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What Works? Evaluating Environmental Policy Mixes Through Emissions-Based Impact Indicators

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Abstract

This paper examines the impact of environmental policy stringency on a set of environmental impact indicators. Using a panel dataset of 19 European countries between 1995 and 2020, we find that more stringent environmental policy regimes are associated with significant reductions in potential harms to human health and the environment. Our estimates indicate reductions in environmental pressures ranging from 10% for global warming potential to 27% for aquatic toxicity potential. A disaggregated analysis of policy instruments reveals that market-based measures exert the strongest influence, followed by non-market-based regulations. In contrast, technology support policies - designed to stimulate innovation and investment in green technologies - yield the smallest gains. Such support can yield substantial environmental benefits, but only when provided at sufficiently high and sustained levels. It is worth-noting that our results are most representative of production-based environmental impact categories. Taking into account consumption-based emissions yields less positive results.

Keywords: environmental performance; environmental policy; Life-cycle analysis; environmental footprint; production-based emissions
JEL codes: Q5, Q48, H1, H5, K32

1 Introduction

The growing urgency to address climate change and environmental degradation has spurred the advancement of sustainable development initiatives. Notably, many of the Sustainable Development Goals (SDGs) outlined in the 2030 Agenda for Sustainable Development explicitly target environmental challenges (UN, 2015). Similarly, the European Green Deal sets an ambitious objective of achieving climate neutrality by mid-century (EC, 2019). In response to these global and regional commitments, environmental policy has intensified significantly. According to the OECD, the stringency of environmental policies in member countries has more than doubled over the past two decades (Kruse et al., 2022). European countries, in particular, have rapidly expanded both the scope and stringency of regulations aimed at curbing air pollution and reducing greenhouse gas emissions, with the overarching goal of reaching net-zero emissions. As these policy efforts continue to accelerate, it becomes increasingly important to evaluate their effectiveness in delivering measurable environmental improvements (Sanye Mengual and Sala, 2023). This is especially critical given the substantial costs such policies impose on both governments and citizens.

Reflecting this importance, a growing body of literature examines the relationship between environmental policies and various environmental or economic indicators. However, much of this research has concentrated on individual pollutants or specific regulatory instruments.[1] In contrast, relatively few studies have undertaken cross-country or cross-sector evaluations of broader environmental policy frameworks (e.g., Dechezleprêtre et al. (2023); Abrell et al. (2011); Costa et al. (2024); Esty and Porter (2005)), and even fewer have assessed their wider impacts on ecosystems and human health. This leaves a significant gap in

[1] See Dechezleprêtre et al. (2019) for a review.

our understanding of how comprehensive policy mixes influence environmental performance across diverse contexts.

This paper addresses that gap by providing a first sector-level, cross-country analysis of the effectiveness of environmental policy regimes across multiple environmental pressures. Using panel data from 19 European countries spanning 1995–2020, we assess the aggregate effects of existing environmental policy frameworks as well as the relative performance of different policy domains (i.e. market-based, non-market-based, and technology support measures). Our approach integrates a broad set of environmental impact indicators derived from key air pollutants, allowing us to assess aspects of all three dimensions of the triple planetary crisis —climate change, biodiversity loss, and pollution - and related health impacts. That is, it enables a more holistic evaluation of environmental outcomes and offers new insights into the comparative effectiveness of various components of environmental policy mixes, contributing to both the academic literature and policy debate.

We employ Life-Cycle Assessment (LCA) methods to construct composite indicators that capture progress across multiple environmental dimensions, including human health, biodiversity, and climate change. LCA has become a widely recognized approach for evaluating environmental performance, and is increasingly used in policy contexts (Hellweg et al., 2023). As an example, the European Commission identifies LCA as a key tool for assessing the environmental sustainability of EU policies through impact assessments and has developed its own LCA-based framework (EC, 2021a,b; Sanye Mengual and Sala, 2023).

Our six environmental impact indicators are derived by aggregating emissions data from key air pollutants using LCA-based characterization factors (Styles et al., 2009; Guinée et al., 2002). This approach enables a more integrated assessment of environmental impacts across sectors and countries than using stand-alone emissions as measures of environmental outcomes. The emissions data are sourced from official air emissions inventories reported under the Convention on Long-Range Transboundary Air Pollution and the United Nations Framework Convention on Climate Change, ensuring consistency and comparability across jurisdictions. By using emissions data at the sector-level, we introduce variation that allows us to capture within-sector dynamics, offering deeper insights into how environmental performance responds to policy stringency.

As a measure of environmental policy stringency, we use the OECD's Environmental Policy Stringency (EPS) index. This index is particularly well-suited for our analysis, as it captures the overall policy mix implemented by countries over time, serving as a proxy for the strictness of environmental governance across national contexts (Kruse et al., 2022). The EPS index includes sub-indices by policy domain - namely, market-based instruments, non-market regulations, and technology support measures - allowing for a more nuanced examination of policy composition, and it is available for the 19 European OECD member countries over the study period.

Our empirical model also includes real GDP growth and energy prices to control for time-specific shocks that might be driving emissions (i.e. supply-side drivers) (Dechezleprêtre et al., 2023). We also account for unobserved, time-invariant characteristics - such as a administrative, political, scientific, and technical capabilities and institutions - through the inclusion of country and sector fixed effects. In our baseline model, we use the scores of the EPS index and sub-indices as variables of interest. In subsequent specifications, we also categorize the EPS index into discrete stringency levels (low, medium, high) to explore potential non-linearities in the effects of policy.

Our findings provide robust evidence that more stringent environmental policies are associated with significant reductions in all six environmental impacts. We find that a one-unit increase in the policy stringency score leads to substantial within-sector reductions in aquatic toxicity potential (27.3%), acidification potential (25.3%), and eutrophication potential (22.2%). More moderate, yet still meaningful, reductions are observed for human toxicity potential (17.8%), tropospheric ozone formation potential (14.9%) and global warming potential (10.3%).

Further analysis reveals that market-based instruments are particularly effective in improving environmental outcomes across most impact categories, despite their uneven implementation across countries. Non-market-based regulations also show consistent and significant associations with environmental improvements, even in outcomes not directly affected by the regulations accounted for in the EPS index. This underscores the EPS's value as a comprehensive proxy for the overall environmental policy stance of a country. In contrast, technology support policies exhibit weaker and more diverse effects, suggesting that the levels of support may have been insufficient to fully harness the potential of green innovation. The results also point to non-linearities in policy effectiveness, with high-stringency regimes delivering the most substantial environmental benefits - and, highlighting the importance of ambitious and sustained policy efforts to meet long-term climate and environmental goals.

In one of the robustness checks, we employ as alternative dependent variables the European Commission's LCA-based indicators, focusing on the two headline metrics: the Domestic Footprint and the Consumption Footprint. The Domestic Footprint captures the environmental impacts associated with domestic production activities, while the Consumption Footprint reflects the impacts embedded in goods and services consumed within the EU, including those arising from imports and excluding exports. The results confirm that EU environmental policies are effective in reducing production-based environmental impacts within member states. However, they appear to have no significant influence on consumption-based impacts. This finding aligns with previous studies such as ¡, which show that while the Domestic Footprint has undergone absolute decoupling from economic growth over the past two decades, the Consumption Footprint has only achieved relative decoupling. These patterns suggest that current policy frameworks (as captured by our policy variable) have had limited influence in promoting more sustainable consumption patterns. Future EU environmental strategies may need to place greater emphasis on influencing consumer behaviour and addressing the environmental consequences of consumption.

The remainder of the paper is structured as follows. Section 2 presents the data and offers insights into environmental impacts and the evolution of environmental policies. Section 3 outlines the empirical methodology employed in the analysis. Section 4 discusses the main results. Finally, Section 5 concludes with a summary of findings and policy implications.

1.1 Literature Review

Our study focuses on the impact of environmental policy stringency on country-sector-specific environmental outcomes, while contributing to several related strands of literature.

First, a substantial body of literature examines the impact of environmental policies on both economic and environmental outcomes. A significant portion of this research focuses on how environmental regulation influences firm-level investment and innovation, often through the lens of two key hypotheses: the "Pollution Haven Hypothesis"(McGuire, 1982; Levinson and Taylor, 2008) and the "Porter Hypothesis" (Porter and Van Der Linde, 1995). Other studies explore broader economic effects or or jointly assess economic and environmental outcomes, such as labour market effects, energy consumption and carbon emissions.

To proxy environmental policy stringency, these papers have employed various measures, including pollution abatement costs (Garofalo and Malhotras, 1995; Jaffe and Palmer, 1997; Gray and Shadbegian, 2003), expenditures on environmental protection (Hamamoto, 2006; Leiter et al., 2011), environmental taxes (Martin et al., 2014), emissions trading schemes (Anger and Oberndorfer, 2008; Martin et al., 2016; Marin et al., 2018; Dechezleprêtre et al., 2023; Colmer et al., 2025), emission regulations (Greenstone, 2002; Greenstone et al., 2012), and energy price fluctuations (Aldy and Pizer, 2015; Dechezleprêtre et al., 2020; Marin and Vona, 2021). While these proxies capture certain aspects of policy dynamics, they often suffer from limited comparability across countries and over time.

Our study contributes to this literature by conducting a cross-country, sector-level panel analysis using the Environmental Policy Stringency (EPS) index. This index enables longitudinal analysis across OECD countries provides a more nuanced measure of policy stringency by encompassing multiple policy domains. While previous studies have used the EPS index primarily to examine economic impacts (Albrizio et al., 2017; Dechezleprêtre et al., 2020; Costa et al., 2024; Hassan et al., 2024), we are the first to integrate it into a holistic analytical framework aimed at evaluating the effectiveness of environmental policies in reducing a broad array of environmental pressures.

A second key contribution of our study is the application of Life Cycle Assessment (LCA) methods to measure environmental pressures. Whereas most existing research relies on single indicators—such as carbon emissions—to assess environmental outcomes (Petrick and Wagner, 2014; Klemetsen et al., 2020; Marin and Vona, 2021; Dechezleprêtre et al., 2023; Hassan et al., 2024; Colmer et al., 2025), we extend this approach by incorporating LCA-based metrics that capture impacts related to the three dimensions of the triple planetary crisis, including climate change, biodiversity loss and pollution-related health impacts (Hellweg et al., 2023). Although LCA methods are widely used in environmental sciences, particularly for evaluating the sustainability of products and production-consumption systems (Welling and Ryding, 2021; Beylot et al., 2019; Hertwich and Peters, 2009), they have not, to the best of our knowledge, been systematically applied in the context of ex-post environmental policy evaluation.

Other relevant strands of the literature, also using LCA, focus on distinguishing between "domestic" and "consumption-based" environmental footprints - particularly in the context of policy design and scenario analysis (Pasqualino et al., 2025; Sanye Mengual and Sala, 2023; Castellani et al., 2019) - and addresses the broader issue of economic decoupling from environmental impacts, and consumption within planetary boundaries (Sala et al., 2020; Sanyé-Mengual et al., 2019; Stoknes and Rockström, 2018; Bjørn et al., 2015; Rockström et al., 2009). Although not the central focus of our study, our findings reveal a weak correlation between economic activity and environmental pressures during the period under analysis. We also observe divergent results regarding the effectiveness of policy interventions on consumption-based versus production-based environmental footprints. These result offer support to existing evidence suggesting a decoupling between economic growth and production-related emissions, but not with consumption-based emissions in Europe.

