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The Impact of Renewable and Non-Renewable Energy Consumption on Economic Growth: A Global Perspective with Developed and Developing Economies

Muhammad Tariq Majeed
School of Economics, Quaid-e-Azam University, Islamabad, Pakistan
Email: tariq@qau.edu.pk

Awais Anwar
School of Economics, Quaid-e-Azam University, Islamabad, Pakistan
Email: awaisanwar306@gmail.com

Tania Luni (Corresponding author)
School of Economics, Quaid-e-Azam University, Islamabad, Pakistan
Email: tania_luni@yahoo.com

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Abstract

This paper investigates the impacts of renewable and non-renewable energy consumption on economic growth employing a global panel data of 174 economies including the sub-samples of developed and developing countries over the time 1980-2019. The renewable energy sources are disaggregated according to their source of production (biomass, solar, wind, and hydro) and their separate impacts on economic growth are estimated. The empirical exercise is based on the fixed effects, random effects, and two-step system GMM estimation approaches. The results reveal that renewable energy consumption exerts a positive influence on global economic prosperity including developed and developing countries. However, non-renewable energy boosts economic growth only in developing countries, while it retards growth in the developed world. The results reveal that alternative renewable energy sources have diverse implications for global growth management policies. On the one hand, biomass and solar energy resources stimulate global growth robustly while, on the other hand, hydro and wind energy sources exert mixed influences on economic growth. The gross capital formation increases while population growth reduces economic growth. Inflation boosts growth in developed economies while reduces in developing economies. For sustainable growth, the use of renewables should be promoted to preserve the environment.

Keywords: renewable energy consumption, non-renewable energy consumption, economic growth, gross fixed capital formation, biomass, solar energy, hydro energy, wind energy.

1. Introduction

Energy boosts economic growth because of its use as a basic input in production and consumption activities. Before the 19th century since the Adam Smith time, labor and capital were considered as the main factors of production and now energy is considered as the fourth factor of production in industrialized nations. Particularly, energy consumption has become a major source of economic growth since the oil shock of 1973 (Noor and Siddiqui, 2010). Whether the economic development dominates over the utilization of energy or energy use itself becomes a stimulus for economic development, this inscrutable statement creates the interest of the researcher to analyze the linkages between energy utilization and economic expansion (Acaravci and Ozturk, 2010).

The uninterrupted energy supply is considered essential for the economic development of both developed and developing countries (Majeed and Luni 2019; Saudi et al., 2019). In the present era, it seems difficult to ensure and sustain the production process and supply of products and services without energy usage (Esen and Bayrak, 2017). The advancement and economic performance of an economy not only depends on the availability of the natural resources, and location of the country but also on the energy supply (Sasana and Ghozali, 2017). As energy occupies a central position in all spheres of life, its uninterrupted and efficient supply has become a key concern. Addressing this concern requires a rise in the proportion of renewables in the total energy mix (United Nations, 2015).

Since non-renewables are depleting, the reliance on non-renewables should be decreased for environmental sustainability. The non-renewables including coal, gas (natural), and oil are used in our day-to-day including transportation, production, heating, cooling, agricultural sector, and industrial sector, therefore lack of access to energy adversely affects the economy's productivity. The contribution of non-renewables including oil, gas (natural), and coal stands at 193.03, 141.45, and 157.86 exajoules in primary consumption in 2019 respectively (BP, 2020).

The theoretical foundations of this study are associated with endogenous growth theory which, unlike neoclassical growth theory, considers technological change as an endogenous factor. We also assume that technologies associated with the deployment of renewables are endogenously determined. Furthermore, circular economy theory is fundamental in the context of renewable energy- economic prosperity nexus. Majeed and Luni (2020) argue that renewable energy serves as a basic dimension of circular economy (CE). Moreover, they assert that. for efficient use of raw materials and energy efficiency, CE requires global efforts to resource efficiency. That promotes use of renewables for energy generation. The CE, renewables, and energy efficiency are interconnected to maintain sustainable development. The firms powering the production of global resources are increasingly searching for solutions to meet market demand by minimizing energy usage and environmental problems.

The empirical studies examining the energy-growth nexus suggests both positive as well as negative influence of conventional energy sources on the growth of different economies. The studies showing favorable impact of conventional energy sources on economic prosperity comprise Fadilah et al. (2020), Le et al. (2020), Shastri et al. (2020), Rahman and Velayutham (2020), Saudi et al. (2019), Asif et al. (2021), Adams et al. (2018), Narayan and Doytch (2017), Ito (2017), Ohlan (2016), Kahia et al. (2016), and Al-Mulali et al. (2014) while the research papers suggesting a negative impact of conventional energy on growth include Mohamed et al. (2019), and Ito (2017). As the non-renewable energy sources are depleting and cause global warming, therefore, to avoid resource depletion, ensure energy security, decrease health effects, price volatility and ensure sustainable development the alternative energy sources such as renewables are required (Amri, 2017).

