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Economic Growth and Energy Consumption in OECD Countries; A Causality Analysis

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Economic Growth and Energy Consumption in OECD Countries:

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Abstract

“Economic Growth and Energy Consumption in OECD Countries: A Causality Analysis” by Daria Kostyannikova examines the relationship between economic growth and different measures of energy consumption such as coal, oil, natural gas and total energy consumption in a panel of 21 OECD countries from 1965 to 2011 by using modern time-series techniques. Toda and Yamamoto procedure is used to determine the direction of causality, and the Bounds test is employed in series integrated of different orders where a Johansen Cointegration test cannot be performed. As a robustness check the same analyses are made but excluding the last seven years of the oil price surge and global financial crisis. Although causality results are not uniform across different countries, the same patterns are found in the US where unidirectional causality runs from economic growth to energy consumption, and no causality is found in UK, Sweden, Denmark and Finland. This paper is a starting point in a further investigation of causal relationship to completely understand it and suggest more specific policies for each country

1. Introduction

Over the past forty years the world economy has more than tripled. Although economic growth raised standards of leaving in most countries, it was also responsible for a reduction in natural resources and an increase in greenhouse gas emissions. Some forecasts suggest that with accelerating growth of population and GDP, by 2050 we will be faced with a major challenge of not having enough resources; this, in turn, will undermine further economic development especially in poor regions (Organisation for Economic Co-operation and Development, 2012).

While GDP of leading economies continues to rise, economic growth in developing regions is even higher, with an average growth of 5.9% or 3.6% of per capita growth in low income countries, and 1.3% total or 0.8% per capita growth in high income countries (World Development Indicators, 2012). In addition, energy use is expected to grow by 80% in 2050, while the reliance on fossil fuels is not expected to change from the current (approximately 85%) (OECD, 2012). Serious environmental consequences are likely to occur; greenhouse gas (GHG) emissions are expected to increase by 50%, and the concentration of GHG of almost 695 parts per million is projected by 2050 (OECD, 2012). Thus, improving energy efficiency and switching to alternative sources of energy is crucial in energy and environmental policies. The benefits of energy efficiency are lower reliance on fossil fuels, reduction of carbon dioxide emission, possible savings in fuel cost and higher consumer welfare. Although recent trends shows improvements in energy indicators, there is more potential for further energy saving in different sectors (IEA, 2005).

Understanding the relationship between energy consumption and economic development will help economies in formulating energy policies and developing energy resources in sustainable ways. This paper answers questions such as can energy consumption be the major factor that promotes economic development or can economic growth be stimulated even with the application of energy conservation policies aimed to lower an impact of climate change. Although the relationship between energy consumption and economic growth is well-studied, conflicting results are found in the same regions by different authors mostly because of different time periods, proxies and empirical methodologies. The direction of causality is highly important from economic and especially energy policy making prospective. Apergis and Payne (2009) summarize directions of causality in four hypothesis. According to the energy conservation hypothesis, economic growth stimulates energy consumption which suggests that energy conservation policies will not adversely affect economic growth. The growth hypothesis indicates the opposite direction of causality and that economic growth is one of the major factors in economic development. Thus, inefficient energy systems and policies aimed to reduce energy use may jeopardize economic growth. The feedback hypothesis considers bidirectional causality; this implies that energy consumption and economic growth are complements, and energy conservation policies may also slow economic development. The neutrality hypothesis suggests no evidence of causal relationship between energy consumption and economic growth.

One of the contributions of this paper is in examination of causal relationship between different measures of energy consumption such as oil, coal, natural gas, total energy and economic growth. Most of the previous studies only determine this relationship between electricity or total energy consumption and economic growth, while only a few papers consider additional energy sources. Secondly, as a robustness check, a causal relationship is studied for the period of 1965 to 2004 to exclude the impact of the oil price peak and global financial crisis. In addition, each country is analyzed individually, as well as a panel of countries to determine the long-run equilibrating relationship. Lastly, unlike most of the previous studies, this paper uses a Toda and Yamamoto (TY) procedure instead of the standard Granger-causality test and the Bounds test which allows even series integrated of different orders to be included in the analysis.

The rest of the paper is organized as follows. Section 2 provides literature review on papers that study the same relationship, their techniques and main results. Section 3 presents data and methodology, while Section 4 presents empirical results and policy implications. Section 5 consists of concluding remarks.

2. Literature Review

Many papers have examined the relationship between energy consumption and economic growth, although not always with the most recent tools of time-series analysis such as the Bounds Test to determine the long-run relationship between economic growth and energy consumption or the Toda and Yamamota (TY) procedure proposed in this study. This paper's contribution to the literature is not only the wider sample of countries but also the use of contemporary analytical tools.

There are a few previous studies that used a wide sample of countries. Jinke, Hualing, Dianming study the causal relationship between coal consumption and GDP for both OECD and non-OECD countries from 1980 to 2005. They employ a standard Granger causality test with the use of Vector Error Correction Model to determine the direction of causality. They find that GDP Granger-causes coal consumption in Japan and China, and no causality in India, South Korea and South Africa. Apergis and Payne (2009) also study the relationship between coal consumption and economic growth from 1980 to 2005, but only in a panel of 25 OECD countries and find bidirectional causality by using dynamic error correction model. Tugcu, Ozturk, Aslan (2012) compare the relationship between renewable, non-renewable energy consumption and economic growth in G7 countries from 1980 to 2009. They find that in Japan non-renewable energy consumption stimulates economic growth, and confirm the neutrality hypothesis for the other six countries. Moreover, they find bidirectional causality between renewable energy consumption and economic growth in Japan and England, and unidirectional causality from GDP to renewable energy consumption supported for Germany. Soytas and Sari (2003) study the relationship between energy consumption and GDP in G-7 and emerging markets from 1950 to 1992. They also employ vector error correction model and find that energy consumption Granger-causes GDP in Turkey, France, Germany and Japan, economic growth Granger causes energy consumption in Italy and Korea, and bidirectional causality in Argentina. Mahadevan, Asafu-Adjaye (2006) study the relationship between energy consumption, economic growth and prices in developed and developing countries from 1971 to 2002. They use error correction model to determine the direction of causality and find that energy consumption Granger causes economic growth in developed and developing countries.

More studies looked at particular subsets of countries, whether distinguished by geography such as those in Africa or Asia or distinguished by natural resources such as oil exporters. Wolde-Rufael (2006) considers the relationship between electricity consumption and economic growth in 17 African countries. The TY procedure is used to determine the relationship between these two variables. The variables are not tested for a unit root, but Bounds Tests are performed to determine whether the series are cointegrated. Based on the results, causality was found in 12 out of 17 countries with unidirectional causality running from electricity consumption to economic growth in Benin, the Democratic Republic of the Congo and Tunisia), unidirectional causality running from economic growth to electricity consumption in Cameroon, Ghana, Nigeria, Senegal, Zambia and Zimbabwe, and bidirectional causality in Egypt, Gabon and Morocco. Nondo, Kahsai and Schaeffer (2012) also study the relationship between energy consumption and economic growth in African countries. They use a panel of 18 COMESA countries and based on the estimation of the error correction model, they find in the long-run bidirectional causality. Fatai, Oxley, Scrimgeour (2004) model the causal relationship between energy consumption and economic growth in New Zealand, Australia, India, Indonesia, The Philippines and Thailand. They employ both ECM and TY procedure to determine the direction of causality, and the autoregressive distributed lag regression approach. They find evidence of unidirectional causality from GDP to energy consumption in New Zealand and Australia, causality running from energy consumption to GDP in India and Indonesia, and bidirectional causality in Thailand and the Philippines.

Then there have been numerous studies of individual countries. Yoo (2005) studies the relationship between energy consumption and economic growth in Korea from 1970 to 2002 and finds bidirectional causality. Glasure and Lee (1997) determine the relationship between GDP and energy consumption in South Korea and Singapore by using error-correction models and also find bidirectional causality between both countries. Zou, Chau (2006) examine the relationship between oil consumption and economic growth in China and find that economic growth Granger-causes oil consumption. Mehrara (2006) determines the causal relationship between energy consumption and economic growth for oil exporting countries by using a panel unit root tests and cointegration analysis from 1971 to 2002 and finds unidirectional causality running from economic growth to energy consumption. Yang (2000) re-examines the causal relationship in Taiwan by expanding the time span from 1954 to 1997. In addition, coal, oil, natural gas and electricity consumption are studied in the paper. Bidirectional causality between total energy consumption and GDP is found. The same relationship is found in coal and electricity consumption. As for the natural gas and oil consumption, unidirectional causality was identified running to GDP. Yong-xiu, De-zhi, Yan (2007) study cointegration relationship between energy consumption and economic growth in Beijing from 1978 to 2006. They use Augmented Dickey-Fuller unit root test, Johansen cointegration test, and ECM. They determine that economic growth Granger causes energy consumption.

3. Data and Methodology

This paper uses annual GDP and energy consumption. There are four types of energy consumption considered in this paper – oil, coal, natural gas, and total energy consumption. Oil consumption is in million tons, while coal, natural gas and total energy are in million tons of oil equivalent (MTOE). The energy consumption series are from "Statistical Review of World Energy Full Report 2012" collected by BP, and were transformed into per capita view with population data from the World Development Indicators. Real GDP per capita data are also from World Development Indicators in constant 2000 US dollars. All the series are in natural logarithms.

Data for this panel of 21 OECD countries from 1965 to 2011 although as a robustness check the same analyses were made but excluding the last seven years of the oil price surge and global financial crisis. Each country is analyzed individually, as well as a part of a panel to determine the long-run relationship. There can be four different directions of causality (Apergis and Payne, 2009):

- The growth hypothesis when unidirectional causality runs from economic growth to energy consumption. This hypothesis suggests that implementing policies that are aimed to increase GDP will lead to higher energy consumption, and energy conservation policies will not affect economic growth;
- The conservations hypothesis when unidirectional causality runs from energy consumption to economic growth. Many countries rely extensively on energy. According to this hypothesis, energy conservation policies will slow economic growth. On the contrary, in order to stimulate economic growth, policies aimed to promote energy consumption should be applied;
- No causal relationship between energy consumption and economic growth (neutrality hypothesis);

- Bidirectional causality between energy consumption and economic growth. This hypothesis implies that energy consumption Granger-causes economic growth and at the same time economic growth Granger-causes energy consumption.

