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RESEARCH ARTICLE

Asymmetric effect of environment tax and spending on CO2 emissions of European Union

Dhyani Mehta[1] · Parth Prajapati[2]

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Abstract
This study investigates the effects of environmental tax and environmental spending on CO2 emissions of 27 countries of the European Union EU27 countries using annual time series data from 1995 to 2022. The study used linear and non-linear autoregressive distributive lag (ARDL and NARDL) to examine the relationship. Estimates claim that the variables have a symmetric and asymmetric long-term and short-term relationship. The negative impacts of environmental taxes on CO2 emissions prove that emissions are reduced when polluting activities are taxed. Fiscal policy instrument such as taxation changes the behaviour of the private sector in the EU27 nations by disincentivizing polluting activities. On the other hand, government investment in environmental protection has encouraged the private sector in the EU27 nations to embrace and invest in green technologies, decreasing CO2 emissions. The ECM term is negative and statistically significant at a 1 percent significance level for ARDL and NARDL models, implying a stable long-run relationship between variables. It demonstrates that short-run disequilibrium converges to long-run equilibrium at a speed of 9.2% (in the ARDL model) and 22.7% (in the NARDL model). The study also sheds fresh light on the effectiveness of environmental taxes vs. expenditure, where taxes serve as a counter-incentive policy for CO2 emissions, and spending is a positive policy intervention.

Keywords ARDL · NARDL · Environmental tax · Environmental spending · Economic growth · Industrial growth · Carbon emissions · Fiscal policy

Introduction

The biggest threat to humankind is environmental deterioration, which harms economic growth and our health (Wolde-Rufael and Mulat-Weldemeskel 2021). As the worldwide population expands, so do the needs and environmental degradation caused by human-caused pollutants. The increasing global temperature, the deterioration of biological equilibrium, and the worsening of the environment all over the globe are severe modern challenges that endanger life on Earth (Aydin and Esen 2018). Most nations are cognizant of the negative consequences of rising CO2 levels in the atmosphere and are taking steps to prepare for the hazards and severe conditions associated with climate change (Farhani and Ozturk 2015; B. Li and Haneklaus 2022; Malinauskaite et al. 2019, 2020; Patel and Mehta 2023). The European Union (EU) is the third largest economy in the world, having $ 16.6 trillion (nominal) GDP and a net wealth of $69 trillion (Redesigning Service Financial 2021).

CO2 emissions in the EU countries were 6.5% (0.17 Gt) in 2020 compared to 2021. However, this rise is only half of the decline between 2019 and 2021 (-10.8%), resulting in a 5% reduction in EU emissions between 2021 and 2019 (Crippa et al. 2022). CO2 emissions in the long run (in the past 20 years) in the EU have been declining, and in 2021, they were 2.78 Gt, or 27.4% lower than in 1990. The contribution of the EU to global emissions has similarly declined in recent years, falling from 16.8% in 1990 to 8.5% in 2015 and 7.3% in 2021 (Crippa et al. 2022). Reducing CO2 emissions and other ecological concerns that make nations accountable to each other is the only sustainable strategy

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Parth Prajapati
parth.prajapati@sot.pdpu.ac.in

[1] Department of Economics and Social Science, School of Liberal Studies, Pandit Deendayal Energy University, Gandhinagar 382426, India

[2] Department of Mechanical Engineering, School of Technology, Pandit Deendayal Energy University, Gandhinagar 382426, India

for the world. In an effort to reduce these emissions, the EU has used subsidies, laws, and a variety of economic tools. Though these measures are routinely out regarding emission-reduction procedures, the argument over which mechanisms are the most effective continues (Aydin and Esen 2018). Environmental taxes and government expenditures on the environment are essential fiscal policy measures for limiting CO2 emissions (Aydin and Esen 2018; Wolde-Rufael and Mulat-weldemeskel 2023, 2021). An environment-focused tax, particularly one that aims at curbing CO2 emissions, is crafted to modify actions by introducing a monetary burden on actions that produce carbon dioxide. The objective of such taxation is to diminish these emissions and motivate people, businesses, and sectors to embrace greener and more enduring approaches (Allan et al. 2014; Bao et al. 2013; Gemechu et al. 2012; Li 2017; Yang 2009) (see Fig. 1).

The relevance of environment tax as a fiscal tool in an effort against environmental issues is emphasised in both the updated Lisbon strategy and the Sixth Environment Action Programme (EAP) of the EU, both of which were agreed by the European Parliament and Council in 2002 (Aydin and Esen 2018). The loss that which represented in market pricing, commonly referred to as externalities or external costs, has an impact on society as a whole, as well as the emitter of pollutants and tax levies, which address these market imperfections (Aydin and Esen 2018; Hanson and Sandalow 2006). Environmental taxes appear as one of the most significant fiscal policy tools employed in internalising "negative externalities." Environmental taxes can impact people's economic choices while also serving to safeguard the environment (Aydin and Esen 2018; Wolde-Rufael and Mulat-Weldemeskel 2021).

Government spending on the environment is a fiscal policy measure aimed at enhancing the sustainability and quality of the environment (Adebola Solarin et al. 2017; Solarin and Al-Mulali 2021). These expenses may reduce CO2 emissions in a number of ways, either directly by supporting initiatives that reduce emissions or indirectly by encouraging environmentally friendly behaviour. Government spending, such as environmental subsidies, may have a big impact on CO2 emissions by supporting practices, technologies, or activities that result in lower emissions and a more sustainable environment overall (Gerlagh and van der Zwaan 2006b; Grafton et al. 2014; Liu et al. 2022; Machado et al. 2021). EU has been successful in curbing its CO2 emissions compared to other countries around the world (see Fig. 2). The contribution of these study is two folds; first, it compares how well environmental spending and taxes work to cut CO2 emissions in the EU, using asymmetric model approach. Policymakers may get important insights from this direct comparison, which enables a greater understanding of which policy option has a more significant impact on carbon reduction. Second, the research adds to the existing literature and provides useful insights to other nations hoping to emulate the EU's achievements. By providing actual data and an asymmetric (positive and negative) effect of fiscal instruments, this research covers a critical gap. Insights of this study can help set the groundwork for future policy