Renewable energy sources are naturally recharged, and the supply of renewable energy is endless and has spillover effects. Renewable resources include solar wind, rain, tides, waves, and geothermal heat. To ensure sustainable development renewable energy is required as it ensures the availability of clean energy for everyone (Majeed and Luni, 2019). It is predicted that the contribution of the renewables towards overall energy sector will surge from 25% in 2017 to 85% by 2050, achieved through the contribution of solar and wind energy (IRENA, 2018). The statistical report of British Petroleum (BP, 2020) shows a 5% contribution of renewable energy sources in the primary energy usage which surged by 0.5% from 2018 to 2019. In 2019 the renewable energy share stands at 10.4% in the electricity generation. Total renewable energy consumption in the world is 28.98 exajoules of total primary energy consumption. Wind energy has more contribution to the generation of energy among the renewable energy sources which is 1429.6 terawatt-hours. The growth rate of renewable resource generation stands at 13.7% in 2019 (BP, 2020).

Thus the literature suggests mixed impacts of renewable energy on growth of different economies. Some empirical papers suggest accelerating growth rates owing to the deployment of renewables to supplement power sector (Wang and Wang, 2020; Charfeddine and Kahia, 2019; Haseeb et al., 2019; Kamoun et al., 2019; Marinaș et al., 2018; Alper and Oguz, 2016; Soava et al., 2018; Koçak and Şarkgüneşi, 2017; Zrelli, 2017; Khobai and Le Roux, 2017; Rafindadi and Ozturk, 2017; Cetin, 2016; Apergis and Payne, 2010) while other studies suggest that the renewable power expansion is negatively associated with economic expansion (Venkatraja, 2020; Tsaurai and Ngcobo, 2020; Ocal and Aslan 2013). Thus, it is important to examine the impact of renewable energy on economic growth at the global level to conclude the contradicting results.

This study extends the literature in many ways: First, this paper examines the influence of renewable and non-renewable energy utilization on the macroeconomic growth at the global level during 1980-2019. Second, the study provides evidence of the growth impact differences of alternative energy forms across developed and developing economies. Third, this study also estimated the disaggregated influence of renewable energy (biomass, solar, hydro, and wind) on economic growth. Fourth, the study provides empirical evidence from well-established techniques including the fixed effects, random effects, and two-step system generalized method of moments (GMM) (panel techniques) which are ignored in the previous studies. Fifth, the study examined the robustness of the results through the sensitivity analysis. Finally, the study controls the impact of population, gross capital formation, and inflation which are the major sources of cross-country growth differences.

The remaining study is divided into following parts: section two of the study reviews the literature on renewable and non-renewable energy utilization and economic growth. Section three comprises of the data and methodology, section four discusses the summary statistics and explains the empirical findings. Section five concludes the discussion.

2. Literature Review

In this section, the recent studies on renewable, non-renewable energy use and economic performance have been discussed that have been conducted in different countries of the world. The commonly used methods in these studies are time series model and panel data model. Over the last few years several studies (Lin and Moubarak, 2014; Kahia et al., 2016; Ito, 2017; Atems and Hotaling, 2018; Haseeb et al., 2019; Shastri et al. 2020; Rahman and Velayutham, 2020; Wang and Wang, 2020; Jafri et al., 2021) have explored the energy-growth nexus. The outcomes of the studies are not yet conclusive.

Four types of hypotheses are used to analyze the association between energy utilization and economic performance. First, the unilateral causality from energy to GDP growth is called the conservation hypothesis. Second, the unilateral causality from GDP growth to energy is called the growth hypothesis. Third, the feedback hypothesis elaborates the two-way between energy utilization and GDP growth. Fourth, when energy use and GDP growth has no association, it is known as the neutrality hypothesis (Marques et al., 2014). Pioneer of the idea of energy consumption was Kraft and Kraft (1978) who analyzed the effect of energy use on the gross national product for the United States over 1947-1974 and supported the growth hypothesis.

One strand of the literature explored the effect of renewable energy use on GDP growth (Wang and Wang, 2020; Venkatraja, 2020; Tsaurai and Ngcobo, 2020; Charfeddine and Kahia, 2019; Haseeb et al., 2019; Kamoun et al., 2019; Marinaș et al., 2018; Alper and Oguz, 2016; Soava et al., 2018; Koçak and Şarkgüneşi, 2017; Zrelli, 2017; Khobai and Le Roux, 2017; Rafindadi and Ozturk, 2017; Cetin, 2016; Apergis and Payne, 2010), while another strand of the literature collectively examined the effect of renewable and non-renewable energy use on GDP growth (Fadilah et al., 2020; Le et al., 2020; Shastri et al. 2020; Rahman and Velayutham, 2020; Shahbaz et al., 2020; Saudi et al., 2019; Asif et al., 2021; Mohamed et al., 2019; Atems and Hotaling, 2018; Adams et al., 2018; Narayan and Doytch, 2017; Ito, 2017; Ohlan, 2016; Kahia et al. 2016; Al-Mulali et al., 2014).

