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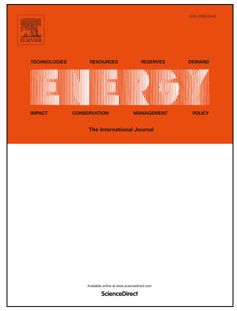

Assessing the advancement of new renewable energy sources in Latin American and Caribbean countries

Nuno Silva, José Alberto Fuinhas, Matheus Koengkan

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Authors Contributions

Nuno Silva: Investigation, Methodology, Validation, Writing-Original draft preparation. ***José Alberto Fuinhas***: Conceptualization, Supervision, Visualization, Writing-Reviewing and Editing. ***Matheus Koengkan***: Data curation, Formal analysis, Investigation.

Assessing the advancement of new renewable energy sources in Latin American and Caribbean countries

Abstract: The research focuses on the evolution of non-hydroelectrical renewable installed capacity from 2001 to 2017 in nineteen countries from the Latin America and the Caribbean (LAC) region. The deployment of new renewables has several characteristics that point to nonlinear relationships with its drivers. In accordance, the quantile regressions econometric technique of Canay was used. The option to use this econometric technique stem from Canay model estimation can capture the variation between different countries (cross-section). The Canay model estimation results support that renewable energy finance flows, economic globalisation index, and carbon dioxide emissions positively affect non-hydroelectrical renewable installed capacity. The positive impact of carbon dioxide (CO_2) emissions on non-hydroelectrical renewable installed capacity could be related to increased environmental, political, and social pressure regarding the increase of environmental degradation caused by the growth in emissions that encouraged the new investments in renewable energy technologies. It also could be related to the consumption of new renewable energy sources that mitigate CO_2 emissions in the LAC countries.

Keywords: new renewable energy sources; quantile regression; Latin American and Caribbean countries; financial development.

1. Introduction

This study focuses on non-hydroelectrical renewable installed capacity in Latin American and Caribbean (LAC) countries. The take-off of new renewables, wind, solar, and bioenergy, puts challenging questions to handle without further research. Traditional econometric approaches are unfeasible in the presence of large variable values that result from the early stages of a growth take-off. In fact, the growth values seem enormous, but only because the starting point is shallow, even without any expression.

Why is it important to research the emergence of new renewable energy? Renewable energy sources tend to be diversified and stand at different levels of technological maturity. Given the dimension of the energy's transition process from fossils to renewables requires the involvement of markets as well as policymaker guidance. Governments have been an active partner and are involved in mitigating several economic and societal problems that arise from the vast transformations underway. Nevertheless, governments have shown a limited capacity to finance the energy transition. The private sector's participation in the rise of new renewables put new renewables' competitiveness at the centre of take-off.

Why is the research of LAC countries necessary for the literature and practitioners? The LAC countries are mostly economies in development. Economies in development are the predominant kind of economies on Earth. LAC countries lessons could be valuable for countries initiating the first stages of the take-off of new renewables. Indeed, the same processes have a high probability of occurring in the same way for new energy sources in the future.

The research question of this study is as follows. What is the impact of the factors behind the high growth of new renewables in LAC countries? Given that the research focuses on analysing the new renewables' growth, the investigation excludes hydroelectrical power. Indeed, hydro should be excluded because most of its capacity was installed in the last century before our new renewable energy dataset starts.

Why can the LAC countries contribute to literature? LAC countries share several common factors that turn them into a unique place in the World. Nevertheless, the LAC region shares the same problems that are frequent in developing countries. Indeed, LAC countries choice is based on the fact that they have exceptional natural conditions to produce energy from renewable sources. They have been exposed to massive growth in non-hydroelectrical installed capacity since the early years of this century. Fortunately, data on the evolution of renewable installed capacity and its drivers are available for 19 countries allowing a representative cover of the LAC region.

What is the novelty of our research? Did it fill a gap in the literature? Our approach was developed to handle the initial stages of non-hydroelectrical renewable installed capacity take-off in LAC countries. To measure new renewable energy sources' growth was used the yearly change of Gigawatts (GW) of non-hydroelectrical installed renewable capacity, and this measure was used as our explained variable. Indeed, the coherence of evolution among the new renewables is necessary to achieve an in-depth vision of the drivers of the evolution of the yearly change. The option to measure the evolution of installed capacity through the yearly change in GW, instead of the most used in literature, the growth rate, is conditional in it may provide more accurate insights about the causal impact of factors that promote renewable energy sources. The use of growth rates has unwanted side effects resulting from high growth rates in the first years of the sample because the initial installed capacity was relatively low in most LAC countries. We also fill the literature gap about non-hydroelectrical renewable installed capacity drivers in its first stages in LAC countries. The econometric analysis of the initial phase of the development of new renewables is essentially an absence in the literature that needs to be fulfilled.

What is under study? In short, the research focuses on the evolution of non-hydroelectrical renewable installed capacity from 2001 to 2017 in 19 countries from the LAC region. The deployment of new renewables has several characteristics that point to nonlinear relationships with its drivers. Indeed, by one hand, it is expected that any process of take-off will behave in a nonlinear way with its determinants. On the other hand, new renewables were under fast technological evolution and achieving maturity or opening a new phase, for example, as energy sources like photovoltaic become market competitive with fossil sources. Technological innovations have been a significant source of change in the process toward achieving energy efficiency. Technological innovation has also led to economic structural changes, mainly in the production's process that influences the renewable energy market competitiveness. As the political option was more often than not to proceed with renewable energy deployment in a market-oriented environment rather than through a public incumbent, renewable energy sources' competitiveness plays a significant role. This role evolves with the deployment of new renewables themselves in a possible nonlinear way. In accordance, the study makes use of the quantile regressions econometric technique. This technique is prepared to handle the heterogeneity that is present at different quantiles of the distribution. One of the advantages of quantile estimation is that it does not require that the variables follow a normal distribution.

The article is organised as follows**. Section 2** analyses the literature. **Section 3** reveal the data and method used in the research. **Section 4** show empirical results. **Section 5** discusses the empirical results. **Section 6** concludes the research and present policy recommendations.