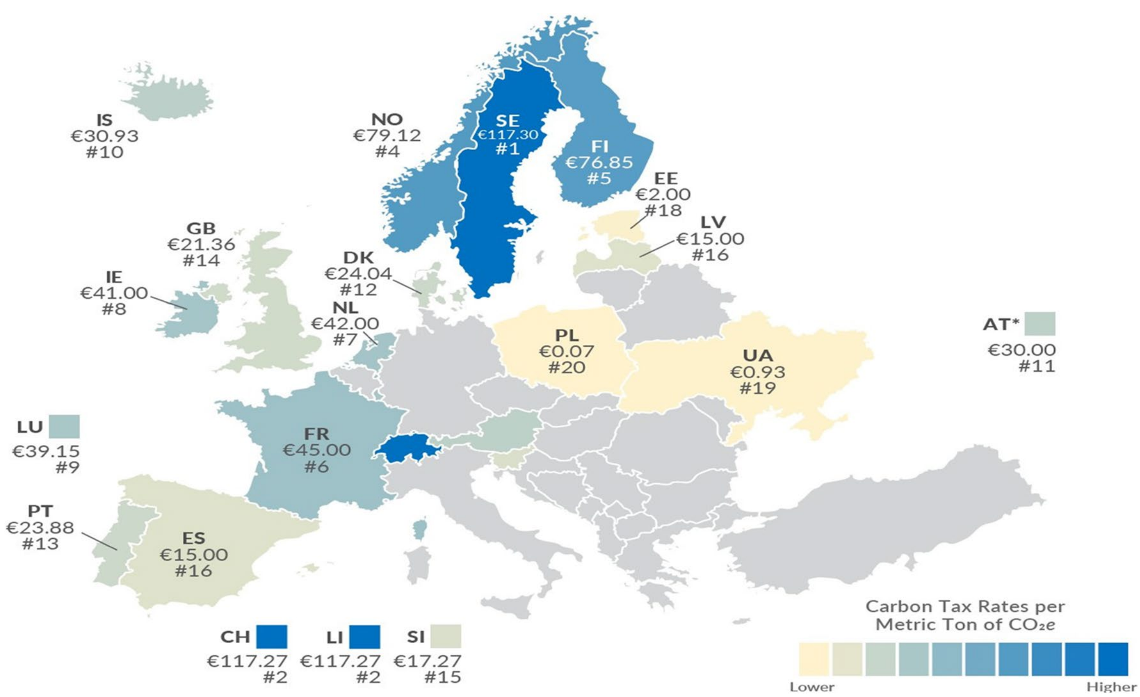

Fig. 1 Carbon tax rates per metric ton of CO2e (2022)

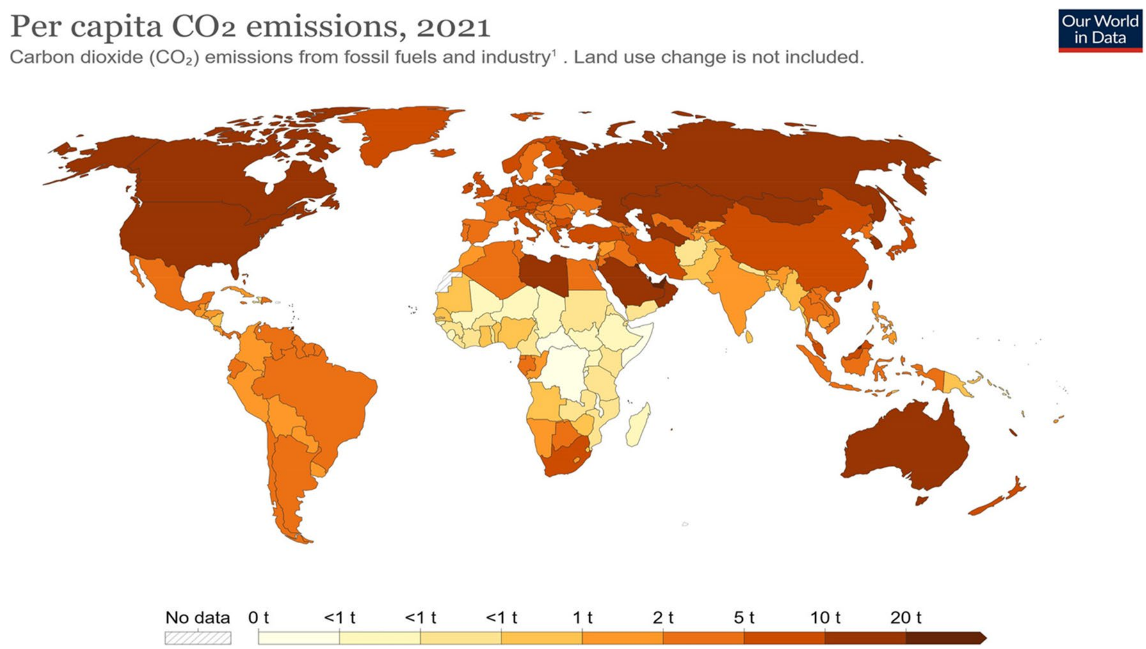

Fig. 2 Annual CO2 emission of world and EU countries (in billion tonnes)

discussions and function as a guide for international efforts to successfully tackle climate change.

This research will cover a wide range of stakeholders, such as governmental organisations, academic institutions, scientific societies, financial institutions, international organisations like the United Nations (UN) and Intergovernmental Panel on Climate Change (IPCC), energy-related industries, the general public, utilities, and technology developers. This study will provide empirical evidence of how policies of environment tax and spending can impact CO2 emissions, which can be very useful for other developing and developed nations. The study will contribute to better understand and mitigate the effects of CO2 emissions through the implementation of solutions aimed policies and funding. Which will address climate change and promoting sustainability. In "Literature review" section, the review of the literature is expanded upon, discussing the research conducted on carbon dioxide emissions, environmental taxes, expenditure, and economic growth. The model and data description are in "Data description and methodology" section, while the findings and interpretations are in "Results and discussion" section. The paper's conclusion, limitations, and future research scope are covered in "Conclusion" section.

Literature review

The goal of environmental policy is not just to raise revenue but also to significantly change consumer and corporate behaviour by encouraging them to buy less harmful goods and corporations to adopt environmentally friendly technology (see Aydin and Esen 2018; Borozan 2019; Shahzad 2020; Wolde-Rufael and Weldemeskel 2020). Legislative measures like taxes and strict environmental laws and regulations are the most effective tools for resolving environmental degradation. Because environmental degradation consists of negative externalities, it should not be left to the market to offer remedies (Haites 2018; Pigou and Aslanbeigui 2017; Wolde-Rufael and Mulat-weldemeskel 2023).

Environmental tax and CO2 emissions

According to (Shahzad 2020) and (Mardones and Baeza 2018), a carbon tax alters the structure of production and consumption by forcing the domestic sector to adopt more environmentally friendly technology, energy-saving measures, and a cleaner, healthier environment; taxes have the potential to cut emissions. Numerous studies on the impact of environmental taxes on a range of pollutants indicators, including carbon dioxide (CO2) emissions, sulphur dioxide emissions, exhaust emissions, wastewater discharge, municipal waste, and deforestation, have found that environmental taxes have a significant impact on environmental improvements (Alfsen et al. 1995; Aydin and Esen 2018; Bohlin 1998; Manne and Richels 1992; Nakata and Lamont 2001; Nordhaus 1991; Whalley and Wigle 2017). A study by (Millock and Nauges 2003) on air pollution tax in France found a negative relationship between tax and emissions of pollutant gas in the air. Using a dynamic recursive general equilibrium model, (Lu et al. 2010) found a negative and significant impact of the carbon tax policy on carbon emissions in China. Complimenting (Lu et al. 2010), a study by (Yang et al. 2014) also discovered that China's carbon tax had a negative impact on the regional emissions of CO2. Furthermore, the impact of carbon taxes in reducing CO2 emissions is significantly hampered by inelastic fuel demand, primarily determined by price elasticity (also see, (Shafi et al. 2023; Xu and Long 2014; Zhang and Lu 2023).

Similar studies done in European economics also assert that environment-related tax will significantly reduce CO2 emissions by de-incentivizing polluting activities (see, (Agostini et al. 1992; Ghazouani et al. 2020). European economics has successfully used its fiscal policy instrument for environmental preservation, a carbon tax intended to help reduce greenhouse gas emissions. Such tax tries to factor costs associated with reducing environmental harm into pricing choices for the pollution-generating sectors. A study by (Hájek et al. 2019) found that the carbon tax in the energy sector is ecologically beneficial, with a higher tax rate enabling the reduction of greenhouse gases output, which is statistically strongly influenced by the use of fossil fuels. The estimates indicate that increasing the carbon price by one euro per tonne can reduce yearly per-person emissions by 11.58 kg. The study by (Hájek et al. 2019) also compliments to the studies like (Alper 2017) and (Charlier et al. 2023) done in the European context, which found a similar relationship between the environmental tax and CO2 emissions (also see, (Bothner et al. 2022).

