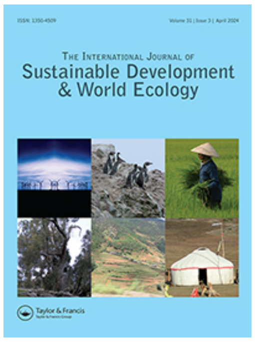

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Impact of environmental policy stringency on sectoral GHG emissions: evidence from Finland and Sweden by nonlinear quantile-based methods

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ABSTRACT

The growing societal concern regarding environmental matters has led to the implementation of many environmental measures intended to protect the environment and address global warming by lessening emissions and mitigating climate change. In line with this movement, this study scrutinizes the impact of these environmental measures on greenhouse gas (GHG) emissions to analyze the cases of Finland and Sweden. More specifically, the study employs the Environmental Policy Stringency (EPS) index as a proxy for environmental measures, explores sector-specific GHG emissions by employing nonlinear quantile-based methodologies (including quantile-on-quantile regression and Granger causality-in-quantiles methods as the primary model and quantile regression for robustness checking) spanning the period from 1991/Q1 to 2020/Q4. The findings show that: (i) EPS lessens GHG emissions from fuel exploitation, industrial combustion, and the power industry sector at lower and middle quantiles in Finland and Sweden; (ii) EPS decreases GHG emissions from processes, transportation, and waste sectors in Finland but increases them in Sweden at higher quantiles; (iii) EPS leads to an increase in GHG emissions from the agriculture and construction sectors at higher quantiles; (iv) EPS has a causal effect on sector-specific GHG emissions across different quantiles; (v) the robustness of the findings is largely confirmed. Hence, the study underscores the varying impacts of EPS on sectoral GHG emissions based on quantiles, sectors, and countries, emphasizing the need for policymakers to adopt environmental policies to comprise these differences and adjust the policy framework accordingly.

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Environmental policy stringency; GHG emissions; sectors; Finland; Sweden; quantile-based methods

1. Introduction

Global environmental degradation has increased at critical levels and global greenhouse gas (GHG) emissions have reached alarming levels (Pata and Kumar 2021; Kartal et al. 2023). These concerning trends necessitated urgent measures to be taken since the rise in global temperatures has caused climate change, posing a significant threat to humanity by irreversibly damaging the structure of nature.

The continuous surge and intensification in global consumption and demand have led to a corresponding upsurge in energy demand. Yet, the use of fossil fuels to satisfy this demand has resulted in a substantial increase in GHG emissions. In response, there has been an increasing emphasis on transformation to clean energy sources. This shift towards clean energy has been accompanied by the implementation of stringent measures such as emissions trading schemes and environmental taxes. Accordingly, there is a widely recognized consensus that efforts should be made to limit the average global temperature increase to 2°C above pre-industrial levels. Consequently, 178 countries have committed to taking action to realize this target as part of global efforts to combat climate change.

To combat the adverse effects of global climate change, policymakers are urged to implement a range of environmental measures, including carbon pricing, emissions trading systems, and environmental taxation (Frohm et al. 2023; Ullah et al. 2023; Kartal 2024a). Among these policy tools, environmental taxes are frequently employed by countries seeking to curb emissions and promote ecological sustainability. Carbon taxes, in particular, have proven to be effective methods for reducing GHG emissions (Haites 2018). As a result of stringent environmental policies adopted by governments, companies are forced to transition to more efficient and environmentally friendly resource utilization methods, thereby mitigating their environmental impacts. Accordingly, EPS exerts an influence on sectoral production. Companies

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occasionally want to impose the costs incurred by these policies on consumers through higher prices. Alternatively, they may choose to relocate production to countries with less stringent environmental regulations.

Stringent environmental policies are intended to boost improvements in production and energy efficiency, foster the adoption of clean energy sources, and stimulate the development of innovative technologies. Furthermore, they seek to motivate consumer behaviors by making environmentally harmful activities costlier and promoting the demand for eco-friendly products. Through such measures, EPS endeavors to curb environmental degradation (Neves et al. 2020).

EPS can be defined as '*an index that calculates the stringency as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behavior. It is constructed on the degree of stringency of 13 environmental policy instruments, primarily related to climate and air pollution. Also, it ranges from 0 (not stringent) to 6 (highest degree of stringency). Besides, it is a country-specific and internationally comparable measure of environmental policy stringency*' (Botta and Koźluk 2014; Kruse et al. 2022). So, EPS can be used as a benchmark index and the study uses the EPS index as the proxy of environmental measures taken by countries.

Porter's (1991) hypothesis postulates that the additional costs incurred as a result of EPS can be offset by fostering the development of more eco-friendly innovative methods. This hypothesis proposes that EPS implementation will not only reveal environmental benefits but also drive economic advantages. Through this mechanism, known as green technological transformation, not only sustainable development can be advanced, but environmental quality also be improved.

As achieving environmental quality remains a global priority, all countries have been aiming to curb all emissions. Within this framework, certain countries have made remarkable improvements compared to others. Markedly, Finland and Sweden have emerged as prominent examples of green economies, characterized by their strenuous efforts to attain significant decreases in emissions. Figure 1 shows the progress of GHG emissions at the sectoral level alongside the path of EPS for these countries.

After 2010, Finland has demonstrated a notable reduction in GHG emissions, largely attributable to improvements within the power sector. Likewise, Sweden has also experienced a decreasing trend in GHG emissions post-2010, although to a lesser extent compared to Finland. EPS values for both countries have revealed significant momentum following the year 2000. In essence, the GHG emissions of both countries have shown a downward path coinciding with the escalation of EPS measures.

In contemporary literature, researchers have lengthily studied the effectiveness of environmental taxes in mitigating environmental degradation (Shahzad 2020; Kartal 2024b). On the other hand, the consideration of EPS in this context has emerged more recently, with studies focusing on various country scopes such as BRICS and OECD (Wang et al. 2020; Guo et al. 2021; Chu and Tran 2022; Li et al. 2023; Udeagha and Muchapondwa 2023; Udeagha and Ngepah 2023). The aforementioned studies typically used panel analysis methods to inspect the impact of EPS on environmental degradation at the country group level. Despite the existing body of literature, there remains a gap that requires further investigation, specifically to implement single-country cases to account for potential

