



# Renewable energy transition and green growth nexus in Latin America

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## ABSTRACT

The prevailing economic growth model prioritizing economic is no longer valid due to a great need for a sustainable and balanced growth model encompassing both economic expansion and environmental sustainability and the natural resource conservation, which is important to explaining carbon neutrality and the sustainable development goals.

The impact of renewable energy transition on green economic growth is examined in this study by a rigorous econometric analysis of the panel data of the fourteen Latin American countries from 2003 to 2020 with special focuses on: identifying the primary mechanisms by which renewable energy transition affects green economic growth, assessing the heterogeneous effects of renewable energy transition considering geographical location and natural resources dependency, and evaluating the spatial spillover effects of renewable energy transition on green economic growth. The results of this study confirm that the transition to renewable energy significantly boosts green economic growth; but its effect differs significantly by country's geographical location, fossil fuel dependence, and mineral resource dependence. This study also identifies five mediating variables between renewable energy transition and green growth: capital investment, dependency on hydropower in electricity generation, residential electricity consumption per capita, human capital, and the creation of formal jobs. Lastly, a negative spatial spillover effect of renewable energy transition is found in the Latin American region.

## 1. Introduction

The prevailing economic growth model, which is primarily based on fossil fuels, focuses on economic expansion at the expense of biodiversity and environmental integrity. However, it is manifestly inadequate to face the pressing challenges posed by climate change and global warming. In this context, the green growth is drawing global attention among the policymakers and academics as a new growth strategy to reconcile economic growth and development with environmental sustainability.

The formal definition of green growth is first made by two multilateral organizations: World Bank (WB) and Organization for Economic Cooperation and Development (OECD). According to the WB [1], “green growth is qualitative growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental damages and resilient in that it responds to natural hazards and the role of environmental management and natural capital in preventing physical disasters.” While the OECD [2] defines green growth as “fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies”.

The core premise of green growth posits that a new economic growth strategy based on low carbon energy sources, as well as improvements in energy efficiency and material utilization not only can improve

environmental quality but can also significantly enhance the socioeconomic well-being of the people [3]. For developing countries, particularly in Latin America (LA), the concept of green growth is gaining attention among policymakers and academics. This is because a green growth strategy is capable of simultaneously enhancing environmental quality and significantly boosting economic growth and development, which is essential for both reducing the high levels of poverty and income inequality prevalent in the LA region, and narrowing the gap facing industrialized countries. Barbier [4] posits that for green growth to be relevant in developing countries, it must address two key structural features: a high dependence on natural resources and pervasive rural poverty. The limited forward and backward linkages of natural resource-based industries with the rest of the economy, combined with a significant proportion of the rural population living in extreme poverty, should be taken into consideration when formulating green growth policies in developing countries [4]. Given that many LA countries heavily rely on the export of agricultural products and raw materials – sectors directly influenced by climatic conditions – and with many large cities located close to coastlines areas susceptible to floods, the region faces significant challenges in the coming decades [5]. Thus, the importance of green growth is growing than ever before to achieving a balance between economic growth and environmental sustainability,

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without hampering the progress of one another.

Nomenclature			
CO <sub>2</sub>	Carbon dioxide	PM 2.5	Cost of Particulate emission damage in current US dollars
GGDPpc	Green gross domestic product per capita	CO <sub>2</sub>	Cost of CO <sub>2</sub> emission damage in current US dollars
RETI	Renewable energy transition index	Pop	Number of population
W	Spatial weight matrix	AFFVadd	Agriculture, forestry, fishery value added
ln	Logarithm	Globalization	Globalization index
i	Country	FinancialDevelopment	Financial development index
t	Year	Gini	Gini index
N	Number of cross-section units	CapitalInv	Capital investment
T	time period	HydroElectDependency	Hydropower dependency in electricity generation
ρ	Spatial autoregressive coefficient	ResidElectConspc	Residential electricity consumption per capita
λ	Spatial autoregressive coefficient for the error term	HCI	Human capital index
Deforestation	Cost of net deforestation in current US	FormalEmp	Formal employment dollars
Abbreviation			
LA	Latin America	MG	Mean group
R&D	Research and development	AMG	Augmented mean group
GGDPpc	Gross domestic product per capita	CCEMG	Common correlated effect mean group
IEA	International Energy Agency	CSD	Cross-section dependence
ESG	Environmental, social and governance	SAR	Spatial autoregressive model
WB	World Bank	SEM	Spatial error model
OECD	Organization for Economic Cooperation and Development	SAC	Spatial autocorrelation model
EKC	Environmental Kuznets curve	SDM	Spatial Durbin model
GTFP	Green total factor productivity	ACME	Average causal mediation effect
BRICS	Brazil, Russia, India, China, and South Africa	GMM	Generalized method of moments
LCCP	Low-carbon city pilot	AIC	Akaike information criterion
G7	Group of Seven	FMOLS	Fully modified ordinary least squares
SDP	Sustainable development policy	RCCE	Regularized common correlated effect
DEA	Data envelopment analysis	2SLS	Two stage least squares

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SBM	Slack based measure.	TNRR	Total natural resource rent
GNI	Gross national income	SIEPAC	Sistema de Interconexión Eléctrica de los Países de
PFA	Principal factor analysis	América Central (Central American Electrical Interconnection System)	
POLS	Pooled ordinary least squares	SDG	Sustainable development goals
RE	Random effects	CIPS	Augmented cross sectional Im-Pesaran-Shin test
FE	Fixed effects		
D-K One way FE	Driscoll-Kraay standard errors estimator with country fixed effect		
D-K Two way FE	Driscoll-Kraay standard errors estimator with both country fixed effect and time fixed effect		

One key pathway to achieving such a green growth involves moving away from carbon-intensive fossil fuels towards clean, renewable energy sources. This transition to renewable energy is imperative because current economic growth has been based on and driven by fossil fuels, which emit significant amounts of carbon dioxide (CO<sub>2</sub>) during combustion, thereby aggravating global warming. However, the transition to renewable energy entails a transformation of the entire energy system, rather than just a simple substitution of one dominant energy source for another [6]. This shift will lead to a profound structural transformation of an economy, having broad implications for the economic, social, political, and environmental spheres [7]. Consequently, in this study, the renewable energy transition index (RETI) has been newly developed to capture these multidimensional and complex features of the renewable energy transition.

Based on the previous considerations, the main objectives of the research are summarized as follows: This study explores the impact of renewable energy transition on green economic growth in the LA region by using standard linear regressions and various estimators that account for the slope heterogeneity of panel data. Given the small sample size of panel data in this study (N = 14, T = 18), a static model is used rather than a dynamic one and several econometric techniques are employed to thoroughly examine consistency and robustness of the empirical findings. Moreover, both country- and time-fixed effects are included in all regression models to control for unobserved heterogeneity.

After confirming a significant relationship between the renewable energy transition and green economic growth, this study analyzes the primary transmission channels through which renewable energy transition influences green economic growth, which is the core of this study. Specifically, five variables are evaluated: capital investment, hydro-power dependency, residential electricity consumption per capita, human capital, and creation of formal jobs. Panel mediation analysis is used to identify the transmission mechanisms of renewable energy transition on green economic growth.

Regarding the heterogeneous impact of renewable energy transition on green economic growth, this study categorizes countries in the LA region into two different groups based on their geographical location, fossil fuels dependency and mineral resources dependency. Based on the framework of the resource curse hypothesis, this study explores how natural resource dependency (proxied by fossil fuel rents and mineral rents) affects the performance of the RETI on green economic growth

across these two groups.

Lastly, the spatial spillover effects of the RETI on green economic growth are examined using panel spatial regression analysis. Specifically, the direct effect (local effect or the impact of the RETI on green economic growth in the same country), indirect effect (spillover effect or the impact of the RETI on green economic growth in surrounding countries), and overall effect (sum of direct and indirect effect) are thoroughly examined to determine whether the influence of a country's RETI extends beyond its own green economic growth, significantly impacting the performance of green economic growth of surrounding countries.

The novelty and main contributions of this research to extant studies are summarized as follows:

First, this study introduces the novel green gross domestic product per capita (GGDPpc) and the RETI to analyze the effect of renewable energy transition on green economic growth in the LA region unlike extant studies which used per capita gross domestic product (GDPpc) and a single-dimensional indicator of renewable energy transition—either renewable energy supply or renewable energy consumption. The use of GGDPpc offers a new perspective to existing research on energy-growth nexus, such as the Environmental Kuznets Curve (EKC) and STRIPAT model by incorporating negative environmental externalities—deforestation, mineral depletion, particulate emissions, and CO<sub>2</sub> emissions—into the conventional GDP, which is based solely on the production of goods and services. Regarding the RETI, it encompasses key aspects of renewable energy transition, extending the energy system structure and efficiency to include crucial factors to a successful renewable energy transition: institutional quality, a favorable environment for attracting capital investment and facility to access financing, competitive advantages in exporting environmental goods, and low-carbon technologies. These factors have not been appropriately taken into account in previous studies. By incorporating both GGDPpc and the RETI, this study can provide valuable insights to policymakers and academics, aiming for a more balanced growth that aligns with the sustainable development goals (SDG), especially in the context of the global climate crisis. It can also provide a more accurate estimation of the impacts of low-carbon energy transition on green economic growth using multidimensional index such as the RETI. Furthermore, this study accounts for slope heterogeneity to derive more robust and unbiased estimates of the effects of the RETI on GGDPpc. Given that the LA region comprises countries with diverse income levels, energy mixes, political systems and institutional qualities, it is important to consider the potential heterogeneous impact that the RETI might have on GGDPpc across these countries. Using slope heterogeneity robust estimators allows for more accurate estimates of the impact of renewable energy transition on green growth.

Second, this study identifies the primary mechanisms through which the RETI influences GGDPpc in the LA region using panel mediation analysis. The mediation analysis can provide valuable insights for policymakers in the region who are aiming to achieve sustainable green growth through renewable energy transition, informing key priority areas the governments should focus on to maximize the benefits of renewable energy transition in achieving green economic growth.

Third, this study is the first attempt to examine the role of a country's geographical location and its natural resource dependency in evaluating the impact of the RETI on GGDPpc within the LA region. Although previous studies have paid more attention to exploring the relationship between natural resource dependency and economic growth based on the resource curse hypothesis, but have never analyzed yet how this dependency might alter the influence of renewable energy transition on green economic growth.

Lastly, this study is distinctive in its focus on analyzing the spatial spillover effects of the RETI on GGDPpc in the LA region. Given that the transition to renewable energy is expected to induce a profound paradigm shift in regional trade patterns and energy markets, thereby influencing green economic growth, investigating the spatial spillover

effects of the RETI on GGDPpc becomes paramount. To validate the robustness of empirical findings, two different approaches were employed to calculate the weight matrix (W): the contiguity matrix and the inverse distance function.

The study is organized as follows: Section 2 delves into the benefits and challenges of the transition to renewable energy in relation to green economic growth in the LA region, examining their evolution in the region over the study period. Section 3 presents a literature review. Section 4 describes the methodology and the dataset used in this study. Section 5 presents empirical results. Section 6 provides discussions of the findings in this study and section 7 conclude with the policy implications derived from this study.

## 2. Green economic growth and renewable energy transition in the context of LA region

In the context of resource-rich developing countries such as the LA, the transition to renewable energy can significantly promote green economic growth for the following reasons:

First, given the yet largely untapped renewable energy potential in the LA region, coupled with excellent climatic conditions and abundant natural resource endowments, many investors perceive the region as the land of opportunities [5,8]. Therefore, in the coming decades, a significant amount of financial flows are expected to be directed toward the LA region as long as governments in the region establish stable and predictable environment for investors. Such financial inflows, including foreign direct investment and financial aid from the multilateral organizations can, in turn, spur economic activity and stimulate green growth within the region [9].

Second, transitioning to non-conventional renewable energy sources, such as solar and wind, has the potential to greatly reduce the LA region's high dependency on hydropower as well as on fossil fuels [8]. Such a shift would diversify the energy mix, thereby enhancing energy security and ensuring a more reliable supply of electricity throughout the region. Historically, the LA region is well known for its significant reliance on hydroelectric power for its total electricity generation [10]. However, frequent and prolonged droughts, coupled with erratic rainfall in recent decades, cast doubt on the reliability and security of hydropower, especially in the context of climate change [11].

Third, the LA region, endowed with rich biodiversity and core ecosystems such as the Amazon (often referred to as the 'lungs of the Earth' and a vital carbon sink) has the potential of a global forerunner in climate change negotiations and dialogues [8]. The more proactive role of the global south such as the LA region can enormously facilitate and accelerate the way for achieving net-zero goals globally and might open windows for close cooperation with the global north (group of industrialized countries).

Fourth, the region holds significant potential to become a key manufacturer and exporter of green and environmentally friendly goods [12]. This is especially true given its abundant reserves of critical minerals, which are essential inputs for clean energy technologies (solar panels, wind blades, lithium-ion battery) [5,13]. The ability to supply these inputs at lower costs by significantly reducing the transportation costs associated with these materials gives the LA a comparative advantage and a privileged position to become a global hub for the manufacturing of green energy technologies [12]. Such a transformation would also facilitate the adaptation and accelerate insertion and integration of many LA countries into a new global market, one characterized by increasing demand for and preference toward eco-friendly products over carbon-intensive ones [14], as well as more stringent environmental regulations on carbon-intensive imported goods. This shift would not only enable the region to comply with evolving global standards but also provide opportunities to move away from low value-added primary products and commodities, which are susceptible to significant price volatility and climatic conditions, towards export of higher value-added products, which are less susceptible to price shocks

and more resilient to climate change, thereby greatly improving the terms of trade and contributing to green growth in the region [12].

Lastly, renewable energy technologies are typically more capital-, technology-, and knowledge-intensive than their traditional fossil fuel counterparts, implying that transitioning to renewable energy demands significant investments, a higher level of specialized knowledge, enhanced technical capabilities, and intensified innovation efforts [8]. This renewable energy transition can enormously boost public and private expenditure on research and development (R&D) as well as education [8,9]. Such investments, in turn, can lead to substantial improvements in green total factor productivity (GTFP), ultimately contributing to green growth in the LA region.

However, the transition to low-carbon economy is also mounting an important challenges to many LA countries due to the following reasons:

First, the revenues generated from the production of fossil fuels still account for a substantial share of the largest economies in the LA region [8]. Furthermore, strong subsidies to these fossil fuels prevailing in the region artificially lower their prices, making it difficult for renewable energy to compete on a level playing field in the energy market [15]. As a result, the shift to clean energy sources may encounter with important challenges and face strong opposition from incumbent fossil fuel companies and fossil fuel-exporting countries due to potential revenue losses. Moreover, with increasing environmental regulations and the associated risk of asset stranding, fossil fuel producers might intensify hydrocarbon production in an attempt to minimize their future losses, a phenomenon referred to as the 'green paradox' [16].

Second, the increasing demand for critical minerals and subsequent increasing mining activities required for decarbonization and renewable energy deployment might encourage rent-seeking behavior, significantly increase country's corruption level, weaken institutional quality, and result in even more unequal distribution of resources revenues in the benefits of only few elite group in mineral-rich countries in the LA region in such a case that revenues from these critical minerals are not managed well [17]. Moreover, large mining projects might generate numerous conflicts over natural resource governance and encounter significant opposition from local communities concerning environmental degradation and pollution [18]. Such opposition can considerably string out the social licensing process, potentially slow down the pace of energy transition aiming for achieving net-zero goals. To address this issue, the tangible benefits of mining projects should be delivered to local communities and be equitably distributed among stakeholders [13].

Third, most countries in the LA region (with a notable exception in Brazil's biofuels and wind energy sector) occupy the low-value-added segments of the renewable energy value chains [12]. This implies that significant efforts are required to overcome their limited manufacturing and innovation capacities. In this context, a more efficient allocation of public spending should be directed towards research and development, retraining programs, and enhancing the education system, since clean energy transition requires a significant number of engineers and technicians with specialized knowledge and high level of expertise, as well as a highly qualified workforce [19]. According to Lebdioui [12], the regions' average R&D expenditure as a share of GDP is among the lowest in the world (less than 0.6 % compared to that with the world average of 2 % or more).

Fourth, the LA region faces the challenge of limited fiscal capacity to address the high upfront costs required for financing large-scale renewable energy deployment [20]. Most countries in the LA region also have underdeveloped financial markets and face serious difficulties for securing funding due to their high financial risks perceived from investors [20].

Lastly, given the region's pressing need for economic development to address income inequality and reduce poverty levels, the efficient and sustainable management of natural resources has not been a primary concern to policymakers in the region [21]. Given this, the implementation of stricter environmental regulations and laws will be essential to ensure companies and stakeholders adhere to

environmental, social, and governance (ESG) standards and promote sustainable and efficient governance of natural resources (i.e. sustainable mining practices). In this sense, concerted efforts by LA countries to harmonize and adopt standardized environmental measures can be helpful to achieve these objectives.

Over the past two decades, countries in the LA region have experienced slow but steady growth in their per capita GDP [5,8]. This has been accompanied by increasing negative environmental externalities associated with economic activities: deforestation, mineral depletion, particulate emissions, and CO<sub>2</sub> emissions. However, the region has historically contributed little to global climate change due to its relatively low emissions intensity and modest emissions per capita [5]. Specifically, the region accounts for approximately 8 percent of the total global greenhouse gas emissions [5]. One of the primary reasons for the low emission intensity and modest emissions per capita in the LA region is its electricity mix [11]. Renewable sources (especially hydropower) constitute a large share of electricity generation in this region, positioning the LA region among those with the greenest electricity mixes in the world [11,18].

As illustrated in Fig. 1, Uruguay, Panama, Chile and Costa Rica have experienced relatively rapid growth in GGDpPc from 2003 to 2020, although with some fluctuations. In contrast, Honduras and Guatemala have either stagnated or shown very slow growth in GGDpPc during the same period. In case of Argentina, Brazil, and Mexico, the three largest economies in the LAC region, there was steady growth until the first decade of the 2000s and followed by a significant decline thereafter. It is important to note that all countries in the LA region saw a decline in their GGDpPc during the Covid-19 pandemic.