Contrarily, (Bruvoll and Larsen 2004) claimed that environmental taxes had a limited impact. They attributed this comparatively small effect to the numerous exemptions from taxation as well as the quite inflexible demand in the industries where these taxes are applied. (Lin and Li 2011) and (Hotunluoğlu and Tekeli 2007) explored the effects of carbon taxes employed for the purposes of reducing emissions by using data from European countries. Other studies which found limited impact of environmental tax and CO2 emissions are (Bruvoll and Larsen 2004; Gerlagh and Lise 2005; Loganathan et al. 2014).

Environment spending and CO2 emissions

According to (Pearce and Palmer 2005), conservation of the environment is an excellent instance of a public good since it addresses market failures caused by environmental externalities and provides improvements that benefit numerous individuals at once. Government expenditure on ecological issues is a fiscal policy tool intended to improve the environment's quality and sustainability (Adebola Solarin et al. 2017; Solarin and Al-Mulali 2021). According to studies like (Gerlagh and van der Zwaan 2006a; Grafton et al. 2014; Machado et al. 2021; Rizwanullah et al. 2022), environmental protection spending, such as subsidies, may have a significant impact on CO2 emissions by fostering behaviours, innovations, and operations that lead to lower emissions and a more sustainable environment as a whole. But there are limited empirical studies measuring the impact of environmental spending on CO2 emission in European context. It is expected that higher spending on environment friendly technologies, subsidies, and research will help in reducing the CO2 emissions (Caglar and Yavuz 2023).

The environmental effects of fiscal expenditure patterns have been investigated by (López et al. 2011); the study concluded that government spending in favour of social and public goods will lower pollution. (Bostan et al. 2016) conducted research on how public spending affects environmental protection in European nations. They discovered that spending on the environment lowers the emissions of air pollutants such CO2, SO2, NOX, and PM10. Similar research by (Ercolano and Romano 2018) equivalently supports a favourable relationship between environmental performance and environmental protection spending in 21 European nations. In order to empirically analyse the impact of environmental protection spending that is insufficient for European Union economies, the study by (Caglar and Yavuz 2023) uses the CS-ARDL technique. They discovered that environmental spending significantly affected CO2 emissions. They also came to the conclusion that nations in the European Union should set aside additional funding from their general budgets for environmental preservation in order to attract the business sector as well as the governmental sector.

Economic growth and CO2 emissions

Following the most well-known EKC theory by (Grossman and Krueger 1991), several research have looked at the connections between economic growth and environment. The majority of research discovered a link between emissions and economic development (Agrawal and Mehta 2016; Ali et al. 2020; Ali et al. 2017; Alshehry and Belloumi 2015; Farhani and Ozturk 2015; Menyah and Wolde-Rufael 2010; Pao and Tsai 2011; Park and Hong 2013; Pata 2018; Saidu Musa and Maijama'a 2020; Sharma et al. 2020; Song 2021; Zaidi and Saidi 2018).

According to study by (Saidu Musa and Maijama'a 2020), a growing the economy uses more energy resulting in the increase of environmental pollution. (Pata 2018) also found that the per capita GDP, per capita energy consumption, financial expansion, urbanisation, and manufacturing are the major were all contributing to a rise in CO2 emissions (also see, (Pata and Caglar 2021). According to the findings of (Sharma et al. 2020), globalisation greatly raises South Asia's carbon emissions, and GDP and CO2 are positively correlated (also see, (Shahbaz et al. 2021). A related research by (Song 2021) discovered a relationship between

GDP per capita and carbon emissions per capita that was positive. Additionally, a linked relationship between GDP and pollution was discovered by (U and Mitra 2020) (also see, (Pal and Mitra 2017).

According to a brief review of the literature, an empirical study that tried to examine the effects of environmental tax, expenditure, and economic growth on CO2 emissions came up with a contradictory outcomes. The mixed results is because of the methodology, time frame, and sample size. Limited empirical research have been conducted, particularly in the European setting, on the effect of expenditure related to environmental issues and CO2 emissions. Given that the European economies has been more successful than the rest of the world in reducing its CO2 emissions, it is necessary to investigate if environmental expenditure or taxation had a more significant role in this achievement.

Data description and methodology

Data description

This study try to measure the impact of environment related taxes and spending on the CO2 emission of European Union countries. Table 1 contains the list of EU countries used for the study based on the availability of the data.

Table 1 List of 27 countries of the European Union (EU27)

Sr. No	Country
1	Austria
2	Belgium
3	Croatia
4	Republic of Cyprus
5	Czech Republic
6	Denmark
7	Estonia
8	Finland
9	Bulgaria
10	Malta
11	Netherlands
12	Poland
13	Slovenia
14	Sweden
15	France
16	Germany
17	Greece
18	Hungary
19	Ireland
20	Italy
21	Latvia
22	Lithuania
23	Luxembourg
24	Portugal
25	Romania
26	Slovakia
27	Spain

Official website of European Union and complied by author

Retrieved from: https://european-union.europa.eu/principles-countries-history/country-profiles_en

The study takes CO2 emissions as the dependent variable and environmental tax, environmental spending, GDP, and manufacturing (value added as % GDP) as independent variables

Environmental fiscal reforms (EFR) policy and CO2 emissions

The role of government policy and its intervention has been a highly debated theme in economics literature. On the one hand, the classical paradigm argues that the self-equilibrating capacity of markets makes government policies irrelevant, and on the other hand, the Keynesian paradigm argues that government policies are designed for economic growth and stabilisation (including externality). Environmental taxes and government spending on the environment are two of the environmental fiscal reforms (EFR) policy tools that the EURO-27 countries have used to reduce their CO2 emissions (Aydin and Esen 2018; Wolde-Rufael and Mulat-weldemeskel 2023, 2021). An environmental tax, especially one that attempts to reduce CO2 emissions, is designed to change behaviour by placing a financial burden on activities that release carbon dioxide. The aim of this kind of taxation is to reduce these emissions and encourage individuals, companies, and industries to adopt more sustainable and environmentally friendly practices. Government spending on the environment is directed at enhancing its sustainability and quality (Adebola Solarin et al. 2017; Mehta and Derbeneva 2024; Solarin and Al-Mulali 2021). By supporting initiatives that do so directly or indirectly by encouraging ecologically conscious behaviour, these expenses may reduce CO2 emissions in a number of ways. Equation (1) shows the linear model for CO2 as a function of environment tax and environment spending by government:

$$CO2_t = f(ETAX_t, EEXP_t) \tag{1}$$

where $CO2_t$ is carbon emissions, $ETAX_t$ is environment tax, and $EEXP_t$ is environment expenditure.

Environmental Kuznets curve

The environmental Kuznets curve (EKC) by (Grossman and Krueger 1991), theory proposes the connections between economic growth and environment. According to EKC hypothesis, growing the economy uses more energy resulting in the increase of environmental pollution. The economic growth is measured by income growth and manufacturing sector contribution (see, (Shahbaz et al. 2021). By adding MUF_t (Manufacturing sector contribution) and Y_t (income growth) in Eq. (1), we get Eq. (2):

$$CO2_t = f(ETAX_t, EEXP_t, MUF_t, Y_t) \tag{2}$$

The time series data of the variables from 1995 to 2022 is considered for the study with data sources and description as mentioned in Table 2.