Determination of the direction of the causality is crucial in formulating policies as well as understanding how economic growth can be expected to affect carbon dioxide emissions.

To determine the causal relationship between energy consumption and economic growth, the Toda and Yamamoto procedure was used. With standard Granger-causality testing the first step is to determine the presence of a unit root. If the series are integrated of the same order, cointegration analysis can be performed. Under the standard causality test, a VAR framework is used if series are not cointegrated, and error correction model (ECM) is used if series are cointegrated (Engle and Granger, 1987). There are several advantages of using Toda and Yamamota procedure over standard Granger-causality testing. First, this procedure does not require for the series to be integrated of the same order. Although many macroeconomic time series are non-stationary processes with one unit root or I (1) series (Nelson and Plosser, 1982), while this may be true for the typical GDP series, this, cannot be assumed for energy consumption without further investigation. In some cases the series would be integrated of different orders, which would mean under a standard Granger-causality testing, that no further analysis can be performed. With the TY procedure, the maximum order of integration will be selected. For example, if one series is found to be I(0), while another series is I(1), 1 will be the maximum order of integration. Moreover, it is important to note that even when testing for a presence of a unit root, most of the available tests have a low power "against the alternative hypothesis of (trend) stationarity" (Toda and Yamamoto, 1995). Most importantly, under the standard causality test, if variables have a unit root, then "the usual Wald test statistic for Granger noncausality based on levels estimation not only has a nonstandard asymptotic distribution but depends on nuisance parameters" (Toda and Yamamoto, 1995). On the other hand, TY procedure allows the test statistic to follow a standard asymptotic distribution.

3.1 Unit Root Test

The first step of this research is to determine the order of integration of each variable. There are many methodologies that are used to check for a presence of a unit root such as Augmented Dickey Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS). This paper will use Phillips-Perron (Phillips and Perron, 1988) unit root test as it accounts for serial correlation and heteroscedasticity in the errors. A unit root for some variable Y implies that $\boldsymbol{Y_t = Y_{t-1} + \varepsilon_t}$ or $\Delta \boldsymbol{Y_t} \equiv (\boldsymbol{Y_t - Y_{t-1}}) = \boldsymbol{\varepsilon_t}$. Both the PP test ad ADF allow additional explanatory variables, x, and estimate:

$$\Delta \boldsymbol{Y_t} = \boldsymbol{\alpha Y_{t-1} + x_t'\delta + \varepsilon_t} \quad (1)$$

Where α=p-1.[1] The null and alternative hypothesis may be written as:

H0: $\boldsymbol{\alpha}$ *=0*

H1: $\boldsymbol{\alpha}$ *<0*

Where the acceptance of the null hypothesis represents a presence of a unit root, and the alternative hypothesis shows that series are stationary. The difference between the ADF and PP tests are in the t-statistic. The PP test statistic can be written as:

$$\boldsymbol{\tilde{t}_a = t_a(\frac{\gamma_0}{f_0})^{1/2} - \frac{T(f_0-\gamma_0)(se(\hat{a}))}{2f_0^{1/2}s}} \quad (2)$$

Where $\boldsymbol{\hat{a}}$ is the estimate, and $\boldsymbol{t_a}$ the t-ratio of a, $\boldsymbol{se(\hat{a})}$ is coefficient standard error, s is the standard error of the test regression, $\boldsymbol{\gamma_0}$ is a consistent estimate of the error variance of equation (1), and $\boldsymbol{f_0}$ is an estimator of the residual spectrum at frequency zero (Phillips and Perron, 1988).

Three models can be estimated – intercept only, intercept and trend, and no intercept, no trend model. This paper will use the intercept and trend model since it is the most general. In this paper each variable is tested individually for a presence of a unit root. If the variables are stationary in levels, they are I(0). If the variables are non-stationary in levels, but are stationary

[1] P is a parameter estimated in an autoregression $y_t = py_{t-1} + x_t'\delta + \varepsilon_t$, with the null hypothesis: $H_0: p = 1$, after subtracting y_{t-1} from both sides, equation 1 is obtained that is further used to evaluate the PP test statistic.

in the first difference, they are considered to be integrated of the first order.[2] In order to perform TY procedure, the maximum order of integration (d max) needs to be selected and then added to the VAR estimated for Granger causality (Giles). Once the order of integration is determined, cointegration analysis can be performed.

3.2 Lag Length Selection

Selecting an appropriate lag length is a matter of great importance According to Stock and Watson (2012), including less lags will result in omitting potentially valuable information, while including too many lags will "over-fit" the model. As a result, not only the cointegration, but the presence and direction of causality may differ significantly by changing the number of lags. To overcome this problem, several lag length criteria will be used in this paper. The most used criteria are Akaike information criterion (AIC), and Schwarz information criterion (SIC), where

$$AIC(p) = ln\left[\frac{SSR(p)}{T}\right] + (p+1)\frac{2}{T} \quad (3)$$

$$SIC(p) = ln\left[\frac{SSR(p)}{T}\right] + (p+1)\frac{\ln(T)}{T} \quad (4)$$

Where SSR(p) is the sum of squared residuals of the estimated autoregression AR(p) and p is the lag length (Stock and Watson, 2012). If the results are conflicting as AIC sometimes tends to include more lags, then Hannan-Quinn criterion (HQ) will also be considered.

After selecting the appropriate lag length, it is important to check for serial correlation in the residuals by applying the LM test for serial independence. If serial correlation is not removed with the lag length selected by using AIC and SIC, the lag length has to be increased until the serial correlation is removed.

3.3 Cointegration Analysis

Two or more time series can move together so closely over the long run that they appear to have the same trend component; that is they appear to have a common trend (Stock and Watson, 2012). Cointegration analysis is a necessary part of the standard Granger causality

[2] The series can also be integrated of second order or I(2) if the unit root is not removed after taking first differences.

test, although in the TY procedure it serves as a cross-check of the validity of the causality results. This paper uses two different approaches for cointegration analysis. The first approach requires both series to be integrated of the first order so, the Johansen cointegration test is employed.

$$\Delta Y_t = \prod Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + BX_t + \varepsilon_t \text{ (5)}$$

Where $\boldsymbol{\Pi} = \sum_{i=1}^{p} \boldsymbol{A_i} - \boldsymbol{I}$, $\boldsymbol{\Gamma_i} = -\sum_{j=i+1}^{p} \boldsymbol{A_j}$, Yt is a k-vector of non-stationary I(1) variables, Xt is a d-vector of deterministic variables, and $\boldsymbol{\varepsilon_t}$ is vector of white noises with zero mean and finite variance. The number of cointegration vectors is represented by the rank of the coefficient matrix $\boldsymbol{\Pi}$. If cointegration is found, to model cointegration relationship further and determine the long-run equilibrating relationship, series will be estimated in levels with an OLS regression (Johansen 1991; Johansen 1995; Hamilton, 1994).

The second approach is used when series are integrated of different orders – typically I(0) and I(1). In this case the Bounds tests are used to determine the short-run and the long-run relationship. Under this test, the unrestricted ECM is estimated in order to get the long-run relationship:

$$\Delta \boldsymbol{y_t} = \boldsymbol{\beta_0} + \sum_{i=1}^{m} \boldsymbol{\beta_{1i}} \boldsymbol{\Delta y_{t-1}} + \sum_{i=1}^{m} \boldsymbol{\theta_{1i}} \boldsymbol{\Delta x_{t-1}} + \boldsymbol{\theta_0} \boldsymbol{y_{t-1}} + \boldsymbol{\theta_1} \boldsymbol{x_{t-1}} + \boldsymbol{e_t}; \text{ (6)}$$

An F-test needs to be performed to determine whether the variables have a long-run relationship, where the null hypothesis can be written as (Pesaran and Smith 1998; Giles):

$$\boldsymbol{H_0}: \boldsymbol{\theta_0} = \boldsymbol{\theta_1}$$

$$\boldsymbol{H_1}: \boldsymbol{\theta_0} \neq \boldsymbol{0}, \boldsymbol{\theta_1} \neq \boldsymbol{0}$$

Acceptance of the null hypothesis represents no long-run equilibrium relationship between economic growth and energy consumption. Rejection of the null hypothesis indicates that the variables do have a long-run relationship.

After the cointegration analysis is performed, the Granger-causality test can be performed.

3.4 Granger Causality

Granger causality means that if X Granger-causes Y, then X is a useful predictor of Y (Stock and Watson, 2012). The Granger test can be written as:

$$\boldsymbol{y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} y_{t-i} + \sum_{j=k+1}^{d\,max} \alpha_{2j} y_{t-j} + \sum_{i=1}^{k} \delta_{1i} x_{t-i} + \sum_{j=k+1}^{d\,max} \delta_{2j} x_{t-j} + \nu_{1t}} \qquad (7)$$

$$\boldsymbol{x_t = \beta_0 + \sum_{i=1}^{k} \beta_{1i} CC_{t-i} + \sum_{j=k+1}^{d\,max} \beta_{2j} CC_{t-j} + \sum_{i=1}^{k} \gamma_{1i} Y_{t-i} + \sum_{j=k+1}^{d\,max} \gamma_{2j} Y_{t-j} + u_{1t}}$$

The null hypothesis is that x does not Granger-cause y in the first regression and that y does not Granger-cause x in the second regression. If the Null Hypothesis is rejected, then X Granger causes Y or Y Granger causes X (Granger, 1969).

The following equations are estimated in this paper.

