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Oil Prices, Financial Development, and Urbanization in the Renewable Energy Transition: Empirical Evidence from E-10 Countries

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Abstract

The factors influencing the use of renewable energy in ten significant emerging economies (E-10: Argentina, Brazil, China, Indonesia, India, Mexico, Poland, Russia, South Africa, and Turkey) are examined in this study for the years 1990–2021. In order to capture both contemporaneous and intertemporal drivers of renewable energy demand, the analysis uses dynamic panel techniques (GMM) in conjunction with static panel estimations (fixed and random effects), drawing on a balanced panel dataset. The empirical findings highlight the path-dependent character of the energy transition by pointing to a clear persistence effect, in which previous renewable energy consumption significantly and favorably influences current levels. While oil prices and carbon emissions exert adverse pressures, economic growth and financial development are consistently recognized as key facilitators of the adoption of renewable energy. In several specifications, population growth appears as a constraining factor. Both static and dynamic models show that urbanization has a negative impact on the use of renewable energy. Therefore, incorporating renewable energy considerations into urban development policies may help reverse this trend and promote increased use of renewable energy. When combined, the results show how strategically important it is to promote economic growth, strengthen financial systems, and incorporate sustainability into urbanization processes. The urgent need to phase out fossil fuel subsidies, reroute financial resources toward green investment, and fortify carbon mitigation frameworks are among the policy implications. In the end, the evidence favors a multifaceted policy framework for the E-10 nations to hasten the switch to renewable energy.

Keywords: renewable energy; financial development; urbanization; population; economic growth; oil price; E-10 countries; dynamic analysis

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1. Introduction

Global energy demand saw a significant increase after the post-1950s period of rapid production expansion [1–3], particularly with the acceleration of technological innovations after the 1990s [4]. Within the framework of the "energy–growth nexus," this increase in global energy demand has been thoroughly examined in the literature. One of the earliest empirical studies to show a causal relationship between energy consumption and economic growth was carried out by Kraft and Kraft [5]. Stern [6] emphasized the macroeconomic role of energy, particularly with regard to the US economy, using multivariate cointegration analyses. In a thorough analysis of the research on this topic, Ozturk [7] demonstrated

how the connection between growth and energy has evolved in different economies. The Environmental Kuznets Curve hypothesis has contributed to bringing attention to the environmental component of the energy–growth relationship by building on these findings. EKC claims that during the early stages of economic development, energy consumption and environmental degradation increase in tandem with industrialization and the expanding use of fossil fuels. However, as income levels rise above a certain threshold, the economy shifts toward cleaner technologies and greater energy efficiency, reducing environmental pressure [8]. This pattern reflects the income effect, which maintains that higher income and improved living conditions encourage investment in renewable energy sources and environmental awareness. Therefore, the way that economic growth, energy demand, and environmental quality interact is increasingly influenced by technological developments, policy formulation, and public preferences for sustainability.

The theoretical framework of this study explains the variables influencing renewable energy consumption (REC) through a variety of interconnected mechanisms. According to the energy substitution theory, renewable energy sources gain popularity as fossil fuel prices rise, encouraging both production and consumption substitution [9]. However, this substitution effect is reduced in economies that heavily rely on oil revenues or have high fossil fuel subsidies because energy prices do not accurately reflect market dynamics. In this framework, carbon emissions also play a complementary role: higher emissions signify a continued reliance on fossil fuels [10], while increased use of renewable energy promotes environmental improvement and decarbonization [11].

According to the finance–energy channel and green finance theory [12], financial development makes investments in renewable energy easier by increasing credit availability, lowering financing costs, and raising money through sustainable funds and green bonds. Consequently, the transition to clean energy is accelerated by deeper and more effective financial systems. Similarly to this, the modernization hypothesis and energy transition theory explain how smart grids, green transportation networks, and energy-efficient infrastructure can encourage the use of renewable energy in well-planned urbanization [13], whereas unplanned urban growth frequently serves to further rely on fossil fuels [14].

Lastly, REC is impacted by population growth through both structural and scale effects. Population growth raises the overall demand for energy, which can be shifted toward renewable sources with the help of suitable income levels, technology, and regulations. Therefore, the influence of the population on REC depends largely on a country's developmental stage and policy orientation.

In light of this, the current study focuses on ten significant emerging economies, which are collectively known as the E-10 countries: South Africa (ZAF), Russia (RUS), Argentina (ARG), Brazil (BRA), China (CHN), Indonesia (IDN), India (IND), Mexico (MEX), Poland (POL), South Africa (ZAF), and Turkey (TUR). The study intends to identify and quantify the key factors driving REC within this group, with an emphasis on how economic, financial, and environmental dynamics interact to shape the renewable energy transition. In order to better understand the structural and policy factors influencing the rate and trajectory of renewable energy adoption in the E-10 economies, this study combines economic and environmental metrics into a single analytical framework.

This research contributes to the literature in several original ways. First, the model includes economic growth (RGDP), carbon dioxide emissions (CO_2), and population (POP) as control variables, and financial development (FD), oil prices (OP), and urbanization (URB) as the primary independent variables. This study is among the first to assess their combined effects within a unified empirical framework because, as far as we are aware, this variable combination has never been jointly analyzed in the context of REC. Furthermore, the model incorporates the lagged value of REC into the dynamic panel specification, which

enhances predictive accuracy and yields more reliable long-term insights by capturing the persistence and path dependence of REC.

Second, unlike many previous studies on emerging economies that employ single-country analyses—such as Han et al. [13], Samour and Pata [15], and Karacan et al. [16]—this paper conducts a comprehensive multi-country assessment focusing on the E-10 countries. The term E-10 countries is used to represent a group of large emerging economies that are simultaneously characterized by rapid industrialization, high energy demand, and growing commitments to clean energy transitions. These countries were selected based on three main criteria: (i) their classification among upper-middle-income or major emerging economies according to the World Bank and IMF, (ii) their substantial contribution to global energy consumption and emissions, and (iii) the availability of consistent long-term data (1990–2021) for all variables considered. This group collectively accounts for a significant share of global renewable energy investment potential and thus provides an ideal framework for examining the drivers of the renewable energy transition in the developing world.

Lastly, by separating short-term adjustments from long-term structural effects, the study's comparative approach—which combines both static and dynamic panel estimations—offers richer policy implications. All things considered, these contributions close a significant gap in the literature by offering fresh empirical data on how demographic, financial, and economic factors interact to influence the use of renewable energy in emerging economies.

The following is a summary of the study's main conclusions: REC is increasingly impacted by economic growth and foreign direct investment in E-10 nations. On the other hand, population growth and increasing OPs have a detrimental effect on REC. The proportion of renewable energy stays low as carbon emissions rise. Furthermore, REC is negatively impacted by the URB rate as well.

The remainder of this paper is organized as follows. The development of renewable energy in the E-10 countries over time is examined in Section 2. Section 3 examines these advancements in light of the corpus of current literature. The dataset and the econometric methodology used are presented in Section 4. The empirical results are presented in Section 5 along with a thorough interpretation of the results. Section 6 brings the study to a close by summarizing the main findings and drawing conclusions about the implications for policy.

2. Renewable Energy Usage in E-10 Countries

The percentages of REC in total energy consumption (TEC) in E-10 nations from 1990 to 2021 are examined in this section. According to the analysis, different countries show different trends, and these trends fall into four different categories:

(i) Declining High-Share Economies (DHSE) are nations that had a high proportion of renewable energy at first but have since seen a decline, frequently as a result of increased reliance on fossil fuels and fast industrialization.

(ii) Persistently Low-Share Economies (PLSE) are nations with a historically low share of renewable energy that have not demonstrated substantial long-term growth, indicating a structural dependence on non-renewable energy sources and a lack of policy support.

(iii) Persistently High-Share Economies (PHSE) are nations that have consistently maintained a high structural share of renewable energy, usually with the help of established renewable energy policies and an abundance of natural resources like hydropower.

(iv) Rising Low-Share Economies (RLSE) are countries that started from low levels but have managed to increase their share of renewable energy over time, largely driven by technological advancement, policy reforms, and international commitments toward

decarbonization. Figure 1 presents the REC rates of countries categorized into these four categories over the period 1990–2021. As can be seen, there are significant differences between countries in terms of both initial levels and long-term trends.