Model

Equation (2) can be further expressed in the form of a linear equation to estimate the impact of ETAX, EEXP, MUF, and Y, on CO2 emissions (see Eq. (3)):

$$CO2_{it} = \beta_0 + \beta_1 ETAX_{it} + \beta_2 EEXP_{it} + \beta_3 MUF_{it} + \beta_4 Y_{it} + \varepsilon_{it} \tag{3}$$

To verify the presence of long-run relationship among the variables of Eq. (2), the cointegration tests of (Pedroni 1999, 2004), (Kao 1999), and Johansen-Fisher are used. The Pedroni tests assess the stationarity of the residual ε_{it} in Eq. (2), and whether it has a unit root. Second, the (Kao 1999) test is similar to the approach of the Pedroni test but imposes the condition that the independent variables are subjected to cross-sectional specific intercepts and homogenous coefficients (Esily et al. 2022).

To measure the long-run and short-run relationship among the variables of Eq. (2), the study has used the pooled group mean (PMG) estimation methods (Pesaran et al. 1999; Pesaran and Smith 1995). PMG is preferred due to its ability to capture both short-run coefficients and error variances while considering a lower degree of heterogeneity. The assumptions of PMG include a normally distributed error correction term that is free from correlation bias and exogeneity of explanatory variables. Furthermore, the equation assumes a long-run relationship between the dependent and explanatory variables, and the long-run parameters remain consistent across countries (Qamruzzaman and Jianguo 2020). The following Eq. (4) is the generalized panel ARDL model proposed from Eq. (3):

Table 2 Data description and sources

Variable	Variable representation	Description and measure	Source
Dependent variable			
CO2 emissions	CO2	*Measured:* Measured as CO2 emissions (metric tons per capita) *Description:* This shows the per capita emission of the carbon dioxide in metric tons for India	World Development Indicators, World Bank
Independent variables			
Environmental tax	ETAX	*Measured:* Tax revenue of countries' government leverages on the negative impacts, as a percentage of the country's GDP *Description:* An environmental tax is a charge levied on a physical unit of an item having negative impact on environment	Government Policy Indicators, Climate change Dashboard IMF
Environmental spending	EEXP	*Measured:* Environmental protection Spending, as a percentage of the country's GDP *Description:* Amount of expenditure each government spends on environmental protection measures	
Control variables			
Value added by manufacturing sector	MUF	*Measured:* Manufacturing, value added (% of GDP) *Description:* The share of the manufacturing output out of the total economy of India is represented by this variable	World Development Indicators, World Bank
Income growth	Y	*Measured:* GDP per capita (constant 2010 US$) *Description:* This represents the India's total economic output per individual belonging to the country	

Compiled by author and retrieved from: https://climatedata.imf.org/pages/go-indicators#gp1 and https://databank.worldbank.org/source/world-development-indicators

$$\Delta CO2_{it} = \delta_{0i} + \delta_{1t}CO2_{it-1} + \delta_{2t}ETAX_{it-1} + \delta_{3t}EEXP_{it-1} + \delta_{4t}MUF_{it-1} + \delta_{5t}Y_{it-1} + \sum_{J=1}^{M-1}\vartheta_{1J}\Delta CO2_{it-J} + \sum_{J=0}^{N-1}\vartheta_{2J}\Delta ETAX_{it-J} + \sum_{J=1}^{O-1}\vartheta_{3J}\Delta EEXP_{it-J} + \sum_{J=1}^{O-1}\vartheta_{4J}\Delta MUF_{it-J} + \sum_{J=1}^{O-1}\vartheta_{5J}\Delta Y_{it-J} + \mu_i + \varepsilon_{it} \quad (4)$$

where i =1……N is the cross-section and t=1……T is the time period. δ_{0i} to δ_{5t} represents long-run coefficient, and ϑ_{1J} to ϑ_{5J} represents short-run coefficients. To estimate the asymmetry effect of explanatory variables, the panel NARDL model incorporates both positive and negative shocks of explanatory variables into the analysis. From Eq. (4), the panel NARDL model is estimated as follows:

$$\Delta CO2_{it} = \beta_{0i} + \beta_{1t}CO2_{it-1} + \beta_{2i}^{+}ETAX_{t-1}^{+} + \beta_{3i}^{-}ETAX_{t-1}^{-} + \beta_{4i}^{+}EEXP_{t-1}^{+} + \beta_{5i}^{-}EEXP_{t-1}^{-} + \beta_{6t}MUF_{it-1} + \beta_{7t}Y_{it-1} + \sum_{J=1}^{M-1}\gamma_{iJ}\Delta CO2_{it-J} + \sum_{J=0}^{N-1}\left(\gamma_{ij}^{+}\Delta ETAX_{ij}^{+} + \gamma_{ij}^{-}\Delta ETAX_{ij}^{-}\right) + \sum_{J=0}^{O-1}\left(\delta_{ij}^{+}\Delta EEXP_{ij}^{+} + \delta_{ij}^{-}\Delta EEXP_{ij}^{-}\right) + \sum_{J=1}^{Q-1}\gamma_{iJ}\Delta MUF_{it-J} + \sum_{J=1}^{R-1}\gamma_{iJ}\Delta Y_{it-J} + \varepsilon_{it} \quad (5)$$

where $ETAX^{+}$ and $ETAX^{-}$ stand for the positive and negative shock of environment tax and $EEXP^{+}$ and $EEXP^{-}$ represents positive and negative shock environment related expenditure. Equation (6) and Eq. (7) represent the positive and negative partial sum decomposition of ETAX and EEXP:

$$\begin{cases} ETAX_i^{+} = \sum_{k=1}^{t}\Delta ETAX_{ik}^{+} = \sum_{k=1}^{T}Max(\Delta ETAX_{ik}, 0) \\ ETAX_i^{-} = \sum_{k=1}^{t}\Delta ETAX_{ik}^{-} = \sum_{k=1}^{T}Min(\Delta ETAX_{ik}, 0) \end{cases} \quad (6)$$

$$\begin{cases} EEXP_i^{+} = \sum_{k=1}^{t}\Delta EEXP_{ik}^{+} = \sum_{k=1}^{T}Max(\Delta EEXP_{ik}, 0) \\ EEXP_i^{-} = \sum_{k=1}^{t}\Delta EEXP_{ik}^{-} = \sum_{k=1}^{T}Min(\Delta EEXP_{ik}, 0) \end{cases} \quad (7)$$

Equation (8) estimates the error correction model of Eq. (5):

$$\Delta CO2_{it} = \sum_{J=1}^{M-1}\gamma_{iJ}\Delta CO2_{it-J} + \sum_{J=0}^{N-1}\left(\gamma_{ij}^{+}\Delta ETAX_{ij}^{+} + \gamma_{ij}^{-}\Delta ETAX_{ij}^{-}\right) + \sum_{J=0}^{O-1}\left(\delta_{ij}^{+}\Delta EEXP_{ij}^{+} + \delta_{ij}^{-}\Delta EEXP_{ij}^{-}\right) + \sum_{J=1}^{Q-1}\gamma_{iJ}\Delta MUF_{it-J} + \sum_{J=1}^{R-1}\gamma_{iJ}\Delta Y_{it-J} + \delta_{iJ}ECT_{t-1} + \varepsilon_{it} \quad (8)$$

