International Journal of Sustainable Development and Planning
Vol. 19, No. 4, April, 2024, pp. 1599-1610
Journal homepage: http://iieta.org/journals/ijsdp

The Long-Run Relationship Between Renewable Energy Consumption, Non-Renewable Energy Consumption, Population, and Economic Growth in G20 Countries

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https://doi.org/10.18280/ijsdp.190436

Received: 3 August 2023
Revised: 25 December 2023
Accepted: 3 February 2024
Available online: 28 April 2024

Keywords:
renewable energy consumption, non-renewable energy consumption, population, GDP growth, G20 countries, panel data analysis

ABSTRACT

This study examines the impacts of renewable and non-renewable energy consumption, urban population, and population size on economic growth. This study utilizes the Panel Unit Root Test, Pedroni's Residual-based Cointegration Test, and Fully Modified Ordinary Least Square (FMOLS) techniques to analyze data from 2010 to 2021 for 19 countries within the Group of Twenty (G20). The cointegration test indicates that renewable energy consumption, non-renewable energy consumption, urban population, and total population are long-term associated with GDP growth. According to FMOLS estimates, renewable energy consumption has a positive impact on GDP growth in G20 countries. The impact of renewable energy consumption on GDP growth varies; natural gas consumption does not affect GDP growth, but petroleum consumption significantly affects GDP growth in G20 countries. Furthermore, the study identifies the urban population as a control variable that harms GDP growth. The empirical evidence derived from this study posits that it would be judicious for G20 policymakers to proactively institute a suite of policies that invigorate the advancement of renewable energy sources, given that such a course of action has been demonstrated to engender a notable augmentation in GDP growth.

1. INTRODUCTION

The energy sector plays a strategic role in economic development in both developed and developing countries, thus energy availability is a crucial variable for a country's economic growth and competitiveness [1, 2]. Energy consumption is often seen as a pro-growth measure, which means that an increase in energy consumption leads to an increase in economic growth [3]. Therefore, the energy sector forms the backbone of the economy, which is very important in driving the economy and supporting development. The association between energy consumption and economic growth is integral to the development process [4, 5]. In addition, energy consumption is also one of the essential wheels of every economy to achieve holistic development [6]. Countries with an efficient energy use strategy will improve economic development [7, 8].

This study examines G20 countries that play an essential role in the global economy in the future. The G20 comprises countries with the most advanced and developing economies in the world, making it a world organization of 20 countries with the world's largest economies. The G20 countries utilize at least 85% of global energy and are the world's most significant emitters of CO_2 [2, 9]. The G20 countries, comprising approximately 23% of the global population, exert significant influence over the global economy, accounting for over 80% of the world's total GDP, 75% of global commerce, and approximately two-thirds of the global population (https://www.oecd.org/g20/about/). Consequently, it may be anticipated that the G20 nations will assume a pivotal position in shaping global economic expansion in the forthcoming years.

The G20 countries consume the most primary energy, fossil fuels such as oil and coal, with China having the highest primary energy consumption and the United States ranking second [10]. Furthermore, the world's three greatest fossil fuel producers are G20 members, notably the United States, Saudi Arabia, and Russia. These countries have the highest per capita emissions from this sector [11]. The G20 countries, on the other hand, account for 85% of global renewable energy investment and are the most significant carbon emitters and renewable energy investors.

The global energy crisis is underway [12, 13]. The primary reasons for the global energy crisis are a limited supply of natural gas and a drop in oil production in the face of rising energy demand. This predicament has exacerbated the global economic situation, as several countries are also on the verge of recession. The conflict between Russia and Ukraine, a G20 member, aggravated the global energy industry [14]. Energy commodity prices skyrocketed, sparking an energy crisis in Europe and other countries. Aside from global geopolitical factors putting pressure on the energy sector, the G20 governments' emphasis on renewable energy and climate-friendly projects is increasing to encourage economic recovery from the Covid-19 pandemic, which has the potential to create more direct jobs in each country while reducing greenhouse gas emissions [13]. Economic growth will benefit from a shift in energy consumption from non-renewable to renewable [1, 15]. The G20 countries, particularly the United States, Brazil, Canada, China, Germany, India, and the United Kingdom, are working to develop renewable energy and accelerate the adjustment of energy structures to be more environmentally friendly [5, 16].

The investigation into the association between energy consumption and energy growth has been largely influenced by the discoveries made by Kraft and Kraft [17] who discovered a unidirectional causal relationship between economic growth and energy consumption in the United States between 1947 and 1974. Subsequent research endeavors have surfaced, leading to the classification of energy consumption into distinct categories: renewable energy and non-renewable energy [2, 3, 6, 18, 19]. However, the relationship between energy use and economic growth continues to spark debate and has yet to yield definitive results. Previous studies have yielded divergent results due to the utilization of different empirical and econometric approaches. Numerous empirical studies have demonstrated a noteworthy correlation between energy consumption and economic growth [2, 19-21]. Similarly, other studies have unveiled a significant influence of energy consumption on economic growth [7, 8, 22]. Therefore, this study aims to achieve three primary objectives: (1) to examine the impact of renewable energy on the economic growth of countries that are members of the G20; (2) to explore the influence of non-renewable energy consumption, specifically natural gas, and petroleum, on the economic growth of G20 countries; and (3) to investigate the relationship between urban population, total population, and economic growth in G20 member countries.