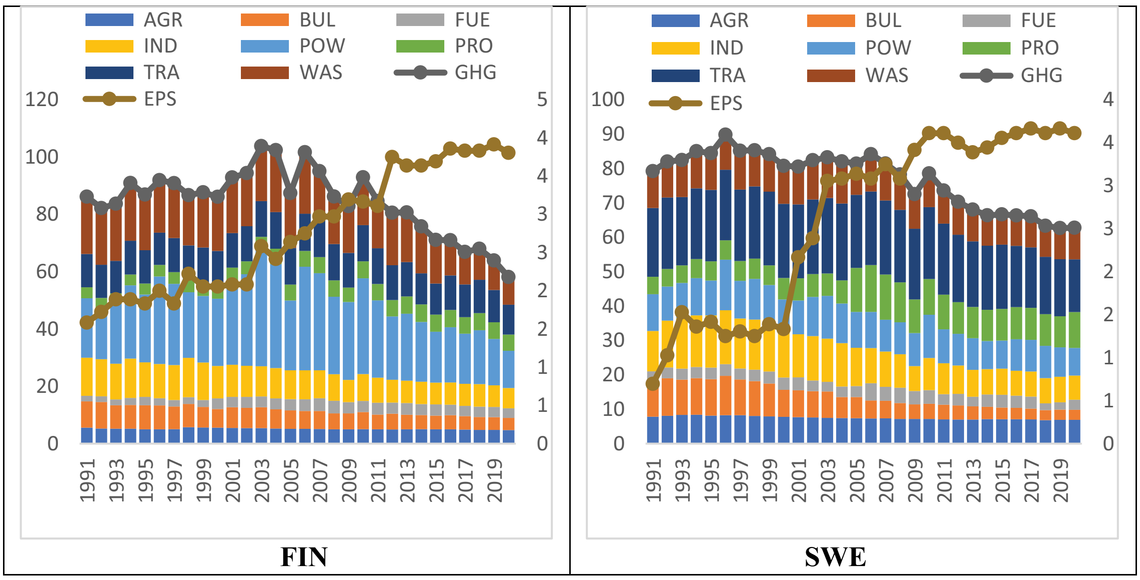

Figure 1. Progress of GHG Emissions and EPS in FIN and SWE. *The unit for all GHG emissions is the million tons. EPS is shown on the right axis of the graphs.*

variations among countries that utilize time series methods instead of panel methods and consider sectoral differences and tail-dependence in the analysis. By incorporating these highlights, future studies can contribute to filling this gap and better understanding of the nexus between EPS and environmental degradation.

Addressing a noteworthy gap in the existing literature, this research endeavors to discover the following research inquiries: (i) What is the extent of the influence of EPS on GHG emissions in top green countries? (ii) Does the impact of EPS on GHG emissions vary across different quantiles, sectors, and countries? (iii) Is there a consistent causal nexus between EPS and GHG emissions across all sectors and quantiles, and does this connection display variations? To address those questions, the study focuses on two distinctive green countries, namely Finland and Sweden. Specifically, the research scrutinizes sector-specific GHG emissions, applies nonlinear quantile-based methodologies, and utilizes quarterly data spanning from 1991/Q1 to 2020/Q4, ensuring the incorporation of the most recent and relevant data available. By implementing this comprehensive approach, the study aims to explain the diverse impacts of EPS on sectoral GHG emissions, delineating variations based on quantiles, sectors, and the unique contexts of Finland and Sweden.

The research contributes novel insights to the existing body of knowledge, enriching the scientific community in several ways. Firstly, it stands out as a pioneering study by examining two environmentally progressive nations that have achieved notable success in mitigating greenhouse gas (GHG) emissions. Secondly, the study delves into sector-specific analysis within these economies, recognizing potential variations in the impact of Environmental Policy Stringency (EPS) across different sectors. Thirdly, by acknowledging the potentially diverse effects of EPS across quantiles, sectors, and countries, the research employs innovative nonlinear quantile-based methodologies, utilizing quarterly data spanning from 1991/Q1 to 2020/Q4, ensuring the incorporation of the most recent and comprehensive dataset available. This multifaceted approach, encompassing both theoretical frameworks and empirical methodologies, distinguishes the study from existing research and underscores its originality within the field.

The remainder of the paper is structured as follows: Section 2 reviews the empirical literature. Section 3 describes the data, variables, and methodology employed to inspect the research questions. Section 4 presents the results, discussion, and policy options. The final part concludes and highlights the contributions of the study to the existing literature as well as limitations and future research directions.

2. Theoretical framework and literature review

2.1. Theoretical background

The research on environmental economics is structured based on the leading study of Grossman and Krueger (1991), which introduced the Environmental Kuznets Curve (EKC) hypothesis. Following this seminal study, numerous research efforts have been dedicated to exploring the environmental implications of various factors, including income. Furthermore, in accordance with the energy-led growth hypothesis pioneered by Kraft and Kraft (1978), several studies (such as Apergis and Tang 2013) have extensively examined the impact of energy usage on environmental progress. Whereas income distribution and energy consumption remain eminent traditional factors, recent research has begun to incorporate more novel factors (such as globalization, political stability, and trade openness) into the investigation of environmental quality.

Many countries have been analyzed for the progress of their environmental degradation over time. While various methods, such as environmental taxes and ETS, have been employed as proxies for environmental metrics (Sharif et al. 2023), unfortunately, these indicators often fail to capture the full scope of measures implemented by policymakers to preserve the environment. Therefore, there is a persistent need to adopt more comprehensive indicators, such as EPS, to examine the environmental quality progress (Botta and Koźluk 2014; Kruse et al. 2022). Identifying this necessity, research exploring the impact of EPS on the environment has been developing.

2.2. Review of the empirical literature

In contemporary literature, there is recurrent contemplation of using EPS as a proxy for environmental measures. Numerous studies have evidently delineated the significant impact of EPS in mitigating emissions. For example, Ahmed and Ahmed (2018) scrutinized the effect of EPS on CO_2 emissions in China, demonstrating that stringent environmental policies could lead to emissions reduction. Wang et al. (2020) conducted a study on 23 OECD countries covering the period from 1990 to 2015, by employing the system generalized method of moments method, and found that EPS has a decreasing effect on CO_2 emissions. Sezgin et al. (2021) examined the impact of EPS on CO_2 emissions in G7 and BRICS countries, concluding that EPS contributes to reducing CO_2 emissions and noting a mutual causality between EPS and CO_2 emissions. Albulescu et al. (2022) investigated the nexus between EPS and CO_2 emissions for 32 OECD countries from 1990 through 2015 and found a negative correlation between EPS and air pollution. Moreover, Frohm et al. (2023) employed a panel regression model for 30 OECD countries to explore the impact of EPS on CO_2 emissions and revealed that a 1% increase in EPS results in a 4% decrease in CO_2 emissions. Udeagha and Muchapondwa (2023) analyzed the influence of EPS on CO_2 emissions in BRICS countries from 1960 to 2020 using the CS-ARDL method and found the long-term mitigating effect of EPS on CO_2 emissions. Likewise, Udeagha and Ngepah (2023) studied the nexus between EPS and CO_2 emissions in BRICS countries throughout 1960–2020, employing the CS-ARDL method, and revealed that EPS has a long-term diminishing effect on CO_2 emissions.

