 5-years delay. The output of the model is summarized in the following Figure 34.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,8055076
R Square	0,64884249
Adjusted R Square	0,63786882
Standard Error	0,07291941
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0,943180701	0,314393567	59,12719814	9,74963E-22
Residual	96	0,510455144	0,005317241		
Total	99	1,453635844			

	Coefficients	*Standard Error*	*t Stat*	*p-value*	*Lower 95%*	*Upper 95%*
Intercept	-0,89470887	0,230023718	-3,88963745	0,000185048	-1,351302342	-0,438115398
ln(GDPPC)	0,59014794	0,052333226	11,27673531	2,77656E-19	0,48626731	0,694028577
ln(EPSlag5)	0,26289028	0,113556257	2,315066428	0,022739429	0,03748289	0,488297668
NOP	0,00446818	0,003150919	1,418057004	0,159412074	-0,001786342	0,010722707

Figure 34. Output of the regression considering EPS lagged-5-years

The values of R square and Adjusted R square are similar to the previous analysis, thus analogous conclusions can be drawn: once again, the model is statistically significant.

Regarding the variables, insights are roughly the same, although small differences arise. The per capita GDP is still statistically significant at 1% and shows almost the same coefficient as in the previous analysis.

The EPS remains statistically significant at 5%, with a *p-value* slightly higher than above. The coefficient, however, shows a small increase, moving from 0.2361 to 0.2629. Therefore, the weak version of the Porter Hypothesis still holds and the impact of stricter regulations on innovation activities is slightly higher when considering a 5-years delay.

Last, the *p-value* related to the number of policies has decreased. Still, this variation did not lead to a statistically significant result, meaning that the influence of the number of policies over the EIS (which would still be very low, given the value of the coefficient) cannot be explained by this model.

In conclusion, the second model enforces the results obtained by the first model, stating that the implementation of stricter policies enhances innovation activity, both with a 1- and 5-year delay.

11 Conclusions

The contribution of this paper is to be found in the aggregated results of the analyses that have been conducted.

First, lite evidence of the Porter Hypothesis appeared in the results of Analysis (1), where the computation of the SII did not show significant differences when altered by the EPS.

Then, by studying the correlation between the quantitative variable EPS and the qualitative attributes derived from the EIS, further evidence has emerged that the weak version of the Porter Hypothesis holds. Both Analyses (2) and (3) show that countries belonging to the lowest innovation performance categories have, on average, implemented the least stringent policies, and, oppositely, governments that have pushed for stricter regulations are recognized as the most innovative ones. Specifically, it's worth mentioning that the output of Analysis (3) is strongly significant.

Last, the regression set on a panel data of 100 observations resulted in a positive correlation with strong significance when considering both 1-year and 5-years lagged effects. Specifically, the last study highlighted that the impact of EPS over innovation activity is not immediate, rather it gets higher with time passing by.

To conclude, all the analyses lead to show evidence that the Porter Hypothesis holds, at least in its weak version. Thus, the main conclusion derived by this paper can be found in the suggestion to implement stricter environmental regulations, as they're more likely to induce innovation activities.

12 Limitations and future developments

The studies conducted in the paper face some structural limitations, as already mentioned throughout the previous chapters. This conclusive paragraph is dedicated to highlight those aspects and to suggest further improvements.

The main limitation of the whole set of analyses is related to the data availability, which is extremely poor. Indeed, a sample composed of only 20 countries studied on a timeframe of 5 years – thus resulting in a total of 100 observations – is poorly representative. Also, all data belong to European countries, which reduces the total variability. It would be valuable to conduct further studies on broader data panels considering other geographical regions, so as to gain a more comprehensive understanding.

In addition, the econometric model was constructed by following the advice of Martinez-Zarzoso et al. (2019) [82], Rubashkina et al. (2015) [77] and Jaffe and Palmer (1997) [62], although the variables considered were not the same. Specifically, the choice of using the EIS as dependent variable could lead to hide the effects of some indicators and measures considered within the computation of the index itself. It could be interesting to extend the analysis made on the EIS as an aggregated measure over the single indicators used to compute the SII.

Finally, the computation of the EPS index shows some structural limitations, as it does not include the whole set of policies issued by governments. For instance, instruments regulating the levels of emissions derived from agricultural production are not considered in the computation of the most updated version of the index. Although the EPS index is an extremely useful and commonly adopted measure for quantitatively assessing the stringency of environmental policies, still it would be interesting to evaluate results of the same model when applying more comprehensive indicators.