This study links energy use, including renewable and non-renewable energy, demographic trends, and economic issues. This study is valuable since it includes several countries, which comprise about two-thirds of the global population in the G20. G20 countries consume 75% of global energy and emit 80% of greenhouse gases [9]. Thus, understanding these G20 countries' renewable and non-renewable energy use trends is crucial. This study proxied energy demand with two control variables, unlike previous research. This control variable was chosen because population growth and urbanization are linked, and nations need a lot of energy for urban development (represented by the urban population) and rapid industrialization to meet financial goals [16, 23].

2. LITERATURE REVIEW

Various scholarly inquiries have acknowledged the significance of utilizing renewable and non-renewable energy sources with economic growth and competitiveness [20, 24, 25]. Energy is an essential resource for producers, as it plays a critical role in setting production costs and subsequently impacts consumer pricing levels. The performance of an economy is ultimately dependent on various elements, as evidenced by the research conducted by Zarkovic et al. [19], Fotourehchi [1], Dai et al. [3]. Therefore, the significance of energy consumption in stimulating economic growth cannot be overstated, as it is a fundamental requirement for attaining development [6, 20]. In the study conducted by Dat et al. [26], a reciprocal relationship was identified between energy consumption in the non-renewable energy sector and economic growth. This situation has made nations increasingly emphasize allocating resources toward the energy industry, specifically focusing on renewable energy technology. Utilizing renewable and non-renewable energy sources has a crucial role in shaping economic growth and enhancing competitiveness.

Several empirical studies undertaken on a global scale have examined the impacts of renewable and non-renewable energy use on economic growth and development. However, further study must be conducted to establish certain conclusions based on the existing findings. Kumari, Kumar and Sahu [2] conducted a study employing the appropriate standard error in panel model, which revealed that the use of non-renewable energy and the quality of the environment have the potential to enhance welfare in G20 nations. The augmentation of welfare programs has a beneficial influence on the economy's expansion. The usage of both renewable and non-renewable energy in the G20 countries not only impacts economic activity but also exerts an influence on individuals' subjective well-being. Their study revealed a positive association between the consumption of renewable energy and improved environmental quality, characterized by fewer carbon emissions, and subjective well-being in G20 countries. Conversely, the consumption of non-renewable energy was found to be negatively associated with subjective well-being.

Zarkovic et al. [19] conducted a study in Europe wherein they employed Pooled Mean Group (PMG) Estimation and Autoregressive distributed lag (ARDL) models to investigate the impact of renewable energy consumption on economic growth in European countries throughout 2000-2020. Their findings revealed a favorable association between these variables. This study provides support for the notion that the utilization of renewable energy is a factor that fosters economic growth, as increased levels of renewable energy consumption are associated with more significant economic expansion. The present analysis, nonetheless, demonstrates that an increase in the utilization of non-renewable energy sources has a significant and unfavorable impact on gross domestic product (GDP) in the European countries under scrutiny, resulting in a deceleration of economic expansion over an extended period.

Likewise, Chen and Pinar [20] also found in their study of 103 countries from 1995 to 2015. Their study also found a link between renewable energy consumption and economic growth, depending on the amount of renewable energy used. The effect of renewable energy consumption on economic growth is positive and significant if developing countries or non-OECD countries exceed certain renewable energy consumption limits. However, if developing countries use renewable energy below a given threshold level, the effect of renewable energy consumption on economic growth is negative. Meanwhile, in developed countries, it was found that renewable energy consumption did not significantly affect economic growth in developed countries and had a positive and significant effect on economic growth in OECD countries. The study's findings indicate that for developing countries to achieve favorable economic growth through their investment in renewable energy, they must surpass specific thresholds of renewable energy consumption. The escalating utilization of non-renewable energy sources poses a significant threat to the environment [27]. Mohsin et al. [27] found a positive association between environmental degradation and economic development - the trend of increasing economic development activity is the leading cause of increasing environmental degradation. Their study confirmed that increasing economic growth, urbanization, and energy consumption have increased transportation-based environmental degradation urbanization.

According to a study by Mardani et al. [28], the adaptive neuro-fuzzy inference system (ANFIS) model was employed to analyze data from G20 countries from 1962 to 2016. The analysis revealed a positive correlation between economic growth and energy consumption in several countries, leading to increased CO_2 emissions. Li et al. [29] conducted research in the G20 countries, employing several econometric techniques such as cross-sectional dependence, cointegration, FMOLS, DOLS, and the pair-wise panel Granger causality test. This analysis reveals a long-term elasticity that demonstrates a notable positive impact of both renewable and non-renewable energy consumption on economic activity within various sectors and overall economic output. This study additionally presents empirical evidence supporting a bidirectional causal relationship between the consumption of renewable energy, non-renewable energy, and economic growth.

Ehigiamusoe and Lean [30] examined 22 countries to examine the cointegration relationship between energy consumption, economic growth, and financial development. They got empirical evidence of a cointegration relationship between energy consumption, economic growth, and financial development. These three variables have a detrimental effect on carbon emissions in the 22 countries studied. Then, they also conclude that financial development mitigates carbon emissions in high-income countries but has the opposite effect on low- and middle-income groups. However, Zaidi et al. [24] using FMOLS and Dynamic Ordinary Least Squares Estimator (DOLS), did not find a two-way causality relationship between energy consumption and economic growth. As with Mahmoodi [18]'s study, using panel cointegration and causality, the panel vector error correction model found a unidirectional causality of GDP and energy consumption.