Regarding the progression of renewable energy development in the LA region from 2003 to 2020, Panama, Uruguay, Chile, and Costa Rica notably stand out, as illustrated in Fig. 2. In contrast, during this period, Guatemala and Honduras exhibited lower levels of RETI. Observations from Figs. 1 and 2 reveal that countries demonstrating high performance in green economic growth also registered high RETI values and vice versa, thereby confirming a positive correlation between these two factors in the LA region.

### 3. Literature review

#### 3.1. The potential trade-offs between economic growth and environmental quality

Wesseh and Lin [22] argued that countries striving for sustainable development encounter significant challenges in reconciling environmental preservation with economic growth. The authors stated that significant costs associated with environmental measures, such as a carbon tax or carbon pricing, might initially lead to a decline in GDP and consumption levels in developing countries. These measures can lead to an increase in production costs, potentially making producers less competitive in the short term. While such measures are likely to be beneficial in the long term by fostering environmental sustainability, the tangible benefits might not be immediately apparent in the short-term. Le and Sarkodie [23] argued that in emerging markets and developing economies, promoting environmental sustainability through reducing energy demand might hinder economic growth, acknowledging the potential trade-off between pursuing environmental sustainability goals and achieving economic growth. According to the authors, to overcome these challenges, emerging markets and developing economies should proactively promote the penetration of renewable energy to the total energy mix while reducing the share of fossil fuels. Feiock and Stream [24] argued that state policies and administrative institutions are determinant to affecting the trade-off between economic growth and environmental sustainability. Adequate policy design and institutional arrangements can significantly reduce the economic costs associated with environmental regulation. This reduction is achieved by diminishing perceptions of risk and uncertainty regarding future



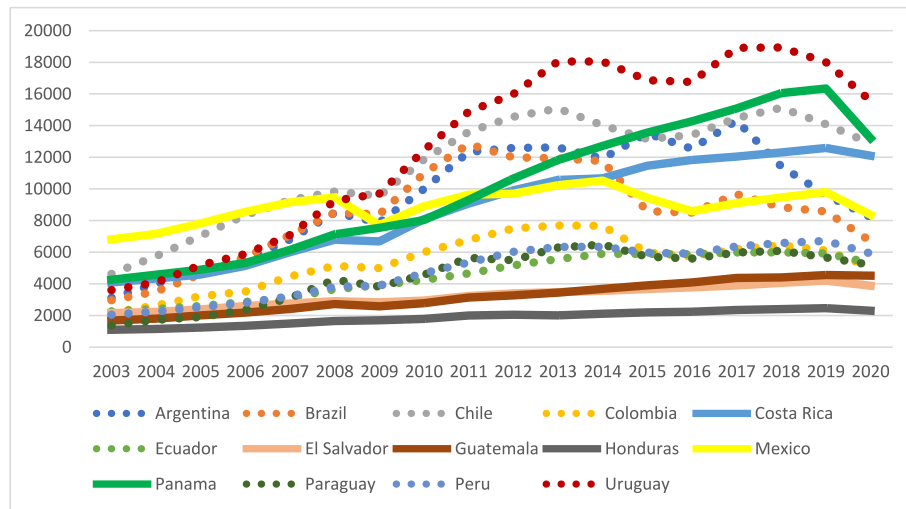


Fig. 1. Green Gross Domestic Production per capita (GGDPpc) of 14 LA countries between 2003 and 2020 based on the World Bank data.

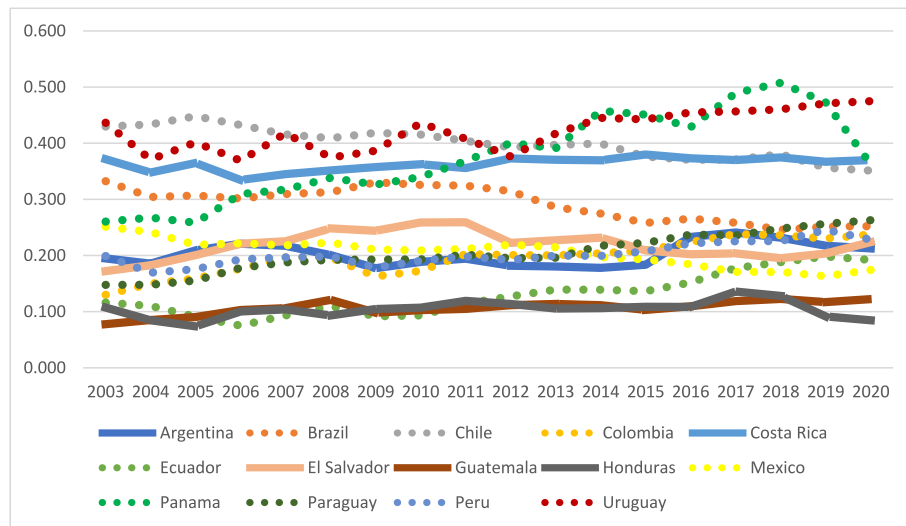


Fig. 2. Renewable Energy Transition Index (RETI) in the LA region from 2003 to 2020 based on RETI.

environmental policies, positively affecting the return on investments and effectively mediating the negative economic impacts of environmental regulation, which can overcome the potential trade-off between economic growth and environmental preservation. Lastly, it is worth noting that the Environmental Kuznets Curve (EKC) hypothesis, proposed by Grossman and Krueger [25] in 1995, advocates the claim that it is possible to overcome the trade-off between economic growth and environmental sustainability. This can be achieved through technical and compositional effects, such as increasing awareness of environmental protection and the adoption of clean energy technologies to the production structure, which can effectively offset scale effects (negative consequences brought about by increasing economic activities). Although the premise of the EKC is promising, it is important to note that the empirical evidence supporting the EKC is weak and far from unambiguous [26].

### 3.2. The nexus between transition to renewable energy and green growth

One of the key pathways to achieving net-zero goals and decoupling economic growth from carbon emissions is the decarbonization of an economy's energy system and production structure. In this regard, the transition to renewable energy, alongside energy efficiency and the

development of carbon capture and storage technology, is considered a central strategy for decarbonization. Given the relevance of the renewable energy transition in achieving green economic growth, several empirical studies have investigated the relationship between them. Yan et al. [27] studied the effects of renewable energy technology innovation on China's green productivity growth and found that the economic development of a province is the determinant of green productivity growth, as only those Chinese provinces with a relatively high income level past a critical turning point exhibited a significant impact of renewable energy technology innovation on green productivity growth. They argued that the provinces with higher income levels are far ahead of the technological frontier compared to those with lower income, giving them a comparative advantage in renewable energy technology innovation capacity. Similarly, Wang et al. [28] examined the effect of renewable energy transition on GTFP, which was used as a proxy for green economic growth, across 30 Chinese provinces from 2006 to 2019. Their estimates indicated that renewable energy transition has a significant positive impact on green economic growth in China. Furthermore, the authors found a heterogeneous impact of renewable energy transition on green economic growth in terms of geographical location and income level: in eastern China, renewable energy transition negatively affected green economic growth, while in central and western

China, a positive impact was observed. Both the energy structure and energy efficiency were identified as the two primary mechanisms through which the renewable energy transition affects green economic growth. Wang et al. [29] analyzed the nexus between renewable energy transition and carbon emissions using a panel of 71 economies from 2003 to 2019. They found that such a transition significantly reduces carbon emissions. Moreover, they also found that both metallic and non-metallic minerals significantly hinder carbon emission reduction during the transition to renewable energy. Wang et al. [30] studied the effect of renewable energy consumption, ecological governance, human development, and R&D spending on green growth within Brazil, Russia, India, China, and South Africa (BRICS) from 1990 to 2019. They found that ecological governance plays a pivotal role in promoting energy transition and green growth. Additionally, they found that the positive influence of renewable energy consumption, ecological governance, human development, and R&D spending become more pronounced at the higher quantiles of green growth. Dong et al. [31] analyzed the non-linear impact of renewable energy development on carbon emission efficiency in 32 developed countries from 2000 to 2018. They found that, in general, the renewable energy development resulted in carbon emission efficiency. However, a significant threshold exists, and the impact of renewable energy varies significantly based on a country's income level. Specifically, when a country's income level is low, the positive correlation between renewable energy development and carbon emission efficiency is significantly diminished. Kahn et al. [32] analyzed the impact of energy transitions, energy consumption, natural resources, and urbanization on the ecological footprint and economic growth of the OECD countries spanning from 1990 to 2015. They found that energy transitions, renewable energy consumption, and natural resources were negatively related to the ecological footprint and economic growth whereas non-renewable energy consumption and urbanization were positively associated with them. The following hypothesis is formulated based on the theoretical foundations established in previous studies.

**Hypothesis 1.** The transition to renewable energy plays a significant role in promoting green economic growth in the LA region.

### 3.3. Mechanisms of transmission between renewable energy transition and green growth

Regarding the importance of capital investment in renewable energy deployment and green growth, Wen et al. [33] stated that renewable energy significantly reinforces the positive impact of capital investment on technological innovation. Based on the panel data of 79 countries from 1995 to 2017, the authors found that capital investment plays a key role in determining the pace of technological innovation and productive capacity of an economy. Similarly, Guo et al. [34] argued that green finance development can promote renewable energy by encouraging innovation efforts towards clean energy technology (clean-biased technical progress) and by reducing financial constraints faced by firms (the financial constraint path). Best [35] emphasized that financial capital is a key enabler in the transition towards more capital-intensive energy sources. Specifically, in high-income countries, financial capital tends to support the transition to clean energy (from carbon-intensive fossil fuels to renewable energy sources), whereas in low-income countries, it tends to accelerate the shift from biomass to fossil fuels. Yi et al. [36] posited that the deployment of renewable energy relies heavily on external capital and is sensitive to investment fluctuations. This is due to the fact that renewable energy requires high upfront costs and long payback durations. Thus, the following hypothesis can be formulated.

**Hypothesis 2a.** The transition to renewable energy positively influences green economic growth in the LA region by encouraging capital investment.

Transition to renewable energy can promote green growth by reducing dependency on dominant energy source. Ozturk [37] argued that energy efficiency and renewable energy sources can play an

important role in energy security, energy dependency, and economic development. Both renewable energy and energy efficiency can strengthen energy supply security through the diversification of the energy mix and reducing dependence on energy imports. Furthermore, they promote environmental sustainability and economic development by reducing CO<sub>2</sub> emissions and creating new jobs. Marques et al. [38] examined the main drivers promoting renewable energy use in twenty-four European countries. According to the authors, the adoption of renewables is primarily motivated by the objective of reducing energy dependency in these countries. Thus, the following hypothesis can be formulated.

**Hypothesis 2b.** The transition to renewable energy positively influences green economic growth in the LA region by reducing dependency on the single dominant energy source in electricity mix (hydropower).

Residential energy consumption is an important driver of economic development in developing countries [39]. Better access to electricity for poor households in marginalized areas, facilitated by renewable energy sources, can yield significant socioeconomic benefits. These benefits include enhanced health of households due to reduced air pollution, achieved by moving away from biomass energy sources for cooking and heating, and improved opportunities for education and economic activities, which in turn, can significantly improve the well-being of citizens and reduce high poverty levels [7,40]. Thus, the following hypothesis can be formulated.

**Hypothesis 2c.** The transition to renewable energy positively influences green economic growth in the LA region by promoting residential electricity consumption per capita.

Given the knowledge- and technology-intensive features of renewable energy technology, human capital accumulation plays an important role in facilitating low-carbon energy transition. Li et al. [41] investigated the key drivers of renewable energy transition in China. According to their study, human capital development is crucial in stimulating renewable energy transition (specifically, a 1 % increase in the human capital index leads to a 0.134 % rise in renewable energy transition). Human capital development can boost innovation capacity and productivity growth within the economy, which also play an important role in diminishing production costs and making the economy more efficient [41,42]. Thus, the following hypothesis can be formulated.

**Hypothesis 2d.** The transition to renewable energy positively influences green economic growth in the LA region by promoting human capital accumulation.

Regarding new job creations triggered by the renewable energy transition, Ram et al. [43] examined the net employment impacts led by renewables by 2050, using the LUT Energy System Transition Model. According to their estimates, the transition to renewable energy will not only create more jobs but also improve the quality of newly created jobs. Specifically, direct energy jobs associated with renewable energy technologies - such as heat storage, hydrogen, and e-fuels - are expected to increase from 57 million in 2020 to nearly 134 million by 2050. The authors also emphasized that substantial efforts should be made in terms of job reskilling and training programs, given the relatively high qualifications required to manage and operate renewable energy technologies. Thus, the following hypothesis can be formulated.

**Hypothesis 2e.** The transition to renewable energy positively influences green economic growth in the LA region by facilitating the creation of formal and high-quality jobs.

### 3.4. Nexus between green growth and natural resources endowment

In relation to theoretical studies examining the connection between (green) economic growth and natural resources, several research works are worth mentioning: Sachs and Warner [44] argue that countries rich in natural resources exhibit in general lower economic growth rates than

their resource-poor counterparts, a phenomenon described by the 'resource curse' hypothesis. The possible explanation of the resource curse observed in these resource-rich countries can be explained by the fact that these economies tend to have higher price levels and they are incapable of capitalizing on export-led growth opportunities. Unlike the explanation, Mehlum et al. [45] contend that the type and the quality of institutions play a key role in determining whether natural resources act as a resource curse or blessing for economies. They emphasized that the effect of natural resources on economic growth can significantly differ depending on whether institutions are grabber friendly or producer friendly. Similarly, Van der Ploeg [17] posits that countries with weak institutions characterized by an absence of rule of law, high corruption level, and underdeveloped financial markets are more prone to suffer from the resource curse. This is because a sudden resource boom and subsequent windfall wealth in these countries might trigger appreciation of the real exchange rate, deindustrialization (phasing-out of manufacturing industries due to the resource-based industries), and rent-seeking behavior. The author emphasizes the substantial challenges faced by resource-rich developing economies in transforming exhaustible natural resources into productive assets. Another study by Brunnschweiler and Bulte [46] investigate the empirical evidence of the resource curse hypothesis. The novelty of this research compared with other previous studies on natural resource curse is that the authors made a clear distinction between resource abundance and resource dependence. They found that resource abundance positively affects economic growth and institutional quality whereas resource dependence does not have significant impact on economic growth.

The interlinkage between green economic growth and natural resources has been investigated in the empirical studies. Ansari and Holz [47] explored the relationship between green transformation and stranded assets of the three resource-rich regions: the Middle East, China, and LA. They investigated which type of fossil fuels were at the highest risk of asset stranding in each region. According to their findings, significant uncertainty exists in the coal sector in China while the crude oil sector in both the Middle East and LA face future uncertainty and a higher risk of becoming stranded assets. Wang et al. [48] examined the nexus between resource abundance and green economic growth in 40 resource-rich developing economies in Asia, Africa, and LA and found that natural resources abundance severely constraints green economic growth in these countries through innovation effect and technical leader transfer effect. Cheng et al. [49] investigated the influence of natural resource abundance and dependency on resource-intensive industries on GTFP in 30 Chinese provinces between 2003 and 2016. Their research revealed that provinces characterized by an abundance of natural resources and a high dependence on resource-intensive industries showed lower GTFP. Several key mechanisms influencing this outcome were identified: the displacement of human capital, technology, declining investment in innovation, and hinderances to the expansion of secondary industries. Similar empirical results were obtained by Fan et al. [50]. The authors examined the potential impact of increased natural resource dependence on carbon emission efficiency using panel data from 283 Chinese cities spanning 2004 to 2017. Their results showed that a high reliance on natural resources adversely affected carbon emission efficiency. This negative impact was attributed to several factors: the crowding out of technological innovation, a reduction in the carbon productivity of investments, and a decreased population density, which in turn hampers the deployment of low-carbon technologies by limiting opportunities for knowledge sharing and technology spillover. Furthermore, the growth of the low-carbon industry was substantially constrained due to the capital siphon effect of resource-based industries. Kahn et al. [51] investigated the impact of natural resources on economic growth in group of seven (G7) economies from 1990 to 2020. They examined both the aggregated (using total natural resource rents) and disaggregated natural resources dependency (analyzing mineral rents, natural gas rents, and oil rents) with green growth as the explanatory variable. The

findings revealed that natural resources dependency had a negative effect on the economic growth of the G7 nations, supporting the resource curse hypothesis for these countries during the study period. Moreover, green growth did not promote economic development within the G7. Lashitew and Werker [52] studied the effect of natural resources as well as the role of institutions during the course of economic development. Unlike other studies, the novelty of their investigation is that they distinguished between resource dependency (resource rents as a share of exports or GDP) and resource abundance (resource stocks or rents per person). According to their findings, resource abundance was found to have positive direct effect on economic development since the revenues obtained from natural resources can be used for provision of public goods and services. However, the resource dependence was found to have negative indirect effect through worsening institutions quality and promotion of rentier social groups and encouraging rent-seeking behaviors among the stakeholders. Li et al. [53] analyzed the impact of sustainable development policy (SDP) on income inequality in resource-based cities in China from 2013 to 2020 and found that the SDP effectively contributes to reducing income inequality by 8.3 percentage in resource-based cities on average. Moreover, they identified that a reduction in natural resource dependence was a main mechanism through which the SDP affects income inequality and the reduction effect of the SDP was more pronounced in central and western cities, resource, energy and mineral-based cities. Lee and He [54] examined the effect of natural resources on green economic growth (proxied by GTFP) under heterogeneous growth path conditions in Chinese provinces from 2008 to 2018. They identified two different growth path conditions: In growth path A, natural resources led to a reduction in green economic growth, causing resource curse phenomenon. In contrast, in Growth Path B, natural resources were found to positively influence green economic growth, causing resource blessing phenomenon. The authors also found that the provinces with more market-oriented institutions are likely to experience a resource blessing phenomenon from natural resources. The following hypothesis is formulated based on the theoretical foundations established in previous studies.

