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The Impact of Environmental Policies on the EKC of OECD Countries: Between Environmental Tax and Environmental Policy Stringency

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Abstract:
This paper explores the effects of environmental policies on environmental Kuznets curve (EKC) by focusing on two main instruments: environmental tax and environmental policy stringency. We propose an original empirical strategy based on the 10 OECD countries (i.e., Australia, Canada, France, Germany, Italy, Japan, Korea, Turkey, UK, and USA) during the period 1995-2020, allowing us to test the EKC hypothesis for both inverted U-shape and N-shaped specification. We use heterogeneous panel data, which takes into account the slope heterogeneity and cross-sectional dependence in panel based on the Augmented Mean Group (AMG) estimator, to identify the long-term relationship between carbon dioxide (CO_2) emissions, real gross domestic product (GDP), non-renewable and renewable energy consumption and trade. The estimation results validated the presence of an inverted U-shaped EKC (except the significant impact of renewable energy) indicating that after achieving a certain threshold level, environmental instruments tend to reduce CO_2 emissions, which promote environmental quality. In addition, the validity of an inverted U-shaped EKC hypothesis also indicated that in the long run, the growth of the industrial sector during recovery phase leads to increase CO_2 emissions. The conclusions of this study show important policy implications for policymakers by: i) improving the energy efficiency to improve environmental quality and ii) applying an environmental policy more stringent using monetary penalties can be effective instrument for reducing CO_2 emissions.

Keywords: Environmental Kuznets Curve (EKC); environmental policy; renewable and non-renewable energy consumption; panel data analysis.

JEL Classification: Q56, Q43, C23

1. Introduction

Climate change and environmental degradation have become a thorny problem facing human society and affect negatively economic growth and human health (Mujtaba and Shahzad, 2021; UN, 2021; IPCC, 2022; Kadria et Cal., 2022, Zhao et al., 2022). The catastrophic effect of climate change because of the constant accumulation of the greenhouse gaz effect (Borunda, 2021) leads to increasing temperatures and global warming. As we all know, the excessive use of energy consumption is the culprit of climate change and environmental pollution (Farhani and Ben Rejeb, 2012; Chontanawat, 2020; Farhani et al., 2021). As reported by the International Energy Agency (IEA), in 2022, the global CO_2 emissions from energy combustion and industrial processes picked up in 2021 to reach their highest ever annual level with 36.3 gigatonnes (Gt) meaning an increase of 6% compared to 2020.

Some few works highlighted that the development of the industrial sector pollutes the environment because it necessitates more resources and energy (Farhani and Tiwari, 2019; Shamsuzzaman et al., 2021). The book of Pigou (1920) had also explained that environmental degradation has negative externalities which should not be regulated only by the market (Hepburn, 2010; Schiller, 2016), but also by the use of environmental rules and regulations in mitigating CO_2 emissions/ or to control the level of energy consumption (Farhani, 2021). In this context, an effective energy policy can be applied to reduce adverse impact of climate change and environmental degradation. Environmental tax (ET) and environmental policy stringency (EPS) are considered as a key driver of the environmental sustainability and can provide solutions to CO_2 emissions (Wolde-Rufael and Mu-lat-Weldemeskel, 2021, 2022).

In this framework, this paper has been conducted on the environmental Kuznets curve (EKC) studying the link between CO_2 emissions and economic growth (Farhani et al., 2014a, 2014b; Farhani and Ozturk, 2015; Wolde-Rufael and Mulat-Weldemeskel, 2021). Given that CO_2 emissions are regarded the most emitting gas in greenhouse gas (GHG) emissions it is necessary to know the influencing factors of environmental quality. Therefore, two appropriate policy instruments (Stringent environmental policy and environmental taxes) are suggested that could deal the issue of negative environmental externalities. In this case, these concerns have attracted a lot of governments attention to put more pressure on firms and sectors targeted in combating environmental degradation. Nonetheless, the Organisation for Economic Cooperation and Development (OECD) created a proxy of EPS to assess its impacts on economic performance, which is based on data associated on selected environmental policies over countries and time (OECD, 2016).

By showing up the importance of these two policy instruments, fixing GHG emissions prices provide solution in reducing CO_2 emissions strategies (Schmalensee and Stavins, 2017; Gillingham and Stock, 2018; Pretis, 2022). According to Haites (2018), the system of carbon taxing determines a price referring to the tax that must be paid on carbon estimated as tons of CO_2 equivalent in metric of product or process. In a similar vein, governments promote more the use of renewable energy to achieve zero emissions and sustainable energy supply (Chen et al., 2022). Similarly, environmental regulations can reduce the negative effects of pollution by adopting environmentally friendly technologies (Rath et al., 2021; Wang et al., 2021a; Chen et al., 2022). Many empirical studies have been conducted to evaluate separately the effectiveness of policies environmental on the quality of the environment such as ET (Aydin and Esen, 2018; Timilsinas, 2018; Shahzad, 2020, Telatar and Birinci, 2022; Tu et al., 2022) or EPS (Wolde-Rufael and Mulat-Weldemichael, 2020; Sezgin et al., 2021).

