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Socioeconomic Productive Capacity and Renewable Energy Development: Empirical Insights from BRICS

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Abstract: Due to the depletion of fossil fuels, empirics began looking at the factors that might encourage investment in renewable energy. Socioeconomic productivity can encourage renewable energy development by encouraging authorities, businesses, and families to rely more on renewable energy sources. Therefore, this analysis is the first-ever effort to detect the impact of socioeconomic productivity on renewable energy development. We have used the panel ARDL and QARDL to examine the estimates. The results of the panel ARDL model predict that national income, financial development, productive capacity index, human capital, ICT, institutional quality, and structural changes are beneficial for renewable energy development in the long run. In the short run, only financial development, productive capacity index, human capital, and ICT promote renewable energy development. Likewise, the panel QARDL model estimates that the national income, financial development, and productive capacity index promote renewable energy development in the long run. However, in the short run, only the productive capacity index and financial development promote renewable energy development. Therefore, by integrating productive assets, entrepreneurial skills, and industrial connections, policymakers must work to boost the productive socioeconomic potential.

Keywords: socioeconomic productive capacity; renewable energy development; BRICS

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1. Introduction

The rising price of energy crises has become a danger to the economic development of developed countries with limited resources [1]. As a result of their excessive reliance on the exploitation of fossil fuels, certain emerging markets with access to rich resources have been dealing with a variety of problems [2]. Following the oil crises of the 1970s, worldwide trends in energy efficiency [3] and growth rate [4] show that some developed nations appear to have benefited from increased energy efficiency in terms of GDP growth, whereas many resource-rich emerging economies continue to depend largely on resource extraction for their socioeconomic activities. The world's consumption and manufacturing have been requiring more energy amid the well-documented strain the deterioration of energy supplies has been placing on the world economic system [5]. Increasing demand has brought forth new social and political problems, such as energy vulnerability and increasing carbon footprint, as a consequence of rapid fossil fuel usage. Fossil fuels remain the largest energy source, accounting for about 80% of global demand in 2008 and 78% in 2030 [6].

Neither a steady decline in energy consumption nor a transformation to clean energy sources is predicted by world energy forecasts for the next several decades [7]. From a strategic viewpoint, the International Energy Agency's (IEA) recent policies statement indicates that assuming current practices are implemented, energy consumption would increase by 1.3% a year from 2018 to 2040. A rise in carbon production of nearly 24%, from 33.2 gigatons in 2018 to 41.3 gigatons in 2040, is predicted in response to this rising demand [7]. These simplified realities have prompted several regional and global energy initiatives to reduce energy waste, bolster power grid resilience, and protect the planet's natural resources. The renewable energy transformation from traditional fossil fuels to carbon-free clean alternatives [8] and significant steps towards energy efficiency [9] are two important factors that must be part of global efforts to achieve energy-related targets.

Energy efficiency refers to reducing excess energy during both the production and consumption of products and services, with its greater energy output and reduced energy intensity implications [10,11]. Since non-renewable forms of energy are scarce and the existing renewable energy production is insufficient, energy efficiency has a number of positive effects on the global economy [12,13]. Energy regulators have been driven to develop solid practices at national and international levels due to the ever-growing demand for ethical energy usage and sustainable power generation [14]. Nevertheless, additional empirical data on the factors influencing energy efficiency are needed for energy efficiency programs.

Numerous pieces of evidence from multiple disciplines have looked at renewable energy efficiency using a variety of approaches, with a focus on the adverse environmental impact and pollution caused by economic activity [15,16]. Additionally, a few non-economic factors affecting renewable energy efficiency have lately been researched for geographical groupings or specific nations. These factors consider the effects of urbanization, population trends, domestic demographic factors, ecological agreements, energy strategies, consumer tastes, schooling, corporate attributes, and others on renewable energy efficiency [17,18]. A fairly recent strategy for renewable energy efficiency from a socioeconomic viewpoint, notably in social sciences, has evolved since most of these sociotechnical variables too have economic roots. Nevertheless, comparatively little work has taken into account socioeconomic factors such as human capital, transport and logistics effectiveness, digitalization, organizational performance, privatization, and business outlook [19–22]. However, most of these studies have analyzed the impact of individual variables on renewable energy efficiency and probably suffer from missing consequences (omitted variables) since they do not account for the total impacts of the interrelated socioeconomic elements.

Socioeconomic productive capacity can have a significant impact on renewable energy production. This is because the development and adoption of renewable energy technologies require a certain level of economic and technological resources, as well as supportive policies and regulations [23,24]. Countries with higher levels of socioeconomic development tend to have greater renewable energy production capacity. This is because they have greater access to financial resources and advanced technologies that are required to develop and deploy renewable energy technologies [25]. Moreover, in countries with greater productive capacity, there is often a higher demand for energy, which can drive investments in renewable energy production. In addition, these countries often have more favorable policies and regulations, such as tax incentives or subsidies that encourage investment in renewable energy. Thus, socioeconomic productive capacity can affect the availability of financial resources, technology, infrastructure, and human resources needed for renewable energy production [26].

