



# Nexus Between Trading Non-Green Products and Environment: Introducing Non-Green Trade Openness Index

Muhlis Can<sup>1†</sup>, Ihsan Oluc<sup>2†</sup>, Bodo Sturm<sup>3</sup>, Ihsan Guzel<sup>4†</sup>, Beata Gavurova<sup>5\*†</sup> and József Popp<sup>6,7</sup>

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### \*Correspondence:

Beata Gavurova  
beata.gavurova@tuke.sk

### †ORCID:

Muhlis Can  
orcid.org/0000-0002-7315-2916  
Ihsan Oluc  
orcid.org/0000-0002-5167-1862  
Ihsan Guzel  
orcid.org/0000-0002-9525-6628  
Beata Gavurova  
orcid.org/0000-0002-0606-879X

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<sup>1</sup>BETA Akademi, Social Sciences Research Lab (SSR Lab), Istanbul, Turkey, <sup>2</sup>Department of Economics, Mehmet Akif Ersoy University, Burdur, Turkey, <sup>3</sup>Faculty of Business Administration and Industrial Engineering, HTWK Leipzig and ZEW, Mannheim, Germany, <sup>4</sup>Department of Economics, Sirmak University, Sirmak, Turkey, <sup>5</sup>Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical University of Košice, Košice, Slovakia, <sup>6</sup>Hungarian National Bank—Research Center, John von Neumann University, Kecskemét, Hungary, <sup>7</sup>TRADE Research Entity, North-West University, Vanderbijlpark, South Africa

Trade is a significant parameter that may impact environment positively or negatively. However, there is no consensus on this issue among the researchers. It seems likely that tradable products will affect the environmental quality level. However, this requires the separation of the international trade basket. Thus, this research asks whether trade in non-green products affects the level of environmental degradation in the 25 European Union (EU) member states? To answer this question, we develop an index of trade openness in non-green products and empirically investigate whether this index influences the ecological footprint. Non-green trade openness index represents the ratio of the total export and import of non-green products in a country's international trade basket to that country's Gross Domestic Product. Advanced panel estimation techniques are employed for a sample of 25 EU countries over the period between 2003 and 2016. The core finding—supporting the Pollution Haven Hypothesis—is that non-green trade openness reduces environmental degradation. We discuss several implications of this result for recent environmental policies, particularly for the EU climate policy.

**Keywords:** carbon neutrality, non-green products trading, non-green openness index, income, environmental sustainability, pollution haven hypothesis (PHH)

## 1 INTRODUCTION

Climate change is without doubt one of the most pressing problems in recent environmental policy. With the Paris climate conference (COP21) in 2015, governments have agreed to keep global warming below 2°C above pre-industrial levels. At this conference, it was stated that greenhouse gas (GHG) emissions are a serious concern that needs to be addressed urgently (UNFCCC, 2015). It has been decided that each country will comprehensively report the national climate action plans that they will prepare by taking into account their own special conditions and the targets they need to achieve in GHG emissions (Mesagan & Chidi, 2020). It was also agreed to review these targets every 5 years in a global stocktake process and to increase the national targets gradually (Horowitz, 2016). In a more broader perspective, climate change can be seen as a very prominent example for anthropogenic environmental degradation (Shpak et al., 2021). Other examples of severe environmental degradation caused by human activity include biodiversity loss, deforestation, and local air pollution (Prokopenko et al., 2020).

The EU has set 2020, 2030 and 2050 targets as a long-term strategy in order to reach the targets set by the Paris climate agreement. Conceptualized as the “Green Deal,” this agreement represents a roadmap of key policies for the EU’s climate agenda (Siddi, 2020). These targets include reducing GHG emissions by 20% in 2020, 40% in 2030, based on 1990 levels, and becoming an economy with net zero GHG emissions by 2050 (European Commission).

While achieving these goals, one of the biggest roles falls on international trade. Since international trade, CO<sub>2</sub> emissions, energy consumption and economic production tend to move together, these variables need to be evaluated together (Nasreen and Anwar, 2014). As a matter of fact, there have been many studies investigating the effects of energy consumption on environmental degradation, along with international trade (Hossain, 2011; Sebri and Ben-Salha, 2014; Ohlan, 2015).

Trade affects the environment in many ways and alone causes 20% of global carbon emissions (Zafar et al., 2019). On the one hand, the increase in trade is connected to more output and more energy demand due to the acceleration of economic activity (Sadorsky, 2012). Therefore, energy serves as an important input in the production process and ensures the operation of machinery and equipment. On the other hand, energy is needed in the process of transporting the outputs after the production process, that is, the finished goods or raw materials. Therefore, there are transportation costs even in the trade of sophisticated products, which increases energy consumption (Anderson and van Wincoop, 2004). In the EU, it is estimated that the share of only transportation-related GHG emissions in total emissions is 24% (Alola et al., 2021).

The strict environmental policies implemented by the EU increase the cost of producing environmentally harmful products in the European continent compared to clean products (Benzerrouk et al., 2021). In this case, products that require high energy consumption in their production are increasingly being produced outside the EU and then imported into this region. At the same time, as a result of the specialization of European countries in more environment-friendly products, it may cause a decrease in environmental pollution in rich countries and an increase in environmentally harmful production in developing countries. There are many studies supporting this process, called the Pollution Haven Hypothesis (PHH) (Cole, 2004; Nasir et al., 2019). Put simply, this could mean a cleaner Europe versus a more polluted rest of the world. As a matter of fact, the EU Emissions Trading System (EU-ETS) introduced by the EU to the energy and industrial sector within the framework of climate policies also brought these concerns along. The EU-ETS, the cornerstone of EU climate policy, is the first and largest international emissions trading system in the world and has been in operation since 2005 (Skjærseth and Wettstad, 2009). The emission trading system directly limits the GHG emissions of the power plants and industrial facilities included in this system, by placing an upper limit on these emitters (Bayer and Aklin, 2020). Therefore, the production of non-green products becomes more costly in the EU.

Within the framework of the EU Green Deal, it is planned to implement the Carbon Border Adjustment Mechanism (CBAM) to prevent carbon leakage predicted by the PHH and reduce total GHG emissions (Eicke et al., 2021). With this regulation, it is

aimed to bring the prices of high-cost low-emission products manufactured as an alternative to high-emission products manufactured at low cost to the same level (Krzyszowski, 2020; Bellora & Fontagne, 2021). Thus, it will protect the competitiveness of low-emission products that will not cause carbon leakage (Mehling and Ritz, 2020).

All over the world and especially in Europe, measures are taken and regulations are made due to global warming and climate change. This situation will deeply affect the international trade and production style in the coming years. Therefore, in this transition period, it is necessary to make preparations to prevent the economies from being damaged. Especially considering the EU-ETS and CBAM regulations, it is clear that EU countries want to avoid trade in non-green products. Therefore, it can be predicted that international trade will be divided into two parts, namely the trade of green products and non-green products. On the one hand, green products can be defined as those increasing energy efficiency and minimizing environmental damage due to energy consumption (Paramati, Mo, and Huang, 2021). On the other hand, non-green products can be considered as products that are subject to restrictions and carbon taxes in national and international trade. Such products are expected not to contribute to the green transformation of countries. Based on this idea, Can, Ben Jebli and Brusselaers (2022) and Can et al. (2021) separated green products from the total international trade basket and constructed a new index labelled as Green Openness Index. The index only consists of the ratio of green product exports and green product imports to Gross Domestic Product. Green trading will be helpful in finding a viable solution for building a green economy and achieving carbon neutral goals (Lengyel et al., 2021; Ahmad et al., 2022a).