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Annex A

Part of the dataset of Directives, Regulations and National transpositions collected.

COD	Country	Level	Year	Topic	Policy Name	
EU_2001_2018_2	EU	Europe	2018	2	Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources	D
AT_2001_2018_150_2021_2	AT	Country	2021	2	Erneuerbaren-Ausbau-Gesetzespaket – EAG-Paket	B
AT_2001_2018_73_2021_2	AT	Country	2021	2	Gesetz, mit dem das Wiener Elektrizitätswirtschaftsgesetz 2005 – WElWG 2005 geändert wird	L
AT_2001_2018_98_2021_2	AT	Country	2021	2	Gesetz, mit dem das Kärntner Elektrizitätswirtschafts- und -organisationsgesetz 2011 geändert wird	L
AT_2001_2018_190_2021_2	AT	Country	2021	2	Gesetz vom 16. Dezember 2021, mit dem das Tiroler Elektrizitätsgesetz 2012 geändert wird	L
AT_2001_2018_115_2021_2	AT	Country	2021	2	Law of 15. December 2021, which amends the Salzburg State Electricity Act 1999	L
AT_2001_2018_14_2022_2	AT	Country	2022	2	Gesetz über eine Änderung des Elektrizitätswirtschaftsgesetzes, LGBl.Nr. 14/2022	L
AT_2001_2018_36_2022_2	AT	Country	2022	2	Landesgesetz, mit dem das Oö. Elektrizitätswirtschafts- und -organisationsgesetz 2006 und das Oö. Starkstromwegegesetz 1970 geändert werden	L
BE_2001_2018_41519_2021_2	BE	Country	2021	2	Decreet tot wijziging van het Energiedecreet van 8 mei 2009 tot gedeeltelijke omzetting van richtlijn (EU) 2018/2001 van het Europees Parlement en de Raad va	[
BE_2001_2018_20646_2022_2	BE	Country	2022	2	Région de Bruxelles-Capitale : 17 MARS 2022. - Ordonnance modifiant l'ordonnance du 19 juillet 2001 relative à l'organisation du marché de l'électricité en R	[
BE_2001_2018_33591_2022_2	BE	Country	2022	2	SERVICE PUBLIC DE WALLONIE – 5 MAI 2022. — Décret modifiant diverses dispositions en matière d'énergie dans le cadre de la transposition partielle des direc	[
HR_2001_2018_138_2021_2	HR	Country	2021	2	Zakon O Obnovljivim Izvorima Energije I Visokoučinkovitoj Kogeneraciji	N
CY_2001_2018_130_2021_2	CY	Country	2021	2	Ο Περί Ρύθμισης της Αγοράς Ηλεκτρισμού Νόμος του 2021	N
CY_2001_2018_106_2022_2	CY	Country	2022	2	Ο περί Προδιαγραφών, Κριτηρίων Αειφορίας και Μείωσης των Εκπομπών των Καυσίμων Νόμος του 2022.	N
CY_2001_2018_107_2022_2	CY	Country	2022	2	Ο περί Προώθησης και Ενθάρρυνσης της Χρήσης των Ανανεώσιμων Πηγών Ενέργειας Νόμος του 2022	N
CZ_2001_2018_382_2021_2	CZ	Country	2021	2	Zákon č. 382/2021 Sb., kterým se mění zákon č. 165/2012 Sb., o podporovaných zdrojích energie a o změně některých zákonů, ve znění pozdějších předpisů, a d	Z
CZ_2001_2018_107_2022_2	CZ	Country	2022	2	Nařízení vlády č. 107/2022 Sb., kterým se mění nařízení vlády č. 189/2018 Sb., o kritériích udržitelnosti biopaliv a snižování emisí skleníkových plynů z pohonn	N
CZ_2001_2018_110_2022_2	CZ	Country	2022	2	Vyhláška č. 110/2022 Sb., o stanovení druhů a parametrů podporovaných obnovitelných zdrojů a kritérií udržitelnosti a úspory emisí skleníkových plynů pro b	V
DK_2001_2018_883_2021_2	DK	Country	2021	2	Lov om ændring af lov om fremme af vedvarende energi, biobrændstofloven, lov om naturgasforsyning og forskellige andre love	L