Haseeb et al. (2019) supported the favorable effect of renewable energy on the economic growth of Malaysia over the time 1980-2016 employing the autoregressive distributed lag (ARDL) bound testing approach. Similar results are found by Rafindadi and Ozturk (2017) and Khobai and Le Roux (2017) for Germany and South Africa, respectively, using the ARDL approach. Bhattacharya et al. (2016) using the fully modified ordinary least square (FMOLS) highlighted the positive and significant influence of renewable energy utilization on economic performance in the top 38 renewable energy consumer countries. Cetin (2016) using the heterogeneous panel test FMOLS, DOLS, and long-run elasticities vindicate that renewable energy boosts the economic performance in the emerging seven (E7) countries.

Zrelli (2017) for Mediterranean countries confirms the positive influence of renewable energy utilization on the economic performance over the period 1980 to 2011. In the same way, Koçak and Şarkgüneşi (2017) using a panel of 9 Balkan and Black sea countries over the period 1990-2012 and employing Panel DOLS and Panel FMOLS find that renewable energy has an efficacious role for economic performance in the case of Balkan and Black sea countries. Marinaș et al. (2018) using the error correction model (ECM) supports that renewable energy enhances the GDP growth in the selected Central and East European economies. The study of Charfeddine and Kahia (2019) support these findings in the Middle East and North Africa (MENA) region using panel vector autoregressive (PVAR). The study of Kamoun et al. (2019) examining the panel of 13 organizations of economic cooperation and development (OECD) economies confirm the positive influence of renewable energy use on sustainable growth performance.

The outcomes of a study conducted by Apergis and Payne (2010) for OECD economies also confirm the positive influence of renewable energy use on economic performance. Similarly, an analysis conducted by Wang and Wang (2020) using threshold regression by controlling for urbanization, technological progress, and per capita income suggested the favorable economic role of renewable energy use for OECD economies. The studies of Alper and Oguz (2016), Soava et al. (2018), and Saad and Taleb (2018) for the panel of European countries, also found similar findings.

In contrast to the above-documented literature, some studies suggest the negative influence of renewable energy utilization on GDP growth. The outcomes of Ocal and Aslan (2013) for Turkey supported the negative influence of renewable energy use on GDP growth over the period 1980-2010 using the ARDL approach. The authors attribute this negative effect to higher initial investment required for renewable energy deployment. The results of Venkatraja (2020) for BRICS economies over the 1990-2015 period using fixed effects estimator support decline in income resulting from renewable energy. The possible reason behind such a negative impact is the high transition cost from conventional energy sources to renewables. Tsaurai and Ngcobo (2020) also reported similar outcomes for BRICS economies because of lack of access to education. Thus, increasing expenditure and ensuring access to education can help to ensure favorable economic effects of renewable energy use.

Another strand of the literature examined the effects of both renewable and non-renewable energy use on GDP growth. The studies by Shastri et al. (2020) and Ohlan (2016) confirmed the improved economic performance resulting from both forms of energy in India by employing non-linear ARDL. Similar, empirical outcomes are shown by Saudi et al. (2019) for Indonesia using ARDL bound test method. Likewise, Al-Mulali et al. (2014) also confirmed such outcomes for 18 Latin American countries during 1980-2010. The study by Kahia et al. (2016) using the FMOLS also confirmed the same results for MENA net oil-exporting countries from 1980 to 2012.

Furthermore, Narayan and Doytch (2017) have shown similar results using a panel of selected eighty-nine countries according to their income levels over 1970-2011 period. The study of Asif et al. (2021) confirmed the favorable growth effects of both renewable and non-renewable energy use for 99 economies during 1995-2017. Similarly, in the case of 5 Asian countries, Rahman and Velayutham (2020) confirmed the positive growth effects of both forms of energy using FMOLS and DOLS methods. Furthermore, Fadilah et al. (2020) substantiated the positive and significant impact of the utilization of both forms of energy on the economic performance of the Association of Southeast Asian Nations (ASEAN). Similarly, Shahbaz et al. (2020) substantiate these positive and significant effects for the top 38 renewable energy user countries.