In panel asymmetric Eq. (8), the error correction term (ECT) reflects how quickly the system adjusts to its long-run equilibrium. On the other hand, the coefficient associated with the explanatory variable explains the adjustment rate for the system to reach its long-run equilibrium in the presence of shocks, during the short run. The research further hypothesized the following relationship between environmental spending, environment tax, economic development, and CO2 emissions (Table 3):

The null hypothesises will stand true if $\delta_{2t}, \beta_{2i}^{+}, \beta_{3i}^{-}, \gamma_{ij}^{+}, and \gamma_{ij}^{-}$ value is zero, invalidating the policy measure of taxing to counter negative externality in from of

Table 3 Hypothesis for symmetric and asymmetric effect of fiscal measures and CO2 emissions

Long run (symmetric and asymmetric effects)	
$H0_A$: $\delta_{2t} = \beta_{2i}^{+} = \beta_{3i}^{-} = 0$ There is no impact of environment tax on CO2 emissions in long run	$H1_A$: $\delta_{2t} \neq \beta_{2i}^{+} \neq \beta_{3i}^{-} \neq 0$ There is impact of environment tax on CO2 emissions in long run
$H0_B$: $\delta_{3t} = \beta_{4i}^{+} = \beta_{5i}^{-} = 0$ There is no impact of environment spending on CO2 emissions in long run	$H1_B$: $\delta_{3t} \neq \beta_{4i}^{+} \neq \beta_{5i}^{-} \neq 0$ There is impact of environment spending on CO2 emissions in long run
Short run (symmetric and asymmetric effects)	
$H0_C$: $\vartheta_{2J} = \gamma_{ij}^{+} = \gamma_{ij}^{-} = 0$ There is no impact of environment tax on CO2 emissions in short-run	$H1_C$: $\vartheta_{2J} \neq \gamma_{ij}^{+} \neq \gamma_{ij}^{-} \neq 0$ There is impact of environment tax on CO2 emissions in short-run
$H0_D$: $\vartheta_{3J} = \delta_{ij}^{+} = \delta_{ij}^{-} = 0$ There is no impact of environment spending on CO2 emissions in short run	$H1_D$: $\vartheta_{3J} \neq \delta_{ij}^{+} \neq \delta_{ij}^{-} \neq 0$ There is impact of environment spending on CO2 emissions in short run

Table 4 Descriptive statistics and pairwise correlation matrix

	CO2	ETAX	EEXP	MUF	Y
Mean	0.3587	2.7116	0.704331	15.04322	2.487080
Median	0.2889	2.5800	0.667375	15.00978	2.567925
Maximum	1.6244	5.3600	1.914624	34.65098	24.37045
Minimum	0.0624	1.1800	-0.258461	3.884792	-14.83861
Std. Dev	0.2493	0.6877	0.363663	5.072340	3.661684
Skewness	1.8678	0.9666	0.642762	0.181696	-0.421344
Kurtosis	7.0828	4.2775	3.455090	3.234657	7.924229
Jarque–Bera	8.8940	1.5594	5.4008	5.4342	7.2482
Observations	697	697	697	697	697
Pairwise correlation (PMG)					
CO2	1				
ETAX	-0.1535*	1			
EEXP	-0.0686*	-0.0438	1		
MUF	0.3210*	-0.1203	0.1265	1	
Y	0.2113*	0.0734*	0.0927	0.2345**	1

*, **, and *** indicate significant at 1%, 5%, and 10% level of significance, respectively

Source: Authors' calculations from Eviews

In order to investigate the long-run and short-run integration for EU27, the panel data of the study employs unit root tests, to check the null hypothesis that all panels are non-stationary (see, (Breitung 2000; Im et al. 2003; Levin et al. 2002)

CO2 emissions in the long run and short run. The alternate hypothesis will stand true if $\delta_{2t}, \beta^+_{2i}, \beta^-_{3i}, \gamma^+_{ij}, and\gamma^-_{ij}$ value is not zero, upholding the policy relevance in form of taxation to control negative externality of CO2 emissions in the long and short run. The null hypothesis $H0_B$ and $H0_D$ will stand true if $\delta_{3t}, \beta^+_{4i}, \beta^-_{5i}, \delta^+_{ij}, and\delta^-_{ij}$ value is zero, invalidating policy measure of environment spending on CO2 emission in long run and short run whereas the alternate hypothesis will stand true if $\beta^+_{4i}, \beta^-_{5i}, \delta^+_{ij}, and\delta^-_{ij}$ value is not zero, validating the impact of environment spending on CO2 emissions in the long run and short run.

Table 5 Panel unit root tests

Variables	LLC	Breitung	IPS	Fisher-ADF	Fisher-PP
CO2	-6.9770	0.1202	-4.1563	112.715*	78.900**
ΔCO2	-7.2742*	-10.6212*	-9.6933*	189.385*	945.58*
ETAX	0.1748	0.9509	-1.0170	66.137	50.741
ΔETAX	-5.9257*	-3.49022*	-8.4546*	178.182*	361.781*
EEXP	-6.1985	0.6643	-4.2709	332.541*	79.886**
ΔEEXP	-16.2500*	-6.6701*	-13.930*	452.312*	919.371*
MUF	-0.4731	0.9207	0.3745	56.554	48.351
ΔMUF	-11.678*	-5.0323*	-11.748*	230.821*	608.631*
Y	-7.8275*	-8.4628*	-7.6486*	154.931*	315.894*
ΔY	-8.0996*	-1.6434*	-17.330*	335.207*	3210.66*

*, **, and ** indicate significant at 1%, 5%, and 10% level of significance, respectively

Authors' calculations from Eviews

Results and discussion

The pairwise correlation and descriptive statistics summary are presented in Table 4 for CO2, ETAX, EEXP, MUF, and Y for the EU27 panel data. The standard deviation of each variable is lower than its mean value, indicating steady variance across the sample period (see Table 4). The insignificant Jarque–Bera test statistic supported all variables' normal distribution. Primary evidence of the negative relationship between CO2 emissions, ETAX, and EEXP is asserted by the pairwise correlation estimates between CO2 and ETXA (-0.1535) and CO2 and EEXP (-0.0686).

The unit root test estimates are shown in Table 5. The findings demonstrate that all variables exhibit stationary at the I(1) level of integration, which satisfies the requirement for panel ARDL and NARDL proposed by (Pesaran et al. 1999) to examine the long- and short-run relationship while taking into account the cross-sectional dependence and heterogeneity of the panel data. Panel data analysis frequently encounters the cross-section dependence problem, in which observations from many countries are correlated to one another because they have the same economic characteristics (Gaibulloev et al. 2014). One of the fundamental premises of panel data analysis, that the observations across several cross-sections are independent of one another, is violated by this connection. Therefore, investigation of the presence of cross-sectional dependency is most likely demand in the empirical investigation with panel data (Breusch and Pagan 1980; Pesaran 2004).

