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Modeling Environmental Degradation: The Effects of Electricity Consumption, Economic Growth and Globalization

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ABSTRACT

This study aims to explore the effects of electricity consumption, economic growth and globalization on CO_2 emissions in the case of the top ten electricity consuming countries. The sample used is annual data covering the period 1990-2018. This paper adopts the cross-sections independence and controls the heterogeneity between cross-sections by using the second generation econometric of panel data. More precisely, the CIPS unit root test, Pedroni (1999) cointegration, Westerlund (2007) bootstrap cointegration, and FMOLS and DOLS techniques have been applied. Additionally, the Dumitrescu and Hurlin (2012) panel causality test is used to investigate the causal nexus among the examined variables. The findings of the study support that all variables are integrated in the long run. Electricity consumption and economic growth have a positive and significant effect on CO_2 emissions in these countries. On the other hand, globalization has a negative and significant effect on CO_2 emissions, implying the improvement of environmental quality. The results also support the Environmental Kuznets Curve (EKC), as well as bidirectional causalities between economic growth and CO_2 emissions, between electricity consumption and CO_2 emissions, and between economic growth and globalization. Furthermore, unidirectional causalities running from globalization to CO_2 emissions, from economic growth to electricity consumption, and from electricity consumption to globalization are found. Policy implications are further discussed.

Keywords: Envrironmental Degradation, Electricity Consumption, Economic Growth, CO_2 Emissions, Globalization, Panel Data
JEL Classifications: C23, Q43, Q56, F60

1. INTRODUCTION

Nowdays, the climate change mitigation combined with securing access to affordable modern energy is one of the biggest issues facing the world. In modern economies, the availability, accessibility and utilization of energy has a crucial role for sustainable growth rates.

Environmental degradation does not only affect human activities but also the economy as a whole. Human activities have detrimental effects to the environment due to the extraction of greenhouse gases (GHG), having as results global warming and climate change. The natural environment contributes significantly in economic growth both directly, through resources and raw materials, and indirectly through the services provided by ecosystems.

Carbon dioxide, which is conisdered as the most harmulf anthropogenic greenhouse gas, is responsible for over 60% of the greenhouse effect (IPCC, 2019). The period 2010-2019 was the warmest decade ever recorded. From the ‘80s onwards, each subsequent decade is warmer than all the previous ones. By 2100, climate change will significantly damage the economies of all countries, whether rich or poor, overturning until recently the data that the poorer and warmer countries will suffer the most (Burke et al., 2015). At the Paris agreement of 2015, governments of 196 nations agreed to limit global warming well under of 2°C compared to the pre-industrials levels and to continue mitigation efforts on 1.5°C. Any deviation from this goal will have consequences on human health, ways of life, natural resources, air quality, biodiversity, legislative and economic issues.

The main reason of the increase in CO_2 emissions is related to the increase of energy consumption, especially, fossil fuels burning such as coal, gas and oil (Rahman, 2017; Dritsaki et al., 2021). In 2017, the increase of energy consumption (in global level) was almost 2% compared to the 0.9% increase in the previous year (2016), and the average increase of about 0.9% during the period 2012-2016 (IEA, 2019). In addition, electricity is consumed in all sectors, with it's increased demand (in global level) to be more than the increased demand of overall energy (IEA, 2019), implying that economic activity is significantly related to electricity consumption. The nexus among electricity consumption and economic activity is very important for improving energy efficiency and further enhancing the growth of the economy and the development of the society. Ferguson et al. (2000) supported the existence of a strong correlation between electricity consumption and wealth creation. Electricity consumption, and especially industrial electricity consumption, is a key index for a country's development level. However, electricity has adverse effect on environmental pollution and degradation too, since it is a kind of secondary energy which is obtained from primary energy conversion (Shaari et al., 2017; Rahman, 2020). The issue of the environmental degradation remains a key topic among policy makers of every country, who try to find out conditions for growth and development without negative effects on the environment (Bilgili and Ulucak, 2018).

The concept of globalization has generated increasing level of interdependence among world countries, through economic, energy trade, social and political means. By this meaning, energy can be considered as a key factor of globalization (Kurtz and Fustes, 2014). Nowdays, the demand of energy consumption has increased significantly due to the rapid population growth, technological progress and trade expansion (Dogan and Deger, 2016; Hlongwane and Daw, 2023). Energy, as significsnt element for industrialized and developing countries constitutes, either directly or indirectly, a major input to the production of goods and services (Tansuchat and Khamkaew, 2011).

Therefore, globalization may have an impact on the environment quality in both developing and developed economies (Shahbaz et al., 2016). Shahbaz et al. (2016) supported that market globalization is related to the globalization of environment problems. On the other hand, it is agrued that globalization can enhance environmental quality through green technology transfer from multinational companies to the countries with *loose environmental* policies (Dogan and Deger, 2016).