**Hypothesis 3.** The impact of renewable energy transition on green economic growth in the LA region might vary significantly in accordance with a country's geographical location and its dependency on natural resources, specifically fossil fuels and minerals. Based on the resource curse hypothesis, the positive impact of RETI on GGDPPC in countries with higher natural resource dependency is expected to be significantly lower than in countries with lower natural resource dependency.

### 3.5. Spatial spillover effect of renewable energy transition

Other studies have investigated the spatial spillover effects of renewable energy transition on green growth, as well as the role of government policy in accelerating both: Ren et al. [55] examined the spatial effects of energy transition and economic growth on CO<sub>2</sub> emissions in 26 European Union countries from 1990 to 2015. According to their estimates, economic growth had a significant negative spatial spillover effect on CO<sub>2</sub> emissions while the spatial effects of renewable energy were not found. Lee et al. [56] examined the impact of Low-carbon City Pilot (LCCP) policy on accelerating green development and energy transition in 253 Chinese cities at the prefecture level. They found that LCCP effectively boosts energy transition through improvement in total factor productivity and its impact depends crucially on the construction of public transportation. Furthermore, the positive impact of LCCP policy on energy transition was especially pronounced in South cities, large cities, resource-based cities, and old-industrial cities. The LCCP affects three dimensions of energy transition differently: Energy Consumption, energy structure, and energy intensity. LCCP was found to have a positive spatial spillover effect on energy consumption and energy intensity and negative spatial spillover effects on energy structure

in non-pilot cities. The following hypothesis is formulated based on the theoretical foundations established in previous studies.

**Hypothesis 4.** Given the high potential for renewable energy transition to induce profound changes in regional trade patterns and energy markets, its influence might extend beyond a country's local green economic growth. Specifically, the renewable energy transition in one economy could significantly impact the green economic growth performance of neighboring countries, leading to spatial spillover effects.

### 3.6. Literature gaps

From the literature review, this research identifies significant gaps in the extant research:

First, only a handful of studies have so far focused on the impact of renewable energy transition on green economic growth in the LA region. Many of these studies analyze the impact of energy transition using a single-dimensional variable-renewable energy consumption or renewable energy supply often being the most commonly used proxies for this transition. Moreover, while a large number of studies examine the impact of such transitions from either an economic growth or environmental sustainability perspective, only a few studies assess the impact of renewable energy transition on a joint outcome variable that combines both aspects such as green economic growth. Many of these studies primarily focus on China and use GTFP as a proxy of green economic growth using data envelopment analysis (DEA) methods, such as the slacks based measure (SBM) and the super efficiency SBM Malmquist-Luenberger, which significantly differs from the approach of this study in measuring green economic growth.

Second, while most previous studies explore the nexus between renewable energy transition and (green) economic growth, only a few delve into the mechanisms through which such a transition influences the performance of green economic growth. When it comes to the LA region, such studies are not yet available.

Third, while most previous studies related to the resource curse primarily focus on the relationship between natural resource dependency and (green) economic growth, they often overlook the examination of how resource dependency might influence the performance of a renewable energy transition in achieving green

economic growth. Furthermore, despite the significant importance in resource-rich countries, especially in the LA economies, no study has yet been initiated to analyze the heterogeneous impact of renewable energy transition on green economic growth based on a country's geographical location and natural resource dependency: fossil fuel and mineral rents.

Finally, despite the significant potential spillover effects of renewable energy transition on green economic growth in the LA region, yet they have rarely been studied. The transition to renewable energy will bring about paradigm shifts in regional trade and energy markets and will trigger profound structural transformations in the LA region. This implies that such a transition will not only influence green economic performance in a specific country but also have considerable implications for neighboring countries.

## 4. Methodology and data

### 4.1. Descriptive statistics

In this study, the dataset of fourteen LA countries are used for the analysis: Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Panama, Paraguay, Peru, and Uruguay. The period of the data spans from 2003 to 2020. The availability of data was most influential in selecting target countries and the time period for this study. Table 1 provides a summary of the definitions for each variable, and the sources from which they were extracted.

As shown in Table 2, all variables in this study have been transformed into logarithmic forms before their use to reduce variability and facilitate the interpretation of their coefficients in terms of elasticity.

### 4.2. Selection of variables

- Key dependent variable: GGDPPc

The conventional GDP fails to successfully account for the negative externalities associated with environmental degradation and resource depletion. Therefore, a new indicator capable of measuring economic performance aligned with the SDG is important in the context of the climate crisis [57]. In this study, the GGDPPc is used as a proxy for

**Table 1**  
Definition of the variables.

Type	Variable	Definition	Unit	Source
Outcome	GGDPpc	Green Gross Domestic Production per capita.	Current US Dollars	World Bank (World Development Indicators)
Explanatory	RETI	Renewable Energy Transition Index.	–	Various
Control	AFFVadd	Agriculture, forestry, and fishing, value added (% of GDP).	% of GDP	World Bank (World Development Indicators)
	Globalization	The Globalization Index covers the economic, social, and political dimensions of globalization.	–	TheGlobalEconomy.com
	FinancialDevelopment	Financial Development Index measures how much developed financial institutions and financial markets are in terms of their depth (size and liquidity), access (ability of individuals and companies to access financial services) and efficiency (ability of institutions to provide financial services at low cost and sustainable revenues and the level of activity of capital markets).	–	IMF
	Gini	Gini index measures the extent to which the distribution of income among individuals or households within an economy deviates from a perfectly equal distribution.	–	World Bank (World Development Indicators)
Mediation	CapitalInv	Capital Investment consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories.	% of GDP	TheGlobalEconomy.com
	HydroElectDependency	Hydroelectric dependence in the renewable total supply index.	–	OLADE
	ResidElectConspc	Residential electricity consumption per capita.	Toe/10 <sup>3</sup> inhab	OLADE
	HCI	Human capital index, based on years of schooling and returns to education.	–	Penn World Table
	FormalEmp	Formal employment refers to wage and salaried workers who hold the type of jobs defined as "paid employment jobs," where the incumbents hold explicit (written or oral) or implicit employment contracts that give them a basic remuneration that is not directly dependent upon the revenue of the unit for which they work.	% of total employment	World Bank (World Development Indicators)

Note: The definitions of the variables have been extracted from the source.



**Table 2**  
Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
lnGGDPpc	252	8.649	0.656	7.002	9.849
lnRETI	252	−1.514	0.473	−2.606	−0.678
lnAFFVadd	252	1.872	0.446	0.858	2.655
lnGlobalization	252	4.180	0.088	3.898	4.362
lnFinancialDevelopment	252	−1.330	0.470	−2.754	−0.412
lnGini	252	3.876	0.094	3.638	4.086
lnCapitalInv	252	3.060	0.237	2.586	3.791
lnHydroElectricityDependency	252	−1.269	0.724	−3.219	−0.248
lnResidElectConspc	252	3.669	0.501	2.546	4.707
lnHCI	252	0.920	0.147	0.480	1.152
lnFormalEmp	252	4.093	0.182	3.648	4.355

measuring green economic growth. It is worth noting that no standard measure for green economic growth is available. There are various proxies employed to assess the green economic growth in the previous studies: GTFP, based on the Malquist-Luenberger method [27,49], DEA and the super-efficient slack-based measure, among others. These proxies have been utilized in the literature to assess the green economic growth of the economy. In this study, the GGDPpc was calculated based on the methodology outlined by Niu et al. [58], Hao et al. [59], and Xu [60].

To obtain GGDPpc, the following formula is applied:

$$GGDPpc_{it} = \frac{(GDP_{it} - Deforestation_{it} - Mineral_{it} - PM2.5_{it} - CO2_{it})}{Pop_{it}}$$

Here, Deforestation, Mineral, PM2.5, and CO2 have negative effects on green economic growth since they are negative externalities concomitant with economic activities, thus those are subtracted from GDP in the formula. The adjusted net national income is not used because its calculation is based on gross national income (GNI) which includes the value of all goods and services produced by the citizens of a country regardless of their physical residences, namely  $GNI = GDP + \text{net income from abroad}$ . Table 3 shows each component of GGDPpc.

- Core explanatory variable

In this study, the Principal Factor Analysis (PFA) was applied to calculate the RETI, in which the complex and multidimensional features of the transition to renewable energy were taken into account. The PFA is a statistical technique widely used in many studies, particularly when more work is required to reduce dimensionality of variables and identify relevant factors in a dataset. According to Little et al. [61], the selection of adequate indicators is critical when constructing a multidimensional index using exploratory factor analysis. If this could not be done properly, the resulting index may be biased and misleading. To conduct the PFA, indicators should meet certain prerequisites, including a meaningful correlation between them, a high reliability coefficient, a low

**Table 3**  
Components of green gross domestic product (GGDPpc).

	Components	Symbol	Units	Source
GGDPpc	Gross Domestic Product	GDP	Current US dollars	World Bank
	Cost of net forest deforestation	Deforestation	Current US dollars	World Bank
	Cost of mineral depletion	Mineral	Current US dollars	World Bank
	Cost of Particulate (PM 2.5) emission damage	PM2.5	Current US dollars	World Bank
	Cost of CO <sub>2</sub> emission damage	CO2	Current US dollars	World Bank
	Population	Pop	Number of residents	World Bank

communality (or high uniqueness), and the validity of measured variables [62]. Before conducting the PFA, preparing proper data is also essential for ensuring stationarity and standardization (or normalization). In this study, all the indicators incorporated into construction of the RETI were found to be stationary at levels, so further transformation such as first-difference was not necessarily required to get rid of unit root problem. However, each indicator had different scale units in the dataset and exhibited a different range of variance, thus standardization (or normalization) of variables should be done before their use to ensure equal weighting in the PFA. This step is crucial since, in the PFA, indicators with higher values will be given greater weight, and standardization helps to avoid dominance by certain indicators due to their large scale. Five factors in total were retained based on the Kaiser criterion, namely, all factors with eigenvalues greater than or equal to 1 were retained. Lastly, five factors extracted from the PFA were grouped into four dimensions to construct the RETI. As shown in Table 4, the RETI is composed of the following dimensions:

- 1) Institutions, governance, regulation and political commitment (38.82 %)
- 2) Competitiveness in green products and technologies (25.03 %)
- 3) Energy system structure and efficiency (14.14 %)
- 4) Favorable environment for investments and facility to access financing (22.02 %).

To mitigate potential omitted variable bias and more precisely estimate the effect of RETI on GGDPpc, the following variables have been selected as control variables in this study:

**Agriculture, Forestry, and Fishing Value added (AFFVadd):** One of the remarkable peculiarity in the LA region with respect to the rest of the regions in the world is that a considerable share of GHG emissions is originated from the land use change and forestry and agriculture. According to the WB [5], the land use change and forestry accounts for 35 % while that of agriculture is responsible for 23 % of regional GHG emissions. Additionally, many LA countries are commodity exporters, and agriculture is an important sector for these countries representing an average of 4,7 % in 2015–2017 [63].

**Globalization (Globalization Index):** Globalization constitutes a significant factor to be considered when examining the impact of energy transition on green economic growth in the LA region [64]. The process of globalization has the potential to accelerate integration of the region into the global supply chain, facilitate the transfer of advanced green and low-carbon technologies and knowledge, and provide the necessary financial means through trade openness and foreign direct investment [64]. Therefore, the process of globalization could result in a positive impact on green economic growth within the LA region, marked by increased innovation and productivity, while simultaneously reducing environmental degradation.

**Financial development (FinancialDevelopment):** The soundness of financial markets and the availability of financial assets for financing the costly development of low-carbon and clean energy technologies are crucial determinants to a country's green economic growth. This is especially true since these types of technologies often entail high upfront costs and possess capital-intensive features. Shahbaz et al. [65] argued that financial development leads to increasing demand for clean energy sources and helps to achieve SDG.

**Gini (Gini):** The LA region is one of the regions with the highest inequality worldwide [5,8,9]. Since green economic growth pursues balanced growth between citizens' well-being and sustainability, the unequal distribution of wealth, income, and opportunities might hinder the achievement of inclusive green growth.

- Mediation variables

**CapitalInv (Capital Investment):** Ensuring a stable source of financing is crucial for achieving a successful clean energy transition,

**Table 4**  
Renewable energy transition index (RETI).

Dimension	Indicators	Explanation	Units	Source
Institutions, governance, regulation and political commitment (38.82 %)	Government effectiveness index (factor 1)	The index of Government Effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.	–	World Bank
	Control of corruption index (factor 1)	The index for Control of Corruption captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as capture of the state by elites and private interests.	–	World Bank
	Regulatory quality index (factor 1)	The index of Regulatory Quality captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.	–	World Bank
	Voice and accountability index (factor 1)	The index for Voice and Accountability captures perceptions of the extent to which the citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.	–	World Bank
	Political stability index (factor 1)	The index of Political Stability and Absence of Violence/Terrorism	–	World Bank

**Table 4 (continued)**

Dimension	Indicators	Explanation	Units	Source
Competitiveness in green products and technologies (25.03 %)	Comparative advantage in environmental goods index (factor2)	measures perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically motivated violence and terrorism.	–	OLADE
		Country's relative advantage in producing and trading goods that contribute to environmental sustainability or address environmental challenges.	–	OLADE
	Comparative advantage in low-carbon technology index (factor2)	Country's relative advantage in the production, adoption, or export of low-carbon technologies.	–	OLADE
		Share of renewable energy in total electricity generation	% of total electricity generation	IRENA
Energy system structure and efficiency (14.14 %)	Renewable share of electricity generation (factor 3)	Efficiency of electricity sector	–	OLADE
	Efficiency of electricity sector (factor 3)			
Favorable environment for investments and facility to access financing (22.02 %)	Investment freedom index (factor 5)	The Investment freedom index evaluates a variety of investment restrictions (burdensome bureaucracy, restrictions on land ownership, expropriation of investments without fair compensation, foreign exchange controls, capital control, security problems, a lack of basic investment infrastructure, etc.).	–	The Global Economy.com
		The Financial freedom index evaluates: the extent of government regulation of financial services, the degree of state intervention in banks and other financial firms	–	The Global Economy.com

(continued on next page)

Table 4 (continued)

Dimension	Indicators	Explanation	Units	Source
		through direct and indirect ownership, the extent of financial and capital market development, government influence on the allocation of credit and openness to foreign competition.		
	Financial market access index (factor 5)	Ease with which individuals, institutions, and businesses can participate in financial markets, such as accessing banking services, credit, investment opportunities, and other financial instruments.	–	IMF

Note: The name of each dimension in parenthesis indicates the weight assigned based on the eigenvalues obtained from the PFA.

- Control variables

especially given that modern renewable energy sources are capital-intensive [35]. In developing countries, limited sources of financing, high costs of credits and loans, and investment shortages in SMEs constitute major stumbling block in moving away from carbon-intensive energy sources towards renewables [66].

**Hydropwer dependency (HydroElectDependency):** In this study, hydropower dependency, which is dominant source of energy in electricity mix in the LA region [5], is used as a mediator between RETI and GGDPPc. The transition to renewable energy presents a significant opportunity for the diversification of the electricity mix. Such diversification can enhance the resilience of the energy system, increases energy security by reducing reliance on a single dominant energy sources like fossil fuels, which are often subject to geopolitical tensions and price instability [67].

**Residential electricity consumption per capita (ResidElectConspc):** Accelerated electrification driven by renewable energy sources can significantly improve the well-being of poor households in developing countries. For instance, substituting clean cooking and heating systems using renewables for polluting biomass energy sources (such as firewood and organic matter) can enhance the health conditions of citizens and labor productivity, thereby promoting green economic growth [7,40]. Narayan and Doytch [39] found that renewable energy consumption leads to economic growth in low and lower-middle-income countries.

**Human capital (HCI):** The accumulation of human capital can facilitate the clean energy transition and ultimately achieve green economic growth by enhancing the innovation capacity and supporting the development of high-quality labour forces [42].

**Formal employment (FormalEmp):** The transition to renewable energy sources can contribute to formal jobs creation and contribute to poverty alleviation [68], thereby reducing the high share of informal economy prevailing in developing countries. This is attributed to providing a stable source of income to households.

- Variables used in heterogeneity analysis

**Geographical location:** This study divides the data sample into two different groups- South American and Central American countries-to examine the heterogeneous impact of RETI on GGDPPc. This is because these two sub-regions in LA are significantly different in terms of climatic conditions (such as continuous and uninterrupted energy supply from solar radiation and wind) and the degree of integration of regional markets.

**Fossil fuel rents:** Given that many LA countries are major fossil fuel producers, and the fiscal capacity of governments in the region largely depends on resource revenues from fossil fuels [8], this study aims to determine to what extent the effect of RETI on GGDPPc is conditioned by fossil fuel dependency.

**Mineral rents:** LA is also well-known for its abundant mineral resources, with mining activity occupying an important share of the GDP in countries like Chile and Peru, contributing 9.9 % and 11.7 % to their GDPs, and accounting for 60 % and 21 % of their exports in 2015, respectively [69]. Therefore, this study aims to determine to what extent the effect of RETI on GGDPPc is influenced by mineral resource dependency.

### 4.3. Methodology

Given the characteristics of a small sample size in this study ( $N = 14$  and  $T = 18$ ), the panel static approach rather than dynamic one is adopted to analyze the impact of the RETI on GGDPPc. Furthermore, both country and time fixed effects (FE) are included in all regression models to control for unobserved heterogeneity which might be correlated with the error term. Including both country and time FE might tackle endogenous problems associated with unobservable time and country-specific invariant variables [70]. To measure the impact of transition to renewable energy on green economic growth, the benchmark regression model in this study can be formulated as follows:

$$\ln GGDPPc_{it} = \alpha_0 + \beta_1 \ln RETI_{it} + \beta_2 \ln AFFVadd_{it} + \beta_3 \ln Globalization_{it} + \beta_4 \ln FinancialDevelopment_{it} + \beta_5 \ln Gini_{it} + \mu_i + \gamma_t + \epsilon_{it} \quad (1)$$

Where  $\alpha_0$  denotes constant term,  $\beta_1$ - $\beta_5$  are the parameters,  $\mu_i$  and  $\gamma_t$  are country fixed-effect and time fixed-effect respectively, and  $\epsilon_{it}$  is independently, and identically distributed error term. In this study,  $\ln GGDPPc$  is used as a dependent variable while  $\ln RETI$ , is core independent variable. The set of control variables are  $\ln AFFVadd$ ,  $\ln Globalization$ ,  $\ln Financial Development$ , and  $\ln Gini$ . The subscripts  $i$  and  $t$  denote country and year respectively.