2. Literature review

Since the note *On the Relationship Between Energy and GNP* (Kraft and Kraft, 1978), the search for the link between energy consumption and economic growth has been an active topic in the field of energy economics. This research has evolved first mostly under the designation of "nexus" and later in the form of an "extended nexus" (Fuinhas and Marques, 2019). This long saga has covered all imaginable energy links, economic growth, and a panoply of variables. Despite some stylised facts, many aspects still require further empirical research.

Indeed, among the less well understood empirical behaviours is promoting an effective increase in renewable energy, specifically wind, solar, and bioenergy.

The deployment of renewables and, in particular, the new renewables in LAC countries were a multidimensional phenomenon that includes several players and the development and implementation of public policies. The deployment of the new renewables has been limited to a non-long time span. Nevertheless, it is visible that the evolution of how it was approached and inflexions can be observable. The deployment of renewable energy (RE) is also linked to political decisions to cope with climate change. Curbing carbon dioxide (CO_2) emissions becomes part of the international political agenda and a source of concern for a growing number of citizens. Political decisions are not subject to market behaviour but cannot ignore it, adding more complexity to the RE deployment phenomenon.

The panorama of promoting RE in Latin American (LA) countries, particularly solar panels, and the establishment of mini-grids, requires policymakers to pay attention to areas that do not achieve economies of scale that turn them profitable (Banal-Estañol et al., 2017). Banal-Estañol et al. (2017) pinpoint that LA countries also have adopted universal service policies to allow low-income households to connect to grids. They also stress the value of establishing strong links between stakeholders to care for the launch of new technologies.

The promotion of renewables in LA countries also has was based on measures that include tax incentives. These tax incentives workout mostly through exemptions in income tax and through sales tax/value-added taxes or via tariffs (Washburn and Pablo-Romero, 2019). Washburn and Pablo-Romero (2019) pinpoint that most LA countries are using active policies to promote RE and that the intensity of promoting RE is related to their RE adoption performance. They also find that they switch from a system based on feed-in tariffs to use the auction system.

Kruckenberg (2015a) pinpoint that international programmes directed to facilitate the adoption of RE technologies among less developed countries have achieved a mixed level of success. The author identifies partnerships as the dominant RE technologies programme. These programmes involve local, national, and international organisations. Nevertheless, Kruckenberg (2015a) stress that the attention should be put on key actors' relationships more than on barriers and drivers to develop RE.

Kruckenberg (2015b) stress that North-South partnerships for sustainable energy face numerous knowledge challenges in implementing off-grid RE technologies. The author concludes that the exchange of knowledge–power in relationships involving sustainable energy is vital in establishing off-grid RE technologies.

Kim and Park (2018) analysed the Clean Development Mechanism, created by the Kyoto Protocol to promote low-carbon development, in a panel of 64 host countries from 2001 to 2014. They found that the adoption of RE is conditional on the level of financial development of countries. More precisely, they found that the Clean Development Mechanism's effect in implementing RE is much more forceful in countries with undeveloped financial markets. The authors also conclude that promoting that kind of RE projects is beneficial to countries with underdeveloped financial markets. Renewable energy sources in developing countries, with unsophisticated financial markets, face, as a rule, scarcity of financing through debt and equity (Kim and Park, 2018). Moreover, Zeng et al. (2017) complement that in developing countries such as Brazil, Russia, India, China, and South Africa, the industry funds play an important role in renewable energy projects, where in the early stage of renewable energy development, their financing models still need to mature. In developing countries, most renewable energy projects raise funds from debt; these funds are provided by banks and related institutions, which offer developers very low-interest loans. The use of RE technologies is severely constrained in countries with limited access to external financing (Kim and Park, 2016).

CO_2 emissions growth has been connected consistently with evolution through the time of several variables. Among these determinants of CO_2 emissions, the literature identifies some drivers, such as energy consumption, globalisation, urbanisation, trade openness (e.g., Zeng et al., 2020; Guan et al., 2018; Ertugrul et al., 2016; Kasman and Duman, 2015) or even more unexpected like obesity and overweight (Koengkan and Fuinhas, 2021) or renewable energy consumption and outdoor air pollution death rate (Koengkan et al., 2021).

The necessity of an initial phase of mitigating and in a second one that achieves carbon neutrality had put pressure on governments to act and citizens to behave in ways that limit CO_2 emissions. For example, Bersalli et al. (2020) support that global decarbonisation strategies are based on electricity generation development built on renewable energy technologies.

One of the most used vehicles to stimulate investment in renewable energies have been public policies. Bersalli et al. (2020) indicate that public policies to boost renewable energies sources began in 1980 in developed economies and spread to emerging countries in the 2000s. For example, these authors found that policy's particularities act to turn auction the elected instrument to promote de diffusion of renewable energies in LA countries.

Bradshaw (2017) analysed market-oriented regulations in Brazil and concluded that reforms in the power sector have begun in the 1990s. The author underlines that Brazil's political and institutional situation act to design a regulatory reform that went beyond the traditional approach centred on efficiency and competition. That include social and environmental concerns in the planning of the energy sector. Indeed, Brazilian regulators followed creative mandates in promoting renewable energy use. Bradshaw also shows that the evolution of wind and solar shares in energy supply was conditioned by the dominance of hydropower infrastructure in Brazil.

Alvarado et al. (2019) found that output causes renewable energy in LAC countries. This causality was independent of countries that were high-income or medium-income. Renewable energy growth was also seen as a current energy policy trend (e.g., Xu et al., 2019). Indeed, renewable energy analysis entails economic, social, political, and technical dimensions.

Bersalli et al. (2020) analyse the public policies promoting renewable energy technologies for electricity generation in a panel of LA countries and a European country panel. They conclude that LA countries have been proactive in their tentative to implement renewable energy. These authors emphasise promoting public policies to increase renewable energy investment. Another finding of these authors' research is that tax incentives are insufficient to deploy renewable energy technologies.