Some studies revealed conflicting findings regarding the impact of EPS on emissions. For instance, Wolde-Rufael and Mulat-Weldemeskel (2020) examined the nexus between EPS and CO_2 emissions by applying the PMG-ARDL model and came up with an inverted U-shaped nexus between EPS and CO_2 emissions. Furthermore, Li et al. (2023) investigated the impact of EPS on production-based CO_2 emissions in 21 OECD countries from 1990 to 2020 and concluded that EPS has a contractionary effect on production-based CO_2 emissions.

Some studies had mixed results on the EPS impact on emissions. For instance, Sarkodie (2021) investigated the role of EPS in improving environmental performance in South Africa and discovered that EPS increased CO_2 emissions by 0.12%, 0.14%, and 0.20% in the agriculture, industry, and energy sectors respectively, while decreasing by 0.34% in the service sector. Wolde-Rufael and Mulat-Weldemeskel (2021) examined the nexus between EPS and CO_2 emissions for seven developing countries using an augmented mean group method for the period of 1994 – 2015, concluding that there exists an inverted U-shaped nexus between EPS and CO_2 emissions. Likewise, Chu and Tran (2022) scrutinized the impact of EPS on the ecological footprint (EF) in 27 OECD countries for the period of 1990 – 2015, determining that EPS has a declining effect on the EF, and the impact is asymmetric.

2.3. Overall evaluation of the literature

Although previous studies have predominantly focused on certain environmental practices such as environmental taxes and ETS, many recent studies have started to explore the EPS to assess the impact of environmental measures on environmental progress. In fact, a review of the literature reveals a growing number of studies utilizing EPS. Among these, some have found that EPS is effective in reducing emissions, while others have produced contradictory or mixed results. Furthermore, studies have typically concentrated on specific groups of countries (e.g. BRICS, G-7, OECD) and employed panel data methods such as CS-ARDL.

While the literature includes various studies on the impact of EPS on the environment, current studies need to pay more attention to potential differences among countries by not applying country-specific analyses. Also, to best of the best knowledge, studies have yet to examine sectoral emissions. Hence, the researchers believe there is a literature gap.

Considering the literature gap and searching for answers to the research questions, the study focuses on Finland and Sweden and analyses sectoral GHG emissions. It performs a time series analysis by performing nonlinear quantile methods to consider tail-dependence that uncovers the impact of EPS across various quantiles. Hence, the study fills in the gap and obtains robust results on the impact of EPS on sectoral GHG emissions in Finland and Sweden over quantiles.

3. Methods

3.1. Data

Data on EPS is collected from the OECD (2023). Data on sectoral GHG emissions was also gathered from EDGAR (2023). Following data collection from these sources, annual data are converted to quarterly frequency by performing the quadratic-sum-method in line with the recent studies (e.g. Kartal and Pata 2023). After, the return series, which includes the logarithm and then the first difference, is calculated (e.g. Ulussever et al. 2023). After all these transformations, the entire dataset is between 1991/Q1 and 2020/Q4. So, Table 1 summarizes the primary information of the variables.

Also, Figure 2 presents the progress trends of the variables.

As shown in Figure 2 and presented in Supplementary Table S1–3, some variables have a decreasing trend, whereas some others have an increasing one. Also, the variables have a mixed

Table 1. Variables.

Symbol	Definition	Unit	Source
AGR	Agriculture Sector GHG Emissions	Million Ton	EDGAR (2023)
BUL	Building Sector GHG Emissions		
FUE	Fuel Exploitation Sector GHG Emissions		
IND	Industrial Combustion Sector GHG Emissions		
POW	Power Industry Sector GHG Emissions		
PRO	Processes Sector GHG Emissions		
TRA	Transport Sector GHG Emissions		
WAS	Waste Sector GHG Emissions		
EPS	EPS Index	Index	OECD (2023)

