Environmental Kuznets Curve (EKC): Empirical Relationship Between Economic Growth, Energy Consumption, and CO_2 Emissions: Evidence from 3 Developed Countries

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Summary: In this study, the environmental Kuznets curve (EKC) hypothesis is examined for 3 developed countries, which are Denmark, the United Kingdom, and Spain, for the period between 1960 and 2014. The EKC hypothesis is examined under 2 nexuses which are GDP, CO_2 and energy consumption, and GDP, CO_2, energy consumption and the square of GDP. Causal and long-term relationships between GDP, CO_2, and energy consumption are examined for these 3 developed countries using the ARDL bounds test, the Toda and Yamamoto Granger non-causality test, the VAR Granger Causality/Block Exogeneity Wald test, and the Johansen cointegration test. Long-term relationships between GDP, CO_2, energy consumption, and the square of GDP are examined by the Johansen cointegration test. The EKC hypothesis is not confirmed for Denmark, the United Kingdom, and Spain, and the neutrality hypothesis is confirmed for these 3 developed countries. Unidirectional causality running from energy consumption to CO_2 is found for Denmark, and unidirectional causality running from CO_2 to energy consumption is found for the United Kingdom.

Keywords: Environmental Kuznets curve, ARDL bounds test, Toda and Yamamoto Granger non-causality test, Developed countries

JEL: Q4, Q5, O5

1. INTRODUCTION

Climate change is a topic discussed worldwide by scientists, politicians, and individuals. Carbon dioxide is also discussed besides climate change because it is one of the major causes of climate change and one of the main greenhouse gas emissions. To cope with climate change and reduce CO_2, many initiatives have taken place at the individual country and global levels. The Paris Agreement and the Kyoto Protocol can be mentioned as 2 global initiatives.

The Kyoto Protocol is an international agreement which was signed and ratified with different parties on December 11, 1997, and is one of the main efforts by humanity to cope with climate change and reduce CO_2 emissions.

The Kyoto Protocol is discussed besides the environmental Kuznets curve (EKC), which states that income increases with CO_2 to a certain level, and after that level is reached, CO_2 starts to decrease while income continues to increase. The impact of the Kyoto Protocol on EKC is one of the determinants for the countries that are involved in the protocol to determine the implications of their policy toward their coping strategies with climate change.

Many studies have examined the dynamic relationships between energy and income; income and emissions; and energy, income, and emissions by taking environmental Kuznets curve (EKC) as a base in the academic literature. To examine these dynamic relationships, the researchers implemented many kinds of econometrical methods, such as Multivariate Regressions, the Johansen cointegration test, the ADF unit root test, the VAR (Vector Autoregressive) model, impulse response analysis, variance decomposition analysis, Granger causality test, and panel data analysis in the methodology section of their articles. Researchers obtained different results for the validity of EKC relationships, depending on different samples, methodologies, and periods.

2. RELEVANT LITERATURE

The main purpose of this study is to reveal the stable long-term relationships and causal relationships between emissions, income, and energy consumption, test the EKC curve for developed countries, and expand literature for individual country studies of developed countries. There are limited individual country studies in the literature for the United Kingdom, Denmark, and Spain, so the main new contribution of this study is to use time series data to test EKC for the United Kingdom, Denmark, and Spain on the individual country level and to assess causal relationships between emissions, income, and energy consumption for these countries.

For individual country studies for Denmark, the United Kingdom, and Spain, Baek (2015) examined EKC with CO_2 emissions, income, and energy consumption nexus and found no EKC for Denmark. Acaravci and Ozturk (2010) examined the relationship between CO_2 emissions, income, and energy consumption and found EKC and short-run causality running from GDP and the square of GDP to CO_2 for Denmark. Baek, Cho, and Koo (2009) examined the relationship between SO_2 emissions, income, and trade and found EKC for Denmark.

Sephton and Mann (2016) examined EKC between CO_2 and SO_2 emissions, and GDP for the United Kingdom and confirmed an EKC relationship between CO_2 and GDP, and between SO_2 and GDP. Figueroa and Pasten (2009) examined EKC for the United Kingdom and found no EKC relationship between SO_2 and GDP. Fosten, Morley, and Taylor (2012) examined the relationship between CO_2 and SO_2 emissions, and energy prices and GDP for the United Kingdom with a long data set beginning from 1830 and confirmed EKC relationships between CO_2 and GDP, and between SO_2 and GDP. Bruyn, Bergh, and Opschoor (1998) examined the relationship between CO_2, NO_x, and SO_2 emissions, and energy prices and GDP for the United Kingdom. Bruyn, Bergh, and Opschoor (1998) did not confirm the EKC hypothesis for the United Kingdom. Ubaidillah (2011) examined the relationship between carbon monoxide (CO) emissions from road transport and GDP for the United Kingdom. Ubaidillah (2011) confirmed an EKC relationship between carbon monoxide (CO) emissions from road transport and GDP for the United Kingdom. Baek, Cho, and Koo (2009) examined the relationship between SO_2 emissions, income, and trade and confirmed EKC for the United Kingdom. Acaravci and Ozturk (2010) examined the relationship between CO_2 emissions, income, and energy consumption and found no EKC for the United Kingdom.

Baek, Cho, and Koo (2009) examined the relationship between SO_2 emissions, income, and trade and confirmed EKC for Spain. Figueroa and Pasten (2009) examined EKC for Spain and found no EKC relationship between SO_2 and GDP. Roca et al. (2001) examined the EKC relationships between carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur dioxide (SO_2), nitrogen oxides (NO_x) and non-methanic volatile organic compounds (NMVOC), and GDP for Spain. Roca et al. (2001) found no EKC for Spain. Balaguer and Cantavella (2016) examined the relationship between CO_2, GDP, and energy prices for Spain between 1874 and 2011. Balaguer and Cantavella (2016) confirmed the EKC hypothesis for Spain. Although Sephton and Mann (2013) and Esteve and Tamarit (2012) confirmed EKC between 1857 and 2007 for Spain, Esteve and Tamarit (2012a) did not confirm EKC for the same period for Spain.

