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Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe

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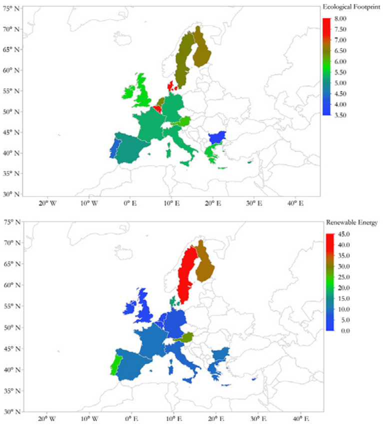
HIGHLIGHTS

- We investigated the drivers that reduce greenhouse gas emissions in EU member countries
- Panel Pool Mean Group Autoregressive distributive lag model was employed in the study
- 1% increase in real GDP increases environmental quality by 0.81% in the long-run
- Renewable energy consumption was found to improve environmental sustainability
- Diversification of the energy mix with renewables is essential to reducing pollution

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change mitigation has become the central theme for many policy initiatives, as such, the European Union (EU) member countries are working assiduously to achieve the emission targets. To provide policy direction in achieving the emission targets, this study investigated the drivers essential to attaining the Sustainable Development Goals in regards to reducing environmental pollution in EU member countries. A balanced panel of 16-EU countries from 1997 to 2014 was estimated with Panel Pool Mean Group Autoregressive distributive lag (PMG-ARDL) model. The study traced the equilibrium relationship between ecological footprint, real gross domestic product, trade openness, fertility rate, renewable and non-renewable energy consumption — suggested by both Kao and Pedroni cointegration tests. The PMG-ARDL analysis confirmed the role of non-renewable energy consumption in depleting environmental quality while renewable energy consumption was found to improve environmental sustainability. Interestingly, the unexpected long-run fertility-ecological footprint nexus was connected with the divergent fertility rate information of the EU member countries. Although, country-specific policy approach is essential, however, such a framework should be compatible with the region's overall Sustainable Development Goals. The call for diversification of existing energy portfolios by either incorporating or enhancing

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Conservative hypothesis
Panel econometrics
Economic growth

renewable energy technologies is essential to sustain the current success strides of most member states. Thus, the EU needs to strengthen its commitments to achieving the emission targets by decarbonizing and sustaining its economic growth trajectory.

1. Introduction

The impact of the pressure exerted by human exploitation of goods and services on the ecosystems is connected with the recent concerns of environmental degradation, climate change, ecological distortions, and economic setbacks. In response, the global awareness and drive toward sustainable development amidst environmental safety (sustainability) has remained the pre-occupation of environmentalist and economist across the globe. With the increasing human activities both directly and indirectly (Alola, 2019a, 2019b; Bekun et al., 2019a), more attention has been given to the environmental responses from the population dynamics, energy usage, economic growth, and several other notable factors (Akadiri et al., 2019, Alola and Alola, 2018; Emir and Bekun, 2018; Sarkodie, 2018; Shahbaz and Sinha, 2019; Wang and Dong, 2019). In addition to utilizing carbon emissions (mostly using CO_2) to account for environmental quality, ecological accounting via the ecological footprint and biocapacity have been adopted to provide broader perspectives. Given the importance of the Intergovernmental Panel on Climate Change (IPCC) report on "climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems" (IPCC, 2017), it definitely suggests a sustained effort toward reducing the pressure on the global ecological carrying capacity. In general, going by the economic expansion of the large economies like the United States, China, and some European countries, the aforesaid impacts remain a major concern of governments, environmentalists, and policy makers of these countries.

In view of the European Union's (EU) drive toward attaining sustainable development and environmental quality, effective policies are being implemented by the union to guide member countries in meeting the Sustainable Development Goals (SDGs). For instance, the amended EU's climate change target of 2030 includes the proposal to minimize greenhouse gas by at least 40% as compared to the 1990 emissions. Thus, attaining at least, 27% of total energy consumption from renewable energy, and a 27% increase in energy efficiency (European Commission, 2019). However, since the introduction of the ecological accounting vis-a-vis the ecological footprint (EFP) by Wackernagel and Rees (1998), the EFP has consistently been used to examine environmental quality. Considering EFP measures the impact of human activities on the earth's available resources [Global Footprint Network, GFN, 2019], examining the dynamics of EFP is poised to reveal further information for policy formulation. Information from the GFN hints on the serious concern of environmental quality in some EU countries, since some member states currently exhibit deficit in ecological resources. Interestingly, although reportedly argued to vary across the member countries, there has been consistent evidence of a decline in the fertility rate of most European countries (Rees, 2015; Coale, 2017). Thus, considering the trilemma of reducing the demand on the continent's EFP, averting the ageing population conundrum, and attaining sustainable development, it is yet empirically unclear if the trend of fertility decline remains desirable. The drive towards economic expansion, vast non-renewable have been mentioned among the determinants of environmental quality in the EU-member countries (Boyce, 1994; Shahbaz et al., 2017).