- Standard linear regressions

First, the set of standard linear regressions based on equation (1) were performed to see whether the RETI has a significant impact on green growth without considering potential slope heterogeneity of coefficients in different countries in the framework of static panel regressions. Four different estimators were employed to examine the consistency and robustness of findings within the framework of standard linear regression. These methods are pooled ordinary least squares (OLS), random effects (RE), Driscoll-Kraay one-way fixed effects (D-K One-way FE), and Driscoll-Kraay two-way fixed effects (D-K Two-way FE).

- Slope heterogeneity

After estimations by the standard linear regression, the mean group (MG), the augmented mean group (AMG), and the common correlated effect mean group (CCEMG) were employed to validate the robustness of the estimates in the presence of cross-section dependence and slope heterogeneity. Before proceeding to the analysis, a slope heterogeneity test based on Swamy's test [71] was conducted to assess the presence of slope heterogeneity across different cross-section units in the panel data.

This test is particularly suitable for the panels with a small number of cross-sectional units (N) compared to the time periods (T), which exactly corresponds to the case of this study with  $N = 14$  and  $T = 18$ . Additionally, it accounts for cross-section heteroskedasticity. The formulation of Swamy's statistics, as proposed by Pesaran and Yamagata [72], is as follows:

$$\hat{S} = \sum_{i=1}^N (\hat{\beta}_i - \hat{\beta}_{WFE})' \frac{X_i' M_T X_i}{\hat{\sigma}_i^2} (\hat{\beta}_i - \hat{\beta}_{WFE}) \quad (2)$$

$$\text{Where } \hat{\sigma}_i^2 = \frac{(Y_i - X_i' \hat{\beta}_i)' M_T (Y_i - X_i' \hat{\beta}_i)}{(T-K-1)} \quad (3)$$

and  $\hat{\beta}_{WFE} = \left( \sum_{i=1}^N \frac{X_i' M_T X_i}{\hat{\sigma}_i^2} \right)^{-1} \sum_{i=1}^N \frac{X_i' M_T Y_i}{\hat{\sigma}_i^2}$  (4)  $\hat{S}$  is the Swamy's statistic,  $\hat{\beta}_i$  and  $\hat{\beta}_{WFE}$  are POLS estimator and weighted FE estimator respectively,  $X_i$  is the matrix of explanatory variables,  $M_T$  is an identity matrix of order  $T$  ( $M_T = I_T - \tau_T (\tau_T' \tau_T)^{-1} \tau_T'$ ), and  $K$  denotes the number of regressors. Based on the Swamy's test, Pesaran and Yamagata [72] further improved slope heterogeneity test using two delta statistics:

$$\hat{\Delta} = \sqrt{N} \left( \frac{N^{-1} \hat{S} - K}{\sqrt{2K}} \right) \sim \chi_k^2 \quad (5)$$

$$\hat{\Delta}_{adj} = \sqrt{N} \left( \frac{N^{-1} \hat{S} - K}{\sqrt{\text{Var}(T, K)}} \right) \sim N(0, 1) \quad (6)$$

$$\text{Where } \text{Var}(T, K) = \frac{2K(T-K-1)^2(T-3)}{(T-K-3)^2(T-K-5)} \quad (7).$$

$\hat{\Delta}$  is the standardized dispersion statistics and  $\hat{\Delta}_{adj}$  represents the mean-variance bias adjusted version of  $\hat{\Delta}$ . The  $\hat{\Delta}$  is more appropriate to estimate large N and T while  $\hat{\Delta}_{adj}$  is more suitable for small N and T.

After confirming the presence of slope heterogeneity in panel data, this research examined the effect of the variable RETI on GGDPPc using three estimators: MG, AMG, and CCEMG, which are selected on the basis of their robustness in handling issues related to slope heterogeneity and/or cross-sectional dependence. These properties fit for the analysis for this study, ensuring more reliable and accurate results. According to Pesaran and Smith [73], MG estimator is an econometric technique with an underlying assumption that the coefficients or parameters of interest are allowed to vary across cross-section units but maintain constant over time. The main advantages of the MG estimator are: it provides consistent estimates of the average of the long-run coefficients and does not impose any restrictions on the slope homogeneity in both the short and long-run. However, one of the limitations of the MG estimator is that it does not allow the parameters to be the same across cross-sectional units. This can be problematic under the assumption that the coefficients are homogeneous across entities, leading to biased estimates. Another drawback of the MG estimator is that it does not consider cross-section dependence (CSD). In the presence of CSD, the MG estimator becomes biased and inconsistent estimator [73]. However, the AMG estimator, developed by Eberhardt and Bond [74], relaxes the assumption of time-invariant coefficients made by the MG estimator. It allows the coefficients to vary over time and across individual units. This makes the AMG more suitable than the MG in panel data analysis with heterogeneous slope in the presence of CSD.

Furthermore, the CCEMG estimator, introduced by Pesaran [75], addresses the issue of unobserved common factors that may be correlated with the independent variable and the error term, providing more robust estimates in the presence of such effects. By estimating individual FE, common effects, and the coefficient of the independent variable separately for each entity, the CCEMG estimator yields more efficient and unbiased estimates for the common effect of the independent variable across all entities. In sum, both the AMG and the CCEMG estimators are extended and improved version of the MG estimator. They overcome the limitations of the traditional MG estimator by taking into account

cross-sectional dependence between individuals in the presence of slope heterogeneity, thereby offering several advantages over the MG.

#### •Panel Mediation Analysis

The panel mediation analysis was conducted to investigate the specific underlying mechanisms or channels through which the RETI influences GGDPPc. Before proceeding to the panel mediation analysis, the Sobel test, the Aroian test, and the Goodman test were employed to determine the presence of a mediation effect. To conduct this analysis, the three-step procedure developed by Baron and Kenny [76] was applied to identify the mediation variables. According to Baron and Kenny [76], the mediation effect between dependent and independent variable exists when:

- 1) The independent variable should have a significant effect on the dependent variable.
- 2) The independent variable should have a significant effect on the mediator variable.
- 3) The mediator variable should have a significant effect on the dependent variable in the presence of independent variable.

The three-step procedure can be formulated as follows:

$$\ln GGDPPc_{it} = \gamma_0 + \gamma_1 \ln RETI_{it} + \gamma_2 \ln AFFVadd_{it} + \gamma_3 \ln Globalization_{it} + \gamma_4 \ln FinancialDevelopment_{it} + \gamma_5 \ln Gini_{it} + \mu_{1i} + \rho_{1t} + \varepsilon_{1it} \quad (8)$$

$$\ln MV_{it} = \delta_0 + \delta_1 \ln RETI_{it} + \delta_2 \ln AFFVadd_{it} + \delta_3 \ln Globalization_{it} + \delta_4 \ln FinancialDevelopment_{it} + \delta_5 \ln Gini_{it} + \mu_{2i} + \rho_{2t} + \varepsilon_{2it} \quad (9)$$

$$\ln GGDPPc_{it} = \beta_0 + \beta_1 \ln RETI_{it} + \beta_2 \ln MV_{it} + \beta_3 \ln AFFVadd_{it} + \beta_4 \ln Globalization_{it} + \beta_5 \ln FinancialDevelopment_{it} + \beta_6 \ln Gini_{it} + \mu_{3i} + \rho_{3t} + \varepsilon_{3it} \quad (10)$$

Where  $\gamma_0$ ,  $\delta_0$ , and  $\beta_0$  are the constant terms,  $\gamma_1 \dots \gamma_5$ ,  $\delta_1 \dots \delta_5$ , and  $\beta_1 \dots \beta_6$  are coefficients or parameters to be estimated,  $MV_{it}$  represents a set of mediation variables,  $\mu_{ki}$  and  $\rho_{kt}$  denote country and time FE respectively, and  $\varepsilon_{kit}$  represents the disturbance term. The mediation effect will only be considered if both  $\gamma_1$  and  $\delta_1$  in equations (8) and (9) are statistically significant and different from 0. Once the existence of mediation effect has been confirmed through  $\gamma_1$  and  $\delta_1$ , the following step is to analyze the magnitude and significance of coefficients  $\beta_1$  and  $\beta_2$  in equation (10). Four different cases can be found depending on the values of the coefficients  $\beta_1$  and  $\beta_2$ , and  $\delta_1$  in equation (10):

- 1) Positive partial mediation effect if  $\beta_1 \neq 0$  and  $\delta_1 \beta_2 > 0$ .
- 2) Negative partial mediation effect if  $\beta_1 \neq 0$  and  $\delta_1 \beta_2 < 0$ .
- 3) Positive complete mediation effect if  $\beta_1 = 0$  and  $\delta_1 \beta_2 > 0$ .
- 4) Negative complete mediation effect if  $\beta_1 = 0$  and  $\delta_1 \beta_2 < 0$ .

Where the coefficient  $\beta_1$  represents the direct effect and the multiplicative term  $\delta_1 \beta_2$  represents the indirect effect. The sum of these two effects, namely  $\beta_1 + \delta_1 \beta_2$ , corresponds to the total effect which coincides with the coefficient  $\gamma_1$  in equation (8).

For cases 1 and 2, the independent variable (RETI) affects the dependent variable (GGDPPc) through the mediation variable, which can either reinforce or counteract the direct effect of the independent variable, depending on the sign of the multiplicative term  $\delta_1 \beta_2$ . If  $\delta_1 \beta_2$  is positive, the mediator variable reinforce the direct effect of RETI on GGDPPc. On the contrary, if  $\delta_1 \beta_2$  is negative, the mediator variable counteract the direct effect of RETI on GGDPPc. For cases 3 and 4, the mediation variable completely explains the relationship between the dependent variable and the independent variable. In case 3, where  $\delta_1 \beta_2$  is positive, the mediator variable fully mediate the relationship between



RETI and GGDPpc, exerting a positive indirect impact on dependent variable. Conversely, in case 4, where  $\delta_1\beta_2$  is negative, the mediator variable fully mediates the relationship between RETI and GGDPpc, exerting a negative indirect impact on dependent variable.

- Heterogeneity analysis

The heterogeneity analysis was conducted to investigate whether the impact of the RETI on GGDPpc varies significantly according to certain country characteristics, including country's geographical location and its reliance on minerals and fossil fuels. For this purpose, the countries in the LAC region were divided into two different groups based on the following criteria:

- 1) Geographical location: Countries are classified as either 'South America' or 'Central America'.
- 2) Dependency on minerals rent: Countries are classified as 'low-dependency on minerals' when the average annual resource rents from minerals (Mineral rent) as a percentage of GDP are less than their median value, and as 'high-dependency on minerals' otherwise.
- 3) Dependency on fossil fuel rent: Countries are classified as 'low-dependency on fossil fuels' when the average annual resource rents from fossil fuels (Fossil fuel rent) as a percentage of GDP are less than their median value, and as 'high-dependency on fossil fuels' otherwise.

- Static Panel Spatial Analysis (with  $\tau = 0$ )

Prior to performing static panel spatial analysis, the Moran's I test of GGDPpc and RETI has been done to see whether there is a significant spatial dependence and spatial correlation among the LAC countries. The Moran's I statistic is calculated as follows:

$$I = \frac{1}{S^2} \frac{\sum_i \sum_j (y_i - \bar{y})(y_j - \bar{y})}{\sum_i \sum_j W_{ij}} \quad (11)$$

Where  $S^2 = n^{-1} \sum (y_i - \bar{y})^2$ ;  $\bar{x} = \sum_{i=1}^n \frac{x_i}{n}$ ;  $\bar{y} = \sum_{i=1}^n \frac{y_i}{n}$ ;  $W_{ij}$ : spatial weight matrix

It is worth noting that two different approaches were applied to obtain spatial weight matrix ( $W_{ij}$ ): contiguity matrix and inverse distance function [77].

The general specification for the panel spatial model in this study can be written as follows:

$$\begin{aligned} \ln GGDPpc_{it} = & \alpha_0 + \rho \sum_{j=1, j \neq i}^N W_{ij} \ln GGDPpc_{it} + \beta_1 \ln RETI_{it} \\ & + \theta_1 \sum_{j=1, j \neq i}^N W_{ij} \ln RETI_{it} + \sum_{k=2}^5 \beta_k Control_{it} + \theta_2 \sum_{j=1, j \neq i}^N W_{ij} Control_{it} + \zeta_i + \sigma_i \\ & + \epsilon_{it} \end{aligned} \quad (12)$$

Where  $\epsilon_{it} = \lambda \sum_{j=1, j \neq i}^N W_{ij} \epsilon_{it} + \nu_{it}$ .

Based on the combination of the values of  $\rho$  and  $\lambda$ , the generic panel spatial model in equation (12) can be classified into spatial regression models with four different specifications in this study:

- 1) Spatial Autoregressive Model (SAR): when  $\rho \neq 0$ ,  $\theta_1 = 0$ ,  $\theta_2 = 0$  and  $\lambda = 0$
- 2) Spatial Error Model (SEM): when  $\rho = 0$ ,  $\theta_1 = 0$ ,  $\theta_2 = 0$  and  $\lambda \neq 0$
- 3) Spatial Autocorrelation Model (SAC): when  $\rho \neq 0$ ,  $\theta_1 = 0$ ,  $\theta_2 = 0$  and  $\lambda \neq 0$
- 4) Spatial Durbin Model (SDM): when  $\rho \neq 0$ ,  $\theta_1 \neq 0$ ,  $\theta_2 \neq 0$  and  $\lambda = 0$

## 5. Empirical results

### 5.1. Preliminary tests

A battery of preliminary tests has been conducted before proceeding with the standard linear regressions. These tests include CSD test, panel unit root test, and panel cointegration test. In the CSD test [78], described in Table 5, strong evidence of cross-sectional dependence among the LA countries was found in all variables (rejecting the null hypothesis of cross-sectional independence at the 1 % level), except for lnHydroElectricityDependency, which showed weak evidence of CSD at the 10 % level. The CSD test indicates that the LAC countries in this study are interdependent, and the behavior or outcome of one country can be influenced by other countries.

After confirming the presence of CSD, two different panel unit root tests: the first-generation Maddala-Wu panel unit root test [79] and the second-generation Pesaran CIPS test [80] were conducted to assess whether the variables in this study are stationary and do not exhibit the unit root problem. The former test does not take into account CSD when examining unit roots, whereas the latter test takes into account CSD and provides robust results in the presence of CSD. Table 6 presents the results of panel unit root test. The second-generation CIPS test indicates that only lnRETI, lnGlobalization, lnFinancialDevelopment, lnGini, and lnHCI are found to be stationary at levels in both specifications (with and without trend). However, when the variables are transformed into their first-order differences, the unit root problem disappears for all variables, and they become stationary.

The step following after the panel unit root test involves analyzing panel cointegration, which examines the long-run equilibrium relationship between the variables. Verifying cointegration is particularly important to panel data analysis since it indicates a meaningful and jointly stable long-run relationship between the variables, thereby avoiding spurious estimation results. To ensure robustness, three different types of cointegration tests were performed: Pedroni [81], Kao [82], and Westerlund [83] cointegration tests. The first two tests belong to the first-generation cointegration test category, while the last one belongs to the second-generation cointegration test, which is robust in the presence of CSD. According to the Westerlund cointegration test shown in Table 7, all variables used in different regression models (from model 1 to model 6) show evidence of cointegration relationships, as all statistics are significant. Additionally, both the Pedroni and Kao cointegration tests also strongly support the evidence of cointegration among the variables, similar to the results obtained from the Westerlund cointegration test. Based on the results of different cointegration tests, it becomes evident that green economic growth, renewable energy transition, a set of control and mediation variables are all cointegrated, linked with meaningful and stable associations, and move jointly during the period of study.

### 5.2. Standard linear regressions

Once the preliminary tests have been done, standard linear regressions were followed by with four different estimators: POLS, RE, D-K One-way FE, and D-K Two-way FE. To select the most appropriate one among standard linear regression models, a battery of tests was went through in advance: the Hausman test, Wald test (temporal effect test), and four specification tests (Friedman test, Breusch-Pagan Lagrange multiplier test, Wooldridge test, and modified Wald test). Firstly, Hausman test indicates that the FE estimator is more efficient than the RE estimator in all models, as a null hypothesis of not systematic difference in coefficients (i.e., RE being more efficient than FE) is strongly rejected at least 5 % level. Secondly, the results obtained from the Wald test suggest a significant time FE in all regression models in this study at the 1 % significance level, emphasizing the importance of including time FE in the regression models. Lastly, different specification tests, namely, Friedman test, Breusch-Pagan Lagrange multiplier test, Wooldridge

**Table 5**

Cross sectional dependence test.

Variable	CD-test	p-value	Average joint T	Mean $\rho$	Mean abs ( $\rho$ )
lnGGDPpc	36.816***	0.000	18.00	0.91	0.91
lnRETI	3.099***	0.002	18.00	0.08	0.56
lnAFFVadd	11.229***	0.000	18.00	0.28	0.42
lnGlobalization	26.136***	0.000	18.00	0.65	0.68
lnFinancialDevelopment	27.046***	0.000	18.00	0.67	0.68
lnGini	28.983***	0.000	18.00	0.72	0.72
lnCapitalInv	14.21***	0.000	18.00	0.35	0.43
lnHydroElectricityDependency	-1.711*	0.087	18.00	-0.04	0.51
lnResidElectConspc	34.648***	0.000	18.00	0.86	0.86
lnHCI	37.853***	0.000	18.00	0.94	0.94
lnFormalEmp	9.569***	0.000	18.00	0.24	0.46

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively;  $H_0$ : cross-section independence.

test, and modified Wald test, were conducted to assess whether the panel data of this study show CSD, heteroskedasticity, and serial correlation problems. Table 8 shows that all of these tests strongly reject the null hypotheses at the 1 % significance level, indicating the presence of CSD, heteroskedasticity, and serial correlation issues.