Table 6 shows the estimation of the cross-section dependence tests. The variables under examination display a cross-sectional dependency, indicating a similarity in their dynamics across all EU27 countries, the estimates rejects the null hypothesis of cross-sectional independence for CO2, ETAX,

Table 6 Cross-section dependency test

Cross-section	CO2	ETAX	EEXP	MUF	Y
LM Breusch-Pagan	7750.91*	2122.89*	1715.13*	3799.06*	3869.87*
LM Pesaran scaled	279.291*	66.876*	51.486*	130.138*	132.811*
$CD_{Pesaran}$	87.8562*	15.2886*	4.6643*	46.5522*	60.0761*

*, **, and *** indicates significant at 1%, 5%, and 10% level of significance, respectively

Authors' calculations from Eviews

Table 7 Panel cointegration test

	Statistic	>Weighted statistic
Pedroni cointegration		
Common AR coefficients (within-dimension)		
Panel v-statistic	-3.2094*	-2.8979*
Panel rho-statistic	4.3318*	4.2422**
Panel PP-statistic	2.8519*	2.8143*
Panel ADF-statistic	2.9677*	2.8852*
Individual AR coefficients (between-dimension)		
	Statistic	
Group rho-statistic	5.2885*	
Group PP-statistic	2.3918*	
Group ADF-statistic	2.9631*	
KAO cointegration		
ADF t-stat	-3.1113*	
Johansen-Fisher cointegration		
Trace test-statistics	488.2*	
Max-Eigen statistics	337.0*	

*, **, and *** indicate significant at 1%, 5%, and 10% level of significance, respectively

Authors' calculations from Eviews

EEXP, MUF and Y asserting the certain common patterns and behaviours across all the EU27 countries.

The estimates of the panel cointegration tests are presented in Table 7. The results of the Pedroni, KAO, and Johansen-Fisher panel cointegration test shows that estimated statistic is significant at a 1% level and confirm that the variables are co-integrated in the long run. The Johansen-Fisher panel cointegration trace-test and maximum Eigen value also confirm a long-run association between the variables at 1% level of significance. Hence, it safe to implies that CO2, ETAX, EEXP, MUF, and Y have a long-run relationship.

The symmetrical and asymmetrical panel ARDL and NARDL models are used for the panel data of EU27 countries by assuming linear and non-linear relationship between CO2, ETAX, EEXP, MUF, and Y using PMG estimation proposed by (Pesaran et al. 1999). The pooled mean group (PMG) is a panel data estimation method that extends the mean group (MG) estimator by allowing for heterogeneous slopes and a common intercept across the panel. In general, the PMG estimator is preferred over the MG estimator when there is a potential for parameter heterogeneity across groups. The PMG model imposes homogeneity in long-term equilibrium across countries but permits heterogeneity in the short-term relationship (Asteriou et al. 2021). The Hausman test to confirm the acceptance of null indicates that PMG is better than MG model (see Table 8).

The long-run estimates of ARDL show that a 1% increase in ETAX reduces CO2 emissions by 0.050%, indicating that the environment protection tax successfully de-incentivises polluting activities, resulting in reduced CO2 emissions (accepting $H1_A$ and rejecting HO_A). It can be inferred that CO2 emission decreases by penalising (through taxing) the polluting activity, and the estimates are in line with the previous studies (see, (Chen et al. 2017; Floros and Vlachou 2005; Lu et al. 2010; Meng et al. 2013). Furthermore, the negative and significant coefficient of EEXP (-0.1837) suggests that a 1% increase in expenditure for environment protection activities leads to a 0.18% reduction in CO2 emissions in EU27 countries (Accepting $H1_B$ and Rejecting HO_B). It can be inferred that by supporting and promoting environment-friendly activities by incentivising through environmental spending (EEXP), it will reduce CO2 emissions in EU27 countries (see, (Adebola Solarin et al. 2017; Caglar and Yavuz 2023; Ercolano and Romano 2018; Solarin and Al-Mulali 2021). The ARDL long-run estimates of control variables for economic growth highlight the positive but diminutive impact on CO2 emissions in EU27 countries. The MUF and Y coefficient show that a 1% increase in manufacturing activities will lead to increase in CO2 emission in EU27 countries by 0.013% and 0.001% respectively. The results support the well-known EKC theory (Grossman and Krueger 1991), which asserts that a growing economy uses more energy for manufacturing, increasing environmental pollution. The estimates are in line with the previous studies done on EKC theory (see, (Pata 2018; Pata and Caglar 2021; Saidu Musa and Maijama'a 2020; Shahbaz et al. 2021; Sharma et al. 2020). The estimates open a new window of further discussion and research on inverting the impact of economic growth on CO2 emissions. The short-run ARDL estimates assert a negative relationship between environmental tax (ETAX) and spending (EEXP) in EU27 countries (see, (Caglar and Yavuz 2023;

Table 8 Panel ARDL and NARDL estimates

Variables	ARDL Coefficient (Prob.)	NARDL Coefficient (Prob.)
Long-run coefficients		
ETAX	-0.0504 (0.0001*)	---
$ETAX^{+}$	---	-0.0315 (0.0000*)
$ETAX^{-}$	---	0.0778 (0.0000*)
EEXP	-0.1837 (0.0000*)	---
$EEXP^{+}$	---	-0.0848 (0.0077*)
$EEXP^{-}$	---	0.1274 (0.0061*)
MUF	0.0137 (0.0000*)	0.0034 (0.0000*)
Y	0.0010 (0.6370)	0.0030 (0.0000*)
Constant	-0.0296 (0.0030*)	0.09194 (0.0001*)
Short-run coefficients		
Δ(CO2 (-1))	0.2040 (0.0233**)	-0.1433 (0.0563**)
Δ(ETAX)	-0.0918 (0.0389**)	---
Δ(ETAX(-1))	-0.0114 (0.1368)	---
$\Delta(ETAX^{+})$	---	-0.0102 (0.0038*)
$\Delta(ETAX^{+}(-1))$	---	0.0274 (0.2442)
$\Delta(ETAX^{-})$	---	0.0724 (0.0420**)
$\Delta(ETAX^{-}(1))$	---	-0.0030 (0.0193**)
Δ(EEXP)	-0.0311 (0.0271**)	---
Δ(EEXP(-1))	0.0201 (0.0316**)	---
$\Delta(EEXP^{+})$	---	-0.0109 (0.0224**)
$\Delta(EEXP^{+}(-1))$	---	0.0643 (0.4173)
$\Delta(EEXP^{-})$	---	0.0012 (0.9876)
$\Delta(EEXP^{-}(-1))$	---	0.0172 (0.1788)
Δ(MUF)	0.0687 (0.0588***)	0.0007 (0.0692***)
Δ(MUF (-1))	0.0033 (0.0027*)	-0.0001 (0.7242)
Δ(Y)	0.0173 (0.0030*)	0.0113 (0.0057*)
Δ(Y (-1))	-0.7390 (0.1253)	0.0005 (0.0434**)
ECT(-1)	-0.0922 (0.0550**)	-0.2270 (0.000*)
Diagnostic tests		
$Wald_{LR}$ asymmetry (ETAX)	---	20.620 (0.000*)
$Wald_{SR}$ asymmetry (ETAX)	---	5.745 (0.001*)
$Wald_{LR}$ asymmetry (EEXP)	---	34.212 (0.000*)
$Wald_{SR}$ asymmetry (EEXP)	---	7.321 (0.049**)
Hausman test	2.539 (0.6375)	4.452 (0.2217)
Observations	697	675
Log likelihood	2233.840	2291.506
Number of cross-sections	27	27

*, **, and *** indicate significant at 1%, 5%, and 10% level of significance, respectively

Authors Calculation using EViews

M. Liu et al. 2020; Solarin and Al-Mulali 2021; Yang et al. 2014). The coefficient of Δ(ETAX) and Δ(EEXP) show that a 1% increase leads to decreased CO2 emissions by 0.09% and 0.03%, respectively (accepting $H1_C$ and $H1_D$). The positive and significant coefficient of Δ(MUF) and Δ(Y) shows that in the short run, a 1% increase in manufacturing activities will increase CO2 emission by 0.06% and 0.01% respectively supporting the EKC theory by (Al-Mulali et al. 2016; Farooq et al. 2022; Grossman and Krueger 1991; Ozturk and Acaravci 2013) (Table 9).

