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Energy and Economic Effects of the COVID-19 Pandemic: Evidence from OECD Countries

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Abstract: The COVID-19 pandemic has caused disruption to the original order of the global economy and has had an influence on the social and economic growth of countries all over the globe. As a result, the aim of this paper is to explore the consequences of the COVID-19 pandemic on a sample of OECD countries with regard to energy and the economy. For empirical investigation, data from the first quarter of 2010 to the first quarter of 2022 are used, and the system generalized method of moments is applied. The findings reveal that during the COVID-19 pandemic, energy consumption impeded economic growth while economic expansion was the primary driver of energy resource consumption. Furthermore, an examination of heterogeneous effects reveals that economic growth and energy consumption are heterogeneous both before and after the COVID-19 pandemic. To conclude, these findings might provide a contribution to the body of research that has already been undertaken on this subject.

Keywords: energy consumption; economic growth; system generalized method of moments; heterogeneous effects; COVID-19 pandemic

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1. Introduction

Because of the COVID-19 pandemic's outbreak, the economy of the whole globe has been going through a period of uncertainty. Of course, the COVID-19 pandemic has come to have a substantial impact on the economies of OECD countries as well as the supply of energy. This is significant since the OECD is an important organization that handles the challenges of social, economic, and political governance generated by global instability such as the COVID-19 pandemic. The global supply chain, investor confidence, consumer spending, and the tourist sector are all impacted by the COVID-19 pandemic, based on the OECD countries' report on the economic forecast for 2021. It has a greater impact on prominent trade partners of China, such as Japan and South Korea. As a result of the COVID-19 pandemic, the OECD estimated that worldwide economic growth would be 2.4% in 2022 (down 0.5% from the previous year), and 1.9% in the United States, 4.9% in China, 0.8% in the euro zone, and 0.2% in Japan. Similarly, as a direct consequence of the COVID-19 pandemic, OECD countries have unavoidably experienced a substantial shock to their energy supplies. The energy markets in the OECD countries have been severely thrown off balance as a result of substantial disruptions caused by insufficient energy supply and increasing energy prices during the COVID-19 pandemic.

Therefore, according to the foregoing study of the existing situation on this topic, this work examines the energy and economic impacts of the COVID-19 pandemic between the first quarters of 2010 and 2022, using OECD countries as examples. When conducting empirical studies employing the approach of the system generalized method of moments, the following findings emerged. First, renewable energy use increased by 1% during the COVID-19 pandemic (January 2020 to January 2022), but economic growth declined by 0.014%. Second, economic prosperity promoted renewable energy consumption during the COVID-19 pandemic. Third, a 1% rise in fossil fuel energy consumption during the COVID-19 pandemic is expected to lower economic growth by 0.064%. Fourth, during the COVID-19 pandemic, economic growth was the main motivation for fossil fuel energy consumption. Moreover, the assessment of heterogeneous effects is used for further discussion. Before and after the COVID-19 pandemic, the connections between energy consumption and economic development are seen to be heterogeneous.

The findings of this research provide three noteworthy additions to the current body of knowledge in their respective fields. To begin with, according to the results of the non-causality test conducted by Dumitrescu and Hurlin [1], a two-way causal link between energy consumption and economic growth in OECD countries is found. Furthermore, economic development is negatively impacted by energy consumption during the COVID-19 pandemic. Finally, while comparing the time periods before and after the COVID-19 pandemic, it is revealed that the relationships between energy consumption and economic growth are heterogeneous.

The rest of this work is formed as follows: The past research on this issue is provided in Section 2. The variables and econometric techniques are presented in Section 3. In Section 4, the findings and a discussion are presented. The conclusion is drawn in Section 5.

2. Literature Review

This section's purpose is to undertake a literature review on the effects of the COVID-19 pandemic on energy and the economy. For a comprehensive examination of the connections between the investigated variables, two subsections are used. The first issue is the impact that the COVID-19 pandemic has had on energy. The second issue is the impact that the COVID-19 pandemic has had on the economy.