Similarly, another study by Atems and Hotaling (2018) using fixed effects (FE), and GMM has also validated the positive and significant role of both forms of energy for growth performance of 174 economies during 1980-2012. A study conducted by Le et al. (2020) for 102 countries using GMM documented the positive influence of both forms of energy on the economic well-being. The study of Adams et al. (2018) supported the positive effects of both forms of the energy for the panel of 30 countries of Sub-Sahara Africa from 1980 to 2012, but non-renewable energy enhances economic performance by a larger proportion than renewable in sub-Sahara Africa.

The study of Mohamed et al. (2019) using the ARDL bound testing approach reveals that renewable energy boosts growth in France whereas non-renewable energy use decreases economic growth. By choosing the panel of 42 developing countries employing the GMM and pooled mean group (PMG). Ito (2017) showed the growth escalating role of renewable energy usage while non-renewable energy negatively affects the economic wellbeing of developing countries.

After review of the existing literature, it is concluded that literature lacks empirical evidence on the impact of renewable and non-renewable energy consumption on economic growth at the global level. Furthermore, this is the first study that analyzed this relationship at the global level and for developed and developing economies separately. This study also provides evidence on the impact of disaggregated measures of renewable energy on economic growth at the global level.

3. Data and Methodology

This research considers the panel of 174 countries from 1980 to 2019. The data of GDP per capita (Y) constant 2010 US$, renewable energy consumption (REC) % of total final energy consumption, non-renewable energy (NREC) % of the total, gross fixed capital formation (GFCF) constant 2010 US$, population (POP) total, and inflation (INF) consumer price index annual percent is taken from World Bank (2020). The study considers both developed (55 countries) and developing countries (119 countries) and for this purpose, the classification of World Bank (2020) is followed as the study examined the disaggregated effects of renewable energy, the data of biomass energy consumption (BMS) domestic extraction for this purpose is extracted from Global material flow database, over the period 1980-2017. For the consistency of the unit, the biomass variable is divided by one billion. The data of the solar (SLR), wind (WND), and hydroelectricity (HYD) is in terawatt-hours and extracted from our world in data for the span 1980-2018.

The energy growth nexus is based on neoclassical production function, where output (Y) is determined by labor (population) and capital (gross fixed capital formation) represented as:

$$Y = f(L, K) \quad (1)$$

The above production function was modified to incorporate the effect of energy consumption (renewable, non-renewable). We follow Ivanovski *et al*. (2021), Majeed and Ayub (2018) and Bhattacharya *et al*. (2016). After controlling for inflation, the model can be stated as:

$$Y_{it} = f(REC, NREC, GFCF, POP, INF)_{it} \quad (2)$$

$$Y_{it} = f(REC_{it} + NREC_{it} + GFCF_{it} + POP_{it} + INF_{it}) \quad (3)$$

$$Y_{it} = REC_{it}^{\alpha} NREC_{it}^{\beta} GFCF_{it}^{\gamma} POP_{it}^{\delta} INF_{it}^{\varphi} \quad (4)$$

Where α, β, γ, δ, and φ provide elasticities with respect to REC, NREC, GFCF, POP and INF respectively. All the variables are log (L) transformed except inflation. Log transformation provides consistent and efficient empirical estimates (Ivanovski *et al*., 2021 and Bhattacharya *et al*., 2016):

$$LY_{it} = \sigma + \alpha LREC_{it} + \beta LNREC_{it} + \gamma LGFCF_{it} + \delta LPOP_{it} + \varphi INF_{it} + u_i + v_t + \varepsilon_{it} \quad (5)$$

$$LY_{it} = \sigma + \omega LY_{it-1} + \alpha LREC_{it} + \beta LNREC_{it} + \gamma LGFCF_{it} + \delta LPOP_{it} + \varphi INF_{it} + u_i + v_t + \varepsilon_{it} \quad (6)$$

$$LY_{it} = \sigma + \beta LNREC_{it} + \gamma LGFCF_{it} + \delta LPOP_{it} + \varphi INF_{it} + \theta BMS_{it} + \tau HYD_{it} + \rho SLR_{it} + \lambda WND_{it} + u_i + v_t + \varepsilon_{it} \quad (7)$$

$$LY_{it} = \sigma + \omega LY_{it-1} + \beta LNREC_{it} + \gamma LGFCF_{it} + \delta LPOP_{it} + \varphi INF_{it} + \theta BMS_{it} + \tau HYD_{it} + \rho SLR_{it} + \lambda WND_{it} + u_i + v_t + \varepsilon_{it} \quad (8)$$

In equations (2-8) LY_{it-1} represents the lag of dependent variable (gross domestic product), u_i, v_t, ε_{it}, and σ represent unobserved country-specific attributes, the time fixed effect, error terms and intercept, respectively.

