Environmental Kuznets Curve (EKC): Empirical Relationship Between Economic Growth, Energy Consumption, and CO₂ 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, CO₂ and energy consumption, and GDP, CO₂, energy consumption and the square of GDP. Causal and long-term relationships between GDP, CO₂, 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, CO₂, 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 CO₂ is found for Denmark, and unidirectional causality running from CO₂ 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$_2$O), sulfur dioxide (SO$_2$), nitrogen oxides (NO$_x$) and non-methane 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:

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

\( \alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4 \) 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 a 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. CO2-GDP-EN nexus also takes into consideration additional explanatory variables to investigate the relationships between CO2, GDP, and EN. Relationships between CO2, 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 CO2, 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 CO2 for Benin, the Democratic Republic of the Congo, Ghana, Nigeria and Senegal, unidirectional causality running from CO2 to GDP for Gabon, Nigeria, and Togo, and bidirectional causality between GDP and CO2 for Nigeria in the short run. They also found bidirectional causality between GDP and CO2 for Congo and Gabon, unidirectional causality running from EN to CO2 for Benin, Congo, Cote d’Ivoire, Gabon, Ghana, Nigeria, Senegal, South Africa, and Togo and unidirectional causality running from GDP to CO2 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 CO2 emission with panel cointegration techniques and the Granger causality test methodologies. They concluded that authorities should invest in renewable energy to reduce CO2 emissions and decrease nuclear energy to reduce CO2 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 CO2, 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 CO2 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.

\[
\ln(CO_2)_t = \alpha_0 + \alpha_1 \ln(GDP)_t + \alpha_2 \ln(EN)_t + e_t \tag{2}
\]

\(\alpha_0, \alpha_1, \alpha_2\) are estimated parameters. t is time index. \(e\) is error term.
\[
\ln(CO_2)_t = \alpha_0 + \alpha_1 \ln(GDP)_t + \alpha_2 \ln(GDP)_t^2 + \alpha_3 \ln(EN)_t + e_t \tag{3}
\]

\(\alpha_0, \alpha_1, \alpha_2\) and \(\alpha_3\) 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                    |
| LNCO2 Denmark     | -1.528636(0)      | -7.955326(0)*                |
| LNEN Denmark      | -4.039929(0)*     | —                            |
| LNGDP Denmark     | -3.623015(0)*     | —                            |
| LNGDP2 Denmark    | -3.391508(0)**    | —                            |
| LNCO2 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)**               |
| LNCO2 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 CO2, GDP, and EN NEXUS

According to the ARDL bounds test results, no cointegration is found between CO2, 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 CO2, GDP, and energy consumption.

The Toda and Yamamoto Granger non-causality test is applied for testing causal relationships between CO2, 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 LNCO2 is found but no causality from LNGDP to LNCO2 is found. Also, there is no causality from LNCO2 and LNGDP to LNEN and no causality from LNCO2 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 | II 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 | Prob. F (1,47) | 0.3847 |
|-------------------------------------------|-------------|----------------|--------|
| Obs*R-squared                             | 0.870241    | Prob. $\chi^2$ (1) | 0.3509 |

**Source:** Authors’ Calculations.

Table 5. Normality Test Results of CO$_2$-GDP-EN for Denmark.

| Normality Test          | Jarque-Bera | Probability  |
|-------------------------|-------------|--------------|
|                         | 0.078324    | 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 | Prob. F (5,48) | 0.0703 |
|---------------------------------------------------|-------------|----------------|--------|
| Obs*R-squared                                     | 10.04570    | Prob. $\chi^2$ (5) | 0.0740 |
| Scaled explained SS                               | 7.904724    | Prob. $\chi^2$ (5) | 0.1616 |

**Source:** Authors’ Calculations.
4.1.2 $\text{CO}_2$, GDP, the square of GDP and EN NEXUS

According to the ARDL bounds test results, no cointegration is found between $\text{CO}_2$, 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 $\text{CO}_2$, 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 $\text{CO}_2$-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 CO₂-GDP-EN for Denmark.