DK_2001_2018_2167_2021_2	DK	Country	2021	2	Bekendtgørelse af lov om bæredygtige biobrændstoffer og om reduktion af drivhusgasser (biobrændstofloven)	L
DK_2001_2018_1944_2021_2	DK	Country	2021	2	Bekendtgørelse af lov om fjernkøling	L
DK_2001_2018_984_2021_2	DK	Country	2021	2	Bekendtgørelse af lov om elforsyning	L
EE_2001_2018_104_2022_2	EE	Country	2022	2	Energiamajanduse korralduse seaduse muutmise ja sellega seonduvalt teiste seaduste muutmise seadus	1
FI_2001_2018_423_2022_2	FI	Country	2022	2	Ilmastolaki	4
FI_2001_2018_418_2019_2	FI	Country	2019	2	Laki biopolttoöljyn käytön edistämisestä	4
FI_2001_2018_1145_2020_2	FI	Country	2020	2	Laki uusiutuvan energian tuotantolaitosten lupamenettelyistä ja eräistä muista hallinnollisista menettelyistä / Lag om tillståndsförfaranden och vissa andra	1
FI_2001_2018_6_2021_2	FI	Country	2021	2	Valtioneuvoston asetus biopolttoaineista, bionesteistä ja biomassapolttoaineista / Statsrådets förordning om biodrivmedel, flytande biobränslen och bioma	6
FI_2001_2018_1050_2021_2	FI	Country	2021	2	Laki energian alkuperätakuista	1
FI_2001_2018_1081_2021_2	FI	Country	2021	2	Valtioneuvoston asetus energian alkuperätakuista	1
FR_2001_2018_1147_2019_2	FR	Country	2019	2	LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat	L
FR_2001_2018_866_2020_2	FR	Country	2020	2	Ordonnance n° 2020-866 du 15 juillet 2020 portant diverses dispositions d'adaptation au droit de l'Union européenne dans le domaine de l'énergie et du clin	O
FR_2001_2018_235_2021_2	FR	Country	2021	2	Ordonnance n° 2021-235 du 3 mars 2021 portant transposition du volet durabilité des bioénergies de la directive (UE) 2018/2001 du Parlement européen et c	O
FR_2001_2018_236_2021_2	FR	Country	2021	2	Ordonnance n° 2021-236 du 3 mars 2021 portant transposition de diverses dispositions de la directive (UE) 2018/2001 du Parlement européen et du Conseil	O
DE_2001_2018_59_2021_2	DE	Country	2021	2	Gesetz zur Umsetzung von Vorgaben der Richtlinie (EU) 2018/2001 des Europäischen Parlaments und des Rates vom 11. Dezember 2018 zur Förderung der Nutz	N
DE_2001_2018_310_2021_2	DE	Country	2021	2	Verordnung zur Umsetzung der Vorgaben zu Fernwärme und Fernkälte in der Richtlinie (EU) 2018/2002 sowie in der Richtlinie (EU) 2018/2001	3
EL_2001_2018_4951_2022_2	EL	Country	2022	2	Εκσυγχρονισμός της αδειοδοτικής διαδικασίας Ανανεώσιμων Πηγών Ενέργειας Β' φάση, Αδειοδότηση παραγωγής και αποθήκευσης ηλεκτρικής ενέργειας, πλαίσι	N
HU_2001_2018_97_2021_2	HU	Country	2021	2	2021. évi LV. törvény egyes törvényeknek a megújuló energiaforrásokból előállított energia használatának előmozdításáról szóló irányelvvel összefüggő módo	9
IE_2001_2018_365_2020_2	IE	Country	2020	2	S.I. No. 365/2020 - European Union (Renewable Energy) Regulations 2020	S
IE_2001_2018_76_2022_2	IE	Country	2022	2	S.I. No. 76/2022 - European Union (Renewable Energy) Regulations 2022	S
IE_2001_2018_350_2022_2	IE	Country	2022	2	S.I. No. 350/2022 - European Union (Renewable Energy) Regulations (2) 2022	S