Long-term relationships between variables are examined through the ARDL bounds test for cointegration by Pesaran, Shin, and Smith (2001), and the Johansen (1991) cointegration test and causal relationships are revealed through the Granger causality test and the Toda and Yamamoto (1995) Granger non-causality test. Also, impulse response and variance decomposition tests are implemented to determine the impact of independent variables on dependent variables for developed countries.

2.1 LITERATURE REVIEW ON EKC AND ENERGY-EMISSIONS-INCOME NEXUS

The environmental Kuznets curve (EKC) was started by Simon Kuznets's 1995 article "Economic Growth and Income Inequality" published in the American Economic Review. Kuznets (1955) aimed to answer his main questions in his article which were whether inequality in the distribution of income decreases or increases during a country's economic growth and which factors determine the secular (not cyclical or seasonal and exists over a long period) level and trends of income inequalities. He analyzed data for the United States, England, and Germany which were industrialized countries. He found an inverted U-shaped relationship between income inequality and economic growth. First, as economic growth increases, income inequality increases. After a certain point, as economic growth increases, income inequality declines.

In the 1990s, the U-shaped environmental Kuznets curve (EKC) was used to examine the relationship between economic growth and environmental degradation which started at low-income levels and, as income increased, environmental degradation increased, but, after a certain point, as income increased, environmental degradation decreased. Gene Grossman and Alan Krueger (1991), Nemat Shafik and Sushenjit Bandyopadhyay (1992), and Theodore Panayotou (1993) were among the first studies for the EKC hypothesis and the U-shaped relationship between economic growth and environmental degradation.

Grossman and Krueger (1991) examined NAFTA's impact on the environment. One of their findings was that, as GDP increased at the low-income level, levels of sulfur dioxide and smoke, which were 2 types of environmental degradation, increased as well. After a certain point, at high-income levels, as GDP increased, levels of sulfur dioxide and smoke declined.

Shafik and Bandyopadhyay (1992) examined the relationship between economic growth and environmental quality for countries at different income levels. They used environmental indicators, such as the lack of clean water and carbon emissions per capita, to examine the relationship between economic growth and environmental quality. For most environmental indicators, as income increased, environmental indicators worsened at low-income levels but improved at high-income levels. Except fecal coliforms in rivers, none of the environmental indicators worsened in high-income levels and fecal coliforms in rivers had an N-shaped relationship with income. Shafik and Bandyopadhyay (1992) concluded that there was an EKC relationship between income and most of the environmental indicators in the study. Some exceptions to this relationship were dissolved oxygen in rivers, municipal waste, and carbon emissions.

Panayotou (1993) tested and verified an EKC relationship between the types of environmental degradation, which are deforestation and air pollution, and level of economic development for a sample of developing and developed countries. He also provided policy implications for developing and developed countries for the areas of employment, technology transfer, and development assistance in his study.

For emissions, income, and energy variables, there are 4 research focuses in the literature (see Table 1).

2.1.1 INCOME—ENVIRONMENTAL DEGRADATION RELATIONSHIP

Literature for the relationship between income and environmental degradation is examined under 2 topics which are EKC relationships and income-emissions nexus. Within the topic of EKC relationships, studies that indicated the validity of EKC relationships are examined. Under income-emissions nexus, causality relationships and long-term and short-term relationships between emissions and income are examined.

Table 1. Research Focuses for Emissions, Income, and Energy Variables.

Research Focus	Studies in Research Focus
Income-emissions nexus	There are studies that test EKC relationships alone, and there are other studies that investigate for causality, long-term, and short-term relationships between income and emissions including explanatory variables.
Income-energy nexus	Studies in this context investigate to verify the neutrality, conservation, growth, and feedback hypotheses. The neutrality hypothesis states that there is no causality between energy consumption and income. The conservation hypothesis states that there is unidirectional causality running from income to energy consumption. The growth hypothesis states that there is unidirectional causality running from energy consumption to income. The feedback hypothesis states that there is bidirectional causality between income and energy consumption.
Emissions-energy nexus	Studies in this context investigate causal, long-term and short-term relationships between emissions, and energy.
Emissions-energy-income nexus	Studies in this context examine causal, long-term, and short-term relationships between emissions, energy, and income.

Source: Authors' Work.

The environmental Kuznets curve (EKC) general model is in the literature as below:

$$\ln\left(\frac{E}{P}\right)_t = \alpha_0 + \alpha_1 \ln\left(\frac{Y}{P}\right)_t + \alpha_2 \ln\left(\frac{Y}{P}\right)_t^2 + \alpha_3 \ln\left(\frac{Y}{P}\right)_t^3 + \alpha_4 x_t + e_t \quad (1)$$

α_0, α_1, α_2, α_3, α_4 are estimated parameters. t is time index. e is error term. x is an explanatory variable which can be energy consumption, trade openness, population, etc. E is the environmental degradation type. Y is the economic activity type. P is population.

Different levels of relationships between environmental degradation and economic activity are as below (Tao Song, Tingguo Zheng, and Lianjun Tong 2008).

(1) $\alpha_1>0$, $\alpha_2<0$ and $\alpha_3>0$ conclude in an N-shaped relationship between environmental degradation type (E) and economic activity (Y).
(2) $\alpha_1<0$, $\alpha_2>0$ and $\alpha_3<0$ conclude in an inverse N-shaped relationship between environmental degradation type (E) and economic activity (Y).
(3) $\alpha_1<0$, $\alpha_2>0$ and $\alpha_3=0$ conclude in a U-shaped relationship between environmental degradation type (E) and economic activity (Y).
(4) $\alpha_1>0$, $\alpha_2<0$ and $\alpha_3=0$ conclude in EKC relationship between environmental degradation type (E) and economic activity (Y).
(5) $\alpha_1=\alpha_2=\alpha_3=0$ conclude in no relationship between environmental degradation type (E) and economic activity (Y).