The available literature on renewable energy development mostly considers economic and environmental factors as determinants of renewable energy and ignores socioeconomic factors. Even though some empirics have investigated the impact of socioeconomic factors on the environmental quality in various regions and countries, none of the studies have incorporated these factors in a renewable energy function. Moreover, the findings of the available studies varied and were susceptible to the variables, measurements, samples, and methodologies. Further, the current studies have utilized individual socioeconomic factors in the environment-energy literature and ignored a comprehensive measure of socioeconomic productive capacity, such as the productive capacities index (PCI). So the question is: what is the relationship between socioeconomic productive capacity and renewable energy production in BRICS countries?

The present study examines the impact of socioeconomic productive capacity on renewable energy production in BRICS. It is important to analyze the BRICS countries. First, these countries represent a significant share of the global economy and population, and their economic and social policies can have significant impacts on global development [27]. Second, the BRICS countries have unique characteristics and challenges, such as high levels of inequality, dependence on natural resources, and diverse cultural and political systems, that require specific policy approaches [28]. Third, the BRICS countries have shown significant interest in renewable energy development, and understanding their experiences and challenges can provide insights into the potential for renewable energy to drive sustainable development [29]. Analyzing the socioeconomic productive capacity and renewable energy development in the BRICS countries can contribute to understanding the research problem in this paper in several ways. First, it can help identify the key drivers and barriers to renewable energy development in these countries and provide insights into how policies and institutions can promote or hinder the transition to renewable energy. Second, analyzing the case of BRICS countries can provide important insights into how renewable energy can contribute to sustainable development in developing countries with diverse socioeconomic contexts.

The research responds to different postulated issues by using a multi-perspective method to examine renewable energy efficiency and its probable socioeconomic causes. For instance, do various nation groups' levels of socioeconomic productivity and per capita wealth have a distinct impact on their renewable energy development? Therefore, the research may contribute uniquely to the body of literature in the following ways. The study makes the following four contributions to the existing literature. Firstly, to our limited knowledge, this inaugural study has investigated the influence of socioeconomic productive capacity on renewable energy development in BRICS economies. Secondly, this is the first study that has utilized the PCI as a determinant of renewable energy development. Thirdly, the study employed the panel ARDL method that can estimate the short and long-run estimates, whereas most past studies have only focused on the long-run estimates. Lastly, the policy suggestions based on the results can prove vital for promoting sustainable and green practices in BRICS.

2. Literature Review

Recent decades have seen a rise in interest in the investigation into the variables that influence the generation of renewable energy. There are several catalysts responsible for this increasing interest in the developing renewable energy industry, such as income, human capital, institutional quality, financial development, and structural change [30]. Such as:

1. Income: The effect of income or per capita income on the development of renewable energy has also been studied by researchers. According to [31], the key factor influencing the per capita use of renewable energy is the rise in real per capita income. In other words, those with higher incomes have a greater capability or resources to encourage the use of renewable energy. The effects of green and traditional energy usage on economic development in the fields of agriculture, manufacturing, services, and total income across a group of G20 countries were examined by [32] using annual data from 1980 to 2012. Their findings demonstrated that the use of green and traditional energy contributed favorably to economic development across all industries. In [33], the authors examined the impact of the use of renewable energy on national income in a worldwide sample of 85 industrialized and emerging nations, together with other important model components. To accomplish the research goals, the authors used annual data from 1991 to 2012 along with various econometric approaches. The system GMM and FMOLS findings showed that the use of renewable energy has a considerable favorable impact on national income.
2. Human capital: While it is commonly recognized that human activities are mostly to blame for resource imbalances, research on renewable energy has seldom taken the influence of human development into account. Since business owners and workers

are drawn from the public, a society's degree of human capital is crucial for both its consumers and its producers. More precisely, customers who have received an education are more informed about the environmental impacts of consuming non-renewable energy sources. The research on the factors that influence energy demand varies according to geographies, nations, time series, and other variables using data from 1965 to 2014, and ref. [34] discovered a conflict between human capital and traditional energy consumption while discovering harmony between human capital with renewable energy consumption. In [35], the authors state that human capital is a significant factor in regulating energy demand. For ten nations with significant ecological footprints, ref. [36] confirm that resource availability harms the ecosystem but that air degradation is reduced by human capital. In contrast, ref. [37] highlighted the positive connection between human capital and ecological footprints in BRICS nations.

