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RESEARCH ARTICLE

Can green trade save the environment? Introducing the Green (Trade) Openness Index

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Abstract
Environmental degradation is one of the main drivers of climate change. One of the most broadly accepted tools to minimize environmental degradation is the introduction of "green products". This paper introduces the "Green Trade Openness Index" to (a) measure the importance of green products in a region and (b) revisit the trade-environment nexus in a sample study of 31 OECD countries over the period 2007–2017. The empirical analysis confirms the environmental Kuznets curve hypothesis and — more importantly — demonstrates for the first time that the presence of green products in a country's trade basket reduces that country's ecological footprint. This is essential information for practitioners and policy makers looking for a pathway to sustainable development. Finally, the novel index creates opportunities for future research, as the index can be used as explanatory variable in different research questions and fields of research.

Keywords Environmental degradation · Green economy · Green Openness Index · Green Trade Openness Index · Green products · Sustainable development

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Highlights
- New index is developed and introduced to measure trading of Green Products.
- Trading Green goods as strategy to break the development – emissions correlation.
- Green Openness reduces environmental degradations.
- Green Openness Index as lever for future research on green economy.

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Introduction

Climate change and environmental degradation are one of the major concerns facing mankind today (World Economic Forum, 2021). CO_2 is the primary greenhouse gas (GHG) emitted through human activities and consequently one of the main drivers of global warming and environmental deterioration (Baek, 2016). A recent report released by the PBL Netherlands Environmental Assessment Agency (2020) revealed that the level of GHG emissions reached 52.4 $GtCO_2$ in 2019 at global level. This is an increase of 59% compared to the 1990s.

This kind of increase is not a new phenomenon. Energy consumption has exploded since the industrial revolution. That industrial revolution has considerably improved the quality of life (Ahmed and Le, 2021) and boosted economic activities levels. However, this evolution, and what followed it, also led to a significant increase in the use of energy and resources. The latter has put an enormous strain on the environment (Du et al. 2019).

The introduction and use of "green products" in an economy is widely accepted as a tool to minimize environmental degradation (Ahmed et al. 2021b; Shah et al. 2021; Biswas and Roy, 2015). Green products particularly tackle the problem of fossil-based energy, which is still the main energy

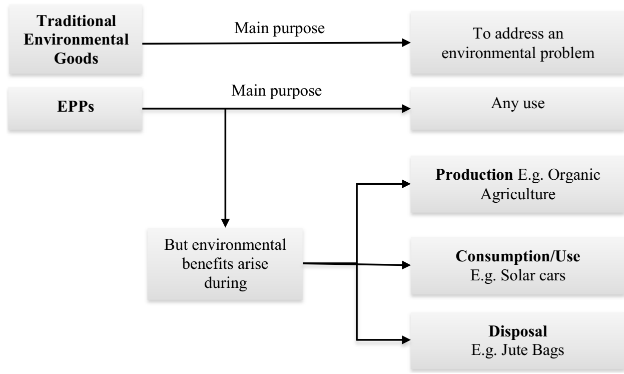

Fig. 1 Traditional environmental goods versus EPPs. Source: Claro et al. (2007)

source for numerous countries. In the Organization for Economic Co-operation and Development (OECD) countries, for example, fossil fuel still accounts for nearly 80% of total energy consumption (World Bank, 2022). Green products can increase the importance of renewable energy production, as green products encompass the renewable energy technologies (Can et al. 2021).

The green products are defined as products which increase efficiency in energy production and minimize environmental damages related to energy consumption (Paramati et al. 2021). The United Nations Conference on Trade and Development (UNCTAD) adheres a broader concept of environmental (green) products. According to the UNCTAD, a green product causes less environmental harm compared to alternative products that serve the same purpose or product which contributes to the preservation of the environment (World Bank, 2008). In principle, it seems possible to distinguish between two main categories of green products. The first category includes traditional environmental goods, which provide solutions to existing environmental problems. The second category includes environmentally preferable products (EPPs). Those products are less harmful to nature than substitute products during their use (UNCTAD, 1995). Detailed description of these types of products is presented in Fig. 1.

Examples of green products are renewable energy technologies, energy efficiency technologies, waste management technology, environmental monitoring devices, solar cars, electric vehicles, and jute bags. The use of these products must result in a significant increase in environmental quality (Gao and Zheng, 2017, Ling Guo et al. 2017), and the IEA (2013) claims that a widespread introduction of green products can reduce CO_2 emissions by 60%.

The use of green products can spread around the world through international trade. For that reason, this paper investigates the impact of trading green products on environmental degradation, accounting for other economic parameters. The analysis concerns a sample of 31 OECD countries in the context of the environmental Kuznets curve (EKC) hypothesis.

To this end, this paper introduces a new index to measure the importance of green products at country level. This provides an essential contribution to the existing body of literature as the index goes beyond the analysis of environmental degradation within more conventional frameworks, using straightforward explanatory variables.