2.1.1.1 EKC RELATIONSHIP

Environmental Kuznets curve (EKC) relationships are examined in the literature in many ways, such as only emissions-income relationship and adding other explanatory variables, such as energy consumption as well. EKC relationships are studied in the literature with different types of studies, such as panel studies, single-country, and multi-country studies. EKC studies in the literature are examined under 2 topics as EKC relationship-verified studies and EKC relationship not-verified studies.

2.1.1.1.1 EKC RELATIONSHIP VERIFIED

EKC relationships in the literature are examined with CO_2 and GDP variables. In some studies, explanatory variables are added to test an EKC relationship with variables, such as energy consumption, renewable and non-renewable energy, primary consumption, oil consumption, economic complexity index, foreign direct investment, industrial value added, financial development, trade openness, population, manufacturing export, manufacturing import, investment, oil price, urbanization, and energy intensity.

For multi-country studies, Mariola Piłatowska, Aneta Włodarczyk, and Marcin Zawada (2015) examined EKC relationships for 14 EU countries, depending on the level of knowledge. Countries were grouped into knowledge level groups according to their positions in Knowledge Economy Index 2008 ranking. They tested for and verified EKC relationships for all high-level knowledge countries, such as Denmark, Finland, Netherlands, Sweden, the United Kingdom, and for some middle-level knowledge countries, such as Belgium and France.

For panel studies, Antonio Musolesi, Massimiliano Mazzanti, and Roberto Zoboli (2010) examined EKC relationships for 109 countries which consisted of G7, OECD, EU15, non-OECD, and poorest countries. They verified EKC relationships for OECD, G7, and EU15 countries which were quadratic relationship between CO_2 and GDP. Monotonic relationships were found between CO_2 and GDP for less developed countries.

2.1.1.1.2 EKC RELATIONSHIP NOT VERIFIED

For multi-country studies, Hiroki Iwata, Keisuke Okada, and Sovannroeun Samreth (2012) indicated that their study did not support EKC relationships for 11 OECD countries which were Belgium, Canada, Finland, Germany, Japan, South Korea, Spain, Sweden, Switzerland, the United Kingdom and the United States.

For panel studies, Inmaculada Martinez-Zarzoso and Aurelia Bengochea-Morancho (2003) examined 19 Latin American and Caribbean countries and found that EKC was not confirmed for panel countries. They also found heterogeneity for EKC relationships among 19 countries and only a few countries showed EKC relationships. Among 19 countries, 9 countries showed an N-shaped curve, 2 countries showed a curve with a decreasing trend, 2 countries showed a U-shaped curve and 6 countries showed an upward sloping curve.

2.1.1.2 EMISSIONS-INCOME-ENERGY NEXUS

2.1.1.2.1 CO2-GDP-EN NEXUS

One of the research focuses in the literature for emissions, income, and energy variables is the emissions-income-energy nexus. Four hypotheses, which are the neutrality, conservation, growth, and feedback hypotheses, were tested for GDP-EN (energy consumption) relationships. EKC relationships are also tested under this research focus. CO_2-GDP-EN nexus also takes into consideration additional explanatory variables to investigate the relationships between CO_2, GDP, and EN. Relationships between CO_2, GDP, and EN are investigated by panel studies, multi-country studies, and single-country studies in the literature.

For multi-country studies, Loesse Jacques Esso and Yaya Keho (2016) studied long-term, short-term, and causal relationships between CO_2, GDP, and EN for 12 selected sub-Saharan countries for between 1971 and 2010 with the Granger causality test and the cointegration bounds testing approach methodologies. They found unidirectional causality running from GDP to CO_2 for Benin, the Democratic Republic of the Congo, Ghana, Nigeria and Senegal, unidirectional causality running from CO_2 to GDP for Gabon, Nigeria, and Togo, and bidirectional causality between GDP and CO_2 for Nigeria in the short run. They also found bidirectional causality between GDP and CO_2 for Congo and Gabon, unidirectional causality running from EN to CO_2 for Benin, Congo, Cote d'Ivoire, Gabon, Ghana, Nigeria, Senegal, South Africa, and Togo and unidirectional causality running from GDP to CO_2 for Benin, Congo, Cote d'Ivoire, Gabon, Ghana, Nigeria, Senegal, South Africa, and Togo in the long run.

For panel studies, Samia Gmidene, Saida Zaidi, and Sonia Zouari Ghorbel (2016) examined the causal relationships between renewable energy, nuclear energy consumption, economic growth, and CO_2 emission with panel cointegration techniques and the Granger causality test methodologies. They concluded that authorities should invest in renewable energy to reduce CO_2 emissions and decrease nuclear energy to reduce CO_2 emissions.

Farhani and Rejeb (2012), Asongu, Montasser, and Toumi (2015) and Wang et al. (2011) verified the conservation hypothesis in the long run for 15 Mena countries, 24 African countries, and China.

For single-country studies, Bikash Chandra Ghosh, Khandakar Jahangir Alam, and Ataul Gani Osmani (2014) studied the relationships between CO_2, GDP, and EN in Bangladesh for the period between 1972 and 2011 with the Johansen and Juselius cointegration test and vector autoregressive (VAR) error correction model methodologies. They found that EN had a significant positive impact on GDP, and CO_2 had an insignificant negative impact on GDP in the long run.

Aviral Kumar Tiwari (2011) confirmed the neutrality hypothesis in India in the long run and short run, and Masoud Mohammed Albiman, Najat Nassor Suleiman, and Hamad Omar Baka (2015) confirmed the neutrality hypothesis in Tazmania.

3. ECONOMETRIC APPROACH

3.1 DATA

The data were derived from the World Bank's official web site for CO_2 emissions (metric tons per capita), energy consumption (kg of oil equivalent per capita), and GDP per capita (constant 2010 US$). The structure of data is annually which exceeds 30 to make it a parametrical test. Data periods are determined according to the availability of data sets for developed countries. The data used in the study are from 1960 to 2014 for developed countries, which are Denmark, Spain, and the United Kingdom.