3. Institutional quality: It has long been believed that for society to become more environmentally conscious and for environmental programs to be effective, there must be well-managed governmental involvement, solid institutions, and excellent democracy [28]. Inside the institutional framework, this process also holds for renewable energy development [38]. There has been a lot of work on how political factors such as democratization affect the ecosystem, but there have been few efforts to analyze institutional factors that impact the use of renewable energy. The initiatives in this category that may be assessed have usually concentrated on how fundamental institutional factors such as lobbying activities, ideology, democracy, and corruption affect renewable energy. The use of clean energy in European nations was shown to be negatively impacted by lobbying operations, according to [39]. The conventional and organizational drivers of renewable energy in the ECO nations from 1992 to 2012 were investigated by [40]. The results showed that the use of renewable energy was favorably impacted by political stability. Contrary to what has been said, corruption was discovered to have a detrimental impact on the use of renewable energy. The political, economic, and ecological factors of clean energy in 26 European nations from 2004 to 2011 were examined by [41]. The usage of clean energy was unfavorably impacted by lobbying and national income but favorably impacted less corruption in society. In more than 100 nations, ref. [42] looked at the connection between democracy and renewable energy. The study's usage of all democratic metrics had a favorable impact on the utilization of renewable energy.
4. Financial development: The relationship between financial growth and renewable energy has drawn considerable attention from the empirical community. Nevertheless, a significant number of empirical studies have looked at the link while considering the demand side of this sector, in other words, the use of renewable energy. For example, ref. [43] highlight how the usage of renewable energy benefits from institutional and financial robustness. For high-income countries, ref. [44] found that financial capital encourages the switch to modern renewable sources of energy, while debt securities and bank loans are thought to have a positive impact on sustainable energy requirements. In [45], the authors investigated the relationship between financial development, economic expansion, and the usage of renewable energy. According to their results, there is no direct causal relationship between the usage of renewable energy and monetary advancement. In four BRICS countries, ref. [46] looked at how FDI and stock market expansion affected the adoption of renewable energy. They showed how FDI and stock market expansion have a big impact on the uptake of renewable energy.
5. Structural change: Energy consumption is greatly influenced by structural change, which is often assessed by comparing sectoral proportions in the domestic economy. For the transitioning nations, structural change includes a shift from centralized planning to economic liberalization. There is a substantial body of literature that supports the idea that structural modifications might increase energy efficiency, but there hasn't

been much empirical research on how structural changes may affect the development of renewable energy [47]. According to [18], structural change has a significant impact on renewable energy in China. Likewise, in [48], the analysis reveals that structural changes improve energy efficiency in various groups of transition countries. In 39 nations between 1995 and 2009, ref. [49] clearly showed that economic transitions from manufacturing to service-led industries increase global energy productivity while increases in industrial output decrease it.

According to a review of the literature, the results are varied and responsive to the variables, measurements, samples, and methodologies. The idea strongly implies that advances in socioeconomic elements' productive capacity provide chances to promote environmental performance. Yet, there is relatively little empirical research looking into the socioeconomic factors that influence renewable energy, especially globally. Thus, this research has tested the following hypothesis: *socioeconomic productive capacity is positively related to renewable energy production*.

3. Model, Methods, and Data

The relationship between socioeconomic productive capacity and renewable energy development can be understood through a variety of theoretical frameworks, including the environmental Kuznets curve (EKC), institutional theory, and ecological modernization theory. Each of these frameworks provides a different perspective on the relationship between these two factors and can be used to inform policies and strategies aimed at promoting renewable energy development [50]. Literature documented a few determinants that affect renewable energy development (RED). These determinants are environmental, social, technical, institutional, and economic. Economic progress is considered an important determinant of RED [51]. Institutional determinant includes rules and regulations that make renewable energy production either harder and slower or easier and faster. Technology development plays an important role in the process of efficient and less costly renewable energy production [52]. Social determinants include various aspects, such as openness towards new ideas and social acceptance. Environmental factors cover the effects of pollution [28]. In our model, the drivers of renewable energy development are selected according to these determinants. Hence, from the previous literature [48], we have borrowed the following long-run equation.

$$\mathrm{REP}_{\mathrm{it}} = \varphi_0 + \varphi_1 \mathrm{PCI}_{\mathrm{it}} + \varphi_2 \mathrm{GNI}_{\mathrm{it}} + \varphi_3 \mathrm{FD}_{\mathrm{it}} + \varepsilon_{\mathrm{it}} \quad (1)$$

where renewable energy production (REP) in BRICS economies is dependent on the productive capacities index (PCI), GNI per capita (GNI), and financial development (FD). Next, we turn Equation (1) into an error-correction modeling approach so that we can also assess the short-run effects. The short-run and long-run effects for REP are specified as follows:

$$\begin{aligned} \Delta\mathrm{REP}_{\mathrm{it}} = \varphi_0 + & \sum_{k=1}^{n} \psi_{1k} \Delta\mathrm{REP}_{\mathrm{it-k}} + \sum_{k=0}^{n} \psi_{2k} \Delta\mathrm{PCI}_{\mathrm{it-k}} + \sum_{k=1}^{n} \psi_{3k} \Delta\mathrm{GNI}_{\mathrm{it-k}} \\ & + \sum_{k=0}^{n} \psi_{4k} \Delta\mathrm{FD}_{\mathrm{it-k}} + +\varphi_1 \mathrm{REP}_{\mathrm{it-1}} + \varphi_2 \mathrm{PCI}_{\mathrm{it-1}} + \varphi_3 \mathrm{GNI}_{\mathrm{it-1}} \\ & + \varphi_4 \mathrm{FD}_{\mathrm{it-1}} + \varepsilon_{\mathrm{it}} \end{aligned} \quad (2)$$

The information in Equation (2) is comparable to that in the ARDL-PMG formula, which was created by Pesaran et al. [53]. Equation (2) includes short- and long-run estimates, represented by "first-differenced" coefficients and φ_1-φ_4 the coefficients, respectively. The long-run relationship is assumed to be incorrect unless we can prove cointegration between the long-run parameters; hence proving cointegration is one major challenge we must tackle when coping with the long-run results. There must be some diagnostic tests to verify the cointegration relationship between the variables. Pesaran et al. [53] developed two tests, the F-test or *t*-test (also known as the ECM test), which is collected via a combination of Equations (1) and (2). The null of the F-test suggests that there is no cointegration, while the alternative hypothesis represents the existence of a long-run relationship. Critical values for the F-test and *t*-test are suggested by Pesaran et al. [53]; they must be lower than estimated values in order to demonstrate long-run cointegration. There are benefits to using this procedure rather than others. To start, compared to numerous panel cointegration techniques, which require parameters to be stationary at (1), this approach may be used with the parameters that are I(0), I(1), or a combination of I(0) and I(1). Even though the ARDL model does not require checking the stationary properties of the variables, the ARDL can't take care of any I(2) variables. Thus, as a precautionary measure and to confirm that none of the variables are I(2), we have applied three unit root tests such as Levin, Lin, and Chu (LLC), Im, Pesaran, and Shin (IPS), and ADF tests. The notion of cross-sectional independence is essential to both IPS and LLC. When doing panel unit root tests, the null hypothesis is that the panel series is stationary, whereas the alternative hypothesis is that the panel series is non-stationary. Second, whereas most other methods can only look into long-term estimations, this approach is one of the uncommon ones that can look into both short- and long-term ones at the same time. Finally, this is an efficient approach to coping with a small data collection. On the opposite side, some other panel cointegration methods can only provide reliable findings if the series has been gathered over a considerable time span. This approach also incorporates a dynamic strategy for short-term change. Thus, any feedback influence between variables may be applied using this method, which aids in getting rid of endogeneity [54]. While ARDL was employed as the primary method for this research, we likewise utilized QARDL to ensure the validity of our findings. When non-normality arises, the QARDL approach yields accurate estimations (see, Figure 1).

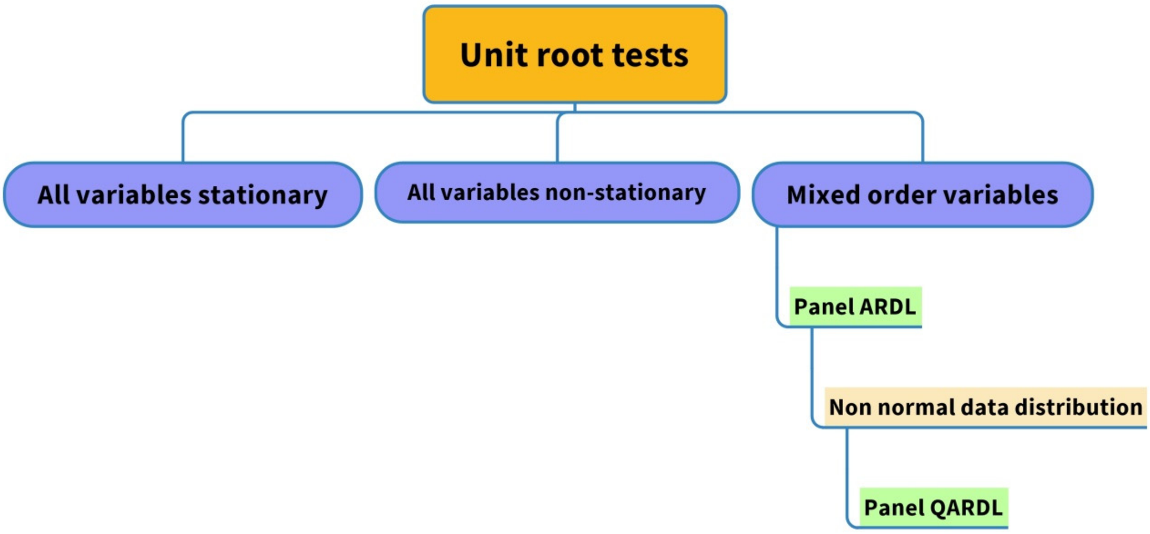

Figure 1. Methodology Framework.