The EKC hypothesis is one of the best-known frameworks. Grossman and Krueger (1991) first described the inverted U relationship between environmental degradation and income (He, 2009). Figure 2 presents this relationship. In addition to income, scholars have recently discussed the impact of other economic parameters on the environment in the context of the EKC hypothesis. Among those, trade is the most frequently used because of its potential to alter a country's environmental quality level by, for example, importing energy-efficient and environmentally friendly products (Hu et al. 2020), clean production technologies, or renewable energy technology (Wang and Lu, 2020; Ahmed et al. 2021c). Different studies focus on different trade-related aspects such as export sophistication, export diversification, or economic complexity (i.e. a region's potential to produce complex products); see, for example, Apergis et al. (2018) and Can et al. (2020). On the other hand, an expansion of international trade could also result in environmental degradation because of the fossil-based energy needed for the production of tradable goods (Gozgor and Can, 2016). Accordingly, international trade depends on logistic activities (e.g. transportation, storage, packaging, and distribution). In case these logistic activities boost the use of vehicles with low energy efficiency, this could again negatively affect the environmental quality (Greene and Plotkin, 2011). In conclusion, consensus on the environmental impact related to international trade is currently missing. Likewise, consensus is missing on the impact of the "trade openness index" (i.e. a measure of the influence of trade on domestic activities) on environmental degradation. While some studies reveal that trade openness positively impacts environmental parameters (Al-Mulali et al. 2015a; Essandoh et al. 2020; Essandoh et al. 2020; Zhang et al. 2017; Al-Mulali et al. 2015a), other studies find a negative impact (Mahmood et al. 2019; Kasman and Duman, 2015; Sebri and Ben-Salha, 2014).

The current paper acknowledges the importance of the conventional parameters such as income, export sophistication, and economic complexity in explaining environmental degradation. However, this paper's analysis differs from the existing studies in many ways. First, and to the best of our knowledge, this paper for the first time quantifies the impact of trade in green products on environmental degradation in a holistic way by means of a new indicator, covering a large sample of OECD countries. We focus on trading green products because they have smaller ecological footprint (Wade et al. 2018). In addition, the use of green products can sustain other parts of an economy because the firms specializing in green products develop interactive relationships with their own suppliers and clients. Examples of stakeholders are universities, other business service firms, retailers, technology and machinery providers, and final users' associations. As such, the introduction of green products creates (and shares) new environmental knowledge and jointly develops even more green products and processes. This is not only a positive result of the introduction of green products, but also a requirement to achieve that introduction (Marchi et al. 2013, Marchi, 2012).

The analysis is completed by means of fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) regression techniques. This allows the calculation of the net effect of trade in green products on environmental parameters to provide an important nuance to the debate on the impact of trade on environment. The rationale of the index presented in this paper is based on the "trade openness" index, which is a frequent metric to investigate foreign trade. However, that trade openness index is transformed into the new "Green Trade Openness Index" (henceforth "Green Openness Index", abbreviated GOP). This is crucial, as the analysis will demonstrate that this approach can break the seemingly inevitable link between trade openness and increased environmental impact. As such, the analysis provides crucial information for practitioners and policy makers seeking for solutions to achieve sustainable development strategies and sustainable energy policies (Hao et al. 2021; Loiseau et al. 2016) by opening up their countries for green trade, and not just any type of trade.

Second, the index provides a better proxy for the importance of green products compared to earlier approaches. Previous studies relied upon proxy indicators to measure the importance of green products in a region. Examples of these proxy indicators are the environmentally adjusted multifactor productivity, patent application, and technological innovations (see, for example, Hao et al. (2021), Ibrahiem, 2020), Ali et al. (2016), Yii and Geetha (2017), Demir et al. (2020), and Paramati et al. (2021)). However, patent applications or innovations cannot be classified as embodied goods (Mohnen and Hall, 2013). In addition, the country where the patent is registered can be different from the country which is manufacturing the products (Dechezleprêtre and Glachant, 2014). The use of the index presented in this paper allows focusing on embodied products instead.

Finally, this paper does not only fill a crucial gap in literature. The proposed methodology also provides ample opportunities to further use of the index in studies on environmental degradation, (green) economy, renewable, and non-renewable energy consumption, especially in the context of economic growth, green growth, unemployment, green jobs, income distribution, and human wellbeing. Moreover, the index provides a means for benchmarking economies.

The rest of the paper is organized as follows. The "Method: introducing the Green Openness Index" section introduces the GOP. The "Data, empirical methodology, and results" section explains the use of data and econometric tools applied. The "Discussion" section provides policy recommendation and research implications of this research in separate sub-sections. Finally, the "Conclusion" section concludes this paper and presents the main conclusions.