2 Data

The empirical analysis is based on sector-level emissions data aggregated at the country level to obtain environmental outcomes, and country-level indicators of environmental policy stringency. The final dataset includes information on 33 industrial activities across 19 European countries, spanning the period from 1995 to 2020.

In addition, we incorporate a set of country-level economic indicators to account for alternative drivers of environmental performance. This section provides a detailed description of the data and the construction of the variables used in the analysis.

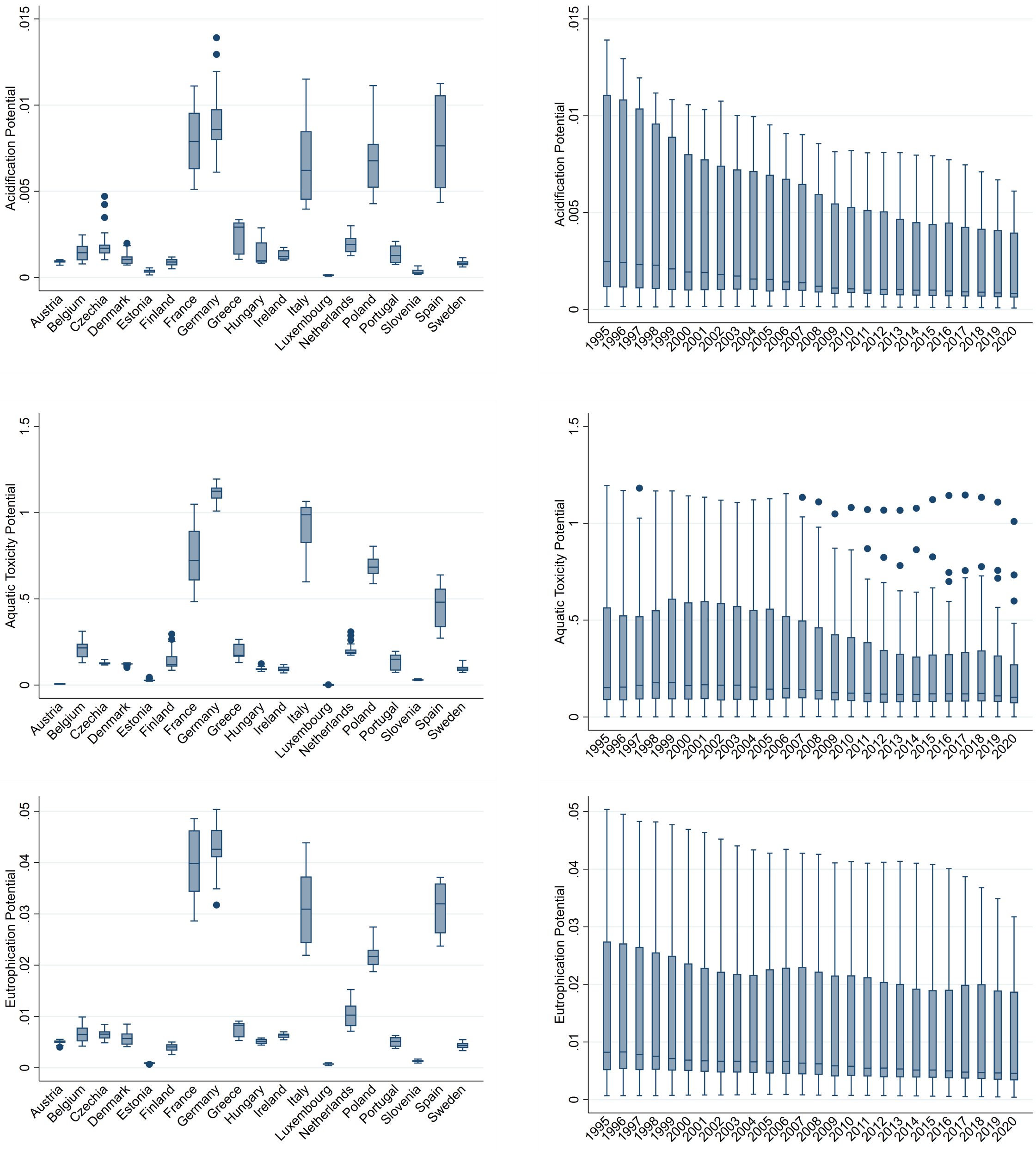
2.1 Environmental impact indicators

As measures of environmental performance, we construct a set of six environmental impact indicators (EIs) which are used as dependent variables in the empirical analysis. The use of environmental impacts, as opposed to emissions of individual pollutants, allows us to capture potential harms posed by emissions to ecosystems and human health. The EIs also account for the fact that a single air pollutant can have an impact on multiple impact categories. The six EIs included in the analysis are global warming potential (GWP), acidification potential (AP), human toxicity potential (HTP), aquatic toxicity potential (ATP), eutrophication potential (EP), and tropospheric ozone formation potential (TOFP).

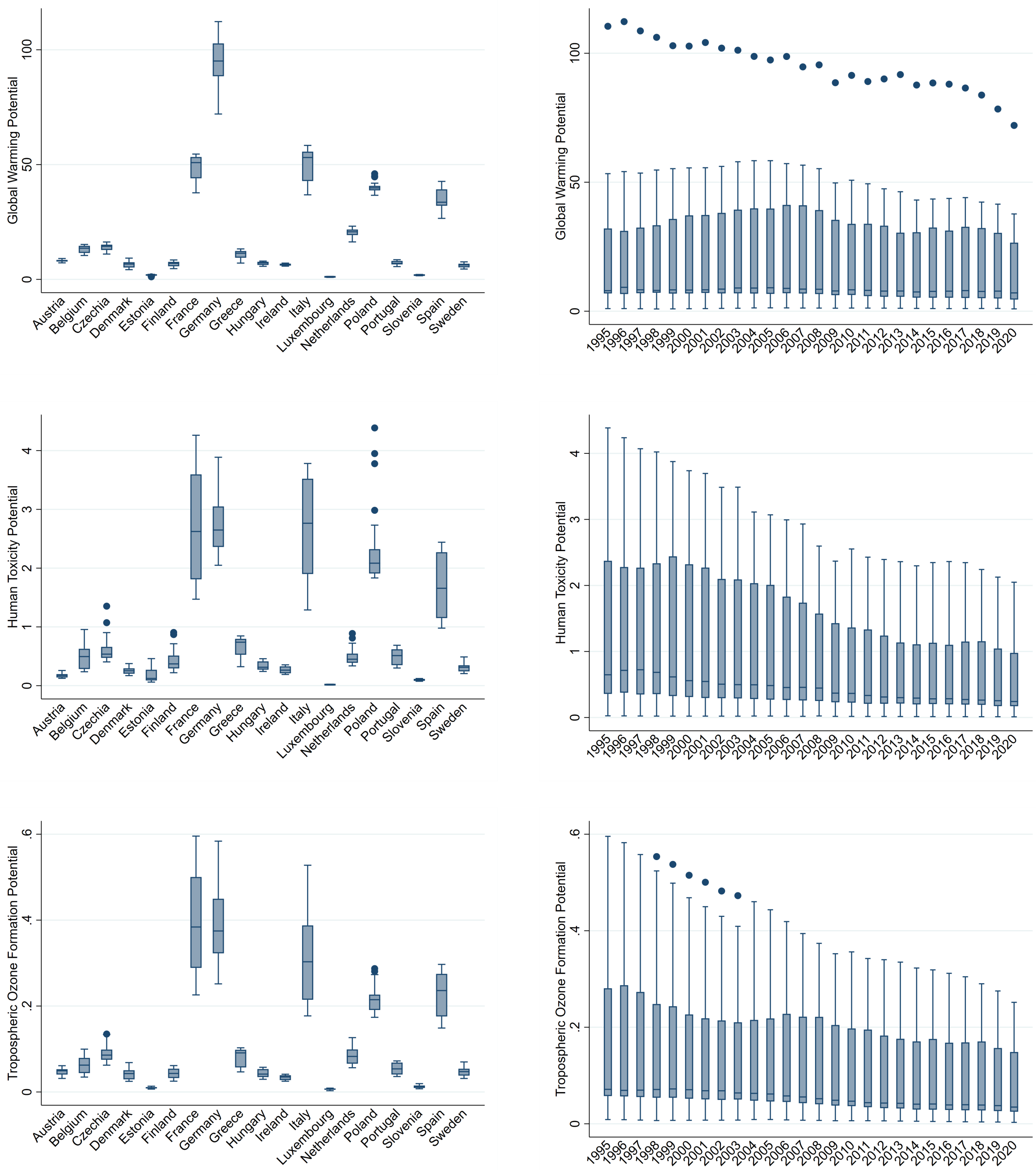
Figure 1 exhibits the evolution of the environmental impact indicators at country-level. We use boxplots to show the distribution of the data. The column on the left-hand side displays the data by country, while the right-hand column presents the data by year. In each box plot, the central line indicates the median (50th percentile). For the country-level charts (left column), this represents the median value for each country over the study period. For the time-series plots (right column), it reflects the median across all countries in a given year. The lower and upper edges of each box correspond to the 25th and 75th percentiles, respectively. The "whiskers" extend to the adjacent values, defined as 1.5 times the interquartile range (IQR) below the 25th percentile and above the 75th percentile. Outliers beyond these bounds are shown as individual dots.

Overall, we observe that all six environmental impact categories improved on average over the study period, although there is substantial variation both across and within countries. France, Germany, Italy, Poland, and Spain exhibit higher environmental impacts. The wider IQRs reflect significant progress over time, as higher values are typically concentrated in the earlier years of the sample and lower values in later years. The time-series plots reveal a downward trend in the 75th percentiles, indicating narrowing IQRs and a convergence toward lower impact levels of all countries. This visualisation of the indicators suggests that global warming potential and eutrophication have achieved the least progress overall.

Figure 1: Environmental Impact Indicators by Country and Year (Part 1 of 2)



Note: See footnote in Figure 1 (cont'd).



Note: The left-hand side (LHS) column displays EIs by country, while the right-hand side (RHS) column presents EIs by year. In each box plot, the centre line represents the median (50th percentile): for the LHS charts, this is the median value for each country over the study period; for the RHS charts, it is the median across all countries in a given year. The lower and upper edges of each box correspond to the 25th and 75th percentiles, respectively. The ”whiskers” extend to the adjacent values, defined as the 25th percentile minus 1.5 times the interquartile range (IQR) and the 75th percentile plus 1.5 times the IQR. Individual dots represent outliers beyond these bounds.