2.1. Effect of the COVID-19 Pandemic on Energy

The COVID-19 pandemic has presented a significant set of difficulties for the energy industry. Therefore, a large number of researchers started using a wide variety of samples and approaches so as to investigate the influence that the COVID-19 pandemic has on energy. Aruga et al. [2] explored how COVID-19 confirmed cases influenced energy consumption in India by assessing whether the release of lockdown had a favorable effect on energy consumption and whether wealthy areas recovered their energy consumption faster than poorer ones. They observed that there was a long-run association between the number of COVID-19 confirmed cases and energy consumption by using the autoregressive distributed lag approach. Furthermore, they also found that the COVID-19 confirmed cases had a beneficial influence on energy consumption. Subsequently, Kang et al. [3] investigated how changes in energy consumption occurred in South Korea because of the COVID-19 pandemic. After conducting an empirical investigation using parametric statistical techniques, they discovered that energy consumption during the COVID-19 pandemic was lower when compared to the energy consumption during the previous year. Meanwhile, Wang et al. [4] identified the influence of the COVID-19 pandemic on energy consumption based on fresh insights derived from the discrepancy between the pandemic-free scenario and real power usage in China. Using the back propagation neural network and autoregressive integrated moving average for empirical research, they revealed that the COVID-19 pandemic had led to a 29% decline in China's electricity use. With a sample of commercial tourism cities, Zhang et al. [5] also found that the COVID-19 pandemic did affect urban energy consumption. López-Sosa et al. [6] undertook research to investigate how the COVID-19 pandemic affected energy consumption at 13 different state institutions in the Mexican state of Michoacán. The use of electricity has been assessed prior to and during the 2019–2020 presence of COVID-19. They discovered a significant drop in electricity use, resulting in an average monthly savings of 76.24 MWh, which equated to a reduction in emissions of roughly 497 TnCO2e every year from 2019 to 2020. Furthermore, these results were supported by García et al. [7–10].

2.2. Effect of the COVID-19 Pandemic on the Economy

The COVID-19 pandemic has ravaged the worldwide economy, leaving a significant portion of the global population poor. In addition, the epidemic has produced considerable economic and social policy uncertainty. As a consequence of the COVID-19 outbreak, the Korean economy has suffered tremendously. On the basis of this context, He and Wang [11] examined the macroeconomic influences of the COVID-19 pandemic. They discovered, using impulse response function analysis, that Korea's key macroeconomic variables can be significantly affected by the COVID-19 pandemic in the short run but not in the long run. Vitenu-Sackey and Barfi [12] explored the influence of the COVID-19 pandemic on the world economy using 170 countries and econometric panel methodologies, such as ordinary least square and robust least square regression. They found that economic growth was negatively affected by the COVID-19 pandemic. Moreover, Alam et al. [13] conducted analyses to determine the possible effects that the COVID-19 pandemic could have on the economic situation in Bangladesh. They discovered that the COVID-19 pandemic had significant effects on the various economic indicators of Bangladesh, particularly the bank and financial institutions, foreign remittances, local trade, gross domestic product, international trade, and employment. Ikram et al. [14] investigated how the COVID-19 outbreak influenced exports of products and services in the Asian nations that were hit the most, including Pakistan, Indonesia, India, Bangladesh, Iran, and the Philippines. Using a conservative model for empirical study, they found that the COVID-19 pandemic had a negative effect on international trade so as to affect economic growth. Meanwhile, Soava et al. [15] conducted research to evaluate the idea that the COVID-19 pandemic had an effect on Romania's gross domestic product and assessed the information to assess whether or not the theory was supported. An examination of the development of these indicators over the period spanning 2007–2020 was carried out by using a time series on quarterly gross domestic product as well as a multi-linear regression model. They verified that the shock of falling activity resulting from the COVID-19 pandemic had a significant negative effect on gross domestic product in the first half of 2020, with a slight rebound. In addition, these results were aligned with Burger and Calitz [16–20].

In conclusion, the aforementioned studies explored the influences of COVID-19 on energy consumption and the economy by employing a variety of approaches and examples. Compared with this previous literature, the approach of generalized method of moments is employed and OECD countries are used in this work to explore the consequences of the COVID-19 pandemic on energy consumption and economic growth, and to examine the heterogeneous effects between economic growth and energy consumption before and after the COVID-19 pandemic. The findings of this work have the potential to add to the existing body of research on the subject that was explored in this paper.

3. Variable Description and Econometric Techniques

3.1. Variable Description

This paper examines the energy and economic consequences of the COVID-19 pandemic on a sample of OECD countries from the first quarter of 2010 to the first quarter of 2022. Therefore, there are four different variables discussed in this work. There are the gross domestic product; renewable energy (which refers to final consumption of non-fossil energy such as wind energy, solar energy, hydro energy, biomass energy, geothermal energy, and clean energy); fossil fuel energy consumption (which comprises the final consumption of coal, oil, petroleum, and natural gas products); and COVID-19 pandemic. They are sourced from OECD data, Statista, and FRED economic data. Table 1 provides the forms and definitions of these three highlighted variables, which are necessary for a complete understanding of these variables.