- Coal Consumption (CC) and Economic Growth (Y)

$$\boldsymbol{Y_{nt} = \alpha_{1n} + \sum_{i=1}^{k} \alpha_{11n,i} Y_{n,t-i} + \sum_{j=k+1}^{d\,max} \alpha_{12n,j} Y_{n,t-j} + \sum_{i=1}^{k} \beta_{11n,i} CC_{n,t-i} + \sum_{j=k+1}^{d\,max} \beta_{12n,j} CC_{n,t-j} + \nu_{1n,t}} \qquad (8)$$

$$\boldsymbol{CC_{n,t} = \alpha_{2n} + \sum_{i=1}^{k} \alpha_{21n,i} CC_{n,t-i} + \sum_{j=k+1}^{d\,max} \alpha_{22n,j} CC_{n,t-j} + \sum_{i=1}^{k} \beta_{21n,i} Y_{n,t-i} + \sum_{j=k+1}^{d\,max} \beta_{22n,j} Y_{n,t-j} + \nu_{2n,t}}$$

- Natural Gas Consumption (NGC) and Economic Growth (Y)

$$\boldsymbol{Y_{n,t} = \alpha_{3n} + \sum_{i=1}^{k} \alpha_{31n,i} Y_{n,t-i} + \sum_{j=k+1}^{d\,max} \alpha_{32n,j} Y_{n,t-j} + \sum_{i=1}^{k} \beta_{31n,i} NGC_{n,t-i} + \sum_{j=k+1}^{d\,max} \beta_{32n,j} NGC_{t-j} + \nu_{3n,t}} \quad (9)$$

$$\boldsymbol{NGC_{n,t} = \alpha_{4n} + \sum_{i=1}^{k} \alpha_{41n,i} NGC_{n,t-i} + \sum_{j=k+1}^{d\,max} \alpha_{42n,j} NGC_{n,t-j} + \sum_{i=1}^{k} \beta_{41n,i} Y_{n,t-i} + \sum_{j=k+1}^{d\,max} \beta_{42n,j} Y_{n,t-j} + \nu_{4n,t}}$$

- Oil Consumption (OC) and Economic Growth (Y)

$$\boldsymbol{Y_{n,t} = \alpha_{5n} + \sum_{i=1}^{k} \alpha_{51n,i} Y_{n,t-i} + \sum_{j=k+1}^{d\,max} \alpha_{52n,j} Y_{n,t-j} + \sum_{i=1}^{k} \beta_{51n,i} OC_{n,t-i} + \sum_{j=k+1}^{d\,max} \beta_{52n,j} OC_{n,t-j} + \nu_{5t}} \quad (10)$$

$$\boldsymbol{OC_{n,t} = \alpha_{6n} + \sum_{i=1}^{k} \alpha_{61n,i} OC_{n,t-i} + \sum_{j=k+1}^{d\,max} \alpha_{62n,j} OC_{n,t-j} + \sum_{i=1}^{k} \beta_{61n,i} Y_{n,t-i} + \sum_{j=k+1}^{d\,max} \beta_{62n,j} Y_{n,t-j} + \nu_{6t}}$$

- Total Energy Consumption (EC) and Economic Growth (Y)

$$\boldsymbol{Y_{n,t} = \alpha_{7n} + \sum_{i=1}^{k} \alpha_{71n,i} Y_{n,t-i} + \sum_{j=k+1}^{d\,max} \alpha_{72n,j} Y_{n,t-j} + \sum_{i=1}^{k} \beta_{71n,i} EC_{n,t-i} + \sum_{j=k+1}^{d\,max} \beta_{72n,j} EC_{n,t-j} + \nu_{7t}} \quad (11)$$

$$\boldsymbol{EC_{n,t} = \alpha_{8n} + \sum_{i=1}^{k} \alpha_{81n,i} EC_{n,t-i} + \sum_{j=k+1}^{d\,max} \alpha_{82n,j} EC_{n,t-j} + \sum_{i=1}^{k} \beta_{81n,i} Y_{n,t-i} + \sum_{j=k+1}^{d\,max} \beta_{82n,j} Y_{n,t-j} + \nu_{8t}}$$

Where *k* is the determined lag length, and *d max* is the maximum order of integration that is determined when testing for a presence of a unit root.

Although the TY procedure may not be approparіate in some cases when the number of variables is small so it might overfit, in this paper, any such inefficiency is expected to be relatively low (Toda and Yamamoto, 1995).

3.5 Panel Cointegration

After determining the direction of causality for each country, a panel cointegration analysis was performed for each measure of energy consumption.

In order to perform a panel cointegration test, both variables had to be tested for a presence of a unit root. There are many panel unit root tests available such as Levin, Lin and Chu (LLC) and Breitung test that assume common unit root process, and In, Pesaran and Shin (IPS); ADF-Fisher, PP-Fisher and Choi tests that assume individual unit root process. Panel unit root tests are considered to have more power than the tests performed for individual time series. The biggest disadvantage of the panel unit root tests is that most of the tests assume cross-sectional independence which is a rough assumption in analysis that involves macro variables (Baltagi, Badi, Bresson, and Pirotte, 2007).

Breitung (2000) examines the results of Monte Carlo simulations and found that LLC and IPS tests have low power in the presence of cross-sectional dependence while the Breitung statistic performs better. In addition, Breitung's test is advised especially when the number of cross sections and the time span are small.

Breitung test is based on the model estimated by the ADF equation 1

$$\boldsymbol{\Delta y_{it} = \alpha y_{it-1} + \textstyle\sum_{j-1}^{p_i} \beta_{ij} \Delta y_{it-j} + X'_{it}\delta + \epsilon_{it}} \quad (12)$$

With the null and alternative hypothesis can be written as:

$$\boldsymbol{H_0}: \boldsymbol{\alpha} = \mathbf{0}$$

$$\boldsymbol{H_1}: \boldsymbol{\alpha} < 0$$

The acceptance of the null hypothesis indicates a unit root, and the rejection of the null hypothesis in favor of the alternative, indicates that series are stationary.

After determining the order of integration, the cointegration analysis can be performed if series are integrated of the same order. This paper employs Engle-Granger based Pedroni cointegration test due to its best performance and is least affected by cross-sectional correlation and when series are possibly integrated of second order (Wagner and Hlouskova, 2009). Pedroni cointegration test computes seven four panel statistics and three group statistics. Also, Engle-Granger based Kao cointegration test is used in this paper. Gutierrez (2003) suggests that Kao and Pedroni cointegration tests have more power compare to other tests. The null hypothesis is of no cointegration in both Pedroni and Kao cointegration tests.

4. Empirical Results

4.1 Oil Consumption and Economic Growth

Unit Root Test and Cointegration Test

Table 1 shows the results of the PP test. As it can be seen from Table1, economic growth series are integrated of first order in the case of every country, while oil consumption series are stationary in levels in Australia, Finland, Germany, Japan and Norway. Hence, oil consumption and economic growth are integrated of different order in these countries. Since none of the countries are integrated of second order, the maximum order of integration is 1. In the next step cointegration analysis is performed by using the Johansen cointegration test in series that are integrated of the same order. Table 2 shows the results of the cointegration analysis.

Table 1: Phillips-Perron Unit Root Test Results

Country	Oil Consumption		Economic Growth	
	levels	first difference	levels	first difference
Australia	-3.45**		-2.55	-7.51***
Austria	-3.28*	-6.04***	-2.11	-7.58***
Belgium	-2.81	-5.90***	-1.67	-7.91***
Canada	-2.40	-6.79***	-2.43	-6.50***
Denmark	-3.01	-5.44***	-1.01	-6.66***
Finland	-5.38***		-2.18	-5.53***
France	-3.40*	-6.56***	-2.04	-6.86***
Germany	-4.15**		-1.98	-12.81***
Greece	-1.52	-6.66***	-2.34	-5.16***
Hungary	-2.73	-5.64***	-2.33	-5.13***
Italy	-3.10	-4.85***	-0.64	-8.34***
Ireland	-2.00	-6.02***	-1.33	-5.88***
Japan	-4.04**		-2.16	-6.15***
Mexico	-0.56	-9.52***	-2.37	-7.43***
Netherlands	-2.33	-7.35***	-2.15	-6.73***
Norway	-4.53***		0.42	-5.51***

Spain	-3.06	-5.92***	-2.07	-5.57***
Sweden	-3.47*	-8.48***	-2.56	-6.37***
Turkey	-1.75	-7.53***	-2.98	-5.59***
United Kingdom	-3.48*	-7.98***	-2.13	-6.50***
US	-2.76	-7.02***	-2.05	-6.37***

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

As it can be seen from Table 2, in most countries, there is no long-run equilibrating relationship between oil consumption and economic growth. Only in Austria, Belgium, France, Greece, Spain, Turkey and US, series are cointegrated. Based on these results, it is assumed that neutrality hypothesis will be supported in most of the countries, and either unidirectional or bidirectional causality will be found in 7 countries listed above.

Granger Causality Test

Granger noncausality results are shown in Table 3. The lag length was consistent in most of the case except for Denmark and Italy, where SIC and HQ suggested using 1 lag, and AIC suggested using 3 lags. After checking for serial correlation in the residuals, 3 lags was determined to be the appropriated lag length.

Table 2: Johansen Cointegration Test Results

	Trace Statistics		Max-Eigenvalue Statistic	
Country	None	At most 1	None	At most 1
US	25.82***	8.83*	16.99**	8.83*
Austria	30.86**	8.83	22.03**	8.83
France	28.00**	10.37	17.63*	10.37
Greece	20.90**	2.29	18.61**	2.29
Turkey	25.60***	0.32	25.28***	0.32
Belgium	27.40**	11.07*	16.33	11.07
Spain	18.66*	5.99	12.67	5.99
Canada	13.03	2.06	10.97	2.06
Denmark	19.71	4.23	15.48	4.23
Hungary	11.30	0.06	11.24	0.06
Italy	14.63	0.54	14.09	0.54
Ireland	4.47	0.82	3.65	0.82
Mexico	9.21	0.24	8.97	0.24
Netherlands	15.39	2.83	12.57	2.83
Sweden	19.28	8.93	10.35	8.93

United Kingdom	12.38	0.52	11.87	0.52

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

Based on the results shown in Table 3, unidirectional causality running from GDP to oil consumption is found in Austria, Greece, Ireland, Spain, Turkey and US. Unidirectional causality running in the opposite direction from oil consumption to economic growth is in Belgium and Canada. Neutrality hypothesis is accepted in other countries. Comparing the causality results to cointegration results, countries that showed long-run relationship between oil consumption and economic growth had unidirectional causality. The only country with inconsistent results is Canada. No cointegration was determined by the Johansen test, while Granger noncausality hypothesis was rejected. Lastly, since no causality was found in the countries where oil consumption and economic growth are integrated of different orders, the ARDL approach will not be performed. After estimating a simple OLS in series that are cointegrated and have causality in either direction, it was found that a unit increase in oil consumption will lead to 1.24 increase in GDP in Austria and 1.08 units in Belgium. A one unit increase in GDP will raise oil consumption by 1.21 units in Greece, 0.94 units in Spain, 0.86 units in Turkey and 1.76 units in US.