Method: introducing the Green Openness Index

There are different approaches to define green products, but there is hitherto no consensus on a "green product list". While the World Trade Organization released "The Friends' List" (WTO, 2009), the Asia–Pacific Economic Cooperation presents the "APEC List of Environmental Goods" consisting of 54 products (APEC, 2012). Simultaneously, the OECD provides the "Plurilateral agreement on environmental goods and services" list (PEGS) consisting of 150 goods. Finally, the OECD compiled the "Combined List of Environmental Goods" (CLEG). While the CLEG consists of 248 products, the Core CLEG products (CLEG +) covers 40 goods (Sauvage, 2014).

This paper presents the GOP index, based upon the CLEG + list. The reason to use the CLEG + list is twofold. First, the CLEG + list combines the three existing list of environmental goods (by the WTO, APEC, and the OECD's PEGS). As such, CLEG + provides a combination of different environmental goods and a holistic approach in this context. Second, the CLEG + is widely accepted and clearly defined, which improves data availability for this measure. Indirectly, this improves its usefulness in explanatory analysis. The index developed on the CLEG + list is labelled as GOPCLEG from this point onward.

Simultaneously, this paper develops a second GOP index based on the APEC list to empirically test the indexes' robustness. This index is labelled as GOPAPEC from this point onward. The data for CLEG + and APEC Environmental Goods is collected from UN Comtrade for every individual green product by following their HS 2007 codes. Subsequently, the authors aggregate that data (Appendix 1 and Appendix 2 present the HS 2007 codes for CLEG + and APEC, respectively). GDP values are obtained from the World Development Indicators database (WDI) by the World Bank (2021).

The following equation defines the GOP:

$$GOP_{i,t} = (\frac{GX_{i,t} + GM_{i,t}}{GDP_{i,t}}) * 100 \quad (1)$$

In Eq. (1), *GX* is the current value of total green goods export to the world by reporter country *i* at time *t*. *GM* is the current value of total green goods import from the world to reporter country *i* at time *t*. GDP is the total value of goods manufactured in current year *t* in country *i*. The calculation finds a value for GOP between 0 and 100, as a percentage of GDP. The index is calculated on an annual basis from 2007 to 2019 for 31 OECD countries (Appendix 3). This period is determined by data availability, i.e. 2007 is the first year in UN Comtrade at HS 2007 level (BETA 2021).

Data, empirical methodology, and results

The aim of the empirical analysis is to assess the impact of trading green products on environmental degradation. In this rationale, the total ecological footprint per capita serves as a proxy for environmental degradation. Compared to CO_2 emissions, the environmental footprint is a better proxy for environmental degradation because the latter provides a more holistic approach to environmental degradation (Ahmed et al. 2021a). In addition to the CO_2 emissions, the environmental footprint also includes built-up land, cropland, fishing grounds, forest products, and grazing land.

Following Al-Mulali et al. (2015b) and Can and Gozgor (2017), the EKC model is estimated as follows:

$$FP_{i,t} = f\left(GDPPC_{i,t}^{\beta_1}, GDPPC2_{i,t}^{\beta_2}, ENPC_{i,t}^{\beta_3}, GOP_{i,t}^{\beta_4}, \right) + e_{i,t} \quad (2)$$

$$FP_{i,t} = \beta_0 + \beta_1 GDPPC_{i,t} + \beta_2 GDPPC2_{i,t} + \beta_3 ENPC_{i,t} + \beta_4 GOP_{i,t} + e_{i,t} \quad (3)$$

where *FP*, *GDPPC*, *GDPPC2*, *ENPC*, and *GOP* represent the ecological footprint, income per capita, square of income per capita, energy consumption per capita, and Green Openness Index, respectively. In the further analysis, *GOP* is defined as GOPCLEG or GOPAPEC, depending on the used index. The data for ecological footprint per capita (FP) is obtained from the Global Footprint Network (2021), per capita income (constant 2010 US$) is derived from the World Development Indicators by the World Bank (2021), and energy consumption per capita is sourced from the IEA (2020). The GOP is calculated by the authors as described in the previous section. Prior to the empirical section, the logarithmic form is taken for all variables, except the GOP.

The empirical study employs panel cointegration techniques and Granger causality test to explore the dynamic interaction between ecological footprint, income per capita and its square, energy consumption per capita, and Green Openness Index for a panel of 31 OECD countries spanning the period 2007–2017. No more recent data is available on the ecological footprint at present. For long run estimations, we employ fully modified OLS (FMOLS) and dynamic OLS (DOLS) approaches developed by Pedroni (2004), respectively. The use of OLS estimation may result in a biased estimator and its distribution depends on nuisance parameters. Instead, FMOLS and DOLS avoid spurious results because they correct for endogeneity and serial correlation problems. The FMOLS applies a non-parametric approach while the DOLS uses a parametric approach.

The empirical analysis develops two separate models to assess the two different GOP indexes. The first model uses the GOPCLEG index; the second model uses the GOPAPEC index. At first stage, the empirical analysis tests the presence of cross-sectional dependence of each variable in both models. In case this test finds cross-sectional dependence in residuals, the second-generation unit root test checks for stationary properties. At this stage, the existence of long-run cointegration between the variables can be computed using various statistic tests (Pedroni, 2004; Kao, 1999). Powerful estimation techniques such as FMOLS and DOLS investigate the effect of each estimated coefficient on the ecological footprint of the selected countries. Finally, Granger causality tests investigate the dynamic association among the variables for the short- and long-run relationships.