Table 1. Results of variable description.

Variable	Form	Definition
Gross domestic product	gdp	Market price gross domestic product (in millions) in log
Renewable energy consumption	new	Renewable energy consumption (1000 ton) in log
Fossil fuel energy consumption	foul	Fossil fuel energy consumption (1000 ton) in log
COVID-19 pandemic	covid	Dummy variable (before the fourth quarter of 2020, the value is zero; otherwise, the value is one)

3.2. Econometric Techniques

3.2.1. Cross-Sectional Dependence Test

There are plenty of panel unit root tests that have been used in previous literature. However, to figure out which kind of unit root test is proper, we should verify the variables' cross-sectional dependence because it leads to the use of specific unit root tests. In the case that a cross-sectional dependence exists, the use of the second-generation panel unit root tests is recommended. There are a number of different cross-sectional dependence tests that can be found in the previous literature that have been performed, such as the LM test that was developed by Breusch and Pagan [21], the cross-sectional dependence test that was developed by Pesaran [22], and the Lagrange Multiplier test that was developed by Baltagi et al. [23]. In contrast to the previous tests, when the number of individuals is greater than that of years, the cross-sectional dependence test that was developed by Pesaran [22] is more appropriate in the case of a small sample. Therefore, this test, which is computed using the pairwise correlation derived from the Augmented Dickey–Fuller test regressions' residuals, is used in this paper. The generation of the cross-sectional dependence (csd) test is shown as follows:

$$\text{csd} = \left(\frac{2t}{n(n-1)}\right)^{\frac{1}{2}} \left(\sum_{i=1}^{n-1} * \sum_{j=i+1}^{n} \widetilde{\rho_{ij}}\right), \tag{1}$$

For Equation (1), the null hypothesis is held when ρ_{ij} is equal to zero. Otherwise, the alternative hypothesis is held when ρ_{ij} is not equal to zero.

3.2.2. Panel Unit Root Test

If a cross-sectional dependence exists, the panel unit root tests, which determine whether or not the impact of dependence should be removed or if its presence should be taken into consideration, are used. To achieve an accurate estimate, two kinds of second-generation panel unit root tests are used in this paper. These two tests are the cross-sectional augmented test that was developed by Breitung and Das [24] and the cross-sectional augmented Dickey–Fuller test that was developed by Pesaran [25]. The following is an expression for the cross-sectional augmented Dickey–Fuller test regression without autocorrelation and associated statistic:

$$\Delta y_{i,t} = a_i + b_i y_{i,t-1} + c_i \overline{y_{t-1}} + d_i \overline{y_t} + \mu_{i,t}, \tag{2}$$

$$t_i^{n,t} = \frac{\Delta y_i^{\sim} \overline{M_w} y_{i,-1}}{\hat{\sigma}_i \left(y_{i,-1}^{\sim} \overline{M_w} y_{i,-1}\right)^{\frac{1}{2}}} \tag{3}$$

the null hypothesis is held when b_i is equal to zero. Otherwise, the alternative hypothesis is held when b_i is not equal to zero. Meanwhile, the expression of the cross-sectional augmented test is shown as follows:

$$\text{cips} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} \Delta y_{i,t} \tag{4}$$

cips denotes the cross-sectional augmented test.

3.2.3. Homogeneity Test

When performing a causality test using panel data, it is essential to determine if the model's parameters are heterogeneous or homogeneous. To put it another way, when the parameters are homogeneous, the panel Granger causality test is the one that should be used as the preferable causality test. The causality test developed by Dumitrescu and Hurlin [1] has to be used on the occasion that the model's parameters exhibit heterogeneous features and the slop parameters fluctuate from one individual to the next. In light of this, it is essential that the parameters' homogeneity be validated before moving on to the causality test. Meanwhile, Swamy [26] designed an approach to investigate whether or not the parameters are heterogeneous or homogeneous. The following is a calculation that can be made for the Swamy S test statistics:

$$\widetilde{S} = \chi^2_{k(n-1)} = \sum_{i=1}^{n} (\widetilde{\alpha}_i - \alpha^*)^{`}\, \widetilde{V}_i^{-1} (\widetilde{\alpha}_i - \alpha^*), \quad (5)$$