Table 3: Granger Causality Test Results

Country	Ln(OC)→Ln(Y)	Ln(Y)→Ln(OC)	Number of lags	Direction of causality
Austria	0.09*	0.88	1	OC to Y
Belgium	0.05**	0.73	1	OC to Y
Canada	0.06*	0.34	2	OC to Y
Greece	0.50	0.05**	2	Y to OC
Ireland	0.68	0.01***	2	Y to OC
Spain	0.96	0.09*	2	Y to OC
Turkey	0.93	0.09*	1	Y to OC
US	0.30	0.03**	3	Y to OC
Australia	0.24	0.24	1	neutrality
Denmark	0.26	0.46	3	neutrality
Finland	0.94	0.34	1	neutrality
France	0.11	0.31	1	neutrality
Germany	0.27	0.95	1	neutrality
Hungary	0.14	0.35	1	neutrality
Italy	0.60	0.83	3	neutrality

Japan	0.21	0.23	4	neutrality
Mexico	0.66	0.17	1	neutrality
Netherlands	0.15	0.19	1	neutrality
Norway	0.82	0.11	2	neutrality
Sweden	0.40	0.88	1	neutrality
United Kingdom	0.93	0.20	1	neutrality

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

4.2 Natural Gas Consumption and Economic Growth

The relationship between natural gas consumption and economic growth is studied in fewer countries due to a structural break in the energy consumption series. A rapid growth in natural gas consumption can be seen in late 60's and early 70's. Also, some countries were excluded due to data availability. After further investigation, a panel of 14 countries was used that consisted of Australia, Austria, Belgium, Canada, France, Germany, Hungary, Italy, Japan, Mexico, Netherlands, Spain, United Kingdom and US.

Unit Root Test and Cointegration Test

Among the countries selected for causality analysis, natural gas consumption and economic growth are mostly integrated of first order. In Germany, Hungary and Netherlands, natural gas consumption is stationary in levels and economic growth is integrated of first order. Therefore, cointegration analysis will not be performed in these countries unless unidirectional or bidirectional causality is present in the series.

Table 4: Phillips-Perron Unit Root Test Results

Country	Natural Gas Consumption		Economic Growth	
	levels	first difference	levels	first difference
Australia	-3.50*	-13.90***	-2.67	-6.67***
Austria	-1.86	-5.52***	-2.11	-7.58***
Belgium	-1.91	-5.66***	-2.42	-8.50***
Canada	-2.31	-7.01***	-2.59	-5.98***
France	-3.26*	-7.62***	-2.06	-7.08***
Germany	-4.48***		-1.96	-9.75***
Hungary	-3.99**		-2.33	-5.13***
Italy	-0.94	-6.21***	-0.64	-8.34***
Japan	-0.83	-5.72***	-2.16	-6.15***
Mexico	-2.07	-5.49***	-2.37	-7.44***

Netherlands	-3.95**		-2.02	-6.62***
Spain	-1.84	-5.18***	-1.56	-5.50***
United Kingdom	-0.84	-6.19***	-1.83	-6.09***
US	-2.56	-5.59***	-2.05	-6.37***

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

The Johansen cointegration test was performed in countries where natural gas consumption and economic growth were integrated of the same order. The results obtained in the Johansen cointegration test are shown below. As it can be seen from Table 5, in Australia, Austria, Canada, Japan, Mexico and US both trace and max-Eigenvalue statistics suggest a presence of the long-run equilibrating relationship between natural gas consumption and economic growth. In the UK only trace statistic shows that two time series are cointegrated at 10% level of significance. Based on the cointegration results, at least unidirectional causality can be assumed in the countries were natural gas consumption and economic growth are cointegrated.

Granger Causality

Granger causality test results show that there is bidirectional causality between natural gas consumption and economic growth in Australia and Mexico. Hence, by stimulating natural gas consumption in these countries, economic growth will be promoted and vice versa. Unidirectional causality running from GDP to natural gas consumption in Canada, Spain and US.

Table 5: Johansen Cointegration Test Results

	Trace Statistics		Max-Eigenvalue Statistic	
Country	None	At most 1	None	At most 1
Japan	30.69***	4.06**	26.63***	4.06**
Mexico	20.96***	4.18**	16.78**	4.18**
Australia	17.03**	0.47	16.56**	0.47
Austria	29.67***	2.14	27.54***	2.14
US	26.06***	6.74	19.32**	6.74
Canada	20.69**	6.13**	14.55	6.13
United Kingdom	25.42*	8.50	16.92	8.50
Belgium	7.36	2.79	4.57	2.79
France	19.92	5.11	14.81	5.11
Italy	10.50	0.23	10.27	0.23
Spain	11.00	0.75	10.25	0.75

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

Unidirectional causality running from natural gas consumption to economic growth was found in Japan. These results are beneficial to Japanese economic development as its current goal is to switch from nuclear energy to other sources of energy including natural gas. Therefore, by stimulating natural gas consumption, economic growth will be promoted in Japan. Comparing cointegration and causality tests results, in most of cases, the results are consistent. One of the exceptions is Austria. Despite two time series being cointegrated, no causality was found. The same pattern was found in coal consumption and total energy consumption – although cointegration was found, no causality was present. Furthermore, in Spain natural gas consumption and economic growth were not found to be cointegrated, but unidirectional causality running from GDP to natural gas consumption was determined. Lastly, neutrality hypothesis is supported in UK, but only trace statistic indicated a presence of the long-run equilibrating relationship between two time-series at 10% level of significance.

Based on the direction of causality and cointegration results, a one unit increase in GDP would raise natural gas consumption by 2.11 units in Australia, 0.95 units in Canada, 1.73 units in Mexico, and 1.62 units in US, while a one unit increase in natural gas consumption will raise GDP by 0.24 units in Australia, 0.28 units in Japan, and 0.52 units in Mexico.

Table 6: Granger Causality Test Results

Country	Ln(NGC)→Ln(Y)	Ln(Y)→Ln(NGC)	Number of lags	Direction of causality
Canada	0.52	0.02**	1	Y to NGC
Spain	0.20	0.00***	1	Y to NGC
US	0.65	0.02**	4	Y to NGC
Japan	0.02**	0.36	1	NGC to Y
Australia	0.01***	0.03**	1	bidirectional
Mexico	0.02**	0.01***	1	bidirectional
Austria	0.40	0.14	4	neutrality
Belgium	0.33	0.94	2	neutrality
France	0.61	0.90	1	neutrality
Germany	0.84	0.39	1	neutrality
Hungary	0.41	0.42	1	neutrality
Italy	0.29	0.93	1	neutrality

Netherlands	0.52	0.46	4	neutrality
United Kingdom	0.81	0.50	1	neutrality

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

4.3 Coal Consumption and Economic Growth

Unit Root Test and Cointegration Test

Table 7 shows results of the Phillips-Perron unit root test. All GDP time series are integrated of the first order. Coal consumption time series, are mostly I(1) except for Finland and France, where series were found to be I(0) at 5% and 10% level of significance. The Johansen cointegration test will be performed for all series that are integrated of the same order. For Finland and Denmark, cointegration analysis will not be performed, unless unidirectional or bidirectional causality is found. In addition, the maximum order of integration (d max) is one in each country.

Table 8 shows the results of the Johansen cointegration test. In the case of Australia, Canada, Denmark, Netherlands, Spain, Sweden, Turkey, and United Kingdom, coal consumption and economic growth have no long-run relationship.

Table 7: Phillips-Perron Unit Root Test Results

Country	Coal Consumption		Economic Growth	
	levels	first difference	levels	first difference
Australia	-1.14	-7.49***	-2.55	-7.51***
Austria	-3.11	-10.24***	-2.11	-7.58***
Belgium	0.38	-7.41***	-1.67	-7.91***
Canada	-1.01	-6.93***	-2.43	-6.50***
Denmark	-0.96	-7.18***	-1.01	-6.66***
Finland	-4.35***		-2.18	-5.53***
France	-3.99**		-2.04	-6.86***
Germany	-1.63	-5.16***	-1.98	-12.81***
Greece	-1.85	-5.20***	-2.34	-5.16***
Hungary	-1.71	-6.59***	-2.33	-5.13***
Italy	-2.14	-6.21***	-0.64	-8.34***
Ireland	-2.03	-5.60***	-1.33	-5.88***
Japan	-2.22	-6.52***	-2.16	-6.15***
Mexico	-1.53	-10.54***	-2.37	-7.43***
Netherlands	-2.54	-5.13***	-2.15	-6.73***
Norway	-2.25	-8.18***	0.42	-5.51***

Spain	-1.46	-5.84***	-2.07	-5.57***
Sweden	-2.22	-9.03***	-2.56	-6.37***
Turkey	-2.24	-7.14***	-2.98	-5.59***
United Kingdom	-2.94	-8.23***	-2.13	-6.50***
US	-0.10	-8.38***	-2.05	-6.37***

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

Therefore, it can be assumed that neutrality hypothesis will be supported. In Germany, Greece, Hungary, Ireland, Italy, Japan, Mexico and US two time series are cointegrated. Hence, either unidirectional causality or bidirectional causality should be present. In Austria and Norway, only trace statistic suggests that variables are cointegrated, while max-eigenvalue statistic shows no long run relationship. Moreover, in Norway, cointegration is only shows at 10% level of significance.

Granger Causality Test

Causality results are shown in Table 9 with p-values, and optimal number of lags. In most countries, no causality between coal consumption and economic growth is found. Since neutrality hypothesis is accepted in Finland and France, ARDL approach will not be implemented to determine the long-run relationship. In Germany, Hungary, Japan, Mexico and US, GDP Granger causes coal consumption. Only in Hungary and Greece, unidirectional causality runs from coal consumption to economic growth.