The significant contribution of the Green Openness Index to the environmental literature is an undeniable fact (Ahmad et al., 2022a; Ahmad et al., 2022b). However, it is necessary to examine the environmental impact of trade consisting of products other than green products by aggregating the remaining part of the separated trade basket. Because, as the share of non-green products in exports and imports increases, the countries’ economies will have difficulties in realizing the green transformation.

The aim of this study is to separate the non-green products from the total foreign trade basket and to bring an alternative perspective to the trade openness variable, which was frequently used in the literature. With this new index, it is aimed to investigate the effects of non-green products on environmental degradation where CO<sub>2</sub> emissions are only a prominent example. In many studies, while the effect of trade on the environment was examined, trade was proxied with trade openness and environmental pollution was discussed in this context. However, there are many green products in total trade, and the trade of more environment-friendly products can increase the environmental quality. On the other hand, studies based on trade volume assume that increasing trade in general increases environmental pollution as a whole. However, in order to clearly observe the net impact of non-green products on the environment, green products that consume less energy and are more environment-friendly should be removed from the trade basket.

**TABLE 1 |** Recent literature testing the impact of international trade on environmental degradation (Summarized Results).

Authors	Duration	Country/Country group	Method(s)	Trade indicator	Results
Can et al. (2022)	2007–2017	31 OECD Countries	FMOLS, DOLS	Green Openness Index	(-)
Ahmad et al. (2022a)	2004–2018	BRICS Countries	CUP-FM, CUP-BC	Green Openness Index	(-)
Can et al. (2021)	2003–2016	35 OECD Countries	AMG, PMG, MG	Green Openness Index	(-)
Mongo et al. (2021)	1991–2014	EU-15 Countries	ARDL	Trade Openness	(+)
Destek et al. (2018)	1980–2013	EU-15 Countries	MG-FMOLS, MG-DOLS, DCCE-MG	Trade Openness	(-)
Abid, (2017)	1990–2011	41 European Countries	GMM	Trade Openness	(-)
Al-Mulali et al. (2015)	1990–2013	23 Selected European Countries	FMOLS	Trade Openness	(-)
Kasman and Duman, (2015)	1992–2010	15 EU and Candidate Countries	FMOLS	Trade Openness	(+)
Iwata et al. (2010)	1960–2003	France	ARDL	Trade Openness	(+)
Tachie et al. (2020)	1990–2015	EU-18 Countries	MG-AMG	Trade Openness	(-)
Destek et al. (2016)	1990–2011	10 for Selected Central and Eastern European Countries (CEECs)	FMOLS	Trade Openness	(-)
Ketenci, (2021)	1960–2015	EU-15 Countries	DOLS	Trade Openness	(+)
Dogan and Seker, (2016)	1980–2012	EU-15 Countries	DOLS	Trade Openness	(-)
Liu et al. (2019)	2000–2014	125 Countries	Driscoll and Kraay estimator	Export Diversification	(-)
Shahzad et al. (2020)	1971–2014	63 Countries	GMM	Export Diversification	(-)
Sharma et al. (2022)	1995–2018	BRICS Countries	ARDL	Import Concentration	(+)
Mania, (2020)	1995–2013	98 Countries	GMM, PMG	Export Diversification	(-)
Apergis et al. (2018)	1962–2010	19 Developed (high-income) Economies	Panel ARDL	Export Concentration	(-)
Can et al. (2020)	1971–2014	84 Developing Countries	DOLS, FMOLS	Export Diversification, Extensive and Intensive Margin	(-), for all indicators
Hu et al. (2020)	1995–2014	35 Developed and 93 Developing Economies	FMOLS	Import Product Diversification	(-) for developed, (+) developing countries
Pié, Fabregat-Aibar, and Saez, (2018)	1992–2012	30 European Countries	Bayesian framework	Export, Import	(-) for export and (+) for import

Note: The table shows a list of selected recent empirical literature on the effect of international trade on environmental degradation. (+), (-) signs indicate the effect of trade indicators on environmental degradation. While (-) sign presents positive effect, (+) represents negative impact, respectively. ARDL, DOLS, FMOLS, AMG, GMM, MG, DCCE-MG, CUP-FM, CUP-BC and PMG represents, autoregressive distributed lag, dynamic ordinary least squares, fully modified ordinary least squares, augmented mean group, generalized methods of moments, mean group, dynamic common correlated effects mean group, continuously updated fully modified, continuously updated bias-corrected and pooled mean group, respectively.

Therefore, this article investigates the effects of non-green product trade on environmental degradation in 25 EU countries, taking into account other economic parameters.<sup>1</sup> The purpose of choosing the EU sample is that this region is the second largest economy in the world with a GDP of 15.292 trillion US Dollars. In addition, considering international trade, it is the region where the most exports and imports take place in the world (The World Bank, 2022). Despite its large foreign trade volume, this region is planning to be the first carbon neutral continent in about 30 years, in line with the decisions taken by the European Commission and displaying a very strict attitude in environmental regulations (EC, 2018). Along with the EU-ETS being implemented in Europe, restrictions such as the carbon tax approach of the CBAM to be imposed by taking into account the carbon intensity of imported products also require an examination of the relationship between the foreign trade of the EU and carbon emissions and environmental degradation in general.

This study contributes to the literature at least in three ways. First, this research develops a new index of non-green products by

separating green products from the trade basket. According to our best knowledge, this is the first study that separated total non-green products from the international trade basket. Secondly, by employing this index, the environmental impact of trade in non-green products was examined in a sample of EU-25 countries. Third, advanced panel estimation techniques are employed in the study to achieve consistent results.

The remainder of the work is organized as follows. In the next section, information about the calculation of the non-green trade openness index will be given. In the third section, the literature study will be presented. In the fourth, we provide data, empirical methodology, and results, respectively. Section five presents discussion and policy recommendation. Section six concludes the study.

## 2 INTRODUCING NON-GREEN TRADE OPENNESS

There is general agreement as to which sectors pollute the air, water and soil the most compared to other sectors. These sectors are mostly carbon-intensive cement, fertilizer, iron and steel, aluminum and fossil fuel based electricity industries. In

<sup>1</sup>EU has 27 member states. However, in our investigation we have to exclude Luxembourg and Malta since for these countries data for trade in green goods are not available.

**TABLE 2 |** Definition of variables.

Variables	Symbol	Measurement	Source of Data
Environmental Degradation	EF	Ecological Footprint of Consumption (Global Hectares)	Global Footprint Network
Non-Green openness Index	NGOP	NGOP index is measured as the sum of a country's non-green exports and imports as a share of that country's GDP (in %)	OECD Stat (2022)
Income	GDP	Gross Domestic Product per capita (constant 2015 US\$)	World Development Indicators. (2021)
Renewable Energy Consumption	RPC	Per capita energy consumption from renewables (kWh)	Our World in Data (2022)
Non-Renewable Energy Consumption	NRENPC	Fossil fuels per capita (kWh)	Our World in Data (2022)

**TABLE 3 |** Descriptive statistics.

Variable	FP	GDP	NGOP	RPC	NRENPC
Mean	0.7075	4.3410	79.6749	0.3802	4.4666
Std. Dev	0.1072	0.2779	36.3806	0.5923	0.1566
Coefficient of Variation	0.0115	0.0770	1319.76	0.3499	0.0245
Skewness	-0.2528	-0.3143	0.6932	-1.8165	0.2599
Curtosis	-0.3487	-1.0412	-0.5695	7.0307	-0.5424
Observations	350	350	350	350	350

addition to these sectors, the sectors producing paper and pulp, petroleum products, stone clay glass, mining and chemicals producing sectors can also be described as “dirty industries” (Jänicke et al., 1997; Nekomahmud et al., 2020). In addition, there are many sectors that pollute the environment, even if they are not as heavy polluting as the mentioned sectors (Blecharz and Stverkova, 2014). Therefore, it is a more correct approach to characterize the products of countries that are subject to international trade as green products and non-green products (Kusumastuti and Sutoyo, 2019; Prokopenko et al., 2020; Can et al., 2022). However, there is no generally accepted “green list” in the literature. Different organizations have prepared different lists of green products. The most comprehensive of these is the “Combined List of Environmental Goods” (CLEG) consisting of 248 green products released by the OECD. It is possible to consider the products other than the green products in this list as non-green.

