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Don’t look up but look at what we have done:

A worldwide story of environmental regulation

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Abstract

With climate change and the collapse of ecosystems, environmental issues are becoming critical to modern societies. In response, policymakers around the world are introducing a growing number of environmental legislations that disrupt the environment-socioeconomic nexus. Identifying environmental policy instruments implemented worldwide and quantifying their stringency would allow for significant new developments in the evaluation of such policies. The existing literature offers databases covering a limited number of countries, years, and environmental aspects. This research bridges this gap by introducing the original comparative Multi-dimensional Environmental Legislation Stringency Index (MELSI). Available for 197 countries, from 1950 to 2020, the MELSI is a composite index that incorporates a large variety of environment dimensions such as terrestrial and marine ecosystems protection, air quality, agriculture, land use, and forest, freshwater and waste management. For each environmental dimension, numerous environmental policies and policy instruments have been tracked and scored in order to build a stringency index. This original dataset provides comprehensive new insights on environmental policies, strongly relevant for future environmental policy evaluations and recommendations.

Keywords: MELSI, Environmental policies, Environmental regulation, Environmental legislation, Environmental policy stringency, Composite indicators, Text mining, Natural Language Processing (NLP), Latent Dirichlet Allocation (LDA) model

JEL classification: K32, Q18, Q28, Q38, Q48, Q58

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Contents

1. Introduction

With the growing climate imbalances and the collapse of ecosystems now observable at the local and global scales, environmental issues are becoming increasingly prominent in modern societies. In response, policymakers around the world are introducing a growing number of environmental policies that disrupt the environment-socioeconomic nexus. Every year, 3000 to 5000 new legislations, treaties and environmental plans are published by government officials around the world. These legal documents detail the ambitions and objectives of the policy, alongside the institutions powers and responsibilities, and the policy instruments implemented.

Since the 2000s, a growing body of economic literature has focused on quantifying the stringency of environmental policies. Environmental policies across the world have often been compiled by surveying governments or large firms (Dasgupta et al., 2001; Eliste and Fredriksson, 2002; Esty and Porter, 2005; Steves and Teytelboym, 2013). Depending on the index, the stringency score of an environmental policy is built upon a variety of subjective ex-post criteria, that differs according to the study and the survey method. The latest and original OECD's Environmental Policy Stringency Index (EPSI) tracks and scores 13 climate mitigation policy instruments for 40 countries through the period 1990-2020 (Botta and Koźluk, 2014; Kruse et al., 2022). EPSI's introduction enabled the development of more in-depth macro-empirical analyses of climate policies by introducing a time varying dimension. Using the EPSI, de Angelis et al. (2019) show that an increase in climate policy stringency decreases growth's environmental damage. Still relying the EPSI, the literature highlights that environmental policies have a positive impact on R&D, innovation (especially green innovation) and efficiency (Martínez-Zarzoso et al., 2019; Wang and Su, 2020).

Recently, new initiatives have been launched to collect and classify all the environmental legal documents produced around the world. The Grantham Research Institute and GLOBE International have collected and classified all climate change-related laws and policies (Averchenkova et al., 2017; Nachmany and Setzer, 2018). Also, the FAO, IUCN and UNEP collect all international soft-law and other non-binding policy and technical guidance documents, national legislation, judicial decisions, and law on the issues of agriculture, the environment and natural resources[1]. Built upon these corpora, new researches in political science and economics studies countries' climate governance and targets (Dubash et al., 2021; Guy et al., 2023) and uses the number of new climate legislation to assess the impact of climate legislation on pollution (Eskander and Fankhauser, 2020; Hargrove et al., 2019; Stef and Ben Jabeur, 2020).

This literature attempts to meet a growing need to monitor, compare and evaluate environmental policies across countries. It also assists policymakers in coordinating and strengthening countries' policy action by helping future research benchmarking environmental policies outcomes and costs (environmental, economic and social). However, despite the growing number of comparative countries' environmental policy indexes and databases, the literature still lacks a comprehensive time-varying index, that incorporates multiple environmental aspects,

[1] The Grantham Research Institute and GLOBE International built the *Climate Change Laws of the World database*, while UN's FAO, IUCN and UNEP created the FAOLEX database.

policy instruments and countries. The environmental policy stringency approach embodies diverse environmental aspects but are limited by the number of available countries and policy instruments. In the meantime, the environmental legislation approach provide a extensive number of countries and a wider time-span. However, the use of the number of environmental legislation as a proxy of the policy stringency might be biased in measuring the quality of the policy stringency. Finally, the whole literature and the overlying researches strongly focuses on air pollution and energy regulating instruments, associated with climate change, but miss other aspects of environmental policy.

This research endeavors to bridge this gap by combining the qualities of both literatures while introducing the original comparative Multi-dimensional Environmental Legislation Stringency Index (MELSI). Rather than relying on surveys, the MELSI is built upon the environmental legislations gathered by the World Bank agencies. This approach allows to substantially expand the number of country, the environmental dimensions and the time span considered. Therefore, the MELSI is available for 197 countries, from 1950 to 2020. Since the legislations address a large variety of environmental aspects (terrestrial and marine ecosystems protection, agriculture, air and water pollution, land use, and forest, freshwater and waste management...), this research uses data driven machine learning methods to distinguish environmental dimensions in the database, mainly to avoid subjective ex-post classification. This method allows to build a composite index incorporating five distinct environmental dimensions. Beyond counting the number of legislation, the MELSI directly exploits the legislations' text content to monitor a large variety of environmental policy instruments in order to assess the quality of the stringency. The policy instruments are classified into 4 groups depending on their approach and scored according to the strength of the policy incentive. Built upon each country's legal documents, this index provides a *de-jure* proxy of each country's environmental policy stringency for each environmental aspect and dimension since 1950. As a result, the MELSI shows a surge in environmental regulation, since 1990, in Europe and the western hemisphere. However, for the vast majority of countries, environmental regulation has exhibited limited progression in the last 30 years. Hence, this database, with its new insights, is essential for our understanding of environmental policies, and is strongly relevant for future environmental policy evaluations and recommendations.

This research introduces several methodological contributions. First, by proposing a data-driven machine learning method, classifying environmental legislation into topic-oriented groups. Secondly, by directly exploiting the environmental legislations text content. And finally, by combining original lexicons and text mining techniques in order to score environmental policies. The contribution also extends to the collection and harmonization of a corpus of over 60,000 environmental legislations, discussing environmental governance, policies and regulations, plus the creation of two lexicons listing environmental policies and policy instruments, built upon scientific and institutional reports. Finally, this research mainly contributes to literature with an original comparative multi-dimensional index of environmental policy stringency, substantially expanding coverage of countries, environmental aspects, and time span.

The rest of the paper is structured as follows. Section 2. provides an overview of the existing cross-country measures of environmental policy stringency. Section 3. details the approach used to assemble a collection of environment oriented legislation (Section 3.1) and the text mining methods used to identify environmental policy instruments and quantify the stringency of each legislation (Section 3.2). Section 4. presents the data, summary statistics and correlation analyses with similar indexes. The last Section offers some concluding remarks.

2. Literature review

The literature offers a growing diversity of internationally-comparable indicators that quantify the stringency of environmental policy. The main features that distinguishes these indices are the economic and environmental dimensions included in the indices, the structure of the index and the scoring method used to capture the stringency.

Most attempts rely on reported information from country officials or firms with international organizations for economic or climate summits. Building on these surveys, the literature attempts to create a stringency score associated with each environmental policy implemented across countries. Dasgupta et al. (2001) exploit 31 reports submitted by governments to the UNCED in 1990. They detail the policies implemented in four major environmental domains (air, water, land and living resources) and five economic sectors and activities (agriculture, industry, energy, transport and urban). For each domain and sector, the survey seeks comprehensive information on the environmental institutions, the regulations and monitoring mechanisms enacted[2]. Dasgupta's index was later partially extended by Eliste and Fredriksson (2002) for agriculture and 31 additional countries. A narrower but similar survey-based index was introduced by Steves and Teytelboym (2013) with the Climate Laws, Institutions, and Measures Index (CLIM Index). The approach relies on 95 government communications to the UNFCCC, accounting for every mitigation policy adopted up to 2011. This indicator combines several aspects such as international cooperation in environmental legislation, national regulation measures on polluting sectors (energy, transport, construction, agriculture, forestry and industry) and the existence of control institutions and long-term objectives in terms of pollution. From the surveys, Dasgupta et al. (2001) and Steves and Teytelboym (2013) attempt to identify and score environmental policies and their stringency. Both indexes, built by scoring governments' officials assertions in the surveys, may present a strong self-reporting bias. The CLIM index partially addresses the bias by cross-checking with several existing databases. Esty and Porter (2005) develop the Environmental Regulatory Regime Index (ERRI), built upon firm-level surveys gathered for the World Competitiveness Reports of the World Economic Forum (WEF). This index proposes the widest approach to environmental policy stringency, gauging multiple types of policy actions regrouped into six composite sub-indexes, covering 70 countries for the year 2000[3]. The use of firm's leaders survey allows to control for the

[2]The UNCED survey consists in 25 questions examining the development of institutions, the number of laws, the nature of the regulations (command and control or market-based), and the explicit objectives of the regulation. The quality of the monitoring is also present with questions on the budget allocated to monitoring agencies, and the degree of inclusion of local and non-governmental organizations in the monitoring and policy-making process. Hence, the index includes aspects regarding environmental awareness and the degree of success.

[3]Similarly to the previous indicators, they create sub-indexes measuring environmental stringency along several dimensions or sectors (air, water, toxic products and discharges), quantifying several aspects of the quality of the environmental institutions, the level of enforcement and international cooperation. This indicator provides new information by creating sub-indexes gauging the government's informational support to transitioning firms and the level of sophistication of the environmental regulatory structure.

self reporting bias. However, Brunel and Levinson (2013) highlight that the ERRI may suffer from a strong bias since a firm leaders opinion may be strongly influenced by economic factors such as the business cycles (as it is the case for social and economic reforms).

These indicators allow for a comprehensive international comparison of the levels of environmental regulation but they are limited when it studies the impact of these regulations on the economic dynamics and environmental performance of countries. The literature highlights that the absence of the time dimension prevents analyzes from correctly and definitively identifying the direction of the causalities (Botta and Koźluk, 2014; Brunel and Levinson, 2013; Dasgupta et al., 2001; Esty and Porter, 2005). This endogeneity issue has led to an emphasis on identifying the determinants of environmental stringency rather than its effects on economic and environmental performance (Eliste and Fredriksson, 2002; Steves and Teytelboym, 2013).

Recently, the OECD developed a non survey-based method to measure environmental policy stringency. OECD's Environmental Policy Stringency index (EPSI) (Botta and Koźluk, 2014; Kruse et al., 2022) introduces a composite index that monitors 13 identified climate-mitigation policy instruments for 40 countries over the period 1990-2020[4]. It differs from the preceding indicators by providing a cross-country, time-varying index and by directly scoring the policy instruments rather than a global policy. This approach allows to exclude the public and private stakeholders' perception of environmental policy issue, but also enables to take into account only policy instruments that are *de facto* implemented. This method grants a high degree of transparency, however, it might not be easily feasible for monitoring a wider range of policy instruments. Although Botta and Koźluk (2014) provide an index that evolves over time, its coverage in terms of countries and environmental policy dimensions or instruments is limited.

Many important areas of environmental policy such as biodiversity, agriculture and waste management, which are included in the early literature, still lacks of a proper time-varying index. Thus, to date, the selection of an index suppose to choose between a large country-time coverage or a wide range of environmental policy dimension. Second, the literature has not yet clearly distinguished the different dimensions of environmental policy. Indeed, the first generation of index composed their dimensions relying on the surveys they are built upon. The structure of surveys also determines the structure of the index within dimension (like awareness or effectiveness).

The latest researches focus on monitoring a set of environmental policy instrument selected *ex ante*. Finally, the instrument or policy specific thresholds used to build the stringency scores, is instrument specific, and are constructed *ad-hoc*. Therefore, this absence of methodological convergence brings strong limitations to cross-index comparison (see Dubash et al. (2013) for an overview on the early indexes completed with Steves and Teytelboym (2013) and Botta and Koźluk (2014)).

[4]It offers a robust composite index oriented toward air polluting sectors such as energy, transport, and industry. The EPSI monitors market-based instruments like taxes on GHG emissions or feed-in tariffs for several renewables, and rule-based instruments such as deposit and refund schemes or emission limit values

Table 1: *Existing cross-country measures of environmental policy stringency and contribution*

Index	Article	Period	Countries	Dimensions	Data source	Instrument classification	Scoring method
Environmental Regulatory Regime Index (ERRI)	Esty and Porter (2005)	2000	70	5 environmental dimensions (air, water, toxic products and discharges)	WCR		Discretionary rule-base rating of policymakers' level of commitment.
Dasgupta index	Dasgupta et al. (2001)	2001	40	20 dimensions: 4 environmental dimensions (air, water, land and living resources) * 5 economic dimensions (agriculture, industry, energy, transport and urban)	UNCED		Discretionary rule-based rating of qualitative information on the environmental policy implemented. Score form 0 to 2 for every 25 questions in each domain and sector.
Dasgupta index (*extension*)	Eliste and Fredriksson (2002)	2001	71	4 dimensions: 4 environmental dimensions (air, water, land and living resources) * 1 economic dimension (agriculture)	UNCED		Same as Dasgupta et al. (2001)
Climate Laws, Institutions, and Measures Index (CLIMI)	Steves and Teytelboym (2013)	2011	95	5 economic sectors relevent to air pollution (energy, transport, construction, agriculture, forestry and industry)	UNFCCC		2 step process: selection, *ex-ante* of 12 policy instruments, then discretionary rule-base rating of qualitative information on the environmental policy instruments implemented. Score form 0 to 2, depending on the level of engagement and regulation.
Environmental Policy Stringency Index (EPSI)	Botta and Koźluk (2014)	1990-2012	33	5 economic sectors relevent to air pollution (energy, transport, construction, agriculture, forestry and industry)		Market based, Command-and-control	2 step process: selection, *ex-ante* of 15 market and non-market instruments. Then discretionary rule-based rating built according to the instrument's characteristics. Score form 0 to 6, depending on the level of stringency of the regulation.
Environmental Policy Stringency Index (EPSI) - *the 2022 update*	Kruse et al. (2022)	1990-2020	40	5 economic sectors relevent to air pollution (energy, transport, construction, agriculture, forestry and industry)		Market based, Command-and-control	2 step process: selection, *ex-ante* of 15 market and non-market instruments. Then discretionary rule-based rating built according to the instrument's characteristics. Score form 0 to 6, depending on the level of stringency of the regulation.
Multi-dimensional Environmental Legislation Stringency Index (MELSI)	*this research*	1950-2020	197	7 environmental dimensions (agriculture, ecosystem management, energy and air pollution, forest management, freshwater management, land and sea, and waste management)	FAOLEX	Enconomic instruments, regulatory approach, government provision, Voluntary actions and Information programs	2 step process to indentify environmental policies and policy instruments in the legislations. Scoring based on the incentives given by each type of policy instrument implemented

3. Methodology

A rather small range of sources has been used to retrieve country's information about environmental regulation. As seen in the literature review, most researches built their index on surveys form policymakers or firms. This section introduces a new information resource provided by the UN and discusses the selection process to build an alternative source of information about environmental regulation. Figure A.1, in appendix, outlines the full structure of the methodology used in this section.

3.1 The database building method

3.1.1 Extraction of the Environmental Legislations

The FAOLEX database is a joint initiative of UN's programs' IUCN, FAO and UNEP, that gather every climate, agricultural and environment related legal documents since 1789 for more than 200 countries/territories. Available in open access on the FAO's website[5] or on the Ecolex web-interface, the database includes various classes of documents, such as international treaties, constitutional laws, national and supra-national legislation, and regulations (see Table A.1 in the Appendix). To expend on a wide range of dimensions, it merges six different datasets: Agriculture dataset, Food and Nutrition dataset, Land and Water dataset, Environment and Ecosystems dataset, Policies dataset and Constitutions dataset. The database was collected on FAO's website, cross-checked and completed using ECOLEX's website[6]. To my knowledge, it is the largest and most complete database listing the climate, agricultural and environment related legal documents (over 190 000 documents to date). More than just listing legislations, the database provides, for each legislation, information on its exact publication day, the title of the legislation, the country/region that issued the legislation, the abstract associated, the language of the document, the corresponding domain(s) and keywords associated with the legislation and finally, the url-link to directly access the legal documents from the FAO's or Ecolex servers.

Although the database offers a large variety of text types, I rule out international treaties, focusing on the legislation group. Indeed, international treaties are multilateral agreements established between countries/regions with heterogeneous economic and political characteristics. Legislations corresponds to legal documents that have been formally adopted by a law-making system and enforced at a national or regional level. Therefore, legislation are providing more country-time specific information on the environmental legal protections. In addition, they have been extensively used in the economic literature to study fiscal policy rules. In the recent literature, the study of legislation has been extended to the various structural regulations, to assess their impact on growth (Ash et al., 2022; Coffey et al., 2016). By narrowing down the sample to one common type of document, I can create a internationally-comparable environmental stringency index based only on legislations. Nevertheless, I still acknowledge that laws may have diverse functions across countries, depending on the constitution, political regime, law culture and governance mode. A time span from 1950 to 2020 was also selected on a relatively large

[5] FAO. FAOLEX Database. License: CC BY-NC-SA 3.0 IGO. Extracted from: www.fao.org/faolex/opendata.