Based on the previous results, the D-K Two-way FE was chosen as a benchmark regression model in standard linear regressions since this estimator is robust in the presence of CSD, heteroskedasticity, and serial correlation while incorporating both country and time FE [84]. The results are summarized in Table 9. According to the findings, the effect of RETI on GGDPpc was positive and statistically significant at the 1 % level in most cases, supporting for the robustness of estimates. Only when the RE with control variables and the Driscoll-Kraay One-way FE with control variables, the coefficient of LnRETI remained positive but was not statistically significant.

### 5.3. Estimation results of MG, AMG and CCEMG considering both CSD and slope heterogeneity

As the LAC region is comprised of a diverse group of countries with different levels of economic development, energy system structures, sectoral composition, institutional quality, and political stability, the effect of renewable energy transition on green economic growth might differ significantly across countries. In this context, the assumption of homogenous slope coefficients in previous standard linear regressions may not hold, and it can lead to biased and inconsistent estimates. To assess the existence of slope heterogeneity, this research applied the standardized Swamy's test for slope homogeneity [71]. As shown in Table 10, strong evidence of slope heterogeneity was found in the regression models, as both the delta and adjusted delta statistics are statistically significant at the 1 % level, rejecting the null hypothesis of slope homogeneity. Additionally, the HAC (heteroskedasticity and autocorrelation consistent) option was incorporated in the test to check the robustness of results, and it also provides strong evidence of slope heterogeneity even in the presence of heteroskedasticity and autocorrelation. After confirming the presence of slope heterogeneity in the regression models, three different estimators-MG, AMG, and CCEMG-were used to estimate the effect of the RETI on GGDPpc, after then, the results obtained from these estimators were compared with the previous results obtained using the D-K Two-way FE estimator to examine the robustness of the findings.

Table 11 shows the results of these estimations, and the findings indicate strong evidence of a positive and meaningful impact of the RETI on GGDPpc across all slope heterogeneity estimators, with the exception of the MG estimator without control variables. This positive impact of the RETI is supported by the fact that the coefficient of the RETI was consistently positive and statistically significant at the 1 % level, suggesting a significant relationship between the RETI and GGDPpc. Also, it is worth noting that the estimates of MG, AMG, and CCEMG do not

significantly differ from those of D-K Two-way FE, showing the robustness of empirical findings of this study regardless of econometric techniques.

### 5.4. Mediation analysis

Prior to the analysis, three different tests, namely the Sobel, Aroian, and Goodman tests were performed to examine the presence of significant mediation effects with the "sgmediation2" command in Stata software. According to the results of these mediation tests, several variables has been revealed as significant mediators between renewable energy transition and green economic growth at least 10 % level. Specifically, the following variables were found to be significant mediators:

- 1) Capital investment (CapitalInv)
- 2) Hydroelectricity dependency (HydroElectricityDependency)
- 3) Residential electricity consumption per capita (ResidElectConspc)
- 4) Human Capital Index (HCI)
- 5) Wage and Salaried Workers as a Percentage of Total Employment (FormalEmp)

Additionally, the command 'medeff' was used to validate the robustness of the findings. The results indicate that the 95 % of confidence interval of average causal mediation effects (ACME) does not contain 0 in any of the estimated models (from 2 to 6), which strongly confirms the presence of a significant mediation effect for all five variables mentioned. Based on the results of the mediation analysis shown in Table 12, several important implications can be drawn. First, a significant positive partial mediation effect was observed between RETI and GGDPpc through CapitalInv, which was 0.036 at the 10 % level. The direct effect of RETI on GGDPpc was 0.152 at the 5 % level, indicating that CapitalInv mediated 19 % of the total effect. Second, HydroElectricityDependency exerted a negative partial mediation effect of 0.072 at the 1 % level, whereas the direct effect of RETI on GGDPpc, was 0.260 at the 1 % significance level, implying that HydroElectricityDependency mediated -38 % of the total effect of RETI on GGDPpc. Third, ResidElectConspc was shown to have a complete mediation effect between RETI and GGDPpc at the 1 % level, with an mediation or indirect effect of 0.090, which means that the impact of RETI on GGDPpc was entirely conveyed through ResidElectConspc (in other words, the direct effect of RETI on GGDPpc, which was 0.098, was fully absorbed by the indirect effect of ResidElectConspc). Fourth, HCI demonstrated a significant positive partial mediation effect of 0.039 at the 5 % level. Meanwhile, the direct effect of RETI on GGDPpc was 0.149 at the 5 % level. This means that HCI mediated 21 % of the total effect. Lastly, for FormalEmp, a significant negative partial mediation effect of 0.034 at the 10 % level was found between RETI and GGDPpc, implying that FormalEmp mediated -18 % of the total effect. In this case, the direct effect of RETI on GGDPpc was 0.222 at the 1 %

**Table 6**

Panel Unit root test.

Maddala and Wu panel unit root test (MW)				
At levels				
Variable	Specification without trend		Specification with trend	
	Chi-sq	p-value	Chi-sq	p-value
lnGGDPpc	100.586***	0.000	1.747	1.000
lnRETI	27.205	0.507	75.045***	0.000
lnAFFVadd	61.753***	0.000	58.812***	0.001
lnGlobalization	166.219***	0.000	50.680***	0.005
lnFinancialDevelopment	38.718*	0.086	46.404**	0.016
lnGini	63.276***	0.000	40.755*	0.057
lnCapitalInv	41.673**	0.047	29.183	0.403
lnHydroElectricityDependency	36.147	0.139	65.975***	0.000
lnResidElectConspc	24.086	0.677	18.424	0.915
lnHCI	133.066***	0.000	19.228	0.891
lnFormalEmp	32.531	0.253	25.032	0.626
At first difference				
Variable	Specification without trend		Specification with trend	
	Chi-sq	p-value	Chi-sq	p-value
dlnGGDPpc	48.919***	0.009	110.633***	0.000
dlnRETI	250.219***	0.000	183.480***	0.000
dlnAFFVadd	205.113***	0.000	173.792***	0.000
dlnGlobalization	139.449***	0.000	200.388***	0.000
dlnFinancialDevelopment	247.354***	0.000	195.591***	0.000
dlnGini	204.693***	0.000	174.273***	0.000
dlnCapitalInv	181.024***	0.000	163.052***	0.000
dlnHydroElectricityDependency	343.359***	0.000	288.329***	0.000
dlnResidElectConspc	106.457***	0.000	78.929***	0.000
dlnHCI	37.249	0.113	25.779	0.585
dlnFormalEmp	234.802	0.000	264.032***	0.000
Second generation Pesaran CIPS test				
At levels				
Variable	Specification without trend		Specification with trend	
	Zt-bar	p-value	Zt-bar	p-value
lnGGDPpc	-1.625*	0.052	1.071	0.858
lnRETI	-2.784***	0.003	-1.749**	0.040
lnAFFVadd	-2.504***	0.006	-1.182	0.119
lnGlobalization	-1.434*	0.076	-2.155**	0.016
lnFinancialDevelopment	-2.859***	0.002	-2.842***	0.002
lnGini	-2.023**	0.109	-1.318*	0.094
lnCapitalInv	-1.039	0.149	0.817	0.793
lnHydroElectricityDependency	-0.784	0.217	-1.944**	0.026
lnResidElectConspc	1.014	0.845	1.313	0.905
lnHCI	-2.674***	0.004	-5.588***	0.000
lnFormalEmp	2.320	0.990	0.649	0.742
At first difference				
Variable	Specification without trend		Specification with trend	
	Zt-bar	p-value	Zt-bar	p-value
dlnGGDPpc	-4.391***	0.000	-2.132**	0.017
dlnRETI	-8.517***	0.000	-6.397***	0.000
dlnAFFVadd	-7.925***	0.000	-6.807***	0.000
dlnGlobalization	-9.251***	0.000	-7.620***	0.000
dlnFinancialDevelopment	-10.148***	0.000	-7.669***	0.000
dlnGini	-6.398***	0.000	-4.769***	0.000
dlnCapitalInv	-3.784***	0.000	-1.546*	0.061
dlnHydroElectricityDependency	-10.286***	0.000	-8.454***	0.000
dlnResidElectConspc	-4.305***	0.000	-3.133***	0.001
dlnHCI	-4.406***	0.000	-1.863**	0.031
dlnFormalEmp	-8.561***	0.000	-8.836***	0.000

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively;  $H_0$ : series is I (1); the prefix 'd' represents first difference.

significance level.

### 5.5. Heterogeneity analysis in terms of income level, geographical location, and natural resources dependency (mineral and fossil fuels)

The heterogeneity analysis was carried out to examine whether the effects of the transition to renewable energy on green economic growth differ significantly across countries in association with their geographical location, reliance on minerals and fossil fuels (proxied by mineral rent and fossil fuel rent as a percentage of GDP, respectively).

As it can be seen from Table 13, in association with geographical location, the effect of RETI on GGDPpc was positive and statistically significant at the 1 % level in both South and Central American countries. However, Central American countries showed a coefficient of 0.408 at the 1 % level for a more substantial positive effect on green economic growth from the transition to renewable energy, compared to South American countries, which had a coefficient of 0.194 at the 1 % level. Concerning dependency on minerals, countries with a high level of dependency demonstrated a coefficient of 0.348 at the 1 % level for a stronger positive effect of RETI on GGDPpc. This result contrasts with countries with a lower dependency on mineral resources, where the impact of RETI on GGDPpc was less pronounced, and is evidenced by a coefficient of 0.154 at the 10 % level. Regarding fossil fuel dependency, the effect of RETI was positive and statistically significant only in countries with high reliance on fossil fuels (0.256 at the 1 % level) whereas in countries with low reliance on fossil fuels, the effect of RETI on GGDPpc was not statistically significant.

### 5.6. Panel spatial regression analysis

Before proceeding to a panel spatial mediation analysis, the Moran's I Index was calculated for RETI and GGDPpc for the time period between 2003 and 2020. According to the results detailed in Table 14, both RETI and GGDPpc displayed a strong spatial autocorrelation among the fourteen LA countries since their coefficients were statistically significant at the 1 % level. The positive values of Moran's I Index for RETI and GGDPpc imply that the impact of these variables was not only limited to individual countries but also they significantly influenced neighboring countries as well. This evidence indicates the presence of regional interconnectedness in both the transition towards renewable energy and green economic growth among the fourteen LA economies.

After confirming significant spatial autocorrelation for both the dependent variable (GGDPpc) and the independent variable (RETI), the panel spatial regression analysis was conducted and the weighted matrix (W) was computed using contiguity matrix. Due to the small sample size of panel data (small N and T), only the static regression model was considered in this study. This is because the dynamic panel data regression model such as generalized methods of moments (GMM) may suffer from the finite sample bias and Nickell bias when the sample size is too small, potentially leading to biased estimates. The estimated results drawn are summarized in Table 15, from which several inferences can be made:

First, all spatial models revealed a positive and statistically significant local effect of RETI at the 1 % level, which provides strong evidence for a positive local impact of the transition to renewable energy on green economic growth. These findings are consistent with the previous estimation results in this study.

Second, the spatial autoregressive coefficient, represented by  $\rho$ , was found to be statistically significant at the 1 % level across four different spatial regression models, which provides strong evidence of spatial dependence, meaning that the value of GGDPpc in one country is strongly influenced by the GGDPpc values of neighboring countries. The value of  $\rho$  was positive in the SAR and the SDM, implying that higher (lower) GGDPpc of neighboring countries corresponded with higher (lower) GGDPpc of a local country. However, in the case of the SAC,  $\rho$  was negative, indicating that higher (lower) GGDPpc of neighboring

**Table 7**  
Panel cointegration test.

Pedroni cointegration test						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
Modified Phillips–Perron t	5.0463***	5.4259***	5.4987***	5.5890***	5.8993***	4.7343***
Phillips–Perron t	−1.1175	−0.3647	−2.1888**	−2.8083***	−4.2326***	−2.9556***
Augmented Dickey–Fuller t	−0.9627	−0.9986	−2.0491**	−2.5683***	−2.2560**	−3.7766***
Kao cointegration test						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
Modified Dickey–Fuller t	−3.2762***		−3.6225***	−2.7507***	−3.3869***	−3.0551***
Dickey–Fuller t	−3.1387***		−2.8103***	−2.1662**	−3.2337***	−2.8965***
Augmented Dickey–Fuller t	−2.8836***		−2.1530**	−1.6688**	−2.9682***	−2.6973***
Unadjusted modified Dickey–Fuller	−2.9069***	−3.7317***	−2.8778***	−2.4358***	−3.0061***	−2.7007***
Unadjusted Dickey–Fuller t	−3.0021***	−3.5199***	−2.5412***	−2.0337**	−3.0956***	−2.7596***
Westerlund cointegration test						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
Variance ratio	2.3153**	2.4243***	2.2537**	1.4818*	2.0493**	1.9673**

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; Model 1 corresponds to equation (1); Model 2, 3, 4, 5, and 6 correspond to equation (10) with MV equals to CapInv (Model 2), HydroElectricityDependency (Model 3), ResidentialElectConspc (Model 4), HCI (Model 5), and FormalEmp (Model 6) respectively; both trend and the option ‘all panels’ were included in Westerlund cointegration test. If the option ‘all panels’ was not set, it has a  $H_0$ : cointegration of some panels, thus  $H_0$ : of no cointegration of all panels,  $H_a$ : cointegration of all panels.

**Table 8**  
Preliminary tests.

Hausman test						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Statistics	chi2(5) = 12.47**	chi2(6) = 14.12**	chi2(6) = 18.09***	chi2(6) = 36.94***	chi2(6) = 64.88***	chi2(6) = 100.94***
P-value	0.0289	0.0283	0.0060	0.0000	0.0000	0.0000
Temporal effect (Wald test)						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Statistics	F(17, 216) = 17.65***	F(17, 215) = 16.78***	F(17, 215) = 16.46***	F(17, 215) = 15.82***	F(17, 215) = 18.29***	F(17, 215) = 17.73***
P-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Specification test						
	Friedman test	Breusch-Pagan LM test	Wooldridge test	Modified Wald test		
Statistics	36.496***	chi2(91) = 442.273***	F(1, 13) = 129.539***	chi2 (14) = 434.19***		
P-value	0.0005	0.0000	0.0000	0.0000		

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively;  $H_0$  (Hausman test): Not systematic difference in coefficients;  $H_0$  (Wald test): time FE not significant;  $H_0$  (Friedman test): Cross-sectional independence;  $H_0$  (Breusch-Pagan LM test): Presence of homoscedasticity;  $H_0$  (Wooldridge test): No serial correlation;  $H_0$  (Modified Wald test): Homoscedasticity; Model 1 corresponds to equation (1); Model 2, 3, 4, 5, and 6 correspond to equation (10) with MV equals to CapInv (Model 2), HydroElectricityDependency (Model 3), ResidentialElectConspc (Model 4), HCI (Model 5), and FormalEmp (Model 6) respectively.

countries corresponded with lower (higher) GGDppc of a local country.

Third, the value of  $\lambda$ , which represents the spatial autoregressive coefficient for the error term (or unobserved factors in the spatial regression models), was found to be positive and statistically significant at the 1 % level in both the SEM and the SAC. This result signifies a substantial positive spatial dependence in the error terms, meaning that the error term associated with a specific country's observations is positively influenced by error terms of its neighboring countries. Concerning the choice of the most suitable spatial regression model for this study, the SDM with control variables was selected as shown in the last column of Table 15. This decision was based on the Akaike information

criterion (AIC) as the SDM had the lowest AIC value, indicating a better model to fit the needs for this study. In the SDM, the multiplicative term between W and RETI ( $W \cdot \ln \text{RETI}$ ) was found to be negative and statistically significant at the 1 % level for both with and without control variables, indicating that neighboring countries' progress in transition to renewable energy impacts negatively on the green economic growth in local country.

Lastly, to estimate the magnitude of its effect more accurately, the spatial effect of RETI on GGDppc was decomposed into three different effects: the direct effect (local effect), the indirect effect (spillover effect), and the total effect. In the SAR, SAC, and SDM, the direct effect of



**Table 9**  
Standard linear regressions.

Dependent variable: lnGGDP <sub>pc</sub>								
Estimation technique	POLS		RE		D-K One-way FE		D-k Two-way FE	
lnRETI	1.020*** (0.059)	0.508*** (0.892)	1.156*** (1.117)	0.141 (0.087)	1.258*** (0.229)	0.126 (0.148)	0.321*** (0.066)	0.188*** (0.044)
lnAFFVadd		−0.324*** (0.089)		−0.708*** (0.085)		−0.746*** (0.120)		−0.535*** (0.040)
lnGlobalization		0.425 (0.394)		1.430*** (0.338)		1.393*** (0.300)		−1.807*** (0.193)
lnFinancialDevelopment		0.328*** (0.077)		0.429*** (0.111)		0.486** (0.191)		0.324*** (0.096)
lnGini		−1.939*** (0.295)		−2.675*** (0.259)		−2.596*** (0.298)		−0.089 (0.323)
Constant	10.194*** (0.094)	16.201*** (2.523)	10.400*** (0.197)	15.153*** (1.885)	10.554*** (0.280)	15.126*** (1.668)	8.409*** (0.106)	17.546*** (0.802)
Country FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No	No	Yes	Yes
R <sup>2</sup>	0.5417	0.7229	0.2283	0.7886	0.2283	0.7889	0.8643	0.9117
Number of obs.	252	252	252	252	252	252	252	252

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; prefix d and l represent the first differences and lagged respectively; for RE, D-K One-way FE, and D-K Two-way FE, the values of R<sup>2</sup> (within) were reported; () indicates standard error.