Table 8: Johansen Cointegration Test Results

	Trace Statistics		Max-Eigenvalue Statistic	
Country	None	At most 1	None	At most 1
Germany	24.80**	5.25	19.55**	5.25
Greece	12.66**	0.75	11.91**	0.75
Hungary	29.03***	5.99	23.04***	5.99
Ireland	19.28*	2.59	16.69**	2.59
Italy	24.47*	4.72	19.75**	4.72
Japan	16.93**	1.49	15.45**	1.49
US	21.68**	2.67	19.01**	2.67
Austria	27.06**	12.30*	14.76	12.30
Belgium	26.65**	9.47	17.18	9.47
Norway	15.01*	6.46	8.55	6.46
Australia	5.23	1.10	4.12	1.10

Canada	5.20	0.84	4.36	0.84
Denmark	9.35	1.86	7.48	1.86
Netherlands	16.42	1.90	14.52	1.90
Spain	16.29	5.83	10.46	5.83
Sweden	6.36	0.15	6.21	0.15
Turkey	16.36	4.07	12.30	4.07
United Kingdom	8.95	1.67	7.28	1.67

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

When selecting the optimal lag length, in most cases, AIC, SIC and HQ findings were consistent, and serial correlation in the residuals was removed. In Hungary and Netherlands AIC suggested using three lags, while SIC and HQ did 1 lag. The LM test showed that serial correlation in the residuals was removed with three lags and was later used in the causality test. In Spain, all criteria suggested using one lag, but serial correlation in the residuals was only removed with three lags. Lastly, causality results are consistent with cointegration test results in most countries except for Italy, where cointegration was found at 10% level of significance only, but no causality was found. Inconsistent results can be explained by decreasing coal consumption and other variables that are not included in this study.

Table 9: Granger Causality Test Results

Country	Ln(CC)→Ln(Y)	Ln(Y)→Ln(CC)	Number of lags	Direction of causality
Germany	0.44	0.05**	1	Y to Coal Consumption
Hungary	0.57	0.02**	3	Y to Coal Consumption
Japan	0.24	0.04**	1	Y to Coal Consumption
Mexico	0.13	0.08*	1	Y to Coal Consumption
US	0.52	0.02**	2	Y to Coal Consumption
Greece	0.09*	0.42	1	Coal consumption to Y
Ireland	0.01***	0.35	1	Coal consumption to Y
Australia	0.30	0.68	1	neutrality
Austria	0.68	0.43	1	neutrality
Belgium	0.88	0.60	1	neutrality
Canada	0.81	0.91	1	neutrality
Denmark	0.90	0.69	1	neutrality
Finland	0.14	0.23	1	neutrality
France	0.90	0.83	1	neutrality
Italy	0.66	0.82	1	neutrality

Netherlands	0.47	0.25	3	neutrality
Norway	0.21	0.46	1	neutrality
Spain	0.76	0.10	3	neutrality
Sweden	0.89	0.58	1	neutrality
Turkey	0.21	0.13	1	neutrality
United Kingdom	0.66	0.40	1	neutrality

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

After estimating a simple OLS regression in series where causality and cointegration were found, it was determined that a one unit increase in coal consumption would raise GDP by 0.54 units increase in Greece, and 0.55 units in Ireland, and a one unit increase in GDP would raise coal consumption by 1.05 in Germany, 0.58 in Japan, 2.14 units in Mexico, and 0.31 units in US.

4.4 Total Energy Consumption and Economic Growth

Unit Root Test and Cointegration

This section will focus on the results of unit root and cointegration tests in total energy consumption and economic growth series. Results of the Phillips-Perron unit root test are presented in Table 10.

Table 10: Phillips-Perron Unit Root Test Results

Country	Energy Consumption		Economic Growth	
	levels	first difference	levels	first difference
Australia	-1.95	-6.74***	-2.55	-7.51***
Austria	-1.31	-7.38***	-2.11	-7.58***
Belgium	-7.93***		-1.67	-7.91***
Canada	-3.69**		-2.43	-6.50***
Denmark	-3.43*	-6.55***	-1.01	-6.66***
Finland	-3.39*	-8.54***	-2.18	-5.53***
France	-1.80	-6.25***	-2.04	-6.86***
Germany	-2.07	-6.66***	-1.98	-12.81***
Greece	-2.01	-4.50***	-2.34	-5.16***
Hungary	-1.39	-5.86***	-2.33	-5.13***
Ireland	-1.78	-5.22***	-1.33	-5.88***
Italy	-3.16	-5.13***	-0.64	-8.34***
Japan	0.91	-4.86***	-2.16	-6.15***
Mexico	-1.01	-6.55***	-2.37	-7.43***
Netherlands	-3.19*	-4.77***	-2.15	-6.73***

Norway	-1.88	-17.66***	0.42	-5.51***
Spain	-2.28	-5.58***	-2.07	-5.57***
Sweden	-2.56	-8.20***	-2.56	-6.37***
Turkey	-2.36	-6.73***	-2.98	-5.59***
United Kingdom	-1.32	-6.61***	-2.13	-6.50***
US	-2.91	-5.75***	-2.05	-6.37***

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

As expected, economic growth in each country is integrated of first order and the null hypothesis of unit root is rejected in first differences at 1%, 5% and 10% level of significance. Energy consumption series are mostly integrated of the first order with the exception for Belgium, Canada, and Japan that are stationary in levels. In Denmark, Finland and Netherlands, the null hypothesis is accepted at 1% and 5% level of significance, but rejected at 10%. In this case, the series are integrated of first order. Based on the results obtained by the Phillips-Perron test, the maximum order of integration (d max) is 1 in all countries. Furthermore, only in Belgium, Canada, and Japan the long-run relationship is determined by modeling an unrestricted error correction model and using the Bounds tests. For the other 18 countries, the Johansen cointegration test is employed.

Table 11: Johansen Cointegration Test Results

	Trace Statistics		Max-Eigenvalue Statistic	
Country	None	At most 1	None	At most 1
France	22.22***	5.31**	16.91**	5.31**
Germany	30.23***	10.55**	19.68**	10.55**
Spain	13.78**	3.06*	10.72*	3.06*
US	23.78**	7.77*	16.01**	7.77*
Austria	15.70**	1.53	14.17*	1.53
Ireland	29.51**	5.32	24.20***	5.32
Mexico	31.81*	10.05	21.76**	10.05
Netherlands	17.61**	0.62	16.99**	0.62
Turkey	22.06**	6.13	15.93**	6.13
Australia	28.32**	11.98*	16.34	11.98
Denmark	14.81*	3.12*	11.68	3.12
Finland	18.02**	7.09***	10.93	7.09
Italy	27.61**	11.50*	16.11	11.50
Norway	19.26**	7.07***	12.19	7.07
Greece	14.95	3.45	11.50	3.45

Hungary	9.15	0.10	9.05	0.10
Sweden	10.72	0.17	10.55	0.17
United Kingdom	6.10	1.30	4.80	1.30

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level.

Cointegration results obtained by using the Johansen cointegration test are presented in Table 11. As it can be seen from the table, Greece, Hungary, Sweden and UK were found to be not cointegrated based on both Trace and max-Eigenvalue statistics. Hence, it can be expected that no causality will be found in these countries. In France, Germany, Spain, and US total energy consumption and economic growth are cointegrated and have two cointegrated equations. In Austria, Ireland, Mexico, Netherlands and Turkey, these variables are cointegrated, but have only one cointegrated equation. Consequently, there should be either unidirectional or bidirectional causality in these countries. Lastly, in Australia, Denmark, Finland, Italy, and Norway, Trace statistic shows that series are cointegrated, have two cointegrated equations, and max-eigenvalue shows no cointegration. The results of causality testing are ambiguous based on cointegration test for these countries.

Granger Causality Results

Table 12 shows the results of Granger causality test between energy consumption and economic growth. As described above, the lag length was selected with AIC, SIC and HQ, and then a LM test to verify that serial correlation in the residuals was eliminated with the lag choice. In some cases, the results of the lag length selection were conflicting. For example, in Australia, Belgium and Japan, SIC and HQ suggested one lag, while AIC suggested 2 lags (4 in Japan). The LM test showed serial correlation was removed with 1 and 2 lags. Since the majority of criteria suggested one lag, it was selected as the optimal lag length. In the case of Canada and Ireland, AIC suggested using 3 lags, while SIC and HQ selected one lags as the optimal lag length (2 lags in Canada). After using the LM test, it was determined that serial correlation was not removed with one or two lags, but the problem was solved with 3 lags. Hence, as suggested by the AIC criterion, 3 lags was chosen as the optimal lag length. Similar problems appeared while determining the optimal lag length in Mexico, Netherlands, Norway, Spain and US, and the same logic was used – to choose the lag length based on the majority's results, and ensure that the serial correlation in the residuals is removed with the selected lag length, otherwise, give a preference to the other lag length criterion.

With those selected lags, unidirectional causality running from energy consumption to economic growth was found in Australia, Belgium, France, and Netherlands. In Canada, Germany, Mexico, Norway, Turkey and US, economic growth Granger-causes energy consumption. Only in Ireland and Spain, energy consumption and economic growth are complements, which is indicated by the bidirectional causality. Other countries support the neutrality hypothesis.

Table 12: Granger Causality Test Results

Country	Ln(EC)→Ln(Y)	Ln(Y)→Ln(EC)	Number of lags	Direction of causality
Australia	0.007***	0.602	2	EC to Y
Belgium	0.011**	0.772	1	EC to Y
France	0.043**	0.895	1	EC to Y
Netherlands	0.037**	0.760	1	EC to Y
Canada	0.515	0.006***	3	Y to EC
Germany	0.544	0.070*	1	Y to EC
Mexico	0.258	0.015**	2	Y to EC
Norway	0.335	0.031**	1	Y to EC
Turkey	0.657	0.035**	1	Y to EC
US	0.716	0.012**	4	Y to EC
Ireland	0.091*	0.000***	3	bidirectional causality
Spain	0.004***	0.075*	1	bidirectional causality
Austria	0.288	0.776	1	neutrality
Denmark	0.239	0.461	1	neutrality
Finland	0.310	0.616	1	neutrality
Greece	0.118	0.972	1	neutrality
Hungary	0.843	0.355	2	neutrality
Italy	0.788	0.665	3	neutrality
Japan	0.266	0.342	1	neutrality
Sweden	0.569	0.529	1	neutrality
United Kingdom	0.439	0.496	1	neutrality

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level, p-values are presented in the table.