For the empirical investigation, the study employs the panel techniques. The fixed-effects model is used to resolve the problem of heterogeneity and to capture the effect of variables that are changing over time and to control the characteristics of unobserved individual correlated with the observed explanatory variables. However, it does not incorporate the time-invariant characteristics and leads to omitted variable bias and endogeneity. The random effects model incorporates the time-invariant characteristics, and the intercept is divided into the fixed and the random components. It also assumes that the random components should be uncorrelated with the explanatory variable otherwise, will lead to unbiased and inconsistent results. Two-Step System GMM tackles with endogeneity. The lags of dependent and explanatory variables are used as instruments. Equations 6 and 8 represent the dynamic specification of the model. The validity of instrumental variables is examined by the Hansen over-identification test.

4. Result and Discussions

4.1 Descriptive Statistics

The empirical results are estimated using the Stata 15 software. The descriptive statistics provide valuable information about central tendency and measure of dispersion and findings are summarized in Table 1. The maximum level of GDP per capita is 116232 which is in the United Arab Emirates and the minimum value is 164.1919 which belongs to Azerbaijan. The maximum renewable energy is consumed in Congo Democratic. The gross fixed capital formation is minimum in Indonesia while maximum in the United States. The minimum population is in Antigua and Barbuda whiles the maximum in China. Maximum inflation is recorded for Congo Democratic while lowest is in Angola.

Table1: Summary Statistics

Variables	Observations	Means	Std. deviation	Min	Max
Y	6434	11485.2	16622.73	164.1919	116232.8
REC	4496	3406090	31.32661	0	98.34261
NREC	4403	65.3012	30.30379	0	100
GFCF	4788	858000	283000	-95000	3880000
POP	6957	3420000	187000	61717	140000
INF	5659	27.91924	394.5165	-60.4964	23773.3

4.2 Correlation Matrix

Table 2 reports the results obtained from the correlation analysis. The GDP per capita is positively associated with non-renewable energy consumption, while negatively associated with renewable energy consumption. These findings coincide with Asif et al. (2021) who also reported positive correlation of GDP per capita with non-renewable energy consumption and capital, and negative correlation of renewable energy with economic growth. Furthermore, negative correlation exists between economic growth and population. Our results contrast with Asif et al. (2021) who reported positive association between labor and economic growth. The negative correlations exist between economic growth and inflation, respectively.

Table 2: Correlation Matrix

Correlation	LY	LREC	LNREC	LGFCF	LPOP	INF
LY	1					
LREC	-0.4604	1				
LNREC	0.5045	-0.6209	1			
LGFCF	0.6092	-.03714	0.4327	1		
LPOP	-0.2005	0.0029	0.284	0.6375	1	
INF	-0.0610	0.0188	-0.0768	-0.0334	0.0310	1

4.3 Results of the Fixed Effects Method

Table 3 presents the findings of the fixed-effects model. The findings reveal that renewable energy consumption is positively associated with economic well-being at the global level as well as across developed and developing countries. Particularly, a 1% rise in renewable energy consumption leads to a 0.078, 0.088, and 0.026 percentage points increase in the growth at the global level, developed and developing countries, respectively. The influence of renewable energy on the economic growth of developed economies is greater than developing countries, evident from the differences in estimated coefficients. The reason behind this might be the efforts taken by developed economies to support green growth that is possible using green technologies (renewables). The findings coincide with the studies of Rafindadi and Ozturk (2017), and Atems and Hotaling (2018). However, the results contrast with the outcome of Venkatraja (2020), who suggested the negative influence of renewable energy on the growth resulting from higher transition (switching) costs. Similarly, Tsaurai and Ngcobo (2020) also showed a decline in income from renewable energy due to lack of access to education. The relative difference of the growth effects is in line with the findings of Majeed (2018) who provided robust evidence of diverse effects of technology across developed and developing counties.

Non-renewable energy use hurts the growth at the global level and in developed countries. An incline in non-renewable energy use by 1% causes a 0.123 and 0.126 percentage points decrease in economic progress globally and in developed economies while the increase in economic growth in developing economies by 0.012 percentage points. The findings are similar to the analysis of Mohamed et al. (2019) who supported a decline in economic growth in France resulting from non-renewable energy usage. The findings contrast with Shastri et al. (2020) and Ohlan (2016), as they supported incline in economic progress from using non-renewable energy. Furthermore, the findings also contrast with Jafri et al. (2021) who reported the insignificant effect of negative and positive shocks to non-renewable energy in the long run for Pakistan. The possible reason behind this insignificant effect is that the country is already using conventional energy to its full potential, therefore, shocks to conventional energy do not contribute to economic prosperity. Similarly, physical capital formation exerts a positive influence on economic growth in all samples. A 1% rise in the physical capital causes a 0.40, 0.50, and 0.65 percent increase in economic growth, globally, developed, and developing countries, respectively. An increase in gross capital formation supports an increase in growth through higher production. The results are in line with Jafri et al. (2021) and Majeed (2017).