3.2 METHODOLOGY

The augmented Dickey-Fuller (1981) unit root test is applied to find stationary levels of each variable (see Table 2). According to the combination of stationary levels of each variable, a different method is used to find cointegration. For variables which have stationary levels with combination of I(1) and I(0), the ARDL bounds test for cointegration by Pesaran, Shin, and Smith (2001) is used to find cointegration between the variables. Normality tests, namely, the Breusch-Godfrey Serial Correlation LM test and Breusch-Pagan-Godfrey heteroscedasticity test, are applied to determine the stability of ARDL model. The Johansen (1991) cointegration test is used for variables which are integrated at I(1) to find cointegration.

The VAR Model is applied for variables which are integrated at I(1) with no cointegration. The Breusch-Godfrey Serial Correlation LM test, the Breusch-Pagan-Godfrey heteroscedasticity test, and the VAR stability test are applied to determine the stability of the VAR model.

Impulse response analysis and variance decomposition analysis are applied to find how each variable impacts and influences the other variables.

The VAR Granger causality method is used to find causal relationships between variables that are integrated at I(1) with no cointegration.

The Toda and Yamamoto (1995) Granger non-causality test is applied to find causal relationships between variables which have stationary levels with a combination of I(0) and I(1). First, the maximum number of stationary levels of variables is determined by ADF unit root tests. Then, a lag order is selected by determining the stability of the VAR model by AR Root Graph and the VAR Residual Serial Correlation LM test, and then the VAR model is developed with the selected lag order. Lag order (Determined lag order + maximum number of stationary levels of variables) of variables are added to exogenous variables, and the VAR model is developed by the determined lag order.

Two models are used in the study which consist of CO_2, GDP, and energy consumption variables, and CO_2, GDP, the square of GDP and energy consumption variables to determine the cointegration and causal relationships between variables.

$$\ln(\mathrm{CO_2})_t = \alpha_0 + \alpha_1 \ln(GDP)_t + \alpha_2 \ln(EN)_t + e_t \quad (2)$$

$\alpha_0, \alpha_1, \alpha_2,$ are estimated parameters. t is time index. e is error term.

$$\ln(\mathrm{CO_2})_t = \alpha_0 + \alpha_1 \ln(GDP)_t + \alpha_2 \ln(GDP)_t^{\,2} + \alpha_3 \ln(EN)_t + e_t \; (3)$$

α_0, α_1, α_2 and α_3, are estimated parameters. t is time index. e is error term.

Table 2. ADF Unit Root Tests for Denmark, Spain, and United Kingdom.

Variable	At Level	At first difference
	Intercept	**Intercept**
$LNCO_2$ Denmark	-1.528636(0)	-7.955326(0)*
LNEN Denmark	-4.039929(0)*	—
LNGDP Denmark	-3.623015(0)*	—
LNGDP2 Denmark	-3.391508(0)**	—
$LNCO_2$ Spain	-3.228253(1)**	—
LNEN Spain	-5.484892(0)*	—
LNGDP Spain	-2.245149(1)	-3.518072(0)**
LNGDP2 Spain	-2.138252(1)	-3.462570(0)**
$LNCO_2$ UK	1.783106(1)	-8.822031(0)*
LNEN UK	-0.581018(0)	-6.910146(0)*
LNGDP UK	-1.438637(1)	-4.901942(0)*
LNGDP2 UK	-1.299673(1)	-4.886959(0)*

Notes: * and ** show the statistical significance at 1% and 5% levels, respectively. The lag length is shown by the values in parentheses.

Source: Authors' Calculations.

4. EMPIRICAL FINDINGS

4.1 DENMARK

4.1.1 CO_2, GDP, and EN NEXUS

According to the ARDL bounds test results, no cointegration is found between CO_2, GDP and energy consumption because the ARDL bounds test is not significant at a level of 5% (see Table 3). With regard to the Normality test, the Breusch-Godfrey Serial Correlation LM test and the Breusch-Pagan-Godfrey test results, the model is stable (see Table 4, Table 5, and Table 6). There is no long-term relationship between CO_2, GDP, and energy consumption.

The Toda and Yamamoto Granger non-causality test is applied for testing causal relationships between CO_2, GDP, and energy consumption. The VAR model is stable, and there is no correlation between variables (see Figure 1 and Table 7). According to the VAR Granger Causality/Block Exogeneity Wald tests results, unidirectional causality running from LNEN to $LNCO_2$ is found but no causality from LNGDP to $LNCO_2$ is found. Also, there is no causality from $LNCO_2$ and LNGDP to LNEN and no causality from $LNCO_2$ and LNEN to LNGDP (see Table 8).

Table 3. ARDL Bounds Test Results of CO_2-GDP-EN for Denmark.

Test Statistic	Value	K
F-Statistic	1.304455	2
Critical Value Bonds		
Significance	I0 Bound	I1 Bound
10%	3.17	4.14
5%	3.79	4.85
2.5%	4.41	5.52
1%	5.15	6.36

Source: Authors' Calculations.

Table 4. Breusch-Godfrey Serial Correlation LM Test Results of CO_2-GDP-EN for Denmark.

Breusch-Godfrey Serial Correlation LM Test			
F-Statistic	0.769838	Prob. F (1,47)	0.3847
Obs*R-squared	0.870241	Prob. χ^2 (1)	0.3509

Source: Authors' Calculations.

Table 5. Normality Test Results of CO_2-GDP-EN for Denmark.

Normality Test	
Jarque-Bera	0.078324
Probability	0.961595

Source: Authors' Calculations.

Table 6. Heteroscedasticity Test Breusch-Pagan-Godfrey Test Results of CO_2-GDP-EN for Denmark.

Heteroscedasticity Test Breusch-Pagan-Godfrey Test			
F-Statistic	2.194069	Prob. F (5,48)	0.0703
Obs*R-squared	10.04570	Prob. χ^2 (5)	0.0740
Scaled explained SS	7.904724	Prob. χ^2 (5)	0.1616

Source: Authors' Calculations.