Based on the Johansen cointegration test and Granger causality test results, it was found that in countries with no cointegration between two time-series, no causality was present. In countries where both trace and max-eigenvalue statistics showed at least one cointegration equation, unidirectional or bidirectional causality was found. The only exception is Austria, where energy consumption and economic growth were found to be cointegrated, but no causality was found. This could be explained either by some omitted variables that have an impact on both total energy consumption and economic growth or by the presence of major financial and energy shocks. The results of an OLS regression show that a one unit increase in energy consumption will raise GDP by 1.36 units in Australia, 1.59 units in France, 1.85 units in Ireland, 1.32 units in Netherlands, 0.85 units in Spain. If GDP increases by 1 unit, then energy consumption will increase by 0.1 units in Germany, 0.51 units in Ireland and Italy, 1.54 units in Mexico, 1.14 units in Spain, 1.55 units in Turkey. In the case of US, a one unit increase in GDP would lead to a 0.72 increase in energy consumption, but the result is not significant (p-value of 0.32).

ARDL Approach. The Bounds Tests

As described above, the cointegration analysis is not necessary in the TY procedure; it serves as a cross-check of the validity of the causality results. While some studies use the Bounds test as the primary procedure to determine whether variables are cointegrated, this paper uses it as a supplementary procedure to check whether the series where energy consumption and economic growth are integrated of different orders have a long-run relationship. Applying the Bounds test after determining the direction of causality, simplifies the task, as it becomes evident which variable should be a dependent variable. If energy consumption Granger-causes economic growth, then the following model will be estimated:

$$\Delta Y_t = \beta_0 + \Sigma\, \beta_i \Delta Y_{t-i} + \Sigma \gamma_j \Delta EC_{t-j} + \vartheta_0 Y_{t-1} + \vartheta_1 EC_{t-1} + e_t \quad (13)$$

If economic growth Granger-causes energy consumption, then the estimated model is:

$$\Delta EC_t = \beta_0 + \Sigma\, \beta_i \Delta EC_{t-i} + \Sigma \gamma_j \Delta Y_{t-j} + \vartheta_0\, EC\ t\text{-}1 + \vartheta 1\ Yt\text{-}1 + e_t \quad (14)$$

If bidirectional causality is found, then to model the long-run relationship, a simultaneous equations model will be used by applying either two-stage least squares (2SLS), three-stage least squares (3SLS) or full information maximum likelihood (FIML).

Equation (13) will be estimated in Belgium, and equation (14) will be used in Canada, based on the causality results. Since no causality was found in the case of Japan, the ARDL approach will not be implemented.

Table 13 represents the results of the Bounds Test. Based on F-statistic and p-value, there is enough evidence to suggest a long-run relationship between economic growth and energy consumption in Belgium and Canada at 1%, 5% and 10% level of significance.

In addition, based on the coefficient of the unrestricted ECM, the long-run multiplier was found in each country. In the long-run in Belgium, an increase of 1 unit in total energy consumption will lead to an increase of 0.8 units in GDP. In Canada an increase of 1 unit in GDP will lead to an increase of 7.1 units in energy consumption.

Table 13: Bounds Test Results

Country	Dependent variable	F-stat	p-value
Belgium	ΔY	11.08	0.0001***
Canada	ΔEC	13.99	0.0000***

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level

Although the purpose of this section was in determination of the long-run relationship, the short-run dynamics was also examined in these two countries by estimating a “restricted” ECM. The following model was estimated in Belgium:

$$Yt=a0+a1ECt+vt \quad (15)$$

In Canada, the “restricted” ECM was estimated:

$$ECt=a0+a1Yt+vt \; (16)$$

The short-run relationship was found between two time-series in Belgium, and it was determined that 11% of any disequilibrium between GDP and total energy consumption is corrected with one year. While in Canada, nearly 17% of any disequilibrium between total energy consumption and economic growth is corrected within one year.

4.5 Total Energy Consumption and Economic Growth from 1965 to 2004

In this section the relationship between energy consumption and economic growth from 1965 to 2004 was studied. The results are expected to be approximately the same, but as described in the literature overview, many papers that have attempted to test causal relationship in the same countries but with different time span found different results.

Unit Root Test and Cointegration

The Phillips-Perron unit root test and Cointegration analysis were performed for the new sample from 1965 to 2004. Table 14 shows the results of the Phillips-Perron test for the energy consumption and economic growth series.

Table 14: Phillips-Perron Unit Root Test Results

Country	Energy Consumption		Economic Growth	
	levels	first difference	levels	first difference
Australia	-2.46	-4.92***	-2.02	-5.44***
Austria	-2.26	-8.10***	-2.32	-5.77***
Belgium	-7.69***		-2.28	-5.89***
Canada	-3.58**		-2.45	-4.56***
Denmark	0.66	-6.67***	-2.97	-5.55***
Finland	-6.10***		-1.80	-3.31**
France	-2.52	-5.64***	-2.79	-4.56***
Germany	-1.96	-6.47***	-1.21	-4.39***
Greece	-2.43	-4.73***	-2.59	-4.20***
Hungary	-1.27	-4.62***	-2.40	-2.96**
Ireland	-1.94	-10.71***	-1.09	-3.55**
Italy	-4.06**		-2.21	-6.14***
Japan	-4.01**		-2.37	-4.53***
Mexico	-1.09	-8.77***	-1.90	-4.90***
Netherlands	-2.97	-5.93***	-2.29	-4.07***
Norway	-1.43	-23.77***	-1.45	-3.82**
Spain	-3.33*	-6.35***	-2.63	-3.23**
Sweden	-2.63	-6.34***	-2.04	-3.51*
Turkey	-1.92	-6.17***	-3.32*	-6.57***
United Kingdom	-2.82	-8.34***	-2.26	-4.66***
US	-3.01	-5.70***	-2.95	-10.77***

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level

As it can be seen, economic growth is still I(1) in all countries which is consistent with the previous section's findings. Energy consumption series are still found to be stationary in Belgium, Canada and Japan. On the contrary, energy consumption in Italy and Finland for the period of 1965 to 2004 is found to be stationary while the full sample's analysis indicated it being I(1). Therefore, the Johansen cointegration test will not be implemented in these four countries, and ARDL approach will be used if unidirectional causality is found. Since none of the series are I(2), then the maximum lag length is 1 in all cases.

The results of the Johansen Cointegration test are shown in the table below. In Austria, France, Ireland, Spain, and US both trace and max-eigenvalue indicated that two series are cointegrated. In Hungary, Mexico, Netherlands, and Norway, only trace statistic showed that energy consumption and economic growth are cointegrated. No cointegration was found in other countries.

Table 15: Johansen Cointegration Test Results

	Trace Statistics		Max-Eigenvalue Statistic	
Country	None	At most 1	None	At most 1
Austria	22.43***	5.08**	17.35**	5.08**
US	28.17***	10.53**	17.64**	10.53**
France	24.65*	7.30	17.35*	7.30
Ireland	20.75***	1.05	19.70***	1.05
Hungary	15.84**	4.75**	11.09	4.75
Spain	18.36*	3.32	15.04*	3.32
Mexico	13.96*	5.12**	8.84	5.12
Netherlands	23.74*	8.97	14.77	8.97
Norway	13.45*	1.70	11.75	1.70
Turkey	16.72*	4.36**	12.36	4.36
Australia	12.92	0.67	12.25	0.67
Denmark	11.14	0.28	10.86	0.28
Germany	11.60	2.39	9.21	2.39
Greece	10.53	4.67	5.85	4.67
Sweden	10.09	0.35	9.74	0.35
United Kingdom	6.46	0.00	6.46	0.00

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level

The results in most countries are consistent with the ones from 1965 to 2011. The results differ in Australia, Denmark, Germany where cointegration was found in the period from 1965 to 2011, and no cointegration was present in the period estimated in this section, while in Ireland energy consumption and economic growth are cointegrated in the period from 1965 to 2004 unlike the full time span.

Granger Causality

Based on the Granger causality results shown in Table 16, unidirectional causality was found running from economic growth to energy consumption in Austria, Canada, Hungary, Italy, Mexico, Spain, Turkey and US. In Belgium and Japan, energy consumption Granger-causes economic growth. In Ireland, bidirectional causality was found between energy consumption and economic growth. Other countries support the neutrality hypothesis. Referring back to the cointegration section, it was determined that two time-series were cointegrated and unidirectional or bidirectional causality was found in the case of Austria, Hungary, Ireland, Mexico, Spain, Turkey and US. Although the Johansen cointegration test indicated presence of the a long-run relationship between energy consumption and economic growth at 10% level of significance, no causality was found between two time-series in Norway, Netherlands and France.

Coefficients of a simple OLS regression suggest that a one unit increase in energy consumption would raise GDP by 1.72 in Ireland and 0.58 units in Turkey, while a one unit increase in GDP would raise energy consumption by 0.59 units in Austria, 0.56 units in Hungary and Ireland, 1.63 units in Mexico, 1.2 units in Spain, and 1.43 units in US. Comparing these results to the full sample results, in the case of Ireland the impact of raising energy consumption is about 7% smaller in the period of 1965 to 2004, while in Mexico and Spain, higher GDP has a greater impact on energy consumption in the smaller sample (5% in Spain and Mexico). In the case of US, the result was found significant of 5% and 10% level, while the result in the full sample was found not significant (p-value of 0.32).

ARDL Approach. The Bounds Tests

The unit root test results indicated that four countries were integrated of different orders – Belgium, Canada, Italy and Japan. Therefore, the Johansen cointegration test was not performed. After testing for causality, it was determined that in Belgium and Japan unidirectional causality was found running from energy consumption to economic growth, therefore, energy consumption will be a dependent variable, equation (13) will be estimated. In Canada and Italy unidirectional causality was found running from economic growth; therefore energy consumption will be a dependent variables in the ARDL approach, and equation (14) will be estimated.

The results of the Bounds test are shown in Table 17. As it can be seen since the p-value is less than 1%, 5% and 10%, there is enough evidence of a long-run relationship between energy consumption and economic growth in Belgium, Canada, Italy and Japan.