The findings suggest that a1 percent surge in population escalates the growth by 0.299 percent globally. It also supports the Neo-classical theory of economic growth which emphasizes that besides the increase in technology and capital, population increase is a key component of economic growth as it increases the labor force. The finding is compatible with the study of Peter and Bakari (2018). In the case of developing countries, a 1% increase in population cause a 0.0214 percent decline in economic growth. The reason behind this decrease in economic growth is due to the diversion of resources from improving productivity and infrastructure to ensuring the availability of necessities including education and health. These findings are similar to the findings of Barlow (1994), Prettner (2014), and Majeed (2017).

Comparably, a 1% increase in inflation enhances economic prosperity by 0.00001% which is consistent with the findings of Majeed (2020). To earn high-profit producers will increase the output which results in higher employment and increase the aggregate demand. The study of Majeed (2020) demonstrates the positive effect of inflation on economic progress in 122 developing countries covering the time span from 2003 to 2015. However, inflation also harms the economic growth in developing countries. Inflation leads to currency devaluation resulting in a decline in exports of the country and increases the imports. Our findings are similar to Kasidi and Mwakanemela (2013) who found the negative effect of inflation on economic growth in the case of Tanzania. Similarly, the study of Majeed (2016) reveals a decline in economic prosperity from inflation for 65 developing economies covering the time span from 1965 to 2010. The study of Majeed and Ayub (2018), however, reported the negative but insignificant effect of inflation on economic growth using the cross-sectional and panel data sets of 149 economies covering the time span 1980-2015. Thus the effect of inflation on growth is sensitive to study time span and sample size.

Furthermore, the disaggregated measures of renewable reveal that a 1 percent rise in the biomass energy use increases the growth by 0.235 percent. This finding is consistent with Ajmi and Inglesi-Lotz (2020). The increase in the utilization of the hydroelectricity decreases the economic progress and the findings are in line with the results of Bildirici and Gokmenoglu (2017).

Table 3: Fixed Effect Results

Variables	**Global Analysis**	**Disaggregated Renewable Energy**	**Developed Countries**	**Developing Countries**
Dependent Variable: GDP Per Capita				
Renewable energy consumption	0.0780***		0.0878***	0.0258***
	(0.00773)		(0.00662)	(0.00490)
Non-Renewable energy consumption	-0.00972	-0.123***	-0.126***	0.0122**
	(0.0185)	(0.0294)	(0.0307)	(0.00621)
Gross fixed capital formation	0.408***	0.403***	0.502***	0.0658***
	(0.00777)	(0.00856)	(0.0106)	(0.00355)
Population	-0.0456	0.299***	-0.0215	-0.0214**
	(0.0293)	(0.0305)	(0.0447)	(0.0104)
Inflation	0.00001**	-0.00001	-0.0001	-0.00001***
	(0.00001)	(0.00001)	(0.00015)	(0.000001)
Biomass		0.235***		
		(0.0448)		
Hydro		-0.000971***		
		(0.000284)		
Solar		0.00608***		
		(0.00160)		
Wind		-0.000594		
		(0.000456)		
Constant	-0.283	-5.041***	-1.490**	-0.429***
	(0.390)	(0.422)	(0.630)	(0.148)
p-value	0.000	0.000	0.000	0.000
Observations	2451	1973	1065	1429
F-test	916.77	658.43	801.21	8199.30
R-square	0.663	0.735	0.798	0.973
Adjusted R-Square	0.645	0.725	0.788	0.972
Parentheses having Standard errors, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$				

4.4 Results of the Random Effects Method

The fixed effects method assumes a correlation between the observed and unobserved explanatory variables however if there is no correlation this assumption will lead to biased results. So, we use the random effects method which assumes no correlation between the observed and unobserved regressors. Table 5 reports the findings of the random effects method. The signs and the estimated values of the variables remain unchanged. Renewable energy supports growth in all samples.

The utilization of non-renewable energy stimulates the growth at the global level and in developing countries while it negatively affects the growth of the developed economies. The formation of capital increases the growth at the global level including the developed and developing countries. The positive influence of physical capital on economic performance is high in developed economies when compared to developing economies and at the global level. Population expansion is associated with a decline in economic growth at the global level, and across developed and developing economies. This outcome is in line with the Malthus theory of population, which shows that the resources of the economies increase less proportionally to the population and lower the economic growth of the world. An inline in inflation leads to lower growth of developing countries. The disaggregated analysis for different forms of energy suggests that the usage of both biomass and solar energy boosts economic growth.