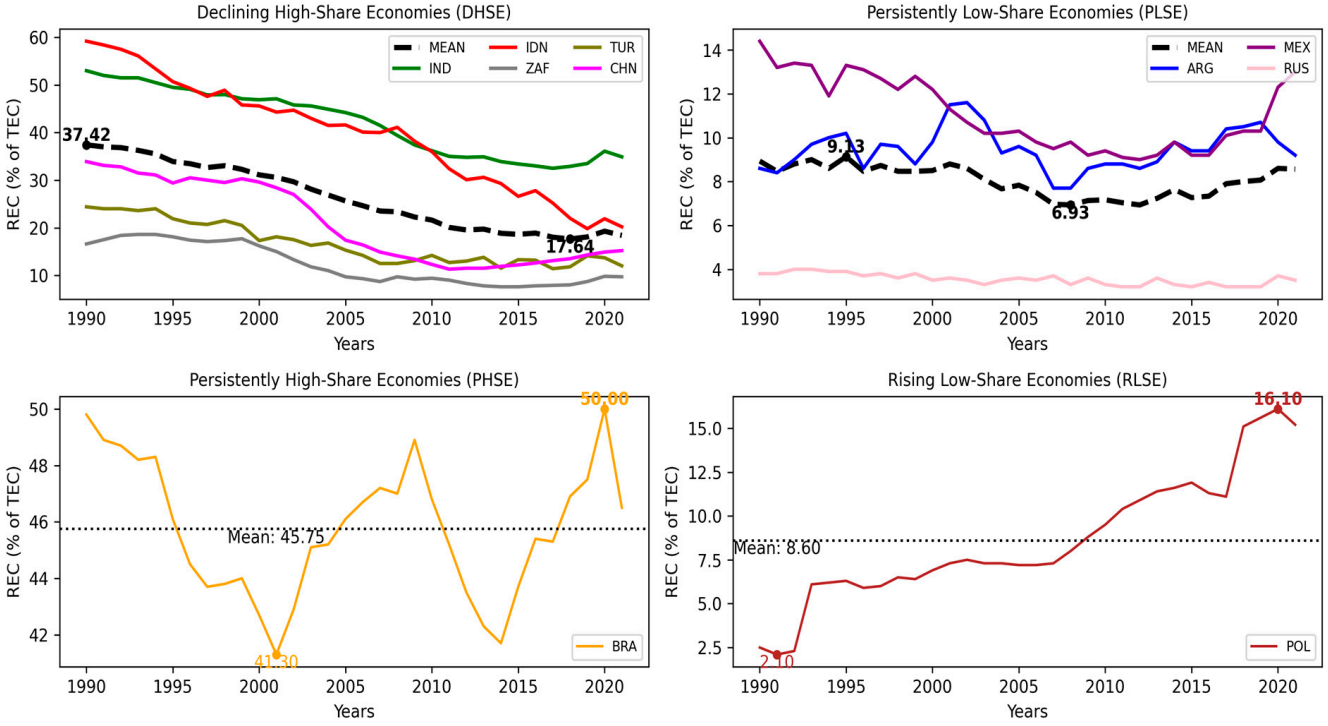


Figure 1. REC to TEC (%). Source: Authors' calculations based on World Bank data ("Renewable energy consumption (% of total final energy consumption)").

To more accurately interpret the trends in Figure 1, Table 1 was prepared. This table presents the compound annual growth rate (CAGR) of TEC and REC for each E-10 country over the period 1990–2021. The TEC CAGR (%) row indicates the growth rate of overall energy consumption, while the REC CAGR (%) row represents the growth rate of renewable energy use. Comparing these two indicators allows for assessing whether the expansion in total energy demand has been accompanied by a proportional increase in renewable energy or whether fossil fuels have continued to dominate the energy mix. Accordingly, Table 1 provides a clearer and more quantitative perspective on the pace of the renewable energy transition across the E-10 countries.

Table 1. CAGR of TEC and REC in E-10 Countries (1990–2021).

	IDN	CHN	IND	TUR	ZAF	MEX	ARG	RUS	BRA	POL
TEC CAGR (%)	3.290	4.890	3.480	2.870	−0.003	−0.160	0.800	−0.130	1.560	−0.200
REC CAGR (%)	−2.370	1.390	1.030	0.050	−1.970	−0.540	1.040	−0.410	1.120	6.260

Source: World Bank Database, Note: TEC CAGR: the compound annual growth rate of total energy consumption [kg of oil equivalent per capita], and REC CAGR: the compound annual growth rate of renewable energy consumption [kg of oil equivalent per capita].

An examination of the DHSE group reveals that it comprises five countries, namely Indonesia, China, India, Türkiye, and South Africa. During the analysis period, the share of renewable energy in these countries averaged around 37%, but by 2021, it had declined by more than half, falling to approximately 18%. Indonesia experienced the largest decrease within the group. While Indonesia had a remarkably high renewable energy share of 59% in 1990, this ratio dropped to around 20% by 2021. The decline of Indonesia, which initially had the highest share among the countries in the analysis, can be explained by a

3.29% growth in TEC and a 2.37% contraction in REC (Table 1). As seen in the graph, the country's nearly 15% decline between 1990 and 2000 was followed by a 25% decrease after 2000. Indonesia's energy policies based on coal reserves [17], fossil fuel subsidies, and the high costs of renewable energy technologies can be considered among the main reasons for this decline.

China, the second-largest economy in the world [18], began the analysis period with a renewable energy share of 33%, but by 2021, this share had fallen to 15%. Among the E-10 countries, China has the fastest-growing TEC (4.89% CAGR). REC has grown by an average of 1.39% annually (Table 1). This suggests that even as renewable energy increases in absolute terms, its share is declining due to the faster growth of total energy demand. Rapid industrialization and URB in China are driving fossil fuel-based growth [19]. Meanwhile, India, one of the rising powers in the global economy [20], reduced its renewable energy share from 53% in 1990 to 35% in 2020. Among the countries under analysis, India experienced the highest energy demand growth (3.48% CAGR) after China (Table 1). Although REC increased by an average of 1.03% annually, its share has decreased due to the much faster growth of total demand.

Türkiye is among the countries in the analysis that exhibited high energy demand growth (2.87% CAGR). However, REC grew by only 0.05%, which is quite insufficient compared to the increase in total energy demand (Table 1). This indicates that while TEC was rising, insufficient resources were allocated to renewable energy. For many years, Türkiye's energy policy has been dominated by investments in natural gas and coal, whereas the transition to renewable energy has only accelerated in recent years [21]. In South Africa, the only country from Africa included in the analysis, the share of renewable energy declined from 16.6% at the beginning of the period to 9.7% in 2020. In this country, both TEC and REC have decreased at a −1.97% CAGR (Table 1). Thus, it became the only country among the DHSE group where both total and renewable consumption contracted. In terms of the decline in the REC, South Africa ranks second after Indonesia. It can be stated that the country's very high dependence on coal for electricity generation and the limitations of renewable energy investments due to financing and infrastructure constraints are the main reasons behind this decline [22]. Mexico, Argentina, and Russia are classified as PLSE, as their REC has historically remained at low levels and exhibited only limited fluctuations in the long run. Throughout the analysis period, the REC ratio of these three countries averaged between 7% and 9%. This indicates that the share of renewable energy in these countries has remained structurally low (Figure 1). Mexico had a renewable energy share of around 14% in 1990, which declined to 9% by 2012. However, in the following eight years, it showed a recovery trend and rose to 13% by 2020. According to Table 1, while Mexico's TEC slightly declined, its REC also recorded negative growth. This reflects the continued dominant role of fossil fuels in the country's energy supply. For many years, Mexico's energy policies relied on fossil fuel subsidies, whereas reforms toward renewable energy gained momentum only after 2010 [23]. Argentina started with a renewable energy share of 8.6% in 1990, reached its highest level of 11.6% in 2002, and fell to its lowest level of 7.7% in 2007. At the end of the analysis period, the renewable energy ratio rose to 9.2%. According to the data in Table 1, Argentina is the only country, excluding Poland, where the growth of REC exceeded that of TEC. This suggests that although the country continues to depend on fossil fuels, it has achieved some limited progress in renewable energy capacity. Particularly, Argentina's advances in wind energy have contributed to the increase in its renewable energy share [24]; however, investment uncertainties and macroeconomic fluctuations have constrained this progress [25]. Russia holds the lowest renewable energy share among the E-10 countries. Throughout the analysis period, its renewable energy ratio remained within the 3–4% band without showing any

significant increase. One of the main reasons for this is that Russia is among the world's richest countries in terms of oil, natural gas, and coal reserves. As a result, renewable energy investments have been considered costly alternatives with low strategic priority [26]. According to Table 1, Russia is one of the three E-10 countries where both total and REC contracted simultaneously.

Brazil is the only country classified under the PHSE category within the scope of the analysis. During the analysis period, its renewable energy share averaged 45.75%. While it fell to its lowest level of 41% in 2001, it reached its highest level of about 60% in 2020. Although the ratio fluctuated throughout the period, it never dropped below 40%. With this feature, Brazil stands out as the country with the highest average renewable energy share among the E-10 countries during the analysis period (Figure 1). According to Table 1, both TEC and REC grew. The growth rates being quite close indicate that the share of renewables in the total energy mix has been structurally maintained in the long run. The main reasons behind this include Brazil's hydro-based energy infrastructure and its biofuel policies introduced since the 1970s (particularly the Proálcool program and ethanol production) [27,28]. In addition, the long-standing state support for renewable energy investments has differentiated Brazil in terms of energy transition. Among the countries in the analysis, only Poland is classified in the RLSE category, as it started from a low level but significantly increased its renewable energy share over time. In 1990, the share of renewable energy was only 2.1%, but it consistently rose throughout the analysis period, reaching 15.2% by 2021 (Figure 1). Thus, Poland became the country with the most remarkable increase among the E-10 countries. According to Table 1, while Poland's TEC recorded negative growth during the period (CAGR −0.20%), its REC grew at an annual average rate of 6.26%. This demonstrates that the country's energy transition has been realized mainly through renewable sources. Poland's progress can largely be explained by its obligation to comply with the European Union's energy and climate policies, its commitments to reduce carbon emissions, and the financial incentives provided for renewable energy [29].

3. Literature Review

Research on the socioeconomic elements influencing REC offers a crucial theoretical and empirical foundation for formulating energy policy. In this regard, the literature has looked at how various factors, including population dynamics, economic growth, carbon emissions, oil prices, financial development, urbanization, and population dynamics, affect the use of renewable energy in various nations and eras. Depending on the countries' energy structure, policy priorities, and degree of development, the findings have produced different outcomes. As shown in Table 2, the results have varied according to the energy structure, policy priorities, and degree of development of the countries.

According to the literature, a nation's energy structure, level of development, and environmental policy priorities all affect the direction of the relationship between GDP and REC. The EKC and the income effect are used to explain findings showing that economic growth raises REC, highlighting the fact that income growth promotes investments in green technologies and environmental awareness [15,30–32]. Conversely, some studies have shown a negative relationship in fossil fuel-based economies [8,14,33]. This result is consistent with the view that growth is driven by fossil fuel-based industrialization, while renewable energy investments remain relatively underrepresented. On the other hand, studies that state that the relationship between GDP and REC is statistically insignificant have argued that REC is determined more by energy policies, price mechanisms, and technological factors than by growth itself [34,35].

Table 2. Summary of Literature Review.