Policy reference	Overlapping	Instrument	Superordinate Law	Policy level	Mechanism	Type_Botta
Directive (EU) 2018/2001	EU_2001_2018_5	Binding targets	/	EU	Market-Based	Subsidy for environmentally-friendly activities
BGBl. I Nr. 150/2021	AT_944_2019_150_2021_2	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
LGBl. Nr. 73/2021	/	National Regulation	Directive (EU) 2018/2001	RE	Non-Market Based	Command-and-control
LGBl. Nr. 98/2021	/	National Regulation	Directive (EU) 2018/2001	RE	Non-Market Based	Command-and-control
LGBl. Nr. 190/2021	/	National Regulation	Directive (EU) 2018/2001	RE	Non-Market Based	Command-and-control
LGBl. Nr. 115/2021	/	National Regulation	Directive (EU) 2018/2001	RE	Non-Market Based	Command-and-control
LGBl. Nr. 14/2022	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
LGBl. Nr. 36/2022	/	National Regulation	Directive (EU) 2018/2001	RE	Non-Market Based	Command-and-control
[C – 2021/41519]	BE_944_2019_41519_2021_2	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
[C – 2022/20646]	/	National Regulation	Directive (EU) 2018/2001	RE	Market-Based	Subsidy for environmentally-friendly activities
[C – 2022/33591]	BE_944_2019_33591_2022_2	National Regulation	Directive (EU) 2018/2001	RE	Non-Market Based	Technology-support
NN 138/2021	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
N. 130(I)/2021	CY_944_2019_130_2021_2; CY_9	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
N. 106(I)/2022	CY_2001_2018_106_2022_5	National Regulation	Directive (EU) 2018/2002	CO	Non-Market Based	Command-and-control
N. 107(I)/2022	CY_2001_2018_107_2022_5	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
Zákon č. 382/2021 Sb.	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
Nařízení vlády č. 107/2022	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
Vyhláška č. 110/2022	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
LOV nr 883 af 12/05/2021	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
LBK nr 2167 af 29/11/2021	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Taxes and charges applied on input or output of a production pr
LBK No 1944 of 12/10/2021	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
LBK nr 984 af 12/05/2021	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
11.05.2022 otsus nr 104	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
423/2022	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
418/2019	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
1145/2020	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
6/2021	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Taxes and charges applied on input or output of a production pr
1050/2021	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
1081/2021	/	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
LOI n° 2019-1147	FR_2002_2018_1147_2019_2;FR	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
Ordonnance n° 2020-866	FR_2002_2018_866_2020_2; FR_	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
Ordonnance n° 2021-235	FR_2001_2018_235_2021_5	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Taxes and charges applied on input or output of a production pr
Ordonnance n° 2021-236	FR_944_2019_236_2021_2; FR_2	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
Nr. 59 vom 30.08.2021	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
310/2021	DE_2002_2018_310_2021_2; DE_	National Regulation	Directive (EU) 2018/2001	CO	Non-Market Based	Command-and-control
N. 4951/2022 (ΦΕΚ A 129 - 04.07.	EL_944_2019_4951_2022_2; EL_9	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
97. szám /2021	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
S.I. No. 365/2020	/	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
S.I. No. 76 of 2022	IE_944_2019_76_2022_2	National Regulation	Directive (EU) 2018/2001	CO	Market-Based	Subsidy for environmentally-friendly activities
S.I. No. 350/2022	IE_2001_2018_350_2022_5	National Regulation	Directive (EU) 2018/2002	CO	Market-Based	Subsidy for environmentally-friendly activities