Our study collects annual data series for BRICS economies over the period 1990 to 2020. The details of the selected variables are given in Table 1. Renewable energy development is measured by renewable energy production (REP), which consists of the production of all energy sources, including nuclear, renewables, and others. Socioeconomic productive capacity is measured by three indicators: GNI, FD, and PCI. GNI per capita is measured at the current US$, which is based on the Atlas method. FD is measured through domestic credit to the private sector as a % of GDP. PCI is based on the productive capacity index. PCI is also used at the disaggregate level. At the disaggregate level, four components of PCI have been used. These are human capital (HC), ICT capital formation (ICT), institution quality (IQ), and structural change (SC). REP data set is obtained from the EIA. The data sets for GNI and FD are taken from the WDI. However, the data sets for PCI, HC, ICT, IQ, and SC are taken from UNCTADstat. The summary of descriptive statistics is provided in

Table 2. Mean values for REP, GNI, FD, PCI, HC, ICT, IQ, and SC are observed as positive. These are reported as 0.697 for REP, 8.246 for GNI, 4.157 for FD, 3.443 for PCI, 3.930 for HC, 2.068 for ICT, 3.894 for IQ, and 3.215 for SC. The J-B stats reveal that the null hypothesis for normality distribution is rejected for PCI and ICT. However, REP, GNI, FD, HC, IQ, and SC series are found normally distributed.

Table 1. Variables and data sources.

Variables	Definitions	Sources
REP	Total production of nuclear, renewables, and other (quad Btu)	EIA
GNI	GNI per capita, Atlas method (current US$)	WDI
FD	Domestic credit to private sector (% of GDP)	WDI
PCI	Productive capacities index: overall index	UNCTADstat
HC	Human capital capacity index	UNCTADstat
ICT	ICT capacity index	UNCTADstat
IQ	Institutional quality capacity index	UNCTADstat
SC	Structural change capacity index	UNCTADstat

Table 2. Descriptive statistics.

	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Prob.
REP	0.697	1.189	3.215	−2.025	1.405	−0.768	2.671	12.32	0.002
GNI	8.246	8.498	9.628	6.016	0.953	−0.647	2.388	10.23	0.006
FD	4.157	4.074	5.209	2.623	0.632	−0.277	2.093	5.646	0.059
PCI	3.443	3.446	3.762	3.200	0.112	0.430	3.376	4.409	0.110
HC	3.930	3.961	4.163	3.604	0.141	−0.434	2.111	7.713	0.021
ICT	2.068	2.077	3.068	0.647	0.546	−0.290	2.246	4.530	0.104
IQ	3.894	3.900	4.189	3.580	0.168	−0.004	1.843	6.689	0.035
SC	3.215	3.176	3.772	2.998	0.151	1.474	5.396	72.19	0.000

4. Empirical Results and Discussion

The results of the LLC, IPS, and ADF unit root tests at the level and the first difference are shown in Table 3. The LLC, IPS, and ADF results suggest that some variables are stationary at a level whereas some variables are stationary at first difference. In the LLC test, GNI, FD, PCI, ICT, and IQ are stationary at level, however, REP, HC, and SC are stationary at first difference. Similarly, in both IPS and ADF tests, only ICT and IQ are stationary at a level, whereas all other variables such as REP, GNI, FDI, PCI, HC, and SC are stationary at first difference. When some variables become stationary at the level and some at the first difference, it is a clue to employ the ARDL technique.

Table 3. Results of panel unit root tests.

	LLC		IPS		ADF	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
REP	−0.165	−5.658 ***	0.857	−5.857 ***	0.804	−5.325 ***
GNI	−2.935 ***		−0.812	−1.897 **	−0.865	−2.023 **
FD	−1.687 *		−0.165	−3.254 ***	−0.154	−3.214 ***
PCI	−1.546 *		0.567	−4.985 ***	0.756	−4.856 ***
HC	−1.089	−6.578 ***	0.915	−5.654 ***	1.058	−4.325 ***
ICT	−5.654 ***		−1.987 **		−1.667 **	
IQ	−1.589 *		−2.456 ***		−2.567 ***	
SC	−1.021	−4.566 ***	−1.356	−5.654 ***	−1.213	−4.521 ***

