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# Energy and economic growth in G20 countries : panel cointegration analysis

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# Energy and economic growth in G20 countries: Panel cointegration analysis

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## Abstract

Rising economic performance has enlarged energy demand, carbon emissions and global warming. Policy makers need to avoid global warming. Therefore, energy-growth nexus is important. This paper empirically investigates the relationship between energy consumption and economic growth for a panel of G20 countries over the period 1990-2016. For this purpose, the paper considers the panel cointegration and panel vector error correction model. Panel cointegration test set out a long-run equilibrium relationship. Long-run relationship is estimated using a Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS). Panel Granger causality and Vector Error Correction Model results show that bidirectional relationship between energy consumption and GDP. It is indicates that "feedback hypothesis" is valid for G20 countries.

*Keywords*: economic growth; energy consumption; panel unit-root; panel Granger causality; cointegration
*JEL Classification Codes*: C33, O44, Q43

## 1. Introduction

Energy is a key factor of the economy. Increasing economic growth hasgrowed energy demand, carbon emissions and global warming.Global warming has forced policymakers to take measures. The measures to reduce energy demand may affect on economic growth.Therefore energy-growth relation is important in the literature. Previous research on energy-growth nexus was widely conducted for countries in Austria, Belgium, Greece, Denmark, France, Italy, Canada, United Kingdom, Cyprus, Italy, Spain, Turkey, New Zealand, Norway and European, OECD, G-7, Asian, Eurasian, BRICTS and Mediterranean countries. Energy-growth literatures are very limited in G20 countries. The G20, created in 1999, covers 19 countries and the European Union. They cover about 85% of the global economic output, 80% of primary energy consumption and global greenhouse gas emissions, 75% of international trade and 66% of the world's population.

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The link among energy consumption and economic growth categorized four hypotheses (Squalli, 2007). The growth hypothesis means that energy consumption provides to economic growth. In energy-dependent economy, shortage of energy may negatively affect to growth.The conservation hypothesis represents that there is unidirectional causality running from economic growth to energy consumption. In less energy-dependent economy, energy conservation policies have no effects on economic growth. The feedback hypothesis argued that there is bidirectional relationship among energy consumption and economic growth. The neutrality hypothesis assumes no link between energy consumption and economic growth. Therefore, energy conservation policies do not affect economic growth.

The study aim is empirically investigates the relationship between energy consumption and economic growth in G20 countries over the period 1990-2016 using panel cointegration, Fully Modified Ordinary Least Square (FMOLS), Dynamic Ordinary Least Square (DOLS) and panel vector error correction model (PVECM). The study contributes to the literature on energy-growth nexus in G20 countries and estimate FMOLS and DOLS estimation for the long-run. It was used GDP growth (annual, %), energy use (kg of oil equivalent per capita), laborforce (total, million) and gross capital formation (% of GDP).

The earliest work of Kraft and Kraft (1978) drived concern in the energy-growth nexus. The debate has been extended to electricity-growth, clean energy-growth and others. Previous research on energy-growth nexus was widely conducted for country/country groups in Austria, Belgium, Greece, Denmark, France, Italy, Canada, United Kingdom, Cyprus, Italy, Spain, Turkey, New Zealand, Norway, Eastern and Southeastern European, G-7 countries, Asian countries, Eurasian countries, BRICTS, South Mediterranean countries.

There are some researches about energy-growth nexus in G20 countries, covered some OECD and EU countries. Yildirim and Aslan (2012) investigate the relation among economic growth, energy consumption, employment and gross fixed capital formation in 17 OECD countries using Toda-Yamamoto framework and bootstrap-corrected causality. The study show that there is bidirectional relationship in Italy, New Zealand, Norway and Spain and feedback hypothesis is valid for these countries. Ucan et al. (2014) analyzed the link between renewable and non-renewable economic growth and energy consumption in EU-15 over the period 1990-2011. Granger causality results represent unidirectional causality between nonrenewable energy consumption and economic growth. Pala (2016) investigates that to find out which energy-growth hypothesis is valid in OECD countries for the period 1995-2013. Granger causality and VECM results suggest that there is evidence bidirectional relation between energy consumption and economic growth in the short-run.

Howarth (2017) researched the relationship between energy consumption (sector level) and economic growth in the GCC. They found that energy consumption and economic growth are strongly linked to all sectors in the GCC. Gozgor et al. (2018) show that renewable and non-renewable energy consumption positively affect on economic growth. Özcan and Özkan (2018) investigate the long-run and causal relationships between energy consumption, economic growth and energy intensity in G20 countries. Results show that it has unidirectional causality from energy intensity to economic movement.

Previous researches used different econometric methods. Oh and Lee (2004a,b), Apergis and Payne (2010a), Yoo (2006), Soytas and Sari (2007), Constantini and Martini (2010), Salahuddin and Gow (2014), Solarin and Ozturk (2016), Bozoklu and Yilanci (2013), Belke et al. (2011) used Granger causality. Fatai et al (2004), Sari et al. (2008), Kumar and Shahbaz (2012) and Bildirici and Kayıkçı (2012) used ARDL test. Lee and Chang (2008), Kumar and Shahbaz (2010), Bildirici and Kayıkçı (2012), Ozturk and Al-Mulali (2015) used FMOLS. Lee and Chang (2007), Coers and Sanders (2013) used ECM and/or VECM. And Omri and Kahouli (2014b) used GMM estimator, Yildirim et al. (2012) used the Hatemi-J test.

In the study, it was used variables as economic growth, energy consumption, labor force and capital formation for the period of 1990-2016 and methods of slope homogeneity test, cross-sectional dependence (CD) test, CADF panel unit root test, cointegration tests and FMOLS, DOLS long-run estimation and VECM. To examine link between energy consumption and economic growth, we follow the aggregate production function used by Oh and Lee (2004 a,b).

This study has differences from other works in the energy-growth literature in some respects. Firstly, the sample includes all of G20 countries. Secondly, we used Pesaran and Yamagata (2018) slope homogeneity test; Pesaran (2004), Friedman (1937) and Frees (1995), Breusch and Pagan (1980), Chudik and Pesaran (2015), Pesaran (2004) scaled LM, Pesaran (2015) and Baltagi (2012) bias-corrected scaled LM cross-sectional dependence tests, Pesaran CADF Panel Unit Root Test; Pedroni (2004), Westerlund (2007), Westerlund and Edgerton (2008) and Kao (1999) panel cointegration tests, long-run estimation (FMOLS, CRR and DOLS) methodologies.