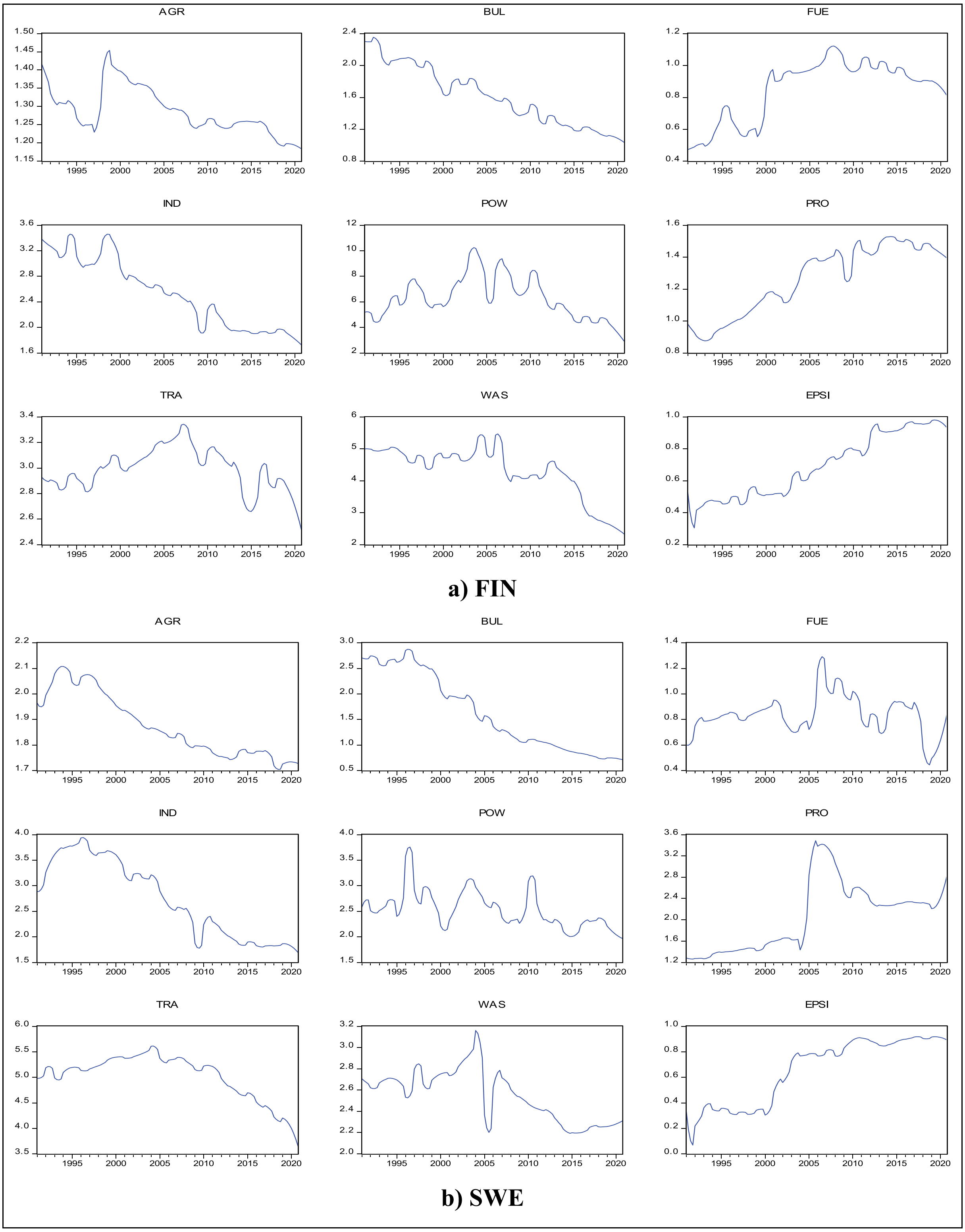

Figure 2. Progress Trend of the Variables.

structure from various points. Most variables do not have a normal distribution and follow a mixed (i.e. linear and nonlinear) structure.

3.2. Empirical methodology

The study applies a comprehensive approach that includes six steps, as visualized in Figure 3, to uncover the impact of the EPS index on sectoral GHG emissions in FIN and SWE.

In the leading three steps, descriptive statistics and correlations are analyzed. In addition, the BDS test (Brock et al. 1996) is applied to check the nonlinearities. In the fourth step, the QQ method (Sim and Zhou 2015) is performed to analyze the quantile-based impact of EPS on sectoral GHG emissions. In the fifth

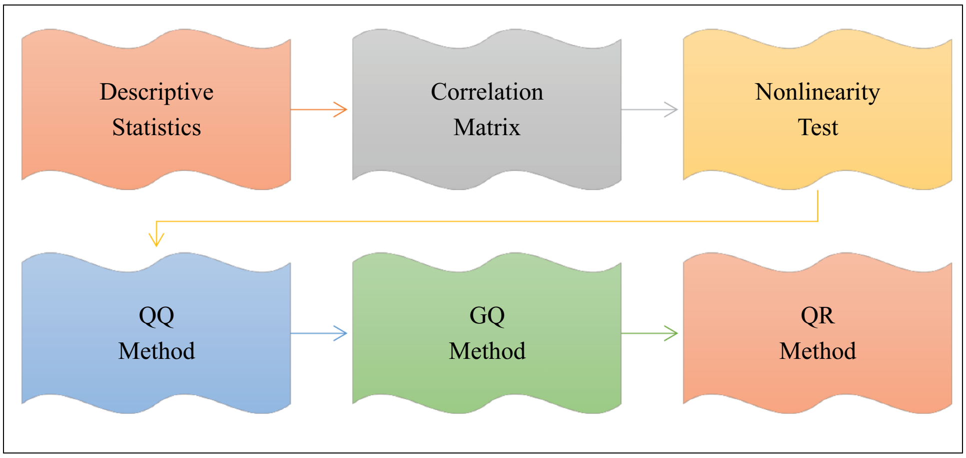

Figure 3. Empirical Processes.

step, the GQ method (Troster 2018) is used to investigate the quantile-based causal impact of EPS on sectoral GHG emissions. Lastly, the QR method (Koenker and Bassett 1978) is run to check the robustness.

The study applies mainly nonlinear quantile-based methods. That is why the use of linear methods is not appropriate in the case of the presence of nonnormal distribution and nonlinear structure of the variables. For this reason, the consideration of characteristics of the data of variables is critical in method selection. Accordingly, nonlinear quantile-based methods (i.e. QQ, GQ, and QR) are selected for the empirical investigation by considering the nonnormal distribution and nonlinear structure of the variables under examination. In addition to being consistent with the data structure, such quantile-based nonlinear methods enable researchers to capture nonlinearities in the analysis and obtain reliable and robust results consistent with the contemporary literature (e.g. Kartal et al. 2024). Besides, these methods enable researchers to analyze various quantiles comprehensively rather than focusing only on the mean point, as with linear methods, such as regression and ARDL-based. Hence, the varying impact across quantiles can be examined by applying these methods, which is impossible in linear methods. In summary, applying these methods makes it possible to obtain robust results for EPS impact on sectoral GHG emissions across quantiles and countries.

The study uses RStudio, MATLAB, and EViews software to apply the empirical methods to the dataset.

4. Results

4.1. Preliminary statistics

The study initially examines the variables' main parameters. Hence, descriptive statistics are presented in Supplementary Table S1. POW and BUL have the highest variations in FIN and SWE, respectively, whereas AGR has the most minor variations among all variables. Besides, all variables except TRA in FIN and WAS in SWE are not linearly distributed, which implies a nonlinear distribution.

Supplementary Table S2 also demonstrates correlations between variables. Accordingly, EPS positively correlates with all sectoral GHG emissions except WAS in FIN. On the other hand, EPS has a negative correlation with PRO and WAS in SWE, whereas other sectoral GHG emissions have a positive correlation.

Moreover, nonlinearity test results are shown in Supplementary Table S3. Accordingly, most variables have a nonlinear structure rather than a linear structure. On the other hand, a few variables have either a linear or a mixed structure. Hence, variables are primarily nonlinear.

The preliminary statistics show significant variations for all variables; almost all variables have a non-normal distribution, and most have a nonlinear structure. In line with these determinations, the study performs nonlinear quantile methods to uncover the impact of EPS on sectoral GHG emissions.

4.2. QQ results

In the subsequent step of the empirical analysis, the study performs the QQ method to analyze the impacts of EPS on sectoral GHG emissions across various quantiles. Figure 4 demonstrates the QQ results.