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The results of the long-run and short-run PMG-ARDL models are described in Table 4. The results show that in model 1, GNI has a positive and significant impact on REP in the long run. A 1% increase in GNI results in a 0.218% increase in REP. Our analysis confirms not only the positive impact of the socioeconomic productivity index on renewable energy development but also observes that a rise in the productive capacity of various individual socioeconomic elements helps promote renewable energy development. For instance, the augmented productive capacity in human capital encourages renewable energy by promoting pro-environmental experiences. Similarly, FD has a positive and significant influence on REP. A 1% increase in FD results in a 0.735% increase in REP over the long term. The impact of PCI on REP is positive and highly significant. A 1% rise in PCI leads to a 1.375% rise in REP. Our empirical findings supported hypothesis (1) in BRICS. As illustrated in Table 4, model 2 observes that the effect of GNI and FD on REP is positive and significant. A 1% increase in GNI and FD causes a 0.497% and 0.411% increase in REP, respectively. Likewise, human capital also has a positive and significant effect on REP. A 1% increase in HC leads to a rise in REP by 1.086%. Highly skilled and trained managers are more likely to care about the environment and thus help promote renewable energy development [55,56]. Similarly, education level and human capital go side by side, improving society's environment-related consciousness and promoting renewable energy development.

Table 4. Results of PMG-ARDL.

	(1)		(2)		(3)		(4)		(5)	
Variable	**Coef.**	***t*-Stat**	**Coef.**	***t*-Stat**	**Coef.**	***t*-Stat**	**Coef.**	***t*-Stat**	**Coef.**	***t*-Stat**
Long-run										
GNI	0.218 **	2.222	0.497 **	2.006	0.268 *	1.928	0.517 *	1.940	0.322 **	2.508
FD	0.735 ***	4.676	0.411 **	2.006	0.368 **	2.518	0.359 *	1.831	0.496 *	1.781
PCI	1.375 ***	5.562								
HC			1.086 **	2.007						
ICT					0.963 ***	4.860				
IQ							1.059 *	1.931		
SC									1.051 *	2.026
Short-run										
D(GNI)	0.048	0.249	0.050	0.289	0.001	0.005	0.098	0.876	0.013	0.085
D(GNI(−1))	0.106	0.372	0.013	0.039	0.145	0.991	0.005	0.024	0.112	0.770
D(FD)	0.045 **	2.277	0.029 **	2.179	0.158 *	1.836	0.048 **	2.463	0.146 *	1.814
D(FD(−1))	0.081	0.816	0.012	1.148	0.055	1.188	0.009	0.136	0.109	1.380
D(PCI)	1.003 **	2.561								
D(PCI(−1))	0.830	1.014								
D(PCI(−2))	0.252	0.389								
D(HC)			1.003	1.004						
D(HC(−1))			0.901	1.142						
D(ICT)					0.482 *	1.688				
D(ICT(−1))					0.020	0.092				
D(IQ)							0.335 *	1.668		
D(IQ(−1))							0.846	1.335		
D(SC)									0.146	0.414
C	2.097 *	1.933	2.174 **	2.085	1.855 **	2.256	2.362 **	2.005	1.861 **	2.031
Diagnostics										
ECM(−1)	−0.369 *	−1.696	−0.401 *	−1.876	−0.290 *	−1.921	−0.286 **	−2.030	−0.326 **	−2.125
Kao-coint test	−2.362 ***	0.009	−2.662 ***	0.004	−1.228	0.110	−1.448 *	0.074	−2.013 **	0.009

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The results of model 3 illustrate that the GNI significantly expands REP. As the GNI increases by 1%, the REP rises by 0.268%. The FD also positively and significantly affects REP. The coefficient of FD entails that a 1% increase in FD increases REP by 0.368%. ICT significantly and positively influences REP. A 1% increase in ICT results in a 0.963% increase in REP. Lastly, higher ICT capacity improves renewable energy development. Digitalization and dematerialization of society are crucial for transforming the energy sector [57] and promoting renewable energy development because users can easily use the internet and mobile phones to control microgrids installed in their homes and businesses. The connection between renewable energy projects in different parts of the country has become easy and helps promote renewable energy development. Model 4 indicates that both GNI and FD are positively and significantly impacting REP. The coefficients of GNI and FD show that a 1% increase in GNI and FD brings about a 0.517% and 0.359% increase in REP in the long run. Along with these, IQ also has a positive and significant effect on REP. A 1% increase in IQ results in a 1.059% rise in REP. Further, institutional capacity is positively associated with renewable energy development because by improving institutional quality, a nation can speed up the deployment of renewable energy projects by removing all administrative hurdles in the way of renewable projects. As society becomes more democratic or more peaceful, the demand for a clean environment and energy also rises [58]. This finding is in line with the findings of Uzar [59]. The results of model 5 reveal that GNI and FD significantly affect REP. A 1% increase in GNI and FD results in a 0.322% and 0.496% increase in REP. The coefficient of structural change indicates that a 1% increase in SC results in a 1.051% increase in REP in the long run. Moreover, structural modification enhances and promotes energy generation. As the economy starts relying more on the services sector instead of industrial and manufacturing, they start thinking more about environmental preservation and increasing investment in renewable energy projects. The positive nexus between structural change and energy efficiency improvement supports the findings of Zhao et al. [60] and Meng et al. [61], who assessed structural change by different indicators.