After Wackernagel and Rees (1998) hinted on the importance of reducing the impacts of human activities on the environment, several studies have further explored the scope of environmental perspectives within the context of ecological footprint (Gössling et al., 2002; Al-Mulali et al., 2015; Ozturk et al., 2016; Baabou et al., 2017; Destek and Sarkodie, 2019). Specifically, Al-Mulali et al. (2015) and Destek and Sarkodie (2019) both validates the environmental Kuznets curve (EKC) hypothesis for 11 newly-developed countries and 93 selected countries respectively. The studies employed the ecological footprint in lieu of the conventional CO_2 as a proxy for environmental quality to examine the validity of the EKC hypothesis. While incorporating other factors like energy consumption and financial development, both studies inferred an inverted U-shaped relationship between GDP and the EFP. In the case of Al-Mulali et al. (2015), the EKC hypothesis was observed to increase with GDP growth. This implies that the low-income countries lack energy-improved technologies, as such the observed countries experience low GDP growth. In a broader perspective, the EFP has been investigated alongside other economic-related factors like tourism, food, transportation, disposable income, infrastructure, and cultural habits (Gössling et al., 2002; Ozturk et al., 2016; Baabou et al., 2017). For instance, Ozturk et al. (2016) found a negative relationship between the EFP and the GDP growth (GDP mainly from tourism), energy consumption, trade openness, and urbanization for 144 countries.

Questions still remain about the role of trade policy, economic development, energy consumption and population growth in climate change mitigation. However, the complexities of these factors due to varied economic structure and environmental regulation among countries make it difficult to build a consensus on the determinants of climate change across different countries. Hence, the empirical evidence presented in this study is useful in climate change related policy formulation. The indication from the above motivations propels the objective of investigating the dynamic impact of trade policy, renewable energy consumption, non-renewable energy, economic growth, and fertility on the EFP in sixteen (16) EU member countries using modern econometric methods. In advancing the study of Bekun et al. (2019a), the current study also restricted the period of the dataset from 1996 to 2014 to 16 EU countries due to data availability. As a contribution to the existing literature, the study considered the use of EFP against the regular CO_2 because many EU countries are currently struggling to cope with challenges related to the ecological deficit (Global Footprint Network, GFN, 2019). In addition, the lingering challenge of low fertility in the EU prompted the incorporation of fertility rate in the model —to examine its impact on the ecological footprint. Most EU member countries are currently confronted with an increase in the older population which is possibly caused by low fertility rate (Hoff, 2016), hence, investigating its implications on environmental quality was informative.

The remaining sections of the study are ordered as follows: Section 2 presents the material and empirical methodologies. While the empirical findings and discussion are reported in Section 3, the concluding remarks and policy implication of the study are provided in Section 4.

2. Materials and methods

2.1. Data

Energy has been identified as an indispensable catalyst for socio-economic activities in developing, transitions economies and developed economies. This is evidenced in the potential of access to energy to improve livelihood and wellbeing. However, a tradeoff for greenhouse gas (GHG) emissions — the burning of fossil fuels leading to CO_2 emissions have been identified as the main contributor of global anthropogenic

GHG emissions. Thus, we sought to decouple environmental pollution from energy consumption-growth trajectory. Based on this highlight, the study focused on the carbon-income function in a modified manner by the disaggregation of energy consumption into renewable and non-renewable sources and the incorporation of the role of trade openness and fertility rate. In terms of variable definition, income level (real economic growth) is measured in 2010 constant USD$. The ecological footprint was employed as a measure of environmental pollution (degradation). The ecological footprint is a distinct measure for environmental quality that accounts for other natural areas that are needed to foster economic growth. Among such natural areas include the availability of water resources, forest reserve, and arable farm/grazing land and fresh air can be sourced through ecological footprint. The availability of the aforementioned natural areas and their capacity to support life could depend on the eutrophication potential, terrestrial acidification and ecotoxicity of the ecosystem and the environment. This is a more boarder proxy for environmental pollution measured in a global hectare of farmland and carbon footprint. The CO_2 component aside forestry land, cropland, fishery, and grazing land composition of ecological footprint makes it more encompassing and broader than just “CO_2 emissions” utilized in the existing literature. Based on this premise, we adopted ecological footprint as an indicator for environment quality contrary to previously used indicators in the literature. This index offered a more enriching picture for environmental quality relative to the CO_2 emissions used by previous studies which have been argued to be flawed. Non-renewable energy is made up of fossil fuels measured in a kilogram of oil equivalent in per capita while renewable energy constitutes the final total share of renewable energy consumption, expressed in percentage. Trade openness is used to measure the impact of globalization across the investigated EU-countries and is a measure of import and export as a share of GDP. Fertility rate is measured in terms of total birth accrue to a woman.[1] The data, unit of measurement and sources are itemized in details in Table 1.