	RGDP	CO_2	OP	FD	URB	Country/Region
Sadorsky [10]	+ →					18 Developing
Sadorsky [30]	+	+	−			G-7
Marques and Fuinhas [34]	X	−	X			24 EU
Apergis and Payne [36]	+ ↔	+ ↔	+ ↔			25 OECD
Omri and Nyugen [35]	X	+	−			64 countries
Mukhtarov et al. [31]	+	X	−			Azerbaijan
Padhan et al. [37]	+	+	+ →			OECD
Doğan et al. [11]	+	−	+			72 countries
Karacan et al. [16]	+	X	−			Russia
Shahbaz et al. [8]	−			+		34 Developing
Wang et al. [38]	+ →			−, + →		Chinese pro.
Han et al. [13]	+				+	China
Lei et al. [33]	−			X		China
Mukhtarov et al. [39]	+			+		Türkiye
Rong and Qamruzzaman [40]			+			Top five oil-m
Ben-Salha et al. [41]		X	+			China
Samour and Pata [15]	+ →		− →			Türkiye
Su et al. [42]					+	116 countries
Dilanchiev et al. [14]	−	+			−	BSEC
Elzaki [43]				+ →		Saudi Arabia
Sun et al. [44]				+		103 countries
Wang et al. [45]				+ ↔	+ ↔	China
Athari [46]	−			+		BRICS
Kılıç et al. [47]				+		Türkiye
Mukhtarov [48]	+	+	+			China
Vo et al. [49]	−,+				−,+	Asean 5
Demirtaş et al. [50]				+		UK
Doğan et al. [32]	+ ↔	− ↔		+		RECAI

Note: A positive relationship is indicated by the symbol "+," a negative relationship by the symbol "−," and a statistically insignificant relationship by the symbol "X." Whereas ↔ denotes a bidirectional causal relationship between the variable and renewable energy, → denotes a unidirectional causal relationship between the correlating variable and renewable energy.

One of the most important aspects of the energy transition and environmental sustainability is the connection between carbon dioxide (CO_2) emissions and REC. Research indicating a positive correlation between higher CO_2 emissions and increased use of renewable energy is interpreted in the context of the environmental pressure hypothesis and energy substitution theory, which emphasize that rising emissions accelerate the transition to cleaner energy sources by raising environmental awareness and regulatory pressure [14,37]. Because they internalize the environmental costs of fossil fuels and make renewable technologies more competitive, the gradual elimination of fossil fuel subsidies and the implementation of carbon pricing mechanisms are crucial in this regard. The adoption of renewable energy is hampered by fossil fuel subsidies, technological inertia, and weak environmental institutions, according to studies showing a negative relationship. These studies contend that economies with persistently high emissions are usually locked into carbon-intensive infrastructures [11,32]. Lastly, studies showing a negligible correlation [16,31] indicate that the growth of renewable energy is more dependent on institutional capacity, financial development, and technological innovation than on present emission levels. In general, CO_2 emissions can be seen as a structural and policy-related factor influencing the course of the renewable energy transition across nations, in addition to being an environmental indicator.

However, factors like energy substitution, price pass-through, and investment costs account for the relationship between OP and REC. The findings that rising oil

prices raise demand for renewable energy are assessed using the framework of energy substitution theory, which states that rising oil prices make fossil fuels comparatively more costly, which in turn pushes producers and consumers toward sustainable and alternative energy sources [37,41]. On the other hand, nations that rely on oil income or that use energy subsidies typically see the opposite outcomes [15,35]. Fossil and renewable energy sources complement one another rather than replace one another in these economies.

The mechanisms of capital access, investment costs, and technology financing are the main factors that influence the relationship between FD and REC. The finance–energy channel hypothesis states that healthy financial systems make it easier for businesses and households to invest in renewable technologies by facilitating capital mobilization and lowering liquidity constraints. The capacity of the public and private sectors to fund long-term green projects, particularly those with high initial capital costs, is improved by effective credit allocation and a variety of financial instruments. Simultaneously, the green finance theory emphasizes how crucial environmentally focused financial products—like green bonds, sustainable investment funds, and concessional loans—are to advancing the clean energy transition [8,43,45]. Through these channels, financial development not only expands the infrastructure for renewable energy but also fosters innovation in energy efficiency and carbon mitigation technologies. However, capital flows might still favor traditional energy sectors in economies with weak financial markets or ineffective environmental governance [38]. The lack of focused green investment channels is reflected in these situations, where the relationship between financial development and REC is weak or statistically insignificant [33].

Numerous factors, such as infrastructure capacity, energy demand, and environmental consciousness, influence the relationship between urbanization and REC. The positive effects of urbanization on REC are evaluated using the modernization hypothesis and energy transition theory; the use of renewable energy is encouraged by the development of technological infrastructure, the electrification of transportation, and increased environmental consciousness during urbanization [13,43]. However, unplanned and fast urbanization strengthens fossil fuel-based infrastructure, which accounts for the negative impacts of urbanization on REC [14,49].

Finally, the literature generally describes the relationship between population growth and REC as positive [13]. Theoretically, population growth increases REC through increased energy demand, economies of scale, and infrastructure expansion. Population growth increases energy demand in the residential, transportation, and industrial sectors, while encouraging a shift toward renewable energy in economies with limited fossil resources. However, for this effect to be sustainable, population growth must be supported by increased productivity and technological advancement; otherwise, rapid population growth could increase energy demand and carbon emissions in the short term.

This study is the first to simultaneously examine renewable energy dynamics by incorporating financial development and a lagged REC variable into the model, in addition to the five main sets of variables found in the literature. On the other hand, the existing literature has largely focused on global panels, OECD country groups, or individual country samples such as China, Russia, and Türkiye. No studies have been found that consider emerging economies as a separate group. In this context, our study addresses this limitation in the literature by holistically analyzing the economic and structural factors that determine REC in developing countries and offers a new and intensifying contribution to the findings on the energy transition process.

4. Model, Development of Hypotheses and Data

4.1. Econometric Model and Development of Hypotheses

Mukhtarov et al. [31] derived the renewable energy equation using the Cobb–Douglas production function and under the cost function constraint. To this derived equation, researchers can add variables they believe may be related to the dependent variables [51]. Based on this method, Mukhtarov et al. [31] and Karacan et al. [16] used the following equation for REC. They added CO_2 and OPs as variables impacting the income variable that accounts for renewable energy. This equation will serve as a benchmark in our study. This equation does not consider several important variables, the first of which is the level of FD.

$$REC_{it} = \alpha_0 + \alpha_1 OP_{it} + \alpha_2 RGDP_{it} + \alpha_3 CO_{2it} + u_{it} \quad (1)$$

FD is thought to affect REC in several ways. First, the expansion of financial markets increases household credit availability and encourages the purchase of durable goods, which in turn boosts demand for renewable energy. Second, firms can finance their operations more easily thanks to improved financial intermediation, which promotes investment and raises energy demand. Third, wealth effects brought about by heightened stock market activity encourage general economic activity, which raises energy consumption [52–55]. Together, these channels provide strong theoretical support for expecting FD and REC to have a positive correlation.

When talking about REC, the population is another consideration. There are three ways to think about the relationship between population and renewable energy. The first is the scale effect, which asserts that the overall amount of energy needed rises in direct proportion to population growth. This increase in demand may encourage more use of renewable energy if it is backed by suitable policy frameworks. Furthermore, URB and population growth are closely related, which could further encourage the use of renewable energy under favorable policy conditions. The second mechanism is the indirect effect, which raises aggregate income as a result of population growth. As rising income levels translate into higher per capita income, the demand for renewable energy is likewise expected to increase [56].

The final variable we will include in the model is URB. As URB rates increase, countries' energy demand and transportation needs also grow. This increased energy demand has been primarily met by fossil fuels, although in the last decade, renewable energy sources have become more prominent. Over time, the shift to electric vehicles for public transportation in some cities increases REC. Secondly, the increase in URB areas, the necessity of district heating and solar energy on new building roofs, and the expansion of electric charging networks in cities will increase renewable energy demand [49,57]. These factors can vary depending on a country's institutional structure, management approach, and funding sources. Therefore, URB can both increase and decrease REC. The last hypothesis of this study is that URB increases REC. Within the framework of the aforementioned hypotheses, the final econometric specification of the model employed in this study can be expressed as follows:

$$REC_{it} = \alpha_0 + \alpha_1 OP_{it} + \alpha_2 RGDP_{it} + \alpha_3 CO_{2it} + \alpha_4 FD_{it} + \alpha_5 POP_{it} + \alpha_6 URB_{it} + u_{it} \quad (2)$$

4.2. Data and Methods

The preceding subsection outlined the development of the model and the underlying hypotheses. The last econometric specification is presented in Equation (2). In this formulation, REC denotes the share of renewable energy in the TEC of the respective country. The OP variable is measured in U.S. dollars per barrel, based on West Texas Intermediate (WTI) crude OPs. GDP captures national income, measured as real gross domestic product

at constant 2015 prices. CO_2 represents per capita carbon dioxide emissions, while FD reflects FD, proxied by the share of total domestic credit allocated to the private sector. POP refers to the total population, and URB measures the degree of URB, expressed as the percentage of the population residing in urban areas. In addition, the variable broad money (BD) is not explicitly presented in the equation, as it serves as an alternative proxy for FD employed in the robustness analysis. The dataset covers the period 1990–2021 for all countries under consideration, and while all variables, except for OPs, were retrieved from the World Bank's World Development Indicators (WDI) database, the OP data were sourced from the Federal Reserve Bank of St. Louis (FRED) database. To ensure comparability and to address potential econometric issues related to scale heterogeneity, the natural logarithm of all variables was employed in the estimation process. Moreover, a summary of the data is provided in Table 3. The logarithmic form of Equation (2) will be estimated as follows.

$$LREC_{it} = \alpha_0 + \alpha_1 LOP_{it} + \alpha_2 LRDPC_{it} + \alpha_3 LCO_{2it} + \alpha_4 LFD_{it} + \alpha_5 LPOP_{it} + \alpha_6 LURB_{it} + u_{it} \quad (3)$$

Table 3. Details of data.