In this study, based on the Green Openness Index developed by Can et al. (2022), the Non-Green Openness Index, which is the complement of this index, was developed. The index was calculated for EU-25 countries using the formula below. The new index is based on the “Combined List of Environmental Goods” (CLEG) consisting of 248 different products. We calculate the index between the years 2003 and 2016 since the data for green products is available between for this time period (Can et al., 2021).

$$NGOP_{i,t} = \left( \frac{(Exp_{i,t} - GRNX_{i,t}) + (Imp_{i,t} - GRNM_{i,t})}{GDP_{i,t}} \right) * 100 \tag{1}$$

In Eq 1, Exp and Imp indicates the current value of total merchandise export and import by reporter country *i* at time *t*. GRNX indicates the current value of total environment related products (green goods) export to the world by reporter country *i* at time *t*. GRNM stands for the current value of total environment related products (green goods) import from the world to reporter country *i* at time *t*. GDP represents the total value of goods manufactured in current year *t* in country *i*. The index is calculated for the period from 2003 to 2016 based on the data available in the OECD Statistics Database. The data for environment related products for both export and import are obtained from OECD Stat, (2022), while the GDP, Exp and Imp are acquired from the World Development Indicator released by World Bank (WDI) (2021).

### 3 LITERATURE REVIEW

There are many parameters that affect environmental degradation. In this context, researchers have studied the effects of many different economic and social parameters on the environment. In this context, trade is one of the most frequently tested parameters. In recent years, researchers have studied the significance of trade on the environment. In these studies, researchers use trade openness, export product diversification, import product diversification or export concentration as a proxy of international trade. These studies are presented in Table 1. While several econometric methods were applied in these studies, in the majority of cases the effect of trade on the environment is negative. However, although the studies on trade and environment nexus contribute to the literature, none of the analyses separated the non-green products from total international trade basket.

### 4 EMPIRICAL METHODOLOGY AND DATA

#### 4.1 Data Measurement and Model Settings

The aim of this study is to investigate the effects of non-green trade openness (NGOP), which can be described as a foreign trade basket separated from green products, on the ecological footprint for EU-25 countries. Rees (2018) defines the ecological footprint as “the area of productive land and water ecosystems that the population requires on a continuous basis to produce the

**TABLE 4 |** Testing the cross-section dependency of the variables and models.

CD-test for countries						
Variables	CDLM1-test	p-value	CDLM2-test	p-value	CDLM3-test	p-value
EF	710.30***	0.000	16.75***	0.000	21.50***	0.000
GDP	1573.54***	0.000	51.99***	0.000	36.69***	0.000
NGOP	1718.49***	0.000	57.91***	0.000	38.74***	0.000
RPC	426.13***	0.000	5.15***	0.000	7.21***	0.000
NRENPC	721.78***	0.000	17.21***	0.000	114.89***	0.000
Equation	Model 1: 1.33	0.09	Model 2 : 0.93	0.17		

Notes: \*\*\* indicates the rejection of the null hypothesis at the 1% significance level. CDLM1 test is based on Breusch-Pagan (1980), CDLM2 and CDLM3 test is based on Pesaran (2008).

**TABLE 5 |** Testing the order of integration of the variables.

CIPS test for countries				
Variable	Level	First difference	Critical value	
			1%	5%
EF	-1.51	-2.27**	-2.34	-2.17
GDP	-1.73	-5.11***	-2.34	-2.17
NGOP	-1.48	-2.99***	-2.34	-2.17
RPC	-1.48	-3.52***	-2.34	-2.17
NRENPC	-1.85	-3.57***	-2.34	-2.17

Notes: \*\* and \*\*\* imply the rejection of the null hypothesis at the 5% and 1% significance levels, respectively.

(bio) resources it consumes, and to assimilate its (mostly carbon) wastes, wherever on Earth the relevant ecosystems may be located.” The ecological footprint allows to measure the pressure of humans on the environment in observing anthropogenic effects (Danish and Wang, 2019). Additionally, since the ecological footprint deals with the effects of human beings on air, water and soil together, it allows a holistic approach to reveal the effects on environmental degradation. Therefore, we prefer to use the ecological footprint as indicator for anthropogenic environmental degradation instead of CO<sub>2</sub> emissions which represent only a small part of the degradation and can be used as indicator for climate change only.

We construct our empirical model following Uddin et al. (2017), Kongbuamai et al. (2020) and Lu (2020). We construct two separated models. The main reason doing this is to observe the effects of both renewable energy and non-renewable energy consumption separately and to test whether the results obtained are robust or not. GDP per capita, non-green trade openness, renewable energy consumption, and non-renewable energy consumption are used as explanatory variables. The empirical economic equations are specified as follows:

$$EF = f(GDP, NGOP, RPC) \tag{2}$$

$$EF_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 NGOP_{it} + \beta_3 RPC_{it} + \varepsilon_{it} \tag{3}$$

$$EF = f(GDP, NGOP, NRENPC) \tag{4}$$

$$EF_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 NGOP_{it} + \beta_3 NRENPC_{it} + \varepsilon_{it} \tag{5}$$

In the equations, *EF* represents the ecological footprint, *GDP* stands for real income per capita, *NGOP* indicates non-green

trade openness index, *RPC* and *NRENPC* represent renewable energy consumption per capita and non-renewable energy consumption per capita, respectively. All variables represent the natural log form except the *NGOP*. The coefficients  $\beta_i$ ,  $i = 1, 2, 3$ , indicate the long-run elasticities.  $t$  represents a time frame ( $t = 1, 2, 3, \dots, 14$ ) of the study, and the stochastic error term is indicated as  $\varepsilon$ . All symbols, measurements, and data sources are displayed in **Table 2**. **Table 3** delivers descriptive statistics for all variables used in our models.

It is expected that the  $\beta_1$  coefficients will be positive in both models since the environmental degradation boosts with the increase in per capita national income (Bölük and Mert, 2014). We expect a negative sign for  $\beta_2$  coefficients. The determination of the EU to reduce carbon emissions and strict environmental regulations facilitate the export of sophisticated products, while paving the way for the import of carbon- and in general pollution-intensive products. Therefore, as non-green trade openness increases, the EU can export pollution to their trading partners. In addition, while the consumption of fossil fuels increases the GHG emissions released to the nature, the use of renewable energy sources in consumption reduces these emissions (Štreimikienė, 2021; Ahmad et al., 2022b). Thus, we expect a negative sign for  $\beta_3$  in **Eq. 3** and a positive sign in **Eq. 5** in accordance with the theoretical expectation (Cherni and Essaber Jouini, 2017; Mensah et al., 2019; Ansari et al., 2021).