2.2. Test processes

The empirical route utilized in this study is structured as follows: (i) we tested for common shock effect using cross-sectional dependency (CSD) tests. This was necessary to circumvent the spurious assumption of the cross-sectional dependency test. (ii) We examined the stationarity properties of interest variables via the Fisher ADF unit root test and the Im et al. (2003) unit root test. (iii) We investigated the equilibrium relationship among the variables through the Pedroni cointegration test advanced by Pedroni (1999) in conjunction with Kao cointegration for robustness. (iv) We tested the long and short run equilibrium relationship through the panel pooled mean group estimator by Pesaran et al. (1999) and (v) we examined the directional flow via the Dumitrescu and Hurlin (2012) causality test. Prior to the unit root investigations, the study conducted a basic summary statistics to offer a glimpse of the characteristics of the data series. Subsequently, Pearson correlation matrix analysis was conducted to observe the pairwise relationship among the variables under review.

2.3. Model specification

This study improves the empirical literature on the nexus between the carbon-income dynamics, by the disaggregation of energy consumption into renewable and non-renewable energy consumption sources. The current study builds on the study of (Bekun et al., 2019a; Balsalobre-Lorente et al., 2018; Khoshnevis Yazdi and Shakouri, 2017) by the incorporation of trade flow and a more border environmental quality measure (ecological footprint) into the model construction. The functional model that capsulated this study is presented below:

Table 1
Data description and measurement units.
Source: Authors' compilation.

Indicator name	Abbreviation	Measurement scale	Source
Real Gross domestic product	RGDP	Constant 2010 $ USD	WDI
Non-renewable energy consumption	NREC	Oil equivalent per capita	WDI
Renewable energy consumption	REC	% of total final energy	WDI
Trade openness	TO	Import + export/GDP	WDI
Fertility rate	FR	Birth/woman total term	WDI
Ecological footprint (EFP)	EFP	Global hectare of land	GFP

Note. WDI represents world development indicator (https://data.worldbank.org/) while GFP denotes global footprint network (https://www.footprintnetwork.org/).

Here,

$$Z_{it} = (RGDP, NREC, REC, TO, FR) \tag{1}$$

$$LnEFP_{i,t} = \alpha + \beta_1 LnRGDP_{i,t} + \beta_2 LnNREC_{i,t} + \beta_3 LnREC_{i,t} + \beta_4 LnTO_{i,t} + \beta_5 LnFR_{i,t} + \varepsilon_{i,t} \tag{2}$$

According to Baltagi et al. (2005), Panel modelling entails the combination of both time series and the cross-sectional dimension of data that renders more insightful meaning into the pool of data. The current study utilized panel procedure to explain how other explanatory variables like real economic growth, renewable energy consumption, non-renewable energy consumption, trade openness and fertility rate explains the quality of the environment as measured by ecological footprint in our case study. In an energy intense region, it would make theoretical and empirical sense to assume that β_1 will have a positive impact on the environment. This is in line with the popular tradeoff between economic growth and environmental quality known in the energy literature as the EKC hypothesis. We envisaged the same positive coefficient for non-renewable energy consumption and fertility rate. On the other hand, as our apriori expectation for renewable energy consumption and trade openness, we expected an inverse relationship.

The logarithm-linear specification in Eq. (2) was necessary to arrive at a homoscedastic model and the log-log relationship made easy the explanation of coefficients and estimates (i.e. computes the coefficients in elasticity form). Also, α indicates the model constant term while the β ' s partial slope parameters (coefficients) to be estimated. $\varepsilon_{i,\ t}$ represents the stochastic term that captures all unobserved variables in the estimated model. The subscripts i and t represent the time dimensions in this case from 1997 to 2014 and cross-sectional dimensions of 16 EU countries respectively for the selected.

This study estimated the short and long run-regression with the Pesaran et al. (1999) methodology. The study proceeded with the following pollution economic growth model within an Autoregressive Distributed Lag (ARDL: p,q) framework that includes the lag of both dependent and independent variable expressed as:

$$\ln EFP_{i,t} = \alpha_i + \textstyle\sum_{j=1}^{p}\delta_{i,j}\ \ln EFP_{i,t-j} + \sum_{j=0}^{q}\varphi_{i,j}Z_{i,t-j} + \varepsilon_{i.t} \tag{3}$$

Here,

$$Z_{it} = (RGDP, NREC, REC, TO, FR)$$

In Eq. (3), as earlier mentioned $i = 1, 2, \dots, N$ and $t = 1, 2, \dots, T$, denotes the time and cross-sectional dimension. The vector $Z_{i,t}$ represents the vector of the explanatory variables of choice and the control variables that are generally employed in energy-growth empirical analyses. While α_i is the country-level fixed effects, $\delta_{i,j}$ represents the coefficient of the lagged $\ln EFP_{i,\ t}$ and $\gamma_{i,\ j}$depicts the coefficients of the lagged explanatory variables.