[6] Web-scraping techniques have been used on ECOLEX's website in order to recreate the FAOLEX database since 1950. Combining ECOLEX's and FAO's datasets was the most efficient approach to build the FAOLEX legislation dataset for the last 70 years.

period, which covers modern growth regimes as well as the emerging scientific consensus on environmental issues. This period, in addition to representing a wide temporal extent recommended to study the climate related phenomena, corresponds strictly to the "Great Acceleration" emphasized by Steffen et al. (2015).

The database proposes a classification of legal documents according to two flexibility levels. First, a relatively general classification by domain of application. The domains are fixed and are 16 in total[7]. They cover all dimensions of agriculture, environment and renewable and non-renewable resources. A legal document can appear in multiple domains. Among the legislation documents, only 25% of them appear in more than one domain and 5% in more than two domains. The domains provide a general overview of the topics covered in the legal documents. Second, a more flexible and comprehensive view of the features and objectives of the legislation is provided using keywords. The complete lexicon contains 440 keywords and is regularly updated[8]. Typically, keywords such as "*Covid-19*" have been added to the lexicon recently. Each keyword in the database has been defined by the UN programs and is also available on the FAOLEX's website for further understanding. With an average of 6.4 keywords per document (and a variance of 4.8), there are thus considerably more keywords per legal document compared to the first approach relying on domains. The keywords give comprehensive information about the topics discussed in the legislations. Some keywords relates to the area targeted by the reform, such as the animal and vegetables species, the pollutant, the ecosystem or the resource. There are also many indications on the type of public action taken, whether it is a tax, use-right, standards, monitoring, or a subsidy or promotion of practices.

In consideration of relevance, cost and efficiency, I filtered the database to extract only legislation dealing directly with environmental legislations. The selection methods was carried out based on FAOLEX keywords associated with each legislation. It ensures a broader capture of the diversity of environmental policies throughout topics, time and countries. From the lexicon provided by FAOLEX and the definition of each terms, I manually selected two groups of keywords. The first gathers 96 keywords associated with the improvement/deterioration of the environmental quality or with economic activities highly relevant to the environment. The second lists all 93 keywords related to public action in terms of regulation, subsidy, monitoring or guidance, tax authorization and environmental institutions. Table A.2 provides the complete lists of the selected keywords. The environmental legislation subset was obtained by filtering the FAOLEX legislation by both lists of keywords. Therefore, all legislation retained in the subset must have at least one keyword in each of the two lists.

As a result, I obtain an environment legislation-oriented database gathering 69 000 legislations, that is 40% of the total number of publications, built upon 189 keywords that represent 43% of the total number of keywords. I recognize that all legislation in the database can potentially hold information on environmental regulations in force, or that non-environmental regulations can impact the environment. As defined, the database does not rule out every legislation from non-environmental domains and still allows for a large variety of keywords to remain.

[7]Agriculture, Fisheries, Forestry, Cultivated plants, Livestock, Environment, Wild species & ecosystems, Waste & hazardous substances, Air & atmosphere, Food & nutrition, Water, Land & soil, Energy, Mineral resources, Sea, and General

[8]Find the complete list of keywords and their definition provided by the UN here: https://www.fao.org/faolex/glossary/en/

Table 2 shows the number of legislations per domain for the FAOLEX database and for the selected sample of environmental legislation (Environmental Legislations subset). The FAOLEX database confirms its strong focus on food and agriculture with the *Livestock*, *Food & Nutrition*, *Fisheries* and *Cultivated plants* domains registering more than 20 000 legislations. Domains such as *Environment*, *Land & soil*, *Water* and *Wild species and Ecosystem* appear as a secondary concern in comparison with 16 000 to 20 000 legislations.

Table 2: *Number of environmental legislations per domain - databases comparison*

FAOLEX dataset	FAOLEX Domain	FAOLEX database	Environmental legislations subset (filtered using keywords lists)	Share kept (in %)
Agriculture	Fisheries	23094	9375	40.59
	Forestry	10597	6936	65.45
	Cultivated plants	20360	6006	29.50
	Agriculture	17565	4204	23.93
	Livestock	22801	3166	13.89
Environment and Ecosystems	Environment	20152	12881	63.92
	Wild species & ecosystems	16775	11446	68.23
	Waste & hazardous substances	9531	8672	90.99
	Air & atmosphere	4848	4337	89.46
Food & nutrition	Food & nutrition	30540	3895	12.75
Land and Water	Water	18209	14204	78.01
	Land & soil	16891	4739	28.06
Other	Energy	8737	6554	75.01
	Mineral resources	5439	4361	80.18
	Sea	6712	3276	48.81
	General	3222	1105	34.30

Note: This table presents the number of legislations in each domain for the FAOLEX database and the Environmental Legislation dataset. It also shows the underlying datasets merged to build the FAOLEX database. The last column displays, for each domain, the share of legislation kept in the Environmental Legislation (EL) dataset. Source: author's calculations.

The environmental legislation dataset refocuses the dataset on topics strongly associated with the environment such as limited resources and ecosystems management, energy production and pollution. *Water*, *Environment*, *Wild species and Ecosystem*, *Waste*, *Forestry* and *Energy* now appear in the most commonly cited domains alongside *Fisheries*. It is noticeable that although the areas of agriculture and nutrition are no longer central, the new database retains 12-30% of the legislation in these domains. At the opposite, only 80-90% of legislations in the domains strongly involving the environment have been incorporated. This might be due to the lack of regulatory or monitoring aspects for some legislation. This is especially the case for the *Environment* and *Wild species and Ecosystem* domains, which are broad domains. Therefore, general and framework legislations might represent an even larger proportion of the overall legislation (30-35%).

3.1.2 Classification method

As highlighted by Brunel and Levinson (2013), the existing literature tackling environmental issues at the macroeconomic level, whether on environmental performance/limits (Hsu and Zomer, 2014; Rockström et al., 2009; Stiglitz et al., 2009) or quantifying environmental policies (Botta and Koźluk, 2014; Brunel and Levinson, 2013; Dasgupta et al., 2001; Esty and Porter, 2005), builds composite indexes to deal with the multidimensionallity of the environment. Although Environmental Legislation subset have been set to provide a strong environmental focus, the wordclouds and network plot performed on its keywords show a great diversity of themes addressed in the selected sample (Figure A.2 & Figure A.3). In line with this literature and this observation, this section first introduces the machine learning method used to regroup legislation into topics.

After considering FAOLEX's domain-based solutions to classify legislations, the classification was performed using a classification machine learning algorithm. FAOLEX's domains, available in the environmental legislation subset, allows legislation to belong to several domains preventing them to be attached to a specific dimension. Moreover, the *Environment* is in itself a domain untied to a specific area of the environment, that can not be ruled out without removing legislations. Built on this premise, I rely on the Latent Dirichlet Allocation (LDA) model to classify legislation into themes. The LDA model is one of the major topic models and has been extensively used for text mining purposes. It was introduced recently in economics to forecast asset prices and political and socio-economic indicators (Azqueta-Gavaldón, 2017; Chakraborty et al., 2016; Dyer et al., 2017). The corpora examined using LDA in the literature are mainly corpora from newspapers or social media contents. Some applications have also been performed on company or institutional reports. Ash et al. (2022) recently provided the first application of a LDA model on U.S. state session laws' text contents.

Developed by Blei et al. (2003), the LDA model is an unsupervised machine learning model that relies on the hidden structures in the text contents of corpses. In this approach, each legislation is seen as a bag-of-words and a combination of topics. Each topic has a probability to be found in a document, and each keywords has a probability to be in a specific topic. Then, it uses a generative probabilistic approach to infer the distribution of keywords that defines a topic, and simultaneously assigning a distribution of topics to each legislation. Since it is unsupervised, the algorithm automatically regroups documents according to their statistical similarities. Only the number of topics are defined ex-ante, the nature of the topics are interpreted ex-post. Applying an LDA model on keywords allows to produce a strict classification of documents into topics while admitting, by construction, that the topics of the environment are strongly linked and a keyword may belong to multiple topics. The algorithm was performed on all keywords associated with the EL dataset. The extreme values, defined here as keywords appearing in less than 100 legislations and in more than 10% of the legislations, were removed. The selection of the optimal model is based on the measures of perplexity and the quality of the interpretation of the topics. Perplexity, in the context of Natural Language Processing (NLP), is a held-out likelihood test measuring the quality of prediction of the probabilistic model for a given sample. I favor the perplexity over other statistical method to choose the number of latent topics since it almost systematically outperforms other methods.

According to the perplexity measure (Figure A.4), the model obtains its best performances for 9, then 12 and 20 topics. This measure seems consistent with the observations made on the network plot (Figure A.3). The topics are also readable and easily separable for each of the three best performing models. However, the model with 12 topics seems to give a better reading of the environment components. Indeed, 9 topics appear to be too few as air and water pollution are not separated. On the other hand, the 20-topic model provides a large number, and yet excessively thin topics. Table 3 introduces the topics identified by the 12 topics-model. The topics are numbered from 1 to 12 by the LDA algorithm. Based on the interpretation of each topic's 20 most relevant keywords, the topics have been manually named and grouped into dimensions according to the issues addressed[9].

[9]The visualizations of each of the three models output can be provided upon request. The topic number is the number associated with each topic in the model visualization plot.

Table 3: *Dimensions and topics identified in the 12-topics LDA model*

Dimension	Topic title	Topic number	20 most relevant keywords of the topic
Ecosystem management	Ecosystems	5	protected area, ecosystem conservation, biodiversity, management/conservation, protection of habitats, wild flora, wild fauna, protection of species, tourism, national parks, wetlands, research, cultural heritage, education, biosphere reserves, zoning, monitoring, policy/planning, endangered species, marine protected areas
	Fishing	3	marine fisheries, fishing gear/fishing method, inland fisheries, fishing authorization, fishing area, marine fishes, fishing vessel, seasons, aquaculture, foreign fishing, non-commercial fishing, freshwater fishes, enforcement/compliance, allocation/quota, crustaceans, artisanal fisheries, size, protected fishing area, total allowable catch, bycatch
	Hunting	12	hunting/capture, protection of species, wild fauna, hunting authorization/permit, endangered species, birds, hunting gear/hunting methods, management/conservation, wildlife products, ranching/captive breeding, international trade, seasons, game, hunting rights, enforcement/compliance, hunting authorization/permit fee, dangerous animal/harmful animal, captive wild animals, registration, basic legislation
	Oceans and coasts	10	environmental impact assessment, marine pollution, liability/compensation, navigation, environmental planning, oil pollution, freshwater quality/freshwater pollution, international agreement-implementation, environmental audit, harbour, enforcement/compliance, ecosystem conservation, environmental fees/charges, coastal zone management, polluter pays principle, maritime zone, hazardous substances, environmental standards, inland waters, sustainable development
Energy and air pollution	Air pollution	9	air quality/air pollution, data collection/reporting, monitoring, emissions, environmental standards, access-to-information, climate change, ozone layer, hazardous substances, noise pollution, enforcement/compliance, environmental planning, international agreement-implementation, registration, ecofriendly products/ecofriendly processes, international agreement-text, ratification, environmental security, basic legislation, certification
	Energy sector	6	energy conservation/energy production, mining, transport/storage, royalties/fees, oil, exploration, internal trade, minerals, renewable energy, natural gas, concession, non-governmental entity, contracts, subsidy/incentive, environmental standards, enforcement/compliance, policy/planning, registration, taxes, hydropower generation
Freshwater management	Freshwater management	1	freshwater quality/freshwater pollution, water supply, effluent waste water/discharge, waterworks, potable water, water resources management, water quality standards, groundwater, surface water, sewerage, water abstraction, inland waters, irrigation, basin/catchment/watershed, water conservation zone, water rights, public water, policy/planning, water charges, monitoring
Land use (AFOLU)	Agricultural management	4	disasters, agricultural development, sustainable development, subsidy/incentive, governance, policy/planning, sustainable use, special fund, public health, risk assessment/management, local government, early warning system/emergency intervention system, procedural matters, financing, research, financial agricultural measures, protection of environment, public participation, business/industry/corporations, food security
	Forest management	7	forest management/forest conservation, timber extraction/logging, afforestation/reforestation, forestry protection measures, planting material/seeds, plant variety, timber, plant production, public forest, forest fires, forest species, non-wood forest products, protection forest, forest service, classification/declassification, private forest, registration, policy/planning, agro-forestry, contracts
	Land and soil	11	soil conservation/soil improvement, soil pollution/quality, land-use planning, agricultural land, soil rehabilitation, land tenure, erosion, public land, urban land, environmental planning, expropriation, fertilizers/nutrients, farming, ownership, drainage/land reclamation, pastoralism, basic legislation, survey/mapping, grazing, cadastre/land registration
Substance management	Chemicals and products management	2	pesticides, international trade, internal trade, food safety and quality, standards, plant protection, packaging/labelling, certification, hygiene/sanitary procedures, registration, animal health, transport/storage, pests/diseases, plant production, GMO, biotechnology, hazardous substances, animal production, animal feed/feedstuffs, processing/handling
	Waste and hazardous substances	8	waste management, waste disposal, hazardous waste, hazardous substances, waste non-domestic sources, recycling/reuse, transport/storage, waste domestic sources, waste prevention, solid waste, radiation, organic waste, nuclear energy, classification/declassification, enforcement/compliance, packaging/labelling, registration, international trade, transboundary movement of waste, environmental fees/charges

Note: The second best model integrates 12 topics presented in the following table. The topics are numbered from 1 to 12 by the LDA algorithm. Based on the interpretation of the 20 most relevant keywords, the topics have been manually named and grouped into dimensions according to the issues addressed. The proposed dimensional classification is consistent with the classification introduced in international reports of institutions and groups of scientists.

Some indexes already investigate several of these areas using cross sectional data. For instance, Steves and Teytelboym (2013) measured environmental policy stringency for *Agriculture*, *Energy* and *Forestry*. Also, Esty and Porter (2005) cover *air pollution*, *water pollution* and *waste management*. This research therefore contributes to the literature by proposing a widened and time-varying indicator for each dimension. This research also brings new dimensions to the examination of environmental policy by incorporating *water management* and *ecosystem management*.

The topics have been grouped according to 5 internationally agreed environmental objectives and challenges presented in the Sustainable Development Goals (SDG)[10]. The first is to limit the temperature increase to less than 2°C above pre-industrial levels, reduce anthropogenic climate change and reduce the air pollution. *Air pollution* and the *Energy sector*, central topics of climate change, are integrated in the indicator in the same dimension. Indeed, the energy sector is the main contributor of greenhouse gas emissions, the regulation of the energy sector mainly modifies the energy mix of countries and thus affects first air quality. The second implies the reduction of desertification, soil erosion and deforestation (area refereed as AFOLU[11] in the UNEP and IPCC reports). *Agricultural management*, *Forest management*, and *Land and soil* are therefore assembled in the same environmental dimension. The third involves reducing the pressure on biodiversity and the promotion of conservation. This dimension combines the protection of natural area alongside the protection of wild life, thus regrouping *Ecosystems*, *Fishing*, *Hunting* and *Oceans and coasts*. The fourth is to reduce chemical pollution to protect human health and the environment, minimize waste, and improve waste disposal and recycling, leading to regroup *Chemicals and product management* and *Waste and hazardous substances*. Finally, the last aims to provide universal and sustained water resources and quality.

The index embodies and deepens most environmental dimensions proposed in the recent literature as, for instance, air quality, energy sector, land use, agriculture, forestry... This research also reintroduces in the scope of the environmental regulation, dimensions such as waste and water management, ecosystems protection, overlooked in the recent literature that focuses on climate.

To some extent, classification into 5 environmental dimensions is very close to early research in political science (Busch et al., 2005; Tews et al., 2003). I acknowledge that environmental aspects are all related and functions as a system. For instance, forests are jointly a carbon capture tool, a biodiversity and water reservoir and a stock of material. However, the 12-topics LDA model highlights significant distances between topics, suggesting that the legislations implemented are strongly topic-oriented.

3.1.3 Data description

I develop a country-based dataset according to the following steps. First, I reintegrated regions and special provinces and territories into the national accounts (French Guiana, for example, was incorporated into France).

[10] UNFCCC's list of environmental sectors has also been considered since multiple topics can already be found in the list. However, due to its strong emphasis on the climate issue, it was considered to be too narrowly focused.

[11] Agriculture, FOrest and Land Use (AFOLU)

Second, I dis-aggregated the regulations voted at the supra-national level such as the European Union to reinsert them at the national level. The premise is that legislation issued at the supra-national level is subsequently incorporated into national law (especially for European legislation with the primacy principle)[12]. Finally, for the largest federal countries, state level legislations have been weighted by the share of the national territory covered by the legislation[13]. This process enables us to reinstate every legislation available at a regional scale to a country-specific level. This country-level dataset has been named Multidimensional Environmental Legisaltion Dataset (MELSD).

Figure 1 shows respectively the distribution of environmental legislation, aggregated at the country level, across topics and dimensions over the period 1950-2020. The most legislated topics are *Chemicals and products management*, *fishing* and *air pollution*, with more than 9000 legislations. *Chemicals and products management* seems to be particularly preponderant with more than 14 000 legislations. This might be due to its broad spectrum, which discusses production methods (pesticides, GMO, animal production, standards), packaging (packaging/labelling, hygiene/sanitary procedures) and transport (transport/storage, trade) of a wide range of agricultural products. *Waste and hazardous substances*, *freshwater management* and *energy sector* follow with between 5000 and 9000 legislations. Finally, topics associated with *Land Use* and *Ecosystem protection*, meaning anthropogenized and natural areas, gather 3000 to 5000 legislations each across the world. *Hunting* is also associated with a lower number of legislation, possibly due to its narrower spectrum.