The purpose of this study is to investigate empirically the effects of electricity consumption, economic growth and globalization on CO_2 emissions (a proxy for environmental quality) for the case of the top ten electricity consuming countries of the world, using annual data for the period 1990-2018.

This article contributes to the existing literature in several ways:

i. This study highlights the role of electricity consumption rather than energy consumption as a variable control, because of it's use in all sectors of economic activity and the higher growth of electricity demand.
ii. A new globalization index proposed by Dreher (2006) is used. With this index, called as KOF globalization index, the impact of the various aspects of globalization on economic development could be controlled simultaneously. KOF takes into consideration various dimensions of globalization such as economic, political and social. The applicaton of KOF index is generally missing from previous research agenda in energy and environmental literature.
iii. The analysis of the validity of the Environmental Kuznets Curve (EKC) is also tested.
iv. The methodology used in the paper relies on recent data and the latest modeling and economic approaches. Since prominent cross-sectional dependence tests have been applied, we employ the CIPS unit root test, Pedroni (1999) cointegration, Westerlund (2007) bootstrap cointegration, and FMOLS and DOLS techniques. In addition, for each individual country, different paremeters of long-run equilibrium are estimated. Accoridng to Ozcan (2013) and Rahman (2017), individual long-run estimates should be applied in the case of the existence of heterogeneity among the parameters.
v. Furthemore, the Dumitrescu and Hurlin (2012) panel causality methodology rather than traditional Graner causality approach, which provides more efficient estimations for heterogeneous panel data, is used to examine the causal relationship among the examined variables.

The rest of the study is organized as follows: The next section reviews the literature. Section 3 presents data and methodology. Empirical results are presented in section 4. Finally, concluding remarks and policy implications are given in section 5.

2. LITERATURE REVIEW

In recent years, there are many studies that highlight the interconnection between economic growth and energy consumption, emphasizing the difficulties in establishing in advance any possible causality relation. Country policies, targeting at higher levels of economic and human development, led to higher demand for fossil fuels (Yang and Zhao, 2014).

Up to a decade ago, a large part of the empirical studies on the energy economics-environmental policy investigate separately the links between economic growth, energy consumption and the environment (within a bivariate framework) (Acheampong, 2018). Since this methodological approach can appear the omitted variables problem, Ang (2007), and Soytas et al. (2007) proposed the consolidated investigation between economic growth, energy consmumption and environment pollution defining in this way a new research area.

However, even today where the agenda of the empirical literature has been set, there is a shortage of empirical studies that explore the interconnections between these factors in a comprehensive manner (Destek and Sarkodie, 2019). Haggar (2012) argued that the results of such studies will determine countries' climate policy agenda. In addition, few studies have examined empirically the relationship between economic growth, energy/electricity consumption and other types of environmental degradation, such as CO_2 emisions, globalization, land-use change, consumption level in respect to natural resources and other combined effects of anthropogenic pressure (Galli et al., 2012; Bagliani et al., 2008).

2.1. Energy/Electricity Consumption and Economic Growth

The energy-growth nexus can be categorized in four hypotheses (Rahman et al., 2016; Apergis and Payne, 2010; Narayan and Popp, 2012). First, the growth hypothesis suggests unidirectional causality relation with direction from energy consumption to economic growth. Second, the conservation hypothesis argues unidirectional causality relation running form economic growth to energy consumption. Third, the feedback hypothesis argues bidirectional (mutual) causality relation between energy consumption and economic growth. Finally, the neutrality hypothesis assumes that there is not any significant correlation among energy consumption and economic growth.

The field provides mixed results, that seems to depend on the different sample characteristics and on the use of different econometric techniques (Apergis and Payne, 2010; Acaravci and Ozturk, 2010). The support of the growth hypothesis is proved in several studies, such as Lee (2006) for the case of Belgium, Netherlands, Switzerland and Canada, Bowden and Payne (2009) for the case of USA, as well as Rahman (2017) using a sample of 11 Asian countries. The conversation hypothesis is validated in some studies, such as Lee (2006) for Italy and France, Soytas and Sari (2009) for Germany, Ozturk and Acaravci (2010) for the Turkey, and Shahbaz (2013) et al. for the case Portugal. On the contrary, neutrality hypothesis is found by Ozturk and Acaravci (2010) for the case of Bulgaria, Albania and Romania, by Cowan et al. (2014) for the case of India, Brazil and China, as well as by Rahman et al. (2016) in Autralia. Finally, the existence of feedback hypothesis is supported by Oh and Lee (2004) in South Korea, by Chang (2010) in China, by Fuinhas and Marques (2012) for PIGST, and by Ozturk and Uddin (2012) for India.

