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From Fossil to Future: The Transformative Role of Renewable Energy in Shaping Economic Landscapes

Misbah Nosheen[1], Ahsan Akbar[2], Mariam Sohail[3]* Javed Iqbal[4], Martina Hedvicakova[2], Sareer Ahmad[4], Syed Arslan Haider[5], Azeem Gul[6]

[1]Department of Economics, Hazara University Mansehra, Pakistan, [2]Department of Informatics and Quantitative Methods, Faculty of Informatics and Management, University of Hradec Kralove, Hradec Kralove, Czech Republic, [3]ESc Clermont Business School, Clermont Ferrand, France, [4]School of Economics, Quaid Azam University Islamabad, Pakistan, [5]Department of Management, Sunway Business School, Sunway University, 47500 Selangor Darul Ehsan, Malaysia, [6]Department of International Relations, National University of Modern Languages, Pakistan. *Email: mariam_sohail10@yahoo.com

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ABSTRACT

In recent years, numerous countries have embarked on a transformative journey to reshape their energy portfolios by transitioning from fossil-based resources to renewable sources, significantly impacting economic growth. This study aims to scrutinize the influence of renewable energy consumption (REC) on GDP growth responsiveness in the top 20 renewable energy-consuming countries over the period from 1990 to 2021. To ensure robust panel analysis, the study addresses cross-sectional dependence using the diagnostic test proposed by Pesaran (2004). The long-run perspective reveals that both conventional factors of production, encompassing both renewable and non-renewable energy (Fossil Fuel Energy - FEF) consumption, make positive contributions to GDP growth in the sampled countries. Single-country time series analyses further underscore the positive long-run output elasticities concerning renewable energy in the majority of these nations. These findings highlight the pivotal role of renewable energy as a key determinant of sustained GDP growth, indicating that these countries are on a trajectory of sustainable development. The study's implications extend to policy considerations, urging collaborative efforts among governments, international organizations, and energy planners. There is a pressing need for the implementation of strategic renewable energy initiatives across nations. Governments are encouraged to adopt incentive-based policies to optimize the harnessing of renewable energy resources, fostering not only economic growth but also contributing to the global pursuit of sustainable and environmentally conscious practices.

Keywords: Fossil-Based Resources, Gross Domestic Product Growth, Renewable Energy, Non-Renewable Energy; Fully Modified Ordinary Least Squares

JEL Classifications: O1, O5, F6

1. INTRODUCTION

Renewable energy is growing more popular across the world as a result of increased resource availability, diminished detrimental consequences of climate change and variable energy prices. Increased consumption has various social benefits, including reducing climate change, improving energy security and cutting air pollution emissions (Akbar et al., 2024). Renewable energy consumption (REC) accounted for about 22% of total world energy consumption by 2015 (Inglesi-Lotz and Dogan 2018; Namahoro et al., 2021). Furthermore, global demand for renewable energy is expected to reach 31% by 2035, due to the numerous advantages of using renewable energy (Conti et al., 2016). Meanwhile, both developed and developing countries are intending to increase their use of renewable energy (Zhang et al., 2017; Khoie et al., 2019; Namahoro et al., 2021).

Over the past few decades, many of the developing economies have emerged as a success story in terms of GDP growth and development (Aqeel and Butt, 2001; Altinay and Karagol, 2005). The mounting economic development and industrialization of the developing economies have led to the opulence and prosperity of an ordinary man to some extent (Martins et al., 2023), yet it is blamed for some major issues such as depletion and exhaustion of non- renewable resources like oil, coal gas and other mineral resources and global warming caused by greenhouse gases (Lee, 2019; Shahbaz et al., 2015). The dwindling non-renewable resources have shifted the attention towards the use of renewables. The GDP growth achieved at the expense of global warming and depleting non-renewable resources is alleged to be un-sustainable in the long run (Tiwari and Mutascu, 2015; Lu et al., 2015; Rafiq et al., 2022). The growing concern about environmental challenges was felt at the global level and was reflected in the Kyoto protocol, 1997 as a milestone agreement aimed to curb the fossil based carbon emission. The agreement imposed a cap on developed economies to reduce the CO_2 emission. Resultantly, many developing and emerging economies were forced to restructure the energy mix from nonrenewable (NRE) resources towards renewable (RE) resources (Bhattacharya et al., 2016; Sasana and Ghozali., 2017; Wang, 2019).

Since that RE now constitutes as an important portion of the energy mix of many emerging economies, the question then arises, is that the way that GDP growth is supposed to respond to renewed energy mix. There are diverse studies in this regard that focus on renewables energy and GDP growth nexus, yet there is lack of harmony in the empirical findings. These inconsistencies in findings can be categorized into four types of theoretical propositions. The first proposition is the growth hypothesis. According to this proposition, GDP growth is supposed to be adversely affected using RE resources and by policies aimed at energy conservations. The second hypothesis is the energy conservation hypothesis that indicates that REC may have a minor or little impact on GDP growth. The third hypothesis is the feedback hypothesis which indicates that energy conservation and GDP growth are complements to each other and an increase in one causes an increase in the other. The fourth hypothesis is the neutrality hypothesis which indicates that the consumption of RE resources and the energy conservation policies do not have an impact on GDP growth. According to the neutrality hypothesis, a causal relation running from RE consumption towards GDP growth tends to be absent.