To discuss the dynamic causal links between the variables under consideration, the analysis should first check for the stationary properties of each series. This requires an analysis of the cross-sectional dependence (CD) in the residuals to choose the appropriate panel generation unit

Table 1 Cross-sectional dependence (CD) test result

Variables	CD test	*P*-value	Corr	Abs(corr)
FP	33.41	0.000***	0.467	0.583
GDPPC	38.23	0.000***	0.534	0.654
ENPC	29.97	0.000***	0.419	0.616
GOPCLEG	11.97	0.000***	0.167	0.437
GOPAPEC	5.51	0.000***	0.077	0.355

Notes: "***" indicates statistical significance at the 1% level. CD test denotes the statistic of cross-sectional independence. The null hypothesis assumes the presence of residual cross-sectional independence of each variable. *FP*, ecological footprint; *GDPPC*, gross domestic product per capita; *ENPC*, energy consumption per capita; *GOPCLEG*, Green Openness Index based on CLEG+; *GOPAPEC*, Green Openness Index based on APEC. "Corr" defines the average correlation.

root tests. The CD statistic test, developed by Pesaran (2021), is used for this purpose and detects the correct unit root tests. In fact, direct use of the first-generation unit root tests may give spurious results in case the degree of cross-sectional dependence of the residuals is sufficiently higher. Therefore, this analysis applies the second-generation unit root test. The Pesaran statistic calculates a simple average of all pairwise correlation coefficients of the OLS residuals obtained from standard augmented Dickey and Fuller regressions for each variable in the panel. The null hypothesis suggests cross-sectional independence for the variable, while the alternative hypothesis assumes the presence of residual cross-sectional dependence.

Table 1 presents the results from the CD and reveals the presence of cross-sectional dependence in the variables and reject the null hypothesis. Thus, the stationary properties must be based on the second-generation unit root test.

In fact, the second-generation unit root tests provide more controlling outcomes. To check for stationary properties of each variable, the analysis uses the cross-sectional augmented IPS (CIPS) unit root statistic proposed by Pesaran (2007). This test's null hypothesis assumes non-stationary variables, while the alternative hypothesis assumes that variables are stationary. Table 2 reports on the outcomes of the CIPS test and indicates that, at level, all series are non-stationary. However, after first difference, all variables became stationary. Thus, our variables are integrated of order one.

Since all variables are stationary after first difference, the analysis proceeds with a test for long-run cointegration among the variables, keeping ecological footprint as an endogenous variable. This is achieved by applying the approach by Pedroni (2004) and Kao (1999) who developed seven statistical tests for heterogeneous panels, classified into two broader categories. The first category ("within dimension") is based on four panel statistical tests: *v*-statistic, rho-statistic, PP-statistic, and ADF-statistic. The second type ("between dimensions") relies on three statistical tests: rho-statistic, PP-statistic and ADF-statistic. According to these statistical tests, the null hypothesis assumes no cointegration between the variables, while the alternative hypothesis suggests long-run association between the variables. The computation of statistical tests for cointegration is based on the residuals of Eq. (3). The confirmation of the existence of long-run association between the variables is established by means of Kao (1999). This test relies on the ADF-statistic.

Table 2 CIPS unit root test result

Variables	CIPS test			
	At level		At first difference	
	Statistic	prob	Statistic	prob
FP	2.610	1.000	−2.707	0.000***
GDPPC	−1.313	0.981	−2.881	0.000***
ENPC	−1.956	0.114	−3.039	0.000***
GOPCLEG	−0.586	0.279	−3.120	0.000***
GOPAPEC	−1.877	0.211	−2.688	0.000***

Notes: "***" denotes statistical significance at 1%. The cross-sectional augmented IPS (CIPS) developed by Pesaran (2004) assuming the null of non-stationary. Tests are computed the case of constant and trend for statistical estimation.

Table 3 Panel residual cointegration results (model with GOPCLEG)

Pedroni cointegration tests				
Alternative hypothesis: common AR coefs. (within dimension)				
	Statistic	Prob	Weighted	
			Statistic	Prob
Panel v-statistic	−0.762178	0.7770	−3.350078	0.9996
Panel rho-statistic	4.493516	1.0000	5.170375	1.0000
Panel PP-statistic	−15.36050	0.0000***	−16.43333	0.0000***
Panel ADF-statistic	−11.50985	0.0000***	−8.580943	0.0000***
Alternative hypothesis: individual AR coefs. (between dimension)				
	Statistic	Prob		
Group rho-statistic	7.047196	1.0000		
Group PP-statistic	−26.82045	0.0000***		
Group ADF-statistic	−12.75660	0.0000***		
Kao cointegration test				
ADF			*t*-statistic	Prob
			−5.409488	0.0000***

Notes: "***" indicates statistical significance at the 1% significance level. Pedroni residual tests are estimated for the case with constant and deterministic trend.