Table 4: Random Effects Results

Variables	Global Analysis	Disaggregated Renewable Energy	Developed Countries	Developing Countries
Dependent Variable: GDP Per Capita				
Renewable energy consumption	0.0200**		0.0742***	0.00746***
	(0.00836)		(0.00684)	(0.00219)
Non-Renewable energy consumption	0.0807***	0.0101	-0.141***	0.0168***
	(0.0205)	(0.0351)	(0.0326)	(0.00397)
Gross fixed capital formation	0.529***	0.533***	0.568***	0.0599***
	(0.00803)	(0.00957)	(0.0109)	(0.00318)
Population	-0.549***	-0.450***	-0.461***	-0.0594***
	(0.0181)	(0.0230)	(0.0222)	(0.00365)
Inflation	0.00001	-0.00001	0.00002	-0.00001***
	(0.00001)	(0.00002)	(0.0002)	(0.000001)
Biomass		0.140***		
		(0.0524)		
Hydro		-0.0000404		
		(0.000310)		
Solar		0.00636***		
		(0.00201)		
Wind		0.000349		
		(0.000567)		
Constant	4.804***	3.692***	4.023***	0.125***
	(0.255)	(0.356)	(0.306)	(0.0390)
p-value	0.000	0.000	0.000	0.000
Observations	2451	1973	1065	1429
Wald-test	4887.12	3636.82	3455.10	198567.68
R-square	0.663	0.735	0.798	0.973
Adjusted R-Square	0.645	0.725	0.788	0.972
Parentheses having Standard errors; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$				

4.5 Results of the Two-Step System GMM

To tackle the problem of endogeneity two-step system GMM is used. Table 5 shows that 1 percent increase in the utilization of renewable energy causes 0.0028, 0.0046, and 0.0065 percentage point escalation in the global growth and across developed and developing countries. Renewable energy is favorable for growth as countries are rich in renewable resources. It does not generate waste and externalities. Furthermore, it does not burden the environment, therefore support green growth. The findings are like results reported by

Charfeddine and Kahia (2019), Kamoun et al. (2019), and Wang and Wang (2020). Similarly, the utilization of non-renewable energy causes an increase in the economic growth of the developed and developing countries by 0.040 and 0.016 percentage points, respectively. The impact of non-renewable energy in boosting growth is more prominent in the developed economies than developing economies. This is in line with the outcomes of Asif et al. (2021), and Fadilah et al. (2020). Physical capital boosts growth globally and across developed and developing countries. This is in line with the outcomes of Pasara and Garidzirai (2020), Santiago et al. (2019), and Majeed (2019). Population expansion has adverse effects on economic growth whereas inflation supports the growth in developed economies while decreases it in developing economies and in the global panel. The disaggregated impact of renewable energy measured by biomass and solar energy represents an increase in economic growth while wind energy decreases it. The influence of hydropower on growth is insignificant. The Hansen test validates the instruments used.

Table 5: Two-Step System GMM Results

Variables	**Global Analysis**	**Disaggregated Renewable Energy**	**Developed Countries**	**Developing Countries**
Dependent Variable: GDP Per Capita				
GDP per capita $_{t-1}$	0.908***	0.957***	0.827***	0.891***
	(0.0132)	(0.0200)	(0.0106)	(0.0113)
Renewable Energy Consumption	0.00281*		0.00456***	0.00651***
	(0.00169)		(0.00170)	(0.00127)
Non-Renewable Energy Consumption	0.00687	0.00612	0.0407***	0.0167***
	(0.00670)	(0.00762)	(0.00545)	(0.00530)
Gross Fixed Capital Formation	0.0878***	0.0429**	0.166***	0.0905***
	(0.0128)	(0.0205)	(0.00624)	(0.00670)
Population	-0.0989***	-0.0496**	-0.186***	-0.0938***
	(0.0148)	(0.0198)	(0.00793)	(0.00615)
Inflation	-0.00002	-0.00003**	0.0006***	-0.00003***
	(0.00002)	(0.00001)	(0.0002)	(0.00001)
Biomass		0.0216**		
		(0.0084)		
Hydro		0.000017		
		(0.000038)		
Solar		0.00171***		
		(0.00065)		
Wind		-0.000489**		
		(0.00021)		
Constant	0.337***	0.171***	0.463***	0
	(0.0796)	(0.0545)	(0.0963)	(0)
Observation	2365	1916	1022	1386
Groups	119	69	45	76
Instruments	96	171	51	51
AR (1) PR>z	0.000	0.00	0.000	0.014
AR (2) PR>z	0.052	0.013	0.001	0.962
Hansen test	0.215	1	0.537	0.075
Parentheses having Standard errors; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$				

4.6 Sensitivity Analysis

Table 6 presents the sensitivity analysis conducted through the two-step system GMM. Even after the incorporation of trade, govt expenditure, foreign direct investment, and net official development assistance, the sign and significance of all focused and control variables are not affected. Renewable energy contributes to economic growth while the impact of non-renewable energy is insignificant. The result of the study remains robust.

