Biomass Energy Consumption, Economic Growth and CO₂ Emission in G-20 Countries

G-20 Ülkelerinde Biyokütle Enerji Tüketimi, Ekonomik Büyüme ve CO₂ Emisyonu

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Introduction

Since the Industrial Revolution, economic development has been rooted in fossil fuel-oriented industries and mass production systems. This economic growth strategy has increased income and reduced poverty. However, such development has triggered some problems, such as environmental issues, global climate change, energy dependency, and limited supplies of fossil fuels (Ulucak and Erdem, 2017). Thus, the dependence on fossil fuels, or the fossil fuel energy sources with renewable and sustainable energy resources, such as biomass.

Due to these issues, countries are now seeking to replace fossil fuel energy sources with renewable and sustainable energy resources, such as biomass. However, such development has triggered some problems, such as environmental issues, global climate change, energy dependency, and limited supplies of fossil fuels (Ulucak and Erdem, 2017). Thus, the dependence on fossil fuels, or the conventional way of development, can no longer be sustained. Because of these serious problems and recent global crises, sustainable development and green, or environmentally sustainable, growth have become parts of a worldwide discourse driven by international treaties, global environmental organizations, and bodies such as the G-20. Due to these issues, countries are now seeking to replace fossil fuel energy sources with renewable and sustainable energy resources, such as biomass.

This study focuses on the G-20 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom, and the United States) and examines the relationship between biomass energy consumption, economic growth, CO₂ emissions, and natural resource depletion in these countries from 1992 to 2013. For this purpose, we used panel unit root tests, the panel cointegration test, the panel fully modified OLS (FMOLS) method, and the panel VECM Granger causality method. The results reveal that biomass energy consumption, economic growth, CO₂ emissions, and natural resource depletion are cointegrated. In addition, increasing biomass energy consumption leads to increased economic growth. On the other hand, the increase in biomass energy consumption reduces CO₂ emissions. Moreover, a unidirectional causality exists from biomass energy consumption to GDP growth, supporting the growth hypothesis. Finally, a bidirectional causal relationship exists between biomass energy consumption and CO₂ emissions.
United States), excluding the European Union, which cause 78.6% of total global CO₂ emissions and consume 74.9% of total global renewable energy production (BP, 2014). Therefore, it is crucial to examine the directions of the causal relationships between biomass energy consumption, GDP, and CO₂ emissions.

Since the third G-20 summit in Pittsburgh, the countries have discussed issues surrounding energy, the volatility of fossil fuel prices, the environment, and climate change. The accepted opinion holds that in order to provide sustainable development, decrease the volatility of energy prices, and decrease environmental degradation, these countries must turn towards alternative renewable energy sources (Kang, 2012).

Based on the above, this study aims to investigate the relationship between biomass energy consumption, GDP, CO₂ emissions, and natural resource depletion in G-20 countries between 1992 and 2013. For this purpose, we employed panel unit root tests, the panel cointegration test, the panel fully modified OLS method, and the panel VECM Granger causality method. This study contributes to existing literature in some aspects. First, while most of previous studies focused on the effects of fossil fuel energy consumption on economic growth or environmental pollution, this study considers the relationship between biomass energy consumption and economic growth for G-20 countries. In addition, the study utilizes multivariate models by adding CO₂ emissions and natural resource depletion.

The rest of the paper is as following; Second section involves the literature review, Third section describes the data, model, methodology and empirical findings, Fourth section presents the conclusion and policy implications of the study.

2. Literature Review

In recent years, it seems that many studies examined the relationship between energy consumption and economic growth. Payne (2010) and Ozturk (2010) reviewed the existing literature and provided four testable hypotheses. First one is called growth hypothesis which indicates that unidirectional causality from energy consumption to economic growth. In such a situation, energy conservation policies are detrimental on economic growth. Second hypothesis is called conservation hypothesis. According to this hypothesis, there is unidirectional causality from economic growth to energy consumption and energy conservation policies may not be harmful on economic growth. Some studies found that bidirectional causality between energy consumption and economic growth which is called feedback hypothesis. If feedback hypothesis is exist then energy reduced policies would be detrimental on economic growth. Finally the last hypothesis is called neutrality hypothesis which implies that there is no causal relationship between energy consumption and economic growth. In such a situation, reducing the energy consumption is ineffective on economic growth.