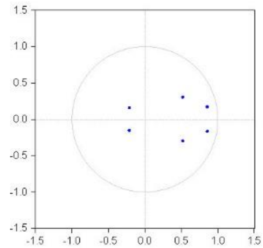

Figure 1. VAR Model Stability Results of CO_2-GDP-EN for Denmark (Inverse Roots of AR Characteristic Polynomial).

Source: Authors' Calculations.

4.1.2 CO_2, GDP, the square of GDP and EN NEXUS

According to the ARDL bounds test results, no cointegration is found between CO_2, GDP, and energy consumption because the ARDL bounds test is not significant at a level of 5% (see Table 9). With regard to the Normality test, the Breusch-Godfrey Serial Correlation LM test, and the Breusch-Pagan-Godfrey test results, the model is stable (see Table 10, Table 11 and Table 12). Because no long-term relationship is found between CO_2, GDP, and the square of GDP and EN, the EKC hypothesis is not confirmed for Denmark.

Table 7. VAR Residual Serial Correlation LM Test Results of CO_2-GDP-EN for Denmark.

Lags	LM-Stat	Prob
1	11.89218	0.2195
2	12.74793	0.1743
3	4.395423	0.8835
4	8.633489	0.4718
5	21.30411	0.0114
6	2.619471	0.9775
7	8.853170	0.4509
8	2.903776	0.9680
9	11.24540	0.2593
10	8.771006	0.4587

Source: Authors' Calculations.

Table 8. VAR Granger Causality/Block Exogeneity Wald Tests Results of CO_2-GDP-EN for Denmark.

Dependent Variable: DLNCO$_2$			
Excluded	χ^2	**df**	**Prob.**
LNEN	7.274759	2	0.0263
LNGDP	1.313481	2	0.5185
All	7.818147	4	0.0985
Dependent Variable: DLNEN			
Excluded	χ^2	**df**	**Prob.**
LNCO$_2$	5.042617	2	0.0804
LNGDP	0.335164	2	0.8457
All	5.770306	4	0.2170
Dependent Variable: DLNGDP			
Excluded	χ^2	**df**	**Prob.**
LNCO$_2$	0.390398	2	0.8227
LNEN	0.747425	2	0.6882
All	1.597744	4	0.8092

Source: Authors' Calculations.

Table 9. ARDL Bounds Test Results of CO_2-GDP-EN-SQUARE of GDP for Denmark.

Test Statistic	**Value**	**K**
F-Statistic	1.668074	3
Critical Value Bonds		
Significance	I0 Bound	I1 Bound
10%	2.72	3.77
5%	3.23	4.35
2.5%	3.69	4.89
1%	4.29	5.61

Source: Authors' Calculations.

Table 10. Breusch-Godfrey Serial Correlation LM Test Results of CO_2-GDP-EN-SQUARE of GDP for Denmark.

Breusch-Godfrey Serial Correlation LM Test			
F-Statistic	3.249617	Prob. F (1,45)	0.0781
Obs*R-squared	3.636906	χ^2 (1)	0.0565

Source: Authors' Calculations.

Table 11. Heteroscedasticity Test Breusch-Pagan-Godfrey Test Results of CO_2-GDP-EN-SQUARE of GDP for Denmark.

Heteroscedasticity Test Breusch-Pagan-Godfrey Test			
F-Statistic	1.541021	Prob. F (7,46)	0.1775
Obs*R-squared	10.25771	Prob. χ^2 (7)	0.1744
Scaled explained SS	7.946134	Prob. χ^2 (7)	0.3374

Source: Authors' Calculations.

Table 12. Normality Test Results of CO_2-GDP-EN-SQUARE of GDP for Denmark.

Normality Test	
Jarque-Bera	0.060910
Probability	0.970004

Source: Authors' Calculations.

4.2 SPAIN

4.2.1 CO_2, GDP and EN NEXUS

According to ARDL bounds test results, no cointegration is found between CO_2, GDP and energy consumption because ARDL bounds test is not significant at a level of 5% (see Table 13). With regard to the Normality test, the Breusch-Godfrey Serial Correlation LM test, and the Breusch-Pagan-Godfrey test results, the model is stable (see Table 14, Table 15, and Table 16). There is no long-term relationship between CO_2, GDP, and energy consumption.

The Toda and Yamamoto Granger non-causality test is applied for testing causal relationships between CO_2, GDP, and energy consumption. The VAR model is stable, and there is no correlation between the variables (see Table 17 and Figure 2). According to the VAR Granger Causality/Block Exogeneity Wald tests results, there is no causality from LNEN and LNGDP to $LNCO_2$, no causality from $LNCO_2$ and LNGDP to LNEN, and no causality from $LNCO_2$ and LNEN to LNGDP (see Table 18).

Table 13. ARDL Bounds Test Results of CO_2-GDP-EN for Spain.

Test Statistic	**Value**	**K**
F-Statistic	0.485180	2
Critical Value Bonds		
Significance	I0 Bound	I1 Bound
10%	3.17	4.14
5%	3.79	4.85
2.5%	4.41	5.52
1%	5.15	6.36

Source: Authors' Calculations.

Table 14. Breusch-Godfrey Serial Correlation LM Test Results of CO_2-GDP-EN for Spain.

Breusch-Godfrey Serial Correlation LM Test			
F-Statistic	1.911894	Prob. F (2,42)	0.1604
Obs*R-squared	4.422610	Prob. χ^2 (2)	0.1096

Source: Authors' Calculations.

Table 15. Heteroscedasticity Test Breusch-Pagan-Godfrey Test Results of CO_2-GDP-EN for Spain.

Heteroscedasticity Test Breusch-Pagan-Godfrey Test			
F-Statistic	1.671547	Prob. *F* (8,44)	0.1326
Obs*R-squared	12.35326	Prob. χ^2 (8)	0.1361
Scaled explained SS	7.546375	Prob. χ^2 (8)	0.4790

Source: Authors' Calculations.