Abbreviation	Variable	Unit	Source
REC	Renewable energy consumption	% of total final energy consumption	World Bank WDI
OP	Oil Price	West Texas Intermediate (WTI) crude oil price ($)	Fed St. Louis FRED
CO_2	Carbon dioxide emissions	t CO_2e/capita	World Bank WDI
GDP	Gross Domestic Product	constant 2015 US$	World Bank WDI
FD	Domestic credit to private sector	% of GDP	World Bank WDI
POP	Population	Total	World Bank WDI
URB	Urban population	% of total population	World Bank WDI
BM	Broad Money	% of GDP	World Bank WDI

Note: All variables were used based on their logarithmic transformations.

Given that the dataset encompasses both time-series and cross-sectional dimensions, panel data techniques were employed in this study. Moreover, considering the relatively long time span and the potential presence of first-order autoregression—AR(1)—, the methodology proposed by Baltagi and Wu [58] was adopted in the classical panel data analyses. This approach ensured that the standard errors derived from both fixed- and random-effects estimations remained unbiased.

In addition, a linear dynamic panel model was estimated to capture potential persistence in LREC. Specifically, the system GMM estimator, which was introduced by Arellano and Bond [59], extended by Arellano and Bover [60], and further developed by Blundell and Bond [61], was employed. This incorporation included the finite-sample correction to standard errors as suggested by Windmeijer [62]. The primary objective of this approach was to assess whether LREC in one period influences consumption in subsequent periods and to examine its interaction with other explanatory variables.

Table 4 displays descriptive statistics for the variables used in the analysis. The LREC variable had a minimum of 0.322 and a maximum of 1.77, with mean and median values of 1.18 and 1.12, respectively. Skewness and kurtosis were determined to be −0.16 and 2.15, respectively, while the standard deviation was 0.36. The values of LOPs range from 1.10 to 2.04, with a mean of 1.60 and a median of 1.63. The near-zero skewness (−0.015) indicates symmetry once more, while the standard deviation of 0.29 indicates moderate variability. In contrast to the typical benchmark, the kurtosis of 1.61 indicates a somewhat flatter distribution. With values ranging from 11.15 (minimum) to 13.20 (maximum), the LRGDP variable reported a mean of 11.89. Skewness and kurtosis were 0.94 and 4.26, respectively, and the standard deviation was 0.94.

Table 4. Descriptive statistics.

	Mean	Median	Max.	Min.	Stn. Dev.	Skewness	Kurtosis	Observations
LREC	11.865	11.239	17.723	0.3222	0.3602	−0.1642	21.597	320
LOP	16.034	16.314	20.476	11.059	0.2910	−0.0151	16.133	320
LRGDP	118.944	118.686	132.001	112.537	0.3892	0.9407	42.697	320
LCO_2	0.5922	0.6038	12.166	−0.1584	0.3308	−0.2096	21.400	320
LFD	15.741	15.600	22.621	0.7008	0.3351	−0.0142	23.382	320
LPOP	81.697	81.303	91.505	75.153	0.5271	0.6957	22.636	320
LURB	17.759	18.045	19.649	14.073	0.1517	−0.9548	28.677	320

The LCO_2 variable showed a median of 0.60 and a mean of 0.59. With a standard deviation of 0.33, the lowest and maximum values were −0.15 and 1.21, respectively. For CO_2, the estimated skewness and kurtosis were −0.16 and 2.15, respectively. A reasonably symmetric distribution around the central tendency is suggested by the LFD variable's mean and median values, which are closely aligned at 1.57 and 1.56, respectively. With a standard deviation of 0.33, the observed range spans from a minimum of 0.70 to a maximum of 2.26. The symmetry is confirmed by the near-zero skewness (−0.014), and a distribution that is marginally flatter than the normal curve is indicated by the kurtosis value of 2.33.

LPOP has a mean of 8.17 and a median of 8.13, with the lowest and highest values recorded at 7.51 and 9.15, respectively. The standard deviation of 0.52 indicates moderate dispersion, while the positive skewness (0.59) suggests that larger populations in some countries pull the distribution to the right. The kurtosis value of 2.26 indicates a distribution somewhat flatter than normal. Finally, the LURB variable records a mean of 1.77 and a median of 1.80, with values ranging between 1.40 and 1.96. The standard deviation of 0.15 reflects relatively low variability, while the skewness of −0.95 indicates a pronounced leftward asymmetry, implying that most countries have relatively high levels of LURB. The kurtosis of 2.86 suggests a distribution moderately close to normality but with slightly lighter tails.

To assess linear association and potential collinearity among regressors, we first report the pairwise correlation matrix (Table 5) and Variance Inflation Factor (VIF) diagnostics. Correlations remain well below the usual red-flag threshold ($|\rho| < 0.90$), and the mean VIF ≈ 1.45 after excluding the population level when used jointly with urbanization, indicating no serious multicollinearity problem in the baseline specification. These diagnostics support the inclusion of the full covariate set in subsequent estimations.

Table 5. Correlation matrix.

	LREC	LOP	LRGDP	LCO_2	LFD	LPOP	LURB
LREC	1						
LOP	−0.1387	1					
LRGDP	0.1485	0.338	1				
LCO_2	−0.8866	0.1814	−0.0587	1			
LFD	0.1774	0.2791	0.3872	0.1237	1		
LPOP	0.4965	0.056	0.7522	−0.4699	0.3588	1	
LURB	−0.5233	0.181	−0.1112	0.5087	−0.268	−0.6917	1

VIFs were computed to detect potential multicollinearity among the explanatory variables. The first specification, including all regressors (Table 6), revealed very high VIF values (Mean VIF ≈ 9.21), primarily due to the simultaneous inclusion of LPOP and LURB, which are strongly correlated measures of demographic size and concentration.

After removing LPOP, the revised specification reduced the average VIF to 1.45, well below the commonly accepted threshold of 10 [63,64]. Hence, the final estimations rely on this adjusted model structure to ensure parameter stability and avoid collinearity-induced bias.

Table 6. Variance inflation factors.

Variable	All Variables Included	Excluding LPOP	Excluding LURB
LOP	1.35	1.27	1.33
LRGDP	14.71	1.3	3.69
LCO_2	2.04	1.53	1.91
LFD	1.51	1.48	1.38
LURB	9.33	1.68	—
LPOP	26.33	—	4.73
Mean VIF	9.21	1.45	2.61

Notes: Where population and urbanization are jointly included, the VIF increase is mechanical, given their conceptual proximity. The preferred baseline excludes the population when urbanization is present; results are robust to alternative selections.

We next examine whether shocks are correlated across E-10 economies in Table 7. Using the Pesaran CD family tests (CD, CD *, and related variants) and the power-enhanced statistics of Juodis and Reese [65], the null of weak/no cross-section dependence is rejected for most variables (p-values < 0.01), implying strong cross-sectional linkages (e.g., common shocks, global factors, regional spillovers) [65,66]. This evidence motivates (i) the use of second-generation unit root tests that are robust to CSD and (ii) inference procedures robust to general forms of cross-sectional correlation in the static panels.

Table 7. Cross-sectional dependence tests.

Variable	CD	*p*-Value	CDw	*p*-Value	CDw+	*p*-Value	CD *	*p*-Value	Decision
LREC	10.94	0.00	−3.13	0.002	138.14	0.00	3.36	0.001	Dependence
LOP	37.95	0.00	−4.22	0.00	250.34	0.00	—	—	Dependence
LRGDP	35.44	0.00	−2.40	0.017	235.33	0.00	−1.01	0.314	Dependence
LCO_2	11.87	0.00	1.32	0.185	155.03	0.00	1.21	0.226	Dependence
LFD	12.08	0.00	−1.63	0.104	112.06	0.00	0.38	0.707	Dependence
LURB	22.64	0.00	−2.45	0.014	233.55	0.00	−1.52	0.128	Dependence
LPOP	14.27	0.00	1.25	0.21	226.98	0.00	4.05	0.00	Dependence

Note: CD: Pesaran [66,67], CDw: Juodis and Reese [65], CDw+: CDw with power enhancement from Fan et al. [68], CD *: Pesaran et al. [69] with 4 PC(s).

Given the presence of CSD, we rely on second-generation procedures. Specifically, we report (i) the cross-sectionally augmented LM (CA-LM) panel test that accommodates endogenous structural breaks [70,71], and (ii) the Hadri–Kurozumi ZA_spac stationarity test, whose spatial correction directly addresses cross-sectional correlation [72]. CA-LM and ZA_spac consistently indicate that LREC, income (LRGDP), LCO_2, LFD are stationary in levels. By contrast, LURB and LPOP are non-stationary in levels but stationary after first differencing (I(1)), a result we document by reporting ΔLURB and ΔLPOP beneath their level tests. LOPs are a common global factor across units; hence, panel tests are not applicable, and a standard time-series augmented Dickey-Fuller on the global series shows stationarity in levels (Table 8).

Table 8. Panel unit root tests.