Nevertheless, despite the fact that the environmental policies play a crucial role to promote economic growth, few empirical researches have analyzed this in the light of stringent environmental policies (Kozluk and Zipperer, 2014, OECD, 2016). To the best of our knowledge, this research is considered as the first attempt to explore the mitigating effects of these two policy instruments on greenhouse emissions.

Therefore, we fill this important gap in the existing literature by examining the effectiveness of environmental taxes and environmental stringency policies linked to the Environmental Kuznets Curve (EKC) hypothesis of in OECD countries (i.e., Australia, Canada, France, Germany, Italy, Japan, Korea, Turkey, UK, and USA) throughout 1995–2020. In addition, this study uses the Augmented Mean Group (AMG) estimator in heterogeneous panel data based on the slope heterogeneity and cross-sectional dependence, to analyze the long-term relationship between CO_2 emissions, real GDP, non-renewable and renewable energy consumption, and trade in % of GDP.

The rest of the paper is structured as follows. The Section 2 provides the literature review. Section 3 indicates data and models specification. Results and interpretations are detailed in Section 4. Conclusion and policy implications are mentioned in Section 5.

2. Literature Review

2.1. The impact of environmental tax (ET) on the environmental degradation

Fixing an ET consists not only to collect monetary penalties from who exceed environmental safe limits but also to essentially change the behavior in order to use friendly eco-technologies in the polluting business and to use less pollutant products; consequently, the environmental pain will be reduced (Pigou, 2013; Timilsinas, 2018; Aydin and Esen, 2018; Borozan 2019; Shahzad, 2020, Wolde-Rufael and Mulat-Weldemeskel, 2020; Telatar and Birinci, 2022; Tu et al., 2022). Many other researchers (Lu et al., 2010; Guo et al., 2014; Xu and Long, 2014; Yang et al., 2014; Zhang et al., 2016; Schmalensee and Stavins, 2017; Haites, 2018; Tol, 2018; Pretis, 2022) show that fixing a tax on carbon as eminent air pollutant may reduce carbon emissions.

Shahzad (2020) also uses some earlier studies like Ligthart and Van Der Ploeg (1999) to show that ET can attain numerous objectives such as obtain greener and cleaner environment, sustain economic development, minimize unemployment rate, and reduce labor taxes cut.

On another side, Mulatu (2018) proves that ET can raise the firms' production cost and can be considered as sabotage for their international competitiveness. Moreover, these firms will transfer this rise to consumers that this situation will more weaken low-income households and aggravate income inequality (Lin and Li, 2011; Oueslati et al., 2017; Fremstad and Paul, 2019).

The empirical results are mixed with some studies prove that ET may mitigate environmental degradation and surely reduce emissions (Lin and Li, 2011; Morley, 2012; Haites, 2018; Nakata and Lamont, 2001), while others did not support the claim that ET improve environmental quality (Timilsinas, 2018; He et al., 2019a; Shahzad, 2020). Working on the energy consumption, Nakata and Lamont (2001), Morley (2012) and Filipović and Golušin (2015) show that energy taxes can decrease energy use as well as reduce GHG emissions; and they also find that ET lead to control the level of energy consumption which automatically generates emissions reduction; but by applying a quantile regression, Borozan (2019) find that energy tax may increase energy use in lower energy-consuming EU countries and it seems insignificantly to reduce energy consumption at higher quantiles.

While the majority of the studies found that ET lead to reduce emissions and to improve the environmental quality, others did not found this result (Gerlagh and Lise, 2005; Lin and Li, 2011; Zhang, 2016; Liobikienė et al., 2019).

According to OECD (2022), ET is considered as a critical and essential instrument for governments to control relative prices of goods and services. The characteristics of all taxes' forms (included: tax base, tax rates, revenue, exemptions, etc.) are considered to assemble the environmentally related tax revenues with a failure by environmental area: "*energy products (including vehicle fuels); motor vehicles and transport services; measured or estimated emissions to air and water, ozone depleting substances, certain non-point sources of water pollution, waste management and noise, as well as management of water, land, soil, forests, biodiversity, wildlife and fish stocks*". These taxes may introduce a price signal that helps polluters to allow for the costs of environmental pollution when they produce or consume. These taxes are a flexible policy instrument that can reduce control costs for some cases or encourage technological innovation for achieving a given pollution target to reduce emissions.

2.2. The impact of environmental policy stringency (EPS) on the environmental degradation

To reduce emissions, governments need to impose high restrictions and regulations on polluters to increase the costs of polluting services and activities (Stavins and Whitehead, 1992; Neves et al. 2020). This is done by discouraging environmentally dirty technologies and adopting environmentally friendly technologies (Porter and van der Linde, 1995; Ambec et al., 2013; Dechezleprêtre and Sato, 2017; Ramanathan et al., 2017; van Leeuwen and Mohnen, 2017; Mulatu, 2018). Thus, like for the case of ET, ESP rules and regulations have the capability to replace the behavior of consumers and producers towards eco-friendly consumption and production of energy products (Lagreid and Povitkina, 2018).