Table 16. Normality Test Results of CO_2-GDP-EN for Spain.

Normality Test	
Jarque-Bera	0.365967
Probability	0.832782

Source: Authors' Calculations.

Table 17. VAR Residual Serial Correlation LM Test Results of CO_2-GDP-EN for Spain.

Lags	LM-Stat	Prob
1	9.864643	0.3616
2	7.682875	0.5664
3	4.390684	0.8839
4	15.14525	0.0870
5	10.26001	0.3298
6	5.630561	0.7762

Source: Authors' Calculations.

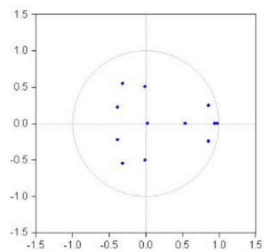

Figure 2. VAR Model Stability Results of CO_2-GDP-EN for Spain (Inverse Roots of AR Characteristic Polynomial).

Source: Authors' Calculations.

4.2.2 CO_2, GDP, the square of GDP and EN NEXUS

According to ARDL bounds test results, no cointegration is found between CO_2, GDP, and energy consumption because ARDL bounds test is not significant at 5% level (see Table 19). With regard to the Normality test, the Breusch-Godfrey Serial Correlation LM test, and the Breusch-Pagan-Godfrey test results, the model is stable (see Table 20, Table 21, and Table 22). Because no long-term relationship is found between CO_2, GDP, square of GDP and EN, the EKC hypothesis is not confirmed for Spain.

4.3 UK

4.3.1 CO_2, GDP, and EN NEXUS

According to the Johansen cointegration test results, no cointegration is found between CO_2, GDP, and energy consumption (see Table 23). There is no long-term relationship between CO_2, GDP, and energy consumption. The VAR model is established, and the VAR Granger Causality/Block Exogeneity Wald tests are applied for causality between CO_2, GDP, and energy consumption. The VAR Residual Serial Correlation LM test and the VAR Residual Heteroscedasticity test results show the model is stable (see Table 24 and Table 25). The VAR satisfies the stability condition (see Figure 3).

According to the VAR Granger Causality/Block Exogeneity Wald tests results, there is no causality from LNEN and LNGDP to $LNCO_2$ and no causality from $LNCO_2$ and LNEN to LNGDP. Unidirectional causality running from $LNCO_2$ to LNEN is found, and no causality is found from LNGDP to LNEN (see Table 26).

Table 18. VAR Granger Causality/Block Exogeneity Wald Tests Results of CO_2-GDP-EN for Spain.

Dependent Variable: $DLNCO_2$			
Excluded	χ^2	***df***	**Prob.**
LNEN	5.324313	4	0.2556
LNGDP	3.091847	4	0.5426
All	9.260283	8	0.3208
Dependent Variable: DLNEN			
Excluded	χ^2	***df***	**Prob.**
$LNCO_2$	3.202790	4	0.5245
LNGDP	6.303044	4	0.1776
All	9.477555	8	0.3036
Dependent Variable: DLNGDP			
Excluded	χ^2	***df***	**Prob.**
$LNCO_2$	2.086595	4	0.7198
LNEN	0.398428	4	0.9826
All	2.942306	8	0.9379

Source: Authors' Calculations.

Table 19. ARDL Bounds Test Results of CO_2-GDP-EN-SQUARE of GDP for Spain.

Test Statistic	**Value**	**K**
F-Statistic	1.332407	3
Critical Value Bonds		
Significance	I0 Bound	I1 Bound
10%	2.72	3.77
5%	3.23	4.35
2.5%	3.69	4.89
1%	4.29	5.61

Source: Authors' Calculations.

Table 20. Breusch-Godfrey Serial Correlation LM Test Results of CO_2-GDP-EN-SQUARE of GDP for Spain.

Breusch-Godfrey Serial Correlation LM Test			
F-Statistic	2.312284	Prob. F (2,39)	0.1125
Obs*R-squared	5.618442	Prob. χ^2 (2)	0.0603

Source: Authors' Calculations.

Table 21. Heteroscedasticity Test Breusch-Pagan-Godfrey Test Results of CO_2-GDP-EN-SQUARE of GDP for Spain.

Heteroscedasticity Test Breusch-Pagan-Godfrey Test			
F-Statistic	1.547478	Prob. F (11,41)	0.1519
Obs*R-squared	15.54886	Prob. χ^2 (11)	0.1587
Scaled explained SS	11.92609	Prob. χ^2 (11)	0.3692

Source: Authors' Calculations.

Table 22. Normality Test Results of CO_2-GDP-EN-SQUARE of GDP for Spain.

Normality Test	
Jarque-Bera	2.791425
Probability	0.247657

Source: Authors' Calculations.

Table 23. Results for Johansen Cointegration Test of CO_2-GDP-EN for UK.

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	**Eigenvalue**	**Trace Statistic**	**0.05 Critical Value**	**Prob.**
None	0.242264	24.61090	29.79707	0.1758
At most 1	0.176619	10.18502	15.49471	0.2668
At most 2	0.001528	0.079516	3.841466	0.7779
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	**Eigenvalue**	**Trace Statistic**	**0.05 Critical Value**	**Prob.**
None	0.242264	14.42588	21.13162	0.3311
At most 1	0.176619	10.10550	14.26460	0.2051
At most 2	0.001528	0.079516	3.841466	0.7779

Source: Authors' Calculations.

Table 24. VAR Residual Serial Correlation LM Test Results of CO_2-GDP-EN for UK.

Lags	LM-Stat	Prob
1	8.195595	0.5146
2	7.834138	0.5509

Source: Authors' Calculations.

Table 25. VAR Residual Heteroscedasticity Tests: No Cross Terms (only levels and squares) of CO_2-GDP-EN for UK.

Joint test		
χ^2	*df*	Prob.
83.06690	72	0.1752

Source: Authors' Calculations.