Table 16: Granger Causality Test Results

Country	Ln(EC)→Ln(Y)	Ln(Y)→Ln(EC)	Number of lags	Direction of causality
Austria	0.44	0.08*	3	Y to EC
Canada	0.86	0.03**	2	Y to EC
Hungary	0.97	0.01***	2	Y to EC
Italy	0.59	0.09*	1	Y to EC
Mexico	0.24	0.05**	1	Y to EC
Spain	0.88	0.07*	2	Y to EC
Turkey	0.14	0.04**	1	Y to EC
US	0.68	0.07*	4	Y to EC
Belgium	0.01***	0.78	1	EC to Y
Japan	0.07*	0.27	1	EC to Y
Ireland	0.04**	0.00***	2	bidirectional
Australia	0.30	0.30	1	neutrality
Denmark	0.27	0.44	1	neutrality
Finland	0.18	0.47	3	neutrality
France	0.29	0.88	1	neutrality
Germany	0.58	0.90	1	neutrality
Greece	0.54	0.98	1	neutrality
Netherlands	0.33	0.17	1	neutrality
Norway	0.59	0.90	2	neutrality

Sweden	0.21	0.40	1	neutrality
United Kingdom	0.54	0.17	1	neutrality

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level

In addition, based on the coefficient of an unrestricted ECM estimated for each country, it was determined that a 1 unit increase in energy consumption will lead to an increase of 0.79 units in economic growth in Belgium, and 0.24 units in Japan. Furthermore, it was determined that in the long run, a 1 unit increase in GDP will lead to an increase of 2.81 in energy consumption in Italy, and 5.22 in Canada.

The short-run dynamic was investigated in the countries mentioned above. A restricted ECM was estimated in Belgium and Japan based on equation (15) and in Canada and Italy based on (16). It was determined that about 8% of any disequilibrium between energy consumption and economic growth was corrected within one year in Belgium, 19% in Canada, and 10% in Italy. No short-run relationship was found in Japan based on the restricted error correction model.

Table 17: Bounds Test Results

Country	Dependent variable	F-stat	p-value
Belgium	ΔY	6.84	0.0033***
Canada	ΔEC	11.34	0.0002***
Italy	ΔEC	6.23	0.0056***
Japan	ΔY	13.65	0.0001***

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level

4.6 Summary of Granger Causality Results and Policy Implications

Table 18 summarizes the causality results based on different type of energy, and the sample size in the case of total energy consumption. As it can be seen from Table 18, the results are consistent based on the neutrality hypothesis in Denmark, Finland, Sweden, and United Kingdom. Based on these results, it can be concluded that there are either energy sources not studied in this paper or other variables that have a greater impact on economic growth. Table 19 shows oil, coal and natural gas as a share of total energy consumption for each country.

Summarizing the results, the following conclusions can be made. In US, unidirectional causality running from economic growth to energy consumption was found. Taking in consideration that the share of oil, coal and natural gas consumption are similar, with higher oil consumption (37%, 28% and 22% respectively), the results are reasonable. In Austria oil consumption is also represented by the greatest share (39%) and unidirectional causality was found in the case of oil consumption. The same direction of causality was present in the case of total energy consumption from 1965 to 2004. On the other hand, no causality was found in the case of coal, natural gas, and total energy consumption from 1965 to 2011. Although a natural gas consumption is the second highest type of energy consumption, reducing the sample size could have affected the results of causality testing. Only 8% of energy consumption comes from coal, therefore, no causality between coal consumption and economic growth seems reasonable. Similar results were found in Belgium, Canada, Germany, Greece, Hungary, Italy, Ireland, Netherland, Norway, Spain and Turkey. In France unidirectional causality was found running from energy consumption to economic growth only in the case of total energy consumption from 1965 to 2011. This can be explained by its large reliance on nuclear energy that was not investigated in this study. In Japan, unidirectional causality running from natural gas consumption to economic growth and unidirectional causality running from economic growth to coal consumption were found. In addition, no causality was found between total energy consumption between 1965 and 2011, but unidirectional causality running from energy consumption to economic growth for the period of 1965 to 2004 was found. Similarly to France, this can be explained by Japanese reliance on nuclear energy.

Table 18: Summary of Granger Causality Results

Country	Oil Consumption	Coal Consumption	Natural Gas Consumption	Total Consumption 1965-2011	Total Consumption 1965-2004
Australia	neutrality	neutrality	Y↔EC	EC→Y	neutrality
Austria	Y→EC	neutrality	neutrality	neutrality	Y→EC
Belgium	EC→Y	neutrality	neutrality	EC→Y	EC→Y
Canada	EC→Y	neutrality	Y→EC	Y→EC	Y→EC
Denmark	neutrality	neutrality	NA	neutrality	neutrality
Finland	neutrality	neutrality	NA	neutrality	neutrality
France	neutrality	neutrality	neutrality	EC→Y	neutrality
Germany	neutrality	Y→EC	NA	Y→EC	neutrality
Greece	Y→EC	EC→Y	NA	neutrality	neutrality
Hungary	neutrality	Y→EC	neutrality	neutrality	EC→Y
Ireland	Y→EC	EC→Y	NA	Y↔EC	Y↔EC
Italy	neutrality	neutrality	neutrality	Y→EC	Y→EC
Japan	neutrality	Y→EC	EC→Y	neutrality	EC→Y
Mexico	neutrality	Y→EC	Y↔EC	Y→EC	Y→EC
Netherlands	neutrality	neutrality	neutrality	EC→Y	neutrality
Norway	neutrality	neutrality	NA	Y→EC	neutrality
Spain	Y→EC	neutrality	Y→EC	Y↔EC	Y→EC
Sweden	neutrality	neutrality	NA	neutrality	neutrality
Turkey	Y→EC	neutrality	NA	Y→EC	EC→Y
United Kingdom	neutrality	neutrality	neutrality	neutrality	neutrality
US	Y→EC	Y→EC	Y→EC	Y→EC	Y→EC

As Table 18 shows, the causal relationship is different across countries. Although only developed countries were studied in this paper, each country has its own economic policies and energy structure. While oil consumption represents the biggest share in total energy consumption in almost every country, followed by natural gas and coal, there are other sources such as nuclear energy that are not considered in this study, that could have affected the results in countries like Belgium, Canada, Finland, France, Germany, Japan, Spain, Sweden, UK and US (World Nuclear Association).

Table 19: Sources of Energy Consumption as a Share of Total Energy Consumption

Country	Oil	Natural gas	Coal
Australia	37%	19%	40%
Austria	39%	27%	8%
Belgium	53%	23%	3%
Canada	31%	29%	7%
Denmark	44%	20%	17%
Finland	38%	12%	12%
France	34%	15%	4%
Germany	36%	21%	25%

Greece	56%	13%	24%
Hungary	29%	40%	12%
Ireland	51%	31%	9%
Italy	42%	38%	9%
Japan	42%	20%	25%
Mexico	52%	36%	6%
Netherlands	52%	36%	8%
Norway	26%	8%	1%
Spain	48%	20%	10%
Sweden	29%	2%	4%
Turkey	27%	35%	27%
United Kingdom	36%	36%	16%
US	37%	28%	22%

Based on the direction of causality between total energy consumption and economic growth, the following policy implications can be made. In countries were unidirectional causality runs from energy consumption to economic growth (Australia, Belgium, France, and Netherlands) energy consumption stimulates economic growth. Although energy consumption is not the only factors that determines economic growth, it is important that the governments increase investment in energy sector and reduce inefficiency in the supply and use of energy. In addition, energy conservation policies aimed to control raising emissions of carbon dioxide in countries that heavily rely on coal and oil would adversely affect economic growth. At the same time, switching to clean energy sources and improving energy efficiency may promote economic development in these countries.

In countries where unidirectional causality was found running from economic growth to energy consumption (Canada, Germany, Italy, Mexico, Norway, Turkey and US), economic growth stimulates energy consumption. Considering that economies will continue to grow, energy consumption will increase based on this hypothesis; this will result in higher emissions of carbon dioxide. Although energy conservation policies can be applied without negatively affecting economic development, in practice, however, reducing energy consumption may not be viable due to growing energy demand. Raising energy efficiency could be one of the strategies to reduce the amount of energy consumed. It is important to note that such a policy cannot be applied without further investigation of other environmental and economic factors.

Bidirectional causality was found in Ireland and Spain. Therefore, energy consumption promotes economic growth and vice versa. This suggests that total energy consumption and economic growth are complements. In this case the adverse effect of energy conservation measure on economic development which in turn have a negative impact on energy consumption should be considered. As it was suggested before, if the goal of policymakers to lower emissions, then demand and supply of alternative energy sources should be stimulated.

In other countries where no causal relationship was found, energy consumption does not have a significant impact on economic growth. Hence, energy conservation policies can be applied without jeopardizing economic growth.

4.7 Panel Cointegration

Breitung's unit root test was used in this paper as it performs better when cross-sectional dependence is present. Table 20 shows the results of a panel unit root test in levels and first difference. It is important to note that two different GDP variables were used – the first GDP variable was the same for oil, coal and total energy consumption, and due to fewer countries and a different time span estimated in the case of natural gas consumption, GDP series were different. All variables are integrated of first order, with a unit root present in levels at 1%, 5%, and 10% level of significance, and variables becoming stationary in first difference.

Table 20: Panel Unit Root Test Results

Variable	level	1st difference
GDP	0.99	0.00***
Total Energy Consumption	0.97	0.00***
Total Energy Consumption[1]	0.88	0.00***
Oil Consumption	0.99	0.00***
Coal Consumption	0.98	0.00***
Natural Gas Consumption	0.99	0.00***
GDP[2]	0.99	0.00***
GDP[3]	0.89	0.00***

[1]Total Energy Consumption from 1965 to 2004
[2] GDP used in the case of natural gas consumption with fewer countries and a different time span
[3] GDP series from 1965 to 2004

Since all variables were found I(1), techniques proposed above – Engle and Granger based Pedroni and Kao cointegration tests were used. Table 21 shows the results of Pedroni and Kao cointegration test results.