In the study, Section 2 contains literature, Section 3 represents data, econometric methodology and results, and Section 4 introduce conclusions.

## 2. Literature review

The literature on energy-growth nexus is examined under four views. The first studies based on Granger causality (Granger, 1969) and VAR methodology (Sims, 1972) assumed the data series were stationary. Kraft and Kraft (1978) revealed proof of causality from income to energy consumption.

Second generation studies consider nonstationarity, implemented Engle-Granger two-step procedure (Granger, 1987) for cointegration. Third generation literature examined multivariate estimators (Johansen, 1991). Masih and Masih (1996), Stern (2000) and Oh and Lee (2004) studies allowed more over two variables testing for cointegration. Paul and Bhattacharya (2004) implement Johansen multivariate cointegration method to analze link among energy demand, economic performance, capital and employment. Results revealed there is bidirectional causal link energy usage and economic performance. Panel unit-root, cointegration and Granger causality tests have been applied in fourth generation literature. Constantini and Martini (2010) proved bidirectional causal relation between energy usage and economic performance for 71 countries using panel vector error correction model.

Soytas and Sari (2006) and Narayan et al. (2010) found that there is unidirectional relation running from economic growth to energy usage in France, Austria, Denmark and Belgium respectively. These studies confirmed the conservation hypothesis. Zachariadis (2007) researched link between energy and growth in UK and Canada. It has been found unidirectional relation, namely, the link from economic growth to energy consumption. Lee and Chang (2008) studied the relationship between energy usage and economic performance in Asian countries using cointegration. The findings showed a relation from energy consumption to economic growth in long-run. Lee et al. (2008) investigated the relation between energy usega and GDP in selected OECD countries applying panel cointegration. Results show bidirectional relationship is valid for these countries. Ozturk et al. (2010) study the causal relationship in 51 countries and found the feedback hypothesis is verified in middle income countries. Apergis and Payne (2010b) investigated the link energy-growth in 13 Eurasian countries applying multivariate panel model. According to the results, feedback hypothesis is verified for Eurasian countries. Apergis and Payne (2010a) represent there is valid feedback hypothesis for 20 OECD countries. Narayan et al. (2010) found unidirectional relation from energy consumption to economic growth for Cyprus, Italy, Spain, Turkey and UK. Results confirmed the growth hypothesis for five countries. Ozturk and Acaravci (2010a) investigated causal relation about energy-growth using ARDL in four European countries and Turkey. It has found that. It approved the neutarility hypothesis, namely, there is no causal relationship between energy usage and economic performance.

Hatzigeorgiou et al. (2011) employed long-run causality relationship among energy-CO2-growth in Greece using Johansen cointegration, Granger causality and VECM. Results represent that there are unidirectional and bidirectional relationship among variables. Belke et al. (2011) examined energy-growth nexus using dynamic panel causality in 25 OECD countries. Results indicated the presence of a bidirectional link between variables. Yildirim and Aslan (2012) investigate the relationship between energy consumption and economic growth using Toda-Yamamoto procedure and bootstrap-corrected causality test in 17 OECD countries. In this study is has been found bidirectional link between energy usage and GDP in Italy, Spain, Norway and New Zealand. The study proved feedback hypothesis.

Bildirici and Bakirtas (2014) have examined the link between coal consumption and economic growth for BRICTS countries.They found that there is no causal relationship between variables in Turkey. Nasreen and Anwar (2014) researched the link among economic performance, energy usage and trade openness for 15 Asian countries applying panel unit root and panel cointegration tests. Results indicate that there is bidirectional causality between economic growth and energy consumption and trade openness. Mohammadi and Amin (2015) investigate the causality relation between energy-growth for 79 countries which are grouped into categories based on growth rates. Results show there is bidirectional relation between variables for all country categories except low-growth category.

Saidi and Hammami (2015) evaluate the link between energy consumption and economic growth in Tunisia for the period 1974 and 2011. The Granger causality results show bi-directional causality between energy consumption and economic growth in Tunisia. Bhattacharya et al. (2016) investigates the effects of renewable energy consumption on economic growth in 38 renewable energy-consuming countries using heterogeneous panel estimation models over the period 1991-2012. The results suggest that renewable energy consumption has a significant positive affect on economic growth in the long-run. Results support the neutrality hypothesis of no causality between real GDP and renewable energy consumption.

Magazzino (2017) examined that the stationary properties of per capita energy use for EU-19 countries using Clemente et al. (1998) unit root test with structural breaks for the period of 1960-2013. The findings of panel unit-root test show that energy use is nonstationary in almost all EU-19 countries. Magazzino (2017) analyzed the relation among energy use, GDP and carbonemissions in the APEC region using the Vector Auto Regression (VAR). The results show that there is no causal relationship between GDP and energy use. Hasanov et al. (2017) reviewed the energy-growth nexus for 10 oil-exporting developing Eurasian countries. The findings indicated that a growth hypothesis verificates in the primary energy consumption-growth nexus. Results show that neutrality hypothesis is valid in the residential electricity consumption-growth nexus. Kahouli (2017) examined the short and long run causality relationship among economic growth, energy consumption and financial development in the South Mediterranean countries and found mixed results. Gozgor et al. (2018) found that renewable and non-renewable energy consumption positively affect on economic growth.

## 3. Data and methodology

This study employed data from 1990 to 2016 in G20. The members of the G20 covers Argentina, Australia, Brasil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa,Turkey, United Kingdom, United States and the European Union. The 28 European Union countries are Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom.

GDP growth (annual, %), energy use (kg of oil equivalent per capita), labor force (total, million) and gross capital formation (% of GDP) variables are collected from the World Bank. It has been used panel approach allowed to minimize multicollinearity and more degreed of freedom.

There are two views about the relation with energy-output: demand and production functions. Energy demand function includes GDP, energy consumption and energy price. Production function covers GDP, energy consumption, capital stock and labor force. We follow production function used by Oh and Lee (2004a,b) to analyse the link between energy usage and economic performance.

$$Y_{tj} = f\left(K_{tj}, L_{tj}, EC_{tj}\right) \tag{1}$$

Where Y, represents GDP; K, represents capital stock; L, represents labor force and EC, represents energy input.