Type_De_Serres	Type_Kruse	Type_An_Economic_Analyses_of_Biodiversity_Policy	Type_From_Farm_to_Fork: Sustainability_Goals_and_Policy_Instruments	Category	Perimeter of application
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Regulatory policy	Member states
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Active (green) technology-support policies	N/A	N/A	N/A	Regulatory policy	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Taxes and charges applied on input or output of a production proces	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Taxes and charges applied on input or output of a production proces	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Taxes and charges applied on input or output of a production proces	N/A	N/A	N/A	Regulatory policy	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Command-and-control	N/A	N/A	N/A	Regulatory policy	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry
Negative tax (or subsidy) for environmentally-friendly activities	N/A	N/A	N/A	Financial Incentives	Electricity industry

Perimeter of application	Technology	Created on	Expired on	Transposition Deadline	Adoption (days)	Adoption (year)	Late	Last amended	Indicator	Stringency	Notes
Member states	Renewable energy	11/12/2018		30/06/2021	EU Law	N/A	Late		32% of total energy from renewable sources withi	-	
Electricity industry	Renewable energy	27/07/2021		30/06/2021	27	0,073972603	Late		100% renewable energy share by 2030 (ENCP)	-	
Electricity industry	Electricity Market	13/12/2021		30/06/2021	166	0,454794521	Late		/	-	
Electricity industry	Electricity Market	15/12/2021		30/06/2021	168	0,460273973	Late		/	-	
Electricity industry	Electricity Market	21/12/2021		30/06/2021	174	0,476712329	Late		/	-	
Electricity industry	Electricity Market	22/12/2021		30/06/2021	175	0,479452055	Late		/	-	
Electricity industry	Electricity Market	22/02/2022		30/06/2021	237	0,649315068	Late		/	-	
Electricity industry	Electricity Market	19/04/2022		30/06/2021	293	0,802739726	Late		/	-	
Electricity industry	Renewable energy	02/04/2021		30/06/2021	-89	-0,243835616	Early		17,5% renewable energy share by 2030 (ENCP)	-	https://www.nationaalenergieklimaatplan.be/admin/stor
Electricity industry	Renewable energy	20/04/2022		30/06/2021	294	0,805479452	Late		/	-	
Electricity industry	Electricity Market	05/05/2022		30/06/2021	309	0,846575342	Late		/	-	
Electricity industry	Renewable energy	15/12/2021		30/06/2021	168	0,460273973	Late		36,6% renewable energy share by 2030 (ENCP)	-	
Electricity industry	Electricity Market	07/10/2021		30/06/2021	99	0,271232877	Late		/	-	articoli 2, 15, 17, 21, 22 e 24
Electricity industry	Fuel Emissions	15/07/2022		30/06/2021	380	1,04109589	Late		/	-	parziale allineamento con gli articoli 1, 2, 27 e 31 e allin
Electricity industry	Renewable energy	15/07/2022		30/06/2021	380	1,04109589	Late		23% renewable energy share by 2030 (ENCP)	-	https://energy.gov.cy/assets/entipo-iliko/%CE%95%CE%A
Electricity industry	Renewable energy	15/09/2021		30/06/2021	77	0,210958904	Late		22% renewable energy share by 2030 (ENCP)	-	https://www.climate-laws.org/documents/national-energ
Electricity industry	Fuel Emissions	06/04/2022		30/06/2021	280	0,767123288	Late		/	-	
Electricity industry	Renewable energy	29/04/2022		30/06/2021	303	0,830136986	Late		/	-	
Electricity industry	Renewable energy	12/05/2021		30/06/2021	-49	-0,134246575	Early		55% renewable energy share by 2030 (ENCP)	-	https://energy.ec.europa.eu/system/files/2020-01/dk_fin
Electricity industry	Fuel Emissions	29/11/2021		30/06/2021	152	0,416438356	Late		/	-	
Electricity industry	Renewable energy	12/10/2021		30/06/2021	104	0,284931507	Late		/	-	
Electricity industry	Electricity Market	12/05/2021		30/06/2021	-49	-0,134246575	Early		/	-	
Electricity industry	Renewable energy	11/05/2022		30/06/2021	315	0,863013699	Late		42% renewable energy share by 2030 (ENCP)	-	
Electricity industry	Renewable energy	10/06/2022		30/06/2021	345	0,945205479	Late		51% renewable energy share by 2030 (ENCP)	-	https://energy.ec.europa.eu/system/files/2020-01/fi_fina
Electricity industry	Fuel Emissions	29/03/2019		30/06/2021	-824	-2,257534247	Early		/	3,8	
Electricity industry	Renewable energy	17/12/2020		30/06/2021	-195	-0,534246575	Early		/	4,1	
Electricity industry	Fuel Emissions	14/01/2021		30/06/2021	-167	-0,457534247	Early		/	-	
Electricity industry	Electricity Market	03/12/2021		30/06/2021	156	0,42739726	Late		/	-	
Electricity industry	Electricity Market	09/12/2021		30/06/2021	162	0,443835616	Late		/	-	
Electricity industry	Renewable energy	08/11/2019		30/06/2021	-600	-1,643835616	Early		33% renewable energy share by 2030 (ENCP)	4,7	
Electricity industry	Renewable energy	15/07/2020		30/06/2021	-350	-0,95890411	Early		/	4,9	
Electricity industry	Renewable energy	03/03/2021		30/06/2021	-119	-0,326027397	Early		/	-	
Electricity industry	Renewable energy	03/03/2021		30/06/2021	-119	-0,326027397	Early		/	-	
Electricity industry	Renewable energy	31/08/2021		30/06/2021	62	0,169863014	Late		80% renewable energy share by 2030 (ENCP)	-	
Electricity industry	Heating / Cooling Systems	15/04/2021		30/06/2021	-76	-0,208219178	Early		/	-	
Electricity industry	Renewable energy	04/07/2022		30/06/2021	369	1,010958904	Late		31% renewable energy share by 2030 (ENCP)	-	https://energy.ec.europa.eu/system/files/2019-06/necp_f
Electricity industry	Renewable energy	01/07/2021		30/06/2021	1	0,002739726	Late		20% renewable energy share by 2030 (ENCP)	-	https://energy.ec.europa.eu/system/files/2019-03/ec_cou
Electricity industry	Renewable energy	25/09/2020		30/06/2021	-278	-0,761643836	Early		/	3,0	article 4 and 6
Electricity industry	Renewable energy	25/02/2022		30/06/2021	240	0,657534247	Late		/	-	article 21 and 22
Electricity industry	Renewable energy	15/07/2022		30/06/2021	380	1,04109589	Late		70% renewable energy share by 2030 (ENCP)	-	Articles 2, 3, 15(2), 16, 17, 18, 19, 23, 24, 25, 26, 27, 28, 2