Table 4 Panel residual cointegration test results (model with GOPAPEC)

Pedroni cointegration tests				
Alternative hypothesis: common AR coefs. (within dimension)				
			Weighted	
	Statistic	Prob	Statistic	Prob
Panel v-statistic	−0.123397	0.5491	−2.079144	0.9812
Panel rho-statistic	3.563578	0.9998	4.045069	1.0000
Panel PP-statistic	−11.72446	0.0000***	−10.74597	0.0000***
Panel ADF-statistic	−11.34307	0.0000***	−8.490528	0.0000***
Alternative hypothesis: individual AR coefs. (between dimension)				
	Statistic	Prob		
Group rho-statistic	6.078694	1.0000		
Group PP-statistic	−14.64423	0.0000***		
Group ADF-statistic	−9.708022	0.0000***		
Kao cointegration test				
ADF			*t*-statistic	Prob
			−5.182547	0.0000***

Notes: "***" indicates statistical significance at the 1% significance level. Pedroni residual tests are estimated for the case with constant and deterministic trend.

Table 3 and Table 4 present these tests' results and indicate that, for both models, two tests among four from the within dimension category and two tests among three from the between dimension category reject the null hypothesis of no cointegration. Thus, in total, four tests among seven from the statistics proposed by Pedroni panel cointegration approve the existence of a long-run relationship between the variables. Also, the developed ADF test by Kao (1999) rejects the null of no cointegration between the variables. Consequently, we authorize that all selected variables are cointegrated when the ecological footprint serves as the dependent variable in both the GOPCLEG and the GOPAPEC model.

Once cointegration between the variables is tested, FMOLS and DOLS techniques estimate the long-run coefficient for the models' explanatory variables. For both models, all estimations are completed for the case with an intercept and a deterministic trend. The FMOLS and DOLS panel method are applied for the weighted pooled event. Table 5 and Table 6 report the results of long-run estimates for the model with GOPCLEG and the model with GOPAPEC, respectively.

For the models with GOPCLEG, all estimated coefficients are statistically significant, except for the GOPCLEG coefficient in the DOLS approach. This model confirms the EKC hypothesis, given that the coefficients of real GDP per capita and its square are positive and negative, respectively. Thus, following the FMOLS approach, a 1% increase in real GDP per capita increases CO_2 emissions per capita by 3.15%, and a 1% increase in the square of real GDP per capita decreases CO_2 emissions per capita by 0.24%. Long-run estimates suggest that per capita energy consumption leads to an increased ecological footprint, while the GOPCLEG index indicates that green products lower a country's ecological footprint in the long run. In other words, the FMOLS model indicates that a 1% increase in energy consumption per capita leads to a 0.8% increase in CO_2 emissions per capita. Taking a closer look at the GOPCLEG index, the findings obtained

Table 5 Long-run estimates (model with GOPCLEG)

Variables	GDPPC	GDPPC2	ECPC	GOPCLEG
FMOLS	3.159765	−0.247263	0.809512	−0.166935
	0.0000***	0.0000***	0.0000***	0.0000***
DOLS	3.149905	−0.143854	0.870986	−0.041374
	0.0005***	0.0007***	0.0000***	0.1961

Notes: "***" indicates statistical significance at 1%. The FMOLS and DOLS are computed for the case with constant and deterministic trend.

Table 6 Long-run estimates (model with GOPAPEC)

Variables	GDPPC	GDPPC2	ECPC	GOPAPEC
FMOLS	2.678887	−0.157107	0.799403	−0.182115
	0.0000***	0.0003***	0.0000***	0.0000***
DOLS	6.159214	−0.251413	0.168062	−0.010681
	0.0000***	0.0000***	0.0155**	0.0546*

Notes: "***" and "**" indicate statistical significance at 1% and 5%, respectively. The FMOLS and DOLS are computed for the case with constant and deterministic trend.

from FMOLS indicate that when a country's green openness increases by 1%, its ecological footprint will decrease by approximately 0.17%. Applying the DOLS approach, the impact of GOPCLEG index on per capita CO_2 emissions is negative but statistically insignificant.

For the model with GOPAPEC, all estimated coefficients are statistically significant at mixed levels (1% and 5%). In fact, for both FMOLS and DOLS approaches, the coefficients of real GDP per capita and its square are found to be positive and negative, respectively. Using DOLS, a 1% increase in real GDP per capita increases CO_2 emissions per capita by 6.15%, while a 1% increase in the square of real GDP per capita decreases CO_2 emissions per capita by 0.25%. This result confirms the validity of the EKC hypothesis in this sample. Interestingly, the estimated coefficients of GOPAPEC and ENPC are negative and positive, respectively. The interpretation of the estimated coefficient for the GOPAPEC index in the FMOLS and DOLS results is as follows: if the green openness increases by 1%, the ecological footprint decreases by 0.18% and 0.01%, respectively. Following the FMOLS estimation, a 1% increase in the growth of real GDP per capita and the consumption of energy per capita lead to an increase of the ecological footprint by 2.67% and 0.8%, respectively. Following the DOLS estimation, a 1% increase in real GDP per capita and energy consumption per capita increases the ecological footprint by 6.16% and 0.17%, respectively.