where $\widetilde{\alpha}_i$ denotes the estimated value of the ordinary least squares coefficient that was obtained from cross-sectional regressions; α^* denotes the coefficient estimated by a pooled weighted regression. In spite of the fact that the Swamy S test is a popular technique for determining whether or not the parameters are consistent with one another, in most cases it yields more accurate findings when the number of periods is greater than that of individuals. As a result of this constraint, the test that was developed by Pesaran and Yamagata [27] is used. In this test, Pesaran and Yamagata [27] adapted the Swamy S test so that it could be used when the number of individuals exceeds the number of periods.

3.2.4. Dumitrescu and Hurlin Causality Test

We should use the panel causality test developed by Dumitrescu and Hurlin [1] to have an understanding of the causal relationship that exists between variables when those variables are held constant in terms of their levels but display heterogeneity in terms of parameters. Although there are fewer periods than there are individuals, the test that was developed by Dumitrescu and Hurlin [1] is still able to produce satisfactory outcomes. However, the panel Granger causality test cannot be used under these conditions. The reason is that the panel Granger causality test can be only used under the condition that all variables are stationary at their levels. The following is a mathematical expression of the panel causality test developed by Dumitrescu and Hurlin [1], along with its respective null hypothesis and alternative hypothesis:

$$y_{i,t} = a_i + \sum_{k=1}^{K} b_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} c_i^{(k)} x_{i,t-k} + \mu_{i,t}, \quad (6)$$

for Equation (6), the null hypothesis is held when c_i is equal to zero with $i \in [1, n]$. On the contrary, the alternative hypothesis is held when c_i is equal to zero with $i \in [1, n_1]$ or when c_i is not equal to zero with $i \in [n_i + 1, n]$. The Wald test statistics are used in the determination of the test statistic for the panel causality test that was conducted by Dumitrescu and Hurlin [1]. The form is shown as follows:

$$W_{n,t} = \frac{\sum_{i=1}^{n} W_{i,t}}{n}. \quad (7)$$

4. Results and Discussion

4.1. Basic Statistical Analysis

To adequately prepare for the empirical studies that will follow, some basic statistical tests such as cross-sectional dependence tests, panel unit root tests, and homogeneity tests, must be performed on the variables that will be evaluated in this study. The results are shown in Table 2.

Table 2. Results of basic statistical analysis.

Panel A: Cross-Sectional Dependence Tests		
Variable	csd-test	correlation
gdp	57.600 *** (0.000)	0.591
new	48.357 *** (0.000)	0.634
foul	29.972 *** (0.000)	0.525
Panel B: panel unit root tests		
Variable	Im et al. [28]	Pesaran [29]
gdp	−5.448 *** (0.000)	−5.285 *** (0.000)
new	−3.121 *** (0.000)	−3.346 *** (0.000)
foul	−6.538 *** (0.000)	−6.304 *** (0.000)
Panel C: homogeneity tests		
Variable	Pesaran and Yamagata [27]	Swamy [26]
gdp	9.276 *** (0.000)	330.79 *** (0.000)
new	5.304 *** (0.000)	318.22 *** (0.000)
foul	8.791 *** (0.000)	539.69 *** (0.000)

Note: *p*-value shown in the parentheses; *** 1% significant level.

Table 2 provides the results estimated by the techniques such as cross-sectional dependence tests, panel unit root tests, and homogeneity tests. The estimated results of cross-sectional dependence tests are shown in Panel A. It is found that the null hypothesis is rejected for these investigated variables. Therefore, it can be confirmed that cross-sectional dependence exists. Moreover, the value of correlation between countries in terms of gross domestic product is 0.591, while the value of correlation between countries in terms of renewable energy is 0.634, and the value of correlation between countries in terms of fossil fuel energy is 0.525. In fact, this is to be expected given that the sample includes countries that belong to the same economic community. As a consequence of the existence of cross-sectional dependence, the second-generation panel root tests are used for further empirical analysis.

The results of panel unit root tests are shown in Panel B. In this article, we use two different types of panel unit root tests that were developed by Breuer et al. [25] to ensure that our findings are as accurate as possible. The reason for this is that they are able to overcome the cross-sectional dependence of the panel data. It has been determined that the null hypothesis is rejected for these three highlighted variables at a 1% significant level. Namely, the variables that were included in this study are stationary in their levels. In light of the findings from the panel unit root tests, the panel causality test is used to investigate the short-run link between these highlighted variables. Assessing the parameters' homogeneity is an essential step that should be taken when evaluating whether panel causality test should be used.