Table 9 Multicollinearity variance inflation factor (VIF) estimates

Variables	(Panel ARDL) coefficient	(Panel NARDL) coefficients	(Panel ARDL) uncentred VIF	(Panel NARDL) uncentred VIF
ETAX	-0.0504*	---	1.2988	---
$ETAX^{+}$	---	-0.0315*	---	2.7419
$ETAX^{-}$	---	0.0778*	---	1.2985
EEXP	-0.1837*	---	1.4799	---
$EEXP^{+}$	---	-0.0848*	---	1.0975
$EEXP^{-}$	---	0.1274	---	2.9478
MUF	0.0137*	0.0034*	1.8694	1.3212
Y	0.0010	0.0030*	1.1058	2.4496

*, **, and *** indicate significant at 1%, 5%, and 10% level of significance, respectively

Authors Calculation using EViews

The NARDL long-run estimates confirm the asymmetry impact of ETAX, EEXP, MUF, and Yon CO2 emissions in EU27 countries. The negative and significant coefficient on ETAX + (-0.0315) professes that a positive change in environment tax will reduce CO2 emissions by 0.03%, whereas the impact of adverse change in ETAX- has a higher impact on CO2 emissions, as a 1% reduction in ETAX will increase CO2 emissions by 0.07% in EU27 countries (accepting $H1_A$). It can be inferred that an increase in environmental tax will reduce CO2 emissions and work as a counter-incentive for polluting activities, but reducing the tax can lead to higher emissions (see, (Gemechu et al. 2014; Lu et al. 2010; Nakata and Lamont 2001). The significant coefficient on EEXP + affirms that increased environment protection spending will reduce CO2 emissions in EU27 countries by 0.08%. Contrary to the negative change of EEXP-, it has a higher impact on CO2 emissions, as a 1% reduction in spending will increase emissions by 0.12%. The estimates of environmental tax and spending align with previous studies on the impact of tax and spending on carbon emissions (accepting $H1_B$) (see, (Caglar and Yavuz 2023; Chen et al. 2017; Solarin and Al-Mulali 2021). The significant and positive coefficients of MUF and Y, though very minuscule, support the EKC theory (see, (Pata and Caglar 2021; Patel and Mehta 2023; Saidu Musa and Maijama'a 2020; Shahbaz et al. 2021).

Short-run non-linear estimates show that an increase in ETAX + and EEXP + reduce CO2 emissions by 0.01%, respectively (accepting $H1_C$ and $H1_D$). Furthermore, adverse

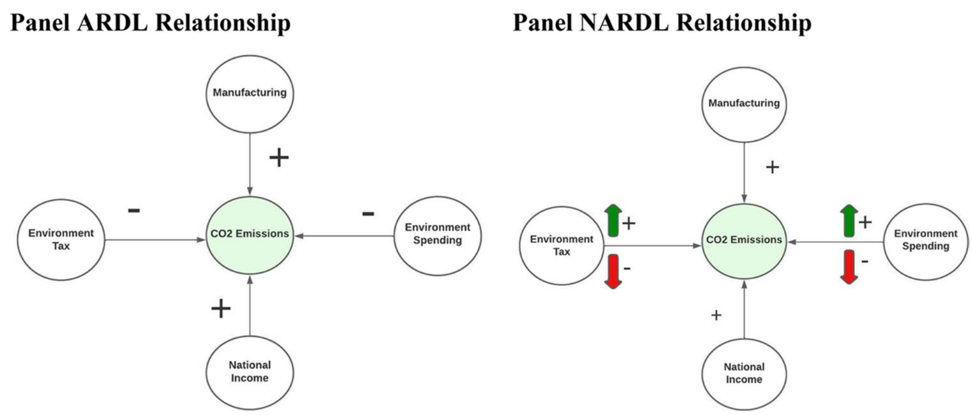

Fig. 3 Symmetrical and asymmetrical relationship plots

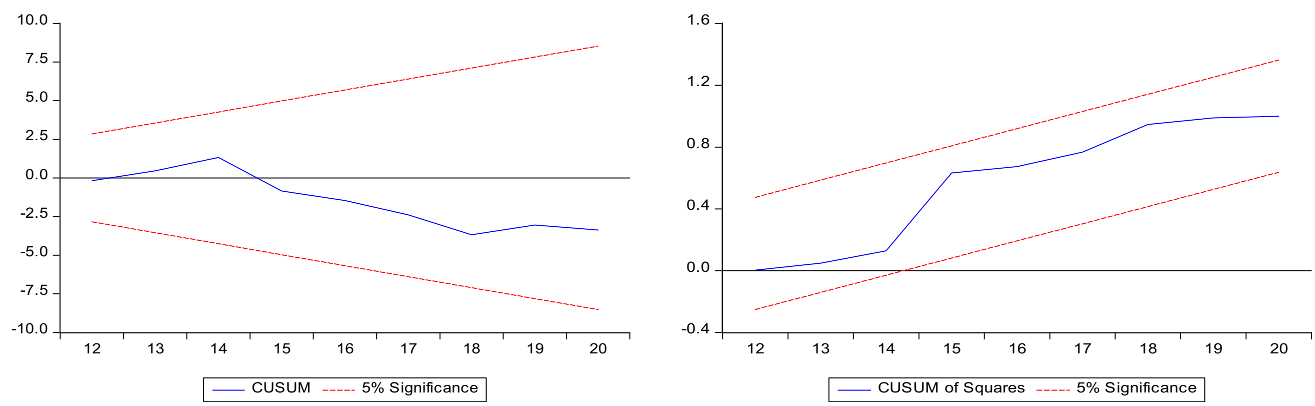

Fig. 4 ARDL Plots of CUSUM, CUSUM of squares

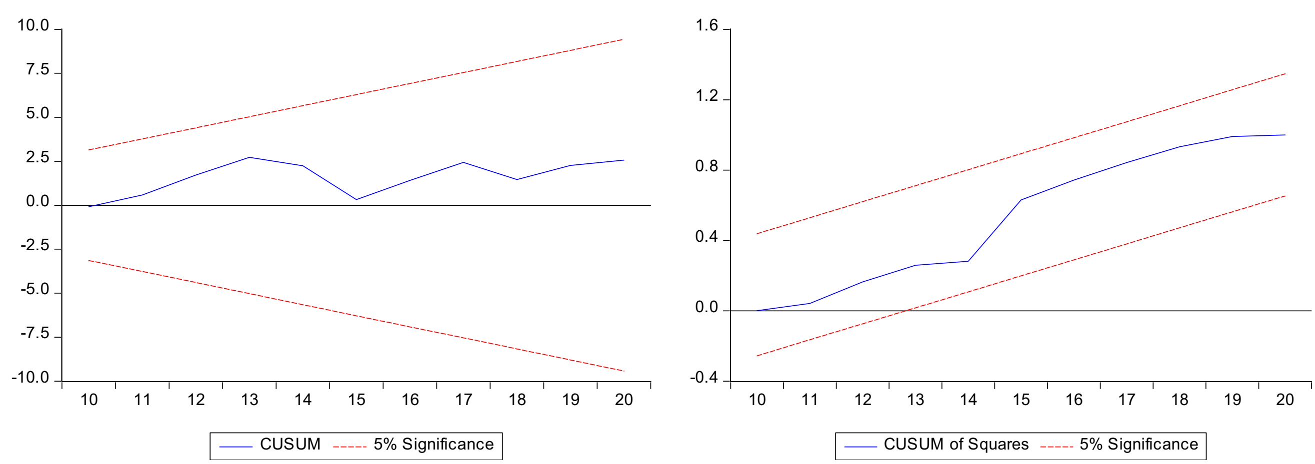

Fig. 5 NARDL plots of CUSUM, CUSUM of squares

changes in ETAX- and EEXP- will increase CO2 emissions by 0.07% and 0.02%, making the impact equivalence in the short-run for EU27 countries. The error correction term in the dynamic model represents the rate of adjustment that restores the equilibrium relationship. The ECM term is negative and statistically significant at a 1% significance level for ARDL and NARDL models, implying a stable long-run relationship between variables. It demonstrates that short-run disequilibrium converges to long-run equilibrium at a speed of 9.2% (in ARDL model) and 22.7% (in the NARDL model); this suggests that the NARDL models provide a better speed adjustment to long-run relationship equilibrium.