2.1.1 Data source and construction of environmental indicators

To construct the EIs, we use annual national emissions of air pollutants reported by countries under the Convention on Long-Range Transboundary Air Pollution (LRTAP Convention) and the United Nations Framework Convention for Climate Change (UNFCCC).[2] We apply Life Cycle Assessment (LCA) methods to transform emissions data into the environmental impacts (Styles et al., 2009). LCA methods have become prominent for monitoring progress in environmental performance. For instance, the European Commission regards these methods as an essential sustainability tool to evaluate environmental impacts (EEA, 2025; Pasqualino et al., 2025; Sanye Mengual and Sala, 2023; Sala et al., 2021; Erhart and Erhart, 2023, 2022). In LCA, the cumulative environmental significance of mass emissions is quantified using characterisation factors (CFs) that measure the ("mid-point") potential impact of a substance to the environment over a certain time period. By multiplying emission masses by their impact-specific CFs, the amount of each emission is converted into a common unit, such as CO_2 equivalents for greenhouse gases. Thus, these amounts are comparable within impact category, and determine their contribution to each impact category's total. Formally,

$$EI^{i}_{s,c,t} = \sum_{p=1}^{n} E_{p,s,c,t} \times CF_{p,i}, \tag{1}$$

where $EI^{i}_{s,c,t}$ is the environmental indicator for environmental impact i for country c and sector s in year t. $E_{p,s,c,t}$ stands for reported mass emissions of pollutant p, and $CF_{p,i}$ is the characterisation factor for emissions of p specific to environmental impact i. To get further information on the characterisation factors and the pollutants used for each impact category, see Section A.2 of the Appendix.[3]

The charts shown in Figure 1 aggregate the 33 sector-level indicators to country-level ($EI^{i}_{c,t} = \sum_{s=1}^{33} EI^{i}_{c,s,t}$). Our definition of sector and parent sectors follows the Nomenclature For Reporting used by the Convention on Long-Range Transboundary Air Pollution ("NFR19 sector classification"). The five parent sectors included in the dataset are energy (1), industrial (2), agricultural (3), waste (5) and other (6). The sectors correspond to the second-level in the NFR nomenclature (i.e. 1A, 1B, etc.).[4] For summary statistics of each sector's environmental impacts, see Table A2 in the Appendix.

2.2 Environmental policies

To capture the evolution of the countries environmental policy regime, we use the Environmental Policy Stringency Index (EPS) developed at the OECD (Kruse et al., 2022). The EPS tracks the development of climate change and air pollution policies through 13 distinct policy instruments. It is constructed as

[2] See here for LRTAP data and here for UNFCCC details.

[3] In brief, the pollutants underlying each EI are as follows: AP: Ammonia (NH_3), nitrogen oxides (NO_x) and sulphur oxides (SO_x). ATP: Non-methane volatile organic compounds (NMVOCs) and heavy metals (HMs). EP: NH_3 and NO_x. GWP : Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). HTP: NO_x, SO_x, NMVOCs, particulate matter (PM) and HMs. TOFP: NO_x, NVMOCs, carbon monoxide (CO) and CH_4.

[4] More details can be found at the EEA's LRTAP data site ('Table definition and look-up tables'), and the EEA's EIONET Central Data Repository.

an equally weighted composite indicator, comprising three sub-indices that reflect the use of market-based instruments, non-market-based regulations, and technology support measures.

Market-based instruments include several taxes and emission trading schemes (i.e. for CO_2 and renewable energies). Non-market based regulations cover emission limit values in the energy generation sector and diesel sulphur content limits for vehicles. Technology support policies include public research and development expenditure (R&D), and renewable energy support for solar and wind energy, including feed-in-tariffs.[5]

Each indicator in the EPS is measured on a scale from 0 to 6, with higher values indicating more stringent environmental policies. These indices are designed to be comparable across countries and over time, making the EPS a useful proxy for assessing the relative strength of national environmental policy mixes — even though it may not encompass all aspects of environmental policy (Kruse et al., 2022).[6]

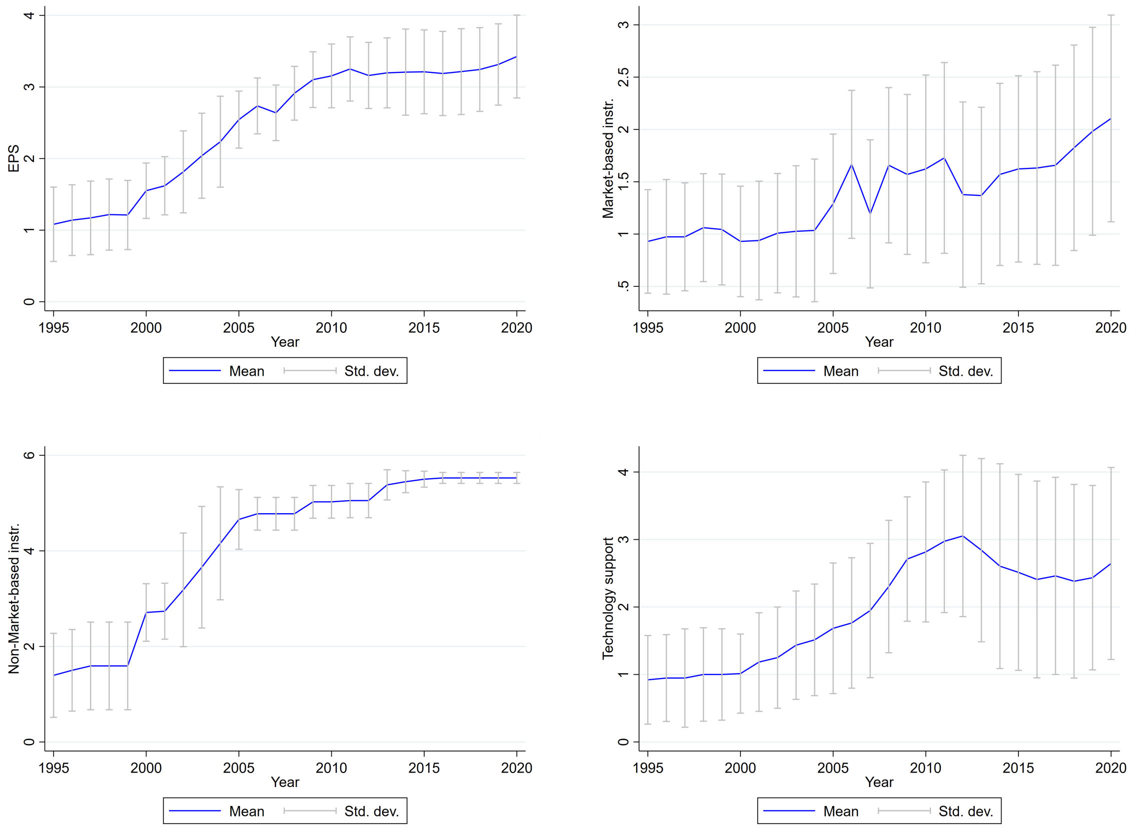
Figure 2 shows the evolution of the EPS and the three sub-indices by plotting the mean and standard deviation across the 19 countries in our sample, and for each year since 1995.[7] The EPS follows an upward trend suggesting, that on average, environmental policy stringency increased markedly until around 2010. However, this momentum slowed considerably in the subsequent years.

[5] The emission limit value indicators for nitrogen oxides (NO_x), sulphur oxides (SO_x) and particulate matter (PM) represents the maximum concentration of each pollutant emissions permitted for a large, newly built coal-fired power plant, as a proxy for emissions standards in the energy generation sector. The sulphur content limit for diesel indicator represents the stringency of the diesel fuel standard with regard to the maximum concentration of sulphur permitted in diesel for automobiles.

[6] For instance, it ignores water, biodiversity, or waste management, for which data is not available in a large cross-country panel.

[7] Our sample comprises the 19 European countries that are members of the OECD, as these are the only European countries with available EPS data.

Figure 2: Environmental Policy Stringency and Sub-Indices



Note: This figure shows the average and standard distribution of the different environmental policy stringency indices. The EPS is an equally- weighted average of the three sub-indices: market-based instrument, non-market based instruments and technology support.

The initial phase of strong growth reflects a period of rapid policy development, characterized by the tightening of regulatory standards across Europe (bottom-left chart). The introduction of EU Directives targetting the energy generation sector, such as the Large Combustion Plant Directive (2001), the IPPC Directive (2008) or Industrial Emissions Directive (2010), and those directed to regulate the maximum sulphur content in diesel fuel for auto-mobiles (i.e. the EU's fuel quality directives) led to a convergence in, and increase in standards across countries. The convergence in standards is evident in the low dispersion of scores in the non-market-based indicator plot. Regulatory standard reached a near maximum score in 2014, and have remained there for the rest of the sample.

In turn, market-based instruments remained relatively underdeveloped in the early years of the sample (top-right chart). It was with the launch of the EU Emissions Trading System (EU ETS) in 2005 and the subsequent introduction of taxes on key pollutants (e.g., CO_2, NO_x, SO_x or Fuel Tax) in different countries that these instruments gained prominence.

Technology support measures, on the other hand, experienced significant growth initially (i.e. particularly up to 2012); but this momentum was disrupted by budgetary constraints following the global financial crisis, leading to a period of stagnation (bottom-right chart). There has been a gradual recovery since 2018, as public investment in clean technologies and innovation support mechanisms began to regain traction.

Despite these general trends in the data, there is considerable heterogeneity across countries for both market-based instruments and technology support measures, as seen by the large standard errors in the corresponding plots in Figure 2.[8]

2.3 Economic performance indicator

2.3.1 Real GDP growth

We use real annual GDP growth to control for the economic cycle and country-specific economic performance in the empirical analysis. The data are sourced from the OECD's Annual National Accounts dataset (expenditure approach). Figure A.2 in the Appendix illustrates the data. Although countries tend to follow broadly a similar economic cycle, there are notable differences in their respective growth rates.

2.3.2 Oil and gas prices

We incorporate annual global crude oil and natural gas prices to account for potential common exogenous shocks that may influence emissions across countries in a given year. The data is sourced from the Energy Institute, based on S&P Global Platts (Energy Institute, a,b). Historical oil price data is available from 1995 onward. For natural gas, we use the UK NBP price series, which closely tracks the Netherlands TTF and Zeebrugge benchmarks during the study period, and it extends further back in time (i.e. the NBP series starts 1996, whereas TTF and Zeebrugge data only begin in 2005). Figure A.3 in the Appendix displays the price trends over time.

[8] For more details, see Figure A.1 in the Appendix, which shows the distribution of the EPS in boxplots by year and country.

3 Empirical methodology

In the empirical analysis, we investigate whether environmental policies have led to measurable improvements in environmental performance using a sector-level panel dataset for the countries in our sample. Specifically, we aim to identify the gains experienced by the different environmental impact categories under study and to assess the relative effectiveness of different policy dimensions. We also explore whether environmental policy exhibits heterogeneous effects on emission reductions based on different policy intensity levels.