The results of the homogeneity tests are shown in Panel C. This article makes use of two distinct approaches for testing homogeneity to guarantee that our findings are as reliable as possible. Using these two approaches, we perform an estimation of a regression in which these highlighted variables are treated as dependent variables, while the lags of these highlighted variables are treated as independent variables. The results of two kinds of homogeneity tests indicate that the null hypothesis is rejected. Therefore, the panel causality test that was developed by Dumitrescu and Hurlin [1] is used in this paper for further study. The reason is that this kind of panel causality test is better than the Granger causality test in dealing with parameters' heterogeneity in the model.

4.2. Results

The results of the non-causality test developed by Dumitrescu and Hurlin [1] are shown in Table 3.

Table 3. Results of the non-causality test developed by Dumitrescu and Hurlin [1].

Hypothesis	W-Bar	Z-Bar Tilde	*p*-Value	BP-Value
gdp → new	3.125	2.913	0.002	0.000
new → gdp	4.226	3.444	0.000	0.000
gdp → foul	2.423	2.129	0.003	0.000
foul → gdp	3.289	2.979	0.001	0.000

Note: → does not homogeneously cause; BP-value boostrap *p*-value.

Table 3 indicates the results of the non-causality test developed by Dumitrescu and Hurlin [1]. On the basis of these findings, we can reach the conclusion that a causal relationship that runs in both directions between the gross domestic product and the renewable energy is found. Moreover, the results in Table 3 also suggest that a two-way causality between fossil fuel energy and the gross domestic product exists. In addition, this feedback hypothesis is supported by Chontanawat et al. [30–35].

The aim of this work is to investigate the energy and economic results of the COVID-19 pandemic. To accomplish this objective, we will define a dummy variable as the COVID-19 pandemic. Specifically, the value is set to zero before the first quarter of 2020; otherwise, the value is set to one. To compute the energy and economic effects of the COVID-19 pandemic, we additionally develop an interaction term between energy and COVID-19 pandemic as well as an interaction term between economic growth and COVID-19 pandemic. Panel analysis approaches can be looked at either as dynamic or static models. Both can be investigated. Following Baum et al. [36], when using the dynamic model rather than the static model, the dataset we are working with has to have a few periods but many more individual dimensions. As a result, the dynamic panel analysis is used for empirical analysis. The system generalized method of moments is presented as follows:

$$\mathrm{gdp}_{i,t} = a_1 + \sum_{i=1}^{n} b_i \mathrm{gdp}_{i,t-1} + \sum_{i=1}^{m} c_i \mathrm{new}_{i,t} + d_1 \mathrm{covid}_t * \mathrm{new}_{i,t} + e_1 \mathrm{covid}_t + \mu_{i,t}, \quad (8)$$

$$\mathrm{gdp}_{i,t} = a_1 + \sum_{i=1}^{n} b_i \mathrm{gdp}_{i,t-1} + \sum_{i=1}^{m} c_i \mathrm{foul}_{i,t} + d_1 \mathrm{covid}_t * \mathrm{foul}_{i,t} + e_1 \mathrm{covid}_t + \mu_{i,t}, \quad (9)$$

$$\mathrm{new}_{i,t} = a_1 + \sum_{i=1}^{n} b_i \mathrm{new}_{i,t-1} + \sum_{i=1}^{m} c_i \mathrm{gdp}_{i,t} + d_1 \mathrm{covid}_t * \mathrm{gdp}_{i,t} + e_1 \mathrm{covid}_t + \mu_{i,t}, \quad (10)$$

$$\mathrm{foul}_{i,t} = a_1 + \sum_{i=1}^{n} b_i \mathrm{foul}_{i,t-1} + \sum_{i=1}^{m} c_i \mathrm{gdp}_{i,t} + d_1 \mathrm{covid}_t * \mathrm{gdp}_{i,t} + e_1 \mathrm{covid}_t + \mu_{i,t}, \quad (11)$$

where a_1 denotes the constant; b_i, c_i, d_1, and e_1 denote the estimated coefficients; $\mu_{i,t}$ denotes the white noise. The results are shown in Table 4.