Classical economic theory has provided perspectives on the relationship between population growth and economic development, and empirical results on this relationship reveal pessimistic and optimistic groups [31]. The proponent of the pessimistic Malthusian View contends that population expansion has a detrimental impact on economic development. This viewpoint was established by Malthus in 1798; for instance, population growth tends to outpace production growth [32]. Optimistic opinion (neoclassical view) asserts that an increase in population affects economic growth by increasing the labor supply [33, 34]. Consequently, population growth has a positive effect on the economy through the provision of labor; an increase in population encourages competition, which fosters innovation, competition, and technological advancement (among others, Bucci [35]). The number and proportion of the world's population living in urban areas continues to increase, and this increase impacts economic growth and energy consumption. For G20 countries, the urban population will reach around 61.2% in 2021, and it is predicted that the urban population will reach 73.6% in 2050 [36].

Based on the above discourse, it can be posited that a scientific endeavor has been undertaken to scrutinize the correlation between economic growth and the utilization of renewable and non-renewable energy sources. Despite several empirical research investigating the impact of population expansion on economic growth, a consensus has yet to be reached about the precise effects of renewable and non-renewable energy consumption, population growth, and urban population on economic growth. The study's primary contribution lies in examining the relationship between renewable and non-renewable energy consumption and the economy. This is achieved through the utilization of panel data obtained from G20 member countries, which collectively account for approximately 80% of global GDP and are responsible for approximately 80% of global greenhouse gas emissions, predominantly originating from the energy sector [37]. Prior studies predominantly utilized single-country analysis or were primarily undertaken in high-income nations, with only a limited number of studies focusing on impoverished countries.

3. METHODOLOGY

3.1 Variables and econometric model

This study utilizes a panel dataset comprising 19 countries from the G20 group for the period spanning from 1990 to 2010. The selection of variables was predicated upon thoroughly examining the scientific literature and pertinent empirical evidence. The variables employed in this study encompass GDP growth, renewable energy consumption, and non-renewable energy consumption, represented by proxies such as natural gas consumption and crude oil consumption. The control variables in this study are the urban population and total Population. Including these two variables is justified as they are recognized predictors of energy consumption in a country, specifically the urban and overall populations [38, 39]. Liu et al. [40] argue that a prominent feature of the process of industrialization involves the relocation of the workforce from rural areas to urban hubs, along with a transition from agricultural activities to industrial pursuits. The situation above holds particular significance inside the G20 nations, where swift advancements in the industrial sector are notable. As a result, these modifications significantly impact the overall economic expansion.

This study uses the standard Cobb-Douglas production function [41]. The Cobb-Douglas production function is commonly employed to depict the intricate interplay between input factors and resulting output in economic production processes. Within the confines of this scholarly investigation, the esteemed Cobb-Douglas production function has been employed as a fundamental framework to elucidate the intricate interplay between production output, colloquially referred to as economic growth, and production input, specifically energy consumption. The Cobb-Douglas production function effectively facilitates the generation of goods and services as collective outputs, optimizing the utilization of energy consumption levels within the G20 nations under examination. The Cobb-Douglas production function is represented by the following equation [41]:

$$Q=f\ (K, L)=AK^{\alpha}L^{\beta} \tag{1}$$

where, Y denotes output as total production which means the value of all goods produced in a year; L stands for human capital (labor); K represents the capital input; A is a positive constant which means total factor productivity; α and β indicate the output elasticity to the capital.

Many earlier empirical studies have considered energy consumption a resource in the production function and a factor influencing output [20, 30, 42]. So, to calculate the impact of nonrenewable energy consumption, natural gas consumption, and petroleum consumption, Eq. (1) above can be written referring to Kumari, Kumar, and Sahu [2] and Paramati et al. [43]. Other explanatory variables, such as total urban population and total population, are added to Eq. (1) following theory and literature to yield:

$$GDP_{it}=\alpha_0+\text{Renewable Energy Consumption}_{it}+\text{Natural Gas Consumption}_{it}+\text{Petroleum Consumption}_{it}+\text{Urban Population}_{it}+\text{Total Population}_{it}+\varepsilon_{it} \quad (2)$$

GDP denotes domestic output of country *i* (1, 2, 3, 19), using real GDP at constant 2010 prices = US$100; *t* denotes the time (2010, 2011, 2012, ... 2021); renewable energy consumption (in exajoules). In this study, non-renewable energy consumption is the sum of natural gas consumption and petroleum consumption [44, 45]. Hence, natural gas consumption (in exajoules); petroleum consumption consists of raw materials for fuel oil, gasoline, and other chemical products (in exajoules). Control variables are urban population (% of total population) and total population in each country; ε denotes error term. Table 1 describes each variable.

Table 1. Variable description

Variables/Symbols	Measurements	Data Source	Units
Gross Domestic Product (GDP) Growth	Growth in gross value added by all resident producers in the economy plus product taxes and minus subsidies that are not included in the product's value. The GDP used is constant price GDP	World Bank Indicators https://data.worldbank.org	US$
Renewable Energy Consumption	The ratio between gross domestic energy consumption from renewable sources and total (primary) gross domestic energy consumption is calculated for one calendar year.	British Petroleum https://www.bp.com	Exajoules*
Natural Gas Consumption	Total consumption of natural gas (industry, housing/services, and electricity production).	British Petroleum https://www.bp.com	Exajoules
Petroleum Consumption	Raw material for fuel oil, gasoline, and many chemical products.	British Petroleum https://www.bp.com	Exajoules
Urban Population	People living in urban areas as defined by the national statistics office. The indicator is calculated using World Bank population estimates and urban ratios from the UN World Urbanization Prospects.	World Bank Indicators https://data.worldbank.org	% of Total Population
Total Population	All residents, regardless of legal status or citizenship (transformed into log).	World Bank Indicators https://data.worldbank.org	Total Population

* 1 exajoule = 174 million barrels of oil equivalent [46].