The last step of the empirical study investigates the short and long run dynamic causal links for both models' variables using the Granger causality tests. To do that, Engle and Granger (1987) developed a two-step procedure. The procedure consists of an estimation of the long-run relationship in Eq. 3 (first step) to recuperate the residuals which are reserved to define the error correction term (second step). The pairwise Granger causality investigates the short-run dynamic causality between variables. The test relies on the significance level of the Fisher statistical test. The null hypothesis confirms absence of causality between two variables, while the alternative suggests causality. The long-run association between the variables is tested using the significance level of the lagged error correction term, which is based on the significance of *t*-student statistic. The null hypothesis confirms the absence of long-run causality, while the alternative hypothesis confirms long-run causality (i.e. significant coefficient of the lagged error correction term). Table 7 and Table 8 present the results of these tests.

For both the GOPAPEC and the GOPCLEG models, the Granger causality reveals that, in the short run, there is a unidirectional causality running from the ecological footprint to energy consumption without feedback. This outcome differs from Shahzad et al. (2021) who find unidirectional short-run causality running from energy use to ecological footprint in the USA using quantile autoregressive distributed

Table 7 Granger causality test results (model with GOPCLEG)

Short-run causality		
Null hypothesis	*F*-statistic	Prob
Y does not Granger cause EF	0.63382	0.4266
EF does not Granger cause Y	1.55998	0.2126
EC does not Granger cause EF	2.15986	0.1427
EF does not Granger cause EC	4.51091	0.0345**
GOPCLEG does not Granger cause EF	0.66547	0.4153
EF does not Granger cause GOPCLEG	6.91638	0.0090***
EC does not Granger cause Y	0.38007	0.5380
Y does not Granger cause EC	1.12128	0.2905
GOPCLEG does not Granger cause Y	4.39768	0.0368**
Y does not Granger cause GOPCLEG	9.35640	0.0024***
GOPCLEG does not Granger cause EC	0.33666	0.5622
EC does not Granger cause GOPCLEG	6.55851	0.0109**
Long-run causality		
EF = *f*(GDPPC, ECPC, GOPCLEG)	−0.038417	[−2.85187]***
GDPPC = *f*(EF, ECPC, GOPCLEG)	−0.002462	[−3.30866]***
ECPC = *f*(EF, GDPPC, GOPCLEG)	0.007223	[3.36723]
GOPCLEG = *f*(EF, GDPPC, ECPPC)	0.013143	[2.96229]

Notes: "***" and "**" indicate statistical significance at 1% and 5%, respectively.

Table 8 Granger causality test results (model with GOPAPEC)

Short-run causality		
Null hypothesis	*F*-statistic	Prob
Y does not Granger cause EF	0.63382	0.4266
EF does not Granger cause Y	1.55998	0.2126
EC does not Granger cause EF	2.15986	0.1427
EF does not Granger cause EC	4.51091	0.0345**
GOPAPEC does not Granger cause EF	0.30391	0.5818
EF does not Granger cause GOPAPEC	4.40761	0.0366**
EC does not Granger cause Y	0.38007	0.5380
Y does not Granger cause EC	1.12128	0.2905
GOPAPEC does not Granger cause Y	2.51979	0.1135
Y does not Granger cause GOPAPEC	9.25995	0.0025***
GOPAPEC does not Granger cause EC	1.22988	0.2683
EC does not Granger cause GOPAPEC	4.90625	0.0275**
Long-run causality	Coefficient	*t*-statistic
EF = *f*(GDPPC, ECPC, GOPAPEC)	−0.039174	[−2.82515]***
GDPPC = *f*(EF, ECPC, GOPAPEC)	−0.000706	[−3.29446]***
ECPC = *f*(EF, GDPPC, GOPAPEC)	0.004874	[3.03888]
GOPAPEC = *f*(EF, GDPPC, ECPPC)	0.004855	[1.34151]

Notes: "***" and "**" indicate statistical significance at 1% and 5%, respectively.

lag (QARDL). Nevertheless, the conclusion remains valid, as countries with high ecological footprints tend to consume larger volumes of products with a high environmental impact. These kinds of products typically require high levels of energy. Finally, Granger suggests no short-run causal links between economic growth and ecological footprint. This result differs from Ikram et al. (2021) who find bidirectional causality between ecological footprint and economic growth in extreme quantiles for Japan using ARDL and QARDL approaches. However, in the long-run, the estimated coefficients of the lagged error correction terms corresponding to ecological footprint and real GDP equations are statistically significant, which confirms the existence of long-run association among these two variables. Thus, any changes in the added value of economic sectors will have an impact on a country's ecological footprint and its contribution to environmental degradation. But also the opposite reasoning appears true: the evolution of a country's ecological footprint will affect economic growth in the long run.