In the literature, another policy instrument other than ET has been used to mitigate environmental degradation, which is the focus of this sub-section; it is the EPS (Wolde-Rufael and Mulat-Weldemichael, 2020; Sezgin et al., 2021). This instrument consists to make high costs on all causes of pollution to replace the behavior of both consumers and producers for getting closer to the use of eco-friendly products (OECD, 2016; Hojnik et al., 2019; Neves et al., 2022; Zeynalova and Namazova, 2022), but on the other hand, these costs of EPS can block firms when searching to adopt

eco-friendly investments that avert them from looking for innovations and technologies that can reduce emissions and also improve environmental quality (Stern and Valero, 2021).
To reduce these costs and avoid the negative EPS, firms in developed countries have used a new strategy based on the exportation of their environmentally dirty goods to countries with limited environmental regulations and rules (Levinson and Taylor 2008; Mulatu 2018). These regulations may negatively affect the international competitiveness (Stewart, 1993). According to this point, Kim and Rhee (2019) prove that developing countries may use this strategy to attenuate their environmental standards in order to improve their international competitiveness and to appeal to foreign capital. But, on a certain level of emergency, these countries became more environmentally stringent. They will apply their own stringent environmental regulations and environmentally friendly technologies to reduce pollution (Dechezleprêtre and Sato, 2017; Ramanathan et al., 2017). This means that at an early stage, environmental rules and regulations based on EPS have no impact on the improvement of environmental quality, but at a later one, they should be applied to ameliorate this quality (Ferris et al., 2017).
Similar to empirical evidence between ET and environmental quality, empirical evidence between EPS and environmental quality are not conclusive. The first group of works shows that environmental regulations may control the high level of energy consumption (Yin et al., 2015), reduce emissions and pollution intensity (Shapiro and Walker, 2018; de Angelis et al., 2019; Pei et al., 2019; Danish et al., 2020; Song et al., 2020a; Wolde-Rufael and Mulat-Weldemeskel, 2020) and generate a positive impact on ecological efficiency with affecting clean production industries (Wang and Shen, 2016; Wang et al., 2021b); while the second group of works show that environmental rules and regulations have no significant impact on the degree of pollution (Hao et al., 2018; Li, 2019; Wang and Wei, 2020; Wolde-Rufael and Mulat-Weldemeskel, 2020).
According to Kruse et al. (2022), OECD countries execute severe environmental policies, where EPS is becoming the more used tool to focus on climate change and mitigation of air pollution policies.

2.3. The impact of both ET and EPS on the environmental degradation

While many researchers believe that environmental regulations fixed by governments may attenuate environmental overruns and also give solutions to environmental problems, some others propose to declare these regulations and to use many policy instruments like ET and EPS at the same time. The use of both instruments together comes from the fact that there is a fear that such policy cannot work alone and properly with the used modelisation and then generate unexpected and unacceptable consequences for environmental degradation (Wolde-Rufael and Mulat-Weldemeskel, 2021, 2022).
While there is a lack of studies that combine policy instruments to reduce emissions, the first work of Wolde-Rufael and Mulat-Weldemeskel (2021) use ET and EPS as central policy instruments for reducing CO_2 emissions. They study the effectiveness of these two policy instruments in a panel of 7 emerging countries between 1994 and 2015. They use heterogeneous panel data considering slope homogeneity, cross-sectional dependence, and homogeneous causality tests by applying the AMG estimator which is unbiased, efficient, and may give consistent estimates. They realize the EKC hypothesis as the inverted U-shaped relationship between CO_2 emissions and EPS is found, and they also show that applying EPS will take time to be effective. They also find that ET instrument may improve environmental quality. In global, Wolde-Rufael and Mulat-Weldemeskel (2021) conclude that both ET and EPS can be effective in reducing CO_2 emissions. The second work of Wolde-Rufael and Mulat-Weldemeskel (2022) uses the same instruments in a panel of 20 European countries between 1995 and 2012, and they find that ET and EPS are considered as the keystones for a sustainable environment. By applying panel cointegration tests, authors conclude two negative relationships between ET and CO_2 emissions and between EPS and CO_2 emissions. Using a quantile regression model, Wolde-Rufael and Mulat-Weldemeskel (2022) conclude that applying the two policy instruments may reduce CO_2 emissions. This may lead policy makers to encourage the use of ET and EPS as the current level of these policy instruments is considered as low relative to levels necessary to reach environmental objectives and to the carbon cost and the used energy.