The ARDL cointegration methodology has been widely used among scholars in the empirical literature on the basis of its unique

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[1] See appendix section for list for countries investigated. The countries restriction is as results of data availability and study scope.

Table 2
Cross sectional dependency results.

Test	Statistic	Prob.
Pearson LM normal	0.8774	0.3802
Pearson CD normal	−0.5820	0.5605

Note. Null hypothesis: cross-sectional independence ($CD \sim (0,1)$).

econometric advantages relative to the traditional panel estimators. The unique feature of the test ranges from its ability to accommodate endogeneity issues in econometric modelling. It is able to simultaneously estimate both short-run and long-run parameter estimates in a single fitted model. The ARDL cointegration test is known for its flexibility in terms of the applicability in cases of mixed order of integration among variables — be it $I(0)$ or/and $I(1)$ but certainly not $I(2)$. Pesaran et al. (1999) revealed that the Pool Mean Group (PMG) estimator is robust and more reliable to lag orders and outliers compared to other estimators.

Eq. (3) was estimated using the PMG-ARDL selected model with the error correction (ECM) form given as:

$$\Delta \ln EFP_{i,t} = \phi_i \ln EFP_{i,t-1} - \theta_i Z_{i,t} + \sum\nolimits_{j=1}^{p-1} \delta^*_{i,j} \Delta \ln EFP_{i,t-j} + \sum\nolimits_{j=0}^{q-1} \gamma^*_{i,j} \Delta Z_{i,t-j} + \varepsilon_{i,t} \qquad (4)$$

Here,

$$\phi_i = -\left(1 - \sum\nolimits_{j=1}^{p} \delta_{i,j}\right), \theta_i = -\frac{\sum_{j=0}^{q} \gamma_{i,j}}{\left(1 - \sum_{j=1}^{p} \delta_{i,j}\right)} = -\frac{\sum_{j=0}^{q} \gamma_{i,j}}{\phi_i}, \delta^*_{i,j} = -\sum_{d=j+1}^{p} \delta_{i,d} \text{ and } \gamma^*_{i,j} = -\sum_{d=j+1}^{q} \gamma_{i,d} \qquad (5)$$

The first part $\phi_i(\ln EFP_{i,\,t-1} - \theta_i Z_{i,\,t})$ of the ARDL model specification in Eq. (4) denotes convergence speed in the level of the pollution-growth model in case of disequilibrium with the explanatory variables, while the latter part depicts the short-run dynamics. The vector parameter θ_i represents the coefficient of the explanatory variables in estimating the long-run coefficient. The coefficient ϕ_i captures the speed of convergence — also known as the error correcting term (ECM).

3. Results and interpretation

This section renders the empirical results and a discussion of all the regression in the study. Table 2 presents the cross-sectional dependency test as reported by Pesaran (2004). The test was necessary to ascertain the common shock phenomenon across the cross-sectional dimension of the panel data. The study shows a failure to reject the null of cross-independence. Thus, the study proceeded to the first generational panel estimation techniques without running into the error of assuming cross-sectional dependence.

The next test conducted was the preliminary descriptive statistics for the indicators considered for the study —this was pertinent in the choice of model estimation technique. Table 3 reports the summary statistics showing the mean, maximum, minimum, and standard deviation of the variables. In addition to the characterization of the summary statistics, it also reflects the peak as revealed by (Kurtosis), the normal distribution pattern with the help of the Jarque-Bera test statistic. Table 3 shows that ecological footprint, real gross domestic product, renewable consumption, non-renewable energy consumption, trade openness and fertility exhibit positive averages over the considered period. The results in Table 3 are derived from the model estimation method presented in Section 2, with computation from the data series sourced from the World Bank development database. All the aforementioned variables show considerable dispersion from their mean values. Real GDP has the highest mean value of 10.4263 with a minimum of 8.2296 and a maximum value of 11.0215 over the sampled period. In terms of average, non-renewable energy consumption follows real GDP with a value of 8.1702 while fertility rate recorded the lowest average among the variables. All the variables are negatively skewed with most of the observation on the left tail with the exception of non-renewable energy consumption, and trade openness. This explains why all the variables are not normally distributed, as evidenced in the Jarque-Bera test statistics (i.e. the probability is rejected indicating the non-normal distribution of the variables under review).