Our empirical analysis is based on the following panel regression model,

$$GDP_{it} = \alpha_{0it} + \beta_{1it}EUSE + \beta_{2it}LF + \beta_{3it}GCF + \varepsilon_{it} \tag{2}$$

Where i=1,…,N, presents G20 countries and t= 1,….T, indicates period of 1995 to 2016. Where GDP is Gross Domestic Production Growth (%); GFCF is Gross Fixed Capital Formation (% of GDP); LF presents Labor Force (total, million); EUSE represents energy use (kg of oil equivalent per capita) and $\alpha_0, \beta_1, \beta_2, \beta_3$ are the unknown parameters to be estimated while $\varepsilon$ is an error term.

**Slope Homogeneity Test**

Slope homogeneity test, to determine of whether slope coefficients of the cointegration equation are homogeneous, developed by Swamy (1970). Pesaran and Yamagata (2018) improved Swamy's slope homogeneity test and formed two test statistics; $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$.

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\bar{S} - k}{\sqrt{2k}}\right) \sim X_k^2 \ (for\ large\ sample) \tag{3}$$

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\bar{S} - k}{v(T,k)}\right) \sim N(0,1) \ (for\ small\ sample) \tag{4}$$

N denotes number of cross-section unit; S denotes the Swamy test statistic; k denotes independent variables. If p value of the test is larger than 5%, the null hypothesis is accepted at a 5% significance level and the cointegrating coefficients are considered homogenous.

We test the hypothesis of slope homogeneity using the test developed by Pesaran and Yamagata (2008). The result of Pesaran and Yamagata (2008) homogeneity test are presented in Table 1. The tests are performed on the GDP, energy consumption, labor force and gross fixed capital formation in G20 countries using Gauss software.

*Table 1.* Pesaran and Yamagata (2008) Slope Homogeneity Tests.

| | Δ statistic | p value |
|---|---|---|
| $\tilde{\Delta}$ test | 21.107* | 0.000 |
| $\tilde{\Delta}_{adj}$ test | 23.383* | 0.000 |

*Note:* *, **, and ***are the significance for at 1%, 5% and 10% level. $\tilde{\Delta}$ test and $\tilde{\Delta}_{adj}$ test denote the slope homogeneity tests proposed by Pesaran and Yamagata (2008)

The null hypothesis of slope homogeneity is can be rejected in all cases because the probability values smaller than 0.05. The slope coefficients are not homogeneous. Heterogeneity exists across sample countries; we should employ heterogeneous panel techniques.

**Cross-Sectional Dependence Tests**

Urbain and Westerlund (2006) supported that hypothesis of “cross-sectional independence” is invalid in macroeconomic or financial analysis that have strong inter-economy relation. The main problem of panel approach is cross-sectional dependence (CSD). On the one part, settle whether the CSD. If there is CSD, panel unit-root tests allowed CSD are used. First generation tests assume cross-sectional independence and/or homogeneity. In case of heterogeneity and cross-sectional dependency, the first-generation tests likely produce inefficient results. We applied second-generation tests allowed cross-sectional dependence and heterogeneity.

Breusgh and Pagan (1980) LM test statistics show notable size distortion, when T<N.[1] Pesaran (2004) (CD), Friedman (1937) and Frees (1995) cross-sectional dependence tests designed for large-N and small-T panels status. In this study, Pesaran (2004), Friedman (1937) and Frees (1995), Breusch and Pagan (1980), Chudik and Pesaran (2015), Pesaran (2004) scaled LM, Pesaran (2015) and Baltagi (2012) bias-corrected scaled LM cross-sectional dependence tests have been used.

Cross-sectional dependence (CD) test proved by Pesaran (2004) has suggested the following,[2]

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{ij}\right).$$

For unbalanced panels, Pesaran (2004) proposes a slightly modified version, which is given by

$$CD = \sqrt{\frac{2}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\sqrt{T_{ij}}\rho_{ij}\right).$$

Friedman (1937) proposed a nonparametric test based on Spearman’s rank correlation coefficient. Friedman’s statistic is based on the Spearman’s correlation and is given by

$$R_{average} = \frac{2}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} r_{ij},$$

where $r_{ij}$ is the sample estimate of rank correlation coefficient of the residuals. Large values of $R_{average}$ show the presence of nonzero cross-sectional correlations.

Frees (1995, 2004) statistic is based on the sum of squared rank correlation coefficients and is given by

$$R^2_{average} = \frac{2}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} r^2_{ij}$$

Table 2 shows the results of Pesaran (2004), Friedman (1937) and Frees (1995), Breusch and Pagan (1980), Chudik and Pesaran (2015), Pesaran (2004) scaled LM, Pesaran (2015) and Baltagi (2012) bias-corrected scaled LM cross-sectional dependence test statistics. The results present that the null hypothesis of cross-sectional independence is rejected at significance level p=0.01. Findings require taking account of cross-section dependence, when applying panel unit-root tests.

[1] See Pesaran (2004) or Sarafadis, Yamagata and Robertson (2006).

[2] The CD test are applied using STATA code “xtcsd” proved by De Hoyos and Sarafidis (2006)

*Table 2.* Cross-sectional Dependence Tests.

| | FE Model | RE Model |
|---|---|---|
| *CD (Pesaran, 2004)* | 130.928* | 130.878* |
| *Friedman (1937)* | 276.092* | 277.195* |
| *Frees (1995)* | 3.710* | 3.715* |
| *Breusch and Pagan LM (1980)* | 2010.371* | 3194.663* |
| *Chudik and Pesaran (2015)* | 32.599* | |
| *Pesaran (2004) Scaled LM* | 26.057* | |
| *Pesaran (2015)* | 45.089* | |
| *Baltagi et al. (2012) Bias-corrected scaled LM* | 25.161* | |

*Note:* The p-values are in parentheses. * indicate the statistical significance at 1 percent level.

### Dickey-Fuller (CADF) Panel Unit-Root Test

Panel unit root tests developed by Levin, Lin and Chu (2002) and Im, Pesaran and Shin (2003) allow cross-sectional independence, but not heterogeneity and heterogenous serial correlation. Pesaran (2007) suggests a cross-sectionally augmented Dickey-Fuller (CADF) test, allowed cross-sectional dependence and heterogeneity. Table 3 includes CADF test results. Results indicate that the null hypothesis of unit-root is rejected at the first differences.[3]All variables are integrated of order 1.