Annex B

Dataset used to perform analysis from (1) to (3).

Year	Zone	Country	CountryName	Indicator	Value	EIS Perf
2016	EU	AT	Austria	1.1 Human resources	112,41	Strong
2016	EU	AT	Austria	1.1.1 New doctorate graduates	100,00	Strong
2016	EU	AT	Austria	1.1.2 Population with tertiary education (Regional)	105,99	Strong
2016	EU	AT	Austria	1.1.3 Population involved in lifelong learning (Regional)	141,76	Strong
2016	EU	AT	Austria	1.2 Attractive research systems	143,33	Strong
2016	EU	AT	Austria	1.2.1 International scientific co-publications (Regional)	186,34	Strong
2016	EU	AT	Austria	1.2.2 Scientific publications among the top 10% most cited (Regional)	111,86	Strong
2016	EU	AT	Austria	1.2.3 Foreign doctorate students as a % of all doctorate students	175,44	Strong
2016	EU	AT	Austria	1.3 Digitalisation	105,50	Strong
2016	EU	AT	Austria	1.3.1 Broadband penetration	81,42	Strong
2016	EU	AT	Austria	1.3.2 Individuals with above basic overall digital skills (Regional)	130,38	Strong
2016	EU	AT	Austria	2.1 Finance and support	121,56	Strong
2016	EU	AT	Austria	2.1.1 R&D expenditure in the public sector (Regional)	120,97	Strong
2016	EU	AT	Austria	2.1.2 Venture capital expenditures	74,04	Strong
2016	EU	AT	Austria	2.1.3 Direct and indirect government support of business R&D	172,54	Strong
2016	EU	AT	Austria	2.2 Firm investments	114,37	Strong
2016	EU	AT	Austria	2.2.1 R&D expenditure in the business sector (Regional)	165,39	Strong
2016	EU	AT	Austria	2.2.2 Non-R&D innovation expenditures (Regional)	75,24	Strong
2016	EU	AT	Austria	2.2.3 Innovation expenditures per person employed (Regional)	99,58	Strong
2016	EU	AT	Austria	2.3 Use of information technologies	139,00	Strong
2016	EU	AT	Austria	2.3.1 Enterprises providing ICT training	179,62	Strong
2016	EU	AT	Austria	2.3.2 Employed ICT specialists	100,00	Strong
2016	EU	AT	Austria	3.1 Innovators	158,73	Strong
2016	EU	AT	Austria	3.1.1 SMEs introducing product innovations (Regional)	137,33	Strong
2016	EU	AT	Austria	3.1.2 SMEs introducing business process innovations (Regional)	181,52	Strong
2016	EU	AT	Austria	3.2 Linkages	211,19	Strong
2016	EU	AT	Austria	3.2.1 Innovative SMEs collaborating with others (Regional)	235,86	Strong
2016	EU	AT	Austria	3.2.2 Public-private co-publications (Regional)	351,06	Strong

Annex C

Results of the F-tests and t-tests related to Analysis (3) are reported below.