Subsequently, the need to investigate the one-one relationship among the variables was worthwhile. Thus, the Pearson correlation analysis was used to explore the pairwise relationship among these variables. Table 4 shows a positive statistically significant relationship between economic growth and non-renewable energy consumption. This implies that the consumption of fossil fuel energy sources will trigger higher income level for the region over the sample period. This is insightful, however, there are environmental implications as there is a tradeoff for environmental quality for higher income level. Thus, nations become more environmentally conscious on their growth trajectory especially at higher threshold level (Alola et al., 2019). In addition, there is an inverse statistical significant relationship between non-renewable energy consumption and environmental quality. This is a significant and desirable stride by most if not all economies to minimize fossil fuel consumption that triggers increased levels of carbon dioxide emissions. This also includes the decoupling of GHG emission from energy consumption. Further estimation was required beyond the correlation analysis to either refute or validate these positions. Thus, more sophisticated econometrics tests were conducted in the study.

The econometrics procedure generally encourages the test for stationarity properties among variables before proceeding to the model estimation. This is crucial in order to avoid variables that are integrated of

Table 3
Summary statistics for EU-16 countries.
Source: Authors computation from the pool of data for EU 16 countries investigated.

	LNEFP	LNRGDP	LNNREC	LNREC	LNTO	LNFR
Mean	1.7243	10.4263	8.1702	2.1878	4.3992	0.4547
Median	1.7374	10.5769	8.1853	2.1902	4.3673	0.4700
Maximum	2.1743	11.0215	8.8727	3.9110	5.3384	0.7227
Minimum	1.1130	8.2296	7.4312	−0.1592	3.6706	0.0862
Std. Dev.	0.2105	0.5429	0.3293	0.9888	0.3887	0.1559
Skewness	−0.5796	−2.4029	0.1517	−0.2963	0.3680	−0.1240
Kurtosis	3.4457	9.0123	2.1459	2.3543	2.0835	1.8154
Jarque-Bera	18.5067	710.9241	9.8585	9.2172	16.5789	17.5782
Probability	0.0001***	0.0000***	0.0072***	0.0100***	0.0003***	0.0002***
Sum	496.6000	3002.7790	2353.0150	630.0782	1266.9730	130.9590
Sum Sq. Dev.	12.7150	84.5946	31.1184	280.5997	43.3552	6.9773
Observations	288	288	288	288	288	288
Time period	1997–2014	1997–2014	1997–2014	1997–2014	1997–2014	1997–2014

*** Represents a rejection of the null hypothesis of normality at 1% significance level.

Table 4
Pearson correlation matrix results.
Source: Authors' computation.

	LNEFP	LNGDP	LNNREC	LNREC	LNTO	LFR
LNEFP	1					
t-Statistic	–					
Prob.-value	–					
LNGDP	0.7528	1				
t-Statistic	19.3412	–				
Prob.-value	0.0000***	–				
LNNREC	0.6803	0.5615	1			
t-Statistic	15.6977	11.4779	–			
Prob.-value	0.0000***	0.0000***	–			
LNREC	−0.1062	0.0109	0.0796	1		
t-Statistic	−1.8060	0.1847	1.3521	–		
Prob.-value	0.072*	0.854	0.1774	–		
LNTO	0.1616	0.1026	0.1550	−0.1748	1	
t-Statistic	2.7689	1.7446	2.6541	−3.0019	–	
Prob.-value	0.006*	0.0821*	0.0084*	0.0029**	–	
LFR	0.4562	0.503	0.4972	−0.1150	0.4058	
t-Statistic	8.6698	9.8423	9.6903	−1.9585	7.5078	1
Prob.-value	0.0000***	0.0000***	0.0000***	0.0511*	0.0000***	–

*** Represents a statistical rejection level of normality test statistics at 1% significance level.
** Represents a statistical rejection level of normality test statistics at 5% significance level.
* Represents a statistical rejection level of normality test statistics at 10% significance level.

Table 6
Pedroni and Kao cointegration results.
Source: Authors computation.

	Statistic	Prob.	Statistic	Prob.
Alternative hypothesis: common AR coefficients (within-dimension)				
Panel v-Statistic	0.051020	0.4797	−1.23802	0.8921
Panel rho-Statistic	0.634692	0.7372	2.108960	0.9825
Panel PP-Statistic	−11.0152	0.0000***	−6.9346	0.0000***
Panel ADF-Statistic	−1.94519	0.0259**	−3.21678	0.0006***

	Stat.	Prob.
Alternative hypothesis: individual AR coefficient (between-dimension)		
Group rho-Statistic	3.687971	0.9999
Group PP-Statistic	−12.173	0.0000***
Group ADF-Statistic	−3.12662	0.0009***

	t-Stat	Prob.
Kao cointegration test		
ADF	−2.2049	0.0137**
Residual variance	3.36E−03	
HAC variance	0.001887	