The empirical analysis procedures include three steps: First, the stationarity of the time series is evaluated using the panel unit root test. Next, the Pedroni panel cointegration test was used to determine whether the selected variables have a cointegration relationship. Lastly, estimate the long-term relationship between the variables being analyzed using FMOLS estimator. FMOLS is utilized to account for nuisance parameters and possible autocorrelation phenomena, and heteroscedasticity of the residues, and FMOLS estimator also corrects for the endogeneity of explanatory variables [47, 48]. While it is true that panel data possesses certain advantages, it is imperative to acknowledge that the analysis of panel data is not without its limitations. One must recognize that panel data analysis has limitations. Such limitations are caused by the possible existence of omitting variables whose time change can cause endogeneity issues. Nevertheless, in the grand scheme of things, the magnitude of omitted variable bias tends to be relatively minor compared to the utilization of cross-sectional data, as elucidated by Wooldridge [49].

4. RESULTS

4.1 Descriptive statistics

The number of G20 countries analyzed was 19 over 12 years, bringing the total number of observations to 228. Table 2 depicts wide variation among the variables in the G20 countries. For 2010-2021, the average value of G20 countries' GDP growth is 2.5%, ranging from -9.03% in 2020 (Italy) to the highest of 11.2% (Turkey) in 2011, with a standard deviation of 3,540. Meanwhile, the average renewable energy consumption value of the G20 countries is 2.9 exajoules, with a range from 0.008 exajoules in 2020 (Saudi Arabia) to the highest of 24,050 exajoules (South Korea) in 2013 with a standard deviation of 4,752. Furthermore, the average natural gas consumption value for G20 countries is 4.6 exajoules, with a range from 0.132 exajoules in 2016 (South Africa) to the highest of 30,625 exajoules (The United States) in 2019, with a standard deviation of 6,315. When compared to the average petroleum consumption, the average is 6.8 exajoules with a range from 0,964 exajoules in 2020 (South Africa) to the highest 37,079 exajoules (The United States) in 2018 with a standard deviation of 8,414. Meanwhile, the average urban population of G20 countries is 75.1%, ranging from 30.93% in 2010 (India) to the highest of 92.23% (Argentina) in 2021, with a standard deviation of 14,220. Finally, the average G20 country population value is 18.5%, ranging from 16.90% in 2010 (Australia) to the highest of 21.06% (China) in 2021, with a standard deviation of 1,104.

4.2 Colinearity test

The collinearity test is a statistical procedure used to assess the presence and strength of linear relationships between predictor variables in a regression model. Examining the correlation coefficient between variables is conducted to assess the presence of multicollinearity, a phenomenon characterized by a strong link between two or more independent variables inside the model. The presence of multicollinearity in a regression model has been found to result in diminished predictive capability [49, 50]. Table 3 presents the correlation values between the series, which predominantly fall within the range of 0.80-1.00. This range is widely seen as a standard for strong correlation, suggesting a lack of multicollinearity issues among the variables [50, 51].

Table 2. Descriptive statistics

Countries	Statistics	GDP Growth	Renewable Energy Consumption	Natural Gas Consumption	Petroleum Consumption	Urban Population	Total Population
The United States	Mean	2.065	4.950	26.96	35.31	81.78	19.58
	Std.D	2.024	1.443	2.504	1.256	0.689	0.023
	Max	5.670	7.480	30.62	37.08	82.87	19.62
	Min	-3.400	2.890	23.33	32.52	80.77	19.54
	Obs	12	12	12	12	12	12
Australia	Mean	2.282	0.273	1.339	2.039	85.75	16.99
	Std.D	0.922	0.149	0.137	0.110	0.378	0.054
	Max	3.920	0.590	1.580	2.200	86.36	17.06
	Min	-0.030	0.100	1.140	1.870	85.18	16.90
	Obs	12	12	12	12	12	12
Argentina	Mean	1.181	0.095	1.656	1.272	91.55	17.58
	Std.D	5.792	0.047	0.070	0.100	0.450	0.038
	Max	10.26	0.200	1.750	1.390	92.23	17.63
	Min	-9.900	0.040	1.520	1.070	90.85	17.52
	Obs	12	12	12	12	12	12
Brazil	Mean	1.262	1.573	1.283	4.767	85.87	19.13
	Std.D	3.469	0.524	0.180	0.351	0.978	0.029
	Max	7.530	2.390	1.550	5.440	87.32	19.18
	Min	-3.880	0.930	0.990	4.220	84.34	19.09
	Obs	12	12	12	12	12	12
China	Mean	7.261	4.440	8.125	24.25	56.03	21.04
	Std.D	2.034	3.327	3.052	3.950	4.377	0.019
	Max	10.64	11.32	13.63	30.60	62.51	21.06
	Min	2.240	0.860	3.920	18.77	49.23	21.01
	Obs	12	12	12	12	12	12
Canada	Mean	1.824	0.446	3.892	4.545	81.29	17.40
	Std.D	2.456	0.130	0.290	0.195	0.203	0.039
	Max	4.560	0.580	4.290	4.730	81.65	17.45
	Min	-5.230	0.250	3.300	4.110	80.94	17.34
	Obs	12	12	12	12	12	12
Germany	Mean	1.504	1.800	3.034	4.648	77.25	18.22
	Std.D	2.275	0.464	0.183	0.224	0.150	0.013
	Max	4.180	2.440	3.260	4.890	77.54	18.23
	Min	-4.570	1.010	2.660	4.180	76.97	18.20
	Obs	12	12	12	12	12	12
France	Mean	1.108	0.509	1.560	3.186	79.79	18.01
	Std.D	3.302	0.162	0.103	0.225	0.942	0.012
	Max	6.960	0.740	1.780	3.530	81.24	18.02
	Min	-7.860	0.260	1.360	2.680	78.37	17.99
	Obs	12	12	12	12	12	12
India	Mean	5.716	0.971	1.994	8.368	33.05	20.99
	Std.D	4.164	0.464	0.188	1.170	1.463	0.039
	Max	8.950	1.790	2.240	9.990	35.39	21.05
	Min	-6.600	0.400	1.720	6.600	30.93	20.93
	Obs	12	12	12	12	12	12
Indonesia	Mean	4.648	0.271	1.545	2.990	53.63	19.37
	Std.D	2.225	0.195	0.100	0.154	2.421	0.043
	Max	6.220	0.630	1.650	3.210	57.29	19.43
	Min	-2.070	0.100	1.330	2.700	49.91	19.30
	Obs	12	12	12	12	12	12
Italy	Mean	0.031	0.650	2.501	2.591	69.73	17.90
	Std.D	3.661	0.134	0.184	0.260	1025	0.010
	Max	6,640	0.760	2,850	3,070	71.35	17.92
	Min	-9,030	0.330	2,120	2,110	68.33	17.89
	Obs	12	12	12	12	12	12
Japan	Means	0.770	0.755	4.101	8024	91.40	18.66
	Std.D	2.019	0.349	0.301	0.914	0.314	0.005
	Max	4.100	1.320	4.490	9.370	91.87	18.66
	Min	-4.510	0.330	3.600	6.490	90.81	18.64
	Obs	12	12	12	12	12	12
Mexico	Mean	1.940	0.199	2.894	3.533	79.42	18.62
	Std.D	3.496	0.102	0.259	0.524	1.049	0.043
	Max	5.120	0.390	3.180	4.040	81.02	18.68
	Min	-8.170	0.090	2.380	2.470	77.82	18.55
	Obs	12	12	12	12	12	12
Saudi Arabia	Mean	2.815	0.013	3.675	6.674	83.29	17.27