For the GOPCLEG model, the Granger causality indicates unidirectional short-run causalities running from the ecological footprint and energy consumption to GOPCLEG and bidirectional short-run causality between economic growth and GOPCLEG. Hence, the presence of green products, measured by the CLEG + index, positively impacts economic growth and vice versa.

For GOPAPEC model, the Granger causality reveals unidirectional short-run causalities running from ecological footprint, economic growth, and energy consumption to GOPAPEC. In conclusion, a country's economic strength, energy consumption, and ecological footprint determine the presence and importance of green products in that country.

Discussion

This paper's analysis demonstrates that economic growth is likely to result in an increased environmental footprint. That finding confirms many previous research, as demonstrated in a meta-analysis by Mardani et al. (2019) who clearly confirm the existence of "bidirectional causality between economic growth and CO_2 emission" trends. This is a problematic finding for developing countries in the process of achieving economic growth and higher welfare levels as it would, by default, imply a growing ecological footprint.

However, this paper's findings provide a strategy to break the seemingly inevitable trend between economic growth and environmental impact. The presence of green products in trade can significantly decrease a country's environmental impact. This confirms more recent findings by, for example, Paramati et al. (2021). The next section discusses the policy implications following these conclusions, as well as the contribution of the results of this study to the controversial debate on the environmental impact of trade openness. Finally, this chapter's last section presents some implications of the introduction of the new index for research.

Policy implications

The analysis demonstrates that increased trade in green products can (partially) counterbalance the negative environmental impact caused by economic growth. Investments in green products can therefore serve as a tool for policy makers responsible for sustainable growth plans. Numerous policy options can foster these investments, including, for example, the support of financial technology, green investments, development of human capital, and public–private partnership investments (Wang et al. 2020). In addition, the cost of these policies can considerably be decreased by the dynamic forces related to innovations and investments as they entail positive learning effects (Bretschger, 2015). In this rationale, a transition is less costly once effectuated earlier because the green products gain early momentum over dirty products and the green alternatives become more competitive (Acemoglu et al. 2012).

The findings also provide an essential contribution to the debate on the environmental impact of trade openness. That debate remains highly controversial. On the one hand, authors such as Wang et al. (2020), Kasman and Duman (2015), Mahmood et al. (2019), and Sebri and Ben-Salha (2014) describe how trade can entail a negative environmental impact. This suggests an inevitable link between engaging in international trade and environmental damage. On the other hand, authors such as Essandoh et al. (2020), Zhang et al. (2017), and Al-Mulali et al. (2015a) find that trade openness can positively impact environmental parameters.

The Green Openness Index presented in this paper provides an escape route out of that deadlock. The analysis clearly demonstrates that an increased Green Openness Index contributes to a shrinking environmental footprint and hence provides an important nuance to the findings by, for example, Wang et al. (2020). This pivotal conclusion suggests that the volume of trade does not necessarily have a negative impact on a country's environmental impact. What really matters is the type of traded products. The latter conclusion also provides an important nuance to the conclusions by McAusland and Millimet (2013), who found a positive impact of trade on environmental impact, without distinguishing between the type of traded products. As such, this paper's approach fits in the set-up proposed by Laplue (2019) who highlighted the need of diversification of sectors to assess the environmental impact of trade.

Finally, the presented index provides a useful tool to policy makers to track the importance of green products in trade flows and benchmark against other countries. There are many policy options available to increase the importance