2.2. CO_2 Emissions and Economic Growth

According to economic theory, the nexus among economic growth and environment is integrated in the environmental Kuznets curve (EKC). The EKC hypothesis argues that environmental pollution increases in parallel with per capita income to a certain level. After this level (threshold) the environmental pollution starts to decrease forming an inverted U-shaped relationship (Dinda, 2004). The reduction of environmental degradation is due to changes of demand and supply of resources in agriculture and service sector.

Based on the study of Kuznets (1955), Grossman and Krueger (1991) examined the link among economic growth and environmental quality which had as a result the formulation of the EKC hypothesis. Since then, there have been many researches focusing on the driving forces of environmental effects. However, the results seem to differ, depending on the sample period of study as well as on the stage of the development of each economy. Prominent studies that investigate EKC hypothesis are, among others, these of He and Richard (2010), Kasman and Duman (2015), Ertugrul et al. (2016), Ozokcu and Ozdemir (2017) and Rahman (2017).

2.3. CO_2 Emissions, Energy/Electricity Consumption and Economic Growth

The third body of research is a combination of the two previous approaches, implying to test the validity of both nexuses within a single framework. This approach investigares the dynamic interconnections among economic growth, energy/electricity consumption and environmental degradation, all together. Given the fact that the literature on the field is enormous, we will mention only recent studies.

The findings obtained related to the direction of causality are not clear including: (i) unidirection causality relations running from economic growth to energy consumption and CO_2 emissions (Lotfalipour et al., 2010; Apergis and Payne, 2011; Rahman and Kashem, 2017), (ii) unidirectional causalities with direction from electricity consumption and CO_2 emissions to economic growth (Lean and Smith, 2010), (iii) no evidence of causality between income and energy consumption, and between income and CO_2 emissions (Soytas nad Sari, 2009), (iv) bidirectional causalities between CO_2 emissions and energy consumption (Alam et al., 2011; Wang et al., 2011), (v) mixed results (Cowan et al., 2014).

2.4. CO_2 Emissions and Globalization

The globalization proces of the international markets has created serious concerns about the features of the globalization process that may endanger environmental sustainability. At low income levels, environmental pollution tends to increase as people are willing to accept increasing environmental pollution for increased consumption. On the other hand, while individuals achieve raised living standards, they become more and more concerned about envrironmental degradation. Hence, a long-term relationship among the process of globalization of the international markets and the envrironmental pollution is obvious (Shahbaz et al., 2017).

In 90s, researchers supported that globalization affects environmental quality through three principle channels: (i) the composition, (ii) the income, and (iii) the technique effects (Grossman and Krueger, 1991; Shahbaz et al., 2018).

i. Composition effect - measures changes in harmul emissions due to the change in a country's industrial composition following trade liberalization.
ii. Technique effect - globalization induces countries to obtain green energy technologies, through knowlegde transfer and trade liberalization, in order to reduce the rate at which industry and households pollute. The technique effect also includes changes in the strictness of environmental legislation in response to rising income or the political climate surrounding regulation (McAusland, 2008)
iii. Income effect - increased globalization, trade openness and economic activity levels, increase in turn emissions having as result environmental degradation (through scale effect, holding the technique effect and the composition effect constant) (Grossman and Krueger, 1991).

The empirical findings on the globalization-CO_2 emissions relationship are mixed and it seems to depend on the different econometric approaches, omitted variables bias and data samples (Rahman, 2020).

The positive effects of the globalization/trade openness on the environmental degradation is supported by the studies of Lee and Min (2014) for the world economy, Shahbaz et al. (2016) for Australia, Dogan and Turkekul (2016) for the USA, as well as Adebayo and Acheampong (2022) for Australia, too. On the contrary, the negative aspects of globalization on the environment are supported by Lee et al. (2006), Shahbaz et al. (2017) and Jun et al. (2021) using data samples of selected 98 countries, 105 countries and South Asian countries, respectively.

3. MODEL, DATA AND METHODOLOGY

3.1. Model

The aim of this paper is to examine the effects of electricity consumption, economic growth and globalization on CO_2 emissions, for the group of the top ten electricity consuming countries. Hence, we specify the function form as shown in the next equation (following Lean and Smyth, 2010; Rahman, 2017; Dogan and Aslan, 2017; Inglesi-Lotz and Dogan, 2017 and Rahman, 2020):

$$CO_{2t} = \alpha + \beta GDP_{it} + \gamma GDP^2{}_{it} + \delta EL_{it} + \zeta KOF_{it} + \varepsilon_{it} \quad (1)$$

where CO_2 stands for the per capita carbon emissions (in metric ton), GDP the per capita real gross domestic product, GDP^2 is the square GDP, EL is the per capita electricity consumption (in kWh), and KOF is the globalization index developed by Dreher (2006), and measures the economic, political and social dimensions of globalization, ε_{it} is the error term, i the number of individual members and t the number of observations over time. The functional relationship in Equation (1) is expressed in natural logarithms, so the estimated coefficients of β, γ, δ and ζ will provide us relatively precise *estimates* of the *long-run elasticities.*