Countries	Statistics	GDP Growth	Renewable Energy Consumption	Natural Gas Consumption	Petroleum Consumption	Urban Population	Total Population
	Std.D	3.496	0.006	0.390	0.501	0.796	0.083
	Max	10.00	0.030	4.220	7.360	84.51	17.38
	Min	-4.140	0.010	3.000	5.740	82.08	17.12
	Obs	12	12	12	12	12	12
Russia	Mean	1.876	2.752	15.57	6.399	74.18	18.78
	Std.D	2.462	1.267	0.638	0.254	0.415	0.004
	Max	4.820	3.610	17.09	6.710	74.93	18.78
	Min	-2.680	0.040	14.71	5,780	73.69	18.77
	Obs	12	12	12	12	12	12
South Africa	Means	1310	8,800	0.148	1.132	65.06	17.83
	Std. D	2,760	4,077	0.009	0.078	1,846	0.052
	Max	4,910	11.77	0.160	1,250	67.85	17.91
	Min	-6.430	0.150	0.130	0.960	62.22	17.75
	Obs	12	12	12	12	12	12
South Korea	Mean	3.040	14.80	1.883	5.060	81.63	17.74
	Std.D	1.701	8.047	0.197	0.332	0.201	0.015
	Max	6.800	24.05	2.250	5.470	81.94	17.76
	Min	-0.850	0.340	1.620	4.590	81.41	17.71
	Obs	12	12	12	12	12	12
Turkey	Mean	5.950	10.85	1.642	1.735	73.80	18.18
	Std.D	3.424	4.902	0.187	0.277	1.884	0.055
	Max	11.20	14.21	2.060	2.070	76.57	18.25
	Min	0.890	0.500	1.290	1.340	70.83	18.09
	Obs	12	12	12	12	12	12
The United Kingdom	Mean	1.536	0.823	2.824	2.990	82.74	17.99
	Std.D	3.769	0.367	0.260	0.274	0.933	0.023
	Max	7.440	1.350	3.550	3.200	84.15	18.02
	Min	-9.270	0.290	2.520	2.350	81.30	17.95
	Obs	12	12	12	12	12	12

Note: SD., Max., and Min. denote standard deviation, maximum, and minimum, respectively.

Table 3. Correlation analysis

	GDP Growth	Renewable Energy Consumption	Natural Gas Consumption	Petroleum Consumption	Urban Population	Total Population
GDP Growth	**1.000**	0.143	-0.005	0.155	-0.375	0.318
Renewable Energy Consumption	0.143	**1.000**	0.070	0.105	-0.043	-0.015
Natural Gas Consumption	-0.005	0.070	**1.000**	0.830	0.074	0.337
Petroleum Consumption	0.155	0.105	0.830	**1.000**	-0.114	0.585
Urban Population	-0.375	-0.043	0.074	-0.114	**1.000**	-0.686
Total Population	0.318	-0.015	0.337	0.585	-0.686	**1.000**

4.3 Panel unit root test

A unit root test was conducted to evaluate the stationarity of the data, thereby ascertaining the level of integration of the variable (i.e., the integration order). The panel unit root test was conducted to assess the analyzed data's stationarity. Stationary data refers to a dataset wherein the statistical properties such as mean, variance, and autocorrelation remain constant and unaltered throughout the temporal domain. If the data under analysis lacks stationarity, it is imperative to acknowledge that regression analysis conducted on panel data may engender the phenomenon of regression spuriousness. This entails the potential for obtaining an elevated r-squared value despite the absence of any genuine correlation within the data [49].