F-Test Two-Sample for Variances
2016

	Slow Innovators	*Fast Innovators*
Mean	2,95833329	3,40555553
Variance	0,303369317	0,277983549
Observations	10	10
df	9	9
F	1,091321119	
P(F<=f) one-tail	0,449280293	
F Critical one-tail	3,178893104	

t_test: Two-Sample Assuming Unequal Variances
2016

	Slow Innovators	*Fast Innovators*
Mean	2,95833329	3,40555553
Variance	0,303369317	0,277983549
Observations	10	10
Total Variance	0,290676433	
Hypothesized Mean Difference	0	
df	18	
t Stat	-1,854827318	
P(T<=t) one-tail	0,040038267	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,080076534	
t Critical two-tail	2,10092204	

F-Test Two-Sample for Variances
2017

	Slow Innovators	*Fast Innovators*
Mean	2,9753086	3,450617244
Variance	0,374121167	0,346600619
Observations	9	9
df	8	8
F	1,079401326	
P(F<=f) one-tail	0,458296321	
F Critical one-tail	3,438101233	

t_test: Two-Sample Assuming Unequal Variances
2017

	Slow Innovators	*Fast Innovators*
Mean	2,94999997	3,39999996
Variance	0,338957416	0,333710534
Observations	10	10
Total Variance	0,336333975	
Hypothesized Mean Difference	0	
df	18	
t Stat	-1,735050566	
P(T<=t) one-tail	0,049910571	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,099821142	
t Critical two-tail	2,10092204	

F-Test Two-Sample for Variances
2018

	Slow Innovators	*Fast Innovators*
Mean	2,89999998	3,51944441
Variance	0,180418377	0,341400831
Observations	10	10
df	9	9
F	0,528464961	
P(F<=f) one-tail	0,17799667	
F Critical one-tail	0,314574906	

t_test: Two-Sample Assuming Unequal Variances
2018

	Slow Innovators	*Fast Innovators*
Mean	2,89999998	3,51944441
Variance	0,180418377	0,341400831
Observations	10	10
Total Variance	0,260909604	
Hypothesized Mean Difference	0	
df	18	
t Stat	-2,711704247	
P(T<=t) one-tail	0,007145882	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,014291765	
t Critical two-tail	2,10092204	

F-Test Two-Sample for Variances
2019

	Slow Innovators	*Fast Innovators*
Mean	2,97500001	3,56666669
Variance	0,179603928	0,351714668
Observations	10	10
df	9	9
F	0,510652367	
P(F<=f) one-tail	0,165575149	
F Critical one-tail	0,314574906	

t_test: Two-Sample Assuming Unequal Variances
2019

	Slow Innovators	*Fast Innovators*
Mean	2,97500001	3,56666669
Variance	0,179603928	0,351714668
Observations	10	10
Total Variance	0,265659298	
Hypothesized Mean Difference	0	
df	18	
t Stat	-2,566844765	
P(T<=t) one-tail	0,009701774	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,01940354 8	
t Critical two-tail	2,10092204	

Annex D

Variables included in the dataset.

Gross Domestic Product Per Capita, USD, current prices					
Country	*2016*	*2017*	*2018*	*2019*	*2020*
AT	52.665,09	54.188,36	56.956,11	59.719,61	57.258,82
BE	48.599,20	50.442,95	52.530,84	55.804,71	54.544,42
CZ	36.101,29	38.842,90	41.157,37	44.223,30	42.817,87
DE	50.579,48	53.071,48	55.195,72	57.411,52	56.454,18
DK	51.967,02	55.356,49	57.479,35	59.884,12	60.768,06
EE	31.310,15	33.867,80	36.488,64	39.068,37	39.460,61
EL	27.511,80	28.604,83	29.617,52	31.155,95	28.416,52
ES	37.333,06	39.601,48	40.776,77	43.135,74	38.039,43
FI	44.934,49	47.570,27	49.573,26	51.811,60	52.294,34
FR	42.855,94	44.444,93	46.336,93	50.226,68	47.829,94
HU	27.941,93	29.496,16	31.908,86	34.645,57	34.169,92
IE	71.505,75	78.252,21	85.034,73	89.759,24	94.646,64
IT	40.267,22	41.951,47	43.427,66	45.799,74	43.150,12
LU	112.955,47	114.862,53	116.334,72	119.364,15	119.407,90
NL	52.289,40	55.089,58	57.825,40	60.208,00	59.821,27
PL	27.830,93	29.609,45	31.662,21	34.592,87	34.896,82
PT	31.607,61	33.044,70	34.928,62	37.299,18	34.955,61
SE	50.430,25	51.947,96	53.521,64	56.404,30	56.140,55
SI	33.942,77	36.517,58	39.008,30	42.118,70	40.885,51
SK	29.737,53	30.147,02	31.374,19	33.458,81	32.911,92

Figure 35. Gross Domestic Product Per Capita - source: OECD.