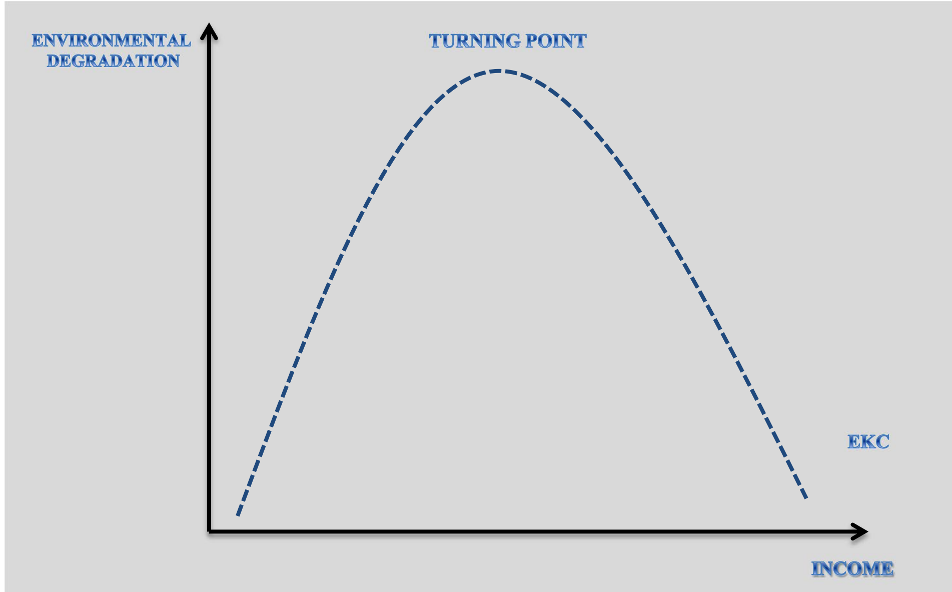

Fig. 2 Traditional U-inverted EKC. Source: Prepared by authors

of green products in an economy. Policy measures to foster investments are listed above, but policy measures can also aim to provide an enabling environment. At the demand side of the market, policies can for example include procurement policies or a green fiscal reform. At the supply side of the market, policies can influence the cost of green technologies, making intermediate inputs of clean technologies cheaper (Fischer and Newell, 2008) or setting standards (Amir et al. 2018, Bruneau, 2004). Dugoua and Dumas (2021) recently described how this kind of policies should especially aim to provide an incentive to a considerable number of firms to switch to green products (instead of a few cutting-edge firms who make the switch). Key in their reasoning is that producers need to coordinate with suppliers to make complementary investments and bring ambitious innovations. The need for collaboration is also described by Jaakkola and Van der Ploeg (2019).

Research implications

The new index developed in this paper will provide a lever for future research as the index can be applied in different research and policy areas (e.g. research on the impact of green technologies on renewable and non-renewable energy consumption). This kind of research on its turn will generate an impact on energy policies. Other potential research areas for application of the index, for example, cover unemployment, green jobs, economic growth or green growth, income distribution, and human well-being. As a final remark, this paper acknowledges that the Green (Trade) Openness Index is used as an explanatory variable in this analysis, but that no attention is paid to the drivers of trade in green products. Hence, future research could aim to discover the factors that drive the presence of trading green products.

Conclusion

This paper presents the first index to measure the importance of green products in a region, i.e. the Green Openness Index. By applying this new index, this paper revisits the trade-environment nexus in a case study for 31 OECD countries over the period between 2007 and 2017 in the context of the EKC hypothesis. To fulfil this study's objective, the paper employs various panel econometric procedures such as Pedroni and Kao cointegration tests, DOLS and FMOLS long-run estimator, and panel Granger causality analysis. The findings provide evidence in favour of the EKC hypothesis. Furthermore, the results clearly indicate that the presence of green products in trade (measured by the index) reduces a country's ecological footprint. This finding is especially crucial for countries seeking for sustainable development strategies. The hitherto paradigm states that economic development results in an increased environmental impact. A comparable paradigm exists in the context of trade: increased trade openness results in increased environmental pressure. This paper describes that focusing on more trade of green products, instead of focusing on more trade in general, provides a way out of these two paradigms and escape the growth-emissions deadlocks. Simultaneously, "trade openness" appears too limited as explanatory variable of environmental impact. Instead, it is important to assess what types of products are traded (green versus not green).

The latter policy recommendation requires improved understanding on the Green Openness Index. Thus, future research can examine the impact of Green Openness Index on various environmental indicators (e.g. air quality, CO_2 emissions), economic indicators (unemployment, income distribution, measures of a green economy, renewable and non-renewable energy consumption, green growth), and human well-being. Finally, future research can also validate this paper's findings by covering other countries and focus on the nexus between Green Openness Index and economic growth.

Appendix 1. Core CLEG + product list according to their HS 2007 codes

380210	731029	841790	847982	902680
730300	732490	841989	848110	902710
730431	761290	842121	848130	902720
730490	840410	842129	848140	902730
730630	840420	842139	850590	902750
730690	840510	842199	901540	902780
730900	841410	842833	901580	902810
731010	841780	846291	902610	902820

Appendix 2. APEC List of Environmental Goods according to their HS 2007 codes

441872	841919	847989	854140	902730
840290	841939	847990	854390	902750
840410	841960	850164	901380	902780
840420	841989	850231	901390	902790
840490	841990	850239	901580	903149
840690	842121	850300	902610	903180
841182	842129	850490	902620	903190
841199	842139	851410	902680	903289
841290	842199	851420	902690	903290
841780	847420	851430	902710	903300
841790	847982	851490	902720	

Appendix 3. OECD country list

Australia	France	Korea	Portugal
Austria	Germany	Lithuania	Slovakia
Belgium	Greece	Luxemburg	Slovenia
Canada	Hungary	Mexico	Spain
Chile	Ireland	Netherland	Sweden
Czechia	Israel	New Zealand	UK
Denmark	Italy	Norway	USA
Finland	Japan	Poland	

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Author contribution **MC:** Conceptualization; data curation; computation of index; writing—original draft. **MBJ:** Formal analysis, data handling, and methodology. **JB:** Writing—original draft, writing—review and editing.

Availability of data and materials All data generated or analysed during this study are included in this article.

Declarations

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Consent for publication Not applicable

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