In AGR, EPS has a declining impact on FIN at lower quantiles. In contrast, the impact increases with the relatively lowest across middle quantiles and the highest across higher quantiles. In the SWE case, EPS has a fully increasing impact across all quantiles, while the increasing power is highest at lower and higher quantiles and relatively lowest across middle quantiles. Thus, EPS is influential in curbing AGR initially in FIN, whereas it is entirely inefficient in SWE. This shows that

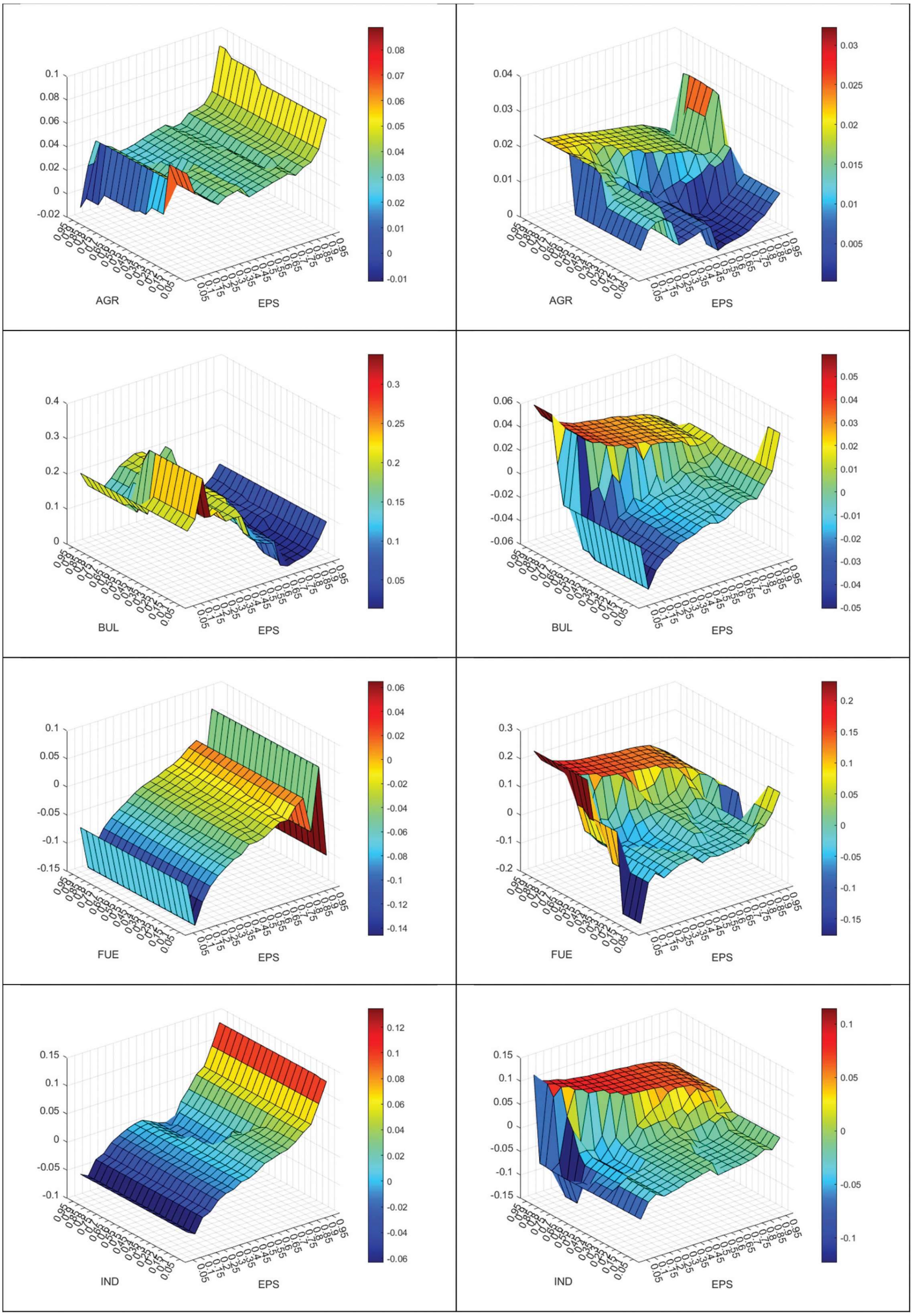

Figure 4a. EPS Impact on Sectoral GHG Emissions.

FIN can benefit slightly from stringent environmental measures to curb AGR when first applied, implying that additional measures should focus on something other than the agriculture sector.

For this reason, although there were a few declining impacts at the beginning, the nexus between EPS and AGR was lost, and, in turn, this impact will be reversed in the coming periods. Hence, the focus of Finnish policymakers should be directed to the agriculture sector while other sectors are still kept under closer supervision. On the other hand, SWE policymakers need to implement well-structured and