3. Data and models specification

3.1. Data and description of the selected OECD countries

As stated in the introduction, the paper examines annual data of ten OECD countries, namely Australia, Canada, France, Germany, Italy, Japan, Korea, Turkey, United Kingdom (UK), and United States of America (USA). The time series data was selected depending on data availability and it indicates the period of 1995–2020. The sources of data come from: i) the recent World Bank Development Indicators (WDI) online database that include the following variables: carbon dioxide emissions (CO_2) (measured in metric tons per capita), real GDP (GDP) (measured in constant 2010 US$ per capita), non-renewable energy consumption (NRE) (measured as fossil fuel energy consumption in % of total final energy consumption), renewable energy consumption (RE) (measured in % of total final energy consumption), and trade (TR) (measured in % of GDP); and ii) the OECD online database that include: Environmental tax (ET) (measured as the environmentally related tax revenues[1] in % of GDP) and Environmental Policy Stringency (EPS) index[2].
Descriptive statistics for the used variables are presented in Table 1.

Table 1. Descriptive statistics.

	CO_2	GDP	NRE	RE	TR	ET	EPS
Mean	10.64298	34313.99	81.71493	8.798751	51.19811	2.150264	2.028913
Median	9.441500	34554.87	83.94999	7.357400	50.74085	2.252953	1.916667
Maximum	20.47200	56863.37	98.05309	22.64220	105.5663	4.004167	4.070000
Minimum	2.877000	5782.253	46.22592	0.443590	16.39010	0.732319	0.460000
Std. Dev.	4.900476	12526.83	11.47744	6.433119	18.15051	0.743084	0.981826
Skewness	0.431770	-0.591108	-1.682471	0.779182	0.359915	-0.018934	0.158754
Kurtosis	1.998406	3.086134	5.337607	2.630883	3.115939	2.496859	1.789718
Jarque-Bera	15.30279	12.29422	146.8883	22.44153	4.651483	2.227615	13.69894
Probability	0.000475	0.002140	0.000000	0.000013	0.097711	0.328307	0.001060
Sum	2235.025	7205938.	17160.13	1847.738	10751.60	451.5554	426.0717
Sum Sq. Dev.	5019.064	3.28E+10	27531.93	8649.469	68853.17	115.4045	201.4724
Observations	260	260	260	260	260	260	260
Cross sections	10	10	10	10	10	10	10
Source of data	WDI	WDI	WDI	WDI	WDI	OECD	OECD

As presented in Table 1, CO_2 emissions show a considerable variation from 2.87 metric tons per capita (detected in Turkey) to 20.47 metric tons per capita (detected in USA). In terms of real GDP per capita, Turkey has the lowest value with 5782.25 and USA has the highest with 56863.37. Non-renewable energy consumption in % of total final energy consumption also considers an important variation from 46.22 (in France) to 98.05 (in Australia). For renewable energy consumption (RE) that measured in % of total final energy consumption, the lowest value is 0.44 (detected in Korea), while the highest is 22.64 (detected in Canada). In terms of trade measured in % of GDP, the lowest value is 16.39 (detected in Japan), while the highest is 105.56 (detected in Korea). The environmentally related tax revenues in % of GDP that indicated ET varies from 0.73 (in USA) to 4 (in Turkey). In terms of EPS index, both Australia and Turkey have the lowest with 0.46 while Australia has the highest with 4.07.

3.2. Models specification

This sub-section helps to verify three points: i) determine the nature of the EKC (Environmental Kuznets Curve) [inverted U-shape or N-shaped form]; ii) test the validity of the EKC (Environmental Kuznets Curve); iii) show the importance of including ET and EPS as determinants of environmental quality to the standard EKC model.

The general functional form of the used EKC model is as follows:

[1] https://data.oecd.org/envpolicy/environmental-tax.htm

[2] Environmental policy stringency (EPS) index ranges from 0 (not stringent) to 6 (highest degree of stringency) (see: Kruse et al., 2022).

$$CO2_{it} = f(GDP_{it}, X_{it}) \quad (1)$$

where X represents exogenous variables other than GDP.

Based on the works of Farhani et al. (2014b)[3] and Allard et al. (2018)[4] in the context of respectively determining and testing the EKC hypothesis for inverted U and N-shaped form, we will develop the two following equations:

$$co2_{it} = \alpha_{0i} + \alpha_{1i} gdp_{it} + \alpha_{2i} gdp_{it}^2 + \alpha_{3i} nre_{it} + \alpha_{4i} re_{it} + \alpha_{5i} tr_{it} + \alpha_{6i} et_{it} + \alpha_{7i} eps_{it} + \varepsilon_{it} \quad (2)$$

$$co2_{it} = \beta_{0i} + \beta_{1i} gdp_{it} + \beta_{2i} gdp_{it}^2 + \beta_{3i} gdp_{it}^3 + \beta_{4i} nre_{it} + \beta_{5i} re_{it} + \beta_{6i} tr_{it} + \beta_{7i} et_{it} + \beta_{8i} eps_{it} + \xi_{it} \quad (3)$$

All variables in equation 2 and equation 3 were transformed into natural logarithms (ln) to avoid heteroscedasticity, where $co2 = \ln \mathrm{CO2}$; $gdp = \ln\mathrm{GDP}$; $nre = \ln\mathrm{NRE}$; $re = \ln\mathrm{RE}$; $tr = \ln\mathrm{TR}$; $et = \ln\mathrm{ET}$; $eps = \ln\mathrm{EPS}$. i and t denote the country and the time, respectively. α_0 and β_0 are the fixed country effect, and ε and ξ are the white noise stochastic disturbance term.