Several studies have supported our findings. For instance, a study by Shahbaz et al. [62] found that higher levels of human capital and industrial development are positively associated with the adoption of renewable energy technologies. Sturiale & Scuderi [63] found that higher levels of economic development and investment in infrastructure are positively associated with the adoption of renewable energy technologies in Pakistan. Guta [64] found that higher levels of technological and institutional capacity are positively associated with the adoption of wind energy technologies in China. Chen et al. [65] found that higher levels of financial and institutional capacity are positively associated with the adoption of renewable energy technologies.

While there are many studies that report a positive relationship between socioeconomic productive capacity and renewable energy development, there are also some studies that have reported negative impacts. For example, Bai et al. [66] found that high levels of income inequality have a negative impact on renewable energy consumption in developing countries. Adom et al. [67] found that high levels of income and urbanization are negatively associated with the adoption of solar energy technologies in Ghana.

The results of the short-run analysis in model 1 indicate that both FD and PCI have a short-run positive impact on REP, whereas GNI has no impact on REP. The results of the short-run analysis in the remaining four models indicate that only FD has a significant impact on REP. The cointegration evidence is supported by both the Kao-Coint test and the ECM (-1) in all five models.

Table 5 depicts the QARDL results. The long-term coefficient findings indicate that GNI significantly influences REP from the 80th to 95th quintiles. FD is positively correlated with the coefficient of REP. The result also illustrates that financial development has an imperative influence on renewable energy production from the 60th to 95th quantiles. The empirical findings show that the PCI coefficient has a positive effect on REP, confirming the long-term relationship between productive capacities and renewable energy production from the 20th to the 95th quantiles. The short-run results show that GNI has no effect on REP. On the other hand, FD and PCI have a significant and positive impact on REP. FD has a significant and positive impact on REP from 80th to 95th quantiles, while PCI has a positive and significant impact on REP from 60th to 95th quantiles.

Table 5. Results of panel QARDL.

		Long-Run				Short-Run					
	ECM	**C**	**GNI**	**FD**	**PCI**	**REPP(−1)**	**GNI**	**GNI(−1)**	**FD**	**FD(−1)**	**PCI**
0.05	−0.114	20.23	−0.144	0.951	1.595	1.025 ***	0.208	0.220	−0.178	−0.189	0.006
	(−1.469)	(0.875)	(−0.191)	(0.780)	(0.969)	(3.718)	(1.113)	(1.205)	(−0.555)	(−0.613)	(0.164)
0.10	−0.117 *	23.88	−0.558	1.001	1.948	1.034 ***	0.043	0.065	−0.049	−0.030	0.015
	(−1.728)	(0.932)	(−0.664)	(0.861)	(1.083)	(3.653)	(0.660)	(0.981)	(−0.417)	(−0.260)	(0.610)
0.20	−0.203 *	27.47	−1.184	1.292	2.063 **	1.030 ***	0.081	0.104	−0.107	−0.121	0.031
	(−1.947)	(1.305)	(−1.094)	(1.005)	(2.053)	(3.572)	(0.987)	(1.287)	(−0.899)	(−1.011)	(1.122)
0.30	−0.254 **	29.04 ***	−0.886	1.491	1.840 **	1.035 ***	0.087	0.108	−0.040	0.056	0.023
	(−2.378)	(6.733)	(−1.033)	(1.121)	(2.361)	(4.144)	(1.052)	(1.348)	(−0.321)	(0.452)	(0.728)
0.40	−0.308 ***	24.53 ***	−0.760	1.503	1.704 ***	1.028 ***	0.142	0.161	−0.203	0.214	0.032
	(−2.611)	(9.088)	(−1.229)	(1.276)	(3.212)	(3.914)	(1.653)	(1.136)	(−1.618)	(0.730)	(1.106)
0.50	−0.411 ***	23.38 ***	−0.381	1.078	1.549 ***	1.017 ***	0.037	0.064	−0.094	0.116	0.047
	(−2.684)	(3.094)	(−1.306)	(1.563)	(2.678)	(3.492)	(0.418)	(0.759)	(−0.691)	(0.873)	(1.490)
0.60	−0.501 ***	21.76 ***	−0.137	0.624 *	1.419 ***	1.018 ***	0.016	0.048	0.076	0.099	0.060 **
	(−3.405)	(3.898)	(−0.825)	(1.936)	(3.243)	(3.250)	(0.213)	(0.665)	(0.653)	(0.895)	(2.088)
0.70	−0.566 ***	19.05 ***	0.025	0.256 **	1.331 ***	1.003 ***	0.011	0.025	0.006	0.031	0.063 **
	(−3.313)	(7.181)	(1.230)	(2.047)	(5.619)	(2.999)	(0.160)	(0.379)	(0.052)	(0.290)	(1.984)
0.80	−0.601 ***	17.28 ***	0.065 *	0.159 **	1.265 ***	1.007 **	0.066	0.006	0.145 *	0.075	0.085 **
	(−4.018)	(9.025)	(1.805)	(2.297)	(6.626)	(2.459)	(0.935)	(0.095)	(1.936)	(0.644)	(2.235)
0.90	−0.651 ***	15.63 ***	0.095 *	0.117 **	0.944 ***	0.997 **	0.088	0.040	0.093 **	0.018	0.061 **
	(−3.411)	(9.392)	(1.911)	(2.354)	(6.268)	(2.239)	(1.247)	(0.592)	(2.234)	(0.132)	(2.304)
0.95	−0.701 **	15.86 ***	0.056 *	0.130 **	0.733 ***	1.006 **	0.032	0.095	0.062 ***	0.004	0.106 **
	(−2.370)	(11.38)	(1.690)	(2.521)	(7.788)	(2.209)	(0.465)	(1.516)	(2.902)	(0.029)	(2.155)