Impulse response analysis is applied to find how each variable impacts and influences the other variables. Energy consumption has a positive impact on CO_2 in the short run but has no impact on CO_2 in the long run. GDP affects CO_2 in the first 2 periods positively, then affects it negatively in the short run after 2 periods (see Figure 4).

CO_2 affects energy consumption negatively and positively in the short run. GDP has a positive impact for the first 2 periods on energy consumption, then GDP has a negative impact on energy consumption after 2 periods in the short run.

CO_2 has a positive impact on GDP in the short run. Energy consumption has a positive impact on GDP in the short run but has no impact on GDP in the long run.

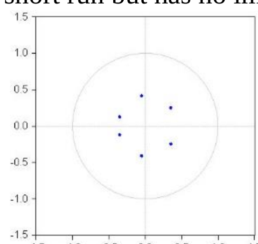

Figure 3. VAR Model Stability Results of CO_2-GDP-EN for UK (Inverse Roots of AR Characteristic Polynomial).

Source: Authors' Calculations.

Table 26. VAR Granger Causality/Block Exogeneity Wald Tests Results of CO_2-GDP-EN for UK.

Dependent Variable: DLNCO$_2$			
Excluded	χ^2	***df***	**Prob.**
LNEN	3.612151	2	0.1643
LNGDP	3.543347	2	0.1700
All	8.336562	4	0.0800
Dependent Variable: DLNEN			
Excluded	χ^2	***df***	**Prob.**
LNCO$_2$	7.274076	2	0.0263
LNGDP	2.839604	2	0.2418
All	8.549627	4	0.0734
Dependent Variable: DLNGDP			
Excluded	χ^2	***df***	**Prob.**
LNCO$_2$	1.029527	2	0.5976
LNEN	2.962186	2	0.2274
All	5.590511	4	0.2319

Source: Authors' Calculations.

Variance decomposition analysis is applied to find how each variable impacts and influences the other variables. Energy consumption can cause a 5.79% fluctuation in CO_2 in the short run and a 5.89% fluctuation in CO_2 in the long run. GDP can cause a 5.58% fluctuation in CO_2 in the short run and a 5.60% fluctuation in CO_2 in the long run (see Table 27).

CO_2 can cause a 67.98% fluctuation in energy consumption in the short run and a 67.93% fluctuation in energy consumption in the long run. GDP can cause a 5.49% fluctuation in energy consumption in the short run and a 5.51% fluctuation in energy consumption in the long run.

CO_2 can cause a 34.38% fluctuation in GDP in the short run and a 34.42% fluctuation in GDP in the long run. Energy consumption can cause an 8.92% fluctuation in GDP in the short run and an 8.98% fluctuation in GDP in the long run.

Table 27. Variance Decomposition of DLNCO$_2$, DLNEN, and DLNGDP of CO$_2$-GDP-EN for the United Kingdom.

Period	S.E.	DLNCO$_2$	DLNEN	DLNGDP
1	0.035394	100.0000	0.000000	0.000000
2	0.039386	89.44278	5.006558	5.550665
3	0.040539	89.30019	5.458222	5.241586
4	0.040717	88.62319	5.795683	5.581132
5	0.040764	88.49796	5.894562	5.607481
6	0.040766	88.49699	5.895695	5.607315
7	0.040766	88.49642	5.896194	5.607387
8	0.040766	88.49605	5.896551	5.607399
9	0.040766	88.49599	5.896586	5.607422
10	0.040766	88.49596	5.896603	5.607435

Period	S.E.	DLNCO$_2$	DLNEN	DLNGDP
1	0.030831	76.83525	23.16475	0.000000
2	0.033473	69.54053	25.46236	4.997113
3	0.034445	68.61800	26.40252	4.979484
4	0.034644	67.98145	26.52429	5.494257
5	0.034697	67.94281	26.54348	5.513718
6	0.034699	67.93857	26.54770	5.513722
7	0.034699	67.93746	26.54884	5.513693
8	0.034700	67.93707	26.54927	5.513665
9	0.034700	67.93698	26.54930	5.513722
10	0.034700	67.93696	26.54930	5.513737

Period	S.E.	DLNCO$_2$	DLNEN	DLNGDP
1	0.019673	34.55082	0.264244	65.18493
2	0.021508	34.77755	4.204115	61.01833
3	0.022480	34.56793	7.831672	57.60040
4	0.022775	34.38095	8.927386	56.69166
5	0.022797	34.42724	8.981596	56.59117
6	0.022797	34.42685	8.984216	56.58894
7	0.022798	34.42647	8.984828	56.58870
8	0.022798	34.42642	8.985397	56.58819
9	0.022798	34.42629	8.985583	56.58812
10	0.022798	34.42631	8.985605	56.58809

Source: Authors' Calculations.

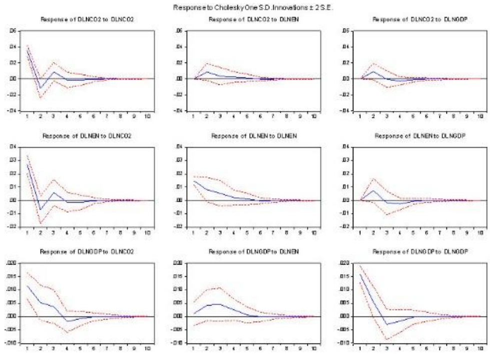

Figure 4. Impulse Response Analysis of CO_2-GDP-EN for the United Kingdom.

Source: Authors' Calculations.

4.3.2 CO_2, GDP, the Square of GDP and EN NEXUS

Table 28. Results for Johansen Cointegration Test of CO_2-GDP-EN-SQUARE of GDP for the United Kingdom.