In the next section, the study consists of choosing for each case of equations 2 and 3 the best model that respects EKC hypothesis and gives acceptable coefficients[5].

4. Results and discussion

Based on the AMG estimator given by Eberhardt (2012) and Bond and Eberhardt (2013), the author estimates and re-estimates the standard EKC model with including ET and EPS. The AMG procedure presents two advantages: i) its estimator does not need any preliminary test of unit root or cointegration, and also may examine the parameters of non-stationary variables (Destek and Sarkodie, 2019); ii) it takes into consideration cross-sectional dependence and country-specific heterogeneity among countries (Eberhardt, 2012; Destek and Sarkodie, 2019; Akgun et al., 2021). The heterogeneous panel Granger non-causality test of Dumitrescu and Hurlin (2012) is proposed to be used for testing the causal relationship between the variables. In their paper, Lopez and Weber (2017) prove that the theory attached to panel causality develops rapidly; thus researchers and practitioners might face problems to run, with large and long panel databases, the most recent techniques that take into account of heterogeneous panel Granger non-causality.

4.1. Cross-sectional Dependence (CD) tests

Before testing cointegration, the use of CD tests seems essential to avoid bias and size distortions (Pesaran, 2006, 2021). Results of the CD tests are presented in Table 2. As can be seen from Table 2, all the three CD tests, namely Breusch-Pagan LM, Pesaran scaled LM and Pesaran CD, did not reject the null hypothesis of no cross-section independence, then we can conclude that all the series are cross-sectionally related.

Table 2. Cross-sectional Dependence (CD) tests results.

Model	Breusch-Pagan LM		Pesaran scaled LM		Pesaran CD	
	Statistic	**p-value**	**Statistic**	**p-value**	**Statistic**	**p-value**
co2=f(gdp, gdp², nre, re, tr)	570.3664***	0.0000	55.37848***	0.0000	22.50990***	0.0000
co2=f(gdp, gdp², nre, re, tr, et)	493.7439***	0.0000	47.30176***	0.0000	14.26048***	0.0000
co2=f(gdp, gdp², nre, re, tr, eps)	242.3162***	0.0000	20.79896***	0.0000	3.277791***	0.0010

[3] For more details about inverted U-shape EKC form, see Farhani et al. (2014b).

[4] For more details about N-shaped EKC form, see Allard et al. (2018).

[5] All details about coefficients' signs of equation 2 and equation 3 are respectively given by Farhani et al. (2014b) and Allard et al. (2018). For the cases of ET and EPS, Wolde-Rufael and Mulat-Weldemeskel (2021) have described the coefficients of these two variables.

co2=f(gdp, gdp², nre, re, tr, et, eps)	222.6415***	0.0000	18.72506***	0.0000	1.947048*	0.0515
co2=f(gdp, gdp², gdp³, nre, re, tr)	664.2104***	0.0000	65.27051***	0.0000	18.25981***	0.0000
co2=f(gdp, gdp², gdp³, nre, re, tr, et)	615.2350***	0.0000	60.10804***	0.0000	16.05213***	0.0000
co2=f(gdp, gdp², gdp³, nre, re, tr, eps)	253.3547***	0.0000	21.96251***	0.0000	3.272945***	0.0011
co2=f(gdp, gdp², gdp³, nre, re, tr, et, eps)	242.5037***	0.0000	20.81871***	0.0000	3.631456***	0.0003

*** and * denote significance levels at the 1% and 10%, respectively.

4.2. Pesaran-Yamagata slope homogeneity test

Cross-sectional related series indicate generally the possible dependence across countries; but in the reality each country seeks to be independent with its own policies. For this reason, it appears to be important to test cross-country heterogeneity. Using Pesaran and Yamagata (2008), the results indicated in Table 3 show that there is a country-specific heterogeneity among the ten OECD countries.

Table 3. Pesaran-Yamagata slope homogeneity test results.