In our baseline specification, we regress log-transformed environmental impact indicators on the lagged EPS index ($EPS_{c,t-1}$) and real GDP growth ($GDPgr_{c,t}$). We then include include benchmark log energy prices (P_{t-1}) in the model, as follows:

$$\log EI^{i}_{s,c,t} = \beta_0 + \beta_1 EPS_{c,t-1} + \gamma GDPgr_{c,t} + \delta \log P_{t-1} + d_{p,c} + d_c + \varepsilon_{s,c,t}, \quad (2)$$

where $EI^{i}_{s,c,t}$ stands for environmental indicator i for industrial sector s and country c in year t. The main coefficient of interest, β_1, captures the effect of a country's environmental policy stringency on the corresponding environmental impact. We lag the EPS to account for the likely delayed effects of policy implementation and to mitigate endogeneity concerns arising from potential omitted variables.

To control for time-specific shocks that might be driving emissions, we include economic activity and energy price indicators. These effects are captured by γ and δ, respectively. Economic activity, as captured by GDP growth ($GDPgr_{c,t}$), is country-specific and controls for the economic cycle of each country (i.e. γ measures how much environmental pressures change when output growth increases by 1 percentage point). Benchmark oil and gas prices (P_{t-1}) in a year are common to all countries in the sample, and thus δ captures the impact of a 1 percent increase in prices on emissions. We rely on internationally determined benchmark prices to ensured that they reflect exogenous market shocks.

We also control for country-by-parent sector ($d_{p,c}$) and country (d_c) fixed effects, which capture factors that can impact country-industry pairs or country-wide unobserved characteristics (i.e. general administrative, political, scientific, and technical capabilities and institutions within country and/or sectors). We do not include year fixed effects because a substantial portion of the variation in the EPS index occurs over time, leading to collinearity with time dummies. This issue is particularly relevant in the European context, where many environmental regulations are implemented simultaneously across countries. Precisely to address this limitation in the data, we account for the most relevant time-specific shocks through the inclusion of key economic indicators as explained above. Thus, our estimates primarily capture the within-sector response to a unit-change in the EPS score, net of a sector's parent- and country- specific unobserved characteristics and common time trends.

$\varepsilon_{s,c,t}$ is an unobserved stochastic error term. Standard errors are clustered at country-sector level to account for serial-correlation in the outcome variables over-time within these industries.

Next in the analysis, we undertake a more granular examination of the effects of policy by extending our baseline model with the inclusion of the three sub-indices capturing the different environmental policy domains behind the EPS, such that:

$$\log EI^{i}_{s,c,t} = \beta_0 + \sum_{j=1}^{3} \beta_j EPS^{j}_{c,t-1} + \gamma GDPgr_{c,t} + \delta P_{t-1} + d_{p,c} + d_c + \varepsilon_{s,c,t}, \tag{3}$$

where $EPS^{j}_{c,t-1}$ denotes the lagged value of sub-index j for country c, with j representing either market-based instruments, non-market based instruments, or technology support.

4 Results

Table 1 presents the results from estimating the model in equation (2). Panel *a* reports a specification controlling for GDP growth only. Panel *b* extends this specification by including energy prices. The results suggest that a more stringent environmental policy is associated with significant reductions in the six environmental impacts under study. The magnitude of these effects varies across outcomes, and are larger when energy prices are taken into account. The largest effects are found for aquatic toxicity potential, acidification potential and eutrophication potential, for which a one-unit increase in the EPS is associated with within-sector reductions of up to 27.3%, 25.3%, and 22.2%, respectively. The effects are more moderate for human toxicity potential, tropospheric ozone formation and global warming potential, for which an EPS increase of one-unit is estimated to reduce these impacts by up to 17.8%, 14.9% and 10.3%, respectively.

GDP growth is positively associated with increases in environmental impacts, but the estimated effects appear to be moderate for the sample under study and mostly insignificant. We find that a 1 percentage point increase in GDP growth is linked to increases in the different environmental impacts ranging from approximately 0.2% to 1%. This may indicate that European countries are expanding economic activity at moderate costs for the environment, possibly reflecting gains in efficiency or the adoption of cleaner technologies. Indeed, ¡ reports a case of absolute decoupling between output growth and environmental impacts during the period from 2010 to 2018.

The oil price coefficients are mostly negative although insignificant, while the gas price coefficients are positive, and for three of the environmental impact indicators significant. These findings are consistent with the notion that rising global oil prices tend to dampen economic activity and reduce oil demand within the EU, thereby leading to lower emissions (Baumeister and Hamilton, 2019; Hamilton, 2009). In contrast, increases in gas prices may trigger a shift in the energy mix toward cheaper but more polluting alternatives—such as coal or oil — resulting in higher emissions (Fulwood, 2024). These results also align with existing literature suggesting that, in the short term, firms find it easier to reduce the use of carbon - intensive fuels than to cut back on electricity and natural gas consumption in response to price changes (Marin and Vona, 2021; Dussaux, 2020).

Table 1: Effects of the Environmental Policy Stringency Index on EIs

	Dependent variable:					
	AP	ATP	EP	GWP	HTP	TOFP
	(1)	(2)	(3)	(4)	(5)	(6)
Panel a. Baseline model						
EPS_{t-1}	-0.150**	-0.211***	-0.131***	-0.093***	-0.160***	-0.128***
	(0.047)	(0.034)	(0.039)	(0.025)	(0.027)	(0.030)
GDP growth$_t$	0.008	0.004	0.003	0.004	0.007**	0.007*
	(0.005)	(0.003)	(0.004)	(0.002)	(0.002)	(0.003)
Observations	6201	7370	6130	9192	7753	8406
Adjusted R^2	0.528	0.486	0.514	0.301	0.549	0.488
Panel b. Additional controls: Energy Prices						
EPS_{t-1}	-0.253***	-0.273***	-0.222***	-0.103***	-0.178***	-0.149***
	(0.053)	(0.042)	(0.051)	(0.028)	(0.032)	(0.035)
Oil Price$_{t-1}$	0.027	-0.016	-0.013	-0.037	-0.023	-0.029
	(0.077)	(0.045)	(0.065)	(0.034)	(0.033)	(0.040)
Gas Price$_{t-1}$	0.117**	0.072*	0.123**	0.035	0.025	0.039
	(0.044)	(0.032)	(0.041)	(0.022)	(0.033)	(0.025)
GDP growth$_t$	0.010	0.002	0.003	0.002	0.005*	0.005
	(0.006)	(0.003)	(0.004)	(0.002)	(0.002)	(0.003)
Observations	5749	6827	5682	8508	7180	7791
Adjusted R^2	0.530	0.489	0.515	0.304	0.551	0.493
Fixed Effects:						
Country	X	X	X	X	X	X
Country × Parent-Sect.	X	X	X	X	X	X

Note: *p<0.1; **p<0.05; ***p<0.01. Dependent variables are in logs. Cluster-robust standard errors at country's sector-level in parentheses.

Table 2: Effects of EPS Policy Dimensions on EIs

	Dependent variable:					
	AP	ATP	EP	GWP	HTP	TOFP
	(1)	(2)	(3)	(4)	(5)	(6)
Panel a. Baseline model						
$Market_{t-1}$	-0.206***	-0.200***	-0.173***	-0.056+	-0.116***	-0.105**
	(0.052)	(0.046)	(0.050)	(0.034)	(0.033)	(0.036)
$Non-Market_{t-1}$	-0.036	-0.053**	-0.013	-0.032*	-0.054**	-0.040*
	(0.029)	(0.018)	(0.025)	(0.015)	(0.017)	(0.018)
$Tehcnology\,Support_{t-1}$	-0.006	-0.046*	-0.045	-0.017	-0.026	-0.020
	(0.033)	(0.021)	(0.029)	(0.021)	(0.020)	(0.020)
GDP growth$_{t-1}$	0.008	0.004	0.002	0.004	0.007**	0.007*
	(0.005)	(0.003)	(0.004)	(0.003)	(0.002)	(0.003)
Observations	6201	7370	6130	9192	7753	8406
Adjusted R^2	0.528	0.486	0.514	0.300	0.549	0.488
Panel b. Additional controls: Energy Prices						
$Market_{t-1}$	-0.187***	-0.200***	-0.164***	-0.048+	-0.126***	-0.099**
	(0.047)	(0.044)	(0.048)	(0.028)	(0.031)	(0.031)
$Non-Market_{t-1}$	-0.091**	-0.085***	-0.057*	-0.041**	-0.058***	-0.053***
	(0.031)	(0.018)	(0.028)	(0.013)	(0.015)	(0.015)
$Tehcnology\,Support_{t-1}$	-0.018	-0.045*	-0.048+	-0.018	-0.027	-0.018
	(0.032)	(0.021)	(0.029)	(0.021)	(0.019)	(0.020)
Oil Price$_{t-1}$	-0.006	-0.040	-0.029	-0.046	-0.040	-0.046
	(0.077)	(0.047)	(0.066)	(0.037)	(0.032)	(0.041)
Gas Price$_{t-1}$	0.142**	0.082*	0.118**	0.046+	0.036	0.052*
	(0.043)	(0.033)	(0.041)	(0.025)	(0.027)	(0.022)
GDP growth$_t$	0.010	0.002	0.002	0.002	0.005*	0.005
	(0.006)	(0.004)	(0.004)	(0.002)	(0.002)	(0.003)
Observations	5749	6827	5682	8508	7180	7791
Adjusted R^2	0.531	0.490	0.515	0.304	0.551	0.493
Fixed Effects:						
Country	X	X	X	X	X	X
Country × Parent-Sect.	X	X	X	X	X	X

Note: *p<0.1; **p<0.05; ***p<0.01. Dependent variables are in logs. Cluster-robust standard errors at country's sector-levels in parentheses.

Table 2 provides a breakdown of the effects of environmental policy by policy dimension. Market-based instruments contribute more prominently to improving environmental outcomes for all environmental impact categories. This suggests that despite a less harmonious implementation of tax instruments and trading schemes compared to non-market-based instruments in Europe, they have had a strong impact in those countries where they have been implemented.

Nonetheless, non-market-based regulations also show strong associations with reductions across all environmental impact indicators - specially when accounting for energy prices (Panel *b*). Notably, the effects of these instruments remain significant even for impact categories not directly targeted by the regulations included in the EPS index (e.g., aquatic toxicity potential). This is partly because several EU directives that introduced emission limit values for the pollutants included in the EPS also addressed additional pollutants — such as ammonia and heavy metals — or were implemented alongside other regulations targeting these other substances. This underscores the robustness of the EPS index as a proxy for capturing the overall environmental policy stance of countries.

In contrast, technology support policies present a mixed picture. While all coefficients have the expected negative sign, they are not so precisely estimated (i.e. their statistical significance differs across impact categories) and their magnitudes are smaller compared to the other two types of environmental policies. This may indicate that the current level of support has not been enough to ensure that the benefits of technological innovation are shared widely across different industries. We explore this further in the next section, in which we analyse the potential for non-linear effects across different policy stringency levels.

It is also worth noting the relatively weak influence of each policy domain on global warming potential. Unfortunately, the study period concludes just before the significant rise in EU ETS carbon prices that began in 2018. During these earlier trading phases, EU ETS prices were highly volatile, which is reflected in the low scores attributed to the market-based policy component in Figure 2. As a result, these findings may not capture the full potential impact of market-based instruments on climate change.