| Dependent Variable: DLNCO₂ | Excluded | \(\chi^2\) | df | Prob. |
|----------------------------|----------|-------------|----|-------|
| LNEN                       | 7.274759 | 2           | 0.0263 |
| LNGDP                      | 1.313481 | 2           | 0.5185 |
| All                        | 7.818147 | 4           | 0.0985 |

| Dependent Variable: DLNEN  | Excluded | \(\chi^2\) | df | Prob. |
|----------------------------|----------|-------------|----|-------|
| LNCO₂                      | 5.042617 | 2           | 0.0804 |
| LNGDP                      | 0.335164 | 2           | 0.8457 |
| All                        | 5.770306 | 4           | 0.2170 |

| Dependent Variable: DLNGDP | Excluded | \(\chi^2\) | df | Prob. |
|----------------------------|----------|-------------|----|-------|
| LNCO₂                      | 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 CO₂-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.
4.2 SPAIN

4.2.1 CO₂, GDP and EN NEXUS

According to ARDL bounds test results, no cointegration is found between CO₂, 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 CO₂, GDP, and energy consumption.

The Toda and Yamamoto Granger non-causality test is applied for testing causal relationships between CO₂, 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 LNCO₂, no causality from LNCO₂ and LNGDP to LNEN, and no causality from LNCO₂ and LNEN to LNGDP (see Table 18).
### Table 13. ARDL Bounds Test Results of CO₂-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 CO₂-GDP-EN for Spain.

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

*Source*: Authors’ Calculations.

### Table 15. Heteroscedasticity Test Breusch-Pagan-Godfrey Test Results of CO₂-GDP-EN for Spain.

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

*Source*: Authors’ Calculations.

### Table 16. Normality Test Results of CO₂-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 LNCO₂ and no causality from LNCO₂ and LNEN to LNGDP. Unidirectional causality running from LNCO₂ 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 CO₂-GDP-EN for Spain.

| Dependent Variable: DLNCO₂ | Excluded | £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 | £² | df | Prob. |
|---------------------------|----------|----|----|-------|
| LNCO₂                     | 3.202790 | 4  | 0.5245 |
| LNGDP                     | 6.303044 | 4  | 0.1776 |
| All                       | 9.477555 | 8  | 0.3036 |

| Dependent Variable: DLNGDP | Excluded | £² | df | Prob. |
|----------------------------|----------|----|----|-------|
| LNCO₂                      | 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 CO₂-GDP-EN-SQUARE of GDP for Spain.

| Test Statistic | Value | K |
|----------------|-------|---|
| F-Statistic    | 1.332407 | 3 |

**Critical Value Bonds**

| Significance | l0 Bound | l1 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 CO₂-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. $\chi^2$ (2) | 0.0603 |

(Source: Authors’ Calculations.)

Table 21. Heteroscedasticity Test Breusch-Pagan-Godfrey Test Results of CO₂-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. $\chi^2$ (11) | 0.1587 |
| Scaled explained SS                               | 11.92609 | Prob. $\chi^2$ (11) | 0.3692 |

(Source: Authors’ Calculations.)

Table 22. Normality Test Results of CO₂-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 CO₂-GDP-EN for UK.

| Unrestricted Cointegration Rank Test (Trace) |       |       |       |       |
|---------------------------------------------|-------|-------|-------|-------|
| Hypothesized No. of CE(s)                   | Eigenvalue | Trace Statistical | 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 Statistical | 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 | $\chi^2$ | 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 | $\chi^2$ | df | Prob. |
|-------------------------------|----------|----------|----|-------|
| LNEN                          | 3.612151 | 2        | 0.1643 |
| LNGDP                         | 3.543347 | 2        | 0.1700 |
| All                           | 8.336562 | 4        | 0.0800 |

| Dependent Variable: DLNEN     | Excluded | $\chi^2$ | 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 | $\chi^2$ | 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 CO₂-GDP-EN for the United Kingdom.

Source: Authors’ Calculations.

4.3.2 CO₂, GDP, the Square of GDP and EN NEXUS

Table 28. Results for Johansen Cointegration Test of CO₂-GDP-EN-SQUARE of GDP for the United Kingdom.

| 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|

Source: Authors’ Calculations.

According to the Johansen cointegration test results, no cointegration is found between CO₂, GDP, the square of GDP and energy consumption (see Table 28). Because no long-term relationship is found between CO₂, 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 transport 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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