Model	**Delta (Δ)**		**Adj. Delta ($\bar{\Delta}$)**	
	value	**p-value**	**value**	**p-value**
co2=f(gdp, gdp², nre, re, tr)	10.472***	0.0000	12.825***	0.0000
co2=f(gdp, gdp², nre, re, tr, et)	9.143***	0.0000	11.620***	0.0000
co2=f(gdp, gdp², nre, re, tr, eps)	9.175***	0.0000	11.661***	0.0000
co2=f(gdp, gdp², nre, re, tr, et, eps)	7.893***	0.0000	10.442***	0.0000
co2=f(gdp, gdp², gdp³, nre, re, tr)	8.350***	0.0000	10.612***	0.0000
co2=f(gdp, gdp², gdp³, nre, re, tr, et)	7.420***	0.0000	9.815***	0.0000
co2=f(gdp, gdp², gdp³, nre, re, tr, eps)	7.224***	0.0000	9.556***	0.0000
co2=f(gdp, gdp², gdp³, nre, re, tr, et, eps)	6.385***	0.0000	8.821***	0.0000

*** denotes rejection of the null hypothesis of slope homogeneity for the analyzed variables at 1% statistical significance.

4.3. Panel long-run estimates

Based on equation 2 and equation 3 indicated in Section 3, Table 4 reports the AMG long-run estimation results for eight models, where the first four models are related to equation 2 and the last four models are related to equation 3.
Model 1 indicates the AMG results without including the real GDP per capita cubed (gdp^3) and the two environmental policy instruments (“et” and “eps”). The results show that under the EKC hypothesis, the AMG long-run estimates indicate that real GDP per capita (gdp) and the square of real GDP per capita (gdp^2) present a positive but non-significant impact on per capita CO_2 emissions (co2) ($\alpha_{1i} > 0$ and $\alpha_{2i} > 0$). These results do not support the validity of EKC hypothesis in the group of ten OECD countries and also mean that these countries present a special attention, since they show a positive monotonic relationship between real GDP and CO_2 emissions (Farhani et al., 2014a; Farhani et al., 2014b; Farhani and Ozturk, 2015). Also, renewable energy (re) and trade (tr) present a positive and non-significant impact on “co2”, and only non-renewable energy (nre) has present a positive and significant impact on “co2”. This means that Model 1 is an inappropriate choice for the case of these economies.
Comparing with Model 1, Model 2 includes environmental tax (et) instrument and shows an amelioration in the significance results. Also, these results support the validity of EKC hypothesis and present a positive and significant impact of “nre” and “tr” on “co2”, and only “re” has present a negative and non-significant impact on “co2”. Coming to the relationship between “co2” and “nre”, the result is positive and statistically significant; this evidence is in line with most studies (Wolde-Rufael and Mulat-Weldemeskel, 2021). Concerning the relationship that related “co2” and “re”, the results is negative but not statistically significant; this evidence is similar to the findings of Pata (2018); Koc and Bulus (2020), and Saidi and Omri (2020). Coming to the relationship between “co2” and “tr”, the expected sign is positive for the reason that the majority of these countries tend to produce without having tools of environment protection. Thus, their industries produce dirty emissions with heavy share of pollutants (Grossman and Krueger 1995; Farhani et al. 2014a). This dirty production coming from feeble environmental regulations gives a higher level of trade that will increase pollution (Jayanthakumaran et al., 2012; Farhani and Ozturk, 2015). Turning to the relationship between “co2” and ”et”, the results show that the relationship is negative but not statistically significant. More

precisely, a 1% increase in "et" decreases "co2" by 0.652%; this means that environmental tax can reduce carbon emissions. This result is in line with Lu et al. (2010); Guo et al. (2014); Xu and Long (2014); Yang et al. (2014); Zhang et al. (2016); He et al. (2019a, 2019b); Neves et al. (2020); Ulucak et al. (2020); Wolde-Rufael and Mulat-Weldemeskel (2021, 2022).

Model 3 includes environmental policy stringency (eps) instrument and shows a similar significance results with Model 1, except for "eps". This due to the fact that "eps" cannot be included alone in the EKC model and also could be non-monotonic with "co2"; if not, this leads to a downward bias in the estimated link (Kim et al., 2020).

According to Model 4, this model includes the two environmental policy instruments ("et" and "eps") and shows similar results to Model 2, with a relevant amelioration in the coefficients. This implies that including "eps" may lead to reduce environmental degradation but with applying "et" and "eps" at the same time. Our evidence is in line with Wolde-Rufael and Mulat-Weldemeskel (2021, 2022).

Models from I to IV use the same approach followed in the last part, but with including real GDP per capita cubed (gdp^3). This means that the use of N-shaped EKC leads to give logic coefficients' signs for all variables. Also, it is clear that the use "eps" or both "et" and eps" leads to significantly affect "co2". Returning to the theory of the N-shaped EKC, omitting the cubic relationship may lead to erroneously support the inverted U-shaped EKC hypothesis (as it appears in Model 1 and Model 3). This relationship indicated that: i) gdp needs to be positive when affects "co2"; ii) "gdp^2" should present a negative effect indicating decreasing emissions with detecting the first turning point; and iii) "gdp^3"should present a positive sign as a recovery phase after detecting the second turning point. In addition, an increase in "nre" should logically increase CO^2 emissions, while an increase and "re" should decrease "co2", except for developing countries or specific economies (Pata, 2018; Saidi and Omri, 2020). This result also indicates that applying an approach based on 'energy efficiency' may play a vital role in reducingCO_2 emission (Akram et al., 2020). According to the pollution hypothesis, trade should generally lead to increase emissions for low- and middle-income countries and to decrease emissions for high-income countries (Allard et al., 2018; Tian et al., 2022). Finally, the results of Model III and Model IV indicate that the use environmental policy instruments leads to reduce CO_2 emissions; this means that institutions are considered as important components for reducing emissions (Allard et al., 2018).