3.2. Data

The analysis includes panel data for the case of the ten most electricity consuming countries: China, Unites States, India, Japan, Russia, South Korea, Brazil, Germany, France and Canada (Statista, 2022). Among others, the advantage of using panel data is that contains more information, more variability and more efficiency than pure single country data. The sample used is annual covering the period 1990-2018. The selection of the sample is based on the data availability. Data are gathered from several databases[1] such as: World Development Indicators (WDI, 2022) of the World Bank (2022), International Monetary Fund (IMF, 2022), Our World in Data (OWID, 2022) and ETH Zurich-Swiss Economic Institute (2022). The descriptive statistics of the variables are displayed on Table 1.

3.3. Methodology

3.3.1. Cross sectional dependence test

The presence of cross-section dependence can lead to biased estimates and misleading statistical results (Pesaran, 2007). So, before applying panel unit root analysis, it's necessary to investigate the existence of dependence among the units and the examined variables in the panel data model under consideration.

Prominent cross-sectional dependence tests are these proposed by Breusch and Pagan (1980) (LM), Pesaran (2004) (scaled LM_s and CD_p), and Baltagi et al. (2012) (bias-corrected scaled LM_{BC}) which are specified as follows:

$$LM = T\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{2}\right) \rightarrow X^2 \text{ with } \frac{N(N-1)}{2} \text{ degrees of freedom} \quad (2)$$

$$LM_s = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T_{ij}\hat{\rho}_{ij}^{2}-1) \rightarrow N(0,1) \quad (3)$$

$$CD_p = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T_{ij}\hat{\rho}_{ij}^{2}) \rightarrow N(0,1) \quad (4)$$

$$LM_{BC} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T_{ij}\hat{\rho}_{ij}^{2}-1) - \frac{N}{2(T-1)} \rightarrow N(0,1) \quad (5)$$

Where T denotes time interval, N is the number of cross section units and $\hat{\rho}_{ij}^{2}$ is the pairwise correlation coefficient between the units.

3.3.2. Panel unit root test

In the presence of cross-section dependence, the first-generation panel unit root analysis tend to be biased and less effective for

1 Due to time constraints, electricity consumption data are gathered combined fromWDI (2021) and OWID (2021) databases (see also in the references).

Table 1: Descriptive statistics

Variable	CO_2		GDP		EL		KOF	
Country	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Brazil	1.82	0.32	6535.97	3466.14	2034.08	393.53	57.05	7.49
Canada	15.93	0.73	34024.25	12395.94	16214.11	676.97	80.13	3.81
China	4.43	2.08	3164.21	3120.90	2065.15	1412.48	54.63	9.34
France	5.65	0.58	32329.15	8464.58	7120.94	445.90	83.10	3.84
Germany	10.00	0.85	34680.35	8902.64	6834.42	340.83	83.46	4.61
India	1.10	0.36	878.23	563.06	532.73	212.51	50.99	10.61
Japan	9.25	0.30	37775.73	5193.77	7977.79	484.23	68.77	6.77
Korea	9.83	1.85	18137.48	8217.55	7089.39	2920.89	67.89	9.26
Russia	11.11	1.22	6629.67	4719.60	5943.15	675.32	64.54	7.26
USA	18.27	1.83	41653.69	11763.81	12991.20	512.70	77.61	3.82
All	8.74	5.48	21580.88	17054.14	6880.29	4758.33	68.82	13.39

the panel series. In this analysis, having determined the cross-sectional dependence among the countries, we proceed with a second generation panel unit root test-the Pesaran (2007) Cross-sectionally Augmented IPS (CIPS) test. Pesaran (2007) proposed a one-factor model with heterogeneous loading factors for residuals for the unit root process.

The starting point of the procedure is the the OLS estimation for the i^{th} unit in the panel in accordance with the next Cross-Sectional Augmented Dickey Fuller (CADF) regression. In the case that there is not serial correlation in the data (residuals), the regression used for the i^{th} cross section is the following:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \delta_i \bar{y}_{t-1} + \sum_{j=0}^{k} \delta_{ij} \Delta \bar{y}_{i,t-j} + \sum_{j=0}^{k} \Delta y_{i,t-j} + \varepsilon_{it} \quad (6)$$

where: $\bar{y}_{i,t-1} = (\frac{1}{N}) \sum_{i=1}^{N} y_{i,t-1}$, $\Delta \bar{y}_t = (\frac{1}{N}) \sum_{i=1}^{N} y_{i,t}$ and t_i (N, T) is the t-statistic of ρ_i that is used for the computation of the individual ADF statistic. The CIPS statistic is shown below:

$$CIPS = (\frac{\sum_{i=1}^{N} CADF_i}{N}) \quad (7)$$

3.3.3. Panel cointegration analysis

The next step in the analysis, is to apply panel cointegration methodology in order to investigate the long run relationship among the examined variables. Pedroni (1999) introduces seven cointegration statistics allowing for heterogeneous slopes coefficients across the units. Four out of seven statistics (panel v-statistic, panel rho statistic, panel PP-statistics and panel ADF-statistic) are based on the within-dimension of the panel, while the rest of them (three statistics-group rho statistic, group PP-statistic and group ADF-statitsic) are based on the between-dimension. The null hypothesis of no cointegration among the variables is the same for all statistics.