Figure 1 also confirms that, with more than 20 000 legislations each, *Ecosystem and Substance management* are major dimensions of the environmental policy. The recent literature, strongly focusing on climate policies, has overlooked these core aspects. Repositioning them at the center of environmental policies allows for a more representative apprehension of the policy efforts. The topics associated with climate change, namely *air pollution* and *energy sector*, both present topics with already 6000 to 9000 legislations which suggests that the issue of climate change still occupies an essential part of environmental policy. These 3 dimensions, counting more that 15 000 legislations each, account for around 85% of the overall environmental legislations produced between 1950 and 2020. Water and Land management policies, often set at the local level, offers dimensions that counts less than 11 000 legislations. The MELSD, relying on national-level legislations, might underestimate the stringency in these dimensions.

Figure 2 shows the overall number of new environmental country-level legislations per year in the world over the period 1950-2020. Prior to the 1970s, the number of new environmental legislations in the world was stable, around 0 and 50 a year. New dynamics appears after 1970 with a steady growth in the number of new environmental legislation. This period matches with the first scientific conferences and reports, raising awareness

[12]The EU defines 3 types of legislation: that is regulations, directives and decisions. The database only includes EU regulations. EU regulations has been defined by the European Commission as a binding legislative act that must be applied in its entirety across the EU. Therefore, the EU members adopt a common approach of the regulation, and the legislation can be disaggregated at the EU member level.

[13]For USA, Canada, Brazil, Russia, Mexico, Argentina, Germany, Spain and India, I identify state level legislations from the titles or abstracts. The literature on aggregation and its weighting schemes often consider three core variables: Population, GDP and Area. To my knowledge, only state level areas are available since 1950, therefore it has been used as a weighting scheme.

Figure 1: *Number of environmental legislation per dimension in the MELSD (1950-2020)*

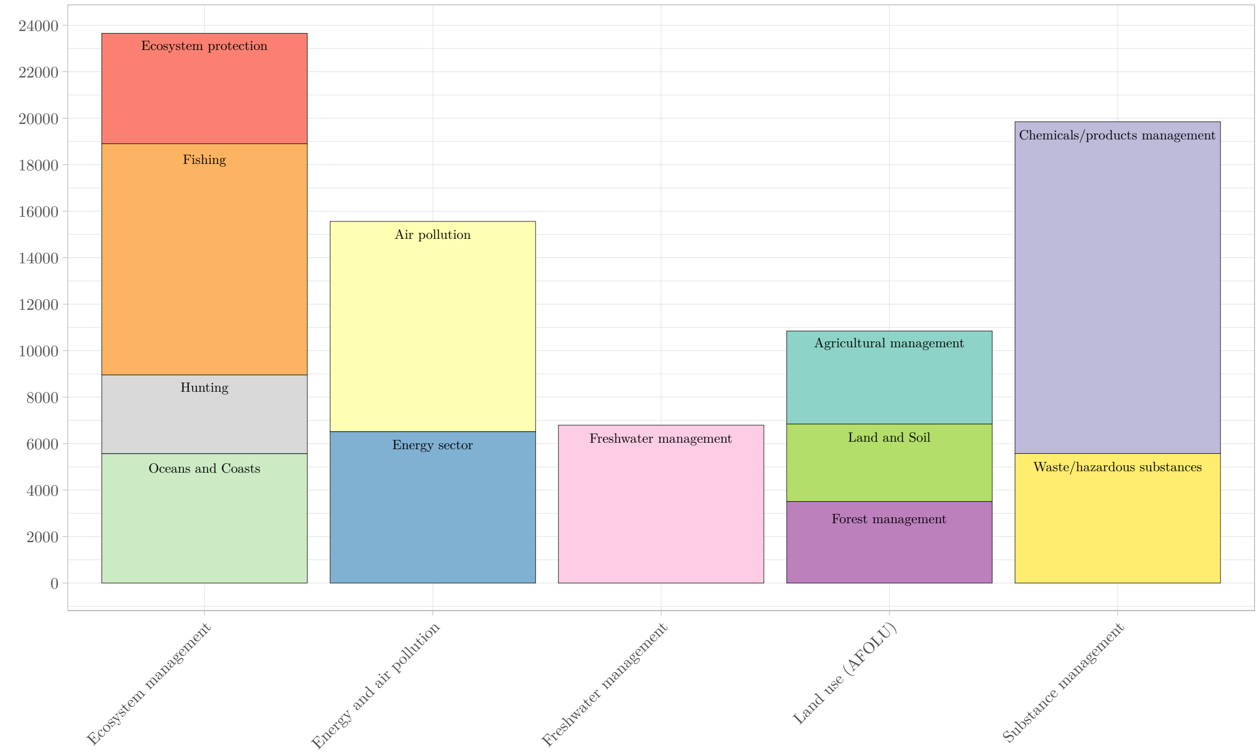
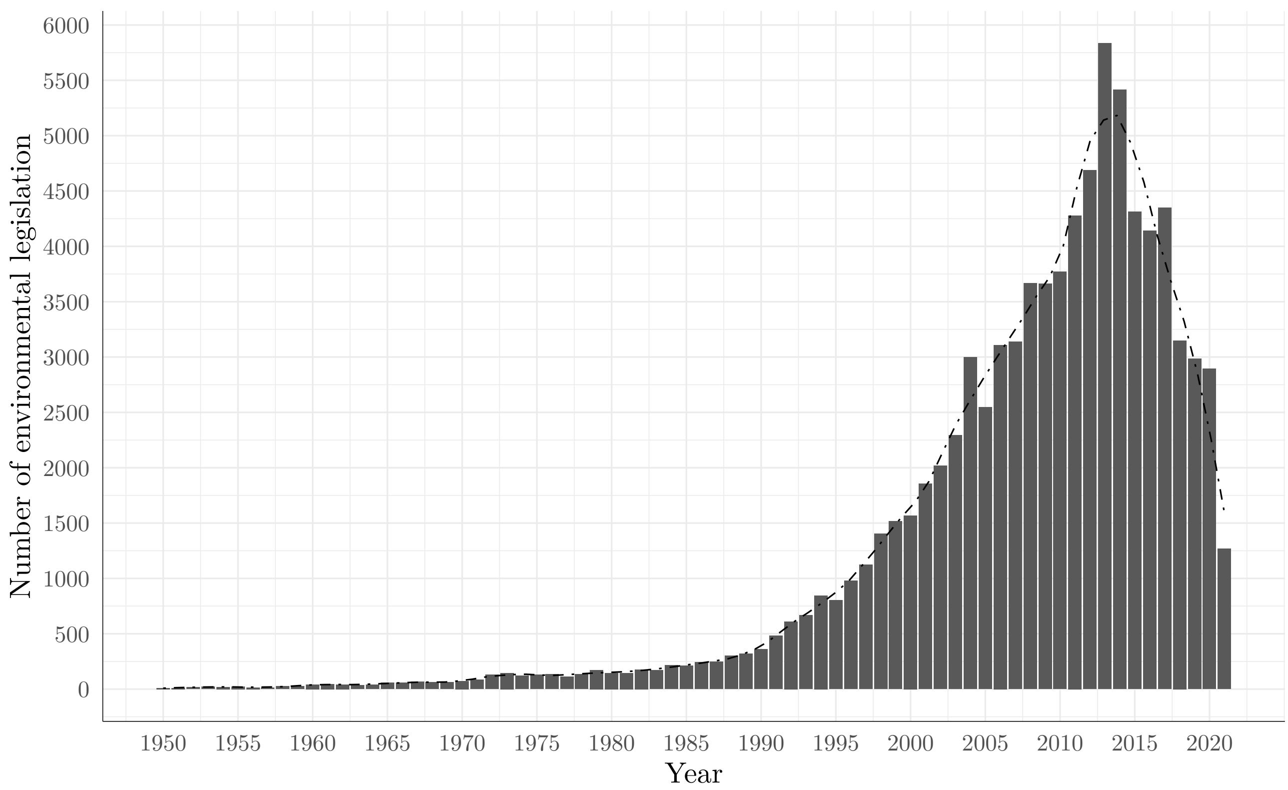


Figure 2: *Number of new environmental country-level legislation per year (1950-2020)*



of environmental issues (Meadows report on the limits to growth; UN's world first conference on the Environment - 1972) and UNEP's appearance. This number skyrocketed after 1990 to peak in 2013-2014 with more than 6 000 new legislations a year. This acceleration may have its source in the political actions promoted by international institutions and conferences such as the IPCC, the Earth Summits or the IPBES, or the rise environmental political movement or NGOs. This acceleration can also be explained by the end of the Cold War, triggering a new dynamic of globalization, increasing trade in resources and developing new economic sectors. Thus, a further need to organize and regulate these activities might have emerged. In the recent years, the number of new environmental legislation significantly dropped. This observation is consistent with Kruse et al. (2022), that shows a reduction of reform dynamics for climate regulation in the last decade.

3.2 Scoring method

Still following the Figure A.1, this section discusses the second and third steps to construct the stringency index from the MELSD. After presenting the method for extracting, transforming and exploiting textual content of legislation in order to perform a textual analysis, this section introduces the narrative and the scoring methods used to identify policy instruments and quantify the stringency of legislations.

3.2.1 Environmental legislations and text mining

As outlined in section 2., most of the existing literature built environmental regulation indicators by scoring public and private communications or pledges statements. This research takes some distance from the established literature by exploiting a new source of information, that is the environmental legislation documents' text content. By nature, legal documents have many qualities relevant for the design of a stringency index. For instance, it retains both the exact date of their promulgation, the certainty of legal enforceability and its longevity (to remove or modify a legislation, another has to be promulgated). Legislation aims to be consistent and clear, making the text direct, simple and comprehensive. Additionally, legislations provide a wide range of information on the structure of environmental bodies and institutions, the nature of the regulatory instruments used and the intentions of the regulator. However, the use of legislation as material for building an index introduces new limits in quantifying countries' environmental policies. Before all else, it implies that governance is achieved through legislations. Yet, some forms of governance, often in undemocratic systems, may be carried out outside the law, and therefore are not covered by such an indicator. Also, as highlighted by Esty and Porter (2005), environmental regulations evolve in a regulatory structure that differs significantly between countries, and over time. The same environmental legislation may have different implications in different countries, due to differences in overall governance. Finally, more than any index of environmental regulation provided by the literature, this research uses a *de jure* approach of environmental regulation, overlooking the enforcement aspects that can vary through time and across countries.

From the MELSD, I apply the following procedure with the objective of creating a corpus that gathers and homogenizes the textual content of all environmental legislations in our sample. (i) Since the database provides the link to all legislation files, I extracted all documents from the FAO servers using web-scrapping technics, regardless of the nature of the file (pdf, docx or HTML format). The English version was prioritized when several versions of the document were available. (ii) For each document, I extracted the textual content in order to standardize the encoding. Even though the documents were in digital formats, their quality and readability remained heterogeneous. Some of the documents were photos, poor quality scans of legal texts, or HTML code within pdf files, making them very difficult to exploit. This procedure resulted in the loss of approximately 7900 legislations, or 11% of the sample, due to document quality issues. (iii) Then, legislation documents were, for the most part, written in the official language(s) of the countries/territories in which it applies. Thus, the corpus presents a great linguistic diversity. In the aim of achieving standardization, a translation into English of 42 000 legal text contents has been carried out using a translation API[14]. (iv) Finally, Ash et al. (2022) show that legislations may be designed to pursue multiple policy objectives, therefore each legislation's text content has been split into law articles. This last step ensures that the scoring strategy is performed at the legislative article level.

Built upon this corpus, this research intents to perform simple and transparent text mining technics, in order to capture the environmental regulation instruments used to capture the intentions of the regulator, and score the stringency based on the type of policy instrument implemented. To the best of my knowledge, only few and novel studies have been conducted using text mining technics to produce macro-level index in environmental economics. Engle et al. (2019) implements a three-step process to create a news-based index of climate change risk (CCR). First, the authors build the "Climate Change Vocabulary" lexicon (CCV) extracting the most common words in 74 scientific and institutional environmental reports. Second, they match the CCV lexicon with WSJ article's text content, allowing them to assemble a climate related corpus. Finally, they conduct a polarity sentiment analysis to distinguish positive and negative news to produce the climate-change risk index. Gavriilidis (2021) uses a similar approach to build the Climate Policy Uncertainty Index (CPU), a EPU style index (Baker et al., 2016). The CPU index refines the CCR index by also filtering the news-based corpus using an additional lexicon listing words associated with regulation, political institutions and uncertainty. Thus, the final corpus has been reduced to news discussing only climate policy reforms[15]. The technique set up in the present research is an adapted combination of both Engle et al. (2019) and Gavriilidis (2021). Using dictionaries built upon scientific and institutional documents, the text contents have been filtered to identify the environmental policies and regulatory instruments introduced by each legislation. Finally, the policy instruments were scored according to the level of intervention of the policymaker.

[14]The translations have been carried out using LectoAI's Translation API. The provider selection is based on performance, diversity of languages handled and pricing.

[15]See Dugoua et al. (2022) for a recent review of the literature on text mining in Environmental Economics

3.2.2 Environmental policies

To date, the literature has had substantial difficulty in capturing the diversity of environmental policy instruments being implemented around the world. Therefore, indicators are often built upon few instruments identified *ex-ante* (Botta and Koźluk, 2014; Steves and Teytelboym, 2013) for one specific environmental aspect. This method provides good transparency and thin monitoring of the policy instruments tracked. However, it introduces strong bias by omitting many potentially effective policies or policy instruments. Since a wide variety of environmental policy aspects are investigated in this research, it is particularly exposed to this selection bias. To my knowledge no extensive list of environmental policies or environmental policy tools has been developed in the literature that could mitigate this bias. Therefore, the list is of environmental policy instruments incorporated in the analysis has been created from last decade's major scientific and international institutions' reports. These institutional and global assessments reports provide a synthesis of the knowledge on the interaction between economies and the environment. Moreover, policymakers' design choices of policy might be both influenced by scientific reports and supported or endorsed by large environmental institutions. Specifically, sections or reports' parts are dedicated to the review of environmental policies and instruments, providing comprehensive knowledge on the design of environmental regulations, strongly relevant for policymakers.

Therefore, I manually extracted the key policies and policy instruments that have been routinely advocated by international organizations and the scientific community such as the United Nations Environmental Program (UNEP), the International Resource Panel (IRP), the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). This includes UNEP's Global Environmental Outlook (2012 and 2019), UNEP's 2022 Strategic Approach to International Chemicals Management report (SAICM), IRP's 2019 Global resource outlook, IPCC's AR5-2014 and AR6-2022 assessment reports (working groups 2 and 3), and IPBES 2022 global assessment report. The reports identify and discusses 712 environmental policies or environmental policy tools[16]. For a same policy objective, environmental policies may differ depending on the country, and the political and the environmental contexts. For example, a policy goal aiming to increase the protection of biodiversity in natural areas may be addressed by multiple policies such as the creation or expansion of protected areas or marine protected areas. Similar approaches would be to create conservation areas, increase the connectivity of natural areas or increase the conservation of semi-natural areas. Different approaches would include the active restoration of depleted natural areas, human-assisted migration or integrated development of wildlife habitats. This text mining method enables the monitoring such large variety of environmental policy approaches, allowing for deeper insight, enhanced international comparability and minimizing selection bias[17].

The policies listed have been matched in the text content of each legislation article, allowing for the selection of legislative articles relevant to environmental regulation. Figure 3 displays, for each dimension, the most common

[16] The list of environmental policies and environmental policy tools are available upon request

[17] UNEP's GEO-2019 report highlights that thousands of environmental policies and policy instruments and that it might not be possible to cover them all. In this research, I attempted to cover the largest number possible with the hypothesis that the most significant ones are discussed in the reports.

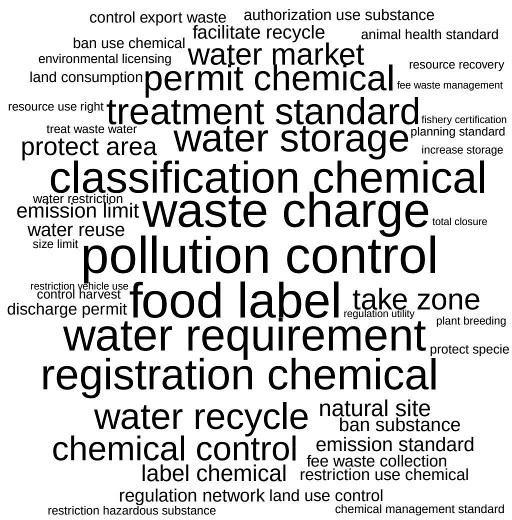
(a) *Overall*

(b) *Ecosystem management*

(c) *Energy and air pollution*

(d) *Freshwater management*

(e) *Land Use (AFOLU)*



(f) *Substance management*

Figure 3: *Most common environmental policies per environmental dimension*

Note: The wordclouds plots, for each environmental policy dimension, the most common environmental policies or environmental policy tools used by the policymakers. The 712 environmental policies and environmental policy tools have been listed from major policy and scientific reports. The environmental dimensions compiles environmental legislations aiming to the same policy objective.

environmental policies and environmental policy tools used across all legislations. The figure shows the strong diversity of environmental policies implemented within and across environmental dimension suggesting a large variety of environmental policies implemented across the world. This characteristic also appears at the topic level (see Figure A.5 for topic specific wordcloud).