In the literature, it seems that various hypotheses were supported about the causal linkage between renewable energy consumption and economic growth. These mixed results could be sourced from using different data sets, econometric techniques or different sample periods. For instance, the growth hypothesis was confirmed by some studies such as Aydin and Esen (2017) for Turkey; Esen and Bayrak (2017) for energy importing countries. The feedback hypothesis was supported in various studies such as Sadorsky (2009a) for emerging countries; Apergis and Payne (2010) for 20 OECD countries; Apergis and Payne (2010) for Eurasia; Apergis et al. (2010) for a group of 19 developed and developing countries; Apergis and Payne (2011) for 6 Central American countries; Tugcu et al. (2012) for G7 countries. The neutrality hypothesis was discovered in some studies such as Payne (2009) for US; Menagaki (2011) for 27 European countries. The conservation hypothesis was confirmed in number of studies such as Menyah and Rufael (2010) for US; Apergis and Payne (2011) for 16 emerging countries.

On the other hand, the studies about the relationship between biomass consumption and economic growth are less. Bildirici (2012) investigated the relationship between biomass energy consumption and economic growth in Argentina, Bolivia, Brazil, Chile, Colombia, Jamaica, and Guatemala for 1980-2009 periods. Using ARDL bound test approach; the findings showed that there is a unidirectional relationship from biomass energy consumption to GDP in these countries. Bildirici (2013) investigated the causality relation between biomass energy consumption and economic growth in the selected 10 developing and emerging countries by using ARDL approach of cointegration and error correction models for periods from 1980 to 2009. In the countries studied, there is a unidirectional relationship from biomass energy consumption to GDP.

Bildirici and Ozaksay (2013) probed the relationship between biomass energy consumption and economic growth in some European countries, the results revealed that feedback hypothesis was valid in all these countries. Bildirici (2014) looked at the relationship between biomass energy and economic growth in transition countries. Using Pedroni (2000) panel cointegration and ARDL bound test, the evidence revealed that feedback hypothesis was existed in the all countries. Bildirici and Ersin (2014) considered the causality analysis among biomass energy consumption and economic growth in Austria, Canada, Germany, Great Britain, Finland, France, Italy, Mexico, Portugal and the U.S. for 1970-2013 periods by using ARDL method, Granger causality and Toda and Yamamoto non-causality test. For Austria, Germany, Finland and Portugal, the granger causality test determined the evidence that the conservation hypothesis is supported. In state of U.S., the feedback hypothesis highlights the interdependent relationship between biomass energy consumption and economic growth.

Ozturk and Bilgili (2015) explored the relationship between economic growth and biomass consumption by applying dynamic panel analyses for Sub-Saharan African countries for 1980–2009 periods. A significant and substantive influence of biomass energy consumption on economic growth was found. Bilgili and Ozturk (2015) used panel data method to investigate the relationship between biomass energy consumption and GDP growth in G7 countries for 1980-2009 periods. The result supported that there is unidirectional causality from biomass energy consumption to economic growth. Therefore, the growth hypothesis was supported. Similarly, the growth hypothesis of biomass energy is also validated by Destek (2017) and Aydin (2018).
Similarly, the results of the studies examining the relationship between renewable energy consumption and CO₂ emissions are mixed. Sadorsky (2009b) estimated an empirical model of renewable energy consumption in the G7 countries spanning the period 1980-2005. Panel cointegration estimation showed that in the long term, increasing CO₂ per capita is found to be major driver behind renewable energy consumption per capita. Menyah and Wolde-Rufael (2010) explored the causal relationship between CO₂ emissions, renewable and nuclear energy consumption in the US for the period 1960-2007. Using a modified version of the granger causality test, they found a unidirectional causality running from nuclear energy consumption to CO₂ emissions but no causality running from renewable energy to CO₂ emissions. Apergis and Payne (2014) investigated the relationship between renewable energy consumption and CO₂ emissions in Central America over the period 1980 to 2010. The bidirectional causality between the variables was found. Jebi et al. (2014) applied panel cointegration techniques and panel granger causality tests to investigate the nexus in Central and South America spanning the period 1995-2010. In the long-run, there is evidence of bidirectional causality between emissions and renewable energy consumption.

Rafiq et al. (2014) considered the dynamic relationships among carbon emission and renewable energy generation of India and China during the period 1972 to 2011 using vector error correction model (VECM). In the long run, bidirectional causality is found between carbon dioxide emissions and renewable energy generation. Zeb et al. (2014) utilized Granger causality test to explore the causal linkage between renewable energy production, CO₂ emissions, natural resource depletion in selected SARC countries over a period of 1975-2010. The results show that increasing renewable energy production leads to decrease in CO₂ emissions. Apergis and Payne (2015) utilized panel cointegration techniques to estimate the causal dynamics between renewable energy consumption per capita, real gross domestic product (GDP) per capita, carbon dioxide emissions per capita, and real oil prices for a panel of 11 South American countries over the period 1980 to 2010. The results of the study revealed a feedback relationship among the variables.