Westerlund (2007) introduced a new panel cointegration approach based on the structular rather than residlual dynamics, proving that this technique is more reliable in terms of size and accuracy compared to the classical method of Pedroni. Westerlund (2007) introduced two types of tests. The first includes the whole panel statistics and it contains P_t and P_a statistics. The second includes the group mean statistics and it contains G_t and G_a statistics. The P_t and G_t statistics are calculated using the standard error parameter of the error correction model. On the contrary, the P_a and G_a are calculated based on the standard errors (with the help of autocorrelations and heteroskedasticity) proposed by Newey and West. One property of the Westerlund (2007) test is that the results (P-values) are quite robust to cross-sectional dependence due to the bootstrap approach used by Chang (2004). The rejection of the null hypothesis of G_a and G_t supports that at least one of the cross-section units must have cointegration. Similaly, the null hypothesis rejection of P_a and P_t implies that panel has cointegration.

3.3.4. Panel model estimation approach

Having defined that the variables are cointegrated, we continue with the estimation of the long-run relationship. According to the panel data analysis, the ordinary least square (OLS) estimator leads to biased and inconsistent estimations when applied to cointegrated panels. So, we estimate the long-run equilibrium relationship using the fully modified OLS (FMOLS) estimator by Pedroni (1999; 2001). Pedroni (2001) supported that only in the case that the regressors are strictly exogenous the OLS method provides unbiased results and could be generally used for valid estimators. This method has the advantages of correcting the serial correlation and endogeneity problems.

Furthemore, as a robustness test, this paper applies the Dynamic Ordinary Least Squares (DOLS) approach proposed by Kao and Chiang (2000) and Mark and Sul (2002). Both FMOLS and DOLS estimators allow for more flexibility in the presence of heterogeneity of the long run relationship (Pedroni, 1999; 2000; 2001; 2004).

3.3.5. Dimitrescu and Hurlin panel causality test

The next step is the application of the Dumitrescu and Hurlin (2012) panel causality approach in order to find the causal relationship between the variables under examination. It's a new approach of non-causality of Granger (1969), robust to cross-section dependence based on a block bootstrapping approach to correct the test critical values. Furthermore, it provides reliable results both in small and large heterogeneous panels. The test takes into consideration two dimensions of heterogeneity: The model heterogeneity (from the regression of the Granger causality approach), as well as the heterogeneity of the causal relationship. The model is specified as follows:

$$y_{it} = a_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + e_{i,t} \quad (8)$$

Where a_i and $\beta_i = (\beta_i^{(1)}, ..., \beta_i^{(k)})$, are the cross sectional results assumed to be constant over time. In addition, the lag order K is assumed to be the same for the cross-section units of the panel data. The autoregressive coefficients and the regression coefficients.

($\gamma_i^{(k)}$ and $\beta_i^{(k)}$ repectively) differ between the cross sectional units.

The null hypothesis of the absence of causal ralathisonhip for any cross-sectional unit (Homogenous Hypothesis of non-causlaity [HNC]) is the following:

H_0: $\beta_i = 0$ for every $i = 1,\ldots N$

The statistic average for the HNC is:

$$W_{N,T}^{HNC} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T} \quad (9)$$

where $W_{i,T}$ shows the individual statistics by Wald for the i^{th} cross-section.

Table 2: Cross-sectional dependence results

Variables	LM		LM_S		LM_{BC}		CD	
	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.
LCO_2	525.88***	0.000	50.68***	0.000	50.51***	0.000	14.16***	0.000
LGDP	961.90***	0.000	96.65***	0.000	96.47***	0.000	30.60***	0.000
$LGDP^2$	961.90***	0.000	96.65***	0.000	96.47***	0.000	30.60***	0.000
LEL	584.28***	0.000	56.84***	0.000	56.66***	0.000	16.51***	0.000
LKOF	1240.19***	0.000	125.98***	0.000	125.80***	0.000	35.21***	0.000

The null hypotheses of the tests are of presence of no cross sectional dependence in panel, *** shows significant at 1% level, d.f. is 45, LM stands for Breuch-Pagan LM, LM_S stands for Pesaran scaled LM, LM_{BC} stands for Bias-corrected scaled LM, and CD_p stands for Pesaran CD. Source: Authors estimation using Eviews

Table 3: Second generation panel unit root tests (Pesaran CIPS test)