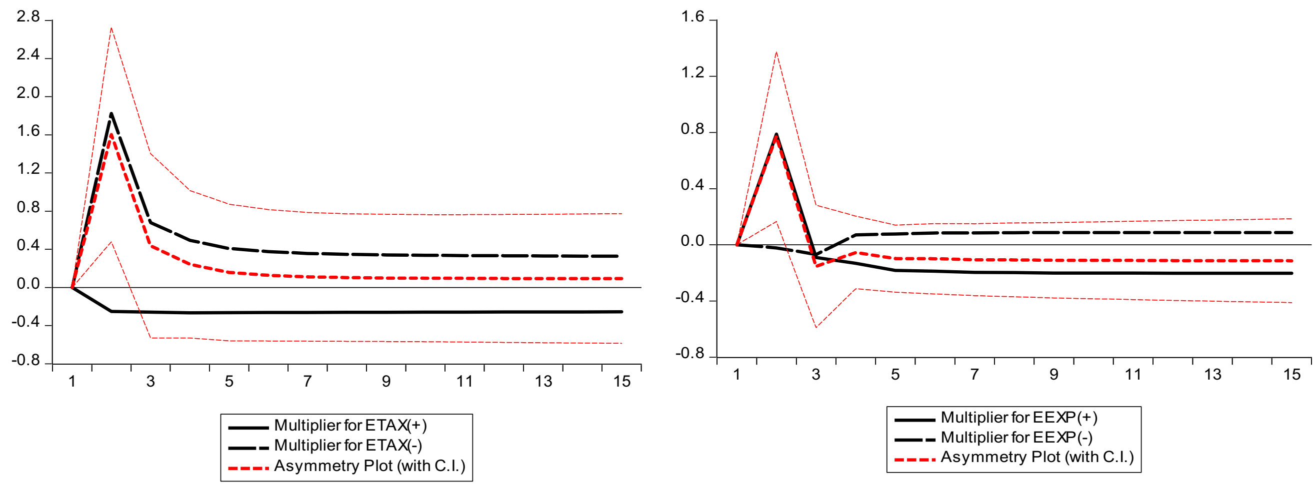

Fig. 6 NARDL dynamic asymmetric multiplier

The symmetric and asymmetric relationship are graphically summarised in Fig. 3.

The plots of CUSUM and CUSUMSQ also confirmed the model stability (see Figs. 4 and 5). The significant Wald test confirms the long-run and short-run asymmetric nexus between CO2 emission and independent variables. The cumulative dynamic multiplier is used to assess the short and long-run asymmetric influence of ETAX and EEXP on CO2 emissions (see Fig. 5). The cumulative dynamic multiplier graphs are shown in Fig. 6. These graphs show how asymmetry varies over time for positive and negative shocks on CO2 emissions. The VIF estimates of panel-ARDL and panel-NARDL coefficients are less than 4 which asserts no multicollinearity among the variables (see Table 4) (see, (Mehta and Mallikarjun 2023; Tamura et al. 2019).

Conclusion

The current study examines the short- and long-term effects of environmental expenditures and taxes on CO2 emissions in a panel of 27 European Union nations. Estimates claim that the variables have a symmetric and asymmetric long-term and short-term relationship. The negative impacts of environmental taxes on CO2 emissions prove that emissions are reduced when polluting activities are taxed. Fiscal policy instrument such as taxation changes the behaviour of the private sector in the EU27 nations by disincentivising polluting activities. On the other hand, government investment in environmental protection has encouraged the private sector in the EU27 nations to embrace and invest in green technologies, decreasing CO2 emissions.

This analysis finds that compared to environmental taxes, environmental spending has more impact on curbing CO2 emissions. Economic expansion and manufacturing activity increase CO2 emissions. It is reasonable to anticipate a positive correlation between industrial development, the production of energy from fossil fuels, and these emissions. By presenting fresh evidence from the European Union, the present study contributes to the literature on CO2 emissions and economic policies. The study also sheds fresh light on the effectiveness of environmental taxes vs. expenditure, where taxes serve as a counter-incentive policy for CO2 emissions, and spending is a positive policy intervention. For correcting their unbalanced energy mix and increasing the amount of cleaner alternative energy sources, EU27 nations serve as examples for policymakers throughout the globe. Global industrialisation has advanced more quickly than before, increasing CO2 emissions. The energy policies of the EU27 serve as an exemplar for both established and emerging nations. If the world wants to uphold its commitment to environmental protection, it must develop laws that support the development of non-polluting industries and more ecologically friendly production methods.

Policy implications

- Sustainable development goals (SDG) number 13 calls for immediate action to mitigate the effects of climate change. One of the main focuses of this objective is CO2 emissions because they are a major cause of climate change and global warming. But CO2 emissions also indirectly affect other sustainable development goals (SDGs), including SDG 7 (affordable and clean energy), SDG 14 (life below water), and SDG 15 (life on land).

Thus, reducing CO2 emissions using environmental taxes and spending is crucial to accomplishing a number of SDGs and guaranteeing a sustainable future for all.

- Putting in place environmental taxes to cut CO2 emissions can help a number of stakeholders, particularly in industrialised and developing nations. A reduction in CO2 will help governments earn tax revenues for climate initiatives and international obligations. Further, it will help businesses innovate and save costs by implementing cleaner technologies; consumers will make more sustainable decisions; and public health outcomes will also improve. Nevertheless, it is important to make sure that these policies are equitable and fair and to take into account any potential distributional effects.
- Government spending on environmental initiatives will cut carbon emissions, which in turn will benefit governments by showcasing their resolve to combat climate change and promoting economic expansion. The businesses will benefit from cleaner practices, cost savings, and improved brand recognition, and consumers will take advantage of better air quality, cheaper energy bills, and easier access to clean energy.

By providing fresh evidence of effective policies like environmental taxes and spending and how they are used to reduce CO2 emissions in EU-27 nations, the research contributed to the current pool of literature on policy relevance and interventions for sustainable environmental initiatives. The research may be extended by adding more macroeconomic factors, such as CO2 emissions and their relationship to health indicators, technological advancements, and other socioeconomic indicators. More investigation may be done by conducting empirical studies on a different panels of comparable economies.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, analysis and writing were performed by DM. The review and editing the drafts of the manuscript was by PP. All authors read and approved the final manuscript.

Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors. The submitted work is original, and it is not published elsewhere in any form or language. No data, text, or theories by others are presented as if they were the author's own.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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