3.2.3 Quantifying policy stringency

The previous section focuses on identifying the regulators' motives by identifying legislation articles containing environmental policies previously identified in scientific and institutional reports. Building on these articles, this section identifies the policy instruments that are implemented or strengthened in order to achieve these policy ambitions.

Previous studies built environmental policy stringency index have developed two scoring methods. The first consists in proposing an ex-post discretionary rule-based rating scale, making it possible to distinguish relative levels of environmental protection between countries and years. This method has been widely used on surveys in the early literature (Dasgupta et al., 2001; Esty and Porter, 2005; Steves and Teytelboym, 2013), and more recently directly on environmental policy instruments for EPSI (Botta and Koźluk, 2014; Kruse et al., 2022). This method allows for good transparency and comparison on a limited number of policies monitored. However, as the number of instruments monitored increases, the weighting rule between indices and the interpretations become more complex. The second method emerges form this limit. This alternative method proposes to approximate the level of environmental regulation by the number of environmental laws or treaties implemented (Eskander and Fankhauser, 2020; Hargrove et al., 2019; Smarzynska and Wei, 2001; Stef and Ben Jabeur, 2020). This method admits the wide variety of possible environmental policies, and therefore gives no prior on the quality of the legislation, the policy or the policy instruments used. Although widely accepted, Brunel and Levinson (2013) points out that the number of yearly new environmental legislation might be better interpreted as an inducement of the regulators' interest or awareness toward environmental issues.

Unable to monitor and create a rating scheme for each environmental policy and aiming to offer a deeper approach than the number of policies, this research serves as a midpoint between both methods to score the environmental policies identified in the corpus. In line with Gavriilidis (2021), that uses two lexicons to build the policy uncertainty index, a policy instruments lexicon has been created from the scientific and institutional reports. Table 4 shows the list of all 96 policy instruments identified in institutional and scientific reports. The instruments listed have been matched in legislation articles that discuss environmental policies. Therefore, a tightening of environmental policy is then approximated by the association of an environmental policy and a regulatory instrument in the same legislation article. To that regard, the methodology is close to the "narrative approach" originally used to identify monetary and fiscal shocks (Romer and Romer, 2004). Duval et al. (2018) has recently expanded the type of policies captured by using this approach to identify structural reforms in the product and labor markets.

Table 4 highlights the strong diversity of environmental policy instruments tracked in the legislations. The policy instruments have been grouped by type following the IPCC's AR5 Working Group III report's part on national and sub-national environmental policies. Consistent with Botta and Koźluk (2014) and de Serres et al. (2011), this research distinguishes 4 types of policy instruments: *economic instruments*, *regulatory instruments*, *government provision*, and *Voluntary actions and information programs*. It broadens the scope of environmental policy instruments by incorporating *Government provision*, and *voluntary actions and information programs* policy instruments, previously overlooked in the literature covering policy stringency index.

Table 4: *List of policy instruments and its variations tracked - grouped by instrument type*

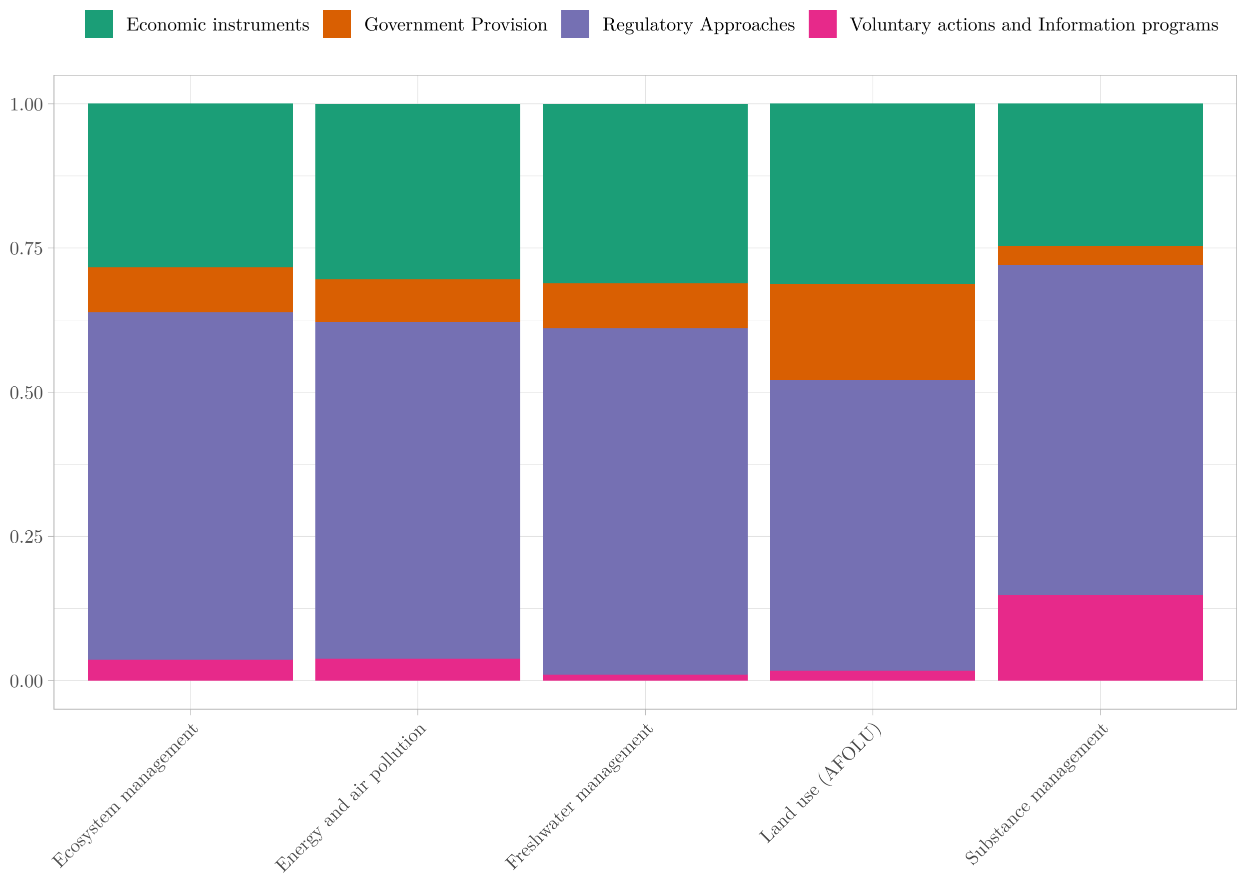
Instrument type	Instrument	Nb of instrument	Weight
Economic instruments	offset; impact bond; feed tariff; tradeable credit; tax break development; taxation scheme; research development subsidy; deposit refund; eco tax; payment ecosystem service; fee; price guarantee; loan guarantee; green equity; property tax abatement; property tax; tradable permit; offset market; user fee; contract difference; cap trade; quota; grant; tradeable allowance; subsidize loan; tax break research; split rate tax; license fee; purchase obligation; tradable certificate; research tax incentive; marketable permit; technology subsidy; tradable quota; reseach subsidy; transferable right; green tax; renewable energy auction; charge; tradable allowance; subsidy; development tax incentive; tax allowance; tax; development subsidy; tax relief; tradeable right; trading system; remittance; effluent charge; green bond; tax credit	52	1
Regulatory Approaches	technology standard; certification; efficiency standard; regulation access; design standard; technical standard; provision; prohibit; access right; progressive criterion; transferable right; progressive standard; ban; process standard; requirement; portfolio standard; procurement; limit; license; public norm; permit; restriction; product standard	23	1
Government Provision	credit provision; micro insurance; fund; public debt forgiveness; credit guarantee; liability insurance; public procurement; index base insurance; publicly fund research; production insurance; plan grant; price guarantee; cash transfer; development aid	14	0.50
Voluntary actions and Information programs	label; progressive label; label requirement; mandatory information disclosure; mandatory label; voluntary information disclosure; mandatory due diligence	7	0.25

Note: This figure displays the list of all 96 policy instruments identified in institutional and scientific reports. Instruments have been grouped by type following Chp. 13 of the IPCC's AR5 Working Group III report (pages 1158-1159). The last two columns display the number of instruments listed in each group and the stringency score associated with each group.

Economic instruments, such as taxes, subsidy and market-based mechanisms, provide direct economic incentives or disincentives, aligning practices with environmental goals through financial motivations. This approach leverages strong economic incentives, thereby ensuring an immediate impact on behaviors. *Regulatory approaches*, through standards, rights, and norms, establishes a strong incentive for compliance, providing a structured and enforceable mechanism to guide practices. In contrast, *government provisions*, often reliant on indirect support, may lack the clarity, specificity, and enforceability necessary to generate comparable levels of incentive. *Voluntary approaches*, such as labels and information disclosure, while valuable in raising awareness, are constrained by their reliance on disseminating information without providing concrete mechanisms for enforcement or tangible incentives for compliance. Thus, economic instruments and regulatory measures offer a more stringent and legally binding framework, then government provisions that provides indirect incentives, and finally the voluntary approach that raises awareness. The last column of Table 4 shows the weighting scheme selected to reflect the difference in stringency across instrument type. In line with Botta and Koźluk (2014), the same weights are provided for *economic instruments* and *regulatory approaches*. Lower weights have been given to *Government* *provision*, and *voluntary actions and information programs* policy instruments.

Figure 4 displays for every environmental dimension, the share of each type of instrument used across legislations. The instrument type most frequently used by regulators is the regulation approach, which accounts for around 50% of the instruments used. Economic instruments account for over a quarter of the instruments implemented. The remaining quarter is divided between voluntary approaches, information programs and government provisions. Government provisions are particularly prominent for *land use*. This can be explained by policies to support agriculture's adaptation to climate change or the transition of agricultural activities towards more sustainable practices (agro-ecology, agro-forestry, organic farming, soil restoration, etc.). Similarly, *substance management* seems to have proportionally more instruments of the voluntary approach and information programs type. Indeed, labeling and the information disclosure would appear important in the management, conditioning and trade of chemicals and waste.

Figure 4: *Share of policy instrument type in each environmental dimension*



Note: This figure displays, for each environmental dimension, the proportion of each type of policy instrument implemented or reinforced. Source: authors' calculation

4. The Multi-dimensional Environmental Legislation Stringency Index

This section analyses how countries score through time and environmental dimension. First, the focus has been on analyzing global trends using regional approaches and statistics. The study then focuses on the relation between the MELS index and major environmental performance and policy indexes.

4.1 MELS index, descriptive statistics, and Environmental Kuznet Curve

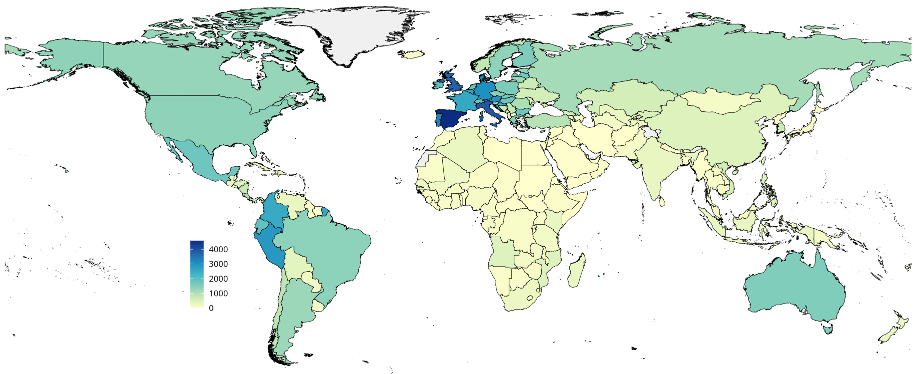
The MELSI has been developed for a total of 197 countries, covering the period from 1950 to 2020 (71 years). This indicator is a composite of 5 sub-indicators, themselves structured by 12 thematic sub-indices (Table 3). A country's environmental stringency is based on the accumulation of environmental stringency recorded in legislation covering its territory, or in proportion to the size of the territory for federal states. The environmental stringency of a legislation is characterized by the combination, in the same article of legislation, of the introduction of an environmental policy and the implementation or reinforcement of a policy instrument. Stringency then varies according to the type of instrument, giving higher weight to instruments with a direct impact and stronger policy incentives. In this context, the MELS index and its sub-indexes reach a theoretical minimum at 0 and has no maximum.

4.1.1 Descriptive statistics and key features

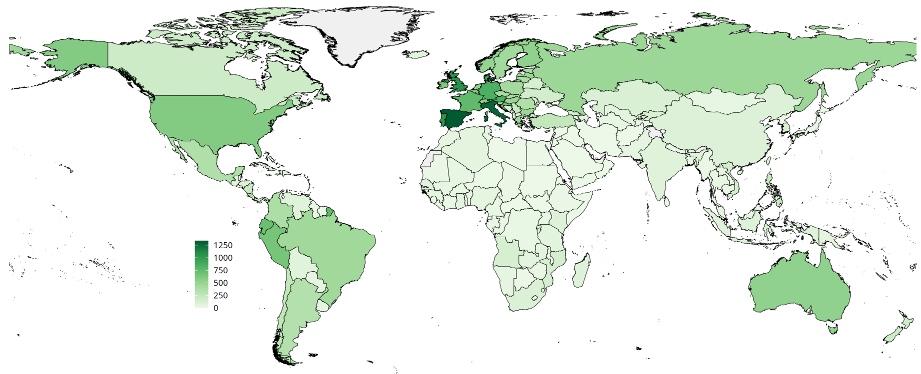
Figure 5 displays world maps of the measure of environmental policy stringency and its key dimensions in 2020 given by the MELS indexes. On these graphs, the darker the country, the stronger the environmental regulation. Figure (a) shows the aggregated MELS index. At first glance, it is clear that Europe is a leader in environmental protection, particularly the countries of Western and Southern Europe. Environmental policy stringency also extends to Eastern and Northern Europe, with a clear break with the borders of the European Union, suggesting the strong influence of the EU in environmental regulation in this region. This leadership seems to be reflected in every dimension of environmental policy, in particular in the management of chemicals and waste, and ecosystems. The American continent also appears to have a relatively high level of environmental regulation, especially in South America for Peru and Colombia. These two countries already stood out for their unusually large number of environmental regulations (See Figure A.6). This can be explained by the size or the topography of these countries, their level of development, the abundance of natural and fossil resources, or the importance of agricultural and forestry areas in their territories. Africa, the Middle East and Central Asia show much lower levels of regulation, although some countries such as China, Vietnam and Angola emerge as slightly more regulated. Regardless of the dimension, the level of development seems to be a major driver of environmental regulation. This observation is consistent with the Environmental Kuznet Curve (EKC), which suggests that with a rising income per capita, the desire for higher environmental quality increases and therefore institutional reforms and environmental legislations emerge (Arrow et al., 1996).