LAC countries are mostly rich in conventional sources of energy. The transition of fossil sources to renewable ones are exposed to prices of exportation of fossil energy. The technology of extraction of non-renewable energy has evolved to allow the exploitation of these reserves abundantly. Cordano and Zellou (2020) dissect the possible consequences of super-cycles in natural gas prices on LA countries' environment. They focus on the use of hydraulic fracturing on underground water. They conclude that the mix of conditions prevalent in LA countries, such as political instability, weak institutions, governmental interventionism, and Brazilian pre-salt endowment, turn the impact of gas-price super-cycle uncertain.

Viviescas et al. (2019) focused their analyses on the impact of renewable energy on energy security in LA countries. They look to the intermittency of renewable energy sources and inquire how to mitigate it by exploring energy sources' complementarities. Their study also probes the impact of climate changes on the interaction of wind and solar sources of energy. They conclude for higher variability for wind than solar power generation. In this context, Brazil is well-positioned to play a significant role in renewable energy integration in LA countries.

3. Data and methodology

This section's main objective is to evidence, clearly and briefly, the data/variables, the group of countries, and the methodological approach that will be used in our experimental study.

3.1. Data

This study focuses on the evolution of non-hydroelectrical renewable installed capacity, between 2001 and 2017, in 19 countries from the Latin America and the Caribbean (LAC) region, such as Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, and Uruguay. Indeed, the choice of this group of countries is motivated by several reasons: (a) they possess exceptional natural conditions to produce energy from renewable sources; (b) they experienced rapid and steady growth in non-hydroelectrical installed capacity since the beginning of the new millennium; (c) data on the evolution of renewable installed capacity and its drivers are available for all these countries.

This paper aims to assess the evolution of new renewable energy sources in the LAC countries. However, our analysis excluded hydroelectrical power because most of its capacity was installed in the last century before our dataset starts. We measure the growth of new renewable energy sources through the yearly change in Gigawatts (GW) of non-hydroelectrical installed renewable capacity (**ΔRen**) and use it as our main dependent variable. We also assess, alternatively, the determinants of the evolution of the yearly change in Gigawatts (GW) of the major components of non-hydroelectrical installed capacity, namely: wind (**ΔWind)**, solar (**ΔSolar)**, and bioenergy (**ΔBio)**. All this data was retrieved from (IRENA, 2020). Our choice of measuring the evolution of installed capacity through the yearly change in GW instead of using the growth rate may provide more accurate insights into the causal impact of factors that promote renewable energy sources. The latter option would produce unreasonably high growth rates in the first years of the sample because the initial installed capacity was fairly low in most countries. Indeed, when computing growth rates, we have very high values in the initial stages, but these values are only very high because they are relative (rate) values. For example, if the initial value is zero, any addition, however insignificant, produces an infinite rate of change. Our approach is, in these cases, more suitable than traditional approaches. Furthermore, several countries have no non-hydroelectrical installed capacity at the beginning of the sample, rendering the computation of growth rates impossible. **Figure 1** below shows that installed capacity from non-hydroelectrical renewable sources increased more than tenfold between 2000 and 2017.

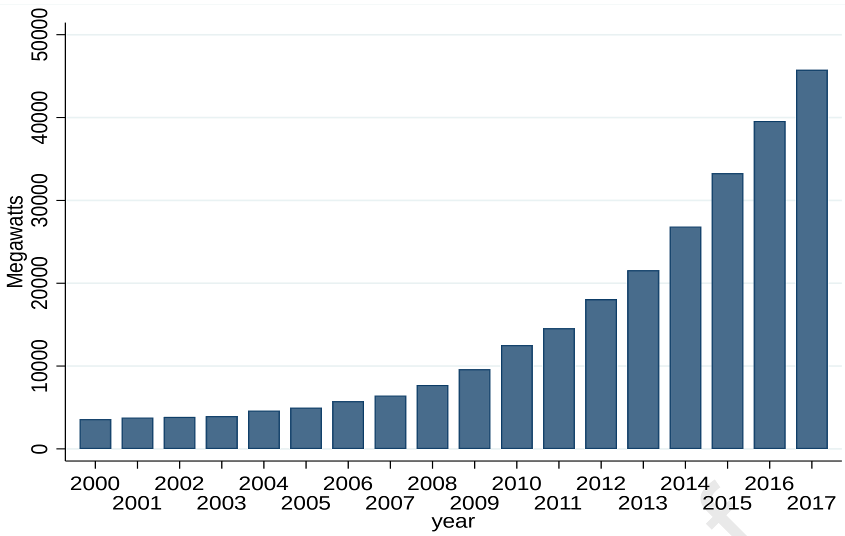

Figure 1. Non-hydroelectrical renewable installed capacity in LAC countries
This figure was created by the authors and based on data from IRENA (2020).

Indeed, to realize the following investigation, we consider several explanatory variables that are expected to have an impact on renewable energy investments, such as:

- **Renewable Energy Finance Flows**: IRENA (2020) provides a database of renewable energy projects that received international financial institutions' support. This database includes information about the projects' recipient country, supporting institution, technology (hydropower, geothermal energy, bioenergy, solar energy, wind energy, marine energy, multiple renewables, and other renewable energy), and instrument type (grant, loan, insurance, credit line, private development finance, equity investment, concessional loan, guarantee, and other official flows). Indeed, we define, as our explanatory variable, in the main regression whose purpose is to assess the evolution of all the non-hydroelectrical installed capacity, the total amount of finance flows, in constant 2010 United States Dollar (USD), directed at the promotion of renewable energy, except hydroelectrical, regardless of the instrument type. In this study, we named this variable as (**REFF**). We also build three other variables that include the finance flows directed, specifically, at the promotion of wind energy (**WFF)**, solar energy (**SFF**), and bioenergy (**BFF**). International finance flows render renewable investment more affordable. They may foster their development, particularly in LAC countries, most of which do not have a sufficiently robust economy to support these investments on their own.