The interaction between ecological footprint, real income per capita, non-green trade openness index, renewable energy consumption per capita and non-renewable energy consumption per capita was investigated for 25 EU countries over the 2003–2016 period. The main reason for the time constraint is that the export and import data of Green Products in the OECD database are only released for the relevant period. For empirical analysis, first of all, cross-section dependence, unit root tests, and homogeneity tests

**TABLE 6 |** Homogeneity test.

Name of test	Model 1		Model 2	
	LM Stat	p-value	LM Stat	p-value
$\hat{\Delta}$	7.861***	0.00	6.650	0.00
$\hat{\Delta}_{adj}$	9.627***	0.00	8.145	0.00

Notes: \*\*\* indicates significance levels at the 1%.



**TABLE 7 |** Durbin-H panel cointegration test.

	Model 1		Model 2	
	Test-stat	p-value	Test-stat	p-value
Durbin-H Group stat	5.306	0.000***	3789.7	0.000***
Durbin-H Panel stat	3.375	0.000***	2.714	0.003***

Notes: \*\*\* indicates significance level at the 1%.

were performed. Then, the cointegration relationship between the series was investigated, and finally, long-run and short-run coefficient estimates were done for the models.

## 4.2 Empirical Methodology

In this study, we apply the following empirical estimation in six different steps.

### 4.2.1 Cross Section Dependency (CD)

The CD test phase is the most important step of panel data studies. Starting the analysis without performing this test may result in inconsistent results. If there is strong correlation between cross-sections, first generation unit root tests are less likely to give reliable outcomes. In this case, a cross-section dependency test should be performed before starting unit root tests. In case of cross-sectional dependence between the units, using the second generation unit root

tests gives more reliable results. The null hypothesis of the CD test is “There is no dependency relationship between cross-sections”.

### 4.2.2 Unit Root Analysis

After cross-sectional dependence test, we apply cross-sectionally augmented IPS (CIPS) unit root test developed by Pesaran (2008). The CIPS test considers the panel as a unit and investigates the stability of the panel. The null hypothesis is “the series are not stationary”. CIPS test statistics are compared with critical values obtained by Pesaran (1999) using Monte Carlo simulation. If the test statistics are greater than the absolute critical values, the null hypothesis is rejected and the series is considered to be stationary.

### 4.2.3 Homogeneity Test

The cointegration relationship should not be investigated after unit root testing since the slope coefficients of the cointegration equation may not be homogeneous. This leads to a misinterpretation of the findings. Therefore, it is beneficial to perform the homogeneity test before the cointegration test. To do that, we employ the homogeneity test developed by Pesaran and Yamagata, (2008). This homogeneity test provides two different test statistics. While  $\hat{\Delta}$  is mostly used for large samples, the  $\hat{\Delta}_{adj}$  test statistic is mostly used for small samples. The null hypothesis for both test statistics is “the null hypothesis of slope homogeneity”.

**TABLE 8 |** Cointegration test with structural breaks.

	Model 1		Model 2	
	Test-stat	Bootstrap-p-value	Test-stat	Bootstrap-p-value
Z $\xi$ (N) stat	-3.523	0.000***	-3.917	0.000***
Z $\phi$ (N) stat	-4.567	0.000***	-3.233	0.000***

Notes: \*\*\* indicates significance levels at the 1%.

**TABLE 9 |** Results for PMG estimations (panel ARDL).

Model 1					
Long run coefficient			Short run coefficient		
Variable	Coefficient	t-stat	Variable	Coefficient	t-stat
GDP	0.0001	11.37***	$\Delta$ GDP	0.0003	4.12***
NGOP	-4.8129	-11.68***	$\Delta$ NGOP	2.6300	2.38***
RPC	-1.3456	-12.82***	$\Delta$ RPC	-0.0465	-0.1163
Error Correction Coefficient	-0.3985	-4.80***			
Model 2					
Long Run Coefficient			Short Run Coefficient		
Variable	coefficient	t-stat	Variable	coefficient	t-stat
GDP	0.0007	5.97***	$\Delta$ GDP	0.0003	4.80***
NGOP	-3.4982	-8.18***	$\Delta$ NGOP	1.6963	1.79*
NRENPC	6.3657	16.49***	$\Delta$ NRENPC	-1.4692	1.31*
Error Correction Coefficient	-0.4819	-5.18***			

Notes: \*\*\*, \*\* and \* indicates significance levels at 1%, 5% and 10%, respectively.  $\Delta$  indicates that the difference of the series is taken. The maximum number of lags for each variable is set at three, and optimal lag lengths are selected by the Akaike Information Criteria. The PMG estimators are computed by “back-substitution” algorithm.

#### 4.2.4 Durbin-Hausman Cointegration Test

In the next step of our investigation, by using Durbin-H approach developed by Westerlund (2008), we performed cointegration analysis to check whether dependent and independent variables move together in the long-run. This method allows to explore the long-run relationship of the series under the cross-sectional dependence. Additionally, Durbin-Hausman's group test (based on panel heterogeneity) and Durbin-Hausman's panel test (based on panel homogeneity) can produce different results depending on panel homogeneity which makes this test more useful compared to other panel cointegration tests. The null hypothesis for this test is "there is no cointegration relationship".

#### 4.2.5 Cointegration Test With Structural Breaks

As a result of the Durbin-H cointegration test, we conclude that there is a long-run link among the series. Durbin-H cointegration test ignores structural breaks, therefore, it may give inconsistent results from time to time. In order to get reliable outcomes, by using Westerlund and Edgerton (2008) accounting structural breaks and autocorrelation, we decided to explore whether there is a cointegration between dependent and independent variables. The null hypothesis of the test is "there is no cointegration relationship".

#### 4.2.6 Long-Run Estimations

After the cointegration process, we moved on to the short- and long-term coefficient estimation phase. The coefficients of the long- and short-term relationship between the variables were estimated using the PMG approach developed by Pesaran, Shin and Smith (1999). Unlike other approaches, the PMG approach allows estimating dynamic panels by taking into account the long-term equilibrium relationships between variables (Jouini, 2015). This is of great interest for our empirical study because of the fact that ecological footprint, economic growth and non-green trade openness measures may be linked by a common trend that pilots their co-movements over the long run. While PMG limits the long-term coefficients to be the same, short-term coefficients and error term variances may differ between groups (Goswami and Junayed, 2006). Since the EU countries have similar political attitudes on environmental degradation, it is in line with the expectations that the long-term trends will be similar but there may be differences in the short-term. Therefore, the PMG estimator was used for both established models.

### 4.3 Empirical Findings

Prior to beginning the empirical findings, the CD test is one of the most essential stages for panel studies. Without doing this examination might cause inconsistent outcomes. In this case, we tested whether there is a cross-sectional dependence between the units and we provide the results in **Table 4**.

As observed from the results of **Table 4**, the null hypothesis is rejected for all variables at 1% significance level. Therefore, the alternative hypothesis should be accepted. In this case, since the first generation unit root tests may not give reliable results, the analysis will be continued by using the second generation unit root tests.

In the second step of our examination, we employ CIPS unit root approach to examine whether the series are stationary or not. The findings are reported in **Table 5**.

As seen in **Table 5**, in the unit root test, it is confirmed that all series become stationary when the first difference is taken which means the series contain a unit root. While ecological footprint is at 5% level of significance, other variables are at 1% level of significance.

In panel studies, checking the slope homogeneity is a vital action to choose appropriate cointegration and long-run estimation techniques. The null hypothesis of "slope homogeneity" is tested and the outcomes are reported in **Table 6**.

According to these findings, the null hypothesis is rejected according to both test statistics. In other words, we reject the assumption that the slope coefficients are homogeneous.

In the next step of our investigation, by employing Durbin-H panel cointegration approach, we tested whether the series are move together in the long-run or not. The findings of panel cointegration are displayed in **Table 7**.