*Table 3.* Pesaran CADF Panel Unit Root Test.

| **Variables** | **t-bar** | **Z** |
|---|---|---|
| *Level* | | |
| *LGDP* | -1.717 | 0.290 (0.614) |
| *LEUSE* | -1.244 | 7.516 (1.000) |
| *LLF* | -1.566 | 1.310 (0.905) |
| *LGFCF* | -1.313 | 3.021 (0.999) |
| *First Difference* | | |
| *DLGDP* | -2.797 | -7.009* (0.000) |
| *DLEUSE* | -2.790 | -6.963* (0.000) |
| *DLLF* | -2.989 | -8.308* (0.000) |
| *DLGFCF* | -3.285 | -10.312* (0.000) |

*Note:* Critical values are -2.25, -2.11 -2.03 for the t-bar statistics at 1%, 5% and 10% significance levels. Z test statistics are -2.326, -1.645 and -1.282 at 1%, 5% and 10% significance levels correspondingly.

### Panel Cointegration Tests

In a Granger causality system, it is required exist of stationary between variables. We use Westerlund (2007), Pedroni (2004), Westerlund and Edgerton (2008) and Kao (1999) panel cointegration test to analyse whether variables are cointegrated. Firstly, we employed the first generation heterogeneous panel cointegration test developed by Pedroni (2004) and Westerlund (2007) to examine the long-run relationship among variables in G20 countries. Secondly, we use the second generation LM-based panel cointegration tests developed by Westerlund and Edgerton (2008) and Kao (1999), which allows for cross-sectional dependence and heterogeneity.

### Pedroni (2004) Cointegration Test

We implemented the Pedroni (2004) panel cointegration test to analyze whether relationship among variables.Seven different statistics referred to as within and between dimensions. Table 4 presents Pedroni (2004) panel cointegration results.It was choosing lag length based

[3]See Pesaran (2007) for critic value.

onSchwarz Information Criterion (SIC). The results indicated three statistics from within-dimension and all statistics from between dimensionis statistically significant. All the test statistics, except panel v-statistic, show that the null hypothesis of no cointegration is rejected at the 1% significance level.

*Table 4.* Pedroni (2004) Panel Cointegration Test.

| ***Within Dimension*** | **Statistic** | **Probability** | **Between-Dimension** | **Statistic** | **Probability** |
|---|---|---|---|---|---|
| *Panel v-statistic* | -0.7576 | 0.2243 | Panel rho-statistic | -2.903*** | 0.0018 |
| *Panel rho-statistic* | -5.071*** | 0.0000 | Panel pp-statistic | -14.937*** | 0.0000 |
| *Panel pp-statistic* | -12.481*** | 0.0000 | Panel ADF-statistic | 13.794*** | 0.0000 |
| *Panel ADF-statistic* | -12.544*** | 0.0000 | | | |

*Note:* The p-values are in parentheses. * indicate the statistical significance at 1 percent level.

### Westerlund (2007) ECM Panel Cointegration Test

ECM panel cointegration test, proved by Westerlund (2007), examine the null hypothesis of no cointegration. The test based on whether the error-correction term is equal to zero, in a conditional panel error-correction model. The test concludes the existence of an error correction for group mean ($G_\tau$ and $G_\alpha$) and for panel ($P_\tau$ and $P_\alpha$). We used Westerlund (2007) ECM panel cointegration test to determine whether there exists cointegration among GDP, energy use, capital stock formation and laborforce. Table 5 represent the results of Westerlund (2007) ECM panel cointegration test.Results show that the null hypothesis of no cointegration is rejected, except $G_\alpha$.

*Table 5.* Westerlund (2007) ECM Panel Cointegration Test.

| **Statistics** | **Value** | **Z-value** |
|---|---|---|
| $G_\tau$ | -2.658* | -2.952* (0.000) |
| $G_\alpha$ | -10.803 | 0.153 (0.561) |
| $P_\tau$ | -16.299* | -3.506* (0.000) |
| $P_\alpha$ | -10.518* | -3.058 (0.001) |

*Note:* $G_\tau$ and $G_\alpha$indicategroup mean,$P_\tau$ and $P_\alpha$presentpanel tests. The Ga statistic can be rejected null hypothesis of no cointegration in small panel (Westerlund, 2007).

### Westerlund and Edgerton (2008) Cointegration Test

We applied the test developed by Westerlund and Edgerton (2008) panel cointegration test allowed for heteroskedastic and serially correlated errors, cross-sectional dependence and structural breaks in both the intercept and slope. Cointegration test proposed by Westerlund and Edgerton (2008) based on Gregory and Hansen (1996) study. Westerlund and Edgerton (2008) define two LM based statistics:

$$LM_\varphi(i) = T\hat{\varphi}_i\left(\frac{\hat{\omega}_i}{\hat{\sigma}_i}\right)$$

$$LM_\tau(i) = \frac{\hat{\varphi}_i}{SE(\hat{\varphi}_i)}$$

where $\hat{\varphi}_i$ is the least square estimate of $\varphi_i$ with $\hat{\sigma}_i$ as its estimated standard error, $\hat{\omega}_i^2$ is the estimated long-run variance of $\Delta v_{it}$ and $SE(\hat{\varphi}_i)$ is estimated standard error of $\hat{\varphi}_i$.

*Table 6.* Westerlund and Edgerton (2008) Panel Cointegration Test with Structural Breaks Results.

| **Model** | $Z_\varphi(N)$ | $Z_\tau(N)$ |
|---|---|---|
| *No Break* | **-15.603*** (0.000)** | **-12.528*** (0.000)** |
| *Level Shift* | **-2.048*** (0.020)** | **-0.805 (0.210)** |
| *Regime Shift* | **-3.614*** (0.000)** | **-2.343*** (0.010)** |

*Note:* *, **, *** indicate significance at the 10%, 5% and 1% levels, respectively.

In this study, it was used the panel cointegration test proposed by Westerlund and Edgerton (2008). Table 6 shows the result of Westerlund and Edgerton (2008) panel cointegration test. Test statistics are significant at the 1% level, except $Z_{\tau}(N)$ statistic for level shift. This result impliedthat the null hypothesis of no cointegration is rejected. There is a cointegration relationship between variables in cases of cross-sectional dependency and structural breaks. Therefore, variables move together in the long run.

### Kao Panel Cointegration Test

We used the Kao panel cointegration test. Test results are represented in Table 7. The findings show that the null hypothesis of no cointegration is rejected at the 1% significance level.

*Table 7.* Kao Panel Cointegration Test.

| | **t-statistic** | **Prob.** |
|---|---|---|
| *ADF* | -5.586* | 0.000 |

*Note:* *, **, *** indicate significance at the 10%, 5% and 1% levels, respectively.