4.1 Robustness checks

4.1.1 Differential effects of policy intensity

The findings in the previous section show that environmental policy has substantial effects on all environmental impact categories. In this section, we examine whether the effectiveness of these policies follows a non-linear pattern. That is, whether a certain level of policy stringency is necessary to trigger meaningful reductions in emissions, or whether significant impacts can be observed even at low levels of policy intensity.

To explore this, we replace the explanatory variables in model (2) and (3) with a set of dummy variables that capture three levels of policy stringency: low, medium and high. These dummies are defined as follows:

$$Low_{j,c,t-1} = \mathbf{1}[EPS^{j}_{c,t-1} < 2] \tag{4}$$

$$Med_{j,c,t-1} = \mathbf{1}[2 \leq EPS^{j}_{c,t-1} < 4] \tag{5}$$

$$High_{j,c,t-1} = \mathbf{1}[4 \leq EPS^{j}_{c,t-1}] \tag{6}$$

where now j can represent either the EPS, or one the three policy dimensions depending on the specification. $Low_{j,c,t-1}$ captures low levels of stringency, and equals one if the score of the policy stringency index is less than 2. $Med_{j,c,t-1}$ represents medium stringency levels, and is equal to one if the underlying score is greater than or equal to 2 but less than 4. The high stringency dummy, $High_{j,c,t-1}$, equals one if the score is greater than or equal to 4; 0 otherwise.

Table 3 provides evidence of heterogeneous effects in the relationship between environmental policy stringency and environmental outcomes, as measured by the EPS index. The results indicate that high-stringency policy regimes are associated with substantially greater reductions in environmental harm compared to lower levels of stringency. The estimated effects of high-stringency policies are, in general, more than twice as large as those associated with medium-stringency regimes. Nonetheless, medium-stringency regimes also yield significantly greater reductions in emissions than low-stringency regimes, although its effects are less precisely estimated.

Specifically, high-stringency policies are estimated to reduce environmental pressures by between 27% and 44% more than low-stringency regimes, depending on the environmental impact considered. The most pronounced effects are observed for aquatic and human toxicity potentials, suggesting that stringent policy regimes are particularly effective in addressing environmental impacts linked to localized issues. This aligns with well-established findings in the literature that environmental regulations tend to be more successful when targeting spatially concentrated problems. For instance, ¡ notes that "income-driven improvements in environmental performance seem to emerge most quickly for the most localized problem (particulates) and least rapidly with regard to energy impacts, in which a significant element of harm (notably greenhouse gas emissions from fossil fuel burning) spreads widely over space and time." Our findings reinforce this perspective, highlighting the greater responsiveness of localized environmental pressures to policy interventions.

We also present results for stringency dummies disaggregated by EPS sub-components (Table 4), providing further insight into the differential effects of specific policy domains. The estimation of this specification is more demanding due to the increased number of explanatory variables. Nevertheless, the findings indicate that a high degree of policy stringency is generally necessary for individual policy dimensions to exert a discernible effect on environmental impacts. Both market- and non-market- based instruments exhibit statistically significant effects at high levels of stringency. Notably, the estimated coefficients for non-market-based instruments are larger in magnitude and more precisely estimated compared to those for market-based instruments. This difference may be reflecting the limited number of observations for which market-based

Table 3: Effects of different Stringency Levels on EIs

	Dependent variable:					
	AP	ATP	EP	GWP	HTP	TOFP
	(1)	(2)	(3)	(4)	(5)	(6)
EPS index:						
$Medium_{t-1}$	-0.127	-0.143**	-0.146+	-0.106**	-0.113**	-0.089*
	(0.083)	(0.052)	(0.077)	(0.033)	(0.043)	(0.045)
$High_{t-1}$	-0.299**	-0.442***	-0.279**	-0.269***	-0.309***	-0.268***
	(0.097)	(0.088)	(0.099)	(0.057)	(0.063)	(0.063)
Oil Price$_{t-1}$	-0.127+	-0.176***	-0.142*	-0.082**	-0.123***	-0.111***
	(0.068)	(0.044)	(0.057)	(0.027)	(0.032)	(0.032)
Gas Price$_{t-1}$	0.073	0.024	0.097*	0.033	0.002	0.016
	(0.050)	(0.034)	(0.041)	(0.024)	(0.031)	(0.024)
GDP growth$_t$	0.013*	0.006	0.005	0.003	0.007**	0.006*
	(0.006)	(0.003)	(0.004)	(0.002)	(0.002)	(0.003)
Observations	5749	6827	5682	8508	7180	7791
Adjusted R^2	0.529	0.489	0.514	0.304	0.550	0.493
Fixed Effects:						
Country	X	X	X	X	X	X
Country × Parent-Sect.	X	X	X	X	X	X

Note: *p<0.1; **p<0.05; ***p<0.01. Dependent variables are in logs. The dummy variable for low policy intensity serves as the reference category and is therefore excluded from the estimation. The Medium stringency dummy corresponds to EPS scores ranging from 2 to less than 4, while the High stringency dummy captures scores of 4 or higher. Cluster-robust standard errors at country's sector-level in parentheses.

instruments achieve high stringency levels (as discussed earlier regarding the evolution of EU ETS prices in this period). In contrast, the strong and consistent significance of non-market-based coefficients shows that rigorous enforcement of environmental standards yields tangible environmental benefits.

Perhaps more revealing now are the estimates for technology support measures, which previously showed limited effects. The results in Table 4 indicate that innovation policy packages achieving higher EPS scores are associated with significantly stronger environmental outcomes compared to low levels of technology support, while moderate stringency appears insufficient to drive transformative change. Overall, these findings highlight the importance of scaling up technology support instruments to achieve meaningful environmental improvements — particularly in the context of climate change mitigation - as emphasized by both practitioners and scholars elsewhere (IEA, 2021; Acemoglu et al., 2012; OECD, 2018).

4.1.2 Using the European Commission's Domestic- and Consumption- Footprint indices

The European Commission has developed its own LCA-based framework to measure the environmental impacts associated to EU production and consumption. It includes two headline indicators. The Domestic Footprint quantifies the environmental impacts of production activities occurring within the borders of European countries, capturing the effects of domestic emissions. It is calculated as a single-weighted average of sixteen environmental impact categories. The Consumption Footprint, on the other hand, measures the environmental impacts linked to the consumption of goods and services within the EU - accounting for impacts embedded in imports and excluding those in exports. This distinction reflects the fact that EU countries are net importers of environmental pressures (Sanyé Mengual et al., 2022; Sanye Mengual and Sala, 2023; Sanye Mengual et al., 2025).

We re-estimate the models in equation (2) and (3) using these indicators and the environmental impact categories closer to those in the main analysis. The data is only available at the country-level (as opposed to sector-level); hence, these estimates provide within-country effects. And the time-series cover a shorter time span. The Domestic Footprint extends back to 2000, while the Consumption Footprint is available from 2010 onwards. Despite these limitations, this exercise serves two key purposes. First, it allows us to verify the robustness of our findings using alternative dependent variables and to extend the results to different impact categories. Second, it provides insights into the effectiveness of environmental policy in shaping consumption-based emissions patterns, offering implications for national-level policy evaluation.

Table 5 presents the regression results. Panel *a* of Column (1) and (2) report the estimates for the Domestic Footprint and Consumption Footprint, respectively. The findings indicate that a one-point increase in environmental policy stringency is associated with a 12% reduction in the Domestic Footprint. In contrast, the coefficient for the Consumption Footprint is positive and statistically insignificant, suggesting limited policy influence on consumption-based environmental impacts.

Panel *b* provides a breakdown of the EPS index by policy domain. The results reaffirm the central role of market-based instruments in driving reductions in domestic environmental pressures, followed by non-market-based instruments. Technology support policies, however, continue to show moderate and less

Table 4: Effects of Policy Stringency Dummies by EPS policy domain on EIs

	Dependent variable:					
	AP	ATP	EP	GWP	HTP	TOFP
	(1)	(2)	(3)	(4)	(5)	(6)
Market:						
$Medium_{t-1}$	-0.040	-0.097	0.001	0.001	-0.088	0.019
	(0.076)	(0.078)	(0.077)	(0.040)	(0.055)	(0.053)
$High_{t-1}$	-0.127+	-0.168*	-0.137+	-0.026	-0.098+	-0.079
	(0.071)	(0.067)	(0.071)	(0.041)	(0.056)	(0.055)
Non-Market:						
$Medium_{t-1}$	-0.134+	0.013	-0.057	0.041	-0.020	0.008
	(0.074)	(0.055)	(0.066)	(0.039)	(0.054)	(0.051)
$High_{t-1}$	-0.185*	-0.275***	-0.144*	-0.141***	-0.179***	-0.164***
	(0.077)	(0.039)	(0.068)	(0.037)	(0.032)	(0.041)
Technology Support:						
$Medium_{t-1}$	-0.014	0.005	-0.071	-0.025	0.037	0.019
	(0.043)	(0.037)	(0.052)	(0.029)	(0.033)	(0.030)
$High_{t-1}$	-0.158+	-0.242**	-0.139	-0.041	-0.190**	-0.142*
	(0.086)	(0.091)	(0.086)	(0.053)	(0.063)	(0.068)
Oil $Price_{t-1}$	-0.101	-0.142**	-0.122*	-0.087**	-0.104***	-0.103**
	(0.069)	(0.046)	(0.056)	(0.030)	(0.030)	(0.036)
Gas $Price_{t-1}$	0.134**	0.097**	0.129**	0.062**	0.039	0.056*
	(0.050)	(0.033)	(0.041)	(0.021)	(0.027)	(0.024)
GDP $growth_t$	0.010+	0.003	0.002	0.002	0.005*	0.005+
	(0.006)	(0.003)	(0.004)	(0.002)	(0.002)	(0.003)
Observations	5749	6827	5682	8508	7180	7791
Adjusted R^2	0.529	0.489	0.514	0.303	0.550	0.493
Fixed Effects:						
Country	X	X	X	X	X	X
Country × Parent-Sect.	X	X	X	X	X	X

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. Dependent variables are in logs. Cluster-robust standard errors at sector-level in parentheses.

precisely estimated effects. The coefficients for the Consumption Footprint regressions remain statistically insignificant across all policy domains.

The coefficient estimates for the various environmental impact categories (Columns 3–12) reinforce the main findings of this paper. At the country level, we observe substantial reductions across most indicators, including several that were not part of our primary analysis. Notably, the coefficient for global warming potential is smaller and statistically insignificant. This may be due to the lack of sectoral granularity in the dataset, which could be missing out sectoral dynamics, or because the indicator does not account for nitrous oxide (N_2O), a key greenhouse gas included in our indicator. Regarding policy domains, we also find similar patterns in the results; that is, in general, the coefficients for market and non-market based instruments are negative and significant.