The findings obtained from both Durbin-H group and Durbin-H panel statistics indicate that the null hypothesis is rejected at 1% significance level. In other words, this indicates that the series move together in country groups and throughout the panel. Then after, to get robust findings, we test again whether there is cointegration the series by using Westerlund and Edgerton (2008) accounting structural breaks and autocorrelation. The empirical findings gained from analysis are provided in **Table 8**.

As a result of the cointegration test, the null hypothesis was rejected at 1% probability level for both models. We observe that the series are cointegrated under structural breaks.<sup>2</sup> In other words, these results confirmed the Durbin-H cointegration test outcomes.

After confirmation of cointegration relationship among the series we intended to get the long run-coefficients of the explanatory variables. We employ PMG estimation techniques and the estimation results are given in **Table 9** below.

The findings obtained from the PMG-ARDL estimation approach confirm that all coefficients are statistically significant at 1% significance level in the long run. Following the PMG-ARDL findings for model 1, we can interpret that a 1% increase in real GDP per capita increases EF by 0.0001%. This means that rise in GDP per capita worsens the ecological footprint in the long run. This finding is also valid in the short run. The outcomes collected from PMG-ARDL provide evidence that our core explanatory variable Non-Green Openness is statistically significant and has a negative sign. If non-green openness increases by one percentage point, EF decreases by 481%.<sup>3</sup> According to our best knowledge, this is the first study

<sup>2</sup>The break dates are presented in **Appendix 1**.

<sup>3</sup>The functional relationship between EF and NGOP is estimated as log-lin model (see Eq. 3), i.e., the estimated coefficient  $\beta_2$  can be interpreted as a semi-elasticity: An increase by the explanatory variable by one unit leads to an approximate change of the dependent variable by  $\beta_2 * 100\%$ . See, for example, Gujarati, (2011: 30-31, 98-99).

that shows the impact of non-green trade basket on environment. In this context, this study is complementary to the Green Openness Index presented by Can et al. (2022). Renewable energy consumption is another significant parameter that impact environmental quality. According to outcomes gained from long-run estimation, if RPC boost by 1%, EF reduces by 1.34%. Furthermore, the negative and significant impact of renewable energy use is consistent with Usman et al. (2021) and Paramati et al. (2021), which show that renewable energy use protects the environment in various ways.

For the second model, we observe that all coefficients are significant at 1% level. Employing PMG-ARDL, results provide evidence that a 1% increase in real GDP per capita increases EF by 0.0007%. This result is in the line with GDP coefficient in model 1. Interestingly, our main indicator, i.e., NGOP, as in model 1, has a negative and significant effect on EF. The analysis of the approximated coefficient for NGOP corresponds to one percentage point increase in NGOP index, resulting in a 349% decrease in EF.<sup>4</sup> This finding also confirms the outcomes for NGOP obtained for model 1. When we evaluate the findings for non-renewable energy consumption, we observe that NRENPC has a substantial negative impact on the environment. PMG-ARDL estimation reveals that a 1% rise in NRENPC results in a boost of the EF by 6.36%. This result is consistent with our expectations since there is widespread agreement in the literature about the harmful effects of fossil fuel-based energy use on the environment (Shafiei and Salim, 2014; Baek, 2015). Lastly, considering the short-term coefficients, the lag error correction term coefficient is negative and significant for both models.

## 5 DISCUSSION AND POLICY RECOMMENDATION

The core result of our estimations is that for the sample of EU-25 countries non-green trade openness (NGOP) has a negative effect on environmental degradation quantified by the Ecological Footprint (EF). Put simply, more dirty trade of the EU with the rest of the world improves the environmental quality in the EU. This observation does support the PHH, which predicts that more ambitious environmental regulation imposed by a region will push pollution abroad. Whether this is a problem for the EU depends on the nature of the environmental problem, the existing environmental regulation and the policy makers' objective function. For CO<sub>2</sub> emissions abatement which contributes to a global public good, the reallocation of CO<sub>2</sub> emissions from the developed world to other, less developed countries, is problematic since the net effect of abatement is reduced and it can even be negative if emitters outside the regulated region produce with higher emissions intensity. Under the existence of the EU ETS without CBAM rules the effect of carbon leakage would be definitely negative since the CO<sub>2</sub> emissions cap is fix and increasing emissions in the rest of world can not be compensated by decreasing emissions in the EU. For local

environmental problems such as local air pollution, e.g., SO<sub>x</sub> emissions, the decrease of pollution in the EU has to be weighed against the increase of pollution abroad which is finally a political decision. If the EU—at least to some extent—also takes into account local environmental effects in other countries caused by increased trade of non-green products the latter effect also creates a need for environmental policy action. Either the EU directly increases the costs for imports of dirty production respectively non-green products linked to local pollution in the exporting countries or the EU supports the implementation of stronger regulation of local pollution in these regions. Overall, our result emphasizes the importance of measures which try to equalize the marginal costs of environmental-friendly behavior between the EU and the rest of the world like the CBAM which is complementing the EU-ETS in the area of climate change mitigation.

Related to the Paris climate agreement and the EU's commitment to make Europe the first climate-neutral continent, legal regulations, policies that support the environment and the creation of a circular economy market are required. Additionally, there is a need for an economic structure that will finance the production of environment-friendly products (Alsaleh, Zubair, & Abdul-Rahim, 2020). Undoubtedly, achieving net zero GHG emissions by 2050 will require deep structural transformation of almost the entire economy (Sachs et al., 2019). Achieving the results of this sweeping transformation will result in major changes in resource use, social and political institutions, and the composition of investment and financial support. However, in order to reach the carbon emission reduction targets until 2030, which are content of the medium-term plans, serious regulations should be made especially in energy use and industrial production (Pablo-Romero & Sánchez-Braza, 2017). Because, according to the European Environment Agency, around 25% of total energy consumption is from industry and more than 80% of total emissions in EU-28 countries are caused by energy consumption (Eurostat, 2020). Such policies include establishment respectively enlargement of effective and well-functioning carbon markets, such as the EU-ETS, and granting of carbon credits to compensate low-carbon emitting firms. All these will ensure that non-renewable energy is used in their most efficient forms with just little adverse impact on the entire ecological system.

## 6 CONCLUSION

In this study, we attempted to explore the relationship between environmental degradation quantified by the ecological footprint and real income per capita, non-green trade openness index, renewable energy consumption and non-renewable energy consumption for 25 EU countries over the period 2003–2016. We employed different panel techniques such as CD, cross-sectionally augmented IPS (CIPS), Durbin-H and cointegration test with structural breaks cointegration approaches and PMG-ARDL techniques. According to the findings obtained from PMG-ARDL results, it is concluded that renewable energy consumption decreases the ecological footprint while non-

<sup>4</sup>See footnote 3.



renewable energy consumption increases the environmental degradation. The outcomes related to our core variable reveal that non-green trade openness decreases the ecological footprint. This result, which supports the Pollution Haven Hypothesis, is the novel contribution of this research to the current literature. It is necessary to pay attention to the fact that non-green trade openness reduces the ecological footprint for the EU-25. The increase in foreign trade volume of non-green products causes an increase in the EU's environmental quality. This situation has the potential to be understood as a problematic finding for global as well as local environmental problems. Global environmental problems such as GHG emissions, increased acidity of the oceans or deforestation that increases the carbon footprint do not have regional solutions. What needs to be done here is to reduce the non-green foreign trade volume as a whole and to ensure that the products subject to international trade consist of environment-friendly products. To do that, policy instruments such as a carbon tax at the border like in the EU's CBAM are important tools that can enable countries to transform their economic structures and increase trade in green products. Given that the EU takes into account damages caused by local pollution in other countries, our result also implies a need for action in this policy area. Imported non-green products goods have to become more expensive in order to set incentives to produce more environment-friendly in the country of origin.