### FMOLS, CRR and DOLS Long-Run Estimation

OLS estimator is inconsistent and biased on the cointegrated panel. We have used fully modified OLS estimator (FMOLS) proved by Pedroni (1999, 2001). Table 8 covers FMOLS, CRR and DOLS estimations. Coefficients are positive and significant, except LF.

*Table 8.* Long-run FMOLS, CRR and DOLS Results (Dependent variable: DLGDP).

| ***Variable*** | ***DLEUSE*** | ***DLLF*** | ***DLGFCF*** | ***Constant*** | ***$R^2$*** | ***Adjusted $R^2$*** |
|---|---|---|---|---|---|---|
| FMOLS | 0.040*<br>(0.000) | 0.187*<br>(0.144) | 0.261*<br>(0.000) | 0.027*<br>(0.000) | 0.062 | 0.059 |
| CRR | 0.089*<br>(0.000) | 0.025*<br>(0.866) | 0.500*<br>(0.000) | 0.029*<br>(0.000) | 0.480 | 0.479 |
| DOLS | 0.070*<br>(0.002) | -0.026*<br>(0.913) | 0.439*<br>(0.000) | 0.028*<br>(0.000) | 0.336 | 0.325 |

*Note: *, **, *** indicate significance at the 10%, 5% and 1% levels, respectively.*

The coefficients of FMOLS estimations for individual countries presented in Table 8 shows that coefficient of energy use are positive and significant for G20 countries, except Malta, Saudi Arabia and United Kingdom. The coefficients of FMOLS estimations for panel presented in Table 9 show that coefficient of energy use are negative and significantin Malta, Saudi Arabia and United Kingdom and positive in others. Labor Force has a negative impact on economic growth in Czech Republic whereas positive in others. In Canada, China, Ireland, Luxembourg, Romania and Saudi Arabia, Gross Fixed Capital Formation has an insignificant impact on economic growth whereas positive and significant in others.

Table 9 shows the results of DOLS at individual. Energy coefficient is negative and significant in Argentina, Czech Republic, Finland, Germany, Luxembourg, Malta, Netherland, Slovak and United States whereas positive in Australia, Belgium, Brazil, Bulgaria, China, Croatia, Cyprus, Estonia, France, Hungary, India, Japan, Latvia, Lithuania, Luxembourg, Mexico, Poland, Korea Rep., Romania, Russia, Saudi Arabia, South Africa and United States. Labor Force has a negative impact on economic growth in Argentina, Australia, Bulgaria, Czech Republic, Denmark, Estonia, Germany, Hungary, Japan, Poland, Portugal, Russia, Saudi Arabia, Slovak and United Kingdom whereas positive in others. In Argentina, Australia, Brazil, Bulgaria, Czech Republic, Denmark, Estonia, Finland, India, Japan, Latvia, Malta, Netherland, Portugal, Romania, Russian, Saudi Arabia, Slovak Rep., Slovenia, South Africa, Spain, Sweden, Turkey, United Kingdom and United States, Gross Fixed Capital Formation has a positive impact on economic growth whereas negative in China, Germany, Luxembourg and Poland.

*Table 9.* FMOLS Country-Spesific Results (Dependent Variable: DLGDP).