Table 4 presents the findings of the influences of the COVID-19 pandemic on renewable energy, fossil fuel energy and economic growth. For model (1), the effect of renewable energy on economic growth during the COVID-19 pandemic is suggested. It is found that the renewable energy coefficient is 0.049 with a statistical significance of 1%. In other words, an increase of 1% in renewable energy results in a rise of 0.049% in economic growth. However, the interaction term coefficient between renewable energy and COVID-19 pandemic is negative and significant at 1%. Specifically, if renewable energy goes up by 1% during the COVID-19 pandemic, economic growth goes down by 0.014%. One possible explanation is that a substantial quantity of renewable energy is consumed to deal with COVID-19, while the amount of renewable energy spent in real production is decreased. As a result, unfavorable impacts are shown. Meanwhile, these outcomes were consistent with Kraft and Kraft [37–41]. For model (2), the effect of economic growth on renewable energy during the COVID-19 pandemic is examined. Similarly, it is observed that economic expansion favorably influences renewable energy. This means that a 1% rise in economic growth results in a 0.272% rise in renewable energy. Moreover, the interaction term coefficient between economic growth and COVID-19 pandemic is positive and significant at 1%. This implies that economic prosperity drives renewable energy development during the COVID-19 pandemic. Furthermore, these outcomes were supported by Bhuiyan et al. [42–45].

Table 4. Results of the energy and economic effects of COVID-19 pandemic.

Variable Model	Model (1) (gdp)	Model (2) (new)	Model (3) (gdp)	Model (4) (foul)
gdp_{-1}	0.734 *** (14.153)	0.272 *** (3.746)	0.733 *** (10.710)	0.166 ** (2.046)
new_{-1}	0.049 *** (5.537)	0.446 *** (4.724)		
$foul_{-1}$			0.083 ** (2.138)	0.608 *** (9.058)
$gdp * covid$		0.259 *** (13.075)		0.348 *** (5.736)
$new * covid$	−0.014 *** (-2.765)			
$foul * covid$			−0.064 *** (2.737)	
covid	0.228 *** (13.177)	−1.253 *** (-13.388)	0.155 * (1.609)	−0.237 *** (−6.214)
Wald test	160.004 ***	206.453 ***	397.243 ***	247.672 ***
Hansen test	30.092	31.872	33.711	29.182
AR (2)	−0.016	−0.182	−0.056	−0.029

Note: t-value shown in the parentheses; *** 1% significant level; ** 5% significant level; * 10% significant level.

For Model (3), during the COVID-19 pandemic the influence of fossil fuel energy on economic growth is explored. It is suggested that the fossil fuel energy coefficient is positive at 5% significant level. This indicates that a 1% rise in fossil fuel energy leads to a 0.083% boost in economic growth. Equally, the interaction term coefficient between fossil fuel energy and COVID-19 pandemic is negative and significant at 1%. To be more specific, during the COVID-19 pandemic, a fall in economic growth of 0.064% is predicted to occur if the percentage of fossil fuel energy increases by 1%. One probable explanation is that a lot of fossil fuel was used in response to COVID-19. Of course, the quantity of fossil fuel used in manufacturing will be reduced accordingly. At the same time, certain factories have been closed due to COVID-19, which has resulted in negative outcomes. Furthermore, Le Billon et al. [46–49] agreed with these findings. For model (4), the effect of economic growth on fossil fuel energy during the COVID-19 pandemic is detected. In a similar vein, it is found that a growing economy has a positive impact on fossil fuel energy. This indicates that a rise in economic growth of 1% leads to an increase in fossil fuel energy of 0.166%. Likewise, at a significance level of 1%, the coefficient of the interaction term between economic growth and the COVID-19 pandemic is positive. The inference may be drawn from this that economic growth is the primary motivator for the consumption of fossil fuel energy sources during the COVID-19 pandemic. Additionally, these outcomes were in keeping with Wang et al. [50–53].

An empirical analysis of OECD countries reveals that the COVID-19 pandemic does matter for energy consumption and economic growth. The next stage, which will be undertaken so as to guarantee the reliability and accuracy of the conclusions of this article, will be to conduct an analysis of the heterogeneous impacts that the COVID-19 pandemic has on energy and economy.

4.3. Heterogeneous Effects Analysis

The focus of this subsection is to examine the link that existed between economic growth and energy consumption before and after the onset of the COVID-19 pandemic. Because of this, the whole sample is divided up into two sub-samples. The first one begins with the first quarter of 2010 and ends with the fourth quarter of 2019, while the second one begins with the first quarter of 2020 and ends with the first quarter of 2022. The results are presented in Table 5.