As we can see that the use of environmental policy instruments with N-shaped EKC models is the best solution, an important point can be concluded from this results is that institutional quality is essential for the ten OECD countries. It is also important to mention that less-developed countries like Turkey often have bad political rights and weak civil liberties; this leads to negatively affect the results of selected OECD countries. In another term, improved institutions with increasing environmental tax in OECD countries might therefore not have a considerable impact on the environment, unless the institution is directly connected to environmental quality because it needs to have an environmental policy stringency and to work on the behavior and using renewable energy (Wolde-Rufael and Mulat-Weldemeskel, 2020).

Table 4. AMG long-run estimation results (Dependent variable: co2).

	Transformations related to Eq.2				**Transformations related to Eq.3**			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model I**	**Model II**	**Model II**	**Model IV**
gdp	0.054941 (0.9716)	4.526738*** (0.0002)	0.596767 (0.6814)	4.959307*** (0.0000)	140.3899*** (0.0000)	106.5890*** (0.0000)	193.6598*** (0.0000)	156.1867*** (0.0000)
gdp^2	0.033053 (0.6725)	-0.203119*** (0.0009)	0.010558 (0.8858)	-0.220241*** (0.0001)	-14.11191*** (0.0000)	-10.49843*** (0.0000)	-19.44027*** (0.0000)	-15.46878*** (0.0000)
gdp^3					0.939262*** (0.0000)	0.345146*** (0.0000)	0.651314*** (0.0000)	0.511066*** (0.0000)
nre	1.025047*** (0.0000)	1.226988*** (0.0000)	0.990256*** (0.0000)	1.191112*** (0.0000)	0.939262*** (0.0000)	1.156938*** (0.0000)	0.862781*** (0.0000)	1.078975*** (0.0000)
re	0.004375 (0.8667)	-0.005823 (0.7628)	0.015734 (0.5222)	0.004967 (0.7754)	0.030913 (0.2313)	0.013891 (0.4682)	0.055333** (0.0184)	0.036688** (0.0242)
tr	0.012045 (0.8324)	0.217419*** (0.0000)	0.086687 (0.1178)	0.283811*** (0.0000)	0.010695 (0.8448)	0.208749*** (0.0000)	0.105318** (0.0384)	0.286543*** (0.0000)

et		-0.652179*** (0.0000)		-0.641378*** (0.0000)		-0.627771*** (0.0000)		-0.602703*** (0.0000)
eps			-0.207034*** (0.0000)	-0.193585*** (0.0000)			-0.263861*** (0.0000)	-0.238987*** (0.0000)
C	-6.414427 (0.4119)	-28.54505*** (0.0000)	-9.644557 (0.1910)	-31.19884*** (0.0000)	-468.6439*** (0.0000)	-364.4363*** (0.0000)	-645.9440*** (0.0000)	-529.1833*** (0.0000)

*** and ** denote significance levels at the 1% and 5%, respectively. P-values are in ( ).

4.4. Homogeneous causality test

The Dumitrescu and Hurlin (2012) panel causality test was used as a robustness check to that of the AMG estimation results. The results of this test are presented in Table 5. Since the main concern of the present study is the EKC (where CO_2 emissions are a dependent variable) with the presence of the two environmental policies ("et" and "eps"), our first attention will be paid to these causal relationships. As can be seen from Table 5, there is a unidirectional causality running from "eps" to CO_2 emissions. In contrast, there is no causality between "et" and CO_2 emissions. Similarly, there are five unidirectional causalities running from "eps" to "gdp", "nre", "re" and "tr". This result is consistent with the results of the AMG estimation results. The causality effect of "et" appears in "gdp", "re" and "tr". These results affirm the interpretations indicated in the previous sub-section.

Table 5. Dumitrescu-Hurlin panel causality tests.