Figure 1 shows the energy consumed by top 20 countries of the world with the growing concern in the face of scarce alternative energy resources; it merits consideration to investigate the ramification of REC for GDP growth. Both industrialized and developing economies tend to differ in terms of capacity and efficiency to shift towards sustainable RE resources. Industrialized economies being at advanced level of technological capabilities may convert their scarce energy resource more prudently towards final goods and GDP growth as well; accordingly, the growth hypothesis may not be supported. On the other hand, developing economies still at the underdeveloped stage may undergo the adjustment process in the face of a shift from a NRE base towards renewable resources, accordingly the developing economies are supposed to pay the cost in terms of GDP growth at least in the short run. For this purpose, this study therefore, intends to explore the impact of RE resources on GDP growth, separately for developed and developing economies (as presented in Table 1).

The paper contributes significantly to the renewable energy-growth literature in energy economics. Almost all studies in literature have employed country panels to explain the dynamic relationship between economic development and the adoption of renewable energy. The panel selection is a major criticism made at the above studies. Countries in the analyzed panel are more diverse, and they may be cross-sectionally dependent across the board. In this work, we apply modern heterogeneous panel estimating methodologies with cross-sectional dependence to overcome this issue. This is significant because international energy policy can influence individual countries at the same time as other external shocks. This is the study to look at renewable energy and growth using heterogeneous panel methodologies for the top 20 renewable energy consuming nations as presented in Figure 2.

Figure 1: Top 20 biggest energy consuming countries (Statistical Review of World Energy 2021)

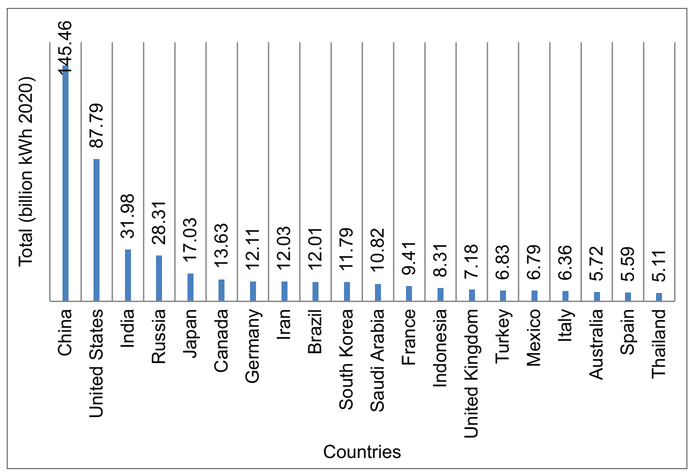
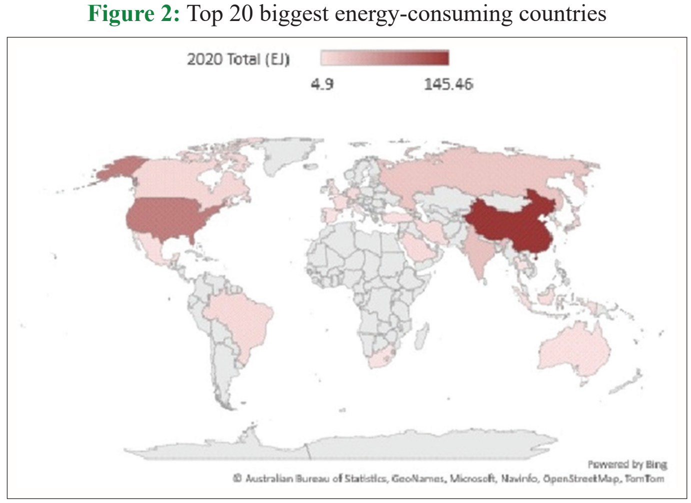


Figure 2: Top 20 biggest energy-consuming countries



Second, in addition to standard inputs, we investigate both renewable and non-renewable energy consumption to determine the proportionate impact of each on the economic growth process. Third, using long-run dynamics, we estimate the panel's and individual nations' long-run output elasticities with respect to each source of energy. These elasticities represent both the time dimensions and the panel's cross-sectional character, and thus give substantial power when compared to research that exclusively use time series approaches. These estimates are relevant for policy purposes because they represent long-run demand for renewable and non-renewable energy sources in these nations' growth processes.