Table 5: Effect of EPS on the EC's Environmental Impact Indicators

	Dependent variable:											
			Domestic-FP's Environmental Impacts									
	Domestic-FP	Consumption-FP	AP	GWP	ET	EP-FW	EP-MW	EP-T	HTP-C	HTP-NC	POF	OD
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel a. EPS aggregate												
EPS_{t-1}	-0.122^{***}	0.013	-0.310^{***}	-0.058	-0.026	-0.098^{***}	-0.158^{***}	-0.143^{***}	-0.153^{***}	-0.142^{***}	-0.270^{***}	-0.301^{***}
	(0.020)	(0.023)	(0.034)	(0.037)	(0.021)	(0.020)	(0.027)	(0.020)	(0.057)	(0.022)	(0.029)	(0.083)
Oil Price$_{t-1}$	-0.045^{*}	-0.131^{***}	-0.064	-0.165^{**}	-0.030	-0.090^{**}	-0.049	-0.060^{**}	-0.0005	-0.061^{**}	-0.068	-0.063
	(0.025)	(0.019)	(0.068)	(0.067)	(0.034)	(0.039)	(0.032)	(0.029)	(0.049)	(0.029)	(0.053)	(0.111)
Gas Price$_{t-1}$	0.064^{***}	0.092^{***}	0.089^{**}	0.130^{***}	-0.004	0.027	0.075^{***}	0.077^{***}	0.026	0.032	0.112^{***}	0.090
	(0.020)	(0.015)	(0.045)	(0.038)	(0.022)	(0.029)	(0.019)	(0.018)	(0.046)	(0.022)	(0.037)	(0.072)
GDP growth	0.004^{***}	0.0001	0.011^{***}	0.006^{*}	0.003	0.003^{*}	0.004^{*}	0.003^{**}	0.003	0.002	0.006^{**}	0.003
	(0.002)	(0.001)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)	(0.003)	(0.002)	(0.003)	(0.010)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Observations	399	209	399	391	399	399	399	399	399	399	399	399
Adjusted R^2	0.536	0.241	0.610	0.147	0.139	0.579	0.559	0.609	0.238	0.619	0.640	0.254
Panel b. EPS policy domains												
$Market_{t-1}$	-0.059^{***}	0.020	-0.122^{***}	-0.060	0.007	-0.035^{**}	-0.055^{***}	-0.059^{***}	-0.121^{**}	-0.044^{**}	-0.110^{***}	-0.313^{***}
	(0.020)	(0.012)	(0.031)	(0.037)	(0.019)	(0.017)	(0.021)	(0.018)	(0.055)	(0.019)	(0.034)	(0.100)
$Non-Market_{t-1}$	-0.031^{***}	-0.013	-0.141^{***}	-0.002	-0.019	-0.039^{***}	-0.048^{***}	-0.046^{***}	-0.039	-0.048^{***}	-0.092^{***}	-0.055^{*}
	(0.011)	(0.019)	(0.027)	(0.024)	(0.013)	(0.010)	(0.014)	(0.011)	(0.032)	(0.015)	(0.022)	(0.031)
$TehcnologicalSupport_{t-1}$	-0.018^{*}	0.003	-0.020	0.015	0.005	-0.028^{**}	-0.038^{*}	-0.023	0.011	-0.040^{**}	-0.036	0.012
	(0.010)	(0.006)	(0.029)	(0.015)	(0.009)	(0.011)	(0.020)	(0.016)	(0.029)	(0.018)	(0.026)	(0.058)
Oil Price$_{t-1}$	-0.050^{*}	-0.146^{***}	-0.162^{**}	-0.187^{**}	-0.070^{*}	-0.122^{***}	-0.062	-0.084^{**}	-0.086	-0.089^{***}	-0.109^{**}	-0.193
	(0.030)	(0.027)	(0.070)	(0.079)	(0.040)	(0.042)	(0.041)	(0.034)	(0.056)	(0.033)	(0.053)	(0.146)
Gas Price$_{t-1}$	0.002	0.133^{***}	0.077	0.092^{*}	0.029	0.039	0.020	0.037^{*}	0.026	0.014	0.028	0.069
	(0.024)	(0.028)	(0.057)	(0.053)	(0.026)	(0.035)	(0.027)	(0.020)	(0.060)	(0.025)	(0.039)	(0.098)
GDP growth	-0.00004	0.002^{*}	0.004	0.003	0.005^{*}	0.002	-0.001	-0.001	0.001	-0.001	-0.002	0.004
	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)	(0.004)	(0.002)	(0.003)	(0.011)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	380	190	380	373	380	380	380	380	380	380	380	380
Adjusted R^2	0.482	0.362	0.582	0.115	0.154	0.573	0.501	0.547	0.218	0.587	0.582	0.294

Note: *p<0.1; **p<0.05; ***p<0.01. Dependent variables are in logs. Cluster-robust standard errors at country's sector-level in parentheses. Dependent variables: ET: Ecotoxicity. EP-FW/M/T: eutrophication fresh water/marine water/terrestrial. HTP-C/NC: human toxicity potential cancer/non-cancer. POF: photochemical ozone formation. OD: ozone depletion.

Overall, these findings demonstrate that EU environmental policies have been effective in improving production-based environmental outcomes within Member State borders. However, they appear to have had little to no impact on promoting sustainable consumption. This finding is consistent with previous studies such as ¡ and ¡, which show that while the Domestic Footprint has undergone absolute decoupling from economic growth over the past two decades, the Consumption Footprint has only achieved relative decoupling - and that indeed, the gap between environmental impacts occurring within the EU's borders and those linked to consumption through global supply chains appears to be widening.

5 Conclusions

This paper has examined the causal impact of environmental policy stringency on a set of environmental impact categories, using sector-level panel data from 19 European countries over the period 1995–2020. By constructing composite indicators from air emissions data, we assess how different policy instruments, captured through the OECD's Environmental Policy Stringency (EPS) index and its sub-components, affect key environmental outcomes.

Our findings indicate that increased policy stringency is associated with statistically significant reductions across all six environmental impact indicators. The strongest effects are observed for aquatic toxicity potential, acidification potential and eutrophication potential. In contrast, the impact on global warming potential is comparatively weaker, despite the implementation of major EU-level initiatives such as the CO_2 Emissions Trading Scheme and carbon taxes during the study period. It is important to acknowledge that one of the limitations of the data is that it doesn't include the most recent years, during which carbon pricing in Europe increased markedly. As a result, these results may provide only a partial view of the full potential impact of market-based instruments on carbon emissions.

When accounting for non-linear effects, the analysis reveals a stronger potential for policy-driven reductions at higher levels of stringency, underscoring the importance of ambitious and sustained regulatory efforts. Notably, non-market-based instruments have proven effective where implemented, particularly given that many have already reached near-maximum levels of stringency. In contrast, market-based instruments still offer untapped potential for mitigating global warming, in particular. These instruments could be further strengthened, for example, by increasing carbon prices, raising CO_2 tax rates, or harmonising renewable energy trading mechanisms across the EU. Enhancing these tools could play a pivotal role in accelerating emissions reductions, especially in sectors where progress remains limited.

The results also underscore the importance of reinforcing technology-support policies to accelerate climate goals. Our analysis reveals that such support can yield substantial environmental benefits, but only when provided at sufficiently high and sustained levels — conditions that have not been consistently met across the countries in our sample. Ensuring long-term and robust investment in clean technologies is therefore essential to unlocking their full potential. Indeed, it is increasingly recognized among policymakers and economists that ambitious carbon pricing alone is insufficient. Complementary policies—particularly those that foster innovation and reduce investment risk are necessary to ensure an investment trajectory aligned with the net-zero objective by 2050 (Blanchard et al., 2023; Nordhaus, 2019; Schubert et al., 2023; Stiglitz, 2019).

Finally, the paper finds that consumption-based emissions are unaffected by existing environmental policy regimes. While there is clear evidence of the success of policy initiatives across Europe in relation to environmental outcomes associated with production activity, there has not been a parallel improvement in the environmental outcomes associated with consumption. This resonates with the concept of environmental outsourcing, reinforcing the observation that the production of consumer goods involving environmentally harmful practices has increasingly been relocated outside of Europe. As the European Green Deal increasingly incorporates transboundary considerations — evidenced by initiatives such as the Carbon Border Adjustment Mechanism —, these findings support the idea that future EU strategies should place greater emphasis on influencing consumer behaviour and mitigating the environmental consequences of consumption.

While our study provides robust evidence of the effectiveness of environmental policy, it is limited by the availability and granularity of emissions data. Future research could explore subnational dynamics or the role of political and institutional factors in shaping policy effectiveness, as well as that of consumer-based policies. Additionally, further investigation into the long-term effects of technology support and innovation policies at firm-level could inform more targeted climate strategies.

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A Appendix

A.1 Summary statistic tables and boxplot charts

Table A1 shows summary statistics of all the variables used in the analysis. Table A2 summarises the values of the EIs. It counts the number of observation for each sector, and it presents the mean and standard deviations for each indicator. Table A3 presents the count of countries that had a positive value for an instrument and the average scores for each of the thirteen individual instruments considered by the EPS. Figure A.1 exhibits a boxplot of the EPS index by year and country, highlighting the evolution and variability of environmental policy stringency across the sample. Figure A.2 presents a boxplot of annual GDP growth by country and year, highlighting the distribution and variability of economic performance across the sample.

Table A1: Summary statistics, 1996-2020.

	Mean	Std. dev	p10	p50	p90	Obs.
Environmental impact indicators:						
Acidification Potential	2.5e-04	8.6e-04	8.0e-08	6.0e-06	5.2e-04	5985
Aquatic Toxicity Potential	2.2e-02	.11	6.7e-07	1.7e-04	1.6e-02	7108
Eutrophication Potential	1.1e-03	3.2e-03	3.6e-07	1.9e-05	2.7e-03	5916
Global Warming Potential	1.1	5.7	1.2e-03	6.3e-02	1.6	8860
Human Toxicity Potential	6.7e-02	.26	2.3e-05	4.4e-03	.1	7476
Tropospheric Ozone Formation Potential	7.8e-03	3.3e-02	5.0e-06	3.1e-04	1.1e-02	8108
OECD's Environmental Policy Stringency and sub-indices:						
EPS	2.54	0.94	1.31	2.72	3.72	15625
Market-based	1.39	0.82	0.67	1.17	2.50	15625
Non-Market-based	4.23	1.55	1.50	5.00	5.50	15625
Technology support	1.99	1.28	0.50	1.75	4.00	15625
CO_2 Trading Schemes	1.26	1.28	0.00	1.00	3.00	15625
CO_2 Tax	1.02	1.73	0.00	0.00	3.00	15625
CO_2 Tax	1.02	1.73	0.00	0.00	3.00	15625
Fuel Tax (Diesel)	3.85	1.10	3.00	4.00	5.00	15625
NO_x Tax	1.08	1.91	0.00	0.00	5.00	15625
SO_x Tax	0.72	1.51	0.00	0.00	2.00	15625
Renewable Trading Schemes	0.42	1.32	0.00	0.00	1.00	15625
ELV - NO_x	4.00	1.78	1.00	5.00	5.00	15625
ELV - SO_x	4.31	1.27	3.00	5.00	5.00	15625
ELV - PM	3.75	2.21	1.00	4.00	6.00	15625
ELV - Diesel SO	4.88	1.69	1.00	5.00	6.00	15625
R&D Expenditure	2.34	1.74	1.00	2.00	6.00	15625
Wind adoption support	1.74	1.75	0.00	1.00	4.00	15625
Solar adoption support	1.55	1.84	0.00	1.00	5.00	15625
Economic performance indicator:						
GDP growth	2.14	3.41	-1.52	2.30	5.38	15625
Oil price	353.28	193.97	120.09	340.86	683.44	15625
Gas price	18.51	9.49	6.37	16.35	32.15	15625