Figure 5: *World maps displaying the MELS index for each country in 2020*

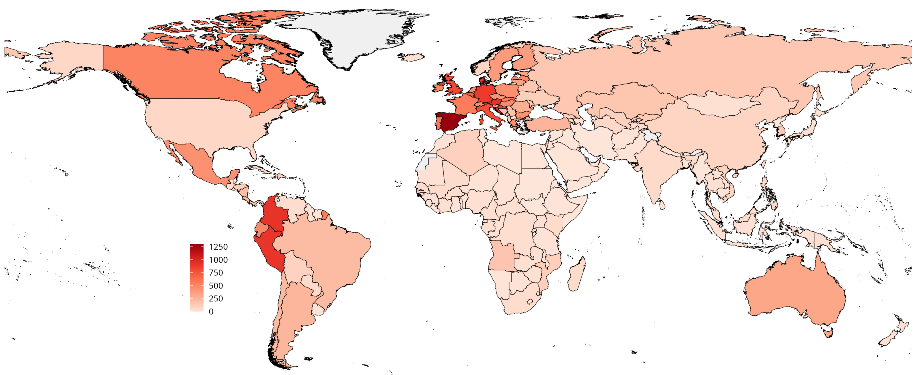
(a) *Overall*



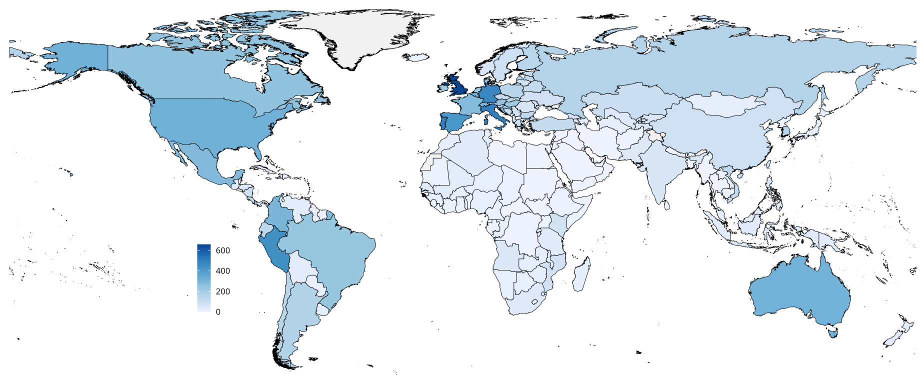
(b) *Ecosystem management*



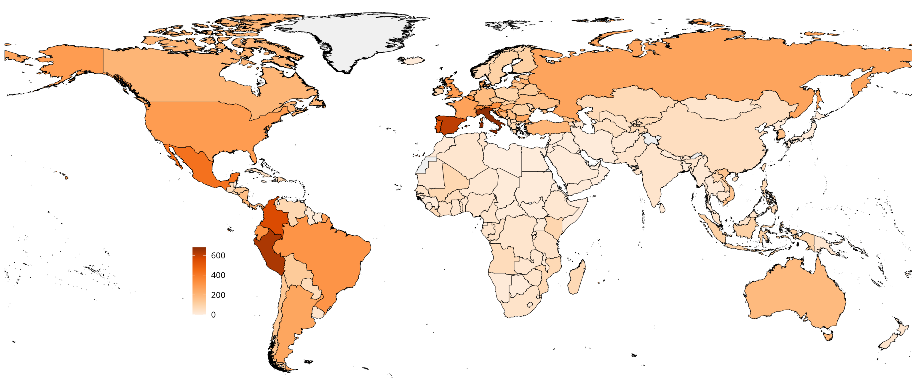
(c) *Energy and air pollution*



(d) *Freshwater management*



(e) *Land Use (AFOLU)*



(f) *Substance management*

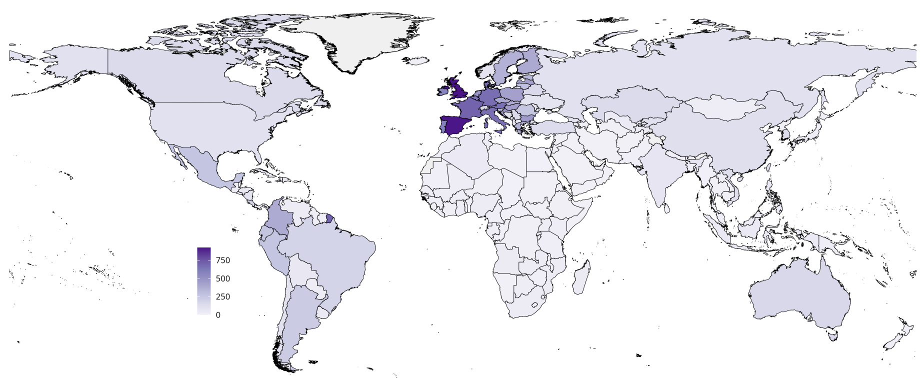


Table 5: *Summary Statistics - MELS index's regional mean yearly growth rate between 1970 and 2020 (in %)*

Variable	N	Mean	Std. Dev.	Min	Pctl. 25	Pctl. 75	Max
Overall							
Central and Eastern Europe (EEU)	12	10	1.3	7.1	9.8	11	12
Centrally planned Asia and China (CPA)	6	6.3	2.7	2.1	5.1	8.2	9.4
Latin America and the Caribbean (LAM)	22	7.6	2.2	2	6.1	8.7	11
Middle East and North Africa (MEA)	20	2.8	1.9	0	1.6	3.6	7.7
Newly Independent States of FSU (FSU)	15	8.8	1.5	6.3	7.7	9.7	11
North America (NAM)	2	9.3	0.12	9.2	9.3	9.3	9.4
Other Pacific Asia (PAS)	9	6.5	1.8	3.7	5.7	7.4	9.7
Pacific OECD (PAO)	3	7.1	3.5	4.5	5.2	8.4	11
South Asia (SAS)	6	4.6	1.3	2.9	3.9	5.4	6.6
Sub-Saharan Africa (AFR)	43	5.2	1.5	1.9	4.5	6.2	8.6
Western Europe (WEU)	18	11	1.3	8.7	11	12	12
Ecosystem management							
Central and Eastern Europe (EEU)	12	11	1.4	8.3	10	12	13
Centrally planned Asia and China (CPA)	6	6.7	2.7	2.2	6.1	8.6	9.6
Latin America and the Caribbean (LAM)	22	8.7	2.3	5.1	7.2	10	13
Middle East and North Africa (MEA)	20	3.1	2.2	0	1.2	4.5	7.9
Newly Independent States of FSU (FSU)	15	9.2	1.8	6.6	7.9	9.9	12
North America (NAM)	2	9.8	0.65	9.4	9.6	10	10
Other Pacific Asia (PAS)	9	7.5	1.4	5.6	6.7	8.8	9.4
Pacific OECD (PAO)	3	9.8	2.7	7	8.6	11	12
South Asia (SAS)	6	4.8	2.6	0	4.4	6.6	7.2
Sub-Saharan Africa (AFR)	43	5.7	2	0	4.5	6.9	9.5
Western Europe (WEU)	18	12	1.3	9.5	12	13	14
Energy and air pollution							
Central and Eastern Europe (EEU)	12	11	1.9	6.2	9.9	12	13
Centrally planned Asia and China (CPA)	6	5.6	3.3	0	4.5	8.2	8.9
Latin America and the Caribbean (LAM)	22	7.7	2.8	0	6.8	9	13
Middle East and North Africa (MEA)	20	2.5	2.3	0	0.6	4	9.1
Newly Independent States of FSU (FSU)	15	9.4	1.5	6.9	8.5	9.9	12
North America (NAM)	2	9.6	1.7	8.4	9	10	11
Other Pacific Asia (PAS)	9	6.8	2.3	1.4	6.4	8.1	9.7
Pacific OECD (PAO)	3	6.8	4.1	3.3	4.6	8.6	11
South Asia (SAS)	6	4.6	1.9	2.7	3.1	5	7.9
Sub-Saharan Africa (AFR)	43	5.6	1.9	0	4.6	6.6	10
Western Europe (WEU)	18	11	1.8	7.8	10	13	14
Freshwater management							
Central and Eastern Europe (EEU)	12	8.7	1.3	5.8	8	9.4	11
Centrally planned Asia and China (CPA)	6	6	2.8	1.8	4.9	8.2	9.4
Latin America and the Caribbean (LAM)	22	6.7	2.1	1.2	5.6	7.8	11
Middle East and North Africa (MEA)	20	2.9	2.3	0	1	4.1	7.3
Newly Independent States of FSU (FSU)	15	8.2	1.2	6.1	7.7	9.1	10
North America (NAM)	2	8.3	0.49	8	8.1	8.5	8.7
Other Pacific Asia (PAS)	9	5.6	2.4	2.2	3.8	6.7	9.8
Pacific OECD (PAO)	3	6	4.6	3.3	3.3	7.3	11
South Asia (SAS)	6	4.1	1.8	2.2	3.5	3.9	7.6
Sub-Saharan Africa (AFR)	43	4.8	1.9	0	3.9	5.9	8.6
Western Europe (WEU)	18	9.9	1.9	6	8.8	11	13
Land use (AFOLU)							
Central and Eastern Europe (EEU)	12	9.6	1.1	7.8	9.1	10	11
Centrally planned Asia and China (CPA)	6	7.3	2	4.1	6.4	8.5	9.9
Latin America and the Caribbean (LAM)	22	7	2.6	1.5	5.3	8.7	11
Middle East and North Africa (MEA)	20	2.7	2.3	0	0	4.2	7
Newly Independent States of FSU (FSU)	15	8.7	1.4	6.2	7.8	9.8	11
North America (NAM)	2	9.2	2.7	7.3	8.3	10	11
Other Pacific Asia (PAS)	9	6.6	2.5	3.3	4.6	8.5	10
Pacific OECD (PAO)	3	6.3	3.5	4	4.3	7.4	10
South Asia (SAS)	6	5	1.3	3.8	4.1	5.8	7
Sub-Saharan Africa (AFR)	43	5.4	1.8	0	4.4	6.7	8.7
Western Europe (WEU)	18	9.6	1.7	5.4	8.8	11	12
Substance management							
Central and Eastern Europe (EEU)	12	11	1.6	7.4	9.6	12	12
Centrally planned Asia and China (CPA)	6	5.8	3.1	2.7	3.1	8.6	9.4
Latin America and the Caribbean (LAM)	22	7.8	2.7	0	6.7	9.4	11
Middle East and North Africa (MEA)	20	2.9	2.4	0	1	4.6	7.4
Newly Independent States of FSU (FSU)	15	8.6	2.3	4.1	7.2	9.9	12
North America (NAM)	2	9.5	0.46	9.2	9.3	9.7	9.8
Other Pacific Asia (PAS)	9	6	2.1	2.7	4.4	7.3	9.6
Pacific OECD (PAO)	3	6.7	2.9	4.7	5	7.6	10
South Asia (SAS)	6	4.6	2.2	1.4	3.6	5.5	7.9
Sub-Saharan Africa (AFR)	43	4.7	1.8	0	3.7	6.2	7.2
Western Europe (WEU)	18	12	1.3	8.7	11	13	13

Note: This figure displays for each environmental dimension, MELS index's summary statisictics through time at the IPCC's SRES regional level between 1970 and 2020 (51 years). Source: author's calculations

Table 5 shows the average annual growth rate of the MELS index and its sub-indexes over the period 1970 to 2020 in IPCC's 11 SERS regions. The early 1970s have been selected to match the dates of the first scientific reports and conferences on climate change and natural resources. The figure shows that environmental policy stringency has the highest average annual growth rate in Western Europe in all dimensions of environmental policy, shortly followed by Central Europe, North America and Eastern Europe (FSU). Next come the Pacific OECD regions, which includes Australia, Japan and New Zealand, and Latin America and the Caribbeans countries, both groups reporting a high average annual MELSI growth rates, but with higher heterogeneity between environmental policy dimensions. On the opposite, regions rich in minerals or fossil fuels, or with a large number of low income countries, show a relatively low average growth rate in environmental regulation. These findings are consistent with the Figure 5. Also, Table 5 displays small standard deviations and Pctl.25 and Pctl.75 values close to the regional mean, which suggests strong regional trends and region specific determinants. However, some minimums specifically for Centrally planned Asia and China (CPA), Sub-Saharan Africa (AFR), and Latin America and the Caribbean (LAM) and maximums, like in Middle East and North Africa (MEA), are distant from their closest percentile, which implies the possibility of divergent behavior. Figure A.7 provides a more comprehensive depiction of the evolution of the MESL index within and across regions [18]. The figure confirms that the upswing in environmental regulation is primarily attributed to Europe, South America, and North America. However, it also highlights that most countries and regions exhibit a limited progression in environmental regulation over the last 30 years. Heterogeneous trends emerge, with a few leaders that widely exceeding regional trends, and therefore dragging up the regional mean.

4.1.2 Economic performance and MELS index

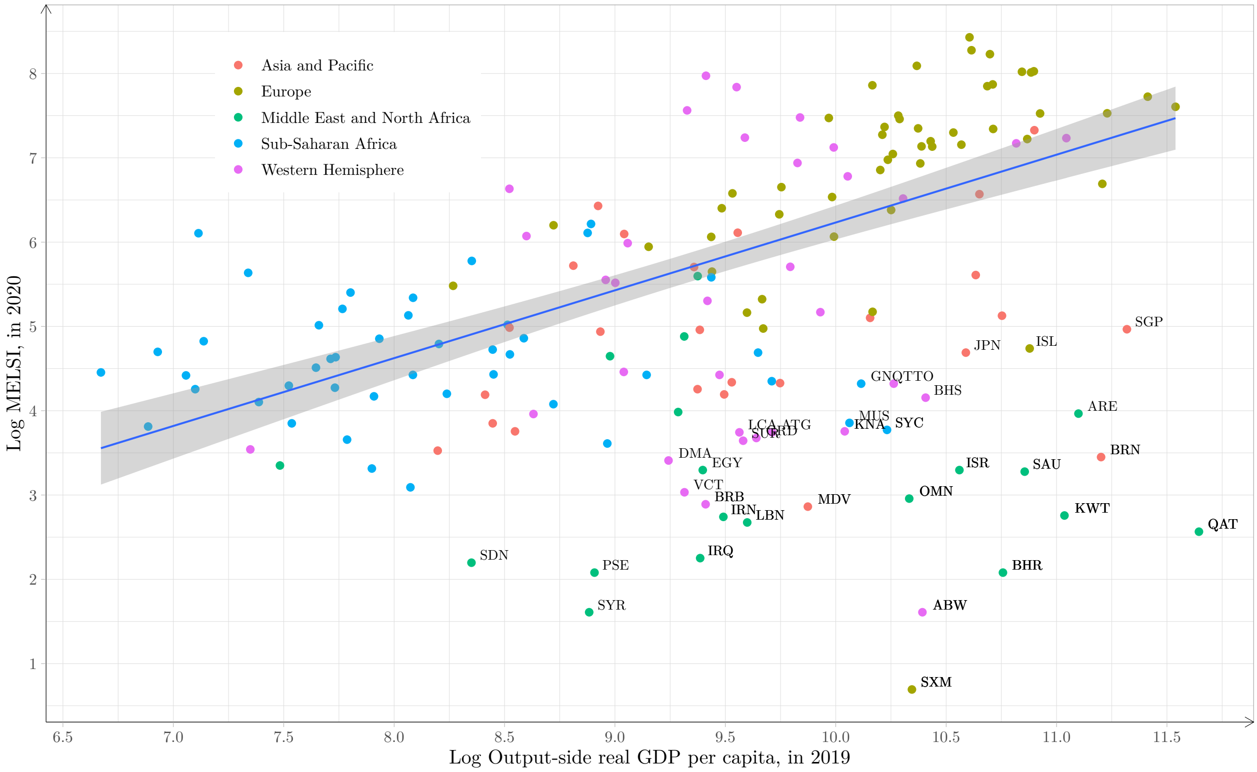
The Environmental Kuznet Curve (EKC), which assumes an inverted U-shaped or N-shaped relation between income per capita and environmental quality (Stern, 2017), has been a consistent aggregate empirical finding in the macro-environmental literature. Central to this literature, Arrow et al. (1996) highlight the central role of environmental institutions and regulations in shaping this relation. Furthermore, they hypothesize a positive causal relation between income per capita and institutional reforms and environmental regulation, through the demand for environmental quality channel. To date, this link has not been tested due to the lack of available for environmental regulation data in many low and middle income countries.

Figure 6 plots the relationship between income per capita and environmental regulation for 173 low, middle and high income countries. Using the extended Penn World Table database of GDP and population, the figure displays the output-side real GDP per capita in 2019 against the MELS index in 2020. The figure also color coded countries according to their regions. The regions have been created by merging some SERS regions according to their MELSI statistic similarities, and in the spirit of recreating IMF regional outlook regions. Consistent with Arrow et al. (1996), the figure shows an overall positive link between environmental regulation

[18] The intricate diversity of these countries is organized into 24 distinct United Nations Geoscheme regions, defined by geographical, economic, and historical criteria. For each plot, each country's evolution is represented by a grey line, while the black line serves to articulate the regional mean, offering a consolidated perspective on the collective trend within each Geoscheme region.

and GDP per capita[19]. Income per capita appears to be strongly correlated with environmental regulation regardless of region, even for low income countries.

Figure 6: *GDP per capita and the MELS index - correlation analysis*



Note: The figure plots 173 countries' output-side real GDP per capita in 2019 (last year available in PWT 10.01 database) against their MELSI score reached in 2020. Boliv. Rep. of Venezuela have been ruled out due to its extreme GDP per capita value. Source: Penn World Table (PWT 10.01), author's calculations.

However, many countries seem to have high income per capita and low environmental regulation (bottom right corner). This group gathers the vast majority of the Middle East and North Africa (MENA) countries. The MENA countries still presents a positive relationship between wealth per capita and environmental regulation, but this relation appears to be not as strong as the rest of the world. These countries share many environmental and economic characteristics such as a large share of desert land, and fossil-fuel rich soils. The latter has already been identified as a driver of weaker environmental regulation. Indeed, Badeeb et al. (2020) show that natural resource abundance, especially oil, leads to more carbon-intensive development behaviors and less environmental regulations. This fossil fuel endowment is a distinctive form of resource curse or Dutch disease known as "Carbon curse" or "Carbon lock-in" (Badeeb et al., 2020; Erickson et al., 2015; Friedrichs and Inderwildi, 2013; Lamb and Minx, 2020). Aside for MENA countries and to a lesser extent, many Caribbean countries and in the Pacific region appear to have high income per capita and low environmental regulation, which may be due to their insular status.