The remainder of the paper is structured as follows. Section 2 presents a summary of the energy consumption-growth hypothesis, with an emphasis on empirical research explaining the dynamics of renewable energy consumption and economic growth. Section 3 examines the model, data, and variable descriptive statistics. Section 4 discusses the econometric technique and empirical findings. Section 5 includes conclusions and policy recommendations.

2. REVIEW OF LITERATURE

In recent years, a growing body of research has delved into the intricate relationship between renewable energy resources, GDP growth, and CO_2 emissions. Among these studies, Bercu et al. (2019) conducted a comprehensive investigation into the long-term association between energy consumption, economic development, and governance quality in 14 central and Eastern European union (CEE) nations spanning the period from 1995 to 2017. The findings of Bercu et al. (2019) study shed light on the multifaceted dynamics at play. One of the pivotal insights unveiled was the discernible link between power consumption and economic growth. The study underscored that deficiencies in energy infrastructure contribute to a deceleration in economic growth. This implies that the robustness and efficiency of a nation's energy systems are integral not only for meeting growing energy demands but also for fostering a conducive environment for sustained economic development.

Moreover, Bercu et al. (2019) research delved into the intersectionality of governance quality, electricity consumption, and GDP growth. The study unearthed a noteworthy impact of effective governance on both electricity consumption and GDP. This implies that nations endowed with good governance structures are better positioned not only to optimize their energy consumption patterns but also to catalyze economic growth. The synergy between governance quality and energy-related variables highlights the importance of institutional frameworks in shaping a nation's energy landscape and, consequently, its economic trajectory.

Further contributing to the discourse on the link between economic growth and renewable energy, Marinaș et al. (2018) undertook an analysis of ten EU member states from central and Eastern Europe over the period from 1990 to 2014. This study focused on investigating the causal relationship between economic growth and renewable energy usage, providing nuanced insights into both short-term and long-term dynamics.

The long-term findings of Marinaș et al. (2018) study revealed a bidirectional correlation between renewable energy usage and economic development. This suggests that as economies in the selected EU member states experienced growth, there was a reciprocal increase in the utilization of renewable energy resources. Such a symbiotic relationship signifies the potential of renewable energy to not only fuel economic activities but also to be bolstered by economic growth. However, the study also unearthed interesting nuances in the short-term causation dynamics. In Romania and Bulgaria, for instance, there was no evidence of short-term causation between economic growth and renewable energy usage. In contrast, data from Hungary, Lithuania, and Slovenia supported the growth theory, indicating a short-term causal relationship between economic expansion and increased reliance on renewable energy sources. These studies by Marinaș et al. (2018) and Bercu et al. (2019) contribute significantly to our understanding of the intricate interplay between energy dynamics, economic development, and governance structures. The findings underscore the importance of robust energy infrastructure and effective governance in driving economic growth. Moreover, the bidirectional correlation between economic development and renewable energy in the long term highlights the potential for renewable resources to play a pivotal role in shaping the economic trajectories of nations. The nuanced insights into short-term causation dynamics further enrich our comprehension of the complex relationships in play, providing valuable implications for policymakers and researchers alike. In the evolving landscape of energy research, a plethora of studies have undertaken the task of unraveling the complex relationship between renewable energy consumption (REC) and GDP growth across diverse regions and economies. Ntanos et al. (2018) examined into this intricate interplay within the European Union (EU) context, utilizing the Autoregressive Distributed Lag (ARDL) technique to estimate the link between REC use and GDP growth from 2007 to 2016.

The findings of Ntanos et al. (2018) study provided nuanced insights, revealing a favorable connection between renewable energy consumption and GDP growth for industrialized countries, while a detrimental relationship was observed for underdeveloped nations. This dichotomy underscores the varying impact of renewable energy on economic growth depending on the level of industrialization and development within a country. Moreover, the researchers concluded that the correlation between GDP growth and REC was stronger in higher-income nations, affirming the pivotal role of economic status in shaping the dynamics between renewable energy use and economic development. Soava et al. (2018) extended the investigation to encompass 28 European nations, offering a broader perspective on the relationship between REC and GDP growth. Meanwhile, Jebli and Youssef (2017) explored the correlation between CO_2 emissions, both renewable (REC) and non-renewable energy consumption, in Tunisia. Their findings indicated a positive correlation, shedding light on the intricate web of interactions between different energy sources and environmental outcomes. In a broader global context, Jebli and Youssef (2015) examined 69 nations, scrutinizing the causal link between renewable and non-renewable energy usage, economic development, and trade. Their results revealed a positive unidirectional causal relationship between renewable and non-renewable energy usage and real GDP, further emphasizing the constructive impact of renewable energy on economic growth.