Table A2: Summary of EIs observation counts and value means by Sector, 1995-2020

NFR code	AP			ATP			EP			GWP			HTP			TOFP		
	C	M	SD	C	M	SD	C	M	SD	C	M	SD	C	M	SD	C	M	SD
1A	494	2.02e-03	2.28e-03	494	2.79e-01	3.07e-01	494	6.82e-03	7.25e-03	494	1.56e+01	1.94e+01	494	6.72e-01	7.48e-01	494	9.16e-02	9.93e-02
1B	430	2.93e-05	5.82e-05	494	1.36e-03	2.77e-03	420	3.20e-05	8.78e-05	494	4.24e-01	7.05e-01	494	2.42e-02	3.04e-02	494	2.77e-03	3.49e-03
1C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2A	238	1.59e-05	4.57e-05	397	1.03e-03	1.54e-03	238	5.38e-05	1.67e-04	494	5.64e-01	6.36e-01	494	9.40e-03	1.19e-02	251	4.93e-04	1.52e-03
2B	450	2.48e-05	3.57e-05	442	8.55e-04	1.54e-03	450	8.18e-05	1.18e-04	442	4.19e-01	5.65e-01	468	5.75e-03	8.09e-03	450	9.28e-04	1.27e-03
2C	442	1.74e-05	3.83e-05	494	2.43e-02	3.46e-02	404	2.71e-05	6.87e-05	475	3.88e-01	5.32e-01	494	6.95e-02	1.56e-01	441	1.54e-03	3.26e-03
2D	172	7.97e-07	1.99e-06	494	1.62e-03	2.26e-03	172	3.11e-06	8.63e-06	494	3.23e-02	4.99e-02	494	1.28e-01	1.67e-01	494	1.47e-02	1.93e-02
2E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2G	494	1.38e-06	1.76e-06	494	1.44e-02	2.62e-02	494	7.41e-06	9.73e-06	494	1.64e-02	2.19e-02	494	1.12e-02	1.77e-02	494	3.26e-04	8.10e-04
2H	317	6.49e-06	1.24e-05	494	1.82e-04	3.43e-04	295	1.78e-05	4.35e-05	197	9.10e-04	2.26e-03	494	9.60e-03	8.71e-03	494	1.18e-03	1.06e-03
2I	36	7.57e-08	3.64e-07	114	3.13e-06	8.39e-06	36	4.09e-07	2.00e-06	0	0	0	215	4.00e-04	1.05e-03	137	4.74e-05	1.17e-04
2J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2K	0	0	0	88	3.11e-05	8.83e-05	0	0	0	0	0	0	88	2.93e-07	8.26e-07	10	2.80e-10	2.78e-09
2L	156	8.30e-08	1.73e-07	116	1.32e-05	6.39e-05	156	4.43e-07	9.09e-07	0	0	0	149	3.05e-04	1.08e-03	87	2.98e-06	1.18e-05
31	0	0	0	0	0	0	0	0	0	494	1.24e+00	1.35e+00	0	0	0	494	5.75e-04	6.29e-04
3A	0	0	0	0	0	0	0	0	0	494	9.12e-01	1.03e+00	0	0	0	494	4.56e-04	5.13e-04
3B	494	4.68e-04	5.06e-04	494	4.28e-04	5.62e-04	494	2.77e-03	3.00e-03	494	3.33e-01	3.52e-01	494	5.31e-02	6.94e-02	494	6.42e-03	8.22e-03
3C	0	0	0	0	0	0	0	0	0	156	1.57e-02	4.61e-02	0	0	0	156	7.83e-06	2.31e-05
3D	494	6.28e-04	7.19e-04	494	1.51e-04	3.05e-04	494	3.73e-03	4.26e-03	494	5.47e-01	5.63e-01	494	2.16e-02	3.94e-02	494	6.20e-03	8.39e-03
3E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3F	260	3.61e-06	1.68e-05	260	3.90e-04	1.57e-03	260	2.02e-05	9.45e-05	260	1.81e-03	7.81e-03	260	2.35e-03	1.08e-02	260	2.58e-04	1.22e-03
3G	0	0	0	0	0	0	0	0	0	468	2.60e-02	4.32e-02	0	0	0	0	0	0
3H	0	0	0	0	0	0	0	0	0	484	1.80e-02	2.73e-02	0	0	0	0	0	0
3I	52	8.97e-07	4.00e-06	0	0	0	52	5.32e-06	2.37e-05	286	4.88e-03	9.01e-03	26	5.64e-07	3.05e-06	26	5.74e-07	3.10e-06
3J	0	0	0	0	0	0	0	0	0	26	4.83e-03	2.60e-02	0	0	0	26	2.06e-06	1.13e-05
5A	165	2.47e-06	8.85e-06	494	1.68e-05	2.22e-05	165	1.46e-05	5.25e-05	494	5.16e-01	6.04e-01	494	1.66e-03	2.39e-03	494	4.54e-04	5.70e-04
5B	488	4.31e-06	6.72e-06	78	1.16e-07	4.65e-07	488	2.56e-05	3.98e-05	473	1.98e-02	2.57e-02	123	1.44e-05	5.67e-05	473	9.35e-06	1.18e-05
5C	442	8.61e-06	2.42e-05	494	3.08e-03	7.68e-03	442	4.67e-05	1.35e-04	416	1.99e-02	4.21e-02	494	8.68e-03	1.69e-02	442	1.04e-03	2.92e-03
5D	263	3.49e-06	8.23e-06	494	3.42e-07	1.36e-06	263	2.07e-05	4.88e-05	494	1.27e-01	1.38e-01	494	3.16e-05	3.80e-05	494	4.94e-05	5.68e-05
5E	177	4.76e-07	1.40e-06	434	4.84e-04	1.56e-03	176	2.39e-06	8.15e-06	94	4.89e-04	1.75e-03	489	8.08e-04	1.44e-03	206	1.68e-05	4.37e-05
6A	130	9.81e-06	2.42e-05	0	0	0	130	5.82e-05	1.44e-04	0	0	0	0	0	0	0	0	0
6B	26	7.27e-07	3.09e-06	26	4.62e-04	1.97e-03	26	4.29e-06	1.83e-05	0	0	0	26	5.65e-02	2.41e-01	26	6.68e-03	2.85e-02

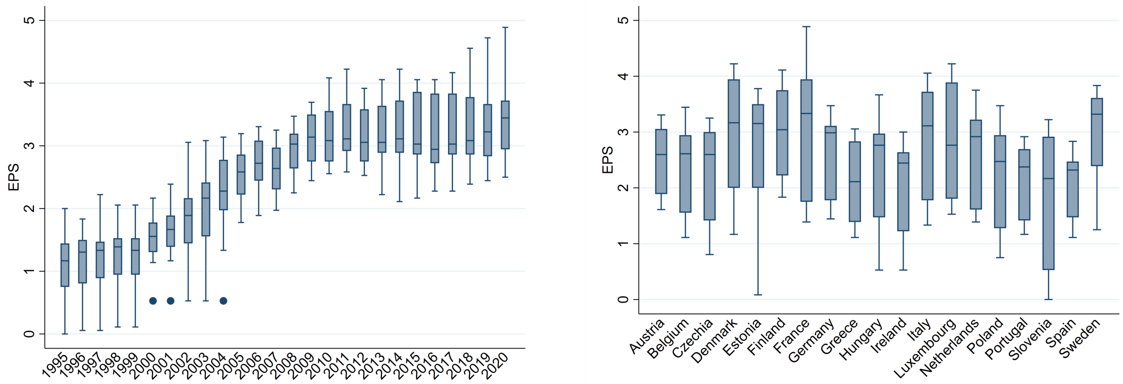
Note: Counts (C) of observations with an EI values greater than zero in each sector. Mean (M) and standard deviation (SD) correspond to the values for all countries and years in the sample. For sector names, see the 'Table definition and look-up tables' in the EEA's LRTAP data site. EIs are expressed in $\times 10^{10}$ kg equivalents per annum.

Table A3: Summary of Policy Instruments: Count of countries (C) and average score (M) in a year, 1995-2020