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	**Eigenvalue**	**Trace Statistic**	**0.05 Critical Value**	**Prob.**
None	0.316013	38.41621	47.85613	0.2842
At most 1	0.253175	18.28592	29.79707	0.5450
At most 2	0.045618	2.813931	15.49471	0.9747
At most 3	0.006381	0.339292	3.841466	0.5602
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	**Eigenvalue**	**Trace Statistic**	**0.05 Critical Value**	**Prob.**
None	0.316013	20.13028	27.58434	0.3322
At most 1	0.253175	15.47199	21.13162	0.2572
At most 2	0.045618	2.474639	14.26460	0.9754
At most 3	0.006381	0.339292	3.841466	0.5602

Source: Authors' Calculations.

According to the Johansen cointegration test results, no cointegration is found between CO_2, GDP, the square of GDP and energy consumption (see Table 28). Because no long-term relationship is found between CO_2, GDP, and the square of GDP and EN, the EKC hypothesis is not confirmed for the UK.

5. CONCLUSION

The EKC hypothesis states that economic growth will lead to reduction in emissions. Results of this study did not verify this statement. Our results are in line for EKC with Bruyn, Bergh, and Opschoor (1998) and Acaravci and Ozturk (2010) for the United Kingdom and Roca et al. (2001) and Esteve and Tamarit (2012a) for Spain.

One of the significant findings of our study is that the EKC hypothesis is rejected, and no causal relationships are found between CO_2 and GDP. Another significant finding of our study is that the neutrality hypothesis is confirmed for 3 developed countries which state there is no causal relationship between energy consumption and income. The other significant finding of our study is that unidirectional causality running from energy consumption to CO_2 is found for Denmark, and unidirectional causality running from CO_2 to energy consumption is found for the UK for emissions-energy nexus.

No causal relationship between GDP and CO_2, which is found for all countries, means that a country's economic growth will not have an effect on emissions. Denmark, Spain, and the United Kingdom are likely to achieve further economic growth without causing environmental degradation because no causal relationship is found between CO_2 and GDP.

No causal relationship between GDP and EN, which is found for all countries, means that a country's economic growth will not have an effect on energy consumption. The economic growth of these countries is not dependent on oil consumption. Also, oil consumption is not a source for economic growth in these countries.

For the United Kingdom, CO_2 causes energy consumption, but in Denmark and Spain, CO_2 does not cause energy consumption. Increasing efficiency of energy technologies and increasing alternatives for replacing oil should be part of the policies that target oil consumption in the United Kingdom. The industry sector constitutes 23% of overall oil consumption in the United Kingdom which has decreased from 82% (1970). Energy efficiency improvements in the industry sector will help to decrease CO_2 emissions. Solar energy can replace further oil consumption in the industry sector. Toyota uses solar energy to power its plant in Deeside, and this example can be used by other firms in the industry sector to replace oil with solar energy and decrease emissions. Increasing natural gas and electricity use can be an alternative for oil too. Thirty-six percent and 33% of overall energy used in industry is from natural gas and electricity, respectively. The household and transport sectors account for 40% and 28% of total final energy consumption in the United Kingdom. Improving home insulation should be continued to maintain energy efficiency in the household sector. Increasing the share of green energy, such as wind in the electricity generation mix, will help decrease emissions for the household sector. The United Kingdom maintained a successful energy efficiency policy for the road, and air transportion which consume 96% of energy in the transport sector. Currently, there are 52,000 electric vehicles in the United Kingdom. Incentives to increase the number of electric vehicles should be continued in the transport sector. Increasing the share of green energy, such as wind in the electricity generation mix, will also help decrease further emissions in the transport sector. Energy efficiency policy should be continued for air transport as well.

For Denmark, energy consumption causes emissions but, in the United Kingdom and Spain, energy consumption does not cause emissions. Oil is the first in Denmark's total primary energy supply and final energy consumption. Oil is mostly used in the transport sector at 65% of all oil consumption. The transport sector is the second highest energy-consuming sector (30%) in Denmark after the residential sector (32%). Denmark should increase its energy efficiency in the transport sector. Electricity is the second in final energy consumption in Denmark, and electricity has almost no share in the transport sector (1.3%). Denmark should increase the percentage of electricity consumption in the transport sector by involving more electric vehicles and providing higher-energy efficiency policy incentives for all types of transport, such as road and air transport. Natural gas has almost no share in the transport sector (0.1%), and increasing the use of natural gas in the transport sector should be included in the climate change policy of Denmark. Investment in battery technology will help to increase the share of electricity usage in the transport sector and increasing the share of green energy, such as wind energy in the electricity generation mix will help to decrease CO_2 emissions in the transport sector.

For Spain, the fuel tax should be increased, especially for diesel fuel consumption. An increase in the fuel tax will encourage more efficient usage of oil in the transport sector. Spain's oil consumption in 2017 is 21% lower than its oil consumption in 2007, and Spain's oil consumption in 2014 is 18.5% lower than its oil consumption in 2000. Oil consumption had decreased by 19.4% in the transport sector, 44.4% in the industry sector, and 25.1% in the household sector between 2007 and 2013. Spain started an efficient vehicle incentive program to provide funding to car owners to replace over 700,000 old cars and vans with new ones until 2020 to reduce each replaced vehicle's emission levels by 30% on average. Although economic recession has helped reduce oil usage, for the overall case beginning from 2000, reductions in oil consumption are mainly due to increases in energy efficiency in the industry sector, home renovations in the household sector for energy efficiency and the aforementioned efficient vehicle incentive program and efficient driving programs for new drivers. These policies should be enhanced and include the increase in fuel tax policy.

Economic growth is not likely to help Spain, Denmark, and the United Kingdom to fight climate change by itself. Increases in the use of renewable energy and improving energy efficiency in the transport, industry, and household sectors will help Spain, Denmark and the United Kingdom to fight climate change and meet emission targets. Authorities in Spain, Denmark, and the United Kingdom should continue to invest in energy conservation and emission reduction policies because these policies are likely to not have a detrimental effect on economic growth. These countries are likely to achieve further economic growth without causing environmental degradation because no causal relationship is found between CO_2 and GDP.

The limitations of our study are that results are obtained for 3 developed countries and the period between 1960 and 2014 are examined for these countries.

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