Similar affirmations emerged from the research of Okyay et al. (2014) for the EU15, Ito (2017) for 42 developed nations, and Salim et al. (2014) for OECD nations. Alper and Oguz (2016) provided insights specific to new EU nations, identifying statistically significant influences on economic production in Bulgaria, Estonia, Poland, and Slovenia. Koçak and Şarkgüneşi (2017) expanded the geographical scope to include Balkan and Black Sea economies, revealing bi-directional causality in Romania and a positive influence of renewable energy consumption on economic growth in Greece and Bulgaria. The research landscape further diversified with the study by Dudzevičiūtė et al. (2017), focusing on 28 EU nations. They found that renewable energy usage positively impacted economic development in 12 of these countries. Luxembourg and Portugal confirmed the neutrality hypothesis, while the Czech Republic, Hungary, Latvia, Lithuania, Romania, and Spain supported the conservation hypothesis. Furuoka (2017) explored Estonia, Latvia, and Lithuania, discovering a unidirectional causation from economic development to renewable energy usage. Bilgili and Ozturk (2015) extended their analysis to G7 nations, reaching comparable conclusions, while Ozturk and Bilgili (2015) explored Sub-Saharan African economies, employing panel data from 1980 to 2009.

In the specific case of Pakistan, Shahbaz et al. (2015) utilized the cointegration technique to evaluate the consequences of renewable energy consumption for GDP growth. Their findings affirmed the favorable contribution of REC to economic growth in the Pakistani context. However, it's worth noting that Pao and Fu (2013) discovered a one-way causation link for Brazil using data from 1980 to 2010, introducing an element of variability in the causal dynamics between renewable energy consumption and economic growth. These diverse studies collectively contribute to the growing body of knowledge surrounding the relationship between renewable energy consumption and GDP growth. The nuanced findings across regions and economies underscore the complexity of these interactions, emphasizing the need for context-specific policies and considerations in the pursuit of sustainable energy transitions and economic development. The intricate relationship between energy consumption, economic development, and the choice between renewable and non-renewable sources has been a focal point of scholarly inquiry. Apergis and Payne (2012) contributed significantly to this discourse by examining 80 established and developing nations. Their findings revealed a bidirectional correlation between renewable and non-renewable energy consumption metrics and economic development in both the short and long run. This underscores the dynamic and interconnected nature of energy choices and economic growth across a diverse set of countries. Tugcu et al. (2012) extended this exploration to the group of seven (G7) nations, delving into the long-term and causative links between renewable and non-renewable energy usage and economic development. Utilizing a classical production function, their results unveiled bidirectional causation between non-renewable energy and economic growth in all G7 nations. This implies a mutual influence, highlighting the interdependence of energy consumption and economic prosperity in some of the world's most developed economies. Pirlogea and Cicea (2012) delved into the specific case of the European Union (EU-27), investigating the long-term influence of various energy sources on economic growth. They also examined the impact of oil on economic growth in Spain and Romania. The study contributed nuanced insights into the complex interplay between different energy sources and economic development within the context of the European Union.

Tiwari and Mutascu (2015) exploration focused on 14 EU countries, Norway, Switzerland, and Turkey, revealing intriguing patterns. While the growth rate of non-renewable energy consumption had a negative impact on GDP growth rates, the growth rate of renewable energy consumption exhibited a positive influence. This suggests a divergent impact of different energy sources on economic growth, emphasizing the importance of considering the composition of energy consumption in economic analyses. Menegaki (2011) employed a multivariate panel framework to assess the causal association between economic development and renewable energy for 27 EU nations from 1997 to 2007. The findings provided support for the neutrality concept, suggesting that renewable energy consumption does not exert a significant causal influence on economic development in the examined EU countries. In the context of the EU's new member states, empirical studies on the link between economic development and energy have been relatively scarce. Saidi and Hammami (2015) addressed this gap by investigating the relationship between renewable energy consumption and economic growth in six central American countries from 1980 to 2006. Their findings supported a two-way causal link between renewable energy consumption and GDP growth, contributing valuable insights into the energy-economic dynamics in this region. In the dynamic landscape of energy economics, a multitude of studies has aimed to unravel the complex relationship between renewable energy consumption (REC) and gross domestic product (GDP) growth, providing valuable insights into the potential impacts of energy choices on economic development.

Kazar and Kazar (2014) contributed to this discourse by investigating the relationship between REC and GDP growth. Their findings suggested that energy, particularly renewable sources, may enhance long-term GDP growth. This underscores the potential positive externalities associated with a transition towards renewable energy, aligning with the global pursuit of sustainable and resilient economic development. Apergis et al. (2010) explored the responsiveness of GDP growth to energy usage, employing the autoregressive distributed lag (ARDL) model for estimation. Their findings suggested a favorable contribution of energy consumption to GDP growth, highlighting the crucial role of energy in supporting economic development. This aligns with the notion that energy is a fundamental driver of economic activity.