This study employs various forms of unit root tests include Levin Lin Chu unit root test (LLC) [52], Augmented Dickey-Fuller test (ADF) [53], Fisher-Philips-Perron (Fisher-PP) [54], and Im, Pesaran, and Shin (IPS) [55] to consider the unique characteristics of individual countries [30]. Results of the unit root test are presented in Table 4. The null hypothesis provided in this test asserts the existence of a unit root. In contrast, the alternative hypothesis suggests the absence of a unit root or the presence of a stationary variable.

The findings in Table 4 indicate that none of the variables exhibit stationarity at the level, but they do exhibit stationarity at the first difference. This implies that all variables are integrated in the first order, denoted as I(1). In addition, GDP growth, renewable energy consumption, natural gas consumption, and petroleum consumption exhibit stationarity at a significant level of 1% (0.01) as determined by the LLC test, ADF Fisher PP, and IPS. In the LLC test, the variable urban population exhibits stationarity at a significance level of 5% (0.05), while in the ADF test, it demonstrates stationarity at a significance level of 10%. The Fisher PP test reveals that the urban population exhibits stationarity at a significance level of 5% (0.05). The IPS test suggests that the urban population remains constant at 1% level of significance (0.01). The stationary nature of the variable log population has been determined at 1% level of significance (0.01) by applying the

LLC, Fisher PP, and IPS techniques. In the ADF unit root test, it was observed that the variable log population exhibited stationarity at a significance level of 5% (0.05). Once the variable has been established as stationary at the first difference, denoted as I(1), the subsequent procedure involves assessing the cointegration between the variables through the utilization of the Pedroni cointegration test.

Table 4. Results of panel unit root tests

Variables	LLC	ADF	Fisher PP	IPS
GDP Growth	-11.791***	-4.093***	-12.309***	-3.622***
Renewable Energy Consumption	-2.870***	-3.061***	-3.684***	-2.977***
Natural Gas Consumption	-5.867***	-4.614***	-7.408***	-4.010***
Petroleum Consumption	-2.575***	-2.524***	-7.217***	-2.393***
Urban Population	-1.659**	-1.296***	-1.813**	-8.698***
Log Total Population	-2.644***	-2.130**	-7.539***	-2.409***

4.4 Panel cointegration test

The Pedroni cointegration technique is employed to examine the presence of cointegration in panel data to ascertain the existence of a durable association between variables over the long run. The null hypothesis posits an absence of a cointegration relationship between the variables. According to the findings presented in Table 5, it is observed that four out of the seven statistics, specifically the PP-Statistics Panel, ADF-Statistics Panel, PP-Statistics Group, and ADF-Statistics Group, exhibit statistical significance at both the 1% and 5% significance levels. Hence, a cointegration and long-term association exists among variables such as GDP growth, renewable energy consumption, natural gas consumption, petroleum consumption, urban population, and total population size.

Table 5. Results of Pedroni's residual-based cointegration test

Alternative Hypothesis: Common AR Coefs. (Within-Dimension)				
	Statistics	**Prob.**	**Weighted Statistic**	**Prob.**
Panel v-Statistic	-0.673	0.749	-2.640**	0.995
Panel rho-Statistic	3.690**	0.999	3.291**	0.999
Panel PP-Statistic	-2.253**	0.012	-7.996***	0.000
Panel ADF-Statistic	-0.181	0.427	-2.151**	0.015
Group rho-Statistic	5.333***	0.000		
Group PP-Statistic	-11.282***	0.000		
Group ADF-Statistic	-0.172	0.431		

*** & ** indicate statistically significant at 1%, and 5%, correspondingly.

4.5 Long-run estimation using FMOLS

Following the identification of cointegration and long-term association among variables, FMOLS method proposed by Pedroni [56] was employed. The FMOLS is employed to address the issues of small sample bias and endogeneity bias by incorporating the inclusion of leads and lags of the first-differentiated regressors, as discussed by Pedroni [56] and Dauda et al. [57]. The FMOLS estimator employs initial estimates of both symmetric and one-sided long-term covariance matrices of the residuals, as discussed by Verma, Dandgawhal and Giri [58]. The FMOLS methodology is employed to estimate long-term parameters because it considers cross-sectional heterogeneity, serial correlation, and endogeneity concerns [30]. Furthermore, it is worth noting that the FMOLS estimator has the desirable property of consistency in estimating parameters, especially when dealing with limited sample sizes [56]. The estimator Phillips and Moon [48] presented incorporates a semi-parametric correction to address the challenges arising from long-run correlations between cointegration equations and stochastic regression.

Furthermore, when panel data is employed, FMOLS method yields an estimator that follows an asymptotic distribution approximated by a normal distribution. Consequently, the FMOLS estimator is not subject to asymptotic bias, enabling the application of the standard Wald test utilizing asymptotic inference chi-square statistics [47]. According to the study conducted by Chen et al. [59], the equation for the FMOLS panel estimator is as follows:

$$\hat{\beta} = \left[\sum_{i=1}^{N} \quad \sum_{t=1}^{T}(X_{it} - \overline{X}_i)\,(X_{it} - \overline{X}_i)\right]^{-1} \tag{3}$$

$$\left[\sum_{i=1}^{N}\left(\sum_{t=1}^{T}(X_{it} - \overline{X}_i)\hat{Y}_{it} T \Delta_{\varepsilon\mu}\right)\right] \tag{4}$$

where, Y_{it} is the endogeneity correlation term; $\Delta_{\varepsilon\mu}$ is the serial correlation correction term. Correction is achieved by assuming that there is a relationship between the residuals of the static regression and the first difference of the lead, lag and contemporaneous values of the regressor in the first difference [51, 56].