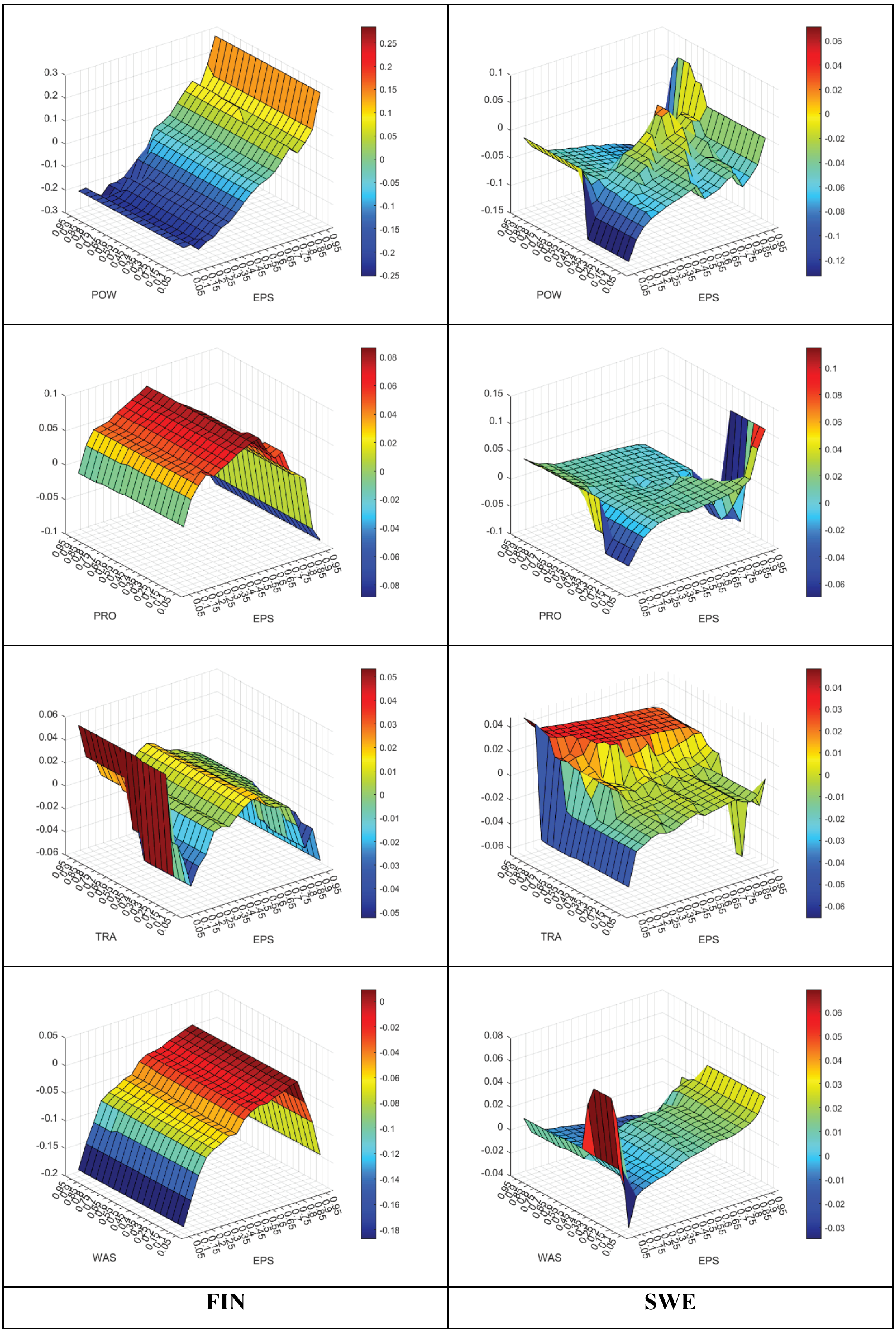

Figure 4b. Continue

stringent environmental policies in the agriculture sector. The possible cause of this condition is that the agriculture sector has a low share of total GHG emissions, which is also the case in FIN. Therefore, FIN and SWE must pay attention to the agriculture sector. Instead, they prefer to focus on other sectors with a much higher share of total GHG emissions.

In BUL, EPS has an increasing impact on FIN. The increasing impact is much higher at lower and middle quantiles but weaker at higher quantiles. In SWE, EPS has a declining impact across some lower and middle quantiles (0.10–0.20), whereas it causes an increase across the remaining middle and higher quantiles (0.25–0.95). Hence, EPS is only helpful in declining BUL in the initial stages of SWE, whereas it is inefficient in FIN. The potential cause of this result is that the building sector has quite a share in total GHG emissions in FIN and has decreased over the years in SWE. This trend causes Finnish and Swedish policymakers to focus on something other than building sector GHG emissions. Instead, they have preferred to focus on highly GHG-emitting countries to take much more stringent environmental measures.

In FUE, EPS has an almost entirely declining impact in FIN across all quantiles except some higher ones (0.75–0.80, 0.90). In SWE, EPS has a curbing impact across lower quantiles, whereas the impact is reversed across middle and higher quantiles. Hence, EPS is only beneficial in declining FUE in FIN, whereas it is not almost fully helpful in SWE. Accordingly, Finnish policymakers have dealt with FUE in curbing total GHG emissions by considering its role in economic growth, energy generation, and industrial activities. However, this is not valid for Swedish policymakers, who have preferred not to have enough stringent measures on FUE to curb GHG emissions.

In IND, EPS significantly decreases FIN at lower and middle quantiles (0.05–0.35). However, it has a stimulating impact at the middle and higher quantiles (0.40–0.95). Like SWE, EPS has a declining impact at lower and middle quantiles (0.05–0.30). However, the impact increases at the remaining quantiles (0.35–0.95). So, EPS helps to achieve a decline in IND in both FIN and SWE across some lower and middle quantiles. This determination shows that while environmental measures taken by policymakers of FIN and SWE have a contributing impact in curbing IND at the beginning, the measures could be more efficient in the later stages. That is because the measures applied have made a few curbing impacts, and they should be reviewed and revised as time passes. Otherwise, the shocks become tentative and inefficient, as was the case for the impact of EPS on IND in both FIN and SWE.

In POW, EPS has a declining impact on FIN across all quantiles except some higher ones (0.65–0.95). Like SWE, EPS curbs POW across all quantiles except some higher ones (0.95). Hence, EPS is beneficial in SWE and partially beneficial in FIN. This determination implies that stringent environmental measures are highly effective in curbing GHG emissions in the power sector. This aligns with the pre-expectations because the power sector has a high share in total GHG emissions.

EPS increasingly impacts FIN across lower and middle quantiles in PRO. However, the impact becomes curbing at higher quantiles (0.90–0.95). On the other hand, EPS has an almost increasing impact on SWE across all quantiles except for some lower and higher ones. Hence, stringent environmental policies are highly beneficial in FIN but less helpful in SWE. It implies some fact. First, stringent environmental policies are only effective in causing a decline in PRO once they reach a mature level, as in the Finnish case. Second, Sweden's policymakers have a relatively horizontal trend in stringent environmental policies. So, it only provides a decline once they have made an essential intervention to the policy set. Hence, as stringent environmental policies pass a level, they begin to make a curbing impact.

In TRA, EPS has an increasing impact in FIN at lower and middle quantiles, whereas it has a curbing impact at higher quantiles. Differently, EPS has a decreasing impact in SWE at lower quantiles, whereas there is an increasing impact across the middle and higher quantiles. So, EPS has a beneficial impact in curbing TRA at higher quantiles in FIN and at lower quantiles in SWE. These results reflect the difference between the two countries in terms of arranging stringent environmental policies in the transport sector. Hence, while FIN can benefit from stringent environmental policies when they mature, SWE can benefit them initially, and their impact becomes inefficient later. Hence, FIN can achieve to decrease the TRA, whereas there is room for growth for SWE in this respect.

In WAS, EPS has a decreasing impact on FIN across almost all quantiles except for some higher ones (0.80). However, EPS increasingly impacts SWE across all quantiles except some lower and middle quantiles (0.10–0.35). Hence, EPS is almost fully helpful in curbing WAS in FIN, whereas this is not valid for SWE. The potential cause of this result is that FIN is much more concerned about waste management than Sweden. Also, because FIN began from a higher level WAS to reach a lower level recently, they can achieve some decreases. However, SWE has almost a horizontal trend over the years that proves the unsuccess of SWE in this area.

4.3. GQ results

The GQ method is applied to uncover the causal impact of EPS on sectoral GHG emissions across quantiles. Table 2 demonstrates the GQ results.