This research is limited by EU-25 countries. We recommend that researchers ought to check the impact of non-green trade on environment for different country groups by using numerous environmental indicators such as CO<sub>2</sub> emissions, SO<sub>x</sub> or other pollutants. Besides, future studies can use different frameworks such as environmental Kuznets curve (EKC) or STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model to explore the impact of non-green trade on different environmental parameters. It might also be worthwhile to investigate the association between NGOP and energy demand. Researchers can examine this question both for non-renewable and renewable energy consumption. We also advice to identify the potential determinants of NGOP for

different country groups. Additionally, it can be expected that NGOP may have potential impact on various economic parameters (e.g. employment, economic growth). We leave these questions for future research.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## AUTHOR CONTRIBUTIONS

MC: Conceptualization, index calculation, data curation, formal analysis, visualization, writing original draft. IO: Conceptualization, index calculation, writing original draft. BS: writing—review, and editing, supervision IG: writing—review and editing. BG: writing—review, and editing, funding acquisition. JP: supervision, project administration, writing—review, and editing.

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## REFERENCES

- Abid, M. (2017). Does Economic, Financial and Institutional Developments Matter for Environmental Quality? A Comparative Analysis of EU and MEA Countries. *J. Environ. Manag.*, 188, 183–194. doi:10.1016/j.jenvman.2016.12.007
- Ahmad, M., Ahmed, Z., Bai, Y., Qiao, G., Popp, J., and Oláh, J. (2022a). Financial Inclusion, Technological Innovations, and Environmental Quality: Analyzing the Role of Green Openness. *Front. Environ. Sci.* 10. doi:10.3389/fenvs.2022.851263
- Ahmad, M., Ahmed, Z., Gavurova, B., and Oláh, J. (2022b). Financial Risk, Renewable Energy Technology Budgets, and Environmental Sustainability: Is Going Green Possible? *Front. Environ. Sci.* 10, 518. doi:10.3389/fenvs.2022.909190
- Al-Mulali, U., Ozturk, I., and Lean, H. H. (2015). The Influence of Economic Growth, Urbanization, Trade Openness, Financial Development, and Renewable Energy on Pollution in Europe. *Nat. Hazards* 79 (1), 621–644. doi:10.1007/s11069-015-1865-9
- Alola, A. A., Akadiri, S. S., and Usman, O. (2021). Domestic Material Consumption and Greenhouse Gas Emissions in the EU -28 Countries: Implications for Environmental Sustainability Targets. *Sustain. Dev.*, 29(2), 388–397. doi:10.1002/sd.2154
- Alsaleh, M., Zubair, A. O., and Abdul-Rahim, A. S. (2020). The Impact of Global Competitiveness on the Growth of Bioenergy Industry in EU -28 Region. *Sustain. Dev.*, 28(5), 1304–1316. doi:10.1002/sd.2085
- Anderson, J. E., and van Wincoop, E. (2004). Trade Costs. *J. Econ. Literature* 42 (3), 691–751. doi:10.1257/0022051042177649
- Ansari, M. A., Haider, S., and Masood, T. (2021). Do renewable Energy and Globalization Enhance Ecological Footprint: an Analysis of Top Renewable Energy Countries? *Environ. Sci. Pollut. Res.* 28 (6), 6719–6732. doi:10.1007/s11356-020-10786-0
- Apergis, N., Can, M., Gozgor, G., and Lau, C. K. M. (2018). Effects of Export Concentration on CO<sub>2</sub> Emissions in Developed Countries: an Empirical Analysis. *Environ. Sci. Pollut. Res.* 25 (14), 14106–14116. doi:10.1007/s11356-018-1634-x
- Bölük, G., and Mert, M. (2014). Fossil & Renewable Energy Consumption, GHGs (Greenhouse Gases) and Economic Growth: Evidence from a Panel of EU