	CIPS test-1st difference				
Variables	LCO_2	LGDP	$LGDP^2$	LEL	LKOF
Intercept	−2.91***	−2.70***	−2.70***	−3.47***	−2.46**
Intercept and trend	−3.46***	−2.92**	−2.92**	−3.91***	−2.88**
	Critical values				
	1%		5%		10%
Intercept	−2.58		−2.33		−2.21
Intercept and trend	−3.11		−2.86		−2.73

***, and ** denote rejection of null hypothesis at 1% and 5% level of significance respectively, critical values obtained from Pesaran (2007), when the calculated CIPS value is less than the table critical value H_0 is rejected. Source: Authors estimation using Eviews

4. EMPIRICAL RESULTS

4.1. Cross Section Dependence Test Results

In order to avoid biased results, we begin the empirical analysis of our panel data model by testing the hypothesis of error cross section independence. The results of cross section dependence tests are presented in Table 2.

As can be seen from above table, the null hypothesis of no cross sectional dependence is strongly rejected at 1% level of significance, for the time series under examination (LCO_2, LGDP, $LGDP^2$, LEL, LKOF).

4.2. Panel Unit Root Analysis

The presence of cross sectional dependence in the panel limits the reliability of the first generation panel unit root tests. Since that cross sectional dependence among countries has been detected, we continue applying the second generation of panel unit root tests in order to specify the integration order of the series. In our analysis, the Cross Sectionally Augmented IPS (CIPS) test proposed by Pesaran (2007) is presented in Table 3.

The results of this approach at first order differential reject the null hypothesis of all panels contain a unit root, at the 1% and 5% level of significance. So, we can support that the variables are non stationary at levels, but show a stationary nature at first differences. Hence, we can say that there is an indication for the existence of a cointegration between the examined variables.

4.3. Panel Cointegration Results

Since the order of integration has been confirmed, the next step in our analysis is to apply panel cointegration methodologies. This paper adopts two cointegration tests of Pedoni (1999, 2004) and Westerlund (2007) in order to test if there is long-run relationship between the variables under examination. The cointegration results of Pedroni (1999) and Westerlund (2007) approaches are reported in Table 4.

Table 4: Panel cointegration results

Pedroni test			
Statistic	Value		Probability
Within-dimension			
Panel-v	2.00**		0.02
Panel-rho	0.00		0.49
Panel-PP	−0.87		0.18
Panel-ADF	−2.46***		0.00
Between-dimension			
Group-rho	−0.16		0.43
Group-PP	−3.04***		0.00
Group-ADF	−5.14***		0.00
Westerlund test			
Statistic	Value	Z-value	P-value
Gt	−3.97***	−2.97***	0.00
Ga	−3.70***	−4.48***	0.00
Pt	−14.01***	−11.14***	0.00
Pa	−30.25***	−5.89***	0.00

Under the null tests, all variables are distributed normal, N (0, 1). *** and ** denote significant at 1% and 5% levels. In Westerlund test, Akaike Information Criterion is used for optimal lag/lead length selection. Source: Authors estimation using Eviews and Stata, respectively

The results of table above show that there is a long run relationsip for the series under examination. The null hypothesis of no cointegration is rejected at panel level with both tests. We observe that two homogenous statistics and two heterogeneous statistics, out of seven of Pedroni (1999, 2004), are statistically significant implying the rejection of the null no cointegration. Furthermore, Westerlund (2007) test also confirms that the null hypothesis of no cointegration is rejected. All statistics reject the null hypothesis of no cointegration between the variables. Thus, the existence of cointegrating vector is confirmed. In other words, the results support that LCO_2, LGDP, $LGDP^2$, LEL and LKOF are moving together in the long run of environmental degradation model.

4.4. Panel Cointegration Estimation Results

Since our series are cointegrated, we continue by estimating the parameters of the long-run equilibrium relationship. The FMOLS technique is the most suitable to be applied in the presence of cointegrated panels (Hamit-Haggar, 2012; Ozcan, 2013), since it resolves endogeneity and autocorrelation issues. In addition to the FMOLS approach, we apply the DOLS method as a robustness test. The results of FMOLS and DOLS estimations are provided in Table 5.

Table 5 presents the long run estimated parameters of environmental degradation model. The model supports that all variables help to increase environmental degradation, except from globalization/openness index. Globalization can enhance the spread of the benefits of eco-innovation from developed to developing countries (i.e. through importing green technologies or developing advanced environmental standards. Thus, the governments should invest a huge budget on energy innovation in a way that countries become eco-friendly in order to reduce environmental degradation.

The findings of the panel estimates give the view of a positive and significant relationship between Carbon dioxide emissions and economi growth meaning that increased income levels lead to increased emissions levels. The GDP^2 coefficient is negative and statistically significant at 5% level. CO_2 emission levels increase initially with the GDP growth, but after exceeding a certain income level, then CO_2 emissions levels start to decrease since GDP is increasing.