Table 21: Pedroni and Kao Cointegration Test Results

	ln(OC); ln(Y)	ln(CC); ln(Y)	ln(EC); ln(Y) 1965-2011	ln(NGC); ln(Y)	Ln(EC);LN(Y) 1965-2004
Engle and Granger based Pedroni cointegration test					
Common AR coefficients					
Panel v-Statistic	0.007***	0.357	0.000***	0.000***	0.190
Panel rho-Statistic	0.002***	0.162	0.373	0.037**	0.009***
Panel PP-Statistic	0.000***	0.07*	0.184	0.009***	0.000***
Panel ADF-Statistic	0.015**	0.608	0.031**	0.480	0.519
Individual AR coefficients					
Group rho-Statistic	0.064*	0.570	0.371	0.270	0.088*
Group PP-Statistic	0.000***	0.351	0.106	0.049**	0.000***
Group ADF-Statistic	0.005***	0.742	0.032**	0.643	0.282
Engle and Granger based Kao cointegration test					
t-Statistic	-4.184	-0.525	-0.022	-0.590	-2.761
p-value	0.000***	0.300	0.491	0.278	0.003***

Where *** represents acceptance of the null hypothesis at 1% level, ** 5%, and * 1% level

As it can be seen from the table above, based on every statistic, in the case of oil consumption and economic growth, a null hypothesis of no cointegration is rejected in favor of the alternative hypothesis at 1% (except for panel ADF-statistic), 5% (except for group rho-Statistic), and 10% level of significance. Therefore, it can be concluded that oil consumption and economic growth are cointegrated or have the long-run equilibrating relationship. Modeling the long-run equilibrating relationship the following results were found: a one unit increase in oil consumption will raise GDP by 0.95 units, and a one unit increase in GDP will raise oil consumption by 0.66 at 1%, 5%, and 10% level of significance (p-value equal to 0.000).

In the case of coal consumption, only panel PP-statistic found that variables are integrated at 10% level of significance which indicates that coal consumption and economic growth are not cointegrated. Panel v-Statistic, PP-Statistic, rho-Statistic and group PP-Statistic found that natural gas consumption and economic growth are cointegrated at 1%, 5% or 10% level of significance. Estimating an OLS regression, it was found that a one unit increase in natural gas consumption will raise GDP by 0.23, while raising GDP by 1 unit will increase natural gas consumption by 0.766 units at 1%, 5% and 10% level of significance.

In the case of total energy consumption and economic growth from 1965 to 2011, panel v-Statistic, ADF-Statistic, and group ADF-Statistics reject the null hypothesis of no cointegration, while other statistics, including Kao t-Statistic suggest that total energy consumption and economic growth are not cointegrated. Considering that total energy consumption and economic growth are cointegrated and estimating a simple OLS regression, it was found that a one unit increase in total energy consumption leads to an increase of 0.86 in GDP in the panel of OECD countries estimated, while a one unit increase in GDP will raise total energy consumption by 0.79 units. Both coefficients were found significant at 1%, 5% and 10% (p-value of 0.000). When a smaller sampler was estimated, panel, group rho-Statistic, PP-Statistic, and Kao t-statistic suggest that energy consumption and economic growth are cointegrated from the period of 1965 to 2004. Based on the results of OLS regression, a one unit increase in total energy consumption will lead to an increase in GDP of 0.84, while a one unit increase in GDP will raise energy consumption by 0.82 units. Both coefficients were also found significant with p-value of 0.000 in each case.

5. Conclusion

The purpose of this research is to determine causal relationship between different measures of energy consumption and economic growth in a panel of 21 OECD countries from 1965 to 2011. Modern time-series techniques were employed by this paper – a standard Granger causality test was replaced with Toda and Yamamoto procedure, and a long-run equilibrating relationship in series integrated of different orders was found with Autoregressive Distributed Lag approach and the Bounds test.

The main conclusion is that causality and cointegration results are not uniform across countries and measures of energy consumption. This can be explained by different economic, energy policies and structures in each country. The results showed that in the case of coal consumption and economic growth, causal relationship was found only in 6 countries. Unidirectional causality was found running from economic growth to energy consumption in Germany, Hungary, Japan, Mexico and US. Hence, higher GDP will increase coal consumption in these countries. This brings an environmental concern; coal is the main source of energy that result in a higher emissions of carbon dioxide. From the energy policy prospective, raising efficient energy use or improving coal burning power plants could solve the problem of the emissions of greenhouse gases. In Ireland and Greece unidirectional causality running from coal consumption to economic growth was found. Although energy consumption is only one of the factors that affect economic growth, in these countries problems associated with coal consumption shortage or infrastructure would adversely affect economic growth. At the same time, if the goal of these countries to conserve energy by reducing coal consumption, then economic development will also be adversely affected.

No causality was found in other countries. Thus, coal consumption has little impact on economic development and vice versa. In 8 countries causal relationship between oil consumption and economic growth was found. Unidirectional causality from economic growth to energy consumption was found in Austria, Greece, Ireland, Spain, Turkey and US was found. Only in Belgium and Canada unidirectional causality running from energy consumption to economic growth was found. Fewer countries were estimated in the case for natural gas consumption. In Canada, Spain and US unidirectional causality running from economic growth to natural gas consumption was found. Causality testing results are especially interesting in Japan were natural gas consumption stimulates economic growth. Since Japan is planning to reduce its reliance on nuclear energy, switching to natural gas not only provide a cleaner alternative compare to oil and coal, but also will stimulate its economic development.

The relationship between total energy consumption and economic growth was estimated for two periods – from 1965 to 2011, and 1965 to 2004. The second period was chosen to exclude the impact of oil prices peaking in 2006 and global financial crisis. In 11 countries the relationship was found consistent. In Canada, Italy, Mexico and US unidirectional causality from economic growth to energy consumption was found. In Belgium the opposite direction was present. In Ireland bidirectional causality was found in both samples. In countries such as Denmark, Finland, Greece, Sweden and UK, no causality was found between two series. Other 10 countries indicate different relationship between energy consumption and economic growth. In Australia, France, Germany, Netherlands and Norway, estimation of the period of 1965 to 2011 showed unidirectional causality, but when a different time span was studied, no causality was found. The opposite trend was found in Austria, Hungary and Japan was found. This can be explained either by the impact of the financial crises and higher oil prices or by other economic and environmental variables that were not included in the analysis.

This paper also performed panel data unit root tests and panel cointegration tests for each measure of energy consumption and economic growth. Breitung unit root test determined that each series was integrated of first order. Engle and Granger based Kao and Pedroni tests were employed to determine presence of long-run equilibrating relationship. While oil consumption and economic growth were cointegrated based on all statistics, only one statistic showed presence of cointegration between coal consumption and economic growth. More statistics suggested that natural gas consumption and economic growth are cointegrated. The results are different in the case for total energy consumption and economic growth. Based on the period of 1965 to 2004, 5 statistics rejected the null hypothesis of no cointegration, while only 3 found long-run equilibrating relationship in the full sample.

This paper is a starting point in a further investigation of causal relationship to completely understand it and suggest more specific policies for each country. In addition, for further study of Granger causality, adding other economic and environmental factors such as energy prices, employment, and emissions of carbon dioxide would result in more reliable results. In addition, a comparison analysis of causality results in OECD and non-OECD countries would be interesting to perform.

Appendix

Appendix 1: Results of OLS regression from a panel and each country individually

Table a1: Regression results. Oil Consumption and Economic Growth

Country	Coefficient	t-Statistic	P-value	Dependent Variable
Oil Consumption				
Austria	1.24	2.11	0.04	Y
Belgium	1.08	5.42	0.00	Y
Greece	1.21	20.76	0.00	OC
Spain	0.94	14.67	0.00	OC
Turkey	0.86	10.44	0.00	OC
US	1.76	11.04	0.00	OC

Table a2: Regression results. Natural Gas Consumption and Economic Growth

Country	Coefficient	t-Statistic	P-value	Dependent Variable
Natural Gas Consumption				
Australia	2.11	6.58	0.00	NGC
Australia	0.24	6.58	0.00	Y
Canada	0.95	18.08	0.00	NGC
Japan	0.28	28.49	0.00	Y
Mexico	0.52	23.15	0.00	Y
Mexico	1.73	23.15	0.00	NGC
US	1.62	10.32	0.00	NGC

Table a3: Regression results. Coal Consumption and Economic Growth

Country	Coefficient	t-Statistic	P-value	Dependent Variable
Coal Consumption				
Germany	1.05	12.17	0.00	CC
Greece	0.54	8.93	0.00	Y
Ireland	0.55	3.39	0.01	Y
Japan	0.58	9.86	0.00	CC
Mexico	2.14	15.74	0.00	CC
US	0.31	8.39	0.00	CC

Table a4: Regression results. Total Energy Consumption and Economic Growth from 1965 to 2011

Country	Coefficient	t-Statistic	P-value	Dependent Variables
Total Energy Consumption		*1965-2011*		
Australia	1.36	16.92	0.00	Y
France	1.59	17.86	0.00	Y
Germany	0.10	3.06	0.00	EC
Ireland	1.85	27.78	0.00	Y
Ireland	0.51	27.78	0.00	EC
Italy	0.51	16.78	0.00	EC
Mexico	1.54	29.57	0.00	EC
Netherlands	1.32	9.31	0.00	Y
Spain	1.14	42.00	0.00	EC
Spain	0.85	42.00	0.00	Y
Turkey	1.55	44.81	0.00	EC
US	0.72	1.00	0.32	EC

Table a5: Regression results. Total Energy Consumption and Economic Growth from 1965 to 2004

Country	Coefficient	t-Statistic	P-value	Dependent Variables
Total Energy Consumption		*1965-2004*		
Austria	0.59	25.51	0.00	EC
Hungary	0.56	13.43	0.00	EC
Ireland	0.56	28.78	0.00	EC
Ireland	1.72	28.78	0.00	Y
Mexico	1.63	28.01	0.00	EC
Spain	1.20	38.45	0.00	EC
Turkey	0.58	48.16	0.00	Y
US	1.43	2.18	0.03	EC

Table a6: Regression results. Panel of 21 OECD countries from 1965 to 2011

Dependent Variable	Coefficient	t-Statistic	p-value
	Total Energy 1965-2011		
EC	0.79	45.27	0.00
Y	0.86	45.27	0.00
	Total Energy 1965-2004		
EC	0.82	43.95	0.00
Y	0.84	43.95	0.00
	Natural Gas		
NGC	0.766	11.87	0.00
Y	0.23	11.87	0.00
	Oil Consumption		
OC	0.66	40.84	0.00
Y	0.95	40.84	0.00

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