Note: *T*-stat in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5. Conclusions

Energy utilization is vital to industrial and production processes. In fact, these initiatives are essential for improving the standard of living for everyone and the nation's economy. However, most of the energy utilized for both manufacturing and consumption originates from fossil fuels, which are also the main cause of carbon emissions and consequent ecological damage. Nevertheless, as fossil fuels quickly run out, people throughout the world are looking for affordable, trustworthy, and renewable energy sources. The answer to these problems is to transition from carbon-heavy to carbon-neutral energy sources. Therefore, substantial investment in renewable energy sources may change the energy industry and aid in raising the share of sustainable energy in the amount of energy. Empirics began looking at the variables that might encourage investment in renewable energy as a result. Socioeconomic productivity can encourage renewable energy development by encouraging authorities, businesses, and families to rely more on renewable energy sources. Previously, no study has investigated the impact of socioeconomic productivity on renewable energy development. Therefore, this analysis is the first-ever effort to detect the impact of socioeconomic on renewable energy development.

We have used the panel ARDL and QARDL to examine the variables' short- and long-term relationships. The results of the ARDL-PMG model predict that national income, financial development, productive capacity index, human capital, ICT, institutional quality, and structural changes are beneficial for renewable energy development in the long run. In the short run, only financial development, productive capacity index, human capital, and ICT promote renewable energy development. Likewise, the QARDL model estimates that the national income, financial development, and productive capacity index promote renewable energy development in the long run. However, the productive capacity index estimates are positively significant in more than half of the quantiles. The national income and financial development estimates are significant and positive only at a few higher quantiles. Similarly, the short-run estimates attached to the productive capacity index are positively significant at more than half of the quantiles, and the estimates of financial development are significant and positive at higher quantiles.

6. Implications

These conclusions can result in significant policy suggestions. Firstly, the analysis confirms the positive impact of socioeconomic productivity on renewable energy development. Therefore, policymakers must try to increase the socioeconomic productive capacity through the partnership between productive resources, entrepreneurial capabilities, and production linkages. Secondly, the study's outcome confirms that human capital promotes renewable energy development. Hence, raising the formal education level and starting skill development programs can produce human capital which is more environmentally friendly and promote pro-environment practices such as promoting renewable energy consumption and production. Thirdly, financial development can provide the necessary funds for the deployment of expensive renewable plants. Fourthly, increased digitalization of society can allow individuals and small businesses to control the energy produced by solar grids through one app. Moreover, digitalization can also help to connect power plants from distant areas to the national grid with the help of one click. Therefore, the role of digitalization should be increased in the energy sector. Lastly, policymakers must direct relevant offices and concerned institutions to grant permission for the deployment of renewable energy projects on a priority basis. Countries with higher levels of socioeconomic productive capacity may be better positioned to invest in renewable energy technologies, as they have the financial resources and institutional frameworks to support these investments. Policymakers can encourage investment in renewable energy by creating a supportive policy environment, such as offering tax incentives, subsidies, or other financial mechanisms to encourage businesses and individuals to invest in renewable energy technologies.

7. Limitations and New Directions

The study focuses on the BRICS countries, which may not be representative of the global picture. The findings may not be generalizable to other countries or regions. Future studies could expand the scope of analysis to include other developing or developed countries. This would provide a broader perspective on the relationships between socioeconomic productive capacity and renewable energy development and enable the identification of cross-country differences and similarities. The study employs a panel ARDL regression model, which may not capture the nonlinear relationships between the variables. Future studies should use a nonlinear panel QARDL approach that may provide a more comprehensive understanding of the relationships.

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