**Table 10**  
Test for slope heterogeneity.

Dependent variable: lnGGDP <sub>pc</sub>		
	Delta	P-value
	9.027***	0.000
Adj.	11.547***	0.000
	Delta (HAC)	P-value
	−2.918***	0.004
Adj.	−3.733***	0.000

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; the option ‘Hac’ which refers to heteroskedasticity and autocorrelation consistent was included in the test; H<sub>0</sub>: slope coefficients are homogenous.

RETI on GGDPPc was found to be positive and statistically significant at the 1 % level. This result means that the local economy’s progress in renewable energy transition has a positive impact on its own GGDPPc, which is consistent with the previous estimates obtained in this study. However, when it comes to the indirect effect of RETI on GGDPPc, different estimation results were found: In the SAR, the indirect effect of RETI was positive and statistically significant at the 1 % level. Specifically, it was 0.103 when control variables were not included in spatial regression model and 0.081 when they were included. For both the SAC and SDM, the indirect effect of RETI was found to be negative and statistically significant at the 1 % level, where the negative effect of RETI on GGDPPc was significantly more pronounced in the SDM compared to the SAC (−0.111 versus −0.952 when control variables were not included and −0.082 versus −0.516 when they were included). Regarding overall effects, namely the sum of local and spillover effect of RETI, they were found to be positive and statistically significant at the 1 % level in both the SAR and SAC. However, in the SDM, overall effects were negative, which can be attributed to the substantial negative spillover effect of RETI on GGDPPc.

### 5.7. Robustness tests

To assess the consistency and reliability of the estimated results, several robustness tests were performed.

- Robustness test for standard panel linear regression models

As for the standard panel linear regression models, the fully modified ordinary least squares (FMOLS), developed by Phillips and Hansen [85],

was used, since this method is robust in the presence of CSD, serial correlation and more importantly, it corrects for potential endogeneity issue, thereby enhancing the reliability of the estimates. Table 16 shows that the FMOLS estimates are not significantly differ from those of the D-K Two-way FE as the coefficient of lnRETI was still positive and statistically significant at the 5 % level.

To examine the robustness of the estimates in panel regression models with heterogeneous slope coefficients, the regularized common correlated effect (RCCE) proposed by Juodis [86] was used. This technique is more improved version of conventional CCE estimator in terms of addressing an excessive number of cross-section averages by eliminating the asymptotically redundant singular values of cross-section averages through the singular value decomposition method [86]. As the results illustrated in Table 17, the sign and magnitude of the coefficient lnRETI remained positive and statistically significant at the 1 % level in the RCCE. This result is consistent with the estimates from MG, AMG, and CCEMG, further confirming the robustness of empirical findings of this study.

To confirm the significant mediation effects, the bootstrap tests were conducted using the ‘sgmediation2’ command in Stata, setting the replication number to 400. As shown in Table 18, most of the previous estimates in panel mediation regression analysis in section 5.3 remain largely consistent after conducting bootstrap tests except for Model 5, in which the indirect effect was found to be statistically insignificant.

To test the robustness of the estimates in the heterogeneity analysis, the lnRETI of the current period was replaced with its lagged term (lnRETI<sub>t-1</sub>). The advantage of using lagged explanatory variable, which is suspected to be endogenous, can help mitigate endogeneity issues to some extent [87]. This is because the past trajectory of the renewable energy transition might be subject to path dependence and may influence the current level of green economic growth, however, the current level of green economic growth cannot retroactively affect the past trajectory of renewable energy transition. The rationale behind not employing more conventional methods such as the GMM or two-stage least squares (2SLS) in this study is two-fold: On the one hand, the GMM is based on the asymptotic approach, so it may become inappropriate when the sample size is too small, susceptible to finite sample bias and Nickell bias. On the other, the challenge of identifying suitable instruments that meet both relevance and exogeneity conditions is considerable in case of 2SLS. The results in Table 19 confirm that the estimates are consistent with and align closely with previous findings shown in Table 13 of section 5.5. Regarding geographical location, the effect of the renewable energy transition on green economic growth was positive and statistically significant at the 1 % level in both regions.

**Table 11**

Mean group, augmented mean group, common correlated effect mean group, and Driscoll-Kraay two-way FE.

Dependent variable: $\ln \text{GGDP}_{pc}$								
Estimation technique	MG		AMG		CCEMG		Two-way D-K FE	
$\ln \text{RETI}$	0.428 (0.433)	0.311*** (0.096)	0.302** (0.122)	0.212** (0.096)	0.362*** (0.122)	0.315** (0.126)	0.321*** (0.066)	0.188*** (0.044)
$\ln \text{AFFVadd}$		−0.629** (0.253)		−0.249** (0.120)		−0.239* (0.133)		−0.535*** (0.040)
$\ln \text{Globalization}$		1.080 (0.786)		−0.771* (0.424)		−1.131*** (0.392)		−1.807*** (0.193)
$\ln \text{FinancialDevelopment}$		−0.089 (0.151)		−0.009 (0.084)		−0.064 (0.080)		0.324*** (0.096)
$\ln \text{Gini}$		−0.322 (0.677)		−0.220 (0.355)		0.099 (0.356)		−0.089 (0.323)
Common Dynamic Process			0.971*** (0.170)	0.868*** (0.168)				
$\overline{\ln \text{GGDP}_{pc}_{it}}$					0.990*** (0.179)	0.863*** (0.174)		
$\overline{\ln \text{RETI}_{it}}$					−0.262 (0.161)	−0.152 (0.264)		
$\overline{\ln \text{AFFVadd}_{it}}$						0.072 (0.166)		
$\overline{\ln \text{Globalization}_{it}}$						1.452 (1.311)		
$\overline{\ln \text{FinancialDevelopment}_{it}}$						−0.034 (0.514)		
$\overline{\ln \text{Gini}_{it}}$						1.338 (1.560)		
Trend	0.063*** (0.001)	0.031*** (0.009)	0.001 (0.009)	0.002 (0.009)	0.001 (0.009)	−0.004 (0.021)		
Constant	8.878*** (0.596)	2.157 (6.210)	8.304*** (0.215)	12.618*** (2.398)	0.151 (1.551)	1.054 (10.887)	8.409*** (0.106)	17.546*** (0.802)
Number of obs.	252	252	252	252	252	252	252	252

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; the symbol – refers to cross-section average.

Consistent with previous findings, the impact was more pronounced in Central America than in South America. As for natural resource dependency, specifically on minerals and fossil fuels, countries with higher dependency showed a stronger effect of RETI on  $\text{GGDP}_{pc}$ , in line with previous findings.

Additionally, a further heterogeneity test was conducted by dividing the fourteen LA into two groups based on their annual average value of total natural resource rent (TNRR). The results presented in Table 20 show that only in countries with an annual average TNRR value greater than the median the effect of the RETI on  $\text{GGDP}_{pc}$  was positive and statistically significant. In contrast, for countries with an annual average TNRR value less than the median, the effect of the RETI was not significant.

To examine the robustness of empirical findings in panel spatial regression models, W was re-estimated using an inverse distance function. Given that the SDM was found to be the most appropriate among the four different specifications according to the AIC both in terms of the contiguity matrix and the inverse distance function— this research uses the SDM as a benchmark panel spatial regression model in this study and only the results from the SDM was reported in Table 21. The outcomes of the SDM corroborate the robustness of the estimates. Notably, the core explanatory variable, RETI, was positive and statistically significant at the 1 % level. This supports the positive local effect of the RETI on green economic growth, as evidenced by prior estimations using the contiguity matrix. Furthermore, the multiplicative term,  $W \cdot \ln \text{RETI}$ , was negative and statistically significant at least 5 % level, aligning with previous findings. The value of  $\rho$  was found to be positive and statistically significant at the 1 % level when control variables were excluded. However,  $\rho$  became insignificant when control variables were incorporated into the SDM with an inverse distance function. Finally, in terms of the decomposition of spatial effects of the RETI on  $\text{GGDP}_{pc}$ , the results from the robustness test echoed earlier conclusions. Only the SDM with control variables and inverse distance function, the total spatial effect of the RETI on  $\text{GGDP}_{pc}$  was not statistically significant, though the

coefficient's sign remained negative.

## 6. Discussion of findings

Based on the empirical results from the previous section, several key findings can be highlighted as follows:

First, Irrespective of the econometric techniques used, the positive and significant impact of the RETI on  $\text{GGDP}_{pc}$  consistently proved robust. This implicates that the transition to renewable energy positively influences green growth across all LA countries during the period 2003–2020, thus verifying the Hypothesis 1 of this study. The results of this study are in line with Wang et al. [21] who observed that renewable energy consumption stimulates green growth in BRICS economies. Similarly, Danish and Ulucak [88] found that both environmental-related technologies and renewable energy promote green growth in BRICS countries but non-renewable energy has an adverse effect on green growth. Dong et al. [31] also found that renewable energy development leads to carbon emission efficiency in 32 developed countries, although significant threshold effect exists among the countries.

Second, based on the panel mediation analysis, five different mechanisms were identified through which the transition to renewable energy affects green economic growth in the LA region: Capital investment, hydroelectricity dependency, residential electricity consumption per capita, human capital, and formal employment.

Regarding capital investment, it had a positive partial mediation effect between the RETI and  $\text{GGDP}_{pc}$ . The findings in this study are consistent with Zhang et al. [89], who argue that the clean energy technology requires a substantial and high-quality capital investment in energy sector. Such investments can spur resource-efficient, low-carbon, and socially inclusive green growth. Concerning hydroelectricity dependency, the estimates indicate a negative partial mediation effect. This means that the positive impact of the RETI on  $\text{GGDP}_{pc}$  is partially offset by dependence on hydroelectricity. The heavy reliance on

**Table 12**  
Mediation analysis.

	Model 1 (Without MV)	Model 2 (MV = lnCapitalInv)		Model 3 (MV = lnHydroElectricityDependency)		Model 4 (MV = lnResidElectConspc)		Model 5 (MV = lnHCI)		Model 6 (MV = lnFormalEmp)	
Dependent Variable	DV	MV	DV	MV	DV	MV	DV	MV	DV	MV	DV
lnRETI	0.184*** (0.063)	0.118** (0.055)	0.152** (0.061)	0.468*** (0.094)	0.260*** (0.065)	0.164*** (0.043)	0.098 (0.060)	−0.058*** (0.014)	0.149** (0.065)	−0.081*** (0.021)	0.222*** (0.065)
lnCapitalInv			0.305*** (0.075)								
lnHydroElectricityDepend-ency					−0.154*** (0.044)						
lnResidElectConspc							0.548*** (0.092)				
lnHCI									−0.667** (0.295)		
lnFormalEmp											0.428** (0.206)
lnAFFVadd	−0.533*** (0.063)	−0.051 (0.056)	−0.519*** (0.061)	0.130 (0.094)	−0.515*** (0.062)	0.022 (0.043)	−0.547*** (0.059)	0.024 (0.144)	−0.519*** (0.063)	0.014 (0.021)	−0.541*** (0.063)
lnGlobalization	−1.807*** (0.311)	0.277 (0.274)	−1.891*** (0.301)	2.112*** (0.465)	−1.481*** (0.317)	−0.434** (0.214)	−1.569*** (0.291)	0.132* (0.071)	−1.718*** (0.310)	0.136 (0.102)	−1.865*** (0.310)
lnFinancialDevelopment	0.324*** (0.091)	−0.016 (0.080)	0.329*** (0.088)	−0.045 (0.136)	0.317*** (0.089)	0.155** (0.063)	0.239*** (0.086)	0.015 (0.021)	0.334*** (0.090)	0.124*** (0.030)	0.271*** (0.094)
lnGini	−0.089 (0.273)	−0.005 (0.241)	−0.087** (0.0264)	−0.948** (0.409)	−0.235 (0.270)	−0.366* (0.188)	0.112 (0.256)	−0.118* (0.063)	−0.168 (0.273)	−0.360*** (0.090)	0.065 (0.281)
Constant	17.984*** (1.391)	1.963 (1.231)	18.102** (1.356)	−5.597*** (2.089)	17.840*** (1.384)	7.900*** (0.960)	14.373*** (1.486)	0.836*** (0.319)	19.260*** (1.405)	5.104*** (0.459)	16.518*** (1.738)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R <sup>2</sup>	0.9117	0.8256	0.9729	0.9463	0.9724	0.9764	0.9750	0.9695	0.9715	0.9590	0.9714
Obs	252	252	252	252	252	252	252	252	252	252	252
	Model 2 (MV = lnCapitalInv)		Model 3 (MV = lnHydroElectricityDependency)		Model 4 (MV = lnResidElectConspc)		Model 5 (MV = lnHCI)		Model 6 (MV = lnFormalEmp)		
Sobel test	0.036* (0.019)		−0.072*** (0.025)		0.090*** (0.028)		0.039** (0.020)		−0.034* (0.019)		
Aroian test	0.036* (0.020)		−0.072*** (0.026)		0.090*** (0.028)		0.039* (0.020)		−0.034* (0.019)		
Goodman test	0.036* (0.019)		−0.072*** (0.025)		0.090*** (0.028)		0.039** (0.019)		−0.034* (0.018)		
Indirect effect	0.036* (0.019)		−0.072*** (0.025)		0.090*** (0.028)		0.039** (0.020)		−0.034* (0.019)		
Direct effect	0.152** (0.061)		0.260*** (0.065)		0.098 (0.060)		0.149** (0.065)		0.222*** (0.065)		
Total effect	0.188*** (0.063)		0.188*** (0.063)		0.188*** (0.063)		0.188*** (0.063)		0.188*** (0.063)		
	Model 2 (MV = lnCapitalInv)		Model 3 (MV = lnHydroElectricityDependency)		Model 4 (MV = lnResidElectConspc)		Model 5 (MV = lnHCI)		Model 6 (MV = lnFormalEmp)		
ACME	0.036 [0.003–0.080]		−0.072 [−0.125 to −0.024]		0.089 [0.044 to −0.154]		0.040 [0.004 to −0.079]		−0.034 [−0.075 to −0.001]		
Direct effect	0.149 [0.035–0.257]		0.257 [0.137–0.371]		0.095 [−0.017–0.201]		0.146 [0.026–0.260]		0.220 [0.100–0.333]		
Total effect	0.185 [0.068–0.299]		0.185 [0.054–0.301]		0.185 [0.071–0.304]		0.186 [0.059–0.303]		0.185 [0.067–0.305]		
% of Total effect mediated	0.194 [0.119–0.525]		−0.384 [−1.157 to −0.238]		0.490 [0.294 to −1.254]		0.216 [0.131 to −0.672]		−0.185 [−0.514 to −0.112]		

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; Mean value,[] indicates 95 % confidence interval,() indicates standard error.

**Table 13**  
Heterogeneity analysis.

Median	Region		Mineral rent		Fossil fuel rent (oil + natural gas + coal)	
	South America	Central America	Low dependency on minerals	High dependency on minerals	Low dependency on fossil fuels	High dependency on fossil fuels
lnRETI	0.194*** (0.067)	0.408*** (0.050)	0.154* (0.089)	0.352*** (0.117)	0.080 (0.117)	0.256*** (0.080)
lnAFFVadd	−0.401*** (0.086)	−0.594*** (0.044)	−0.370*** (0.102)	−0.404*** (0.136)	−0.381*** (0.096)	−0.620*** (0.144)
lnGlobalization	−1.632*** (0.331)	−1.464*** (0.219)	−1.296* (0.709)	−1.772*** (0.412)	−1.758** (0.751)	−1.096*** (0.398)
lnFinancialDevelopment	0.326*** (0.084)	0.112 (0.106)	0.508*** (0.129)	0.081 (0.165)	0.520*** (0.135)	0.097 (0.154)
lnGini	0.138 (0.341)	0.214 (0.179)	0.974** (0.380)	−1.086** (0.426)	0.975** (0.381)	−1.168*** (0.420)
Constant	15.651*** (1.517)	15.121*** (0.994)	11.262*** (3.415)	20.995*** (1.774)	13.078*** (3.507)	18.861*** (1.689)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
R <sup>2</sup> (within)	0.9577	0.9797	0.9282	0.9182	0.9279	0.9145
Obs	144	108	126	126	126	126

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; the median is less affected by outliers and skewed data than the mean and is usually the preferred measure of central tendency when the distribution is not symmetrical; () indicates standard error; South American countries are Argentina, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, and Uruguay; Central American countries include Costa Rica, El Salvador, Guatemala, Honduras, Mexico, and Panama; countries with low dependency on mineral resources, namely those with a mean value of mineral rent as a share of GDP (%) equal or lower than 0.2430242 are Costa Rica, Ecuador, El Salvador, Honduras, Panama, Paraguay and Uruguay; countries with high dependency on mineral resources, namely those with a mean value of mineral rent as a share of GDP (%) higher than 0.2430242 include Argentina, Brazil, Chile, Colombia, Guatemala, Mexico, and Peru; countries with low dependency on fossil fuel resources, namely those with a mean value of fossil fuel rent as a share of GDP (%) equal or lower than 0.2835653 are Chile, Costa Rica, El Salvador, Honduras, Panama, Paraguay and Uruguay; countries with high dependency on fossil fuel resources, namely those with a mean value of fossil fuel rent as a share of GDP (%) higher than 0.2835653 include Argentina, Brazil, Colombia, Ecuador, Guatemala, Mexico, and Peru.