*** Represents a statistical rejection level of the null of no co-integration at 1% significance level.
** Represents a statistical rejection level of the null of no co-integration at 5% significance level.

order 2 that is, ~I(2) and at large spurious analysis that influences policy formulation. It is in this light that the study conducted the panel unit root test (ADF Fisher and Im Pesaran shin tests) for the bloc of countries presented in Table 5. The unit root test was conducted at both levels and the first difference for both ADF and Im Pesaran Shin unit root test. At the level form of the unit root test, all variables under reviews were statistically insignificant at all conventional statistical significant levels with the exception of trade openness (TO) at a 10% statistical significance level. However, we observe a difference after first differencing utilized in the panel unit root tests at 1% significance level for all the variables considered. The results reveal that all the variables are integrated of mixed order at either levels or first difference. Thus, adequate modelling estimation technique (PMG-ARDL approach) that supports the outcome of the panel unit root was applied accordingly. Subsequently, the study proceeded to investigate the long-run equilibrium relationship to ascertain the existence of convergence among the investigated variables. The Pedroni cointegration test advanced by Pedroni (1999) in conjunction with the Kao cointegration test was used to investigate the equilibrium relationship for the study presented in Table 6. Both co-integration tests by Kao and Pedroni are in harmony of a cointegration relationship between ecological footprint, real gross domestic product, renewable consumption, non-renewable energy consumption, trade openness over 1997–2014 for 16 EU-countries with the rejection of the null hypothesis of no cointegration at 1% statistically significant level.

Table 5
Unit root results.

	ADF-Fisher (unit root)		Im, Pesaran Shin (unit root)	
	Level	Δ	Level	Δ
LNRGDP	25.3499	72.6194***	0.7507	−4.2593***
LNREC	26.2639	67.1698***	0.5725	−3.5928***
LNNREC	15.2683	94.5382***	3.7769	−6.2410***
LNEFP	16.0884	85.4929***	3.1242	−5.1989***
LNTO	45.6757*	68.2794***	−1.5185*	−4.1477***
LNFR	29.5346	53.2433**	2.5452	−2.3000**

The symbol (Δ) means the first difference for the model with both intercept and trend at level.
*** Represents 1% statistical rejection level.
** Represents 5% statistical rejection level.
* Represents 10% statistical rejection level.

After meeting the precondition (equilibrium relationship between the variables) of the model estimation method, the study investigated the magnitude of cointegration in terms of coefficients. Panel PMG-ARDL was used to explore the short-long dynamics between the dependent variable and its explanatory variables. In Table 7, the independent variables converge to their long-run path by a magnitude −0.5940, which is statistically significant at 1% level by the contribution of its explanatory variables (real economic growth, renewable energy consumption, non-renewable energy consumption, trade openness and fertility rate). The statistical significant error correction term (ECM_{t-1}) affirms the equilibrium relationship between the variables. This indicates that deviation toward the equilibrium is correct by approximately 59% annually by the contribution of the explanatory variables. The long-run panel fitted model shows that real output (GDP) exerts a positive impact on environmental quality in both short and long run over the sampled period as measured by ecological footprint. In essence, a 1%

Table 7
Result of PMG-ARDL (2,1,1,1,1,1).
Source: Authors computation.

Model: LNEFP = *f* (LNRGDP, LNNREC, LNREN, LNTO, LNFR)

Variable	Coefficient	Std. Error	T-stat.	*P*-value
Long run				
LNRGDP	0.7892***	0.1187	6.6467	0.0000
LNNREC	0.9861***	0.0920	10.1752	0.0000
LNREC	0.0374*	0.0193	1.9422	0.0539
LNTO	−0.2999***	0.06143	4.828	0.0000
LNFR	−0.2262**	0.0910	−2.4845	0.0140
Short run				
ECT(−1)	−0.5940***	0.1511	−3.9299	0.0001
ΔLNRGDP	0.8121**	0.3140	2.5857	0.0106
ΔLNREC	−0.0855	0.0694	−1.2317	0.2199
ΔLNNREC	−0.1294	0.1279	−1.0122	0.3130
ΔLNTO	0.0949	0.0679	1.3970	0.1644
ΔLNFR	0.0067	0.2073	0.0321	0.9744
Constant	−8.0217***	2.0907	−3.8369	0.0002

The fitted model is based on maximum lag 1 as suggested by Akaike information criterion with 256 observations.
*** Represents a statistical rejection level of the null hypothesis of no co-integration at 1% significance level.
** Represents a statistical rejection level of the null hypothesis of no co-integration at 5% significance level.
* Represents a statistical rejection level of the null hypothesis of no co-integration at 10% significance level.