[19]This relationship has also been tested using Expenditure-side real GDP per capita available form the Penn World Table database as a robustness, which shows no significant changes

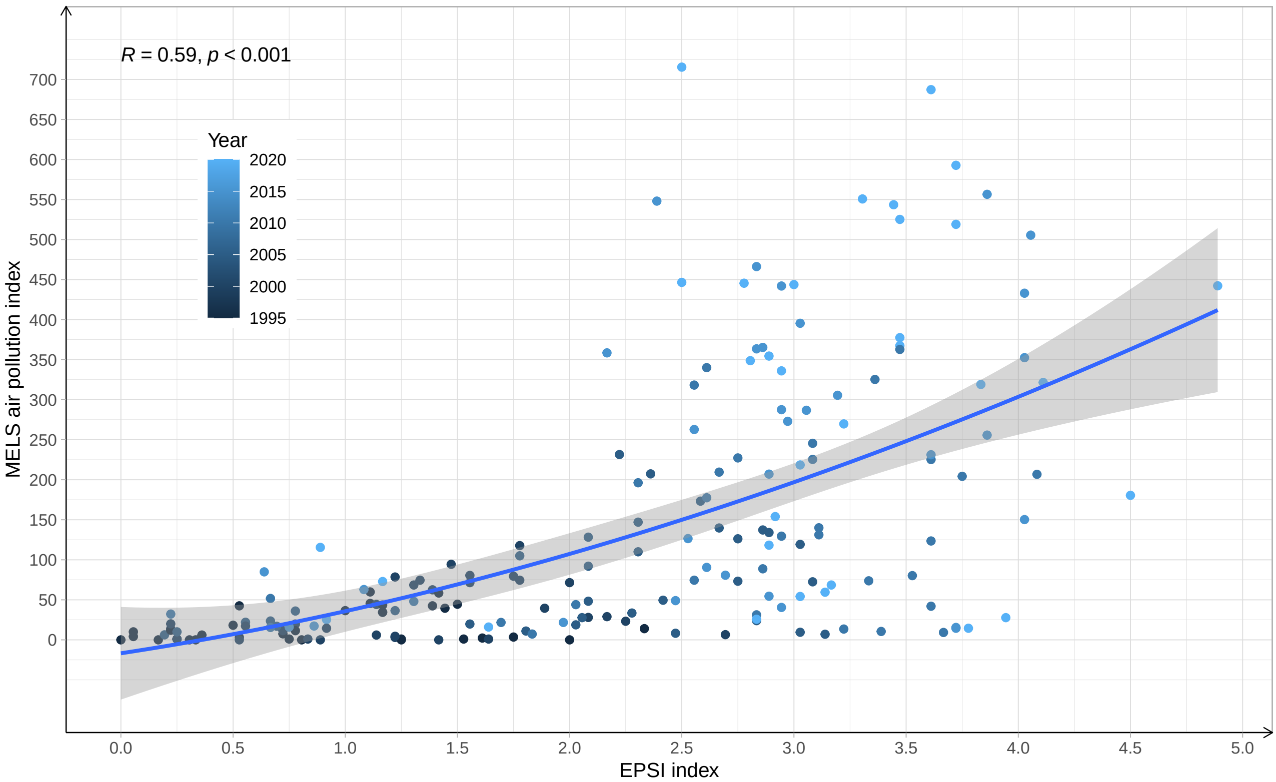
4.2 MELS index, environmental outcomes indicators and external validation

The existing measures of environmental stringency vary widely depending on their coverage, approach or method. Because of these differences, each approach results in its own ranking of stringency. One way to evaluate how well the approaches measure stringency is to compare them with one another and observe how they relate to economic and environmental key variables. In this section, the MELS index has been tested against comparable indicators of environmental policy stringency and environmental performance indexes, and analyses the direction and degree to which the MELS index co-varies with them. Given the very large sample of countries in the database, I have excluded countries with a population of less than on million for reasons of simplification and analysis quality (following Mankiw et al. (1992)).

4.2.1 External validation

The OECD Environmental Policy Stringency Index (EPS) is a country-specific and internationally-comparable measure of the stringency of environmental policy that has become a widely used tool for policy analysis since its creation in 2014. The index monitors 13 environmental policy instruments, primarily related to climate and air pollution, and covers 40 countries for the period 1990-2020. It is also targets production-based emissions, its stringency is defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behaviors.

Figure 7: *EPS index and MELS index*



Note: The figure plots the relationship between the EPS index and the MELS air pollution sub-index for 40 countries and the years 1995, 2000, 2005, 2010, 2015 and 2020. The MELS air pollution sub-index has been created from the legislation gathered in the air pollution topic. The years are represented by shades of blue, the clearer the more recent.
Source: EPSI-2020 Kruse et al. (2022), author's calculations.

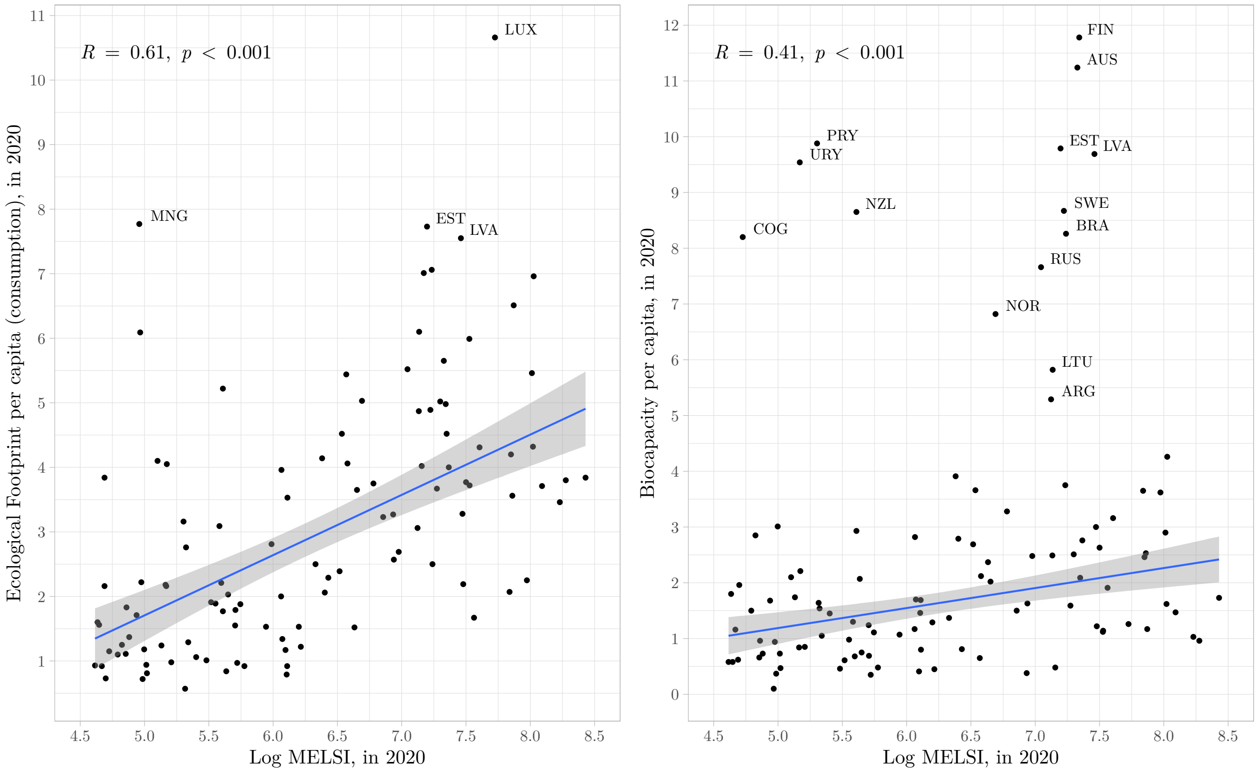
Figure 7 shows the relationship between the EPS index and the MELS air pollution sub-index for 40 countries and the years 1995, 2000, 2005, 2010, 2015 and 2020. On this graph, the more recent the date, the clearer the point. The first thing to note is the positive relationship between the two indices, with an increasing dispersion as the EPS index rises, particularly when it exceeds 2.25. We can also see that the darkest points are in the bottom left-hand corner and the lightest in the top right-hand corner, demonstrating the stringency of the construction dynamic. This graph suggests that the years 1990 to 2005 saw the emergence of the first environmental policies targeting greenhouse gas emissions in particular, regulating in the EPSI's narrower scope. However, because it captures a broader spectrum of air policies, the MELS index also shows a diversification of air policies between 2005 and 2010. In this sample, EPSI and MELSI are 60% correlated, with intra-annual correlations for each of the 6 years considered ranging between 30% and 45%. Compared with the established correlations of other indicators such as abatement cost or the CLIM index, the correlation observed between EPSI and MELSI is above average. The literature explains the weak correlations observed is that the information contained in the indexes lacks consistency across various measures. In this view, even if one index effectively encompasses a comprehensive assessment of stringency, the remaining indexes may fall short. Conversely, a more optimistic interpretation suggests that regulatory stringency is multifaceted, with each index reflecting distinct facets of that stringency (Brunel and Levinson, 2013).

4.2.2 Environmental performance and MELS index

Developed by the York University Ecological Footprint Initiative & Global Footprint Network, the ecological footprint measures the amount of pressure exerted on biosphere by human consumption, while biocapacity is a measure of the potential carrying capacity of an area to support an ecological footprint. It uses global hectare as standardized unit, which represents a hectare of land that provides a world-average amount of biological regeneration each year. The ecological footprint is seen as human demand of nature or ecosystems. It regroups the consumption of natural resources (plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure), and waste absorption. Biocapacity represents the ecological assets available (including cropland, grazing land, forest land, fishing grounds, and built-up land), that could diminish if the ecological footprint exceeds the biocapacity. Environmental legislations intervene in the structuring and organization of the interaction of human demand for nature and nature's supply capacity.

Figure 8 displays the ecological footprint of consumption and biocapacity per capita (in global hectares) against the MELS index in 2020. The sample covers 110 sample countries with a MELSI score over 100 in 2020. The left plot shows the MELS index against the carbon footprint of consumption. A higher environmental footprint implies a higher pressure biospherical resources form humans. Similar to Kruse et al. (2022), the figure shows a positive correlation between environmental regulation and consumption-based ecological footprint (0.61 against 0.34 for the EPSI in 2017). However, empirical evidence suggests that stringent environmental policies have the potential to mitigate pollution originating from domestic production. Therefore, while caution must be exercised in deriving definitive conclusions from cross-sectional correlations, it is possible that countries

Figure 8: *MELS index, Ecological footprint, and biocapacity - correlation analysis*

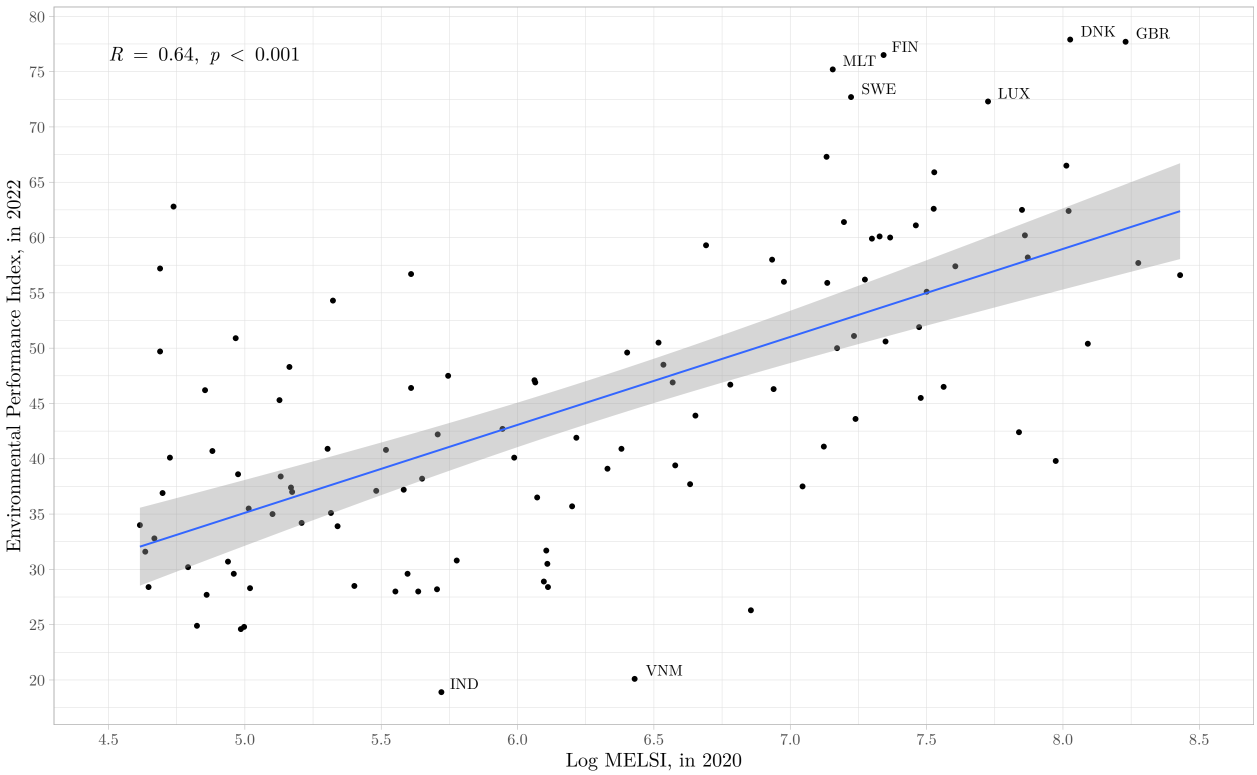


Note: Theses figures plot countries' Ecological Footprint of consumption and Biocapacity per capita (in global hectares), against the MELS index for the year 2020. Each point represents one of the 110 countries of the sample with a MELSI score over 100 in 2020. For the right graph, Bolivia, Canada, Gabon, and Mongolia have been ruled out due to extremely high biocapacity per capita values. Source: National Ecological Footprint and Biocapacity Accounts, author's calculations.

might offset these reductions by importing carbon-intensive goods, thereby augmenting their consumption-based ecological footprint, thus explaining this positive relation. On the right plot, Figure 8 indicates that the MELSI is positively correlated with biocapacity, with a correlation coefficient of 0.41. A higher environmental policy stringency correlates with an improved management practices of biologically productive land and ocean areas, that provide food, fiber, and timber, accommodate urban infrastructure, and absorb excess CO2. This correlation is in line with the literature that suggests that climate regulation mitigate air pollution and therefore improve environmental quality (Kruse et al., 2022; OECD, 2021). It's worth noticing the presence of many countries considered to be outliers, and the similarities they share. Many of them are characterized by a population concentrated on a small part of the territory, often the coastline, leaving vast natural areas with a high level of biodiversity.

An alternative and comprenhensive mesure of environmental performance is given by the Environmental Performance Index (EPI). Available for 180 countries, this composite index monitors 40 environmental performance indicators across 11 issue categories involving environmental health and ecosystem vitality, and mitigating climate change. It includes a large variety of indexes such as *fish stock status*, *tree cover loss*, *sustainable pesticide use*, *greenhouse gas exposure*, *unsafe drinking water*, *controlled solid waste*, *ocean plastic*,.... Produced on a biennial basis, the EPI is built upon the most recent year of data available in order to score each country on a scale from 0 to 100 (with higher values indicating a better performance). It defers from the ecological footprint and biocapacities indices by measuring countries' observed performance in environmental outcomes. Apart from

Figure 9: *Environmental performance Index and the MELS index - correlation analysis*



Note: This figure plots countries' 2022 Environmental Performance Index against the 2020 MELS index. Each point represents one of the 112 countries of the sample with a MELSI score over 100 in 2020. Source: Wolf et al. (2022), author's calculations.

the classification method, weighting scheme and a few environmental aspects, the EPI offers relatively similar coverage in comparison to the MELSI. However, due to methodology and the underlying data change between the EPI versions, the EPI can not be used in its time dimension. EPI's correlation analyses usually demonstrates that financial resources, good governance, human development, and regulatory quality are strongly associated with environmental performance (Wolf et al., 2022).

Figure 9 introduces the link between the 2022 Environmental performance Index and the MELS index. The 2022 EPI index have been selected over the 2020 EPI index, due to delays in the application of environmental legislations, especially during the Covid period. Each point represents one of the 112 countries of the sample with a MELSI score over 100 in 2020. The graph shows a strong cross-sectional relationship between the 2022 EPI and the MELS index. The MELS index has a correlation coefficient of 0.64 with the environmental performance index, a higher value than the EPSI-2020 (0.54), EPSI-2010 (0.33) and WEF's CLIMI-2010 (0.36). Consequently, in addition to financial resources, good governance, human development, and regulatory quality, environmental policy stringency appears to be extremely relevant to environmental quality.

5. Conclusion

In conclusion, this research represents a pivotal advancement in the literature by providing the first worldwide cross-country measures of environmental policy stringency. Addressing existing challenges associated with comparative environmental policy indexes, characterized by limitations in both country-time coverage and quality of stringency scoring method, this study introduces the Multi-dimensional Environmental Legislation Stringency Index (MELSI) as major data contribution and pioneering methodological approach.

Built upon an extensive corpus of more than 60 000 environmental legislations compiled by the World Bank agencies, the MELSI encompasses an extended coverage of 197 countries over the last 70 years. This indicator is a composite of 5 environment oriented sub-indicators, themselves structured by 12 thematic sub-indices. A country's environmental stringency is based on the accumulation of environmental stringency recorded in legislation covering its territory, or in proportion to the size of the territory for federal states. The environmental stringency of a legislation is characterized by the combination, in the same article of legislation, of the introduction of an environmental policy and the implementation or reinforcement of a policy instrument. Stringency then varies according to the type of instrument, giving higher weight to instruments with a direct impact and stronger policy incentives. In this context, the MELS index and its sub-indexes reach a theoretical minimum at 0 and has no maximum.

Carefully constructed and methodologically rigorous, this research departs from the conventional methodologies on several significant methodological points. First, it introduces a data-driven machine learning classification algorithm, classifying environmental legislation into topic-oriented groups (terrestrial and marine ecosystems protection, agriculture, air and water pollution, land use, and forest, freshwater and waste management...), thence avoiding potential subjective biases. Second, this study delves into the text content of legislations, performing simple and transparent text mining technics to retrieve qualitative information on the environmental policies implemented and their supporting policy instruments. Finally, the policy instrument have been systematically classified into four groups based on their approach and scored according to the strength of their policy incentives. As a *de-jure* proxy for each country's environmental policy stringency across diverse dimensions since 1950, the MELSI encapsulates a comprehensive understanding of the evolutionary trajectories of environmental policy and governance.