Acaravci and Ozturk (2010) focused on the causal link between energy and economic growth in Albania, Bulgaria, Hungary, and Romania from 1980 to 2006. Their study provided evidence of a long-run link between energy usage and real GDP, indicating the interconnectedness of energy and economic development. Bidirectional Granger causality was observed in Hungary, suggesting mutual influences between energy consumption and GDP growth. However, the neutrality hypothesis was supported in Albania, Bulgaria, and Romania, highlighting the contextual variability in the energy-economic dynamics among these countries. Sharma (2010) expanded the scope to 66 nations, examining the link between energy and economic growth from 1986 to 2005. Their findings emphasized the significant influence of both electricity and non-electricity energy factors on EU economic development. This broad analysis reinforced the idea that diverse energy sources play a crucial role in shaping economic trajectories on a global scale. In the specific cases of Saudi Arabia and the UAE, Squalli (2007) explored the effects of energy consumption on GDP growth, revealing a negative relationship. This suggests that in these oil-dependent economies, where fossil fuel resources dominate, increased energy consumption might not necessarily translate into proportional economic growth. Similarly, Erbaykal and Okuyan (2008) calculated a negative correlation between energy and economic development for Turkey. This indicates the need for nuanced energy policies that consider the specificities of each country's energy mix and economic structure. In conclusion, these studies collectively paint a nuanced picture of the relationship between renewable energy consumption and economic growth. While renewable energy sources appear to contribute positively to GDP growth, the context-specific nature of these relationships underscores the importance of tailored energy policies. The negative correlations observed in fossil fuel-dependent economies highlight the challenges associated with decoupling economic growth from traditional energy sources. As the world grapples with the imperative of sustainable development, these findings contribute valuable insights to inform policy decisions and pave the way for a more resilient and environmentally sustainable future.

3. MODEL AND DATA

Our model is based on simple neo-classical production function where, we have labor, capital renewable and non-renewable sources of energy as factors of production.

$$GDP_{it} = f(CF_{it}, LAB_{it} RECit, FEF_{it}) \quad (1)$$

"The subscripts i and t denote country and time respectively. We use real GDP in constant 2010 US dollars as a measure of GDP growth, real gross fixed capital formation (CF) in constant 2010 US dollars is used as capital stock, and total labour force (LAB) is used for available market labour." We have taken data from World Bank. The data on "renewable and non-REC is collected from the U.S. Energy Information Administration (EIA). Following Al-Mulali and Mohammed (2015) use electricity consumption as a proxy for consumption. Alternatively, oil, coal and natural gas are used as NRE" sources.

Equation (1) can be written as

$$Yit = CFit^{\beta 1i}\ LABit^{\beta 2i}\ RECit^{\beta 3i}\ FEFit^{\beta 4i} \quad (2)$$

Equation 2 is nonlinear model. To make it linear, logarithm transformation is required. Each resulting coefficient is interpreted as elasticities. Log linear model is given as

$$lnYit = \beta 1i\ ln\ CFit + \beta 2i\ lnLABit + \beta 3i\ lnRECit + \beta 4i\ FEFit + \varphi it \quad (3)$$

where, $\beta 1i$, $\beta 2i$, $\beta 3i$, and $\beta 4i$ "are elasticities of output with respect to capital, labour, renewables, and non-renewables energy consumption, respectively. φ is the error term. We use panel data of 20 countries covering the period from 1990 to 2021." We selected top 20 countries based on their use of energy. These are China, United States, India, Russia, Japan, Canada, Germany, Iran, Brazil, South Korea, Saudi Arabia, France, Indonesia, United Kingdom, Turkey, Mexico, Italy, Australia, Spain and Thailand.

4. ANALYSIS AND RESULTS

In this comprehensive section, we delve into the intricacies of data analysis and present the results for our selected sample of 20 countries, each exhibiting various degrees of heterogeneity. Table 2 serves as a focal point, illustrating the correlations matrix among the key variables under scrutiny. Notably, GDP and capital formation emerge with the highest correlation, underscoring the interplay between economic output and investment in capital. The second-highest correlation is discerned between GDP and non-renewable energy consumption (non-REC). Intriguingly,

Table 1: Top 20 biggest energy-consuming countries

No.	Country	2020 total (EJ)
1	China	145.46
2	United States	87.79
3	India	31.98
4	Russia	28.31
5	Japan	17.03
6	Canada	13.63
7	Germany	12.11
8	Iran	12.03
9	Brazil	12.01
10	South Korea	11.79
11	Saudi Arabia	10.56
12	France	8.7
13	Indonesia	8.1
14	United Kingdom	6.89
15	Mexico	6.48
16	Turkey	6.29
17	Italy	5.86
18	Australia	5.57
19	Thailand	5.12
20	Spain	4.97

Table 2: Correlation matrix

Variable	GDP	CF	LAB	REC	FFE
GDP	1				
CF	0.785	1			
LAB	0.421	0.193	1		
REC	0.513	0.251	0.419	1	
FFE	0.592	0.284	0.789	0.632	1

Variables in natural logarithmic, GDP: Gross domestic product, CF: Capital formation, LAB: Labour, REC: Renewable energy consumption, FFE: Fossil fuel energy