Table 5. Results of heterogeneous effects analysis.

Sub-Sample	**Before the COVID-19 Pandemic**		**After the COVID-19 Pandemic**	
Variable Model	**Model (5) (gdp)**	**Model (6) (new)**	**Model (7) (gdp)**	**Model (8) (new)**
gdp_{-1}	0.971 *** (8.577)	0.570 * (1.856)	0.391 * (1.746)	0.152 ** (2.129)
new_{-1}	0.095 *** (5.112)	0.218 *** (5.863)	0.075 *** (3.607)	0.193 ** (2.158)
Wald test	191.462 ***	186.343 ***	158.857 ***	139.394 ***
Hansen test	28.195	28.817	31.080	25.500
AR (2)	−0.153	−1.332	−1.044	−0.252
Variable Model	Mode (9) (gdp)	Mode (10) (foul)	Mode (11) (gdp)	Mode (12) (foul)
gdp_{-1}	0.892 *** (3.543)	0.282 *** (5.149)	0.519 *** (8.760)	0.249 *** (2.785)
$foul_{-1}$	0.139 *** (5.740)	0.641 *** (8.907)	0.122 * (2.030)	0.152 * (1.786)
Wald test	136.103 ***	127.219 ***	143.054 ***	169.366 ***
Hansen test	30.493	33.002	31.880	33.831
AR (2)	−0.173	−0.165	−0.226	−0.667

Note: t-value shown in the parentheses; *** 1% significant level; ** 5% significant level; * 10% significant level.

The findings of this study are shown in Table 5, which examines the connection between economic growth and energy consumption both before and after the outbreak of the COVID-19 pandemic. It is discovered in models (5) and (6) that the association between economic growth and renewable energy is positive and statistically significant before the COVID-19 pandemic. Equally, it is shown that the link between economic growth and renewable energy is positive and statistically significant after the COVID-19 pandemic. This conclusion is based on the findings of models (7) and (8), respectively. Nevertheless, there are disparities between these estimated coefficients with regard to the magnitude and significant levels of the discrepancies. Therefore, it is possible to reach the conclusion that a heterogeneity between renewable energy and economic growth both before and after the COVID-19 pandemic is found. Before the COVID-19 pandemic, it is suggested that a positive association between fossil fuel energy and economic growth is found in models (9) and (10). Similarly, after the COVID-19 pandemic, it is also found that economic growth and fossil fuel energy positively affected each other in models (11) and (12). However, there are obvious differences between these estimated coefficients in terms of both the size and the levels of the discrepancies that are significant. In other words, it is feasible to conclude that there is heterogeneity between economic growth and fossil fuel energy both before and after the COVID-19 pandemic. These results add new information to the body of research that has already been undertaken on this subject when compared to previous studies [43,44].

4.4. Discussion

With reference to the empirical findings presented in this article, a comprehensive discussion of this study is offered in this subsection. Specifically, the contribution of renewable energy to the expansion of the economy is favorable. However, a negative interaction term coefficient between renewable energy and the COVID-19 pandemic has been discovered. One probable reason is that a significant proportion of renewable energy is used to combat COVID-19, although the amount of renewable energy used in actual manufacturing has declined. As a consequence, a negative effect has been found. In a similar vein, it has been noted that a growing economy has a positive impact on renewable sources of energy. Equally, there is a positive value for the coefficient of the interaction term between economic growth and the COVID-19 pandemic. This suggests that economic growth is the primary driver of progress toward the development of renewable energy sources during the COVID-19 pandemic. In addition, it has been discovered that fossil fuel energy contributes positively to economic growth. Similarly, the interaction coefficient between fossil fuel energy and the COVID-19 pandemic is negative. A possible argument is that a substantial amount of fossil fuel was used in the reaction to COVID-19. Consequently, the amount of fossil fuel needed in production will be lower, and several factories have been shut down because of COVID-19. These result in unfavorable effects. Moreover, an expanding economy is proven to have a favorable effect on fossil fuel energy. Moreover, the interaction term between economic growth and the COVID-19 pandemic has a positive coefficient. This suggests that economic expansion is the driving force behind the use of fossil fuel energy sources during the COVID-19 pandemic. Finally, we also come to the conclusion that the use of energy and the expansion of the economy were not homogenous either before or after the COVID-19 pandemic.