In FIN, EPS has a causal impact from EPS to AGR except for 0.05 and 0.50 quantiles. Also, EPS has a causal impact on BUL except 0.05, 0.40–0.60, and 0.95 quantiles. Similarly, EPS has a causal impact on FUE except 0.05, 0.40–0.50, and 0.95 quantiles. Also, EPS has a causal impact on IND except 0.45–0.50 quantiles. Partially the same, EPS has a causal impact on PRO except 0.45–0.55 quantiles. Moreover, EPS has a causal impact on POW except 0.30–0.50, 0.60–0.65, and 0.85–0.95 quantiles. EPS has a causal impact on TRA except 0.25–0.60 and 0.95 quantiles. Furthermore, EPS has a causal impact on WAS except 0.45–0.55 and 0.95 quantiles.

In SWE, EPS has a causal impact from EPS to AGR except 0.40–0.45 and 0.90–0.95 quantiles. Also, EPS has

Table 2. GQ results.

Country	Way	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
FIN	EPS⇨AGR	0.45	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.69	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05
	EPS⇨BUL	1.00	0.06	0.01	0.01	0.01	0.01	0.01	0.10	0.06	0.42	0.14	0.18	0.01	0.01	0.01	0.01	0.01	0.01	1.00
	EPS⇨FUE	0.43	0.01	0.01	0.01	0.01	0.01	0.01	0.13	0.14	0.46	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.06	0.33
	EPS⇨IND	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.40	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.04
	EPS⇨POW	0.04	0.01	0.01	0.01	0.01	0.32	0.19	0.61	0.46	0.46	0.02	0.10	0.15	0.01	0.01	0.04	0.18	0.44	0.30
	EPS⇨PRO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.61	0.85	0.39	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
	EPS⇨TRA	0.06	0.01	0.01	0.02	0.23	0.14	0.10	0.24	0.71	0.56	0.80	0.06	0.01	0.02	0.01	0.01	0.01	0.01	0.46
	EPS⇨WAS	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.45	0.82	0.36	0.01	0.01	0.01	0.01	0.01	0.01	0.01	1.00
SWE	EPS⇨AGR	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.40	0.81	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.07	1.00
	EPS⇨BUL	0.18	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.33	0.20	0.08	0.01	0.01	0.01	0.01	0.01	0.15	0.64
	EPS⇨FUE	0.23	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.07	0.30	0.04	0.01	0.02	0.05	0.06	0.01	0.01	0.01	1.00
	EPS⇨IND	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.81	0.08	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06
	EPS⇨POW	0.67	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.12	0.62	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	EPS⇨PRO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.19	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.49
	EPS⇨TRA	0.15	0.82	0.01	0.56	0.02	0.05	0.14	0.19	0.21	0.18	0.37	0.26	0.07	0.01	0.04	0.01	0.10	0.64	0.43
	EPS⇨WAS	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.40	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06

Numbers represent p-values.

a causal impact on BUL except 0.05, 0.50–0.60, and 0.90–0.95 quantiles. Similarly, EPS has a causal impact on FUE except 0.05, 0.45–0.50, 0.75, and 0.95 quantiles. Also, EPS has a causal impact on IND except for 0.50–0.55 quantiles. Partially the same, EPS has a causal impact on PRO except for 0.45 AND 0.95 quantiles. Moreover, EPS has a causal impact on POW except for 0.05 and 0.45–0.50 quantiles. EPS has a causal impact on TRA except 0.05–0.10, 0.20, 0.35–0.65, and 0.85–0.95 quantiles. Furthermore, EPS has a causal impact on WAS except for 0.50 quantiles.

The GQ results demonstrate that EPS generally impacts sectoral GHG emissions across all quantiles, whereas the causality impact cannot be seen at some quantiles. Also, the existence of causal impacts varies across sectors. These results imply that although FIN and SWE have taken various environmental measures to make them stringent to prevent sectoral GHG emissions, they have yet to influence them at all levels. Accordingly, policymakers should follow up on the effectiveness of the stringent environmental measures over time and take necessary corrective actions on time. Unfortunately, environmental measures cannot provide the expected benefits in curbing GHG emissions in the respective sectors in case of a delay.

4.4. Robustness check

Lastly, the consistency of the QQ results is checked by applying the QR method. Supplementary Fig. S1 demonstrates the details of the comparison between the QQ and QR methods, and Table 3 summarizes the comparison.

Table 3. Correlations between the QQ and QR methods.

Variable	FIN	SWE
EPS on AGR	96.88	39.20
EPS on BUL	90.47	94.77
EPS on FUE	99.98	68.72
EPS on IND	99.25	86.60
EPS on POW	99.87	66.04
EPS on PRO	99.83	59.35
EPS on TRA	92.24	77.58
EPS on WAS	99.99	73.75

It is clear that both QQ and QR methods provide similar observations for FIN, and the correlation between the methods reaches ~ 99.99%. On the other hand, in SWE, there is high consistency between the variable pairs, with the correlations reaching ~ 94.77%, whereas they are relatively low for some variable pairs. Hence, the results are robust, and various policy options can be discussed based on them.

4.5. Discussion and policy implications

The research results demonstrate the nonlinear impact of stringent environmental measures on sectoral GHG emissions in FIN and SWE. According to this determination, FIN and SWE cannot rely on a linear approach in environmental policy formulation based on the assumption that environmental measures are linearly effective on sectoral GHG emissions. So, policymakers should consider nonlinear impacts across various sectors and quantiles and consider country-based differences.

Also, the nonlinear impact of environmental measures on sectoral GHG emissions requires policymakers to follow up on the progress of the impact of environmental measures continuously rather than in intermittent periods (e.g. yearly or quarterly). Hence, when environmental measures become either inefficient or nonbeneficial, policymakers can have the opportunity to take immediate action without causing any delay. In this way, the environmental benefits of stringent policies, which are expected to be obtained, can be guaranteed.

Besides, there are differences in the impacts of environmental measures on sectoral GHG emissions across sectors. Stringent environmental measures have a decreasing or inefficient impact across sectoral GHG emissions. The study's empirical results show that stringent environmental measures have a different impact across sectors or on the same sectors across countries. The hidden clue can be found in the calculation of the EPS index. In the calculation of the EPS index, there are three main pillars: market-based policies, nonmarket-based policies, and technology support (Kruse et al. 2022). When these main pillars and their sub-components are examined, it can be seen that stringent environmental policies are mainly based on energy use, carbon allowances, environmental taxes, and energy-related public R&D investments. Hence, this content of the EPS index explains why the EPS index is effective in some sectors, whereas it is not the case for others. Due to such content, EPS is efficient in curbing emissions in the sectors, either the power industry sector or the sectors where energy is highly used. However, in some other sectors (e.g. agriculture), EPS is ineffective because energy use is limited. So, energy-based environmental policies cannot be effective.