Environmental Policy Stringency

Country	*2016*	*2017*	*2018*	*2019*	*2020*
AT	2,9444	2,9444	3,0833	3,1389	3,3056
BE	2,8889	2,9444	3,0000	3,2222	3,4444
CZ	2,7222	2,7222	2,8889	3,1111	2,9444
DE	3,0833	3,0278	3,2500	3,3056	3,4722
DK	3,9444	4,0278	3,7778	3,6667	3,7222
EE	3,7222	3,7778	3,3333	3,1667	3,2778
EL	2,8889	2,8611	2,8611	2,8333	2,8889
ES	2,2778	2,2778	2,4444	2,4444	2,5000
FI	3,8333	3,8333	3,9167	3,8056	4,1111
FR	3,9167	4,1667	4,5556	4,7222	4,8889
HU	2,6944	3,1111	2,6944	2,7500	2,8056
IE	2,5000	2,4444	2,5000	2,5556	3,0000
IT	4,0556	4,0556	3,7778	3,7500	3,7222
LU	3,9444	3,8889	3,9444	4,1667	4,2222
NL	3,3333	3,1111	3,5000	3,4722	3,4722
PL	2,8333	2,8889	3,0556	3,4167	3,4722
PT	2,3889	2,3889	2,3889	2,6667	2,7778
SE	3,6667	3,6111	3,6667	3,6111	3,8333
SI	2,9444	3,0000	3,0000	3,1667	3,2222
SK	3,0556	2,4167	2,5556	2,4444	2,5000

Figure 36. Environmental Policy Stringency Index - Source: OECD.

European Innovation Scoreboard

Country	*2016*	*2017*	*2018*	*2019*	*2020*
AT	123,5980	123,9610	122,9690	124,3120	124,0060
BE	122,3470	123,6880	125,9410	129,2600	127,5960
CZ	81,7450	81,7100	82,1080	83,2440	85,7320
DE	120,1560	120,4140	121,1150	121,6060	122,0680
DK	133,2510	134,5200	134,1570	137,7870	140,0580
EE	77,7160	78,8340	77,8440	96,4100	98,7800
EL	63,9820	64,7470	64,8850	72,1870	75,2060
ES	87,0810	88,1570	89,0200	90,4690	91,9430
FI	127,3180	125,6560	125,8310	133,0280	134,4200
FR	115,8410	115,5700	116,4340	114,2360	114,7090
HU	68,5680	68,4820	68,5190	66,9240	67,9600
IE	123,3160	123,8800	125,0960	123,2250	120,7840
IT	82,3680	83,5590	84,3960	89,8690	92,9400
LU	128,6790	128,7590	128,4660	129,7050	128,4450
NL	130,9570	132,3350	133,6600	137,1680	137,8120
PL	54,7900	56,4250	56,5370	58,8650	58,3420
PT	85,1510	85,0160	83,9120	93,7520	96,9660
SE	135,4860	137,6570	138,3360	138,1770	138,1900
SI	100,1670	98,0810	97,3750	92,4010	91,5260
SK	64,8120	66,0760	63,2280	65,9940	66,6900

Figure 37. European Innovation Scoreboard - Source: EIS Report.

Number of Policies

Country	*2016*	*2017*	*2018*	*2019*	*2020*
AT	0	0	0	4	5
BE	1	3	2	3	6
CZ	2	3	1	2	4
DE	0	1	0	2	3
DK	3	0	0	2	10
EE	4	1	3	1	5
EL	0	2	0	3	2
ES	0	1	0	7	8
FI	1	1	4	4	3
FR	1	2	0	8	8
HU	0	0	0	1	1
IE	0	0	0	1	7
IT	1	2	0	3	4
LU	0	2	1	1	1
NL	1	0	1	3	6
PL	1	0	0	4	2
PT	0	1	0	4	7
SE	1	0	2	1	9
SI	0	2	1	0	2
SK	2	2	2	6	2

Figure 38. Number of Policies - Source: Created Database.