There are few studies investigating the relationship between biomass energy consumption and CO₂ emissions. For instance, Bilgili (2012) utilized Hatemi-J (2008) and Gregory-Hansen (1996) cointegration tests to examine the possible impact of biomass energy consumption on CO₂ emissions for the period from January 1990 to September 2011 in the US, the results of study showed that biomass energy consumption affects CO₂ emissions negatively. Hayfa and Rania (2014) examined the impact of the biomass energy use on CO₂ emissions by using panel data model for 15 countries during the period 1991-2011. The results showed that the biomass reduces the CO₂ emissions.

3. Data and Method

This study utilizes annual data from 1992 to 2013 for the G-20 countries, excluding the European Union: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom, and the United States. Following the energy demand models of Sadorsky (2009), Salim and Rafiq (2012), and Zeb et al. (2014), biomass energy consumption operates as a function of real GDP, CO₂ emissions, and natural resource depletion.

Biomass energy consumption (BIO) is the dependent variable measured in extraction per capita. The GNP per capita (Y) is measured in millions of constant 2005 US dollars. Carbon dioxide emissions (CO) are measured in metric tons per capita. Finally, natural resource depletion (NRD) is measured in natural resource depletion percentage of GNI. The data of Y, CO, and NRD are sourced from WDI (2015), and BIO is from the Global Material Flow database. The panel version of model can be shown as follows:

\[
lnBIO_{it} = \beta_0 + \beta_1 lnY_{it} + \beta_2 lnCO_{it} + \beta_3 lnNRD_{it} + \epsilon_{it} \tag{1}
\]

where lnBIO, lnY, lnCO and lnNRD indicate the natural log of biomass consumption per capita, gross domestic product per capita, carbon dioxide emissions per capita and natural resource depletion respectively.

The crucial step of econometric analysis is to investigate the stationary properties of variables. We used two panel unit root test such as LLC unit root test developed by Levin, Lin, and Chu (2002) and IPS unit root test developed by Im, Pesaran, and Shin (2003) in order to determine the order of integration of the variables. The null hypothesis of both test indicate unit root process.

In order to examine the long-run relationship between variables, the panel cointegration test developed by Pedroni (1999) is utilized. Pedroni (1999) developed seven statistics to analyze the possible long-run relation and the test which is based on estimation of Eq 1. with estimation of \(\delta_1 \epsilon_{it-1} + \sum_{k=1}^{K} \delta_k \epsilon_{it-k} + \nu_{it}\) regression model. The null hypothesis of test indicates that there is no cointegration between variables.

The next step is to examine the long-run coefficients of cointegrated variables. The long-run coefficients of variables are estimated with fully modified ordinary least squares (FMOLS) developed by Pedroni (2000). The estimation of FMOLS can be constructed as \(\beta_{fmols} = N^{-1} \sum_{i=1}^{N} \hat{\beta}_{Fmols}\) where \(\beta_{fmols}\) is acquired from individual FMOLS estimation of Eq 1.

In case of the existence of the long-run relationship between variables, the causality connections between variables can be examined. We utilized with the panel Granger causality test which is based on vector error correction model (VECM) to investigate the directions of causal linkage between biomass energy consumption, GDP growth, CO₂ emissions and natural resource depletion. The panel VECM can be written as follows:

\[
\Delta BIO_{it} = \delta_{1i} + \sum_{q=1}^{K} \delta_{1iq} \Delta BIO_{it-q} + \sum_{a=1}^{k} \delta_{a1q} \Delta Y_{it-q} + \sum_{q=1}^{K} \delta_{13iq} \Delta CO_{it-q} + \sum_{a=1}^{k} \delta_{a3q} \Delta NRD_{it-q} + \varphi_{11} \epsilon_{it-1} + \nu_{1it} \tag{2}
\]
\[ \Delta Y_{it} = \delta_{2t} + \sum_{q=1}^{k} \delta_{21tq} \Delta Y_{it-q} + \sum_{q=1}^{k} \delta_{22tq} \Delta CO_{it-q} + \varphi_{2t} \varepsilon_{it-1} + \nu_{2it} \]

\[ \Delta CO_{it} = \delta_{3t} + \sum_{q=1}^{k} \delta_{31tq} \Delta CO_{it-q} + \sum_{q=1}^{k} \delta_{32tq} \Delta BIO_{it-q} + \varphi_{3t} \varepsilon_{it-1} + \nu_{3it} \]

\[ \Delta NRD_{it} = \delta_{4t} + \sum_{q=1}^{k} \delta_{41tq} \Delta NRD_{it-q} + \sum_{q=1}^{k} \delta_{42tq} \Delta BIO_{it-q} + \varphi_{4t} \varepsilon_{it-1} + \nu_{4it} \]

where \( \Delta \) is the lag operator, \( k \) is the lag length and \( \varepsilon_{it} \) is the residual term.