- **Financial Development Index:** This variable was retrieved from the International Monetary Fund (IMF) Financial Development Index (2020) and provides a development index of financial institutions and financial services, and efficiency (the ability of institutions to provide financial services at low cost and with sustainable revenues and the level of activity of capital markets. Indeed, as we already know, electricity production from renewable energy sources, such as wind and solar, requires a large upfront investment but has lower running costs compared to fossil fuels. Thus, an accessible and efficient financial system is fundamental to support these projects and make them profitable for the investor. We measure the LAC countries' financial systems' soundness through the IMF Financial Development Index (Svirydzenka, 2016) and it is expected a positive relationship between this indicator and the dependent variable. Moreover, in this study, we renamed the variable as (**FDI).**

- **Economic Globalisation Index *De facto*:** This variable was retrieved from KOF Swiss Economics Institute (2020) and was developed by Gygli et al. (2019). The index contemplates two sub-dimensions: (i) trade globalisation, which assesses the importance of a country's trade in goods and services relative to GDP, and the diversity of trading partners; (ii) financial globalisation, which is measured by capital flows and stocks of foreign assets and liabilities. As already know, an economically globalised country may find it easier to import state-of-the-art technology designed to produce energy from new renewable sources. Thus, we expect economic globalisation to have a positive effect on the dependent variable. Furthermore, in this analysis, we renamed the variable as (**EG**).

- **Carbon dioxide emissions:** This variable was retrieved from the World Bank Open Data (2020) and provided a database of the amount of CO_2 emissions in Kilotons per capita. Indeed, CO_2 is correlated with other pollutants' emissions, and it may be used as a proxy for air pollution. Thus, higher values of this variable are expected to raise public awareness about the environment and increase the political pressure to promote the deployment of renewable energy sources. Moreover, in this investigation, we renamed the variable as (**CO_2**).

- **Gross Domestic Product (GDP) (cyclical component):** The gross domestic product in constant local currency units were retrieved from the World Bank Open Data (2020). Then we applied the Hamilton (2018) filter, with four lags and the differentiation parameter equal to 2, following the author's recommendation, and computed the cyclical component of GDP. An above-trend growth may generate a positive investor sentiment that raises the investment in renewable sources. On the other hand, it could increase the expectation of a reversal in the growth trend that causes renewable energy investors to postpone their projects. Thus, the expected effect of this variable on renewable energy installed capacity is ambiguous. Moreover, in this empirical investigation, we renamed the variable as (**GDP_Cyc**).

In this investigation, we converted the variables **ΔRen**, **ΔWind, ΔSolar, ΔBio, REFF**, **WFF**, **SFF**, and **BFF** into per capita values through their division by the population of each country. Indeed, per capita values allow us to reduce the disparities between the variables caused by population growth over time. Certainly, the descriptive statistics of all variables that will be used in this empirical investigation are shown in **Table 1** below.

Table 1. Descriptive statistics of variables

Variables	Descriptive statistics				
	Obs	Mean	Std. dev	Min	Max
ΔRen	323	4.8966	15.5919	-2.0529	131.6383
ΔWind	323	2.7228	12.4824	-0.2345	124.0724
ΔSolar	323	1.0456	4.8523	-0.8106	44.9566
ΔBio	323	1.3422	5.2247	-25.5991	51.9247
REFF	323	3.5667	10.2401	0.000	70.6254
FDI	323	24.6110	12.2706	6.2964	63.3827
CO_2	323	1.9575	1.2129	0.1584	4.6916
EGI	323	50.6871	12.8314	22.0174	83.4947
GDP_Cyc	323	1.0456	4.4273	-19.6317	13.8450

Notes: Obs denotes the number of observations; Std. dev denotes standard deviation; Min denotes minimum, and Max denotes maximum. This table was built using the Stata function *summarize*.

Indeed, before the execution of the main regression model, we applied the Shapiro-Wilk test to verify the presence of normality in the model. The null hypothesis of this test is that the variables follow a normal distribution. **Table 2** below displays the results from the Shapiro-Wilk test for normality test.

Table 2. Shapiro-Wilk test for normality

Variables	Obs	W	V	Z	Prob > z
ΔRen	323	0.3327	151.794	11.831	0.00000
ΔWind	323	0.3090	157.192	11.914	0.00000
ΔSolar	323	0.2717	165.685	12.038	0.00000
ΔBio	323	0.4148	133.142	11.523	0.00000
REFF	323	0.4215	131.600	11.495	0.00000
FDI	323	0.9175	18.770	6.907	0.00000
CO2	323	0.9059	21.404	7.217	0.00000
EGI	323	0.9752	5.649	4.079	0.00002
GDP_Cyc	323	0.9782	4.960	3.772	0.00008

Notes: This table was built using the Stata function *swilk*.

As can be observed in the table above, the p-values of this test lead to a clear rejection of the null hypothesis that the variables follow a normal distribution in all cases. Thus, traditional panel regression methods which rely on the normality of the variables are inadequate and may generate misleading conclusions. In this subsection, we approached the group of countries and the variables that will be used in our empirical study. In the next section, we briefly show the methodological approach that this investigation will use.

3.2. Methodology

As mentioned before, this subsection will approach the methodology that will be used in this empirical investigation. Indeed, to assess the effect of the explanatory variables on the change of non-hydroelectrical renewable installed capacity, this investigation will use the panel quantile regression model. This method presents several advantages relative to traditional least-square methods. It provides a complete picture of the independent variables' impact over all the dependent variable distribution, whereas least-square methods focus only on its conditional mean. Furthermore, quantile regression is broadly insensitive to outliers and, unlike least-square methods, does not require data to be normally distributed (Koenker, 2005; Onyedikachi, 2015). This characteristic is especially important for this study, given that our data is strongly non-normal (see **Table 2** above).