| | DLEUSE | DLLF | DLGFCF | Constant | $R^2$ | Adj.$R^2$ |
|---|---|---|---|---|---|---|
| *Argentina* | 0.336* (0.046) | -0.359 (0.504) | 0.458* (0.000) | 0.025* (0.009) | 0.607 | 0.525 |
| *Australia* | 0.066 (0.220) | 0.057 (0.798) | 0.180* (0.000) | 0.036* (0.000) | 0.623 | 0.543 |
| *Austria* | 0.101 (0.121) | -0.045 (0.817) | 0.205* (0.013) | 0.032* (0.000) | -0.015 | -0.228 |
| *Belgium* | 0.072 (0.064) | 0.345* (0.009) | 0.279* (0.000) | 0.019* (0.000) | 0.213 | 0.047 |
| *Brazil* | 0.418* (0.000) | -0.508 (0.248) | 0.228* (0.000) | 0.030* (0.000) | 0.105 | -0.084 |
| *Bulgaria* | 0.424* (0.000) | 0.656* (0.025) | 0.047* (0.009) | 0.020 (0.089) | 0.456 | 0.342 |
| *Canada* | 0.380* (0.004) | 0.794 (0.089) | 0.113 (0.116) | 0.031* (0.000) | 0.478 | 0.368 |
| *China* | 0.445* (0.000) | 3.061 (0.035) | 0.001 (0.980) | 0.115* (0.000) | 0.437 | 0.318 |
| *Croatia* | 0.403* (0.004) | 0.524 (0.205) | 0.184* (0.005) | 0.015 (0.162) | 0.556 | 0.462 |
| *Cyprus* | 0.144* (0.001) | -0.376 (0.314) | 0.158* (0.000) | 0.062* (0.000) | 0.464 | 0.351 |
| *Czech* | 0.344* (0.005) | -2.154* (0.005) | 0.207* (0.004) | 0.006 (0.572) | 0.358 | 0.223 |
| *Denmark* | 0.008 (0.803) | -0.081 (0.610) | 0.264* (0.000) | 0.027* (0.000) | 0.333 | 0.193 |
| *Estonia* | 0.177* (0.024) | -0.331 (0.588) | 0.481* (0.000) | 0.047* (0.007) | 0.442 | 0.324 |
| *Finland* | 0.162* (0.000) | 1.308* (0.000) | 0.305* (0.000) | 0.046* (0.000) | 0.723 | 0.665 |
| *France* | 0.075 (0.161) | -0.682 (0.051) | 0.349* (0.000) | 0.031* (0.000) | 0.408 | 0.284 |
| *Germany* | 0.237* (0.005) | -0.080 (0.844) | 0.464* (0.000) | 0.028* (0.000) | 0.601 | 0.517 |
| *Greece* | 0.627* (0.001) | 0.038 (0.959) | 0.322* (0.000) | 0.017 (0.316) | 0.622 | 0.542 |
| *Hungary* | 0.494* (0.000) | 0.952* (0.000) | 0.274* (0.000) | 0.040* (0.000) | 0.652 | 0.579 |
| *India* | 0.304* (0.006) | 0.034 (0.884) | 0.074* (0.015) | 0.046* (0.000) | 0.252 | 0.094 |
| *Indonesia* | 0.513* (0.002) | -1.265 (0.273) | 0.305* (0.000) | 0.047* (0.006) | 0.137 | -0.044 |
| *Ireland* | 0.846* (0.004) | 0.327 (0.681) | 0.201 (0.057) | 0.024 (0.225) | 0.184 | 0.012 |
| *Italy* | 0.105 (0.128) | -0.145 (0.372) | 0.293* (0.000) | 0.018* (0.000) | 0.327 | 0.186 |
| *Japan* | 0.483* (0.000) | -0.463 (0.199) | 0.317* (0.000) | 0.015* (0.000) | 0.519 | 0.418 |
| *Latvia* | 0.406* (0.001) | 0.839 (0.075) | 0.299* (0.000) | 0.051* (0.002) | 0.205 | 0.038 |
| *Lithuania* | 0.165* (0.000) | -0.587 (0.061) | 0.351* (0.000) | 0.041* (0.000) | 0.766 | 0.717 |
| *Luxembourg* | 0.068 (0.606) | -0.026 (0.961) | 0.060 (0.517) | 0.041* (0.002) | -0.076 | -0.303 |
| *Malta* | -0.094* (0.007) | 1.263* (0.000) | 0.129* (0.000) | 0.061* (0.000) | -0.072 | -0.298 |
| *Mexico* | 0.037 (0.818) | 0.233 (0.614) | 0.310* (0.000) | 0.028* (0.002) | 0.387 | 0.259 |
| *Netherlands* | 0.181* (0.004) | 0.735* (0.004) | 0.361* (0.000) | 0.023* (0.000) | 0.258 | 0.102 |
| *Poland* | 0.141* (0.000) | 0.052 (0.640) | 0.166* (0.000) | 0.050* (0.000) | 0.657 | 0.585 |
| *Portugal* | 0.128* (0.044) | 0.571* (0.025) | 0.287* (0.000) | 0.021* (0.000) | 0.805 | 0.764 |
| *Korea, Rep.* | 0.406* (0.000) | 0.783* (0.013) | 0.239* (0.001) | 0.053* (0.000) | 0.726 | 0.669 |
| *Romania* | 0.547* (0.001) | -0.572 (0.174) | 0.022 (0.731) | 0.009 (0.618) | 0.487 | 0.380 |
| *Russian* | 1.466* (0.000) | -0.112 (0.742) | 0.262* (0.000) | 0.022 (0.071) | 0.754 | 0.702 |
| *Saudi* | -0.007 (0.953) | 1.185 (0.084) | -0.030 (0.676) | 0.026 (0.134) | 0.144 | -0.036 |
| *Slovak* | 0.260 (0.188) | -0.824 (0.223) | 0.098* (0.109) | 0.049* (0.006) | 0.273 | 0.120 |
| *Slovenia* | 0.214 (0.153) | 0.423 (0.333) | 0.442* (0.000) | 0.007 (0.563) | 0.583 | 0.495 |
| *South Africa* | 0.004 (0.128) | 0.030 (0.907) | 0.276* (0.000) | 0.030* (0.000) | -0.050 | -0.271 |
| *Spain* | 0.001 (0.985) | 0.201 (0.186) | 0.356* (0.000) | 0.032* (0.000) | 0.866 | 0.838 |
| *Sweden* | 0.195* (0.000) | -0.472 (0.077) | 0.398* (0.000) | 0.027* (0.000) | 0.295 | 0.146 |
| *Turkey* | 0.367* (0.000) | -0.075 (0.633) | 0.301* (0.000) | 0.020* (0.011) | 0.736 | 0.680 |
| *U. Kingdom* | -0.010 (0.869) | 1.131* (0.026) | 0.371* (0.000) | 0.042* (0.000) | 0.200 | 0.032 |
| *U.States* | 0.368* (0.000) | 0.361 (0.389) | 0.277* (0.000) | 0.033* (0.000) | 0.778 | 0.731 |

*Note:* *, **, *** indicate significance at the 10%, 5% and 1% levels, respectively.

### The Eagle-Granger (1987) Two-Step Procedure

To determine the link relationship between variables, a panel vector error correction model (Pesaran et al., 1999) is estimated to perform Granger causality tests. We use the two-step procedure proved by Engle and Granger (1987) study. In the first step, the long-run model for Eq. (2) is estimated to obtain ECT($\varphi$). In the second step, Granger causality model is estimated using by dynamic error correction model (Lee and Chang, 2008). The panel VECM can be written as follows:

*Table 10.* DOLS Country-Spesific Results (Dependent variable: DLGDP)