The results of the FMOLS estimation are presented in Table 6. Based on the findings obtained from the FMOLS estimation, it can be concluded that there exists a strong and positive association between renewable energy consumption and economic growth. This conclusion is supported by the statistical analysis, which yielded a t-statistic of 3.33 and a coefficient (β) value of 17.79. This discovery suggests that a rise in the utilization of renewable energy sources will lead to a corresponding increase in economic development. The use of renewable energy has been found to benefit economic growth, indicating that a 1% increase in renewable energy consumption leads to a significant 17,893% rise in economic growth, assuming all other factors remain constant. The results obtained from the FMOLS calculation indicate no statistically significant impact of natural gas usage on economic growth.

In addition, it is observed that petroleum consumption exhibits a noteworthy and favorable impact on economic growth, as evidenced by the coefficient β = 7,032 and the corresponding t-statistic of 6,801. The factors related to petroleum consumption suggest that a 1% rise leads to a substantial increase of 7,032% in economic growth, provided all other independent variables remain constant. The observed probability of 0.000, less than the predetermined significance level of 0.05, indicates that the effect under consideration is statistically significant. The present discovery demonstrates a statistically significant and adverse effect on economic growth, with a magnitude of -3.128 and a significance level of 1%. This suggests that a more significant proportion of urban population is associated with declining economic growth. The findings indicate that a one percent increase in urban population is linked to a substantial fall of 3,128 percent in GDP growth. The regression coefficient associated with the log population variable is determined to be 11,281. However, the analysis conducted on the G20 countries reveals that this coefficient does not yield a statistically significant impact on economic growth.

Table 6. Results of FMOLS estimation GDP growth is the dependent variable

Independent Variables	Coefficients	t-statistics
Renewable Energy Consumption	17.793	3.332***
Natural Gas Consumption	3.825	1.429
Petroleum Consumption	7.0328	6.801***
Urban Population	-3.128	-1.674**
Log Total Population	11.2819	1.300
Adjusted R-Squared	*0.294*	
N	228	

Notes: ***, and ** indicate that the coefficients are significant at the 5% and 10% level of significance, respectively.
Source: Author's own calculation using EVIEWS 12.

5. DISCUSSION

This research presents empirical findings regarding the relationship between renewable energy, nonrenewable energy consumption, and economic growth over the long term. This analysis utilizes a sample of 19 G20 members from 1990 to 2021. The analysis consists of three sections: observations on the stationarity of time series variables. Then, conduct the cointegration test between the observed variables and identify the variable-based causal relationships. The key findings of this study are as follows.

According to the magnitude of the regression coefficient obtained, renewable energy consumption has a significant positive impact on economic growth in the G20 countries, and this variable is the variable that plays the most critical role in the GDP growth of the G20 countries. These findings align with other research findings that have demonstrated a favorable correlation between renewable energy consumption and the growth of GDP, as evidenced by the previous studies [2, 19-21] which reported that renewable energy consumption has a favorable impact on economic growth. However, the results contrast with the outcome of Polat [60], who suggested the negative influence of renewable energy on GDP growth in the case of developed countries. The favorable influence of consumption on GDP development in the G20 countries appears straightforward since G-20 policymakers, businesses, and government officials have implemented various strategies to increase renewable energy consumption usage [13].

In addition, the G20 nations have placed significant emphasis on advancing renewable energy within their member countries and enforcing energy consumption regulations that are environmentally sustainable [12]. This study further corroborates the assertion that the G20 nations possess approximately 80% of the global renewable energy infrastructure, accounting for approximately 87% of the world's renewable energy output [61]. Furthermore, there has been a notable rise in the count of G20 nations that are actively pursuing the adoption of renewable electricity. This trend is exemplified by three G20 countries, namely Canada, Germany, and the United Kingdom, which have emerged as frontrunners by publicly declaring their commitment to achieving 100% renewable electricity by 2035 [62].

As anticipated, using petroleum exhibits a favorable and noteworthy impact on economic advancement among the G20 nations. The present study aligns with previous research conducted by Ha and Ngoc [63] and Habib [64], which both found evidence supporting the notion that petroleum consumption positively influences economic growth. Ha and Ngoc's study specifically demonstrated a significant positive effect of petroleum consumption on Vietnam's economic growth. At the same time, Habib's research similarly reported a significant impact of petroleum consumption on India's economic growth. In contrast to the overall population, it is observed that the urban population exerts a noteworthy and adverse influence on the economic growth of G20 nations. One plausible hypothesis for the adverse effects of urban population on GDP growth is the insufficient alignment between the growth rate of the urban population and the corresponding expansion in production and food supply, as well as the accessibility of fundamental necessities such as clean water, food, healthcare, and educational facilities [65].

Moreover, the detrimental effect of the urban populace on GDP growth can be attributed to the proliferation of urban territory, resulting in a dearth of land within urban regions for productive endeavors [66]. Moreover, the existence of a substantial urban populace can have detrimental effects on the economy, particularly in instances where metropolitan regions have excessive overcrowding. This phenomenon might lead to a rise in prices and a decrease in savings. The limited availability of savings and investment impedes the promotion of economic development [65].