Table 3: Cross sectional dependence and CIPS tests

Variable	GDP	CF	LAB	REC	FFE
Pesran CD test	110.34	85.77	56.23	43.87	40.78
P-value	"0.000"	"0.000"	"0.000"	"0.000"	"0.000"
Unit root test for cross section dependence					
CIPS test (level)	4.345	6.254	3.678	1.987	1.243
CIPS test (At first difference)	−3.234***	−5.345***	−4.786***	−6.723***	−9.235***

"**" and "***" indicates the "rejection of null hypothesis of cross-sectional independence (CD test) and the null hypothesis of unit root at 5% and 1% significance level, respectively. CIPS test is estimated using constant and trend" with 1 lag, GDP: Gross domestic product, CF: Capital formation, LAB: Labour, REC: Renewable energy consumption, FFE: Fossil fuel energy, CIPS: Cross sectional augmented Pesaran and Shin

Table 4: Pedroni panel cointegration test results

Alternative hypothesis: Common AR coefs, (within dimensions)		
Within dimension	**Statistics**	**Probability**
"Panel v-Statistic"	−2.985	0.9986
"Panel rho-Statistic"	−0.127***	0.0005
"Panel PP-Statistic"	−6.144***	0.0000
"Panel ADF-Statistic"	−4.556***	0.0000
Alternative hypothesis: individual AR coefs, (between dimensions)		
Between dimensions	**Statistics**	**Probability**
"Group rho Statistic"	0.002990	0.4988
"Group PP-Statistic"	−9.300***	0.0000
"Group ADF-Statistic"	−3.567***	0.0002

Trend assumption: Deterministic intercept and trend; Lag selection: Automatic based on SIC; Newey-West Automatic bandwidth selection with: Barlett kernel;*** denote significant at 1%", AR: Autoregressive

the analysis reveals the lowest correlation between GDP and labor, signifying a nuanced relationship between economic growth and labor input. Meanwhile, a substantial correlation is identified between capital and non-REC, shedding light on the interconnectedness of capital investment and non-renewable energy consumption. These findings collectively emphasize the pivotal role of energy resources in influencing the GDP growth trajectory of any given country.

Given the diverse characteristics of the sampled countries and the potential impact of various global shocks such as the great recession, Asian financial crisis, and shifts in energy and fiscal policies, addressing cross-country dependence becomes imperative. The presence of common global shocks and their ramifications on macroeconomic growth relationships necessitate the application of suitable estimation techniques to derive efficient panel estimates. Furthermore, the likelihood of cross-sectional dependence implies that unobserved common factors may manifest as global cycles. Consequently, relying on estimation from a single time series becomes problematic. Standard panel unit root tests, as acknowledged in studies by Im et al. (2003) and Maddala and Wu (1999), may exhibit biases in the presence of cross-sectional dependence.

To circumvent these challenges, a meticulous approach to estimation is crucial. The utilization of appropriate techniques becomes paramount to capture the diverse characteristics of the sampled countries and account for the potential influence of global shocks. Addressing cross-sectional dependence requires robust estimation methods to ensure the accuracy and reliability of panel estimates. By acknowledging the complexity of global economic dynamics and the potential bias introduced by cross-sectional dependence, our analytical framework aims to provide nuanced insights into the intricate relationship between renewable energy use, economic variables, and global macroeconomic dynamics. Through these considerations, we strive to contribute methodologically sound findings that enhance our understanding of the multifaceted factors influencing economic growth in the selected countries.

In this advanced phase of our analysis, we address critical considerations regarding the potential drawbacks associated with the use of the Im, Pesaran, and Shin (IPS) test, as highlighted by Pesaran (2007). It is underscored that the application of the IPS test may yield undesirable finite sample properties. To rigorously examine the existence of cross-sectional dependence in panels, we deploy the diagnostic test proposed by Pesaran (2004). This diagnostic test posits a null hypothesis of no cross-sectional dependence against the alternative hypothesis of the presence of cross-sectional dependence. Our results decisively reject the null hypothesis, affirming the existence of cross-sectional independence within the model.

Recognizing the significance of accounting for cross-sectional dependence, we employ the cross-sectional augmented IPS (CIPS) test (Table 3). The outcomes of this test provide confirmation that the variables under scrutiny share the same order, indicating integration of order 1. This crucial insight informs the subsequent steps in our analytical framework, ensuring the robustness of our estimation techniques.

Moving forward, the analysis incorporates the panel cointegration test developed by Pedroni (1999; 2004), as shown in Table 4. This test comprises two dimensions: within dimension and between dimensions. Within dimension, four statistics-Panel V, Panel Rho, Panel PP, and Panel ADF-are considered. Simultaneously, three statistical groups-Rho, Group PP, and Group ADF-are evaluated in the between-dimension dimension. Remarkably, the probability values associated with the three within-dimension statistics (Panel Rho, Panel PP, and Panel ADF) are all <0.05%, indicating strong evidence of cointegration. Equally noteworthy, two of the between-dimension statistics (Group PP and Group ADF) also exhibit probability values below 0.05%. This comprehensive cointegration test unequivocally substantiates the presence of cointegration among the variables.