The MELSI uncovers a discernible uptick in environmental regulation, particularly clear in Europe and the western hemisphere since 1990. However, the vast majority of countries portray limited progression in environmental regulation over the past three decades, highlighting the nuanced dynamics inherent in global environmental policy landscapes. Incidentally, MELSI appears to be strongly positively correlated with major multidimensional indices of environmental quality, suggesting that, alongside financial resources, good governance, human development, and regulatory quality, environmental regulation has a major role in environmental quality across the globe.

The novel MELS index not only fills a gap in the environmental policy stringency index literature but also holds immense academic and practical significance for future environmental policy research and policy recommendations. The MELSI database emerges as an indispensable instrument that will facilitate more sophisticated analyses and contributing substantively to the literature on environmental policies and governance.

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Appendix

Figure A.1: *Description of the MELSI construction method*

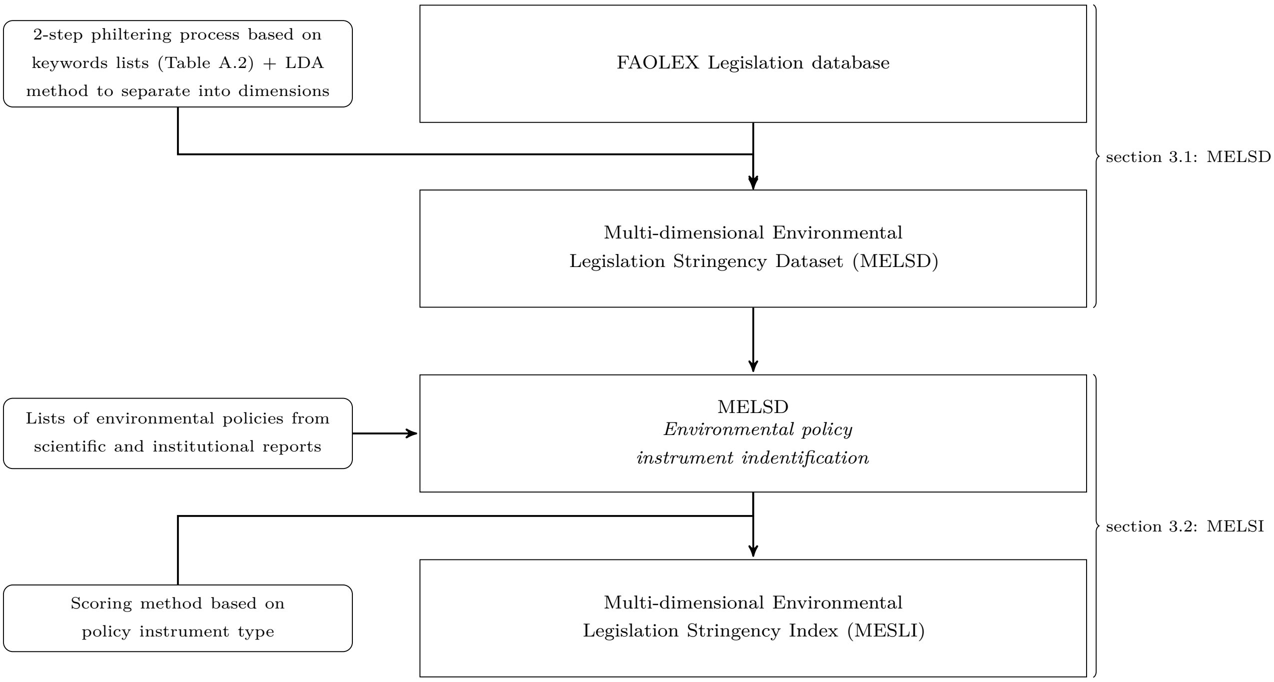


Table A.1: *Description of the different types of documents available in the FAOLEX database*

Type of text	***Definition***
Constitutions	Fundamental Law of a sovereign country. A constitution is a set of rules that guides how a country, state, or other political organization works.
Policies	National Strategies, Programmes, Plans, Plans of Action, etc. covering a specific sector and National Development Plans. National Policies, Strategies and Plans play an essential role in defining a country's vision, policy directions and strategies for its population.
Legislation	"Primary legislation" – Acts or Statutes that have been formally adopted at the national level following the official parliamentary procedure for the passage of laws (in parliamentary systems); (ii) other acts at the national level with the force of law, such as decree-laws and legislative decrees and otherwise (in parliamentary systems); (iii) other legal instruments that have been formally endorsed by a law-making body, for instance presidential and royal orders or presidential and royal decrees (in non-parliamentary systems or systems where law-making power lies in an additional institution to the parliament).
Regulation	"Secondary legislation"- subsidiary, delegated or subordinate legal instruments that have the force of law, are binding and shall not be in contradiction with primary legislation. They are usually passed by the executive, such as national regulations, rules, by-laws, determinations, directions, circulars, orders and implementing decrees.
International Agreements	Bilateral or multilateral international Agreements.
Miscellaneous	Other "soft law", non-binding documents like guidelines, declarations, proclamations, etc.

Source: FAOLEX Metadata description.

Table A.2: *List of keywords used to filter the FAOLEX database*

List of keywords associated with environmental quality improvement/depletion
afforestation/reforestation; agro-forestry; agroecology; air quality/air pollution; biodiversity; bioenergy; biofuel; biological agents; biosphere reserves; biotechnology; bycatch; clean development mechanism; cleaning agents/detergents; climate change; coal; collecting/harvesting; desertification; disasters; drainage/land reclamation; ecofriendly products/ecofriendly processes; ecological production/organic production; effluent waste water/discharge; emissions; endangered species; energy conservation/energy production; environmental security; erosion; fishing gear/fishing method; flood; food loss and waste; forest fires; forest species; freshwater quality/freshwater pollution; fuelwood; genetic resources; GMO; hazardous substances; hazardous waste; hunting/capture; hydropower generation; Illegal unreported and unregulated fishing (IUU fishing); industrial water use; inland fisheries; inland waters; innovation; invasive alien species; irrigation; land clearing; livestock water use; marine pollution; minerals; mining; natural gas; noise pollution; non-commercial fishing; non-wood forest products; nuclear energy; oil; oil pollution; organic waste; ozone layer; pesticides; plant variety; plastic; potable water; private forest; rainwater; ranching/captive breeding; recreational forest; recreational water use; recycling/reuse; renewable energy; saltwater intrusion/siltation; soil conservation/soil improvement; soil pollution/quality; soil rehabilitation; solid waste; stock enhancement/repopulation; sustainable development; sustainable use; timber extraction/logging; tourism; trade in species; transboundary effects; transboundary movement of waste; waste disposal; waste domestic sources; water abstraction; water desalination; water shortage/drought; waterworks; well sinking/boreholes; wetlands; wild fauna; wild flora; wildlife products.
List of keywords associated with environmental policies, policy stringency and monitoring
access and benefit-sharing; access right; access-to-information; access-to-justice; allocation/quota; authorization/permit; cadastre/land registration; classification/declassification; common property; community management; concession; data collection/reporting; dispute settlement; ecosystem conservation; emissions trading; enforcement/compliance; environmental audit; environmental fees/charges; environmental impact assessment; environmental planning; environmental standards; ex-situ conservation; fiscal and market measures; fishery management and conservation; fishing authorization; fishing charge; food assistance; forest management/forest conservation; forest service; forestry protection measures; framework law; fraud/deceit/adulteration; governance; hunting authorization/permit; hunting authorization/permit fee; hunting gear/hunting methods; hunting rights; inspection; integrated management; integrated pest management-IPM/pest management strategies; intellectual property rights; international agreement-implementation; international agreement-text; international cooperation; international organization; land-use planning; management/conservation; marine protected areas; monitoring; national parks; non-governmental entity; offences/penalties; payments for ecosystem services/ payment for environmental services (PES); PIC-prior informed consent; policy/planning; polluter pays principle; pollution control; precautionary principle; procedural matters; prohibited fishing area; property rights; protected area; protected fishing area; protection forest; protection of environment; protection of habitats; protection of species; public forest; public participation; public water; research; resource/damage valuation; right of use; right to clean/healthy environment; right to water; risk assessment/management; river basin institution; royalties/fees; size; special fund; standards; subsidy/incentive; survey/mapping; taxes; total allowable catch; traceability; use restrictions; waste management; waste prevention; water charges; water conservation zone; water resources management; water rights.

The lists were manually built upon the keywords available in the FAOLEX database and their definition available on the FAO website. The first list gathers all the keywords associate to activity, sectors or phenomenon explicitly related to environmental quality depletion or improvement. The second list capture every keywords matching policy regulation, stringency, environmental institutional quality and monitoring. 1. 96 environment related keywords, 2. 93 environmental policy keywords

(a) *440 Overall Keywords*

(b) *189 Selected Keywords*

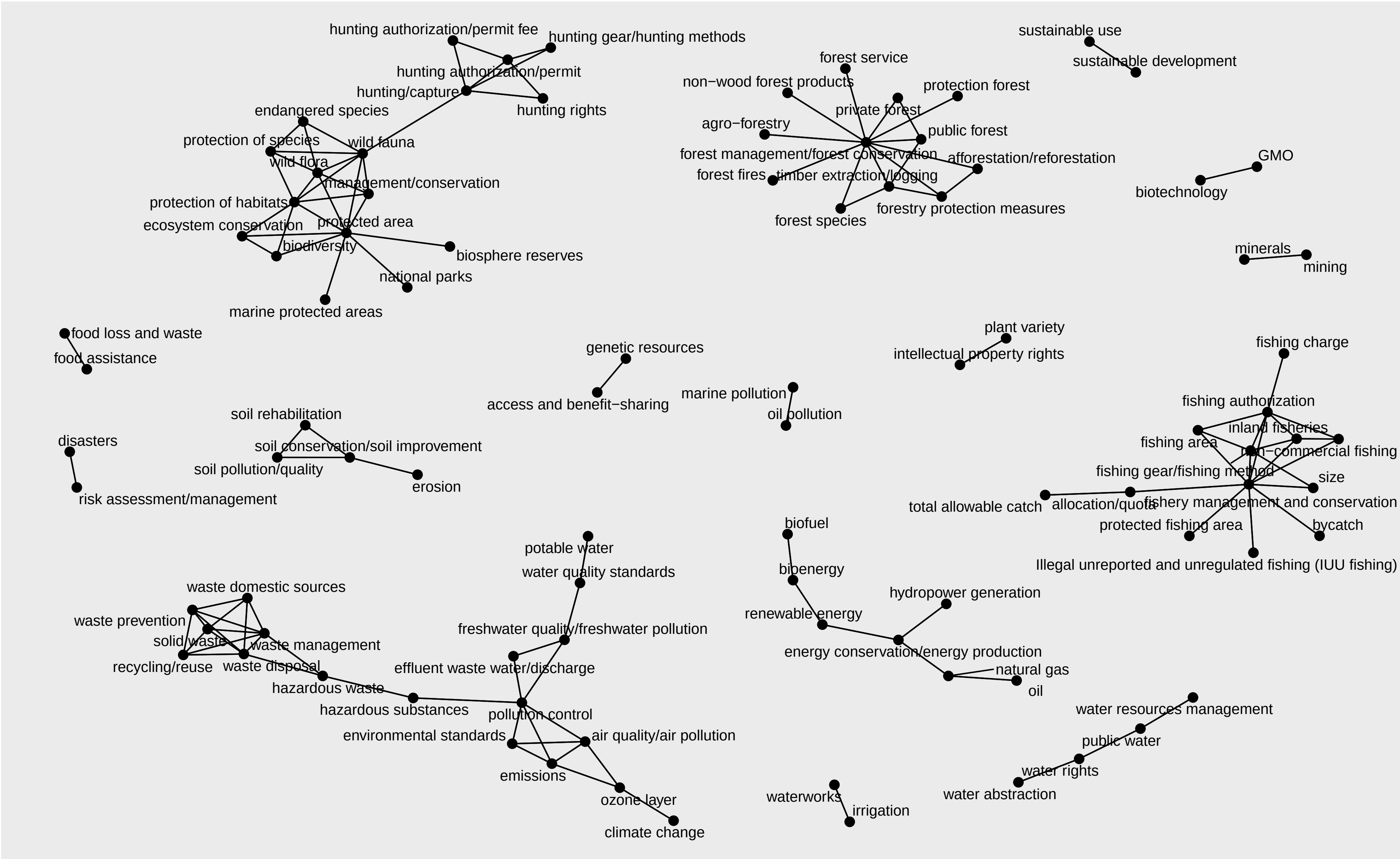
(c) *96 Environmental Quality Keywords*

(d) *93 Environmental Policy Keywords*

Figure A.2: *Wordcloud of the 50 most prominent keywords of the Environmental Legislation subset (1950-2020)*

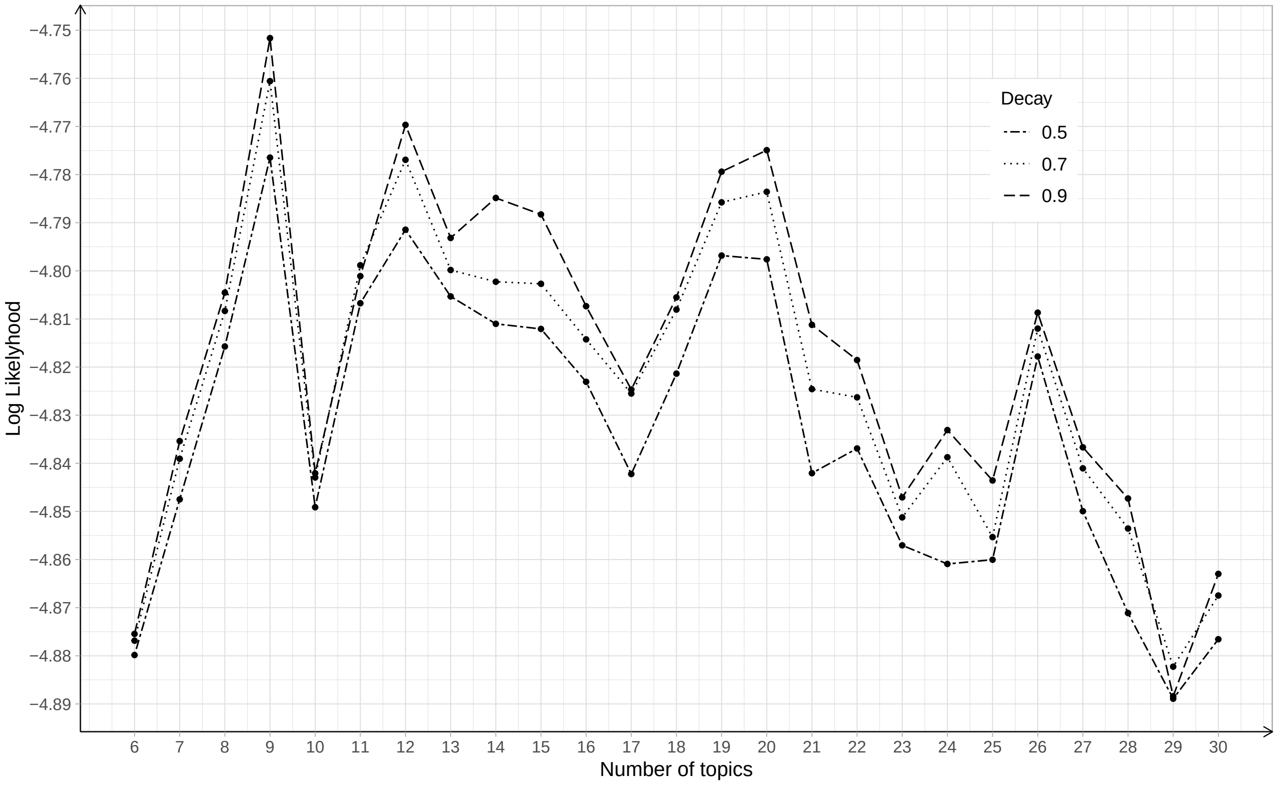
*The wordclouds are built upon the 69 011 legislation that compose the EL dataset. The wordcloud **(b)** relies exclusively on the keywords previously selected to constitute the EL dataset. The wordcloud **(a)** includes all the keywords of the EL dataset with no distinction. Wordcloud **(b)** is a constrained form of the wordcloud **(a)** where the count of the keywords not appearing in the selected sample (Table A.2) is equal to 0. Wordclouds **(c)** and **(d)** plots the most frequent keywords of each of the two sub-sample across the EL dataset. The size of the words indicates the frequency of use across all environmental legislations between 1950 and 2020; that is, larger keywords have a larger count across legislation.*

Figure A.3: *Network plot of the most correlated keywords in the EL dataset*



Note: Relying of Pearson product-moment correlation coefficient matrix, the network graph represents the most correlated keywords' appearances in EL dataset's 69 000 legislation. The minimum correlation coefficient was set at 25%. Source: Author's calculation.