| | DLEUSE | DLLF | DLGFCF | Constant | $R^2$ | Adj.$R^2$ |
|---|---|---|---|---|---|---|
| *Argentina* | -1.033 (0.064) | -2.294* (0.000) | 1.121* (0.000) | 0.053* (0.000) | 0.999 | 0.982 |
| *Australia* | 0.263* (0.000) | -2.765* (0.000) | 0.169* (0.000) | 0.038* (0.000) | 0.996 | 0.931 |
| *Austria* | 1.354 (0.265) | 1.736 (0.548) | 0.899 (0.603) | 0.009 (0.616) | 0.860 | -1.663 |
| *Belgium* | 0.309* (0.000) | 1.709* (0.000) | -0.061 (0.378) | 0.011* (0.000) | 0.998 | 0.964 |
| *Brazil* | 0.931* (0.001) | 3.060* (0.000) | 0.680* (0.000) | 0.004 (0.596) | 0.969 | 0.418 |
| *Bulgaria* | 0.994* (0.000) | -0.239* (0.000) | 0.138* (0.000) | 0.026* (0.000) | 0.999 | 0.999 |
| *Canada* | 0.365 (0.445) | 2.933* (0.004) | -0.232 (0.619) | 0.022* (0.000) | 0.991 | 0.830 |
| *China* | 3.405* (0.000) | 22.015* (0.000) | -3.222* (0.000) | 0.083* (0.000) | 0.988 | 0.779 |
| *Croatia* | 0.950* (0.045) | 5.091* (0.000) | 0.290 (0.095) | 0.009* (0.001) | 0.949 | 0.027 |
| *Cyprus* | 0.837* (0.000) | 5.188* (0.000) | 0.220 (0.072) | 0.013* (0.020) | 0.989 | 0.790 |
| *Czech* | -0.294* (0.000) | -7.651* (0.000) | 0.844* (0.000) | 0.026* (0.000) | 0.999 | 0.979 |
| *Denmark* | 0.443 (0.159) | -5.544* (0.005) | 1.779* (0.000) | 0.017* (0.000) | 0.977 | 0.561 |
| *Estonia* | 3.316* (0.000) | -8.390* (0.000) | 1.246* (0.000) | 0.044* (0.000) | 0.995 | 0.898 |
| *Finland* | -1.918* (0.000) | 12.590* (0.000) | 1.397* (0.000) | 0.018* (0.000) | 0.990 | 0.816 |
| *France* | 0.667* (0.000) | 0.339 (0.759) | 0.193 (0.132) | 0.017* (0.000) | 0.999 | 0.980 |
| *Germany* | -1.888* (0.000) | -1.197* (0.000) | -0.633* (0.000) | 0.005* (0.001) | 0.998 | 0.958 |
| *Greece* | 0.305 (0.868) | -2.067 (0.304) | 0.914 (0.375) | 0.042* (0.045) | 0.999 | 0.989 |
| *Hungary* | 1.223* (0.000) | -1.730* (0.000) | 0.073 (0.378) | 0.036* (0.000) | 0.999 | 0.984 |
| *India* | 6.940* (0.000) | 12.339* (0.000) | 0.622* (0.000) | -0.048* (0.000) | 0.999 | 0.975 |
| *Indonesia* | -1.245 (0.585) | 0.615 (0.951) | 0.350 (0.247) | 0.057* (0.000) | 0.990 | 0.814 |
| *Ireland* | 2.125 (0.420) | -2.280 (0.892) | -1.218 (0.419) | 0.049 (0.610) | 0.941 | -0.119 |
| *Italy* | -0.178 (0.607) | 0.383 (0.368) | 0.520 (0.094) | 0.010* (0.036) | 0.974 | 0.509 |
| *Japan* | 0.621* (0.000) | -5.761* (0.000) | 1.559* (0.000) | 0.048* (0.000) | 0.993 | 0.875 |
| *Latvia* | 0.481* (0.018) | 0.429 (0.373) | 0.568* (0.000) | 0.029* (0.000) | 0.992 | 0.841 |
| *Lithuania* | 1.705* (0.005) | 4.440 (0.217) | -0.124 (0.660) | 0.055* (0.000) | 0.985 | 0.722 |
| *Luxembourg* | -1.597* (0.047) | 15.443* (0.014) | -3.867* (0.027) | -0.102 (0.059) | 0.769 | -3.388 |
| *Malta* | -0.559* (0.009) | 1.838* (0.050) | 0.833* (0.001) | 0.048* (0.000) | 0.961 | 0.255 |
| *Mexico* | 0.606* (0.000) | 0.426 (0.447) | 0.700* (0.002) | 0.013* (0.000) | 0.991 | 0.831 |
| *Netherlands* | -0.424* (0.000) | 1.274* (0.000) | 2.285* (0.000) | 0.028* (0.000) | 1.000 | 0.998 |
| *Poland* | 1.229* (0.000) | -2.525* (0.000) | -0.192* (0.000) | 0.046* (0.000) | 0.999 | 0.974 |
| *Portugal* | 0.312 (0.186) | -2.750* (0.002) | 0.474* (0.002) | 0.026* (0.000) | 0.990 | 0.813 |
| *Korea, Rep.* | 0.596* (0.000) | -3.198 (0.096) | -0.100 (0.314) | 0.035* (0.000) | 0.997 | 0.940 |
| *Romania* | 0.811* (0.037) | 2.153* (0.000) | 0.997* (0.000) | 0.035* (0.000) | 0.982 | 0.658 |
| *Russian* | 9.208* (0.000) | -35.799* (0.000) | 3.557* (0.000) | -0.005* (0.268) | 0.994 | 0.883 |
| *Saudi* | 2.061* (0.000) | -0.589* (0.000) | 0.191* (0.000) | -0.027* (0.000) | 1.000 | 0.998 |
| *Slovak* | -0.912* (0.000) | -4.228* (0.000) | 0.369* (0.000) | 0.046* (0.000) | 0.999 | 0.999 |
| *Slovenia* | 0.042 (0.948) | 3.818* (0.002) | 0.694* (0.013) | 0.017 (0.082) | 0.975 | 0.533 |
| *South Africa* | 1.568* (0.009) | -0.088 (0.903) | -0.333* (0.044) | 0.023* (0.000) | 0.975 | 0.519 |
| *Spain* | 0.111 (0.687) | -0.172 (0.794) | 0.432 (0.057) | 0.026* (0.006) | 0.996 | 0.921 |
| *Sweden* | 1.376* (0.000) | -0.008 (0.991) | 0.750* (0.000) | 0.037* (0.000) | 0.993 | 0.875 |
| *Turkey* | 1.671 (0.094) | 0.264 (0.506) | 0.836* (0.000) | 0.013 (0.557) | 0.972 | 0.470 |
| *U. Kingdom* | -0.004 (0.991) | -15.405* (0.007) | 3.507* (0.000) | 0.069* (0.000) | 0.996 | 0.921 |
| *U.States* | -1.459* (0.000) | 2.784* (0.000) | 0.993* (0.000) | 0.043 (0.000) | 0.998 | 0.965 |

*Note:* *, **, *** indicate significance at the 10%, 5% and 1% levels, respectively.

$$\Delta GDP_{it} = \delta_{1i} + \sum_{p=1}^{k} \delta_{11ip} \Delta GDP_{it-p} + \sum_{p=1}^{k} \delta_{12ip} \Delta GCF_{it-p} + \sum_{p=1}^{k} \delta_{13ip} \Delta LF_{it-p} + \sum_{p=1}^{k} \delta_{14ip} \Delta ENU_{it-p} + \varphi_{1i}\varepsilon_{it-1} + \vartheta_{1it} \quad (5a)$$

$$\Delta GCF_{it} = \delta_{2i} + \sum_{p=1}^{k} \delta_{21ip}\Delta GCF_{it-p} + \sum_{p=1}^{k} \delta_{22ip}\Delta GDP_{it-p} + \sum_{p=1}^{k} \delta_{23ip}\Delta LF_{it-p} + \sum_{p=1}^{k} \delta_{24ip}\Delta ENU_{it-p} + \varphi_{2i}\varepsilon_{it-1} + \vartheta_{2it} \quad (5b)$$

$$\Delta LF_{it} = \delta_{3i} + \sum_{p=1}^{k} \delta_{31ip}\Delta LF_{it-p} + \sum_{p=1}^{k} \delta_{32ip}\Delta GDP_{it-p} + \sum_{p=1}^{k} \delta_{33ip}\Delta GCF_{it-p} + \sum_{p=1}^{k} \delta_{34ip}\Delta ENU_{it-p} + \varphi_{3i}\varepsilon_{it-1} + \vartheta_{3it} \quad (5c)$$

$$\Delta ENU_{it} = \delta_{4i} + \sum_{p=1}^{k} \delta_{41ip}\Delta ENU_{it-p} + \sum_{p=1}^{k} \delta_{42ip}\Delta GDP_{it-p} + \sum_{p=1}^{k} \delta_{43ip}\Delta GCF_{it-p} + \sum_{p=1}^{k} \delta_{44ip}\Delta LF_{it-p} + \varphi_{4i}\varepsilon_{it-1} + \vartheta_{4it} \quad (5d)$$