Transitioning from cointegration verification to long-run output elasticities estimation, we employ two prominent techniques-the dynamic OLS (DOLS) and fully modified OLS (FMOLS) models. The results of these estimations, meticulously presented in Table 5, reveal a noteworthy consistency in terms of both sign and significance between the two methods. This alignment lends robustness to our findings, enhancing confidence in the estimated long-run output elasticities. In conclusion, our analytical journey has navigated through intricate considerations related to cross-sectional dependence, cointegration, and the estimation of long-run output elasticities. By adopting advanced diagnostic tests and cointegration assessments, we have fortified the methodological underpinnings of our analysis. The convergence of results from DOLS and FMOLS models further underscores the reliability of our findings. In the subsequent sections, we delve into the nuanced interpretation of these results, unraveling the intricate dynamics of the relationship between renewable energy use and economic variables in the context of global macroeconomic dynamics.

In our meticulous examination of the relationship between renewable energy use, economic variables, and global macroeconomic dynamics, the utilization of two robust methods, dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS), has proven instrumental. Not only do these methods address concerns of serial correlation, but they also grapple with the challenge of endogeneity, enhancing the reliability and depth of our analysis.

According to the DOLS results, a 1% rise in consumption yields a commendable 0.520% increase in output, underscoring the positive impact of consumption on economic growth. Simultaneously, a 1% increase in non-renewable energy consumption (non-REC) is associated with a 0.052% rise in output. Transitioning to the FMOLS results, we observe a nuanced picture. A 1% increase in consumption significantly boosts output by 0.784%, emphasizing the critical role of consumption in driving economic growth. Similarly, a 1% increase in non-REC is linked to a 0.130% rise in output. These findings collectively suggest that, in the long run, both conventional factors of production and non-renewable energy play pivotal roles in fostering GDP growth across the sampled countries.

Table 5: Long run output elasticities

Variable	DOLS		FMOLS	
	Coefficient	t-statistics	Coefficient	t-statistics
CF	0.251	10.545	0.248	7.767
LAB	0.002	6.355	0.007	5.318
REC	0.520	4.467	0.784	3.021
FFE	0.052	2.130	0.130	5.326
R-squared	0.973		0.942	

GDP: Gross domestic product, CF: Capital formation, LAB: Labour, REC: Renewable energy consumption, FFE: Fossil fuel energy, DOLS: Dynamic ordinary least squares, FMOLS: Fully modified ordinary least squares.***denotes the significant level at 1%

Having delved into the long-run dynamics among the variables in Table 6, our analytical journey advances to the determination of short-run causality. To unravel this aspect, we employ the Dumitrescu Hurlin panel causality test. The results unveil a unidirectional causality between capital and GDP, highlighting the influence of capital on economic output. Additionally, a non-directional causality relationship emerges between labor and non-renewable energy consumption in the short run. This intricate web of short-run causality further elucidates the nuanced interactions among the variables, contributing to a comprehensive understanding of their dynamic relationships.

As we shift focus to long-run time series analysis through FMOLS for individual countries, the empirical results in Table 7 paint a diverse picture. Long-run output with respect to renewable energy consumption (REC) is consistently positive across all cases except for Russia, China, Turkey, Iran, and Spain. These findings underscore the multifaceted nature of the impact of renewable energy on GDP growth. In 15 countries, renewable energy consumption emerges as a vital factor propelling sustainable growth in the years ahead. However, in some cases, REC has been associated with a decline in economic growth, indicating a shift towards non-renewable energy consumption in these countries over time. In conclusion, our in-depth analysis, spanning both long-run and short-run perspectives, offers valuable insights into the intricate dynamics between renewable energy use, conventional factors of production, and economic growth. The positive and

Table 6: Dumitrescu Hurlin panel causality tests

Hypothesis	W statistic	Probability	Result	Conclusion
CF→GDP	7.745	0.000	Yes	Uni-directional causality between CF and GDP
GDP→CF	5.008	0.460	No	
LAB→GDP	3.967	0.6170	No	Non-directional causality between GDP and LAB
GDP→LAB	3.561	0.4132	No	
REC→GDP	4.075	0.6803	No	Uni-directional causality between GDP and REC
GDP→REC	7.086	0.051	Yes	
FFE→GDP	5.100	3.125	No	Non-directional causality between FFE and GDP
GDP→FFE	3.125	0.2807	No	
CF→LAB	5.307	0.672	No	Non-directional causality between CF and LAB
LAB→CF	5.832	0.734	No	
REC→CF	3.345	0.675	No	Non-directional causality between CF and REC
CF→REC	5.678	0.345	No	
FFE→CF	4.652	0.691	No	Non-directional causality between FFE and CF
CF→FFE	2.622	0.118	No	
REC→LAB	28.007	0.000	Yes	Unidirectional causality between LAB and REC
LAB→REC	14.193	0.567	No	
FFE→LAB	70.416	0.000	Yes	Bidirectional causality between FFE and LAB
LAB→FFE	17.602	0.000	Yes	
FFE→REC	21.564	0.000	Yes	Bidirectional causality between FFE and REC
REC→FFE	35.675	0.000	Yes	