The varying impact of environmental measures on sectoral GHG emissions across sectors requires policymakers to rely on the declining impact of environmental measures where they have a curbing impact (e.g. in fuel exploitation, industrial combustion, and power industry sectors). On the other hand, policymakers should re-structure the environmental measures where they have an inefficient impact (e.g. in agriculture and building sectors). Policymakers should consider applying much more stringent environmental measures to turn inefficient ones into efficient ones or solve the measures taken and replace them with new measures that can be influential in curbing sectoral GHG emissions. Even these findings imply they should have calculated a much better and more comprehensive index indicator for environmental measures across sectors. Hence, the impact of environmental measures across sectors can be examined in a much more appropriate and suitable way.

Moreover, policymakers need to be aware that environmental measures have a mixed impact on sectoral GHG emissions. Specifically, either directional (i.e. increasing or decreasing) way (e.g. transport & waste) or power of the impact (e.g. agriculture) of the environmental measures varies across quantiles in almost all sectors. Therefore, it is critical to handle each sectoral GHG emission separately rather than considering the overall GHG emissions in a specific country. Hence, it is possible to monitor the impact of environmental measures on sectoral GHG emissions and take corrective actions on a sector basis without delay.

Furthermore, it is critical to consider the behaviors of both companies and citizens when formulating environmental policies. That is why both these factors have a high impact on the effectiveness of stringent environmental policies applied. They can impact by following a green approach, supporting innovation, and applying new technologies. Hence, they can impact the success of the environmental policies, either supporting or opposing the measures applied. Therefore, it is essential to provide support from the public and business world in the countries.

The researchers believe policymakers can benefit much more from stringent environmental measures in curbing GHG emissions by reforming policy frameworks and considering the abovementioned policy points. In this way, countries can contribute to combating climate change by curbing sectoral GHG emissions and achieving climate-related sustainable development goals.

5. Conclusion, limitations, and future research

5.1. Conclusion

Due to the increasing environmental problems, countries and societies have been applying various measures to combat climate change. Although such measures aim to make a declining or slowing down impact on climate change, it is much more important to consider the measures to determine whether they are beneficial. Therefore, this study considers the EPS index a proxy for stringent environmental measures. Besides, the study focuses on Finland and Sweden, among leading green economies, to investigate the impact of stringent environmental measures. Moreover, the study uncovers the impact by considering GHG emissions instead of only CO_2 emissions. This is why although almost 70% of GHG emissions consist of CO_2 emissions, there is a 30% share of GHG emissions rather than CO_2 emissions, a considerable amount that cannot be ignored. So, the study considers GHG emissions instead of CO_2 emissions to have a broader context. The empirical analysis uses quarterly data from 1991/Q1–2020/Q4 and performs nonlinear quantile-based methods. Hence, from these perspectives, the study differs from the present studies (e.g. Sharif et al. 2023; Ullah et al. 2023) and achieves various novelties in searching for answers to the research questions.

The empirical results reveal the nonlinear impact of EPS on sectoral GHG emissions. In detail, EPS has a declining impact on some sectors' GHG emissions (e.g. agriculture and building), whereas it is inefficient in others (e.g. fuel exploitation, industrial combustion, and power sectors). Also, the causal impact of stringent environmental measures varies according to quantiles, sectors, and countries.

Overall, applying a comprehensive approach reveals the impact of EPS on GHG emissions in Finland and Sweden, whereas the power of impact changes based on quantiles, sectors, and countries combating climate change by declining GHG emissions. The results reached for some sectors are mainly consistent with the current studies (e.g. Chu and Tran 2022 for OECD countries; Li et al. 2023 for OECD countries; Udeagha and Muchapondwa 2023 for BRICS countries; Udeagha and Ngepah 2023 for BRICS countries), whereas the case is not valid for some others. However, it is much broader by extending the knowledge from various perspectives, such as defining the changing impact and determining the varying power of impacts and causal impact on the sectors across quantiles.

5.2. Limitations and future research

Although this research follows a comprehensive approach, it has some drawbacks that scholars can consider in future research. First, new studies may include more green countries because the study handles two leading green countries (i.e. Finland and Sweden). A comparative analysis can be made between green and nongreen countries by including them simultaneously in the same study.

Also, the study focuses only on the supply side of environmental degradation, considering GHG emissions as a proxy. So, new research can use other environmental indicators. In this context, the recently emerged load capacity factor can be used in new studies. Hence, the impact of EPS on nature can be investigated by considering both sides (i.e. supply and demand).

Besides, this study uses relatively low-frequency (i.e. quarterly) data for the empirical investigation. Hence, new studies can be analyzed by using much higher-frequency data. Hence, time and frequency-based dependency between EPS and the progress of the environment over the years can be analyzed.

Moreover, the study relies mainly on nonlinear quantile-based methods. Therefore, new studies may prefer to apply other novel econometric techniques, such as Fourier and Wavelet-based methods, that have recently emerged. Hence, the current knowledge about the impact of EPS on the environment can be extended further by considering the various perspectives these methods provide.

Furthermore, the study uses sectoral GHG emission data. However, using the same case for the EPS index is impossible. If sector-based EPS data are available, it would be great if they were included in new studies while analyzing sectors. Also, scholars can consider using sub-components of the EPS index for further analysis in the coming periods.

Finally, because the EPS index is mainly constructed on energy-related issues, new indicators to proxy environmental measures can be developed by considering potential differences among sectors. From this perspective, a sector-specific EPS index can even be calculated. This way, detailed empirical analysis can be performed using a sector-specific EPS index.

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The authors have contributed equally to this work. All authors read and approved the final manuscript.

Acronyms

ARDL	Autoregressive Distributed Lags
BDS	Broock, Scheinkman, Dechert, and LeBaron
CO_2	Carbon Dioxide
CS-ARDL	Cross-Sectional ARDL
EDGAR	Emissions Database for Global Atmospheric Research
EF	Ecological Footprint
EKC	Environmental Kuznets Curve
EPS	Environmental Policy Stringency
ETS	Emission Trading System
G-7	Group of Seven
GHG	Greenhouse Gas
GQ	Granger Causality-in-Quantiles
OECD	Organization for Economic Co-operation and Development
PMG	Pooled Mean Group
QQ	Quantile-on-Quantile Regression
QR	Quantile Regression

Availability of data and materials

Data will be made available on request.

Consent for publication

The authors are willing to permit the Journal to publish the article.

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