increase in the real GDP decreases the quality of the environment (increase in environmental degradation) by 0.81% and 0.79% in the short and long run respectively. This is in line with our earlier *apriori* expectation, suggesting an expected linear relationship between income and environmental pollution (Ulucak and Bilgili, 2018; Dogan et al., 2019). Although the current study did not look at the situation when income is squared (the Environmental Kuznets Curve hypothesis), we expect a decline in environmental deterioration (negative relationship) in such a situation. The plausible explanation is that most of the EU-member countries are more environmentally conscious in their growth trajectory, however, some of the member states are still dragging behind the attainment of major sustainable energy targets. This further explains the milestone achievements of most EU countries and the benefits of being signatories to the Kyoto Protocol and other country-specific targets and energy commitments. It is also worthy of mention here that most of the member countries that are meeting their renewable energy target still have a huge task in respect to other member countries that are yet to meet the energy targets. For instance, Romanian met its energy targets a decade before the actual stated dates (Emir and Bekun, 2018). This means EU countries are on the path of attaining their climate goals of more efficient consumption through the incorporation of renewable energy technologies. This is further resonated in the study of (Akadiri et al., 2019; Bekun and Agboola, 2019 Bekun et al., 2019b; Balcilar et al., 2019; Sarkodie and Adams, 2018; Sarkodie and Strezov, 2018b) that renewables like wind energy, photovoltaic, biofuel are the pathway for a cleaner environment. As earlier stated in this study, energy consumption is disaggregated into non-renewable and renewable sources. The long-run estimate shows non-renewable energy consumption intensely depletes (with about 98% increase in degradation as fossil fuel consumption increases by 1%) the quality of the environment, which in turn increases global GHG emissions. Unexpectedly, the evidence in the current study indicates that the share in renewable energy (from the total energy consumption) in the bloc countries is not sufficient to improve the quality of the environment, especially in the long run. Considering the current study employs the ecological footprint that accounts for larger content of the ecosystem against CO_2 emissions commonly used in previous studies, as the share of the consumption of renewable energy increases, there is no corresponding increase in environmental quality in the entire panel countries, indicating that the failure of few or some is a failure of all. This outcome is however not in line with the study of Emir and Bekun (2018) for an individual case study in Romania. In the current study, a 1% increase in the share of renewable energy in total energy consumption increases environmental deterioration by approximately 0.04% in the long run (this sign indicates far lower damage to the environment as compared to 0.98% for non-renewable energy consumption). This means the EU countries are in conformation to energy targets like the Kyoto protocol and Paris agreements to decline the global average temperature to below 2 °C. However, a cautious effort is needed, as we observe that an inflow of free trade (trade openness) and the increase in fertility rate in the long-run are responsible for decreasing environmental deterioration. Empirical evidence from this study negates the normal expectation of high fertility-ecological footprint nexus. This observation is likely to be unconnected with the United Nations Population Fund (United Nations Population Fund, 2018) observation of non-uniformity in the trend of fertility rate across the EU countries. For instance, the UNPF noted that the Southern and Eastern European regions (such as Ukraine, Italy, Spain, Greece, Portugal, and Poland) are associated with *low fertility* rates while the North-Western European countries (like Denmark, France, Holland, Norway, United Kingdom or Sweden) have *very low fertility* rates. Conversely, the short-run estimate of the study expectedly implies that fertility rate positively affects ecological footprint (0.0067), however, the impact is not statistically significant.

The need to explore the direction of causality was necessary for studies of this sort, hence, Dumitrescu and Hurlin (2012) Panel causality test was estimated with results presented in Table 8. We observe that real income drives environmental quality in one-way for the region investigated. This is insightful as policymakers and environmentalist are to pay close attention to the adverse effect of uncontrolled growth on environmental quality for EU member countries which have had substantial strides in their energy and environmental goals (Sarkodie and Strezov, 2018a). The study further observes significant evidence of Granger causality for renewable energy and trade openness with environmental quality. Feedback causality is observed running from renewable energy consumption and real GDP. The bidirectional causality between renewable energy consumption and real GDP means that the strides to decouple fossil fuel energy sources from economic growth is in progress, as renewable energy consumption is found to drive economic development. In addition, a statistically significant Granger causality with feedback is observed between fertility rate and ecological footprint. Expectedly, this implies that the historical information of each of the factors will statistically predict future characteristics of the other. This empirical evidence corroborates the statistical significance of both the dynamic relationship between fertility rate and ecological footprint and their corresponding correlation presented in Table 4.

4. Conclusion

Energy consumption has been identified as a key driver of the socio-economic activities across the globe. However, the vital role of energy consumption comes with its cost implications on environmental quality. This has been the bane of most economies to reduce the adverse impact of increased energy consumption on environmental pollution and degradation. Against the backdrop, the study focused on the role of trade policy, energy consumption, economic growth, and fertility rate on environmental pollution in 16 European member countries from

Table 8
Results of the Dumitrescu and Hurlin (2012) Panel causality.
Source: Authors computation.