Null Hypothesis:	W-Stat.	Zbar-Stat.	p-value		Null Hypothesis:	W-Stat.	Zbar-Stat.	p-value	
gdp ↛ co2	4.80732	2.83372	0.0046	*Uni*	**re ↛ nre**	6.94980	5.28772	0.0000	*Bi*
co2 ↛ gdp	2.61386	0.32132	0.7480	*No*	**nre ↛ re**	4.03387	1.94781	0.0514	*Bi*
nre ↛ co2	2.68815	0.40641	0.6844	*No*	**tr ↛ nre**	4.93388	2.97868	0.0029	*Bi*
co2 ↛ nre	4.96531	3.01468	0.0026	*Uni*	**nre ↛ tr**	4.08063	2.00137	0.0454	*Bi*
re ↛ co2	5.46088	3.58231	0.0003	*Bi*	**et ↛ nre**	3.49497	1.33055	0.1833	*No*
co2 ↛ re	4.32475	2.28098	0.0225	*Bi*	**nre ↛ et**	2.09072	-0.27790	0.7811	*No*
tr ↛ co2	5.58989	3.73007	0.0002	*Bi*	**eps ↛ nre**	5.45629	3.57705	0.0003	*Uni*
co2 ↛ tr	5.25771	3.34960	0.0008	*Bi*	**nre ↛ eps**	1.68524	-0.74233	0.4579	*No*
et ↛ co2	3.60955	1.46178	0.1438	*No*	**tr ↛ re**	3.55773	1.40243	0.1608	*No*
co2 ↛ et	2.72264	0.44591	0.6557	*No*	**re ↛ tr**	3.91480	1.81142	0.0701	*Uni*
eps ↛ co2	6.12399	4.34183	0.0000	*Uni*	**et ↛ re**	6.09508	4.30872	0 .0000	*Uni*
co2 ↛ eps	2.42034	0.09965	0.9206	*No*	**re ↛ et**	3.35595	1.17131	0.2415	*No*
nre ↛ gdp	4.18519	2.12113	0.0339	*Bi*	**eps ↛ re**	12.5756	11.7316	0.0000	*Uni*
gdp ↛ nre	3.77643	1.65293	0.0983	*Bi*	**re ↛ eps**	2.01161	-0.36851	0.7125	*No*
re ↛ gdp	2.34534	0.01375	0.9890	*No*	**et ↛ tr**	5.26290	3.35554	0.0008	*Uni*
gdp ↛ re	3.33738	1.15004	0.2501	*No*	**tr ↛ et**	2.12852	-0.23459	0.8145	*No*
tr ↛ gdp	3.41343	1.23715	0.2160	*No*	**eps ↛ tr**	6.81743	5.13611	0.0000	*Uni*
gdp ↛ tr	4.90265	2.94291	0.0033	*Uni*	**tr ↛ eps**	2.69977	0.41971	0.6747	*No*
et ↛ gdp	6.00118	4.20117	0.0000	*Bi*	**eps ↛ et**	2.85878	0.60185	0.5473	*No*
gdp ↛ et	7.22707	5.60532	0.0000	*Bi*	**et ↛ eps**	3.72487	1.59387	0.1110	*No*
eps ↛ gdp	6.09325	4.30663	0.0000	*Uni*					
gdp ↛ eps	3.69769	1.56274	0.1181	*No*					

No: no causality ; *Uni*: unidirectional ; *Bi*: bidirectional.
↛ : "does not homogeneously cause".

5. Conclusion and policy implications

As there is an insufficiency of papers that study with details the impact two environmental policy instruments (ET and EPS) on CO_2 emissions, the present paper developed this idea for ten OECD countries during the period 1995–2020. Our evidence indicates that only a unidirectional causality running from EPS to CO_2 emissions is detected. This means that the use of ET without stringency will be present a significant effect for the selected OECD economies. Our results verified the inverted U–shaped EKC form (except the significant impact of renewable energy) suggesting that initially strict environmental instruments do not lead to reduce CO2 emissions but after reaching a certain threshold,

they will improve the environmental quality. Concerning the negative signs of two environmental instruments and the direction causalities, these results suggest that ET and EPS can effectively mitigate emissions and reduce pollution. These results seem as more improved for the case of N–shaped EKC form meaning that developing the production sectors with using the same environmental instruments for a long time will reach a recovery phase that will automatically increase CO2 emissions. This N–shaped EKC form presents the best solution because it offers new chances for some industries (firms) to be not weak or non-competitive (avoid bankruptcy or closure).
The first policy implication is that using individual environmental instrument or without stringency will not give attention to the objective of environmental rules and regulations which applied to reduce emissions. Second, these two environmental policy instruments alone are in themselves insufficient to reduce the damaging effects of the huge use of non-energy consumption, the lack of using renewables and the rapid increase of environmental degradation. Our findings have also highlighted some important conclusions for the ten OECD countries: i) The roles of economic development and sustainable development are essential for encouraging industries of the selected economies to safeguard their environmental quality through promoting economic growth; ii) Promoting the use of renewable energy in order to balance the huge use of fossil energy and to obtain a certain energy efficiency as a vital goal of mitigating emissions and pollution; iii) These countries should not only be based on applying environmental tax or force stringency, they must search to encourage citizens to be responsible through the consumption of more eco-friendly goods and services; iv) The use of a specific trade based on the investment in innovative green and clean technologies and renewables may help to reduce non-significant importations and to concentrate on how to sustain energy development and ameliorate environmental quality; this can be realized through the increasing of energy efficiency and balancing the use of fossil energy by starting to investigate in using renewable energy.

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