Table 6: Sensitivity analysis

Sensitivity Analysis				
Variables	**Trade**	**Govt. Expenditure**	**Foreign Direct Investment**	**Net official Development Assistance**
Dependent variable: GDP per capita				
Renewable energy consumption	0.00301*	0.00288*	0.00258*	0.00622**
	(0.00174)	(0.00168)	(0.00159)	(0.00249)
Non-Renewable energy consumption	0.00872	0.00419	0.00571	-0.00560
	(0.00651)	(0.00741)	(0.00664)	(0.00959)
Parentheses having Standard errors * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$				

5. Conclusion and Policy Recommendation

The present study explored the influence of renewable and non-renewable energy utilization on economic growth for the span of 1980 to 2019. The relationship is analyzed at the global level, and for the developed and developing economies. The study also investigated the influence of disaggregated renewable energy sources on economic growth. For this purpose, panel techniques are used. The sensitivity analysis has been conducted to assess the robustness of the findings.

This study concludes that both renewable and non-renewable energy consumption boost economic growth at the global level, and across developed and developing economies. The findings are in line with the studies of Rafindadi and Ozturk (2017) and Atems and Hotaling (2018). Comparatively, the influence of renewable energy usage on economic growth is greater for of developed countries in comparison to developing countries. This finding reflects the stronger efforts by the developed world for the substitution of non-renewable energy sources with renewables and adoption of green technologies. This finding is consistent with Majeed (2018) who has provided the evidence of heterogenous effects of technology across developed and developing countries. The disaggregation of renewable energy sources into biomass, hydropower, solar, and wind suggests that biomass and solar energy enhance economic growth while wind energy decreases economic growth. The impact of hydropower, however, turns out to be insignificant. Since wind energy requires a specific geographical location for installation and it also comprises initial high costs, therefore its effect on economic growth turns out to be negative in linear modeling. Among control variables, the effect of physical capital on economic growth is positive in all samples. Population expansion, however, results in a decline in economic growth. The influence of inflation is positive and significant for developed economies while it decreases the economic growth of developing economies.

5.1 Contribution of the Study

The study occupies a special place in the literature by providing linkage of present study not only to endogenous growth theory but the theory of circular economy which are prerequisite for the sustainable development. The circular economy can lead to decline in exploitation of resources by using renewables. The dependence on renewables supports growth, mitigates climate change, and avoids resource depletion. Furthermore, this study contributes to the literature by providing evidence on the impact of renewable and non-renewable energy consumption on the economic growth at the global level over the period 1980-2019. The study provides evidence of the difference in the impact of renewable and non-renewable energy on economic growth across developed and developing economies. As renewables differ in their potential impact, the disaggregated impact of renewable energy (biomass, solar, hydro, and wind) on economic growth has been analyzed as well. The empirical evidence is based on well-established panel techniques which are ignored in the previous studies. The sensitivity analysis conducted using the two-step system GMM also validates the robustness of the findings. The study controls the impact of population, gross capital formation, and inflation which are the important determinants of economic growth.

5.2 Theoretical and Policy Implications

The theories of sustainable development and circular economy emphasize the need of using resources efficiently and in a manner that is environment friendly and available for future generations. Our results are consistent with the theory of sustainable development and the theory of circular economy as the use of renewables to support growth does not lead to depletion of virgin resources. Renewables do not compromise the regenerative capacity of the earth and support growth without degrading environmental quality. Thus, the use of renewables to support growth can help to achieve climate goal through energy transition (Majeed and Luni, 2019) along with improving health status, and decline in environmental degradation (Majeed and Ozturk, 2020).

Therefore, based on the result it can be suggested that the government of all countries should design energy policies in such a way that promotes the use of renewable energy to stimulates economic growth. However, the influence of non-renewable energy sources on growth is positive but due to depleting nature, deteriorating environmental quality, global warming, and adverse health effects the use of non-renewable energy should be minimized and the power of renewables should be harnessed. Among the renewable energy sources, the use of solar and biomass should be increased as their impacts on economic expansion are more prominent.

5.3 Research Limitations

The limitations of the study include: First, the study did not examine the non-linearities in the renewable energy growth nexus. Second, the study did not examine the separate impact of different renewables on growth.

5.4 Future Research Directions

Future studies can extend the analysis by performing asymmetric analysis and comparing the economic growth of countries resulting from the use of renewable energy resources.

As renewable energy is a basic pillar of circular economy, future studies can explore renewable energy and growth nexus in the perspective of the circular economy by analyzing the impact of diverse circular economy indicators on economic growth. Furthermore, future research can explore the impact of renewable energy usage on sustainable development indicators. Finally, the effect of wind energy on growth needs further investigation whether its negative effect on growth represents a country-specific issue, linear modeling bias, study time covered, or study sample size-specific outcome.

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