Variable	Panel CA-LM Stat	*p*-Value	ZA-Spac Stat	*p*-Value	Stationarity Conclusion
LREC	−3.870	0.000	−1.2336	0.8913	I(0)
LOP	—	—	—	—	I(0) *(ADF, Z(t) = −5.193, p < 0.01)*
LRGDP	−3.764	0.000	−0.6284	0.7351	I(0)
LCO_2	−2.699	0.003	−0.0780	0.5311	I(0)
LFD	−4.532	0.000	−0.4598	0.6772	I(0)
LPOP	−2.058	0.020	33.8726	0.000	-
ΔLPOP	-	-	−0.0967	0.5385	I(1)
LURB	−2.790	0.003	245.907	0.000	-
ΔLURB	-	-	0.2025	0.4198	I(1)

Since the results of the panel unit root tests, the Panel LM [70] and Hadri–Kurozumi [72] confirmed that most variables are stationary in levels, the analysis begins with a static panel specification. The Fixed-Effects (FE) estimator was chosen over the Random-Effects (RE) model according to the Hausman test, which indicated a systematic correlation between the unobserved individual effects and the regressors. The FE estimator effectively accounts for unobserved, country-specific heterogeneity such as structural, institutional, or geographical characteristics that remain constant over time, thereby minimizing omitted-variable bias [73]. Moreover, diagnostic tests revealed the existence of heteroskedasticity, serial correlation, and cross-sectional dependence across panels. To obtain robust inference under these conditions, the study employed Driscoll and Kraay [74] standard errors, which are heteroskedasticity and autocorrelation-consistent (HAC) and remain valid even in the presence of moderate cross-sectional dependence [75]. This estimator is particularly suited for macro panels characterized by a small cross-section (N) and relatively long-time dimension (T), as in the present study. Accordingly, the FE–Driscoll–Kraay model provides consistent and efficient short-run estimates of the determinants of REC across the examined economies.

The System Generalized Method of Moments (System GMM), created by Arellano and Bover [60] and Blundell and Bond [61], was then used to estimate a dynamic panel model in order to supplement the static analysis and handle any endogeneity concerns. To capture the persistence and adjustment dynamics of LREC, the dynamic specification includes the lagged dependent variable. Nevertheless, dynamic panel bias is introduced when a lagged dependent variable is included in a fixed-effects framework [76], making OLS and within estimators inconsistent. By utilizing internal tools derived from the lag structure of endogenous variables, System GMM rectifies this bias by combining moment conditions in both first differences and levels. Since System GMM only requires mean reversion and does not require strict stationarity, it is still appropriate and statistically valid given that the explanatory variables are primarily I(0) and show mild persistence (with LURB being slightly I(1)).

5. Results

5.1. Econometric Results for Main Models

The dataset employed in this study covers ten countries over a 32-year period, forming a balanced panel that integrates both cross-sectional and time-series dimensions. To mitigate potential serial correlation, first-order autoregressive dynamics were eliminated prior to estimation, and the models were analyzed under both RE and FE frameworks. Following the relevant literature, autoregressive patterns tend to intensify in long-span macro panels [58]. The estimation results for RE and FE specifications using Driscoll–Kraay robust errors are presented in Table 9.

Table 9. Results for RE and FE estimation.

Variables	Model 1		Model 2		Model 3		Model 4		Model 5	
	RE	FE	RE	FE	RE	FE	RE	FE	RE	FE
LOP	−0.0752 (0.0714)	−0.0811 *** (0.0168)	−0.0622 (0.0725)	−0.0690 *** (0.0157)	−0.0756 (0.0657)	−0.0811 *** (0.0212)	−0.0572 (0.0738)	−0.0656 *** (0.0145)	−0.0708 (0.0692)	−0.0785 *** (0.0205)
LRGDP	0.4772 (0.3262)	0.5255 *** (0.1085)	0.3518 (0.2790)	0.6132 *** (0.1333)	0.2994 (0.2399)	0.5524 *** (0.1235)	0.3663 (0.2710)	0.5815 *** (0.1314)	0.3425 (0.2451)	0.5599 *** (0.1217)
LCO_2	−1.3117 *** (0.4474)	−1.3678 *** (0.1238)	−1.1892 *** (0.3475)	−1.4476 *** (0.1452)	−1.2249 *** (0.3164)	−1.4613 *** (0.1265)	−1.1634 *** (0.3403)	−1.3942 *** (0.1388)	−1.2167 *** (0.3265)	−1.442 *** (0.1230)
LFD	—	—	0.0213 (0.0716)	−0.0787 * (0.0433)	0.0418 (0.0668)	−0.0621 (0.0461)	0.0067 (0.0686)	−0.0735 (0.0452)	0.0153 (0.0663)	−0.0690 (0.0444)
ΔLPOP	—	—	—	—	−13.0626 ** (5.3279)	−12.5118 *** (3.1707)	—	—	−13.2216 ** (5.1871)	−12.6137 *** (3.2446)
ΔLURB	—	—	—	—	—	—	6.5567 (4.3321)	3.3733 (5.1150)	7.0336 ** (3.4875)	3.7341 (5.1211)
Constant	0.3068 (0.9713)	0.1694 (0.3215)	0.6467 (0.8421)	−0.0054 (0.3610)	0.9081 (0.7059)	0.2757 (0.3335)	0.5680 (0.8174)	0.0549 (0.3638)	0.7506 (0.7267)	0.2296 (0.3376)
R^2 (Within)	0.5735	0.5741	0.5605	0.5837	0.5794	0.6026	0.5684	0.5864	0.5851	0.6041
Obs./Groups	320/10	320/10	320/10	320/10	310/10	310/10	310/10	310/10	310/10	310/10
Wald χ^2/ F-stat (p)	71.6 (0.000)	536.3 (0.000)	178.5 (0.000)	571.7 (0.000)	778.8 (0.000)	468.6 (0.000)	316.5 (0.000)	602.8 (0.000)	2143.5 (0.000)	751.9 (0.000)

Note: ***, **, * show that the coefficient is significant at 1%, 5% and 10%, respectively. The estimation is done dealing with homoscedasticity and autocorrelation.

In the baseline specification (Model 1), LOPs were found to be statistically insignificant, whereas both LCO_2 emissions and real income exhibited strong statistical significance. A 1% increase in real income led to an approximate 0.53% rise in LREC, while a 1% increase in LCO_2 emissions resulted in a comparable decrease in LREC. The FE estimator confirmed these relationships with slightly larger coefficients and higher precision compared with the RE model.

In Model 2, LFD was introduced as an additional determinant. Similarly to the baseline results, LOPs and LFD remained statistically insignificant in both the RE and FE estimations, while income and LCO_2 continued to exert strong effects on LREC in the expected directions. Although LFD's sign was negative under FE, the effect was small and statistically weak, indicating that the financial sector's contribution to renewable deployment may be limited in the short run within E-10 economies.

Model 3 incorporated the LPOP variable to capture demographic effects. Under the RE specification, population growth significantly enhanced LREC, whereas in the FE estimation, the coefficient became negative and statistically significant. This reversal suggests that, after controlling for country-specific heterogeneity, population growth may exert downward pressure on renewable energy adoption due to infrastructure constraints or energy-demand surges that disproportionately favor fossil fuels.

Model 4 replaced LPOP with LURB to mitigate the multicollinearity arising from their joint inclusion. The results show that LURB is statistically insignificant in both the FE and RE estimations, while income and LCO_2 emissions remained highly significant. This implies that, in the short run, the level of urbanization per se does not directly promote renewable energy expansion once structural effects are absorbed by fixed effects.

Finally, Model 5 combined both population and urbanization to examine their joint influence. In this model, population retained its negative and significant coefficient under both estimators, while LURB remained statistically insignificant. Thus, demographic expansion appears to hinder the renewable transition, whereas urban concentration has no clear short-term effect.

The Hausman specification test was conducted for all five models to determine the appropriate estimator between FE and RE. The test statistics ranged between $\chi^2(4) = 27.48$ ($p = 0.001$) and $\chi^2(5) = 44.11$ ($p = 0.0000$), consistently rejecting the null hypothesis of no systematic difference between the two estimators. These results confirm that the FE estimator provides consistent and efficient estimates across all model specifications, whereas the RE model would yield biased coefficients due to the correlation between the unobserved individual effects and the regressors. The overall findings, therefore, rely on FE estimates, which indicate that oil prices and financial development do not exhibit statistically significant relationships with renewable energy consumption, whereas income and LCO_2 emissions remain robust and significant determinants of LREC across specifications.

To capture potential persistence and address endogeneity among regressors, a dynamic specification was subsequently estimated using the two-step System GMM developed by Arellano and Bover [60] and Blundell and Bond [61]. Motivated by the assumption that LREC in the previous period influences current consumption. This persistence can be attributed to two channels: (i) once households and firms adopt renewable energy, they are more likely to continue its use in subsequent periods, and (ii) past investments in renewable energy infrastructure create momentum for future production and consumption. The results of the dynamic panel estimations are presented in Table 10.

Table 10 displays the estimation outcomes for the five dynamic panel models. With coefficients ranging from 0.61 to 0.80, the results show that the lagged LREC variable is highly statistically significant across all model specifications. This finding demonstrates that past consumption has a significant positive impact on current levels and supports

the strong persistence of renewable energy use. With the exception of Model 1, where significance is noted at the 5% level, the coefficients for the LOP variable are statistically significant at the 1% level in accordance with the static panel estimates. Every coefficient has a negative sign, indicating that rising oil prices discourage the use of renewable energy. This negative relationship likely reflects the structural dependence of E-10 economies on fossil fuel–based energy systems and the inertia associated with transitioning to cleaner energy sources.

Table 10. Results from dynamics GMM estimation.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
LREC (−1)	0.61976 ***	0.79208 ***	0.79905 ***	0.78999 ***	0.77978 ***
	(0.171925)	(0.0767924)	(0.0737449)	(0.0772173)	(0.0791842)
LOP	−0.02326 **	−0.02958 ***	−0.02967 ***	−0.03603 ***	−0.03366 ***
	(0.010753)	(0.010794)	(0.010988)	(0.010961)	(0.011539)
LRGDP	0.0584 **	0.02742 ***	0.02687 ***	0.02826 ***	0.02802 ***
	(0.165771)	(0.010011)	(0.009882)	(0.010037)	(0.01013)
LCO_2	−0.35088 **	−0.18938 **	−0.18518 **	−0.20221 ***	−0.20006 ***
	(0.165771)	(0.075911)	(0.074927)	(0.075857)	(0.07658)
LFD	—	0.04943 **	0.0481 **	0.06092 ***	0.0614 ***
	—	(0.019833)	(0.019377)	(0.019944)	(0.02013)
ΔLPOP	—	—	−0.48544	—	−1.9387 ***
	—	—	(1.010649)	—	(0.733482)
ΔLURB	—	—	—	−2.02182 ***	2.11941
	—	—	—	(0.717984)	(2.953833)

Note: The two-way specification was estimated using the GMM approach. To mitigate the risk of instrument proliferation, the collapse option was employed, and the lag length of the instrumental variables was restricted to ensure robustness. The dynamic models were estimated with between 8 and 10 instruments. For comparison, all models were also estimated under a one-way specification; however, as the results were largely consistent with the two-way estimates, they are not reported here to conserve space. These results are available from the authors upon request. *** and ** shows the coefficient is significant at 1%, and 5%, respectively.