**Table 14**  
Moran's I statistic (2003–2020).

Period	lnGGDPpc		lnRETI	
	Moran's I	P-value	Moran's I	P-value
2003–2020	0.650***	0.0000	0.903***	0.0000

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

hydropower in electricity generation and supply poses significant challenges for diversifying electricity mix in the LA region, and it can slow down significantly the speed of the transition towards non-conventional renewable energy sources like solar and wind. Furthermore, given the foreseeable prolonged drought seasons in the LA region in coming decades due to climate change and global warming, the capacity of hydropower to supply electricity may be compromised, this is particularly true in the Andean Region where hydropower has historically been a dominant electricity source [10]. Regarding residential electricity consumption per capita, this study indicates a complete positive mediation effect, showing that a positive effect of transition to renewable energy on green economic growth is entirely mediated by residential electricity consumption per capita. There has been a notable rise in electricity coverage in the LA region over two decades, increasing from 50 % to 90 % [90]. However, despite this significant improvement, 20 million people still lack access to electricity, and 80 million continue to rely on traditional biomass fuels for cooking and heating. In this sense, transition to renewable energy comes to be a promising solution, particularly in enhancing energy accessibility in remote areas via decentralized energy systems. This eliminates the need for constructing electricity grid infrastructure costly, enhancing energy access and accelerating electrification in the areas that conventional centralized energy systems might find challenging to serve. This transition could, in turn, lead to a significant rise in residential electricity consumption per capita, replacing air polluting biomass energy sources for cooking and heating, thereby fostering green economic growth in the LA region.

Regarding human capital, the positive partial mediation effect was

found. The findings in this study are consistent with Zhang et al. [89], who argue that public spending on human resources and R&D technologies could accelerate sustainable green economy through labor and technology-oriented production activities.

Regarding a formal employment, it was found to have a negative partial mediation effect, meaning that transition to renewable energy has an adverse impact on formal job creations in fourteen LA economies for the period of this study. According to the OECD [2], the clean energy transition implies significant adjustment costs in labor markets and many of workers employed in fossil fuel industries will lose their jobs. Moreover, highly skilled workforce required for renewable energy sector might pose serious challenges for many LA countries given the prevalent informality in their labor markets and a shortage of high-skilled workers. Considering the previous estimates, the validity of the **Hypothesis 2** in this study is partially confirmed (**Hypothesis 2a**, **2b**, **2c**, and **2d**). This is because formal employment (**Hypothesis 2e**) had a negative partial mediation effect between the renewable energy transition and green economic growth in the LA region, which is contrary to the expectations of this study. However, the impacts of other mediating variables are consistent with the Hypothesis 2 of this study.

Third, the heterogeneity analysis revealed a notable regional difference in terms of the effect of the RETI on GGDPpc, thus confirming the validity of **Hypothesis 3**. According to the analysis, the impact of the renewable energy transition on green growth was substantially stronger in Central American countries than in South American ones. This difference can be attributed to Central America's more integrated regional power system and renewable energy market compared to South America's. Concretely, in 1996, the six countries of Central America (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama) decided to carry out the process of electric integration through the interconnection of their national electric networks aiming for promoting the development of the electrical industry and satisfying the electricity needs of the region. The SIEPAC (Central American Electrical Interconnection System) line is affordable to Central American countries, which consists of a 230-kV power transmission line with a net transfer capacity of up to 300 mega-watts [91]. Furthermore, the establishment of regional electricity market in the region allows member countries to



**Table 15**

Spatial panel regressions using contiguity matrix as W (static model with tau = 0).

Model	SAR		SEM		SAC		SDM	
Main								
lnRETI	0.378*** (0.064)	0.252*** (0.051)	0.508*** (0.054)	0.328*** (0.046)	0.457*** (0.049)	0.265*** (0.040)	0.382*** (0.055)	0.278*** (0.044)
lnAFFVadd		−0.500*** (0.050)		−0.434*** (0.052)		−0.474*** (0.046)		−0.328*** (0.051)
lnGlobalization		−1.979*** (0.249)		−1.212*** (0.231)		−0.922*** (0.196)		−1.730*** (0.225)
lnFinancialDevelopment		0.424*** (0.073)		0.388*** (0.059)		0.208*** (0.057)		0.310*** (0.067)
lnGini		0.047 (0.219)		−0.076 (0.201)		−0.113 (0.171)		0.345* (0.202)
W*lnRETI							−1.418*** (0.198)	−0.881*** (0.172)
W*lnAFFVadd								−0.562** (0.221)
W*lnGlobalization								−2.031** (0.819)
W*lnFinancialDevelopment								−0.949*** (0.270)
W*lnGini								1.801*** (0.680)
Rho (ρ)	0.418*** (0.067)	0.477*** (0.053)			−0.561*** (0.133)	−0.723*** (0.120)	0.692*** (0.103)	0.455*** (0.113)
Lambda (λ)			0.990*** (0.081)	1.034*** (0.074)	1.269*** (0.053)	1.353*** (0.031)		
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AIC	−275.882	−409.639	−314.730	−422.051	−327.217	−441.639	−326.149	−475.676
Decomposition of spatial effects of RETI on GGDPPc								
Direct effect (long run)	0.389*** (0.067)	0.261*** (0.054)			0.474*** (0.050)	0.281*** (0.042)	0.277*** (0.063)	0.239*** (0.048)
Indirect effect (long run)	0.103*** (0.030)	0.082*** (0.022)			−0.111*** (0.024)	−0.082*** (0.014)	−0.952*** (0.189)	−0.507*** (0.120)
Total effect (long run)	0.492*** (0.091)	0.343*** (0.073)			0.363*** (0.048)	0.199*** (0.034)	−0.675*** (0.229)	−0.268* (0.146)
R <sup>2</sup> (within)	0.8665	0.9271	0.8428	0.8929	0.8096	0.8361	0.9082	0.9580
Obs	252	252	252	252	252	252	252	252

\*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

**Table 16**

Estimation results of FMOLS.

Dependent variable: lnGGDPpc		
Estimation technique	FMOLS	D-K Two-way FE
lnRETI	0.195** (0.098)	0.188*** (0.044)
lnAFFVadd	−0.644*** (0.100)	−0.535*** (0.040)
lnGlobalization	−2.221*** (0.490)	−1.807*** (0.193)
lnFinancialDevelopment	0.307** (0.142)	0.324*** (0.096)
lnGini	−0.354 (0.426)	−0.089 (0.323)
Constant	20.956*** (2.229)	17.546*** (0.802)
Country FE	Yes	Yes
Year FE	Yes	Yes
R <sup>2</sup>	0.934	0.912
Number of Obs.	251	252

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; the parenthesis indicates standard error.

- Robustness test for panel regressions with heterogenous slope

export or import energy more efficiently [91]. Such regional energy system and energy market integration allows Central America to benefit from economies of scale by decreasing energy costs and marginal price of energy as well as fostering the integration of renewables. As for resource dependence, a significant heterogeneous effect of the RETI on GGDPPc was observed. For countries with high resource dependence, whether on critical minerals or fossil fuels, the positive effect of the RETI

on GGDPPc was consistently greater than in countries with low resource dependence. These results show that revenues obtained from natural resource wealth account for an important portion of a government's fiscal capacity to finance large-scale renewable energy deployment in the LA region. It's worth noting that when considering resource dependency in its aggregated form (i.e., total natural resource rents), the positive effect of the RETI on GGDPPc was also verified and its impact was significantly higher in high-resource dependent countries (just as observed in its disaggregated form), namely, those countries with average annual total natural resource rents higher than the median value than those with low-resource dependence. The findings in this study are in line with Xu et al. [92], who found that both renewable energy consumption and natural resources are key determinant factors of economic performance of the BRICS economies from 1991 to 2014. According to them, natural resources and renewable energy contribute to economic growth by increasing energy supply and creating employment. Given that BRICS economies are those emerging countries with high dependence on fossil fuels, an attempt to reduce their importance within an economy might have a negative consequences for the economic performance of these countries. Similarly, Niu et al. [58] argue that renewable energy transition, natural resource abundance significantly improve environmental sustainability in China from 1970 to 2019. However, the findings in this study contrast with those of Fan et al. [50], who found that natural resource dependence has a crowding-out effect of green technological innovation and severely limit the carbon productivity of investment as well as lower population density which hinders the improvement of carbon emission efficiency. Similarly, Kahn et al. [34] studied the aggregate and disaggregate impact of natural resources on economic performance of G7 economies

**Table 17**  
Estimation results of RCCE.

Dependent variable: lnGDPpc							
Estimation technique	RCCE		MG		AMG		CCEMG
lnRETI	0.382*** (0.108)	0.262*** (0.081)	0.428 (0.433)	0.311*** (0.096)	0.302** (0.122)	0.212** (0.096)	0.362*** (0.122)
lnAFFVadd		−0.324* (0.173)		−0.629** (0.253)		−0.249** (0.120)	−0.239* (0.133)
lnGlobalization		−0.987* (0.511)		1.080 (0.786)		−0.771* (0.424)	−1.131*** (0.392)
lnFinancialDevelopment		−0.128 (0.092)		−0.089 (0.151)		−0.009 (0.084)	−0.064 (0.080)
lnGini		−0.586 (0.521)		−0.322 (0.677)		−0.220 (0.355)	0.099 (0.356)
Constant	0.116 (1.433)	4.995 (3.530)	8.878*** (0.596)	2.157 (6.210)	8.304*** (0.215)	12.618*** (2.398)	0.151 (1.551)
Trend	0.0002 (0.008)	−0.003 (0.009)	0.063*** (0.001)	0.031*** (0.009)	0.001 (0.009)	0.002 (0.009)	0.001 (0.009)
Number of obs.	252	252	252	252	252	252	252

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

- Robustness test for panel mediation analysis

**Table 18**  
Bootstrap tests for mediation effect.

	Model 2 (MV = lnCapitalInv)	Model 3 (MV = lnHydroElectDependency)	Model 4 (MV = lnResidElectConspc)	Model 5 (MV = lnHCI)	Model 6 (MV = FormalEmp)
Indirect effect	0.036** (0.018)	−0.072** (0.028)	0.090*** (0.030)	0.039* (0.021)	−0.034* (0.021)
Direct effect	0.152** (0.069)	0.260*** (0.072)	0.098 (0.064)	0.149** (0.072)	0.222*** (0.072)
Total Effect	0.188*** (0.066)	0.188*** (0.069)	0.188*** (0.070)	0.188*** (0.066)	0.188*** (0.069)

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; [] indicates bootstrap standard error.

- Robustness test for heterogeneity analysis

**Table 19**  
Robustness test for heterogeneity analysis replacing lnRETI with lnRETI.

Dependent variable: lnGDPpc						
	Region		MineralRent		FossilFuelsRent (Oil + N.Gas + Coal)	
Median	South America	Central America	Low dependency on minerals	High dependency on minerals	Low dependency on fossil fuels	High dependency on fossil fuels
lnRETI	0.240*** (0.065)	0.341*** (0.048)	0.155 (0.095)	0.223* (0.115)	0.116 (0.109)	0.244*** (0.078)
lnAFFVadd	−0.388*** (0.085)	−0.655*** (0.048)	−0.388*** (0.103)	−0.393*** (0.141)	−0.388*** (0.096)	−0.515*** (0.144)
lnGlobalization	−1.919*** (0.347)	−1.522*** (0.255)	−1.154* (0.705)	−1.931*** (0.434)	−1.318* (0.741)	−1.411*** (0.431)
lnFinancialDevelopment	0.308*** (0.085)	0.006 (0.119)	0.313** (0.146)	0.185 (0.163)	0.317** (0.148)	0.128 (0.146)
lnGini	−0.135 (0.341)	0.217 (0.186)	0.705* (0.378)	−1.320*** (0.437)	0.772** (0.374)	−1.308*** (0.426)
Constant	18.098*** (1.651)	15.280*** (1.023)	11.548*** (3.357)	22.617*** (1.898)	11.937*** (3.383)	20.607*** (1.776)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
R <sup>2</sup> (within)	0.9518	0.9774	0.9228	0.9044	0.9210	0.9049
Obs	136	102	119	119	119	119

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels respectively; the median is less affected by outliers and skewed data than the mean and is usually the preferred measure of central tendency when the distribution is not symmetrical.

and found a negative relationship among them. Wang et al. [48] argue that in resource-rich developing countries, natural resource abundance constraints severely green economic growth through hindering technological spillovers from technological innovation, human capital investment, and opening up to the global market.

Lastly, based on the estimates from the panel spatial regressions, the results reveal strong spatial dependence among LA countries. This

implies that the green growth performance of one country is intrinsically related to that of its neighboring countries. Moreover, the substantial negative spatial spillover effect of renewable energy transition on green growth was found, indicating that the RETI of one country can adversely influence the green economic performance of its neighboring countries. The negative spatial spillover effect of the RETI can be attributed to the siphon effects. Specifically, LA countries with advanced clean energy

**Table 20**  
Robustness test for heterogeneity analysis using TNRR.

Dependent variable: lnGGDPpc		
	TNRR	
	Low dependency on natural resources	High dependency on natural resources
Median		
lnRETI	0.193 (0.120)	0.255*** (0.078)
lnAFFVadd	−0.434*** (0.106)	−0.501*** (0.133)
lnGlobalization	−1.994*** (0.656)	−1.131*** (0.394)
lnFinancialDevelopment	0.442*** (0.142)	0.081 (0.145)
lnGini	0.746* (0.378)	−1.234*** (0.461)
Constant	15.025*** (3.369)	19.020*** (1.808)
Country FE	Yes	Yes
Time FE	Yes	Yes
R <sup>2</sup> (within)	0.9230	0.9216
Obs	126	126

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively; the median is less affected by outliers and skewed data than the mean and is usually the preferred measure of central tendency when the distribution is not symmetrical; () indicates standard error; countries with low dependency on natural resources, namely those with a mean value of TNRR equal or lower than 2.560033 are Costa Rica, El Salvador, Guatemala, Honduras, Panama, Paraguay and Uruguay; countries with high dependency on natural resources, namely those with a mean value of TNRR higher than 2.560033 include Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, and Peru.

- Robustness test for panel spatial regression models

technologies and a significant share of renewable energy in their electricity mix tend to require more talent, highly-skilled workers, and investments. Consequently, the renewable energy transition can boost green economic growth in the local economy. In contrast, neighboring countries, due to their lagging technological advancements, limited innovation capacities, and lower levels of economic development, might experience outflows of these resources. These findings indicate that the progress of a local economy in renewable energy development has a significant spatial spillover effect on the green economic growth of neighboring countries (albeit negatively), thus confirming the validity of **Hypothesis 4** of this study. Lee et al. [56] analyzed the impact of LCCP policy in 253 Chinese cities and they found that LCCP policy significantly accelerate energy transition in pilot cities but it negatively affects energy transition in surrounding non-pilot cities in China. The summary of the research is shown in [Table 22](#).

The new insights from empirical results and new theoretical findings of this study can be summarized as follows:

First, this study demonstrated that transitioning to renewable energy sources significantly fosters green economic growth, effectively addressing the trade-off between economic growth and environmental degradation. Moreover, the use of GGDPpc, which appropriately accounts for the valuation of ecosystems, offers a much better way to measure balanced economic growth aligned with environmental sustainability, which is a core aspect of green growth strategies [68]. This finding can contribute significantly to the existing body of research on the energy-growth nexus. Specifically, this approach may offer new perspectives on studies that focus on the relationship between economic progress and environmental degradation, such as the Environmental Kuznets Curve (EKC) hypothesis. By providing a unified framework using green economic growth — instead of separately analyzing the

**Table 21**  
Panel spatial regressions using an inverse distance function as W.

Dependent variable: lnGGDPpc				
Model	SDM with inverse distance function		SDM with contiguity matrix	
lnRETI	0.326*** (0.067)	0.269*** (0.058)	0.382*** (0.055)	0.278*** (0.044)
lnAFFVadd		−0.515*** (0.055)		−0.328*** (0.051)
lnGlobalization		−1.565*** (0.268)		−1.730*** (0.225)
lnFinancialDevelopment		0.327*** (0.081)		0.310*** (0.067)
lnGini		−0.235 (0.248)		0.345* (0.202)
W*lnRETI	−1.519*** (0.274)	−0.655** (0.264)	−1.418*** (0.198)	−0.881*** (0.172)
W*lnAFFVadd		−0.249 (0.325)		−0.562** (0.221)
W*lnGlobalization		−2.912*** (0.834)		−2.031** (0.819)
W*lnFinancialDevelopment		−0.008 (0.469)		−0.949*** (0.270)
W*lnGini		0.415 (0.783)		1.801*** (0.680)
Rho (ρ)	0.129 (0.103)	0.091 (0.152)	0.692*** (0.103)	0.455*** (0.113)
Lambda (λ)				
Country FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Decomposition of spatial effects of RETI on GGDPpc				
Direct effect (long run)	0.303*** (0.074)	0.262*** (0.061)	0.277*** (0.063)	0.239*** (0.048)
Indirect effect (long run)	−1.306*** (0.305)	−0.538** (0.237)	−0.952*** (0.189)	−0.507*** (0.120)
Total effect (long run)	−1.004*** (0.339)	−0.276 (0.264)	−0.675*** (0.229)	−0.268* (0.146)
Obs	252	252	252	252

Note: \*\*\*, \*\*, \* denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

**Table 22**  
Summary of the research.

Research objectives	Hypothesis	Methodology	Empirical findings	Hypothesis verified
Determine the effect of renewable energy transition on green economic growth in the LA region.	H1: Renewable energy transition significantly promotes green economic growth in the LA region.	Standard linear regressions and Slope heterogeneity analysis (MG, AMG, CCEMG).	Renewable energy significantly boosts green economic growth in the LA region.	Yes
Identify the primary mechanisms through which renewable energy transition affects green economic growth in the LA region.	Renewable energy transition significantly boosts green economic growth through H2a: increasing capital investment, H2b: reducing dependency on hydropower, H2c: promoting per capita electricity consumption in residential sector, H2d: enhancing human capital, and H2e: contributing to the creation of formal jobs.	Panel mediation analysis	Except for the creation of formal jobs, the impacts of all other mediating variables align with the hypothesis.	Hypotheses H2a, H2b, H2c, and H2d were verified.
Analyze the heterogeneous impacts of renewable energy transition on green economic growth in the LA region in accordance with the geographical location of a country and its dependence on minerals and fossil fuels.	The impact of renewable energy transition on green economic growth might be significantly different depending on country's geographical location and its dependency on critical minerals and fossil fuels rents.	Heterogeneity analysis	The impact of the renewable energy transition on green economic growth is significantly greater in Central American countries than in those in South America. In countries with a high reliance on critical minerals and fossil fuels, the positive impact of renewable energy is more pronounced.	Yes
Analyze the spatial spillover effects of renewable energy transition on green economic growth in the LA region.	Renewable energy transition not only affects local country's green economic growth but also exerts significant influence on surrounding countries' green economic growth.	Spatial regression analysis	Renewable energy has a significant positive impact on a local economy's green economic growth. However, negative spatial spillover effects (siphon effects) were observed. This implies that the renewable energy development in local country adversely affects the green economic growth of neighboring countries	Yes

relationship between economic growth and environmental degradation — and employing the RETI as a proxy for the transition to renewable energy, this approach might provide new insights on the major impacts of how increased adoption of renewable energy affects the progress of sustainable green growth. These insights might significantly alter the implications of scale, composition, and technical effects, which are the three primary mechanisms through which economic progress impacts on environmental quality in the traditional EKC hypothesis.