Where $\Delta$ represents first-difference operator; p, presents optimal lag legths and $\varepsilon_{it}$ shows residuals from FMOLS estimation for equation 1. Two step procedures allow forming both the short-run and long-run causalities. The short-run causality is tested with Wald test for first-differenced variables. The long-run causalities are examined by t-statistic of the error correction coefficients ($\varphi$) (ECT).

*Table 11.* Panel Granger Causality and VECM test Results (Full Sample).

| | ***Source of Causation (Independent Variables)*** | | | | | |
|---|---|---|---|---|---|---|
| | ***Short-run Causality*** | | | | | ***Long-run Causality*** |
| ***Dependent Variable*** | **DGDP(-1)** | **DGCF(-1)** | **DENU(-1)** | **DLF(-1)** | **C** | **ECT** |
| *DGDP* | -0.078* | -0.021* | 0.040* | 0.045 | 0.001 | -0.560* |
| | (-2.131) | (-1.983) | (2.100) | (0.635) | (0.833) | (-9.425) |
| *DGCF* | 0.519* | -0.477* | -0.108* | -0.017 | 0.002 | 0.226 |
| | (4.817) | (-15.281) | (-1.964) | (-0.082) | (0.500) | (1.300) |
| *DENU* | -0.239* | 0.025 | -0.567* | -0.091 | -0.001 | -0.211* |
| | (-4.485) | (1.642) | (-20.757) | (-0.888) | (-0.492) | (-2.448) |
| *DLF* | 0.008 | 0.008* | -0.001 | -0.436* | 0.000 | 0.021 |
| | (0.568) | (1.981) | (-0.167) | (-15.507) | (0.046) | (0.888) |

*Note:* t stats are in parentheses. * indicate the statistical significance at 1 percent level.

Table 11 shows Panel Granger Causality and VECM test statistics. Asa result of test, GCF and ENU has a negative and positive statistically significant impact on economic growth in short-run respectively. GDP have a negative and statistically significant impact on ENU in short-run. In the short-run, there is bidirectional causal relationship between gdp and energy and uni-directional relation from GFCF to GDP. The ECT in the GDP equation and energy equation is statistically significant, which means that GDP and energy have bidirectional relation in the long-run and feedback hypothesis is valid in G20 countries.

Findings revealed that there is a bidirectional relation between energy consumption and economic growth in short and long-run for G-20 countries. Our conclusion matches with Pala (2016), Belke et al. (2011), Khachoo and Sofi (2014), Al-Mulali (2012), Ozturk and Al-Mulali (2015), Fuinhas and Marques (2012) and Apergis et al (2010). Pala (2016) found feedback hypothesis is valid using Granger causality and VECM for OECD countries in short and long-run. Belke et al. (2011) investigated energy-growth nexus in 25 OECD countries by using vector error correction. Results show that there is feedback hypothesis between energy consumption and GDP growth. Khachoo and Sofi (2014) deduced that bidirectional causality between energy ad growth for BRICSAM in short and long-run. Al-Mulali (2012) analysed energy-growth hypothesis for 12 Middle Eastern countries, findings supported feedback hypothesis in short run. Ozturk and Al-Mulali (2015) found that feedback hypothesis exists between natural gas consumption and economic growth for 7 GCC countries. Fuinhas and Marques (2012) examine the nexus between primary energy consumption and economic growth in Portugal, Italy, Greece, Spain and Turkey (PIGST), by using ARDL bounds test approach. They found the feedback hypothesis for these countries. Apergis et al. (2010) showed the feedback hypothesis is valid in 19 developed and developing economies.

## 4. Conclusion

This paper investigates relationship among economic growth and energy use in G20 countries over the period 1995-2016.We have applied slope homogeneity test, Pesaran (2004) Cross-Sectional Dependence (CD) Test and Pesaran (2007) cross-sectionally augmented Dickey-Fuller (CADF) unit-root test. To examine cointegration among variables, we have applied Pedroni (2004), Westerlund (2007) and Westerlund and Edgerton (2008) cointegration tests. We used Fully-Modified Ordinary Least Square (FMOLS), Canonical Cointegration Regression (CRR) and Dynamic Ordinary Least Square (DOLS) for long-run estimation and panel Granger causality and VECM test. Results of unit-root test indicate that all variables are integrated at I(1). Pedroni and Westerlund (2007) cointegration tests confirm the presence of a long-run equilibrium relationship among GDP, EUSE, LF and GCF in the G20 countries.Westerlund and Edgerton (2008) panel cointegration test results show a cointegration relationship between GDP and energy consumption in cases of cross-sectional dependency and structural breaks. The FMOLS, CRR and DOLS estimation analysis reveals a positive and significance relationship between variables -except coefficient of LF. The results of Granger causality with ECM confirm the validation of feedback hypothesis between economic growth and energy consumption in G20 countries. This suggests that energy consumption and economic growth are interrelated.

An important policy implication based on the result of the study is that to care should be taken in making energy conservation policies in G20 countries. For the long run, the bidirectional causality relationship between economic growth and energy consumption suggests that the energy conservation policy must be carefully crafted to avoid undesirable impact on economic development. One main task of energy policy is the conservation of energy which means a more efficient use of energy and a reduction in greenhouse gas emissions using alternative energy options. Our results can help policy makers to develop methods to improve energy efficiency. Furthermore, while energy conservation policies that reduce energy consumption may have an adverse impact on growth. Policy makers need to balance sustained economic growth, environmental costs and excessive energy consumption. Governments must hold in regard the development of energy technology for the development of energy efficiency technology and clean energy technology.

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