Across the majority of models, the real income (LRGDP) variable continues to have a positive and statistically significant correlation with the use of renewable energy, albeit with a relatively small effect size. Similarly, all models show consistently negative and statistically significant coefficients for LCO_2 emissions, which range from −0.35 to −0.19. This suggests that a decrease in the use of renewable energy is linked to an increase in LCO_2 emissions. These coefficients imply that, in comparison to other explanatory variables, environmental degradation has a greater dampening effect on the use of renewable energy.

LFD, introduced in Model 2, exhibits a positive and statistically significant impact on renewable energy consumption, indicating that an expansion of the financial sector contributes—albeit moderately—to the growth of renewable energy utilization in the E-10 countries. In Model 3, the inclusion of LPOP yields an insignificant coefficient; however, in Model 5, where all variables are incorporated, the population variable becomes highly significant and negative, suggesting that population growth tends to constrain renewable energy consumption. The LURB variable is statistically significant and negative in Model 4, implying that urban growth currently undermines renewable energy use in the E-10 context, possibly due to inadequate urban energy policies or insufficient integration of renewable infrastructure in urban planning. When both LURB and LPOP are included in Model 5, the LURB variable loses significance—a likely consequence of multicollinearity between the two variables, as confirmed by the VIF analysis.

Table 11 displays the dynamic model's diagnostic results. The Arellano-Bond tests, which determine whether serial correlation exists, are represented by the AR(1) and AR(2)

statistics. AR(2) shouldn't exhibit significance, but AR(1) usually should. While AR(2) consistently produces *p*-values well above 0.05 across the five specifications, the AR(1) statistic in the current analysis is significant at the 10% level for all models but the first. These results imply that the models do not contain second-order autocorrelation. The Sargan chi-square tests evaluate the validity of the instruments, with nine instruments employed in some models and ten in others. Both the Sargan and Hansen test results support instrument validity, as their associated probabilities are comfortably above the 0.05 threshold. Finally, the Hansen difference-in-Hansen tests, which examine the exogeneity of instrument subsets, indicate that the instruments are exogenous and thus consistent with the theoretical framework of the models. Additionally, the Pesaran–Yamagata [77] (HAC-adjusted Δ) test results indicate that the null hypothesis of slope homogeneity cannot be rejected ($p > 0.05$) across all model specifications. This implies that the estimated coefficients are statistically similar across countries once dynamic effects are included, confirming that the System GMM estimations capture average relationships representative of the overall panel.

Table 11. Diagnostic tests for panel dynamic GMM.

Statistic/Test	Model 1	Model 2	Model 3	Model 4	Model 5
AR(1) z (*p*)	−2.44 (0.015)	−4.49 (0)	−4.56 (0)	−4.45 (0)	−4.38 (0)
AR(2) z (*p*)	−0.79 (0.428)	−1.22 (0.223)	−1.23 (0.218)	−1.19 (0.218)	−1.19 (0.234)
Sargan χ^2 (*p*)	1.29 (0.863)	1.13 (0.889)	1.26 (0.869)	1.2 (0.878)	0.66 (0.882)
Hansen χ^2 (*p*)	0.81 (0.847)	0.95 (0.813)	1.2 (0.753)	1.15 (0.765)	0.52 (0.711)
Diff-in-Hansen χ^2 (*p*)	0.48 (0.489)	1.13 (0.889)	0.00 (0.998)	0.05 (0.826)	0.14 (0.711)
Δ (HAC) (*p*)	1.583 (0.113)	0.996 (0.319)	0.573 (0.567)	0.066 (0.947)	−0.273 (0.785)
Adj. Δ (HAC) (*p*)	1.762 (0.078)	1.132 (0.258)	0.665 (0.506)	0.077 (0.938)	−0.324 (0.746)

Note: AR(1) denotes the Arellano–Bond test for first-order serial correlation, while AR(2) refers to the corresponding test for second-order serial correlation. The Sargan χ^2 statistic evaluates the validity of the overidentifying restrictions, and the Hansen χ^2 statistic tests the overall validity of the instruments and provides a heteroskedasticity-robust alternative to the Sargan test. The Difference-in-Hansen χ^2 test examines the exogeneity of instrument subsets. The HAC-adjusted Δ (Pesaran–Yamagata) test assesses the null hypothesis of slope homogeneity against the alternative of heterogeneous slope coefficients across cross-sectional units.

In summary, the dynamic panel estimations confirm the persistence of LREC, as past usage exerts a strong and positive effect on current levels. This inertia indicates that renewable adoption in the E-10 countries follows a path-dependent process shaped by prior investments and institutional learning. The negative impact of rising LOPs on renewable energy adoption, consistent with previous studies [15,31,39,41,48,78], can be explained by the fact that many E-10 economies are net oil importers that maintain fossil-fuel subsidies to stabilize domestic prices. These policy distortions weaken market incentives to invest in renewables—a mechanism also emphasized by [31,41]. Conversely, in high-income or diversified economies, rising LOPs tend to accelerate renewable investment, suggesting that structural and policy heterogeneity may underline the observed regional differences. Real income consistently promotes LREC across specifications, corroborating the growth–energy nexus established in [30,36]. This finding implies that higher income levels not only raise energy demand but also enhance fiscal and technological capacity for renewable deployment. LFD also emerges as a significant driver, reinforcing evidence from [11,35], who emphasize that deeper financial systems reduce financing constraints and mobilize capital toward clean-energy projects. In contrast, carbon dioxide emissions and population growth exert negative effects on LREC, consistent with the environmental degradation hypothesis and earlier findings [39,79,80]. This pattern suggests that rapid population expansion and emissions-intensive development place additional pressure on energy infrastructure, delaying the transition toward sustainable sources. Finally, LURB negatively influences LREC, supporting the conclusions of [14,49]. The negative LURB–LREC link indicates that politicians should revise urban centers, infrastructure

modernization, and sustainable-city policies, which may lead to turning LURB effects from negative to positive. Taken together, these results highlight the interplay between income, finance, urban structure, and fossil-fuel dependence in shaping the renewable energy transition in the E-10 region. Cross-country heterogeneity exemplified by Brazil's hydro- and biofuel-based system and Poland's rapid post-accession progress illustrates how different policy regimes and resource endowments modulate these relationships.

5.2. Econometric Results for Sub-Group Estimations

Firstly, dynamic model estimation was performed for the DSHE group of countries, which includes five countries. The results of the dynamic panel estimation for Models 1 through 5 are presented in Table 12. Across all specifications, the coefficient of the lagged renewable energy consumption variable is positive and statistically significant at the 1% level, ranging between 0.63 and 0.87. This finding indicates a strong persistence in renewable energy consumption, implying that past consumption patterns exert a substantial influence on current levels. The high magnitude of these coefficients reflects the sluggish adjustment process in renewable energy demand and suggests that renewable energy consumption exhibits a high degree of inertia over time.

Table 12. Results from Dynamics GMM estimation for DHSE countries.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
LREC (−1)	0.8658 ***	0.8384 ***	0.7798 ***	0.8076 ***	0.6290 ***
	(0.0748)	(0.0618)	(0.073)	(0.0842)	(0.188)
LOP	−0.0229 **	−0.0343 ***	−0.0404 ***	−0.0376 ***	−0.0508 ***
	(0.011)	(0.0123)	(0.0135)	(0.0129)	(0.0194)
LRGDP	0.0215 *	0.0221 ***	0.0278 ***	0.0262 **	0.0456 **
	(0.0119)	(0.0085)	(0.0095)	(0.0113)	(0.0219)
LCO_2	−0.1167 *	−0.1484 **	−0.1861 **	−0.1742 **	−0.2906 **
	(0.0687)	(0.0592)	(0.0661)	(0.0736)	(0.136)
LFD		0.0385 **	0.0490 **	0.0417 ***	0.0550 ***
		(0.0152)	(0.0174)	(0.0139)	(0.0204)
ΔLPOP		—	3.5781 **	—	6.2303
		—	(1.6854)	—	(5.5295)
ΔLURB		—	—	0.5927	4.3081
		—	—	(1.3446)	(3.6713)

Note: The two-way specification was estimated using the GMM approach. To mitigate the risk of instrument proliferation, the collapse option was employed, and the lag length of the instrumental variables was restricted to ensure robustness. The dynamic models were estimated with between 8 and 10 instruments. For comparison, all models were also estimated under a one-way specification; however, as the results were largely consistent with the two-way estimates, they are not reported here to conserve space. These results are available from the authors upon request. ***, **, * shows the coefficient is significant at 1%, 5% and 10%, respectively. The diagnostic test results are presented in Appendix A, Table A1.

In all models, the coefficient of LOPs is negative and statistically significant, indicating that the use of renewable energy decreases as oil prices rise. In economies with inflexible energy structures or inadequate renewable infrastructure, higher oil prices may reduce overall energy demand, including that from renewables. This inverse relationship may be a reflection of the substitution effect between fossil fuels and renewable energy sources.

Across all model specifications, the consumption of renewable energy is positively and significantly impacted by economic growth. The coefficient's magnitude ranges from 0.021 to 0.046, suggesting that higher real GDP levels are linked to higher use of renewable energy. The findings lend credence to the idea that economic growth encourages investment in renewable technologies by raising incomes, financial resources, and energy consumption.