Figure A.4: *Perplexity of the LDA model according to the number of topics*

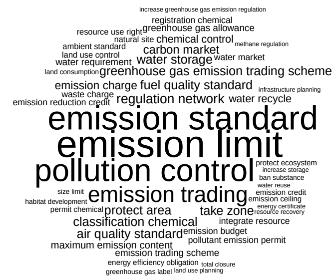


Note: Perplexity of LDA models with different numbers of topics and learning decay. Perplexity is a statistical measure of how well a probability model predicts an held-out set of test documents (similar to the out-of-sample approach in econometrics). A higher log-likelihood indicates a better predictability of the LDA model.

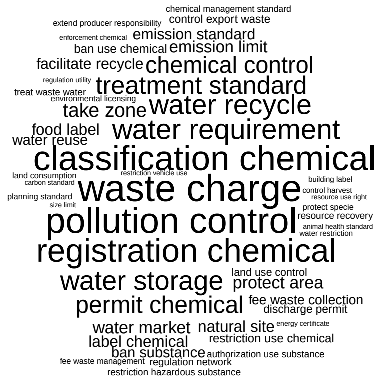
Table A.3: *List of the 197 countries that compose the panel*

Afghanistan; Albania; Algeria; Andorra; Angola; Antigua and Barbuda; Argentina; Armenia; Aruba; Australia; Austria; Azerbaijan; Bahamas; Bahrain; Bangladesh; Barbados; Belarus; Belgium; Belize; Benin; Bhutan; Bolivia (Plurinational State of); Bosnia and Herzegovina; Botswana; Brazil; Brunei Darussalam; Bulgaria; Burkina Faso; Burundi; Cabo Verde; Cambodia; Cameroon; Canada; Central African Republic; Chad; Chile; China; Colombia; Comoros; Congo; Congo, Dem. Rep. of; Cook Islands; Costa Rica; Croatia; Cuba; Curaçao; Cyprus; Czech Republic; Côte d'Ivoire; Denmark; Djibouti; Dominica; Dominican Republic; Ecuador; Egypt; El Salvador; Equatorial Guinea; Eritrea; Estonia; Eswatini; Ethiopia; Fiji; Finland; France; Gabon; Gambia; Georgia; Germany; Ghana; Gibraltar; Greece; Grenada; Guatemala; Guinea; Guinea-Bissau; Guyana; Haiti; Honduras; Hungary; Iceland; India; Indonesia; Iran, Islamic Republic of; Iraq; Ireland; Israel; Italy; Jamaica; Japan; Jordan; Kazakhstan; Kenya; Kiribati; Kuwait; Kyrgyzstan; Laos; Latvia; Lebanon; Lesotho; Liberia; Libya; Liechtenstein; Lithuania; Luxembourg; Madagascar; Malawi; Malaysia; Maldives; Mali; Malta; Malvinas; Marshall Islands; Mauritania; Mauritius; Mexico; Micronesia, Fed. States; Moldova, Republic of; Monaco; Mongolia; Montenegro; Morocco; Mozambique; Myanmar; Namibia; Nauru; Nepal; Netherlands; New Zealand; Nicaragua; Niger; Nigeria; North Korea; North Macedonia; Norway; Oman; Pakistan; Palau; Palestine; Panama; Papua New Guinea; Paraguay; Peru; Philippines; Poland; Portugal; Qatar; Romania; Russian Federation; Rwanda; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Samoa; San Marino; Sao Tome and Principe; Saudi Arabia; Senegal; Serbia; Seychelles; Sierra Leone; Singapore; Sint Maarten; Slovakia; Slovenia; Solomon Islands; Somalia; South Africa; South Korea; South Sudan; Spain; Sri Lanka; Sudan; Suriname; Sweden; Switzerland; Syrian Arab Republic; Taiwan Province of China; Tajikistan; Tanzania, Un. Rep. of; Thailand; Timor-Leste; Togo; Tonga; Trinidad and Tobago; Tunisia; Turkey; Turkmenistan; Tuvalu; USA; Uganda; Ukraine; United Arab Emirates; United Kingdom; Uruguay; Uzbekistan; Vanuatu; Venezuela, Boliv. Rep. of; Viet Nam; Yemen; Zambia; Zimbabwe

(a) *Agricultural management*



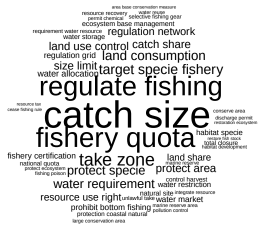
(b) *Air pollution*



(c) *Chemicals and products management*

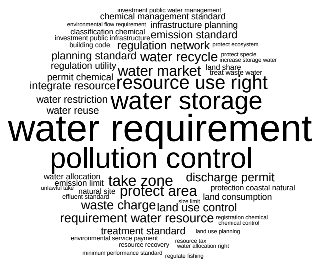
(d) *Ecosystems*

(e) *Energy sector*



(f) *Fishing*

(g) *Forest management*

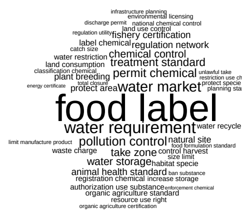


(h) *Freshwater management*

(i) *Hunting*

(j) *Land and soil*

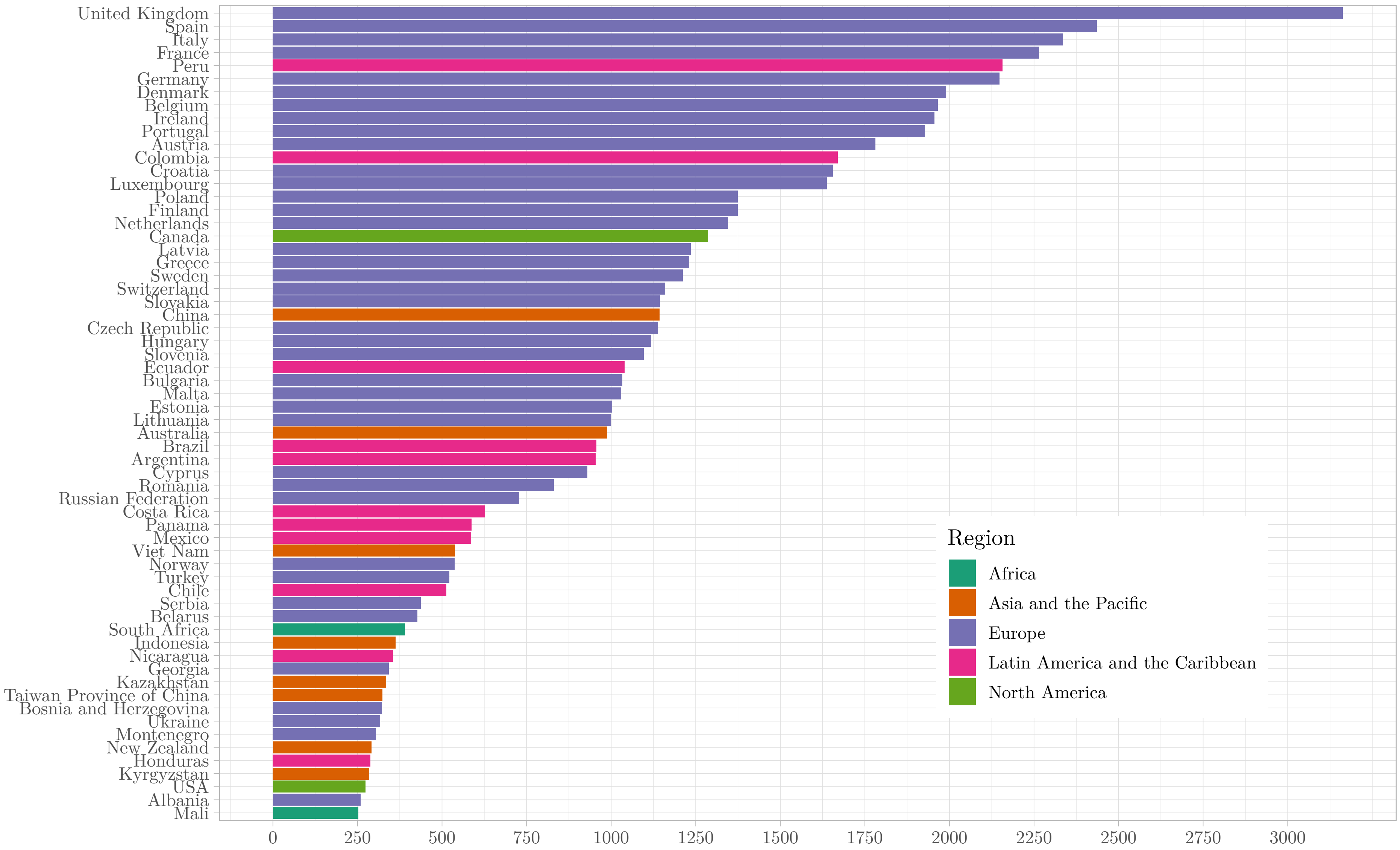
(k) *Oceans and coasts*



(l) *Waste and hazardous substances*

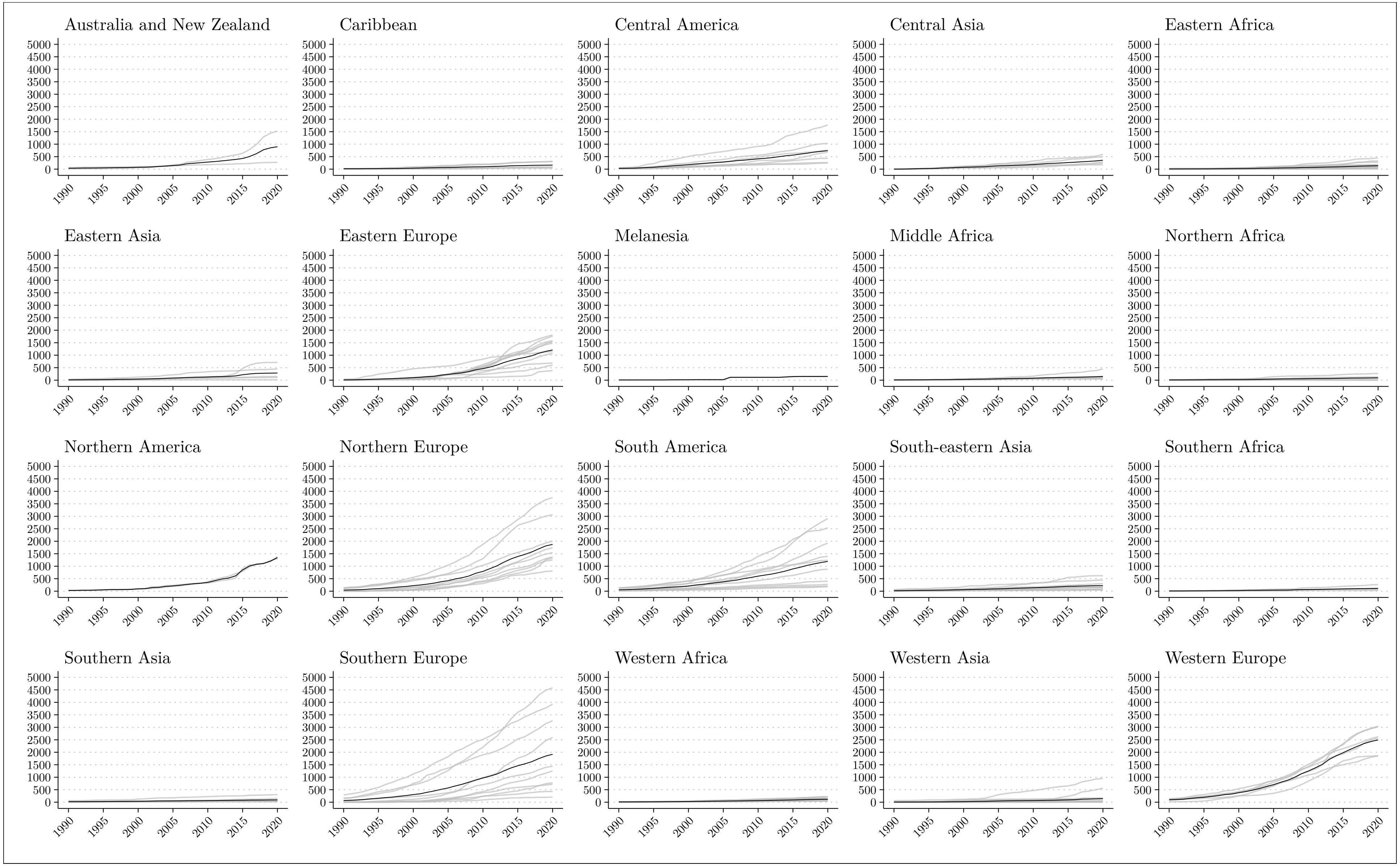
Figure A.5: *Wordcloud of the most commun environmental policies in each topic*

Figure A.6: *Countries with the highest mumber of legislation (in 2020)*



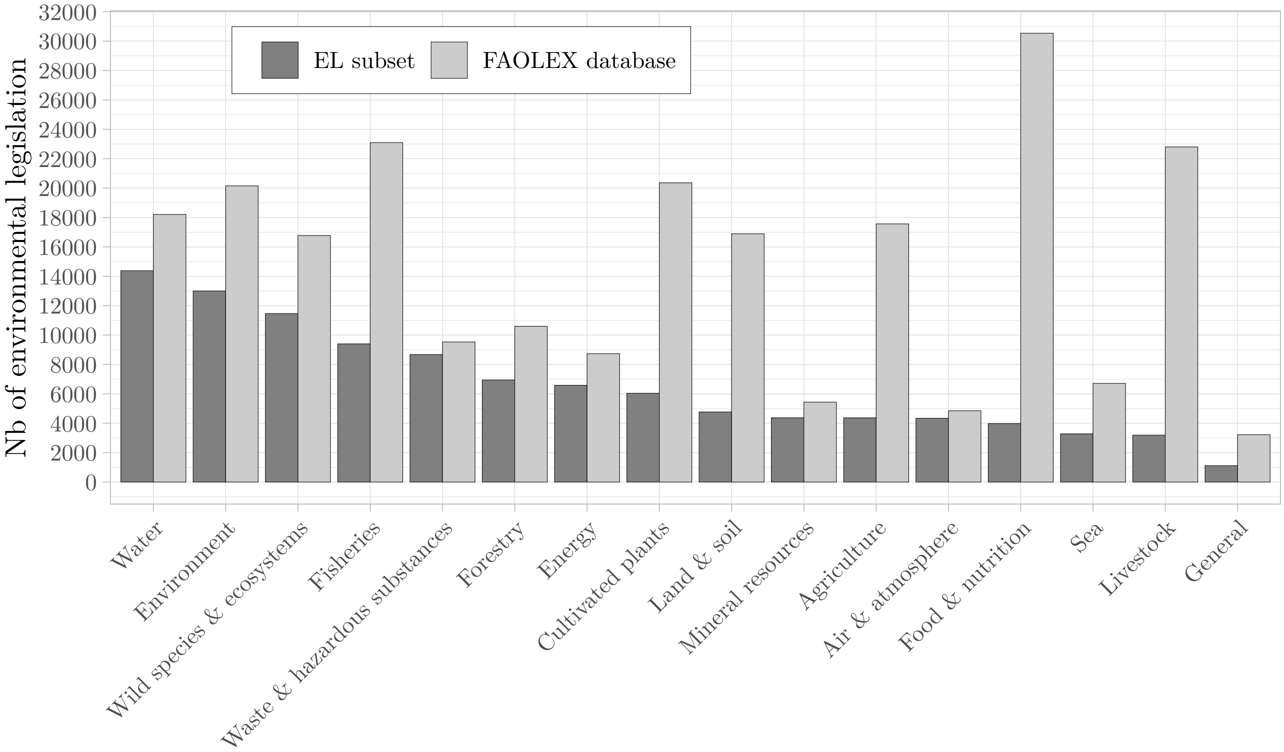
Source: Author's calculation.

Figure A.7: *MELSI's evolution through time and UN regions*



Note: For each plot, a grey line represents a country while the black line gives the regional mean. The country have been grouped according to the United Nations Geoscheme regions (M49 standard). All countries with a population over a million in 1990 are represented. Source: author's calculation

Figure A.8: *Number of environmental legislation per domain - databases comparison*



Note: This figure plots the number of legislation per domain for the FAOLEX database (lightest shades) and the Environmental Legislation dataset (darkest shades). The domains are sorted according to the number of legislation per domain in the EL dataset. FAOLEX database display 150 000 legislation documents and the EL dataset counts 70 000 legislation documents. The EL dataset is a subset of the FAOLEX database focusing on environmental policies. Source: author's calculation.

Table A.4: *List of the 70 possible languages of the legislations*

Afrikaans; Albanian; Amharic; Arabic; Armenian; Azerbaijani; Bosnian; Bulgarian; Burmese; Catalan; Chinese; Chinese; Croatian; Czech; Danish; Dhivehi; Dutch; Dzongkha; English; Estonian; French; Galician; Georgian; German; Greek; Hebrew; Hindi; Hungarian; Icelandic; Igbo; Indonesian; Italian; Japanese; Kazakh; Khmer; Kinyarwanda; Korean; Laothian; Latvian; Lithuanian; Macedonian; Malagasy; Malay; Maltese; Mongolian; Norwegian; Norwegian; Oromo; Persian; Polish; Portuguese; Romanian; Rundi; Russian; Serbian; Slovak; Slovenian; Somali; Spanish; Swedish; Thai; Tonga; Turkish; Turkmen; Ukrainian; Uzbek; Venda; Vietnamese; Welsh; Zulu