We model the relation between the change in renewable energy installed capacity and the explanatory variables through the following Equation,

$$\Delta\text{Ren}_{i,t} = X'_{i,t-1}\beta\left(U_{i,t}\right) + \alpha_i, \quad \textbf{(1)}$$

where i =1,…,19 identifies the country, t =2001,…2017, corresponds to the observation year, $X'_{i,t-1} = \left(1, REFF_{i,t-1}, FDI_{i,t-1}, CO2_{i,t-1}, EGI_{i,t-1}, GDP\_Cyc_{i,t-1}, TREND\right)$ is the explanatory variables vector, $\beta\left(U_{i,t}\right) = (\beta_0, \ldots, \beta_6)$ is the coefficients vector, α_i is an unobserved fixed effect, $U_{i,t} \sim U(0,1)$, and TREND represents a time trend that may be seen as a proxy for the reduction in the levelized cost of renewable energy over time. Indeed, in this investigation, we choose to lag the explanatory variables by one year because it takes a substantial amount of time for renewable energy investments to materialize in new installed capacity.

The fixed effect's unobservability renders the traditional quantile regression unable to identify the covariates' coefficients because α_i can be arbitrarily related to the remaining variables. To circumvent this problem, we follow Canay (2011), who proposed a simple two-stage method that achieves identification, assuming that the fixed effect is a pure location shift, and α_i and $U_{i,t}$ are independent. Let $u_{i,t} \equiv X'_{i,t}\left[\beta\left(U_{i,t}\right) - \beta_\mu\right]$, and $\beta_\mu = \left[\beta_{0,\mu} \ldots \beta_{6,\mu}\right]$, the conditional mean of $\beta\left(U_{i,t}\right)$. Then, using Equation (1) we have,

$$\Delta\text{Ren}_{i,t} = X'_{i,t-1}\beta_\mu + \alpha_i + u_{i,t} \quad \textbf{(2)}$$

The estimator proposed by Canay (2011), for quantile τ, involves two steps:

(1) Obtain a consistent estimator[1] of β_μ from **Equation (2)** and define $\hat{\alpha}_i \equiv \left[\Delta\text{Ren}_{i,t} - X'_{i,t}\hat{\beta}_\mu\right]$

(2) Estimate the covariates' coefficients through the solution of the following problem,

$$\hat{\beta}(\tau) \equiv argmin_\beta \frac{1}{T \times n}\sum_{t=1}^{T}\sum_{i=1}^{n}\left[\rho_\tau\left(\widehat{\Delta\text{Ren}}_{i,t} - X'_{i,t}\beta\right)\right], \quad \textbf{(3)}$$

where $\widehat{\Delta\text{Ren}}_{i,t} \equiv \Delta\text{Ren}_{i,t} - \hat{\alpha}_i$, T and n denote the number of years and countries included in the estimation, respectively, and ρ_τ is the check function for quantile τ. Canay (2011) shows that the resulting estimates are consistent and asymptotically normal.

We also evaluate the determinants of the evolution of wind, solar, and bioenergy installed capacities, with the dual purpose of testing the robustness of our results regarding the main dependent variable (**ΔRen**) and assessing the possible differential impact of the covariates on the individual components of renewable energy installed capacity. Specifically, we model the relation between the covariates and the various sources of renewable through the following equations.

$$\Delta\text{Wind}_{i,t} = X^{W\prime}_{i,t-1}\beta^W\left(U^W_{i,t}\right) + \alpha^W_i, \quad \textbf{(4)}$$

[1] We use the fixed effects method.

$$\Delta \text{Solar}_{i,t} = X^{S\prime}_{i,t-1}\beta^{S}(U^{S}_{i,t}) + \alpha^{S}_{i}, \quad (5)$$

$$\Delta \text{Bio}_{i,t} = X^{B\prime}_{i,t-1}\beta^{B}(U^{B}_{i,t}) + \alpha^{B}_{i}, \quad (6)$$

where i =1,…,19 identifies the country, t =2001,…2017, corresponds to the observation year, $X^{W\prime}_{i,t-1} = (1, WFF_{i,t-1}, FDI_{i,t-1}, CO2_{i,t-1}, EGI_{i,t-1}, GDP\_Cyc_{i,t-1}, TREND)$, $X^{S\prime}_{i,t-1} = (1, SFF_{i,t-1}, FDI_{i,t-1}, CO2_{i,t-1}, EGI_{i,t-1}, GDP\_Cyc_{i,t-1}, TREND)$, $X^{B\prime}_{i,t-1} = (1, BFF_{i,t-1}, FDI_{i,t-1}, CO2_{i,t-1}, EGI_{i,t-1}, GDP\_Cyc_{i,t-1}, TREND)$, are the explanatory variables vectors for the wind, solar and bioenergy equations, $\beta^{W}(U^{W}_{i,t}) = (\beta^{W}_{0}, \dots, \beta^{W}_{6})$, $\beta^{S}(U^{S}_{i,t}) = (\beta^{S}_{0}, \dots, \beta^{S}_{6})$, $\beta^{B}(U^{B}_{i,t}) = (\beta^{B}_{0}, \dots, \beta^{B}_{6})$ are the corresponding coefficients vectors, α^{W}_{i}, α^{S}_{i}, α^{B}_{i} are the unobserved fixed effects, and $U^{W}_{i,t} \sim U(0,1)$, $U^{S}_{i,t} \sim U(0,1)$, $U^{B}_{i,t} \sim U(0,1)$ are uniformly distributed random variables. Equations (4)-(6) are estimated through the same procedure described above for the main dependent variable, **ΔRen**.

All the estimations were executed in the software **R**, using the **QRPanel.R** code provided by Canay.

Figure 2 shows the methodological steps we follow in this research. First, we present descriptive statistics for all the variables and perform the Shapiro-Wilk and Pesaran tests to check their normality and stationarity, respectively. Then, we assess the impact of the covariates on the dependent variables through the estimation of panel quantile regressions, using Canay's method. Finally, we check the robustness of our results to the presence of outliers using dummy variables.