4. Empirical Findings

In the first step of empirical analysis, the stationary process of variables are examined with panel unit root tests and test results are shown in Table 1. At a first glance, the null of unit root can’t be rejected clearly at 1% percent level. When the difference operator is used, the null of unit root can be rejected strongly and all variables become stationary. The variables are integrated of order one therefore it seems there is possible long-run relationship between variables.

Table 1. The Results of Panel Unit Root Test

| Variable | LLC Constant | LLC Trend | IPS Constant | IPS Trend |
|----------|--------------|-----------|--------------|-----------|
| lnBIO    | -0.8770      | 0.1902    | 0.0000       | 0.0000    |
| lnY      | -0.2845      | 0.1918    | 0.5761       | 0.6305    |
| lnCO     | 1.8418       | 0.4823    | 0.4020       | 0.3409    |
| lnNRD    | -1.9592      | 0.0250    | 0.0003       | 0.4378    |
| lnBIO    | -19.7641     | -17.9867  | -17.0624     | -14.8293  |
| lnY      | -10.4721     | -10.3147  | -5.1252      | -4.2660   |
| lnCO     | -11.5946     | -14.1715  | -9.9335      | -12.0506  |
| lnNRD    | -11.6946     | -10.2028  | -10.8139     | -8.2947   |

\( \Delta \) is the first difference operator. The maximum lag lengths were selected automatically using with Schwarz Information Criteria. Numbers in brackets are \( p \)-values. Newey-West bandwidth selection with Bartlett kernel is used for LLC test. Numbers in brackets are \( p \)-values.

In the second step, the panel cointegration test results are presented in Table 2. We used each variable as a dependent variable and investigated the cointegration relationship for four models. The results show that the null of no cointegration can be rejected for all models. Therefore, it can be said that the biomass consumption, economic growth, \( CO_2 \) emissions and natural resource depletion are cointegrated.

Table 2. The Results of Panel Cointegration Test

| Dependent variable: lnBIO |
|---------------------------|
| Constant & Trend          |
|---------------------------|
| Panel \( \gamma \)-statistic | 1.1504 | 2.0975*** |
| Panel \( \rho \)-statistic | -0.0836 | 1.6232 |
| Panel PP-statistic | -6.1002*** | -7.8412*** |
| Panel ADF-statistic | -4.3176*** | -7.4777*** |
| Group \( \rho \)-statistic | 0.3060 | 2.2899 |
| Group PP-statistic | -6.0368*** | -9.6942*** |
| Group ADF-statistic | -5.5689*** | -7.3531*** |

| Dependent variable: lnGDP |
|---------------------------|
|---------------------------|
| Panel \( \gamma \)-statistic | 1.4931* | 0.9777 |
| Panel \( \rho \)-statistic | 0.6493 | 1.8564 |
| Panel PP-statistic | -1.0863 | -1.7421** |
| Panel ADF-statistic | -1.4935* | -2.5461*** |
| Group \( \rho \)-statistic | 2.3136 | 2.3572 |
| Group PP-statistic | -1.8041** | -4.7585*** |
| Group ADF-statistic | -1.7910*** | -5.7920*** |

| Dependent variable: lnNRD |
|---------------------------|
|---------------------------|
| Panel \( \gamma \)-statistic | 0.5588 | -1.2417 |
| Panel \( \rho \)-statistic | -0.1924 | 1.3484 |
| Panel PP-statistic | -4.9731*** | -6.5361*** |
| Panel ADF-statistic | -3.6507*** | -6.6144*** |
| Group \( \rho \)-statistic | 2.3099 | 3.5072 |
| Group PP-statistic | -5.0645*** | -7.6100*** |
| Group ADF-statistic | -4.0004*** | -5.1886*** |

*, ** and *** indicates statistically significance at 10, 5 and 1 percent level respectively.