GDP: Gross domestic product, CF: Capital formation, LAB: Labour, REC: Renewable energy consumption, FFE: Fossil fuel energy

Table 7: FMOLS models (long-run output elasticities)

				Dependent variable: GDP				
No	Country	CF	LAB	REC	FFE	C	R^2	Adj R^2
1	China	0.234***	1.736***	0.741	0.340***	3.747	0.923	0.921
2	United States	0.377***	0.320	0.434***	0.654	−1.345***	0.923	0.921
3	India	0.254	−2.965***	0.847	0.364***	2.674	0.973	0.961
4	Russia	0.612***	1.543	−0.645***	0.462	−0.515***	0.993	0.991
5	Japan	0.054***	3.912***	0.543	1.171***	2.546***	0.993	0.981
6	Canada	0.837	−0.134	0.654***	0.748	11.234	0.943	0.931
7	Germany	0.236***	0.345***	0.745	−0.987***	4.253***	0.953	0.941
8	Iran	0.863***	0.549	−0.365***	0.870	3.387***	0.973	0.962
9	Brazil	−0.832***	0.123***	0.532***	0.545	−1.786*	0.993	0.981
10	South Korea	0.674	2.706	0.742	0.346***	3.821	0.933	0.922
11	Saudi Arabia	0.213***	0.548***	0.540***	0.254	10.735*	0.973	0.961
12	France	0.412	0.698	0.434***	−0.634	2.811	0.993	0.981
13	Indonesia	0.653***	0.452***	0.254	0.545***	5.615***	0.972	0.962
14	United Kingdom	0.542***	0.574	−0.134***	0.878***	2.879	0.983	0.971
15	Turkey	0.123	1.245***	−0.875	−0.539***	5.271	0.943	0.941
16	Mexico	0.315***	0.869	0.367	0.546***	7.874***	0.953	0.951
17	Italy	1.873	0.454	0.458***	0.204	−3.342	0.961	0.952
18	Australia	0.531***	0.753***	0.256*	0.540	2.832***	0.971	0.960
19	Spain	−0.783***	1.457*	−0.436	0.764***	−2.134	0.981	0.970
20	Thailand	0.735	−2.678***	0.787***	0.248	9.326***	0.992	0.991

*'** and *** shows 10%, 5% and 1% level of significance, GDP: Gross domestic product, CF: Capital formation, LAB: Labour, REC: Renewable energy consumption, FFE: Fossil fuel energy, FMOLS: Fully modified ordinary least squares.

significant impact of renewable energy consumption in the long run reinforces its role as a catalyst for sustainable economic growth in the majority of sampled countries. Nevertheless, the nuanced variations observed in individual country analyses underscore the importance of context-specific policies to navigate the complex interplay between renewable and non-renewable energy in the pursuit of enduring economic development.

5. CONCLUSION AND POLICY IMPLICATION

The present study explores the implications of renewable and non-renewables for economic development of selected top 20 countries with respect to consumption. The study covers the period from 1990 to 2021. "To account for" the issue of "cross sectional dependence in panels," we use the general diagnostic test proposed by Pesaran (2004). Hence, to investigate "the order of integration and the stationarity properties" of the variables in presence of "cross-sectional dependence, here the cross sectional augmented IPS (CIPS)" test is considered. While, to find the "long run cointegration" relationship, we follow the panel "cointegration test developed by Pedroni (1999; 2004)" which confirms cointegration existence between the variables. Moreover, in order to get the long run elasticities, we have used the DOLS and the FMOLS techniques. The findings show that in long run conventional factors of production RE and NRE have contributed substantially towards economic development of the respective sampled economies. We also apply Dumitrescu Hurlin panel causality for finding a causal association between variables. The findings indicate existence of a uni-directional causation "between capital and growth. On the other hand, there exists non-directional causality relationship between labour and non-renewable energy in the short run.

Results for single country time series show that over "a longer period of time, renewable energy" induced elasticities of growth are positive in most of sampled countries. The evidence shows that renewable energy contributes to economic development in these countries have better prospects of future growth and development. The important policy implication in this regard is governments, international organization and energy planners, should work together to implement strategies for renewable arrangement across borders. Furthermore, the governments of these countries should follow incentive based policy to optimally exploit FEF.

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