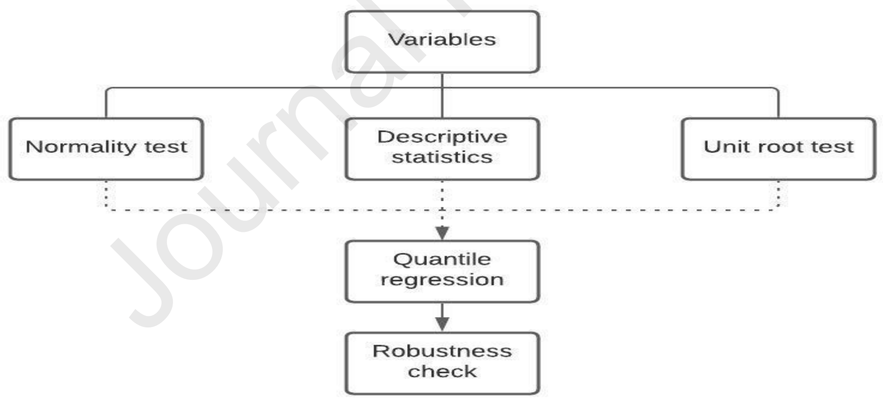

Figure 2. Methodology flowchart.

4. Empirical results

As mentioned previously in the introduction of this investigation, this section will present the quantile regressions' estimation results, using the Canay (2011) method. In this investigation, we choose to estimate the effect of the covariates on the change in non-hydroelectrical renewable installed capacity for the 25%, 50%, and 75% quantiles and the 90% quantile because we want to find the main drivers of the substantial increases in renewable installed capacity in the recent years.

Before estimating the quantile regressions, we perform the Pesaran (2007) panel unit root test to assess the series stationarity. This test, whose null hypothesis assumes that the variable is non-stationary, follows a non-standard distribution, even when the number of members in the sample is large. It is based on the averaging of panel-member specific Dickey-

Fuller type regressions' coefficients and is robust in the presence of cross-section dependence. Indeed, **Table 3** below shows that the null non-stationarity hypothesis is strongly rejected for all the dependent variables in both specifications. This hypothesis is also rejected for most explanatory variables, except CO_2 emissions, in the test with a time trend and the economic globalisation Index in both tests.

Table 3. Panel unit root test (CIPS test)

Variables	Panel unit root test (CIPS) (Zt-bar)		
	Without trend		With trend
	Lags	Zt-bar	Zt-bar
ΔRen	0	-8.907 ***	-8.131 ***
ΔWind	0	-6.237 ***	-5.671 ***
ΔSolar	0	-2.815 ***	-1.973 **
ΔBio	0	-4.909 ***	-4.460 ***
REFF	0	-4.480 ***	-2.426 ***
FDI	0	-3.245 ***	-2.964 ***
CO_2	0	-0.842 **	0.633
EGI	0	-0.637	-1.257
GDP_Cyc	0	-4.521 ***	-2.871 ***

Notes: This table was built using the Stata function *multipurt*. The null hypothesis for CIPS stipulates that the series have a unit root. ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

Table 4 below shows the estimated coefficients for the change in the non-hydroelectrical installed capacity equation. The effect of Finance Flows on renewable energy development is positive and statistically significant for all the quantiles, except the fiftieth. Its impact is increasing across the quantiles, suggesting that it plays a crucial role in promoting renewable energy in LAC countries, particularly in large projects. The estimates for CO_2 emissions are positive, sizable, and broadly similar for all the quantiles. This evidence is consistent with the hypothesis that CO_2 emissions generate political pressure that fosters renewable energy development. The dependent variable also bears a significant positive relation with economic globalisation for all the quantiles. Thus, countries with an economically open economy are more prone to develop new renewable energy sources. The time trend, which may be interpreted as a proxy for reducing the levelized cost of renewable energy over time, also positively affects the dependent variable in the lowest and highest quantiles. Finally, neither the financial development index nor cyclical GDP seems to be associated with renewable energy development.

Table 4. Estimation results - **ΔRen**

Independent variables	Dependent variable (ΔRen)			
	Quantiles			
	25th	50th	75th	90th
REFF	0.1557 ***	0.3520	1.3034 **	1.8932 ***
FDI	-0.0330	0.0221	-0.0235	-0.0612
CO_2	2.6207 ***	2.3734 ***	2.3609 ***	2.8066 ***
EGI	0.1422 ***	0.1514 ***	0.1839 ***	0.2173 ***
GDP_Cyc	0.0255	-0.0557	-0.0863	-0.1689
TREND	0.0885 **	0.0913	0.0789	0.2654 *
Obs	323	323	323	323

Notes: The estimations were performed using the R code **QRPanel.R**; ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

The results for the wind installed capacity determinants' (**Table 5)** is strongly consistent with the main estimation **(ΔRen**) about the impact of finance flows, CO_2 emissions, and the economic globalisation index: all these covariates exert a positive effect on installed capacity and the impact of financial flows is particularly prevalent at the highest quantiles. However, unlike in the **(ΔRen**) estimation, the financial development index negatively affects wind installed capacity.

Table 5. Estimation results - **ΔWind**

Independent variables	Dependent variable (ΔWind)							
	Quantiles							
	25th		50th		75th		90th	
WFF	0.7788	***	1.5451	***	2.3467	***	3.6648	***
FDI	-0.0709	***	-0.0889	***	-0.0487	***	-0.0479	***
CO_2	2.0195	***	2.4668	***	2.4109	***	2.4716	***
EGI	0.0835	***	0.0942	***	0.1136	***	0.1288	***
GDP_Cyc	0.0183		-0.0055		-0.0089		-0.0349	*
TREND	0.0052		0.0105		0.0259		0.2457	***
Obs	323		323		323		323	

Notes: The estimations were performed using the R code **QRPanel.R**; ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

Table 6, which displays the estimated coefficients for the solar energy equation, corroborates our previous findings regarding the importance of finance flows, CO_2 emissions, and time for the promotion of renewable energy sources, but it shows that the financial development index and the economic globalisation index may hinder the increase in solar installed capacity.