Null hypothesis	Causality flow	W-Stat.	P-value
LNRGDP ≠ > LNEFP	RGDP → EFP	5.25335^{***}	0.0002
LNEFP ≠ > LNRGDP	2.17538	0.7254	
LNNREC ≠ > LNEFP	REC↔EFP	5.09948^{***}	0.0005
LNEFP ≠ > LNNREC	4.36508^{***}	0.0122	
LNREC ≠ > LNEFP	REC → EFP	7.29235^{***}	0.0000
LNEFP ≠ > LNREC	3.49048	0.1721	
LNTO ≠ > LNEFP	TO→EFP	4.98706^{***}	0.0009
LNEFP ≠ > LNTO	3.59893	0.1318	
LFR ≠ > LNEFP	FR↔EFP	5.57758^{***}	0.0000
LNEFP ≠ > LFR	6.30617^{***}	0.0000	
LNNREC ≠ > LNRGDP	RGDP→REC	2.35572	0.9078
LNGDP ≠ > LNNREC	6.01397^{***}	0.0000	
LNREC ≠ > LNRGDP	REC↔RGDP	3.92929^{*}	0.0526
LNRGDP ≠ > LNREC	6.93994^{***}	0.0000	
LNTO ≠ > LNRGDP	TO ≠RGDP	3.33413	0.2455
LNRGDP ≠ > LNTO	3.46503	0.1828	
LFR ≠ > LNRGDP	RGDP → FR	2.89150	0.5595
LNRGDP ≠ > LFR	7.11539^{***}	0.0000	
LNREC ≠ > LNNREC	REC ↔ NREC	10.7237^{***}	0.0000
LNNREC ≠ > LNREC	6.08126^{***}	0.0000	
LNTO ≠ > LNNREC	TO → REC	4.71665^{***}	0.0030
LNNREC ≠ > LNTO	3.66059	0.1124	
LFR ≠ > LNNREC	FR ↔ NREC	4.78195^{***}	0.0023
LNNREC ≠ > LFR	5.82716^{***}	0.0000	
LNTO ≠ > LNREC	REC → TO	3.32857	0.2485
LNREC ≠ > LNTO	6.58293	0.0000	
LFR ≠ > LNREC	FR ↔ REC	7.12778^{***}	0.0000
LNREC ≠ > LFR	5.49205^{***}	0.0000	
LFR ≠ > LNTO	FR → TO	4.53087^{***}	0.0065
LNTO ≠ > LFR	2.48278	0.9601	

***, ** and *) means statistical rejection level. While ≠ > indicate does not reject. → represents one-way causality flow. ↔ denotes bi-directional causality flow and ≠ means neutrality(no causality flow in either direction).

1997 to 2014. The PMG-ARDL estimation technique employed produced robust results to ensure insightful policy direction.

The long-run equilibrium relationship validated the vital role of renewable energy consumption in improving environmental and health quality — as less atmospheric emissions enhance air quality. However, there is a need to improve and strengthen environmental policies in the blocs investigated given that some member countries are yet to match-up to the Paris treaty for a decline in the global emission levels. The study further observed that a decline in environmental pollution in one member country is unlikely to translate to environmental sustainability for all member countries. Hence, the target should be environmental sustainability for all member countries without any isolated case, thus suggesting a joint approach toward attaining the sustainable development goals by 2030. The following pragmatic policy recommendations emanate from the study:

(i) The incorporation of more efficient, modern and cleaner energy technologies like renewables and nuclear in the energy portfolio is the pre-requisite for a successful transition from fossil fuel consumption while achieving a decarbonized economy. An effective policy that targets more structural changes like women's participation in the labour market, social norms, and fertility behaviour is worthy of implementation across the region.

(ii) The member countries should reconcile their individual state interests with larger interest especially of the EU in order not to jeopardize the courageous effort of the member states that are ahead in attaining the SDGs 2030 and other regional policy drives.

Although the UNPF (2018) attributed the decline in fertility rate especially of the developed countries as the by-product of sustainable development, the organization, however, cautioned that the age structure of the populations is primarily hampered. Since ageing and low fertility are the prevalent issues of the EU member countries, an adequate study should be devoted at underpinning and closing the gap between the very low fertility and the fertility near replacement countries (Billari, 2018). This study could be extended in the future by incorporating further demographic components that include household and gender classifications in an experimental model. Future research could weigh in from the perspective of forecasting the EFP and biocapacity comparatively in order to further improve the environmental sustainability actions of the EU member countries.

Appendix A

List of investigated European countries studied for this study.

Source: Authors computation.

Austria	Greece
Belgium	Ireland
Bulgaria	Italy
Denmark	Netherland
Finland	Portugal
France	Spain
Germany	Sweden
Cyprus	United Kingdom

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