In every model, LCO_2 has a negative and statistically significant coefficient, suggesting that lower use of renewable energy is linked to higher emissions. This finding might suggest that economies with higher emission intensities are more dependent on fossil fuels, which limits the growth of renewable energy sources. When more control variables are added, the coefficient's magnitude increases in extended specifications (up to −0.29), indicating a stronger negative relationship.

Every model in which LFD is included shows a positive and statistically significant effect (Models 2–5). This finding indicates that deeper financial systems contribute to the expansion of renewable energy consumption, likely by facilitating access to credit, enhancing investment capacity, and lowering financing costs for renewable projects.

Among the demographic factors, LPOP and LURB yield mixed results. LPOP is positively associated with renewable energy consumption in the models where it appears, with statistical significance in Model 3 and a relatively large coefficient in Model 5, suggesting that larger populations drive higher energy demand, including renewables. LURB, although positive, is statistically insignificant, implying that urban expansion alone does not necessarily lead to greater renewable energy use, possibly due to structural or policy-related constraints in urban energy systems.

Overall, the dynamic panel results confirm that renewable energy consumption exhibits strong persistence and is positively influenced by economic growth and financial development, while it is negatively affected by LOPs and LCO_2 emissions. These findings highlight the importance of economic and financial factors in shaping the trajectory of renewable energy adoption.

An eight-country model, which excluded Brazil and Poland from the sample, was estimated as a second subgroup. Table 13 presents the estimation results for this subgroup, which includes the DHSE and PLSE countries. The highly significant and positive coefficients of the lagged dependent variable, which range from 0.77 to 0.88 across all specifications, show a clear persistence in renewable energy consumption in the dynamic panel estimation results reported in Table 13. This result emphasizes the path-dependent character of renewable energy use by indicating that past consumption has a significant impact on current levels.

LOPs continuously have a negative and statistically significant impact, suggesting that rising oil prices tend to reduce the use of renewable energy, perhaps as a result of temporary substitution or financial limitations in the energy mix. On the other hand, consumption of renewable energy is positively and significantly correlated with real economic growth (LRGDP) across all models, indicating that rising income levels and economic expansion encourage the use of renewable energy.

In every specification, the coefficient of LCO_2 is negative and significant, indicating that economies with higher emission intensities continue to rely more heavily on fossil fuels, thereby impeding the growth of renewable energy. The extended models show that LFD has a positive impact on renewable energy consumption, suggesting that deeper financial systems make it easier to invest in and finance renewable projects.

To sum up, the dynamic GMM results consistently indicate strong persistence in renewable energy consumption, with the lagged dependent variable (LREC (−1)) remaining positive and highly significant across all models LOPs exert a negative and significant effect, suggesting that higher fossil fuel prices reduce renewable energy demand, while real GDP (LRGDP) positively influences renewable energy use, supporting the growth–energy nexus. LCO_2 is negatively associated with renewable energy consumption, reflecting continued reliance on fossil fuels. LFD positively and significantly affects renewable energy consumption in the extended models, underscoring the role of financial systems in supporting clean energy investment. Demographic variables show mixed outcomes:

LPOP tends to promote renewable energy demand, whereas LURB often has a negative or insignificant effect, especially in sub-country-group estimations.

Table 13. Results from Dynamics GMM estimation DSHE and PLSE countries.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
LREC (−1)	0.8634 ***	0.8659 ***	0.7845 ***	0.8823 ***	0.7690 ***
	(0.0499)	(0.0494)	(0.0555)	(0.0501)	(0.1089)
LOP	−0.0433 ***	−0.0436 ***	−0.0547 ***	−0.0457 ***	−0.0581 ***
	(0.0139)	(0.0139)	(0.0146)	(0.0139)	(0.0175)
LRGDP	0.0240 ***	0.0225 ***	0.0314 ***	0.0204 **	0.0327 **
	(0.0086)	(0.0085)	(0.009)	(0.0085)	(0.0137)
LCO_2	−0.0857 **	−0.0903 ***	−0.1341 ***	−0.0858 **	−0.1433 **
	(0.0337)	(0.0345)	(0.0376)	(0.0346)	(0.0587)
LFD	—	0.0103	0.0175 *	0.0176 *	0.0228 *
	—	(0.0087)	(0.009)	(0.0093)	(0.013)
ΔLPOP	—	—	5.4969 ***	—	7.4362
	—	—	(1.269)	—	(5.3416)
ΔLURB	—	—	—	−1.4393 **	−0.6199
	—	—	—	(0.6347)	(2.2567)

Note: The two-way specification was estimated using the GMM approach. To mitigate the risk of instrument proliferation, the collapse option was employed, and the lag length of the instrumental variables was restricted to ensure robustness. The dynamic models were estimated with between 8 and 10 instruments. For comparison, all models were also estimated under a one-way specification; however, as the results were largely consistent with the two-way estimates, they are not reported here to conserve space. These results are available from the authors upon request. ***, **, * shows the coefficient is significant at 1%, 5% and 10%, respectively. The diagnostic test results are presented in Appendix A, Table A2.

5.3. Robustness for Financial Developments

As a final analysis, the main model was re-estimated using a different financial variable. In this model, our variable is the ratio of broad money supply to GDP. The estimation results using financial development defined in this way are reported in Table 14.

The dynamic GMM estimation results presented in Table 14 reveal a strong degree of persistence in renewable energy consumption, as the lagged dependent variable (LREC (−1)) is positive and highly significant across all models, with coefficients ranging from 0.62 to 0.81. This highlights the path-dependent nature of renewable energy and shows that past consumption has a significant impact on current levels. Higher oil prices tend to lower the use of renewable energy, perhaps as a result of short-term substitution or demand contraction effects, according to the coefficient of LOPs, which is consistently negative and significant.

All models show a positive and significant impact from real LRGDP, confirming that economic growth encourages the development of renewable energy through increased energy demand and investment capacity. On the other hand, LCO_2 emissions show a consistently negative and significant relationship, indicating that economies with higher emission intensities are more dependent on fossil fuels, which impedes the growth of renewable energy. The consumption of renewable energy is positively and significantly impacted by LFD, underscoring the function of financial systems in promoting the adoption and financing of renewable energy.

LURB has a negative effect in Model 4 and a positive but weakly significant one in Model 5, while population growth is insignificant in most specifications but becomes negative and significant in Model 5. Overall, the results emphasize the persistence of renewable energy use and identify economic growth and financial development as key

drivers of the renewable energy transition, while fossil fuel dependence and emissions remain major barriers.

Table 14. Results for robustness.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
LREC (−1)	0.61976 *** (0.171925)	0.79866 *** (0.0872428)	0.77736 *** (0.0918318)	0.81066 *** (0.0873346)	0.71562 *** (0.109726)
LOP	−0.02326 ** (0.010753)	−0.03407 *** (0.012618)	−0.03515 *** (0.01284)	−0.04264 *** (0.012848)	−0.04825 *** (0.014708)
LRGDP	0.0584 ** (0.165771)	0.0225 ** (0.009956)	0.02355 ** (0.010157)	0.02064 ** (0.009982)	0.02309 ** (0.011272)
LCO_2	−0.35088 ** (0.165771)	−0.17064 ** (0.081084)	−0.1825 ** (0.083415)	−0.17009 ** (0.081033)	−0.21414 ** (0.093759)
LFD	— —	0.03219 ** (0.013593)	0.03626 ** (0.014509)	0.04035 *** (0.013782)	0.06281 *** (0.019373)
LPOP	— —	— —	1.39081 (1.03248)	— —	−3.42057 *** (0.896754)
LURB	— —	— —	— —	−2.69104 *** (0.724344)	8.29878 * (4.310331)

Note: The GMM method was used to estimate the two-way specification. The lag length of the instrumental variables was limited to ensure robustness, and the collapse option was used to reduce the risk of instrument proliferation. Eight to ten instruments were used to estimate the dynamic models. To save space, all models were also estimated under a one-way specification for comparison; however, since the results were mainly in agreement with the two-way estimates, they are not presented here. The authors can provide these results upon request. The coefficient is significant at 1%, 5%, and 10%, respectively, as indicated by the symbols ***, **, and *. The diagnostic test results are presented in Appendix A, Table A3.

6. Conclusions and Policy Recommendations

As policymakers recognize the environmental costs of using fossil fuels and the pressing need to slow down environmental degradation, renewable energy has grown in importance. The proportion of renewable energy in the overall energy mix is still below ideal levels, despite a plethora of policies and programs aimed at encouraging investments in renewable energy. Even though previous research offers insightful information, the scope and conclusions of these studies frequently vary, underscoring the lack of agreement in the literature. The importance of regional or multi-country studies to inform more effective policy interventions is highlighted by the fact that, while informative, country-specific analyses may not adequately capture the broader dynamics. In this regard, the current study looks at the factors that determine LREC in E-10.

Empirical findings suggest that static panel models alone may not be sufficient to produce significant policy implications. For instance, although LOPs appear to be negligible in the static models, dynamic analyses reveal a negative relationship with LREC. Since government actions like fuel price subsidies can distort market signals, the fact that many E-10 countries import oil may be the reason for this outcome. Thus, reducing or restructuring these subsidies could promote the use of renewable energy. The negative effects of population growth also suggest that policies aimed at reducing demographic pressures, such as reducing immigration or slowing population growth, may unintentionally promote the use of renewable energy. There are drawbacks to population growth as well, suggesting that policies aimed at reducing demographic pressures—such as reducing immigration or slowing population growth—may unintentionally promote the use of renewable energy. Carbon dioxide emissions and LREC are negatively correlated in both static and dynamic

models, highlighting the importance of emissions reduction strategies as a catalyst for the expansion of renewable energy.