Table 6. Estimation results - **ΔSolar**

Independent variables	Dependent variable (ΔSolar)							
	Quantiles							
	25th		50th		75th		90th	
SFF	0.0354	***	0.2111	***	0.2727		1.4467	***
FDI	-0.2598	***	-0.2477	***	-0.2453	***	-0.2339	***
CO_2	0.7301	***	0.7918	***	0.8283	***	0.8706	***
EGI	-0.0320	***	-0.0207	***	-0.0132		-0.0041	
GDP_Cyc	-0.0336		-0.0404	*	-0.0228		-0.0432	
TREND	0.1677	***	0.1720		0.1662	***	0.1554	***
Obs	323		323		323		323	

Notes: The estimations were performed using the R code **QRPanel.R**; ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

The estimation for bioenergy (**Table 7**) reveals that CO_2 emissions, the economic globalisation index, the financial development index, and finance flows (only in the 75th quantile) foster the increase in bioenergy installed capacity. However, unlike in the previous estimations for other renewable sources, time appears to have a detrimental effect on bioenergy.

Table 7. Estimation results - **ΔBio**

Independent variables	Dependent variable (ΔBio)							
	Quantiles							
	25th		50th		75th		90th	
BFF	0.0983		0.3685		0.8479	***	0.9930	
FDI	0.1421	***	0.1473	***	0.1406	***	0.1406	***
CO_2	1.9514	***	1.9026	***	1.8436	***	1.4957	***
EGI	0.0697	***	0.0795	***	0.1057	***	0.1114	***
GDP_Cyc	0.0027		-0.0338		-0.0487	*	0.0007	
TREND	-0.0844	***	-0.1030	***	-0.0858		-0.0048	
Obs	323		323		323		323	

Notes: The estimations were performed using the R code **QRPanel.R**; ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

It is well known that in a relatively short panel, such as ours, the estimation results may be driven by a few extreme observations, which distort the causal link between the covariates and the dependent variable and leads the researcher to draw wrong conclusions. To check our results' robustness to the presence of outliers, we identified as outliers those observations whose residuals are more than three standard deviations away from the mean. Then, we created a dummy variable for each one of these observations and re-estimated all the models. These exercise results are presented in **Tables 8**, **9**, **10**, and **11** below.

Table 8. Estimation results (with dummies) - **ΔRen**

Independent variables	Dependent variable (ΔRen)							
	Quantiles							
	25th		50th		75th		90th	
REFF	0.1269	***	0.3155	***	1.4292	***	2.3875	***
FDI	-0.0107		0.0045		-0.1329	***	-0.1383	***
CO_2	3.3662	***	3.1722	***	2.7964	***	4.0406	***
EGI	0.0416	***	0.0527	***	0.1251	***	0.2379	***
GDP_Cyc	-0.0006		-0.0013		-0.0802		0.0125	
TREND	0.0565		0.0912		0.1783	***	0.1692	
Obs	323		323		323		323	

Notes: The estimations were performed using the R code **QRPanel.R**; ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

The comparison of **Tables 4** and **8** reveals that the results remain broadly unchanged when dummies are included in the estimation of the evolution of non-hydroelectrical installed capacity: finance flows, CO_2 emissions, and the economic globalisation index remain its main drivers, while the time trend impacts it only in the 25th and 90th quantiles, in the baseline estimation, and the 75th quantile in the estimation with dummies.

Table 9. Estimation results (with dummies) - **ΔWind**

Independent variables	Dependent variable (ΔWind)			
	Quantiles			
	25th	50th	75th	90th
WFF	0.3001 ***	0.8894 ***	2.6437 ***	4.0447 ***
FDI	-0.0927 ***	-0.0781 ***	-0.1436 ***	-0.0479 ***
CO_2	2.0901 ***	1.9496 ***	0.6409 ***	0.9926 ***
EGI	-0.0045	-0.0068	0.0316 ***	0.0997 ***
GDP_Cyc	-0.0241	0.0062	0.0271	0.0103
TREND	0.0450 ***	0.0291 **	0.0861 ***	0.2313 **
Obs	323	323	323	323

Notes: The estimations were performed using the R code **QRPanel.R**; ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

Tables 5 and **9** confirm the positive influence of finance flows and CO_2 emissions on wind energy installed capacity. However, the inclusion of dummies weakens the positive effect of the economic globalisation index and strengthens the time trend's impact.

Table 10. Estimation results (with dummies) - **ΔSolar**

Independent variables	Dependent variable (ΔSolar)			
	Quantiles			
	25th	50th	75th	90th
SFF	0.0297 ***	0.2912 ***	0.4642 ***	2.5146 ***
FDI	-0.0521 ***	-0.0707 ***	-0.0570 ***	-0.2140 ***
CO_2	-0.3701 ***	-0.2463 ***	-0.3227 ***	0.9518 ***
EGI	-0.0085 *	-0.0076 **	0.0035	0.0090
GDP_Cyc	0.0101	0.0010	0.0090	-0.0186
TREND	0.0573 ***	0.0618 ***	0.0566 ***	0.0055 ***
Obs	323	323	323	323

Notes: The estimations were performed using the R code **QRPanel.R**; ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

Solar energy results seem to be the most sensitive to outliers (**Tables 6** and **10**). Even though the effect of finance flows remains broadly unchanged, dummies lead to a total reversion in the coefficients related to CO_2 emissions. This instability is hardly surprising, given that solar energy was the newest energy source to be widely deployed in LAC countries. Thus, in the early years of our sample, most countries did not install new solar capacity, which effectively reduces our sample's information content for this energy source.

Table 11. Estimation results (with dummies) - **ΔBio**

Independent variables	Dependent variable (ΔBio)							
	Quantiles							
	25th		50th		75^{th}		90th	
BFF	0.0194		0.3471	**	0.8316	***	0.6750	***
FDI	0.0913	***	0.1030	***	0.1068	***	0.0812	***
CO_2	0.4595	***	0.3726	***	0.2794	***	-0.5431	**
EGI	-0.0203		-0.0066		0.0001		0.0078	
GDP_Cyc	0.0290		-0.0338		-0.0074		0.0272	
TREND	-0.0473	***	-0.0322	**	-0.0196		0.0048	
Obs	323		323		323		323	

Notes: The estimations were performed using the R code **QRPanel.R**; ***, **, and * denote a statistically significant rejection of the null hypothesis at the 1%, 5%, and 10% levels, respectively.