5. Conclusions

The consequences of the COVID-19 pandemic have been felt in every facet of civilization in every region of the planet. Consequently, the aim of this paper is to investigate the consequences of the COVID-19 pandemic on a sample of OECD countries from the perspectives of energy and economic growth. Using data covering from the first quarter of 2010 to the first quarter of 2022, and employing the approach of the system generalized method of moments for empirical studies, the findings show that: (1) renewable energy increased by 1% while economic growth decreased by 0.014% during the COVID-19 pandemic; (2) during the COVID-19 pandemic, economic prosperity propelled the use of renewable energy; (3) during the COVID-19 pandemic, a rise of 1% in the proportion of fossil fuel energy is anticipated to reduce economic growth by 0.064%; and (4) economic expansion was the principal driver of the utilization of fossil fuel energy sources during the COVID-19 pandemic. Furthermore, using heterogeneous effects analysis, we discover that economic growth and energy consumption are heterogeneous both before and after the COVID-19 pandemic. Because fossil fuels are the primary source of carbon emissions, OECD countries need to make changes to their energy systems in order to replace fossil fuels. This has led to the energy transition that has been taking place in OECD countries toward renewable energy and possibly other types of sustainable energy as well. The main reason for this is that all countries recognize that carbon emissions must be reduced to zero. The information presented in this research bolsters the objective of achieving an energy transition in OECD countries. Moreover, it is possible for OECD countries to achieve their climate goals, promote economic growth, create millions of jobs, and improve people's quality of life if they take steps to transform their energy systems so that they are based on renewable energy sources. This would be one of the many benefits of doing so. After the occurrence of COVID-19, this may also enable OECD countries to return more rapidly to their usual production activities.

Several policy implications have been provided in light of the aforementioned empirical findings. First, when economic growth was negatively impacted by energy consumption during the COVID-19 pandemic, the government could establish other channels for economic growth, such as exporting surplus energy or integrating advanced technology, to unleash the beneficial influence of energy consumption on economic growth. Second, due to the heterogeneous effects between energy consumption and economic growth before and after the COVID-19 pandemic, governments may implement energy policy, monetary policy, and fiscal policy to achieve rapid economic recovery in the post-COVID-19 pandemic period. Third, to achieve environmentally friendly economic growth, the government should either accelerate the development of renewable energy, minimize the usage of fossil fuels, or identify pollution-free alternatives to fossil fuels in order to accomplish sustainable economic development. Fourth, to ensure that the economy continues to grow in a sustainable manner, it is imperative that the government make use of high efficiency technology in order to increase the proportion of available energy that is put to productive use. Fifth, taxes proportional to the usage of highly polluting fossil fuels might be levied by the government. These taxes, in turn, could encourage the transformation of highly polluting industries or the development of new technologies, with the end goal of achieving healthy economic growth.

The results of this paper make three distinct contributions to the existing field of knowledge. First, according to the findings of the Dumitrescu and Hurlin non-causality test, a bidirectional causal relationship between energy consumption and economic growth is found in OECD countries. Second, energy consumption had a detrimental effect on economic growth during the COVID-19 pandemic. Third, before and after the COVID-19 pandemic, energy consumption and economic growth are shown to be heterogeneous.

Finally, both the limitations of this work and potential future directions for research on this subject are highlighted. First, this article focuses only on OECD countries. Future researchers may increase the sample size to reevaluate this subject. Obtaining more trustworthy outcomes is possible. Second, due to the heterogeneity of the COVID-19 pandemic in each country, particularly in India and the United States, academics may discuss this subject using samples from these countries, which may lead to more intriguing conclusions. Third, in this work, some variables may have been omitted. This may result in an overestimate. These omitted variables might be added to this work by future researchers to generate more reliable findings. Fourth, this work uses the system generalized method of moments only for empirical studies. Future researchers may use alternative, more advanced approaches, such as the panel vector error correction model, the country and year fixed-effect model, or the panel vector autoregressive model. Potentially, more intriguing findings might be obtained. Fifth, the direct consequences that COVID-19 has had on economic growth and energy are the topics of the discussion in this article. Researchers in the future will be able to investigate both the direct and indirect impacts. It is possible that this conclusion is worth expecting. Sixth, during the COVID-19 pandemic, the governments of a number of different countries released a variety of precautions that are pertinent. In the future, researchers may choose to revisit the topic presented in this article in conjunction with these guidelines. It is possible that this will result in outcomes that are more desirable.

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