One of the most crucial factors is real income, which consistently improves LREC. The demand for renewable energy can be increased by policies that support consistent economic growth and income gains because they increase household affordability and government financial capacity for clean energy investments. LFD is also important. Some ways to encourage investments in renewable energy include strengthening financial institutions, increasing credit availability, and putting more money into the private sector. LURB also appears as a significant LREC driver in the E-10 countries. Initiatives to support sustainable energy transitions in the E-10 countries may be jeopardized by the continued growth of urban areas unless the negative relationship between urbanization and the use of renewable energy is effectively addressed. In order to tackle this, urban transformation processes should include comprehensive policy frameworks that include the development of energy-efficient infrastructure, incentives for green housing, and the adoption of resilient and intelligent urban technologies. Strengthening these regulations would not only mitigate the negative impacts of urbanization on the use of renewable energy but also transform urban growth into a catalyst for long-term energy sustainability. By concentrating people and energy demand, urban areas may also provide economies of scale that facilitate investments in renewable energy systems. Thus, when paired with supportive policy frameworks, the evidence indicates that LURB can hasten the transition to renewable energy in developing economies.

All things considered, the results show how important it is for the E-10 nations to have a varied policy framework to hasten the transition to renewable energy. Policymakers should take into account the intricate interactions between LOP dynamics, demographic shifts, environmental regulations, income growth, and the development of the financial sector to expedite this process. Since there is a great chance to match sustainable energy goals with the fast growth of cities, special attention should be paid to integrating green technologies into the larger LURB process. E-10 nations can improve long-term energy security and environmental sustainability while also significantly raising LREC in the short to medium term by carefully incorporating these goals into national and regional policy agendas.

Three practical policy recommendations are highlighted in this study: (i) progressively eliminating fossil fuel subsidies and shifting money to renewable incentives; (ii) bolstering green finance mechanisms to lower investment risks and increase private sector involvement; and (iii) incorporating renewable infrastructure into urban planning to take advantage of population density for energy efficiency.

Future research could broaden this framework by including supply-side and policy-mediated components such as carbon pricing schemes, subsidies for fossil fuels, the possibility of renewable resources, and the application of nuclear, wind, solar, and hydropower technologies. Furthermore, a more detailed cross-country comparison would be made possible by the availability of harmonized data sets on government pledges, carbon targets, and renewable capacity additions. A more comprehensive understanding of the renewable energy transition would result from integrating these supply-side and institutional factors to help determine whether the observed demand-driven effects operate directly through demographic and economic channels or indirectly through market and policy mechanisms. Furthermore, because of the significant multicollinearity between LURB and LPOP, extra caution should be used when interpreting and implementing the policy implications of Model 5. Despite the preceding analyses clearly identifying Model 4 as the more appropriate specification, the coefficients obtained from Model 5 should be approached with prudence for the reasons previously outlined. This issue constitutes an additional limitation inherent in the present study.

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Abbreviations

The following abbreviations are used in this manuscript:

AMG	Augmented mean group
AR	Autoregression
ARDL	Autoregressive Distributed Lag
CAGR	Compound annual growth rate
CO_2	Carbon dioxide emissions
COVID-19	Coronavirus disease 2019
DHSE	Declining High-Share Economies
E-10 countries	Argentina (ARG), Brazil (BRA), China (CHN), Indonesia (IDN), India (IND), Mexico (MEX), Poland (POL), Russia (RUS), South Africa (ZAF), and Türkiye (TUR)
EKC	Environmental Kuznets Curve
FEVD	Forecast-error variance decomposition
FD	Financial Development
FEFRED	Panel Fixed Effect ModelFederal Reserve Bank of St. Louis Database
GDP	Gross Domestic Product
GDPC	Gross Domestic Product per capita
GMM	Generalized method of moments
G7	7 major industrial countries: Canada, France, Germany, Italy, Japan, the United Kingdom, and the U.S.
IRF	Impulse response function
NARDL	Nonlinear Autoregressive Distributed Lag
OLS	Ordinary least squares
OP	Oil price
PMG-ARDL	Pooled Mean Group Autoregressive Distributed Lag
PHSE	Persistently High-Share Economies
PLSE	Persistently Low-Share Economies
POP	Population
RE	Panel Random Effect Model
REC	Renewable energy consumption
RLSE	Rising Low-Share Economies
TEC	Total Energy Consumption
URB	Urbanization
VECM	Vector Error Correction Model
WDI	World Bank's World Development Indicators
WETI	World Energy Trilemma Index

Appendix A

Table A1. Diagnostic Results for Dynamics GMM estimation for DHSE countries (Table 12).

Statistics/Test	Model 1	Model 2	Model 3	Model 4	Model 5
AR(1) z (p)	−4.01 (0.000)	−4.08 (0.000)	−3.98 (0.000)	−4.10 (0.000)	−3.84 (0.001)
AR(2) z (p)	−1.08 (0.281)	−1.08 (0.279)	−0.82 (0.353)	−0.77 (0.223)	−0.39 (0.371)
Sargan χ^2 (p)	2.25 (0.690)	2.20 (0.699)	2.03 (0.942)	2.18 (0.547)	0.45 (0.952)
Hansen χ^2 (p)	2.15 (0.522)	2.20 (0.519)	2.08 (0.580)	2.18 (0.547)	2.15 (0.704)
Diff-in-Hansen χ^2 (p)	0.48 (0.489)	1.13 (0.889)	0.00 (0.998)	0.05 (0.826)	0.14 (0.711)
Δ (HAC) (p)	1.342 (0.156)	1.285 (0.044)	2.345 (0.021)	2.304 (0.021)	3.115 (0.002)
Adj. Δ (HAC) (p)	1.404 (0.112)	1.365 (0.091)	2.409 (0.014)	2.364 (0.017)	3.155 (0.002)

Note: AR(1) denotes the Arellano–Bond test for first-order serial correlation, while AR(2) refers to the corresponding test for second-order serial correlation. The Sargan χ^2 statistic evaluates the validity of the overidentifying restrictions, and the Hansen χ^2 statistic tests the overall validity of the instruments and provides a heteroskedasticity-robust alternative to the Sargan test. The Difference-in-Hansen χ^2 test examines the exogeneity of instrument subsets. The HAC-adjusted Δ (Pesaran–Yamagata) test assesses the null hypothesis of slope homogeneity against the alternative of heterogeneous slope coefficients across cross-sectional units.

Table A2. Diagnostic Results for Dynamics GMM estimation DSHE and PLSE countries (Table 13).

Statistics/Test	Model 1	Model 2	Model 3	Model 4	Model 5
AR(1) z (p)	−5.07 (0.000)	−5.08 (0.000)	−5.09 (0.000)	−4.95 (0.000)	−4.88 (0.000)
AR(2) z (p)	−1.05 (0.293)	−1.06 (0.291)	−1.02 (0.310)	−1.11 (0.266)	−1.03 (0.302)
Sargan χ^2 (p)	1.81 (0.823)	1.94 (0.831)	1.69 (0.844)	1.83 (0.835)	1.89 (0.829)
Hansen χ^2 (p)	2.05 (0.793)	2.25 (0.781)	2.00 (0.804)	2.10 (0.799)	2.15 (0.797)
Diff-in-Hansen χ^2 (p)	0.35 (0.890)	0.48 (0.875)	0.32 (0.898)	0.41 (0.883)	0.39 (0.887)
Δ (HAC) (p)	−4.636 (0.000)	−4.585 (0.000)	−4.552 (0.000)	−4.538 (0.000)	−4.537 (0.000)
Adj. Δ (HAC) (p)	−4.673 (0.000)	−4.623 (0.000)	−4.584 (0.000)	−4.563 (0.000)	−4.555 (0.000)

Note: AR(1) denotes the Arellano–Bond test for first-order serial correlation, while AR(2) refers to the corresponding test for second-order serial correlation. The Sargan χ^2 statistic evaluates the validity of the overidentifying restrictions, and the Hansen χ^2 statistic tests the overall validity of the instruments and provides a heteroskedasticity-robust alternative to the Sargan test. The Difference-in-Hansen χ^2 test examines the exogeneity of instrument subsets. The HAC-adjusted Δ (Pesaran–Yamagata) test assesses the null hypothesis of slope homogeneity against the alternative of heterogeneous slope coefficients across cross-sectional units.

Table A3. Diagnostic Results for Robustness (Table 14).

Statistics/Test	Model 1	Model 2	Model 3	Model 4	Model 5
AR(1) z (p)	−5.77 (0.000)	−4.43 (0.000)	−4.25 (0.000)	−4.45 (0.000)	−3.68 (0.000)
AR(2) z (p)	−1.60 (0.110)	−1.08 (0.279)	−1.25 (0.210)	−1.03 (0.194)	−1.14 (0.252)
Sargan χ^2 (p)	7.65 (0.665)	2.72 (0.605)	2.00 (0.572)	3.56 (0.261)	3.47 (0.325)
Hansen χ^2 (p)	5.49 (0.240)	2.51 (0.645)	2.00 (0.991)	3.16 (0.368)	2.62 (0.457)
Diff-in-Hansen χ^2 (p)	2.15 (0.932)	2.00 (0.985)	2.00 (0.991)	2.00 (0.945)	2.00 (0.981)
Δ (HAC) (p)	−2.894 (0.006)	−2.526 (0.014)	−2.998 (0.004)	−3.071 (0.002)	−3.338 (0.001)
Adj. Δ (HAC) (p)	−2.846 (0.008)	−2.485 (0.016)	−2.954 (0.005)	−3.024 (0.003)	−3.298 (0.001)

Note: AR(1) denotes the Arellano–Bond test for first-order serial correlation, while AR(2) refers to the corresponding test for second-order serial correlation. The Sargan χ^2 statistic evaluates the validity of the overidentifying restrictions, and the Hansen χ^2 statistic tests the overall validity of the instruments and provides a heteroskedasticity-robust alternative to the Sargan test. The Difference-in-Hansen χ^2 test examines the exogeneity of instrument subsets. The HAC-adjusted Δ (Pesaran–Yamagata) test assesses the null hypothesis of slope homogeneity against the alternative of heterogeneous slope coefficients across cross-sectional units.

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