Year	CO_2 TS		CO_2 Tax		Fuel Tax		NO_x Tax		SO_x Tax		Renew-TS		ELV NO_x		ELV SO_x		ELV PM		ELV Die-SO		R&D Exp.		Wind FIT		Solar FIT	
	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	M
1995	0	0.0	4	0.5	17	4.5	4	0.5	2	0.1	0	0.0	14	1.7	14	2.2	12	0.6	18	1.0	15	1.4	7	0.5	6	0.3
1996	0	0.0	5	0.6	17	4.3	5	0.5	4	0.5	0	0.0	15	1.8	15	2.4	13	0.7	18	1.2	15	1.4	8	0.6	6	0.3
1997	0	0.0	5	0.6	17	4.3	5	0.5	4	0.5	0	0.0	15	1.9	15	2.5	13	0.7	18	1.3	15	1.5	8	0.5	6	0.3
1998	0	0.0	5	0.6	17	4.6	6	0.6	5	0.5	0	0.0	15	1.9	15	2.5	13	0.7	18	1.3	15	1.5	8	0.7	7	0.4
1999	0	0.0	5	0.6	17	4.5	6	0.6	5	0.5	0	0.0	15	1.9	15	2.5	13	0.7	18	1.3	16	1.5	8	0.5	7	0.4
2000	0	0.0	6	0.7	17	3.7	6	0.6	5	0.5	0	0.0	18	2.1	18	3.0	16	0.8	19	4.9	16	1.5	9	0.5	8	0.5
2001	0	0.0	6	0.7	17	3.7	6	0.7	5	0.5	0	0.0	18	2.1	18	3.0	17	0.9	19	5.0	16	1.7	10	0.7	10	0.6
2002	0	0.0	6	0.7	17	4.1	6	0.7	5	0.5	1	0.1	18	2.3	18	3.5	18	1.9	19	5.0	16	1.7	11	0.9	11	0.6
2003	0	0.0	6	0.7	17	4.1	6	0.7	5	0.5	2	0.2	18	3.2	18	3.9	18	2.6	19	5.0	17	1.8	13	1.3	12	0.8
2004	0	0.0	6	0.8	17	3.9	6	0.7	5	0.6	2	0.2	18	4.0	18	4.3	18	3.3	19	5.0	17	1.9	13	1.3	12	0.9
2005	15	1.6	6	0.8	19	3.8	6	0.7	5	0.6	3	0.3	19	4.6	19	4.9	19	4.1	19	5.0	17	2.1	12	1.5	12	1.1
2006	19	4.0	6	0.8	19	3.5	6	0.8	5	0.6	3	0.3	19	4.8	19	5.0	19	4.3	19	5.0	17	2.2	13	1.4	12	1.3
2007	19	1.0	6	0.8	19	3.6	6	0.8	5	0.6	3	0.4	19	4.8	19	5.0	19	4.3	19	5.0	17	2.4	13	1.6	13	1.5
2008	19	4.0	6	0.9	19	3.2	6	0.8	5	0.6	3	0.4	19	4.8	19	5.0	19	4.3	19	5.0	18	2.6	13	2.2	13	1.8
2009	19	2.0	6	0.8	19	4.2	7	1.1	6	0.8	3	0.5	19	4.8	19	5.0	19	4.3	19	6.0	18	2.9	14	2.4	14	2.6
2010	19	2.0	7	1.0	19	3.6	8	1.6	7	0.8	4	0.6	19	4.8	19	5.0	19	4.3	19	6.0	19	3.2	14	2.3	14	2.7
2011	19	3.0	7	1.2	19	3.1	8	1.6	7	0.8	4	0.7	19	4.8	19	5.0	19	4.4	19	6.0	19	3.1	15	2.8	14	2.8
2012	19	1.0	7	1.1	19	3.1	8	1.6	7	0.8	3	0.6	19	4.8	19	5.0	19	4.4	19	6.0	19	3.2	15	2.8	14	3.0
2013	19	1.0	7	1.2	19	3.1	8	1.6	7	0.8	3	0.6	19	4.8	19	5.0	19	5.7	19	6.0	19	3.0	14	2.7	13	2.7
2014	19	1.0	9	1.4	19	3.5	8	1.8	7	1.0	3	0.7	19	5.1	19	5.1	19	5.7	19	6.0	19	3.0	12	2.5	10	1.9
2015	19	1.0	10	1.5	19	3.9	8	1.7	7	0.9	3	0.7	19	5.1	19	5.1	19	5.9	19	6.0	19	2.8	12	2.5	10	1.9
2016	19	1.0	9	1.4	19	4.4	7	1.3	6	0.8	3	0.8	19	5.1	19	5.1	19	6.0	19	6.0	19	2.7	11	2.3	10	1.8
2017	19	1.0	9	1.5	19	4.2	7	1.5	6	0.9	3	0.9	19	5.1	19	5.1	19	6.0	19	6.0	19	2.8	11	2.2	10	2.0
2018	19	2.0	10	1.7	19	3.8	7	1.5	6	1.0	3	0.9	19	5.1	19	5.1	19	6.0	19	6.0	19	2.5	12	2.4	10	2.1
2019	19	3.0	10	1.7	19	3.7	7	1.5	6	1.1	3	0.9	19	5.1	19	5.1	19	6.0	19	6.0	19	2.6	12	2.4	11	2.2
2020	19	3.0	10	1.8	19	4.4	7	1.5	6	1.1	3	0.9	19	5.1	19	5.1	19	6.0	19	6.0	19	2.8	12	2.5	12	2.4

Note: Counts (C) of countries with a score greater than zero in each year (i.e. with the policy instrument in place). Mean (M) is the average score of all countries in a year.

Figure A.1: Environmental Policy Stringency - Distributions by Year and Country



Note: These charts are intended to show the evolution and heterogeneity in the EPS variable. The left-hand side (LHS) column displays the EPS by year, while the right-hand side (RHS) column presents the same data by country. In each box plot, the centre line represents the median (50th percentile): for the LHS charts, this is the median value across all countries in a given year; for the RHS charts, it is the median value for each country over the study period. The lower and upper edges of each box correspond to the 25th and 75th percentiles, respectively. The "whiskers" extend to the adjacent values, defined as the 25th percentile minus 1.5 times the interquartile range (IQR) and the 75th percentile plus 1.5 times the IQR. Individual dots represent outliers beyond these bounds.

A.2 Characterisation Factors

The CFs used are presented in Table A4. The CFs can be found at the CML-IA database and ¡. The CML-IA database has been constructed by Leiden University's Institute of Environmental Sciences (CML). This dataset is publicly accessible and it is continuously updated to conform with the operational guide to ISO-standard LCA implementation (Guinée et al., 2002; Oers, 2015). Multiple mid-point CFs datasets are presented according to the spatial and temporal scale of interest. Their toxicity CFs are derived from the modified Uniform System for the Evaluation of Substances- (USES-) LCA model and account for transfers among environmental compartments.[9] For TOFP and AP, the mid-point CFs developed by ¡ are used.

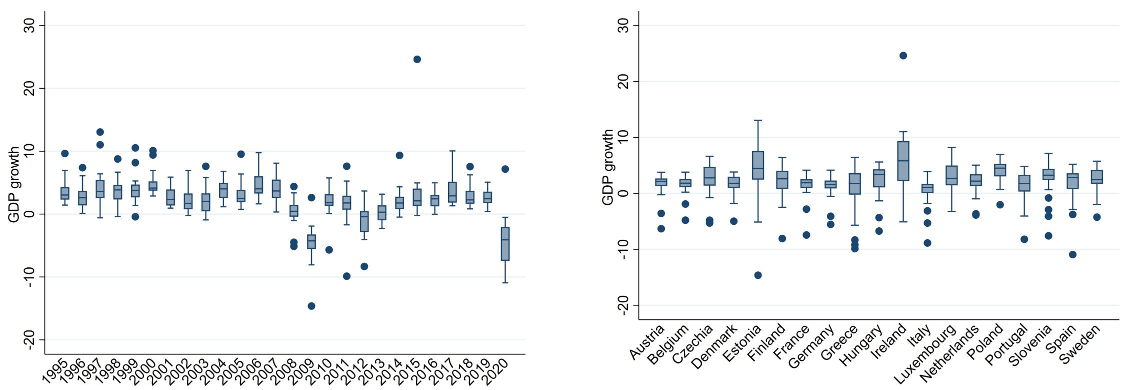
[9] See Guinée et al. 2002, Oers 2015; Rybaczewska-Błażejowska and Jezierski 2024 and Crenna et al. 2019 for more details. Find website here.

Table A4: Mass-based characterisation factors for environmental impact categories

Pollutants	**GWP**	**AP**	**TOFP**	**EP**	**ATP**	**HTP**
NH_3		0.06		0.35		
NO_x		0.02	1.22	0.13		1.20
SO_x		0.03				0.10
NMVOC			1.00		0.07	8.67
CO			0.11			
Particulates						0.82
Greenhouse Gases						
CO_2	1.00					
CH_4	28.00		0.01			
N_2O	265.00					
Heavy Metals						
As					1103.98	347699.70
Cd					22605.16	145040.54
Cr					105.76	36.83
Cu					13624.84	4282.89
Hg					28225.00	264.34
Ni					15738.59	35032.84
Pb					151.60	29.14
Zn					1313.23	95.77
Unit	CO2 eq.	Acid eq.	NMVOC eq.	PO4 eq.	1,4-DCB eq.	1,4-DCB eq.

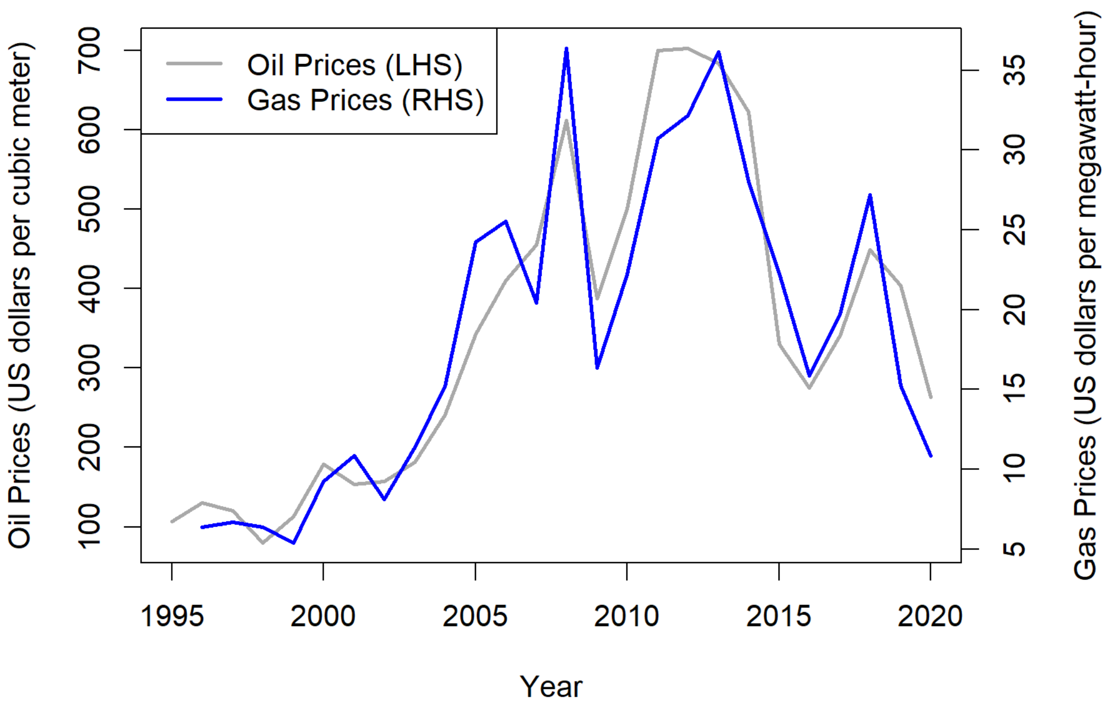
Notes: These CFs are used to multiply by mass substance emitted. Each column correspond to one of the environmental impact categories. Values within columns indicate the relative importance of each substance to each impact category. The source for the CFs in each column are respectively: IPCC, 2013 (GWP100); de Leeuw, 2002; de Leeuw, 2002; Heijungs et al., 1992; Huijbregts, 1999 & 2000 (FAETP 100, MAETP 100); Huijbregts, 1999 & 2000 (HTP 100).

Figure A.2: Real GDP Growth - Distributions by Year and Country



Note: These charts present real Gross Domestic Product (GDP) growth calculated according to the expenditure approach. They show the evolution and heterogeneity in GDP growth data. The left-hand side (LHS) column displays the data by year, while the right-hand side (RHS) column presents it by country. In each box plot, the centre line represents the median (50th percentile): for the LHS charts, this is the median value across all countries in a given year; for the RHS charts, it is the median value for each country over the study period. The lower and upper edges of each box correspond to the 25th and 75th percentiles, respectively. The ”whiskers” extend to the adjacent values, defined as the 25th percentile minus 1.5 times the interquartile range (IQR) and the 75th percentile plus 1.5 times the IQR. Individual dots represent outliers beyond these bounds.

Figure A.3: Energy prices: crude oil and natural gas prices



Note: This figure presents annual crude oil and natural gas prices, sourced from the Energy Institute based on S&P Global Platts (Statistical Review of World Energy (2024)) with major processing by Our World in Data.