- (European Union) Countries. *Energy*, 74, 439–446. doi:10.1016/j.energy.2014.07.008
- Baek, J. (2015). Environmental Kuznets Curve for CO<sub>2</sub> Emissions: the Case of Arctic Countries. *Energy Econ.* 50, 13–17. doi:10.1016/j.eneco.2015.04.010
- Bayer, P., and Aklın, M. (2020). The European Union Emissions Trading System Reduced CO<sub>2</sub> Emissions Despite Low Prices. *Proc. Natl. Acad. Sci. U.S.A.* 117 (16), 8804–8812. LP – 8812. doi:10.1073/pnas.1918128117
- Bellora, C., and Fontagne, L. (2021). *EU in Search of a WTO-Compatible Carbon Border Adjustment Mechanism*. Mimeo. Available: <http://www.wlionel-fontagne/uploads/9/8/3/3/98330770>.
- Benzerrouk, Z., Abid, M., and Sekrafi, H. (2021). Pollution Haven or Halo Effect? A Comparative Analysis of Developing and Developed Countries. *Energy Rep.*, 7, 4862–4871. doi:10.1016/j.egyr.2021.07.076
- Blecharz, P., and Stverková, H. (2014). Assessing the Service Quality in Small and Medium-Sized Companies. *Актуальні Проблеми Економіки* (4), 206–217.
- Can, M., Dogan, B., and Saboori, B. (2020). Does Trade Matter for Environmental Degradation in Developing Countries? New Evidence in the Context of Export Product Diversification. *Environ. Sci. Pollut. Res. Int.* 27, 14702–14710. doi:10.1007/s11356-020-08000-2
- Can, M., Ahmed, Z., Mercan, M., and Kalugina, O. A. (2021). The Role of Trading Environment-Friendly Goods in Environmental Sustainability: Does Green Openness Matter for OECD Countries? *J. Environ. Manag.*, 295, 113038. doi:10.1016/j.jenvman.2021.113038
- Can, M., Ben Jebli, M., and Brussaels, J. (2022). Can Green Trade Save the Environment? Introducing the Green (Trade) Openness Index. *Environ. Sci. Pollut. Res.* doi:10.1007/s11356-022-18920-w
- Cherni, A., and Essaber Jouini, S. (2017). An ARDL Approach to the CO<sub>2</sub> Emissions, Renewable Energy and Economic Growth Nexus: Tunisian Evidence. *Int. J. Hydrogen Energy*, 42(48), 29056–29066. doi:10.1016/j.ijhydene.2017.08.072
- Cole, M. A. (2004). Trade, the Pollution Haven Hypothesis and the Environmental Kuznets Curve: Examining the Linkages. *Ecol. Econ.* 48 (1), 71–81. doi:10.1016/j.ecolecon.2003.09.007
- Commission, European (2022). *Climate Strategies & Targets*. Available: [https://ec.europa.eu/clima/eu-action/climate-strategies-targets\\_en](https://ec.europa.eu/clima/eu-action/climate-strategies-targets_en).
- Danishand wang, Z. (2019). Investigation of the Ecological Footprint's Driving Factors: What We Learn from the Experience of Emerging Economies. *Sustain. Cities Soc.*, 49, 101626. doi:10.1016/j.scs.2019.101626
- Destek, M. A., Balli, E., and Manga, M. (2016). The Relationship between CO<sub>2</sub> Emission, Energy Consumption, Urbanization and Trade Openness for Selected CEECs. *Res. World Econ.* 7 (1), 52–58. doi:10.5430/rwe.v7n1p52
- Destek, M. A., Ulucak, R., and Dogan, E. (2018). Analyzing the Environmental Kuznets Curve for the EU Countries: the Role of Ecological Footprint. *Environ. Sci. Pollut. Res.* 25 (29), 29387–29396. doi:10.1007/s11356-018-2911-4
- Dogan, E., and Seker, F. (2016). Determinants of CO<sub>2</sub> Emissions in the European Union: The Role of Renewable and Non-renewable Energy. *Renew. Energy*, 94, 429–439. doi:10.1016/j.renene.2016.03.078
- Ec, D. (2018). *A Clean Planet for All. A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee*. Brussels: ComThe Committee Of The Regions And The European Investment Bank, 773.
- Eicke, L., Weko, S., Aperi, M., and Marian, A. (2021). Pulling up the Carbon Ladder? Decarbonization, Dependence, and Third-Country Risks from the European Carbon Border Adjustment Mechanism. *Energy Res. Soc. Sci.*, 80, 102240. doi:10.1016/j.erss.2021.102240
- Eurostat European Union (2020). Final Energy Consumption by Sector - European Environment Agency (EEA). Available: [http://www.eea.europa.eu/data-and-maps/daviz/total-final-energy-consumption-by-sector-1#tab-chart\\_5](http://www.eea.europa.eu/data-and-maps/daviz/total-final-energy-consumption-by-sector-1#tab-chart_5).
- Global Footprint Network (2022). Global Footprint Network. Available: <https://www.footprintnetwork.org/>.
- Goswami, G. G., and Junayed, S. H. (2006). Pooled Mean Group Estimation of the Bilateral Trade Balance Equation: USAVis-à-viser Trading Partners. *Int. Rev. Appl. Econ.* 20 (4), 515–526. doi:10.1080/02692170600874218
- Gujarati, D. N. (2011). *Econometrics by Example*, 1. New York: Palgrave Macmillan.
- Hashem Pesaran, M., and Yamagata, T. (2008). Testing Slope Homogeneity in Large Panels. *J. Econ.* 142 (1), 50–93. doi:10.1016/j.jeconom.2007.05.010
- Horowitz, C. A. (2016). Paris Agreement. *Int. Leg. Mat.* 55, 740–755. doi:10.1017/s0020782900004253
- Hu, G., Can, M., Paramati, S. R., Doğan, B., and Fang, J. (2020). The Effect of Import Product Diversification on Carbon Emissions: New Evidence for Sustainable Economic Policies. *Econ. Analysis Policy* 65, 198–210. doi:10.1016/j.eap.2020.01.004
- Iwata, H., Okada, K., and Samreth, S. (2010). Empirical Study on the Environmental Kuznets Curve for CO<sub>2</sub> in France: The Role of Nuclear Energy. *Energy Policy*, 38(8), 4057–4063. doi:10.1016/j.enpol.2010.03.031
- Jänicke, M., Binder, M., and Mönch, H. (1997). 'Dirty Industries': Patterns of Change in Industrial Countries. *Environ. Resour. Econ.* 9 (4), 467–491. doi:10.1007/BF02441762
- Jouini, J. (2015). Linkage between International Trade and Economic Growth in GCC Countries: Empirical Evidence from PMG Estimation Approach. *J. Int. Trade & Econ. Dev.* 24 (3), 341–372. doi:10.1080/09638199.2014.904394
- Kasman, A., and Duman, Y. S. (2015). CO<sub>2</sub> Emissions, Economic Growth, Energy Consumption, Trade and Urbanization in New EU Member and Candidate Countries: A Panel Data Analysis. *Econ. Model.* 44, 97–103. doi:10.1016/j.econmod.2014.10.022
- Ketenci, N. (2021). Environmental Kuznets Curve in the Presence of Structural Breaks: New Evidence for Individual European Countries. *Environ. Sci. Pollut. Res.* 28 (24), 31520–31538. doi:10.1007/s11356-021-12677-4
- Kongbuamai, N., Zafar, M. W., Zaidi, S. A. H., and Liu, Y. (2020). Determinants of the Ecological Footprint in Thailand: the Influences of Tourism, Trade Openness, and Population Density. *Environ. Sci. Pollut. Res.* 27 (32), 40171–40186. doi:10.1007/s11356-020-09977-6
- Krzyszowski, A. (2020). The European Union and the United Arab Emirates as Civilian and Soft Powers Engaged in Sustainable Development Goals. *J. Int. Stud.* 13 (3), 41–58. doi:10.14254/2071-8330.2020/13-3/3
- Liu, H., Kim, H., and Choe, J. (2019). Export Diversification, CO<sub>2</sub> Emissions and EKC: Panel Data Analysis of 125 Countries. *Asia-Pac J. Reg. Sci.* 3 (2), 361–393. doi:10.1007/s41685-018-0099-8
- Lu, W.-C. (2020). The Interplay Among Ecological Footprint, Real Income, Energy Consumption, and Trade Openness in 13 Asian Countries. *Environ. Sci. Pollut. Res.* 27 (36), 45148–45160. doi:10.1007/s11356-020-10399-7
- Mania, E. (2020). Export Diversification and CO<sub>2</sub> Emissions: An Augmented Environmental Kuznets Curve. *J. Int. Dev.*, 32(2), 168–85. doi:10.1002/jid.3441
- Mehling, M. A., and Ritz, R. A. (2020). *Going beyond Default Intensities in an EU Carbon Border Adjustment Mechanism*. New York: JSTOR.
- Mensah, I. A., Sun, M., Gao, C., Omari-Sasu, A. Y., Zhu, D., Ampimah, B. C., et al. (2019). Analysis on the Nexus of Economic Growth, Fossil Fuel Energy Consumption, CO<sub>2</sub> Emissions and Oil Price in Africa Based on a PMG Panel ARDL Approach. *J. Clean. Prod.*, 228, 161–174. doi:10.1016/j.jclepro.2019.04.281
- Mesagan, E. P., and Chidi, O. N. (2020). Energy Consumption, Capital Investment and Environmental Degradation: The African Experience. *Forum Sci. Oeconomia* 8, 1. doi:10.23762/FSO\_VOL8\_NO1\_1
- Mongo, M., Belaïd, F., and Ramdani, B. (2021). The Effects of Environmental Innovations on CO<sub>2</sub> Emissions: Empirical Evidence from Europe. *Environ. Sci. Policy*, 118, 1–9. doi:10.1016/j.envsci.2020.12.004
- Nasir, M. A., Duc Huynh, T. L., and Xuan Tram, H. T. (2019). Role of Financial Development, Economic Growth & Foreign Direct Investment in Driving Climate Change: A Case of Emerging ASEAN. *J. Environ. Manag.* 242, 131–141. doi:10.1016/j.jenvman.2019.03.112
- Nasreen, S., and Anwar, S. (2014). Causal Relationship between Trade Openness, Economic Growth and Energy Consumption: A Panel Data Analysis of Asian Countries. *Energy Policy*, 69, 82–91. doi:10.1016/j.enpol.2014.02.009
- OECD Stat (2022). *OECD Data*. Available: <https://data.oecd.org/>.
- Ohlan, R. (2015). The Impact of Population Density, Energy Consumption, Economic Growth and Trade Openness on CO<sub>2</sub> Emissions in India. *Nat. Hazards* 79 (2), 1409–1428. doi:10.1007/s11069-015-1898-0
- Our World in Data (2022). *Our World in Data*. Available: <https://ourworldindata.org/> April 2, 2022).
- Pablo-Romero, M. D. P., and Sánchez-Braza, A. (2017). Residential Energy Environmental Kuznets Curve in the EU-28. *Energy*, 125, 44–54. doi:10.1016/j.energy.2017.02.091