The findings support the inverted U-shaped EKC for the sample countries. Countries do not have to worry about increasing environmental pollution, starting with economic development costs, because after a while it will help make the country environmentally friendly with the help of technological development. The results are similar to these of recent prominent studies of Kasman and Duman (2015), Ertugrul et al. (2016), Rehman and Rashid (2017) and Rahman (2020).

In addition, the findings support that electricity consumption has a positive effect on carbon dioxide emissions emissions in 1% level of significance. The sesults reveal that a 1% increase in electricity consumption per capita causes an increase in CO_2 emissions per capita by 0.72%. These findings are in line with these of previous studies of Shahbaz et al. (2013) and Kasman and Duman (2015).

Furthemore, the results from the estimated cointegrating relationship present a negative and significant relationship between CO_2 emissions and globalization index, supporting that countries with higher degree of globalization have reduced environmental pollution. An increase in electricity by 1% will cause a decrease in carbon dioxide emissions per capita by 0.14%. Finally the DOLS results, as a robustness test, confirm the results of our FMOLS estimates.

Ozcan (2013) and Rahman (2017) supported that a different long-run equilibrium relationship for each individual country should be estimated, in the case of the existence of heterogeneity among the long run parameters. So, individual FMOLS estimates are applied for each of the sample countries. From the results of Table 6 we see that a U-shaped relationship between CO_2 emissions and economic growth appears for the cases of China, USA and Russia. In contrast, the evidence supports the validity of the EKC in Japan, South Korea and Germany. In addition, the findings show that electricity consumption has a positive and significant impact on CO_2 emissions in China, USA, India, Japan and Russia. On the other hand, the analysis shows a negative relationship between electricity consumption and CO_2 emissions for the case of France. Finally, globalization is found to have a negative and significant effect on CO_2 emissions in China, USA and Russia. For the case of Brazil, this relationship found to be positive. It's worth mentioning that the panel data regression model fulfills the assumptions of heteroskedasticity and autocorrelation.

4.5. Panel Causality Test Results

Finally, we examine the causality direction between economic growth, electricity consumption, globalization and environmental quality (CO_2 emissions). To this goal, we applie the Dumitrescu and Hurlin (2012) panel causality methodology. The results of this approach are presented in Table 7.

The outcomes support the existence of bidirectional causality relationships between economic growth and CO_2 emissions, electricity consumption and CO_2 emissions, and economic growth and globalization. Furthermore, from the above table we can see that there are unidirectional causality relationships running from

Table 5: Panel FMOLS and DOLS estimations results (for the group of countries)

FMOLS Estimates	FMOLS			
	Independent variables			
	LGDP	$LGDP^2$	LEL	LKOF
Coef.	1.01 (2.78)***	−0.38 (−4.17)**	0.72 (5.02)***	−0.14 (−1.90)**
R^2		0.983		
Adj. R^2		0.982		
DOLS Estimates	**DOLS**			
	Independent variables			
	LGDP	**$LGDP^2$**	**LEL**	**LKOF**
Coef.	1.14 (1.97)*	−0.20 (−2.17)**	0.68 (2.32)***	−0.26 (−0.67)*
R^2		0.997		
Adj. R^2		0.994		

The numbers in parentheses denotes t-statistic. Asymptotic distribution of t-statistic is standard normal as T and N go to infinity. ***, ** and * denote significant at 1%, 5% and 10% level respectively. Lag and lead method selected by Akaike in DOLS. **Source:** Authors estimation using Eviews

Table 6: Panel FMOLS estimations results for each of the sample countries

Country		FMOLS			
		Independent variables			
		LGDP	$LGDP^2$	LEL	LKOF
China	Coef.	−0.21 (−3.44)***	0.04 (−3.85)***	0.67 (6.54)***	−0.44 (4.04)***
USA	Coef.	−26.07 (−3.53)***	2.88 (6.74)***	1.06 (7.39)***	−0.98 (−2.98)***
India	Coef.	−0.92 (1.52)	0.11 (4.22)***	0.15 (2.13)**	−0.01 (1.45)
Japan	Coef.	2.01 (4.07)***	−0.33 (2.73)**	0.55 (7.12)***	0.10 (0.98)
Russia	Coef.	−2.88 (−5.04)***	2.18 (8.31)***	1.90 (8.39)***	−0.15 (2.11)**
S. Korea	Coef.	1.52 (2.31)**	−0.09 (2.13)**	0.15 (−0.31)	0.23 (−0.09)
Brazil	Coef.	1.14 (0.38)	−0.99 (−0.10)	−0.12 (1.13)	0.30 (2.01)*
Germany	Coef.	6.80 (−5.37)***	−0.81 (6.93)***	−0.03 (0.94)	−0.45 (0.83)
France	Coef.	18.50 (−1.06)	−1.80 (−−0.60)	−0.91 (9.94)***	0.24 (−1.13)
Canada	Coef.	−4.42 (−0.14)	0.55 (1.51)	0.14 (−1.20)	0.22 (0.41)