The analysis of G20 countries reveals that natural gas consumption and overall population exhibit no statistically significant impact on economic growth, indicating two independent variables with negligible effects. In the context of the worldwide market, there has been a notable surge in the demand for natural gas to mitigate carbon dioxide (CO_2) emissions. However, the rise in demand does not influence the growth of GDP in the investigated G20 nations. The findings of the empirical investigation also indicated that there was no statistically significant relationship between Natural Gas Consumption and GDP growth. The results are consistent with the studies conducted by Kum et al. [67] and Fatai et al. [68], which indicate no discernible causal connection between natural gas consumption and economic growth. This observation holds for various nations, including prominent G20 members like India and China.

Moreover, one could contend that the influence of population size on GDP growth in the G20 nations needs more statistical significance due to many circumstances. The current state of population growth among G20 member countries, collectively representing more than 50% of the world population, is sluggish. The combined population of the member countries of the G20 represented nearly 60% of the total world population, estimated to reach 7.7 billion individuals in 2019. Nevertheless, according to forecasts, it is anticipated that the population of G20 nations will have a moderate growth trajectory, ultimately reaching a cumulative figure of five billion individuals by the year 2050. Moreover, it is expected that an increasing number of G20 countries will experience a population decrease in the forthcoming decades. Moreover, it is worth mentioning that there is a constant increase in the percentage of elderly adults across all demographic groups in G20 countries [69].

Considering the research findings, particular efforts should be made to enhance renewable energy investments in G20 countries. Renewable energy consumption is a significant driver of economic growth in G20 countries. As a result, G20 countries must establish policies to further stimulate the use of renewable energy, such as rules regarding renewable energy production or supply by granting tax breaks to investors and enterprises that produce renewable energy. Apart from that, petroleum consumption in G20 countries substantially impacts economic growth; yet, because petroleum is a non-renewable energy source, efforts must be made to transition petroleum consumption to renewable energy sources, as excessive use of fossil fuels hurts the environment. Excessive petroleum usage contributes to pollution and the generation of carbon dioxide, one of the most damaging greenhouse gases.

6. CONCLUSIONS

Investigating the long-term association between energy consumption and economic growth, specifically regarding GDP, has garnered significant scholarly interest. This phenomenon arises due to the pivotal role of energy in a nation's advancement and competitive edge. A further argument is that it increases the global energy demand and promotes the exploration and utilization of renewable energy sources. Given these circumstances, analyzing the importance of renewable and nonrenewable energy use in relation to economic growth is imperative.

Numerous scholarly investigations have been conducted to explore the association between energy consumption and economic growth. Nevertheless, the utilization of panel datasets derived from G20 nations has not been substantially reviewed in existing research. The present study aims to examine the association between the variables above within the context of 19 member nations of the G20, thereby addressing a research vacuum in the existing literature. The data that was studied in this study were sourced from the statistics provided by the World Bank and British Petroleum, covering the period from 1990 to 2021. The study's results have substantially contributed to the existing knowledge of the association between renewable energy usage and economic output across countries. The findings of the FMOLS estimator support the notion that there is a statistically significant long-term equilibrium relationship between renewable energy consumption, petroleum consumption and GDP growth. Including the urban population as a control variable has a statistically significant negative impact on the G20 country's GDP growth. Furthermore, this study could not demonstrate a causal relationship between natural gas consumption, total population, and GDP growth.

The empirical evidence presented in this study supports the positive association between GDP growth and the utilization of renewable energy sources within the G20 countries. The association's establishment can be ascribed to the endeavors and goals established by the G20 nations to foster the progress and use of renewable energy sources. Moreover, the results of this study reveal that renewable energy consumption has a more positive impact on the economies of the G20 countries when compared to the use of non-renewable energy sources.

The research findings have significant consequences, one of which pertains to the growing emphasis by policymakers on implementing measures that promote the proliferation of both local and foreign investments in renewable energy projects. Furthermore, it is imperative to enhance the assortment of incentives to promote renewable energy production. Additionally, there is a pressing need to foster the development of fresh market prospects for renewable energy. This is particularly crucial for G20 member nations that have yet to establish a robust market structure for renewable energy sources.

The G20 nations have the potential to implement progressive policy measures aimed at advancing renewable energy, including establishing a low-carbon economy and creating market mechanisms to encourage investment in renewable energy sources. The G20 nations should enhance their global collaboration with energy suppliers, governments, and relevant organizations to augment renewable energy investments collectively. This concerted effort is crucial for fostering low-carbon economic growth throughout most of these economies.

A further study can be undertaken to examine the association between alternative forms of energy, such as electricity consumption, internet usage, and economic progress. This study has the potential for use in diverse countries, particularly those in the process of development, to examine the correlation between electricity consumption, internet usage, and economic progress. Furthermore, this research can be expanded by augmenting the sample size, incorporating additional variables, and including a broader range of countries for comparative analysis.

Certain facets can be improved upon in this study. Future studies can emphasize examining groups of nations with broader economic attributes, as the existing research solely investigated the G20 countries. The Dumitrescu Hurlin panel cointegration approaches can be employed in future research. These techniques have gained popularity in examining causal connections among variables. In addition to demographic features, it is possible to analyze other variables to determine their influence on economic growth when they are simultaneously regressed on indicators of renewable energy use and non-renewable energy consumption. Furthermore, there is potential for additional research investigating the association between renewable and non-renewable energy consumption in different countries throughout continents. This approach would provide significant contributions to the existing literature.

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