Next, the results of panel group FMOLS estimation are reported in Table 3. The panel group FMOLS estimation results show that the increase in \( CO_2 \) emissions by 1% will increase biomass energy consumption by 0.3098%. In addition, the increase in natural resource depletion by 1% will increase biomass energy consumption by 0.0249%. It also shows that the increase in biomass consumption, \( CO_2 \) emissions and natural resource depletion by 1% will increase GDP growth by 0.2164%, 0.6748% and 0.0481% respectively. Moreover, the increase in biomass energy consumption by 1% will decrease \( CO_2 \) emissions by 0.2565% and the increase in GDP growth by 1% will increase in \( CO_2 \) emissions by 0.5686%. The results also reveal that the increase in biomass energy consumption by 1% will decrease natural resource depletion by 0.8801% and the increase in GDP growth by 1% will increase natural resource depletion by 1.9618%.
Finally, Table 4 represents the panel granger causality test results. In the short-run, there is a unidirectional causality from biomass energy consumption to GDP growth. Furthermore, there is bidirectional causality between biomass energy consumption and CO$_2$ emissions. In addition, the unidirectional causal relationship exists from GDP growth to CO$_2$ emissions. In the long-run, on the one hand, the biomass energy consumption, CO$_2$ emissions and natural resource depletion causes GDP growth. On the other hand, GDP growth, CO$_2$ emissions and natural resource depletion do not cause the biomass energy consumption. To sum up, the unidirectional causality from the biomass energy consumption to GDP growth indicates that the growth hypothesis is supported in G-20 countries for both of the short-run and the long-run. Similarly, the biomass energy consumption causes the CO$_2$ emissions for both of the short-run and the long-run.

![Table 3. The Results of Panel Group FMOLS Estimation](image)

| Variables | Coefficients | t-statistics |
|-----------|--------------|--------------|
| lnY       | -0.1130      | -1.6415      |
| lnCO      | 0.3098***    | 3.5625       |
| lnNRD     | -0.0249*     | -1.8266      |
| lnBIO     | 0.2164**     | 3.3729       |
| lnNRD     | 0.0481**     | 5.2642       |

![Table 4. The Results of Panel Granger Causality Test](image)

| Independent Variables | Short-run causality | Long-run causality |
|-----------------------|---------------------|--------------------|
| lnBIO                 | lnY                 | lnCO               | lnNRD | ECT(1)  |
| ΔlnBIO               | -                   | 2.1017             |       | -0.0080 [1.4079] |
| ΔlnY                 | 6.5240***           | -                  | 2.8637 | 0.3592 [-4.4650] |
| ΔlnCO                | 4.8450*             | 6.5899**           | -     | 1.0656 [-4.2692] |
| ΔlnNRD               | 1.0751              | 6.2185             | 0.4630 | -     | -0.0015 [-0.5337] |

*, ** and *** indicates statistically significance at 10, 5 and 1 percent level respectively. Numbers in brackets are t-statistics. The optimal lag length is selected with using Schwarz Information Criteria.

5. Conclusions and Policy Implications

This study empirically investigate the relationship between biomass energy consumption, GDP growth, CO$_2$ emissions, and natural resource depletion in G-20 countries excluding the European Union, from 1992 to 2013. We applied panel unit root tests, the panel cointegration test, the panel FMOLS method, and panel VECM Granger causality methods in order to examine the nexus.

The results of the panel cointegration test reveal that biomass energy consumption, GDP growth, CO$_2$ emissions, and natural resource depletion are cointegrated. In addition, the panel FMOLS estimation results demonstrate that an increase in CO$_2$ emissions by 1% increases biomass energy consumption by 0.3098%. Furthermore, an increase in natural resource depletion by 1% decreases biomass energy consumption by 0.0249%. An increase in biomass consumption, CO$_2$ emissions, and natural resource depletion by 1% increases GDP growth by 0.2164%, 0.6748%, and 0.0481%, respectively. Moreover, an increase in biomass energy consumption by 1% decreases CO$_2$ emissions by 0.2565%, while an increase in GDP growth by 1% increases CO$_2$ emissions by 0.5686%. An increase in biomass energy consumption by 1% decreases natural resource depletion by 0.8801%, and an increase in GDP growth by 1% increases natural resource depletion by 1.9618%. The panel VECM Granger causality test results indicate that unidirectional causality exists from biomass energy consumption to GDP growth and from GDP growth to CO$_2$ emissions. In addition, bidirectional causality exists between biomass energy consumption and CO$_2$ emissions.

These empirical findings suggest some policy implications. Since the growth hypothesis is supported, the G-20 countries should increase investments in the production of biomass energy and increase the share of biomass consumption of total energy consumption. Using biomass energy plays a crucial role in reducing pollution and providing sustainable development. Moreover, investment in biomass energy should be encouraged because an increase in biomass energy consumption leads to a decrease in natural resource depletion. In summary, biomass energy is an appropriate energy source to reduce countries’ dependence on energy import energy dependency, to avoid energy price volatility, and to provide green growth sustainability for the G-20 countries.

Kaynakça

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