The numbers in parentheses denotes t-statistic. Asymptotic distribution of t-statistic is standard normal as T and N go to infinity. ***, ** and * denote significant at 1%, 5% and 10% level respectively. Source: Authors estimation using Eviews

Table 7: Panel causality analysis results

Dimitrescu and hurlin causality analysis			
Hypothesis	W-Stat.	Zbar-Stat.	Direction of causality
lnGDP ($lnGDP^2$) → $lnCO_2$	4.31***	2.75***	lnGDP↔$lnCO_2$
$lnCO_2$ → lnGDP ($lnGDP^2$)	4.23***	2.64***	
lnEL→$lnCO_2$	3.87**	2.18**	lnEL↔$lnCO_2$
$lnCO_2$→lnEL	3.80**	2.08**	
lnKOF→$lnCO_2$	5.81***	4.70***	lnKOF→$lnCO_2$
$lnCO_2$→lnKOF	3.33	1.47	
lnEL → lnGDP ($lnGDP^2$)	3.16	1.24	lnGDP→lnEL
lnGDP ($lnGDP^2$) → lnEL	4.20***	2.90***	
lnKOF → lnGDP ($lnGDP^2$)	4.70***	3.64***	lnKOF↔lnGDP
lnGDP ($lnGDP^2$) → lnKOF	4.94***	3.57***	
lnKOF → lnEL	3.16	1.24	lnEL→lnKOF
lnEL → lnKOF	6.36***	5.41***	

*** and ** denote significant at 1% and 5% level respectively. Source: Authors estimation using Eviews

globalization to CO_2 emissions, from economic growth to electricity consumption, and from electricity consumption to globalization.

5. CONCLUSION AND POLICY IMPLICATIONS

This study aims to find out the role of electricity consumption, economic growth and globalization on CO_2 emissions by utilizing a multivariate structure and a panel data set of the top ten electricity consuming countries during the period 1990-2018. We apply the panel unit root analysis, the panel cointegration analysis, where FMOLS and DOLS are used to examine the long run effects, and the non-causality Granger causality test for heterogenous data, by Dumitrescu and Hurlin (2012).

The panel causality results reveal bidirectional causality relationships between economic growth and CO_2 emissions, electricity consumption and CO_2 emissions, and economic growth and globalization. Furthermore, unidirectional causalities with directions from globalization to CO_2 emissions, economic growth to electricity consumption, and electricity consumption to globalization are supported.

This study unearths the following findings. Firstly, the validity of the Environmental Kuznets Curve (EKC) is supported for the group of countries. The same result is also found for Japan, South Korea and Germany when individual estimates are applied. These countries need to develop proper economic policies in combination with an overall energy strategy. According to this curve, an increase in production and then in energy/electricity consumption will increase the use of natural resources or the use of carbon. While an economy develops, the environmental damage is increased. However, the environmental damage is decreased after a certain level of economic growth meaning that environmental damage is inevitable in the early stages of economic development. The reduction of environmental pollution is due to the change of demand and supply of resources in agriculture and service sector. Therefore, the governments of these countries should avoid a significant reduction of of energy/electricity consumption and withstand this damage until the curve is reversed.

On the other hand, a U-shaped relationship between CO_2 emissions and economic growth appears for the cases of China, USA and Russia. These countries should implement an energy conservation strategy in order to reduce environmental damage without negative impact on the process of economic development. Policymakers should shift the use of energy from carbon to alternative renewable energy sources even faster.

Thirdly, the results support that electricity consumption is positively and significantly linked to CO_2, for the sample countries.

Tax measures and regulatory policies should be applied in order to ensure the process of transformation to a low carbon economy. This is especially true for China, USA, India, Japan and Russia where clean energy technologies, combined with proper environmental laws and auditing legislation will help these countries to increase the share of alternative energy sources. More concentration should be given in the alternative energy sources in electricity consumption such as wind, solar, hydrothermal, ocean energy, geothermal and biomass (i.e "soft" energy forms). High energy efficiency not only will contributes on reducing CO_2 emissions, but also will bring economic benefits and maintain growth expectations of the economies (also Stamatiou and Dritsakis, 2019; Stamatiou, 2022).

Finally, globalization is shown to have a negative and significant effect on CO_2 emissions for the whole panel, as well as for China, USA and Russia. Globalization can be the trigger for eco-friendly technologies that can be transferred from countries with high environmental standards to others with loose environmental regulations. Multinational companies with clean state-of-the-art technologies can encourage their green technology know how to the local firms. Deglobalization may mean that these green technologies aren't being transferred to countries that are moving towards to green growth.

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