- Paramati, S. R., Alam, M. S., Hammoudeh, S., and Hafeez, K. (2021). Long-run Relationship between R&D Investment and Environmental Sustainability: Evidence from the European Union Member Countries. *Int. J. Fin. Econ.* 26 (4), 5775–5792. doi:10.1002/ijfe.2093
- Paramati, S. R., Mo, D., and Huang, R. (2021). The Role of Financial Deepening and Green Technology on Carbon Emissions: Evidence from Major OECD Economies. *Finance Res. Lett.*, 41, 101794. doi:10.1016/j.frl.2020.101794
- Pesaran, M. H., Shin, Y., and Smith, R. P. (1999). Pooled Mean Group Estimation of Dynamic Heterogeneous Panels. *J. Am. Stat. Assoc.* 94 (446), 621–634. doi:10.1080/01621459.1999.10474156
- Pié, L., Fabregat-Aibar, L., and Saez, M. (2018). The Influence of Imports and Exports on the Evolution of Greenhouse Gas Emissions: The Case for the European Union. *Energies* 11, 1644. doi:10.3390/en11071644
- Prokopenko, O., Mishenin, Y., Mura, L., and Yarova, I. (2020). Environmental and Economic Regulation of Sustainable Spatial Agroforestry. *Ijgenvi* 19 (1–3), 109–128. doi:10.1504/IJGENVI.2020.114868
- Rees, W. (2018). “Ecological Footprint,” in *Companion to Environmental Studies* (London: Routledge), 43–48. doi:10.4324/9781315640051-10
- Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., and Rockström, J. (2019). Six Transformations to Achieve the Sustainable Development Goals. *Nat. Sustain* 2 (9), 805–814. doi:10.1038/s41893-019-0352-9
- Sadorsky, P. (2012). Energy Consumption, Output and Trade in South America. *Energy Econ.* 34 (2), 476–488. doi:10.1016/j.eneco.2011.12.008
- Sebri, M., and Ben-Salha, O. (2014). On the Causal Dynamics between Economic Growth, Renewable Energy Consumption, CO<sub>2</sub> Emissions and Trade Openness: Fresh Evidence from BRICS Countries. *Renew. Sustain. Energy Rev.*, 39, 14–23. doi:10.1016/j.rser.2014.07.033
- Shafiei, S., and Salim, R. A. (2014). Non-renewable and Renewable Energy Consumption and CO<sub>2</sub> Emissions in OECD Countries: A Comparative Analysis. *Energy Policy*, 66, 547–556. doi:10.1016/j.enpol.2013.10.064
- Shahzad, U., Ferraz, D., Doğan, B., and Aparecida do Nascimento Rebelatto, D. (2020). Export Product Diversification and CO<sub>2</sub> Emissions: Contextual Evidences from Developing and Developed Economies. *J. Clean. Prod.*, 276, 124146. doi:10.1016/j.jclepro.2020.124146
- Sharif Hossain, M. (2011). Panel Estimation for CO<sub>2</sub> Emissions, Energy Consumption, Economic Growth, Trade Openness and Urbanization of Newly Industrialized Countries. *Energy Policy*, 39(11), 6991–6999. doi:10.1016/j.enpol.2011.07.042
- Sharma, R., Shahbaz, M., Kautish, P., and Vo, X. V. (2022). Diversified Imports as Catalysts for Ecological Footprint: Examining the BRICS Experience. *Environ. Dev. Sustain.* doi:10.1007/s10668-022-02177-x
- Shpak, N., Melnyk, O., HORBAL, N., Ruda, M., and Sroka, W. (2021). Assessing the Implementation of the Circular Economy in the EU Countries. *Forum Sci. Oeconomia* 9, 25–39.
- Siddi, M. (2020). *The European Green Deal: Assessing its Current State and Future Implementation*. UPI Report Available at: <https://iris.unica.it/handle/11584/313484>.
- Skjærseth, J. B., and Wettestad, J. (2009). The Origin, Evolution and Consequences of the EU Emissions Trading System. *Glob. Environ. Polit.* 9 (2), 101–122. doi:10.1162/glep.2009.9.2.101
- Štreimikienė, D. (2021). Externalities of Power Generation in Visegrad Countries and Their Integration through Support of Renewables. *Econ. Sociol.* 14 (1), 89–102. doi:10.14254/2071-789X.2021/14-1/6
- Tachie, A. K., Xingle, L., Dauda, L., Mensah, C. N., Appiah-Twum, F., and Adjei Mensah, I. (2020). The Influence of Trade Openness on Environmental Pollution in EU-18 Countries. *Environ. Sci. Pollut. Res.* 27 (28), 35535–35555. doi:10.1007/s11356-020-09718-9
- Uddin, G. A., Salahuddin, M., Alam, K., and Gow, J. (2017). Ecological Footprint and Real Income: Panel Data Evidence from the 27 Highest Emitting Countries. *Ecol. Indic.*, 77, 166–175. doi:10.1016/j.ecolind.2017.01.003
- UNFCCC (2015). *Adoption of the Paris Agreement*. FCCC/CP/2015/L. 9/Rev. 1. Available at: <https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf>.
- Usman, O., Iorember, P. T., Jelilov, G., Isik, A., Ike, G. N., and Sarkodie, S. A. (2021). Towards Mitigating Ecological Degradation in G-7 Countries: Accounting for Economic Effect Dynamics, Renewable Energy Consumption, and Innovation. *Heliyon*, 7(12), e08592. doi:10.1016/j.heliyon.2021.e08592
- Westerlund, J., and Edgerton, D. L. (2008). A Simple Test for Cointegration in Dependent Panels with Structural Breaks\*. *Oxf. Bull. Econ. Statistics* 70 (5), 665–704. doi:10.1111/j.1468-0084.2008.00513.x
- Westerlund, J. (2008). Panel Cointegration Tests of the Fisher Effect. *J. Appl. Econ.*, 23(2), 193–233. doi:10.1002/jae.967
- World Bank (2022). *Data World Bank*. Available: <https://data.worldbank.org/> February 16, 2022). Retrieved.
- World Development Indicators (Wdi) (2021). *World Development Indicators (Wdi)*. Available: <https://databank.worldbank.org/source/world-development-indicators>.
- Zafar, M. W., Mirza, F. M., Zaidi, S. A. H., and Hou, F. (2019). The Nexus of Renewable and Nonrenewable Energy Consumption, Trade Openness, and CO<sub>2</sub> Emissions in the Framework of EKC: Evidence from Emerging Economies. *Environ. Sci. Pollut. Res.* 26 (15), 15162–15173. doi:10.1007/s11356-019-04912-w

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## APPENDIX 1 STRUCTURAL BREAK DATES FOR COUNTRIES

Country	Break Date		Country	Break Date		Country	Break Date	
	Model 1	Model 2		Model 1	Model2		Model 1	Model 2
Germany	2010	2010	Croatia	2010	2010	Portugal	2010	2010
Austria	2011	2011	Netherlands	2009	2009	Romania	2010	2010
Belgium	2011	2011	Ireland	2008	2008	Slovakia	2011	2011
Bulgaria	2008	2008	Spain	2012	2012	Slovenia	2009	2009
Czechia	2009	2009	Sweden	2006	2005	Greece	2010	2013
Denmark	2008	2008	Italy	2011	2011			
Estonia	2011	2011	Latvia	2007	2007			
Finland	2012	2012	Lithuania	2009	2013			
France	2007	2007	Hungary	2007	2007			
Cyprus	2012	2013	Poland	2009	2009			