Second, this study not only demonstrated the positive effect of the RETI on GGDPpc but also identified the specific channels through which the RETI affects GGDPpc in the LA region, which constitutes an important value-added aspect of this study. According to the empirical findings of this study, renewable energy sources are shown to foster green economic growth by promoting capital investment, reducing dependency on the dominant source of the energy mix (hydropower), increasing electricity consumption among the population, and supporting human capital accumulation. Thus, governments in the LA region should use these channels to exploit the potential benefits of renewables in fostering green economic growth. Furthermore, the estimates suggest that governments in the LA region should be aware of potential job losses caused by the clean energy transition and proactively support laborers displaced by such a transition, helping them to adapt to new labor markets by providing adequate reskilling programs.

Third, this study is differentiated from existing research on the resource curse in demonstrating that the impact of RETI on GGDPpc is consistently higher in countries with high natural resource dependency than those with lower dependency, indicating that natural resource wealth can have a blessing effect on the pathway to a low-carbon energy transition for resource-rich countries in the LA region. In the LA region, revenues stemming from natural resource wealth play a crucial role to determining the success or failure of a clean energy transition, which calls for the importance of efficient allocation of these revenues by governments. Additionally, the results point out significant challenges faced by many LA countries on the path to a low-carbon energy transition, due to their excessive dependence on natural resource rents for

government expenditure and limited financing sources to fund the costly renewable energy deployment.

Lastly, the negative spatial spillover effect (siphon effect) of the RETI on GGDPpc, as observed in this study, deserves careful attention from both academics and policymakers. Contrary to the hypothesis of this study, the RETI negatively impacts GGDPpc of surrounding countries. Given that a low-carbon energy transition will not only affect the performance of green economic growth in the local economy but will also have significant repercussions for surrounding economies, leading to paradigm shifts in regional energy markets, trade patterns, labor markets, and industry dynamics, governments in the LA region should be aware of potential adverse effects. These include the migration of talented workers from one country to another to search for better labor conditions (the brain drain effect), and the reallocation of industries and firms to countries with less stringent environmental policies (the pollution haven effect).

Although this research is primarily focused on the LA region, the conclusions drawn from the research bring valuable insights into other developing countries in the globe. The transition to renewable energy is crucial to achieving SDG in developing countries, as it simultaneously addresses both socioeconomic and environmental challenges. Renewable energy provides reliable, affordable, and clean energy without the need for expensive electricity grid infrastructure. Its decentralized nature also allows access for vulnerable populations in remote areas, significantly improving their well-being and helping to reduce poverty and income inequality. Moreover, by lowering greenhouse gas (GHG) emissions, renewable energy enhances environmental quality and the health status of populations. It's worth noting that developing countries, where future energy demand is expected to increase rapidly due to the rapid population growth and the expansion of the middle class, renewable energy might play a vital role in staying on track for net zero goals.

The limitations and potential sources of error in the study can be summarized as follows:

Firstly, the use of dynamic panel data estimators, such as the GMM, was not feasible in this study due to the limited sample size of panel data



( $N = 14$ ,  $T = 18$ ). Although unobserved heterogeneity—such as country fixed effects and time fixed effects—along with relevant control variables were appropriately incorporated in all regression models to minimize omitted variable bias and to some extent address endogeneity issues [70], further studies will be needed to address potential reverse causality and endogeneity issues thoroughly by employing GMM estimator or including instrumental variable approach for a larger number of countries. Also, it is worth noting that both RETI and GGDPpc might exhibit path dependence features and a dynamic approach could provide more accurate estimation results than a static one.

Secondly, concerning the accounting method of GGDPpc, the negative environmental externalities included in this study—deforestation, mineral depletion, particulate matter and CO<sub>2</sub> emissions—might be subject to some measurement error due to the difficulty in inferring correct economic values of environmental goods and services [68]. Also, a broader environmental externalities associated with economic activities, such as water pollution, natural disasters, and land use changes due to the expansion of agricultural production or mining activities, should be included in further studies as they become available. Additionally, the social dimension of green economic growth, which encompasses factors such as equitable income distribution, gender equality, opportunities for quality education, and access to affordable, high-quality energy sources, is not incorporated into the calculation of GGDPpc due to the unavailability of the data. However, the social dimension is one of the three key pillars of the SDG, alongside the economic and environmental dimensions. Therefore, it is paramount to include the social dimension in the accounting of GGDPpc to derive more comprehensive and holistic indicator of green economic growth that is aligned with the SDG.

Third, it is worth noting that the calculation of GGDPpc in this study is based on the current value of US dollars rather than on real GDP. This approach is due to the challenges encountered in obtaining real GDP for many LA countries, each using deflators with different base years. However, GGDPpc based on the value of real GDP will be necessary to derive robust indicator less affected by inflation or deflation.

Third, this study has identified the primary mechanisms by which the RETI affects GGDPpc at the country-level. However, this approach may be overly general, considering that energy transition does not impact all industries and firms uniformly throughout the supply chain. The impact of the RETI might vary significantly across industries and sectors in terms of energy intensity, penetration of fossil fuels, and the ease of adopting renewable energy in their production structures. Therefore, a more in-depth, sector-level analysis will be needed to gain a better understanding of the real impact of the RETI on the GGDPpc within an economy.

Lastly, this study examined the heterogeneous effect of the RETI on GGDPpc, in association with a country's geographical location and dependency on natural resources (fossil fuels and minerals). However, a more detailed analysis focusing on specific types of fossil fuels and minerals would be desirable. This is because not all fossil fuels face the same risk of asset stranding. For instance, natural gas is often considered an intermediary or 'bridge' energy source for the low-carbon energy transition, in contrast to oil and coal, which are more carbon-intensive and likely to suffer from earlier devaluations. Similarly, investigating the heterogeneous impact of the RETI on GGDPpc in terms of critical mineral endowments, especially lithium and copper, will be necessary. This is particularly relevant to the fact that the LA region is one of the largest producers of these minerals and the implications of achieving successful low-carbon economy transition might be huge accordingly, given that these critical minerals are crucial components to many renewable energy technologies.

## 7. Conclusion and policy recommendations

### 7.1. Conclusions

In this study, a panel dataset of fourteen LA countries spanning from 2003 to 2020 was used to assess the impact of the transition to renewable energy on green economic growth. Furthermore, this research identified the key mechanisms through which this transition affects green economic growth. It also examined the heterogeneous impact of renewable energy transition on green economic growth, taking into account the geographical location of countries and their dependency on natural resources, specifically minerals and fossil fuels. Lastly, the study assessed the presence of spatial spillover effects of the transition to renewable energy on green economic growth in the LA region. Based on the empirical findings of this study, the following conclusions can be drawn:

First, the positive impact of the renewable energy transition on green economic growth has been confirmed to be robust. This is evident from various standard linear regression models, as well as MG, AMG, and CCEMG estimators, all of which provide consistent estimation results even in the presence of slope heterogeneity. Moreover, the robustness of empirical findings in this study is reinforced through the application of alternative econometric techniques, namely, FMOLS for standard linear regressions and RCCE for panel regressions with heterogeneous slopes.

Second, capital investment, hydroelectricity dependency, per capita residential electricity consumption, human capital, and formal jobs creation were found to have significant mediation effects between renewable energy transition and green economic growth in the LA region. Among these factors, capital investment and human capital were found to have a partial positive mediating effect, whereas residential electricity consumption per capita had a complete positive mediating effect, meaning that the impact of the transition to renewable energy on green economic growth was entirely conveyed through per capita residential electricity consumption. In the cases of hydroelectricity dependency and formal job creation, they showed a partial negative mediating effect, indicating that the positive impact of the transition to renewable energy on green economic growth was partially counteracted by these two factors. Furthermore, bootstrap tests for the mediation effects were conducted to assess the robustness of empirical findings of this study, and they consistently confirmed the existence of mediation effects for the factors mentioned, and the sign and the significance level of the indirect, direct, and total effects remained consistent.

Third, the significant heterogeneous effect of renewable energy transition on green economic growth was observed in the LA region. Specifically, the impact of renewable energy transition varies significantly based on a country's geographical location and its dependence on minerals and fossil fuels. Central American countries exhibited a stronger positive effect of renewable energy transition compared to their South American counterparts. Furthermore, countries with a high dependence on minerals and fossil fuels showed a significant and stronger positive impact of renewable energy transition on green economic growth. When using an aggregated measure of resource dependency (total natural resource rents) instead of a disaggregated measure (dependence on minerals and fossil fuels), a similar pattern was observed. This confirms the robustness of empirical findings of this study. Lastly, based on the estimates from the spatial panel regressions, a significant spatial correlation among the fourteen LA countries was confirmed, indicating that the green economic growth in the LA region shows a significant spatial dependence. According to the estimates, the renewable energy transition was found to have a substantial negative spatial spillover effect (siphon effect). This implies that a local country's renewable energy transition negatively impacts the green economic growth of its neighboring countries. The direct effect (or local effect) of the RETI on GGDPpc was positive and significant at the 1 % level, corroborating the earlier estimates in this study. Nevertheless, this positive effect is offset by the siphon effect, resulting in an overall

negative spatial effect of the renewable energy transition on green economic growth within the LA region. The robustness of these findings was further tested by an inverse distance matrix after replacing the contiguity matrix. The results remained consistent with the initial observations of this study.

## 7.2. Policy recommendations

Based on the findings of the study, several important policy recommendations can be made as follows:

First, as the transition to renewable energy has been shown to significantly boost green economic growth in the LA region, the policymakers in the region should implement adaptable strategies to facilitate the adoption of renewable energy technologies and accelerate renewable energy transition. A primary challenge for many LA countries to face, when adopting clean energy technologies and scaling up renewable energy deployment, is the capital-intensive nature of these projects and the substantial upfront costs they require. Stimulating investments to finance costly renewable energy initiatives, governments in the region should endeavor to build up predictable and stable investment ecosystem for private investors and financiers. Given that many LA countries are heavily burdened with public debts and associated high risk-premiums, it is essential for regional governments to adopt de-risking measures to significantly lower potential high risk of the investors and financing costs. In tandem with this, governments in the LA region can adopt innovative financial tools. These includes debt-for-climate swaps, which are partial debt relief operations conditional on the evidence of the commitments of the debtors to undertaking climate related investments particularly suitable for highly-indebted nations like those in the LA region [93], the issuance of green bonds to finance environmental sustainability projects, and offering loan guarantees which can facilitate credit access for SMEs and small stakeholders who, despite their interest in adopting green technologies, are frequently constrained by limited funding opportunities.

Second, as renewable energy transition has been demonstrated to boost green economic growth through capital investments, reduction in hydroelectricity dependency, increase in electricity consumption in residential sector, and human capital enhancement in the LA region, regional governments should continue to exploit these channels and further leverage them to reap significant benefits from decarbonization, ultimately aiming to achieve the SDG in the region. In relation to capital investments, the policymakers in the LA region might consider introducing financial incentives, including tax credits and exemptions, to encourage enterprises to invest in clean energy technologies and incorporate them into their supply chains. Implementing such measures can significantly stimulate capital investments in the region, which in turn could catalyze economic activities and green economic growth in the region. Regarding hydropower dependency, a transition towards non-conventional renewables, such as solar and wind, might provide a significant opportunity for LA countries to enhance the resilience of their energy systems and promote energy security through diversification of the energy mix. This is particularly important given that prolonged drought seasons and changes in the hydrological cycle caused by climate change, pose serious threats to the LA electricity mix dominated by hydropower. To further accelerate the integration of renewables in energy mix and boost their capacity installations, the governments in the LA region might consider providing guarantees for power purchase agreements for renewable energy producers. The transition to renewable energy can also significantly enhance energy services in the residential sector by providing affordable, secure, and clean electricity. This might have important implications for those living in marginalized and remote areas, who often lack access to high-quality energy services such as electricity and predominantly rely on traditional biomass energy sources for cooking and heating. An enhanced access to electricity generated from renewable sources in residential sector could significantly reduce indoor air pollution and the associated health risks,

resulting in considerable savings in health-related expenditures and a marked improvement in the well-being of the citizens. Such improvements would, in turn, positively influence green economic growth in the LA region. The transition to renewable energy offers the LA region a significant opportunity to capitalize on green growth through human capital enhancement as well. Given the technology- and knowledge-intensive nature of renewable energy technologies, it's imperative for the policymakers in the LA region to build the necessary capabilities to prepare for the clean energy transition. To achieve this, the governments in the LA region should allocate their public spendings more efficiently, placing a strong emphasis on R&D initiatives and education. Additionally, they should provide effective training programs and foster close collaboration among various stakeholders, including government entities, academic institutions, and the industrial sector, to cultivate a highly-qualified workforce. Lastly, concerning the creation of formal jobs, it is worth noting that this research could not find evidence of renewable energy transition driving green economic growth through this channel. In fact, the transition to renewable energy resulted in a reduction in formal jobs creation. Thus, governments in the LA region should intensify their efforts to capitalize on employment opportunities in the green energy sector brought about by the renewable energy transition. At the same time, they should mitigate potential adverse effects, such as job losses in the fossil fuel sector, by facilitating the reallocation and reintegration of these workers through targeted retraining programs.

Third, the heterogenous effect of renewable energy transition on green economic growth observed in terms of geographical location and natural resource dependency in the LA region suggests that different approaches will be required for achieving successful decarbonization and green growth in the region. Given that the transition to renewable energy in South American countries was found to have a significantly lower positive impact on green economic growth compared to Central American countries, the former should intensify their efforts to integrate their regional renewable power systems and energy markets, thereby benefiting from economies of scale as well as relevant energy information and sharing the know-hows among member states, similar to the achievements of Central American countries with SIEPAC. The more pronounced positive effect of renewable energy transition on green economic growth in high-resource-dependent countries indicates that they have opportunities to utilize revenues obtained from critical mineral or fossil fuel production in such an efficient manner that the benefits are more evenly distributed among stakeholders, paving the way for inclusive green growth and sustainable development. Considering that the transition to renewable energy will significantly boost demands for critical minerals while decreasing demands for carbon-intensive fossil fuels in the coming decades, governments should be aware of potential windfall gains from critical mineral booms and the risk of stranded assets in fossil fuel sectors. In the former case, governments have an opportunity to invest revenues derived from sales of critical minerals in the development of local manufacturing capacities for clean energy technologies and local economic development. In the latter case, governments should support for those who are adversely affected by the clean energy transition. Offering tax incentives and providing technical support and assistance to fossil fuel production companies that shift towards green energy, implementing retraining programs for displaced workers in the fossil fuel sectors can be helpful to minimize the adverse effects of stranded assets and facilitate a smooth transition to renewable energy.

Lastly, the observed negative spatial spillover effects of renewable energy transition on green economic growth in the LA region indicate strong need for enhanced cooperation and collaboration among regional countries. Initiatives such as the Escazú Agreement, which is a regional agreement on access to information, public participation, and justice in environmental matters, will be helpful in preventing this 'siphon effect', where investments and high-quality workforces migrate to countries with more favorable socioeconomic conditions.

### 7.3. Limitations of the study and future research directions

In this study, the impact of the renewable energy transition on green economic growth, as well as the primary mechanisms through which such a transition affects green economic growth, was thoroughly examined using rigorous econometric techniques. However, this study has certain limitations and encourages further research is necessitated to address the following issues:

Firstly, the small sample size due to unavailability of the data in the LA region prevented us from using widely accepted econometric techniques such as GMM, which are robust to endogeneity issues. For the same reason, a static model was used instead of a dynamic one in the panel regressions. However, given the path-dependent nature of renewable energy transition, a dynamic model would be crucial for obtaining more accurate estimates of its impact on green growth for future research. Furthermore, expanding the dataset to include more countries and extending the time frame will be important to obtain more robust results. Secondly, when calculating GGDPpc as a proxy for green economic growth, only deforestation, mineral depletion, particulate emission damage, and CO<sub>2</sub> emission damage were included as negative externalities due to limited data availability. Further research would be of interest when incorporating additional negative environmental externalities, such as water pollution and costs of natural disasters, to provide a more comprehensive indicator of green economic growth. Additionally, the social dimension of green economic growth—including a more equitable distribution of income, poverty reduction, gender equality, opportunities for quality education—should be incorporated into GGDPpc, given that equitable and just green economic growth is crucial for achieving SDG. Thirdly, when it comes to identifying the primary channels through which RETI affects green growth, a sectoral-level approach will be desirable instead of a regional or country-level approach in order to provide more accurate guidelines for policy-makers and stakeholders. Given that the low-carbon energy transition does not equally affect industries and sectors within an economy, identifying the primary mechanisms of the RETI on green growth for strategic sector is critical to support those adversely affected by the energy transition and to exploit the maximum potential of those benefiting from it. Lastly, in relation to the heterogeneous effects of the RETI on GGDPpc, a more detailed analysis concerning different types of critical mineral endowments—lithium, nickel, cobalt, copper—would be interesting research as well.

### CRedit authorship contribution statement

**Young Kyu Hwang:** Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing – original draft. **Ángeles Sánchez Díez:** Supervision.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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