Finally, **Table 11** confirms the positive impact of finance flows, time, and CO_2 emissions (except in the 90th quantile) on bioenergy found in **Table 7**. However, the inclusion of dummies leads to the disappearance of the statistical significance for the variable economic globalisation index.

5. Discussion

As mentioned before, this section will present the possible explanations which were found in this empirical investigation. Well, the results from the preliminary tests show the non-presence of normal distribution (see **Table 2**, above), the indication that the variables ~~and~~ are on the borderline between the I(0) and I(1) orders of integration (see **Table 3**, above). Indeed, both two results had been already confirmed by Koengkan et al. (2020) and Fuinhas et al., 2017), that studied the LAC region and found the same variable characteristics in their investigations. This is pointing that the results from the preliminary tests that were found in this empirical study are in consonance with the literature review.

Moreover, the model estimations' results indicate that the independent variables of renewable energy finance flows, economic globalisation index, and carbon dioxide emissions positively affect our dependent variable named change in non-hydroelectrical renewable installed capacity. Besides, **Figure 3** below summarises the effect of independent variables on the dependent one. This figure was based on the results of the Canay model estimation.

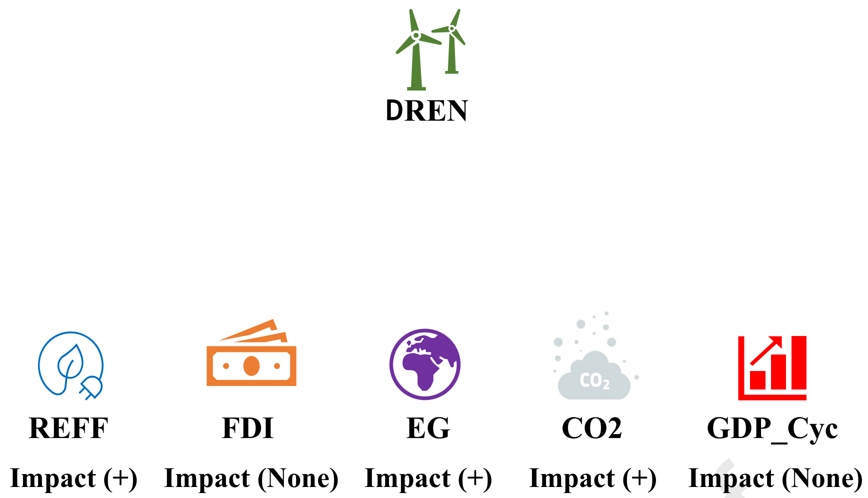

Figure 3. Summary of the variable's effect.

Then, based on these empirical founds we elaborate on the following question - **What are the explanations for the positive impact of these variables in our model?** – Well, the positive effect of renewable energy finance flows could be related to the increase of capital inflow for finance the new renewable energy projects caused by the restructure plans, for example, 'Washington consensus' and 'Brady Plan', which were adopted to promote the restructuring of external debts and the macroeconomic adjustments and mentioned by Koengkan (2020), and Santiago et al. (2019). Indeed, this period of adjustments occurred between 1989 and 1992, in several LAC countries (e.g., Argentina, Brazil, Costa Rica, Mexico, Venezuela (RB), and Uruguay) adopted these strategies. The restructuring plans and macroeconomic adjustments allowed a deep financial, trade, and foreign investment liberalisation, as well as the privatisation of significant portions of the public sector and the reduction of import barriers in most countries from the LAC region. As a result, the capital inflows reappearance in the 1990s, at the middle of the decade (1994), the gross fixed capital stock per capita in the LAC region (Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, and Venezuela) reached a mean value of 11,260 US$ (in 1980 international dollars) that compares with 54,089 US$ for the USA (Hofman, 2000). Indeed, the LAC region's capital inflows accelerated again between 2004-2014, caused by the "commodities boom" where the capital inflows registered a growth rate of 25% during this period and reached a value of 1,743.936 US$ in 2014 (Koengkan, 2020). That is, the renewable energy finance flows followed the same trend, where the inflows of investments in new renewable energy sources (e.g., marine, wind, solar, geothermal, solid biofuels and waste and liquid biofuels) were a value of 1.6 US$ billion in 2014 and 2016 reached 8.7 US$ billion (Koengkan, 2020).

Therefore, the increase of capital inflows caused by financial liberalisation will reduce the financing costs and consequently will encourage the development and investment in new renewable energy technologies. This explanation is confirmed by Narayan and Smyth (2008), and Koengkan et al. (2020), where the increase of capital inflows to invest in renewable energy projects will reduce their costs of financing, making the credit cheaper and makes the new energy sources more feasible. Moreover, another factor that could be related to this positive impact is the existence of efficient renewable energy financial policies that encourage public and private financing in new renewable energy projects.

Regarding the positive impact of economic globalisation index on change in non-hydroelectrical renewable installed capacity, also could be related to the process of deep financial, trade, and foreign investment liberalisation, as well as the privatisation of significant portions of the public sector, and the reduction of import barriers as was mentioned before. All these changes in the economic structure consequently affect the index of globalisation, where financial and trade liberalisation are the main components of this index. Indeed, as we already know, the process of financial and trade liberalisation will boost the capital inflows to realize a new investment in the productive sectors or speculative, the economic activity, and so the energy demand. However, to attend to the energy demand will be necessary more investments in alternative energy sources. Moreover, this economic liberalisation process will boost the imports of renewable energy technologies to increase energy efficiency and reduce the consumption of non-renewable energy sources.

Finally, the positive impact of CO_2 emissions could be related to the increase of environmental, political, and social pressure about the increase of environmental degradation caused by these emissions' growth. Indeed, this pressure will encourage the development of renewable energy policies that will facilitate investments, development, and the consumption of renewable energy sources in the LAC countries. Another explanation is related to the capacity to consume new renewable energy sources to mitigate these CO_2 emissions in the LAC region. This section showed the results from the main model and a brief explanation for this study's results. The next section will show the conclusions of this experimental investigation.

6. Conclusion

This analysis assessed the advancement of new renewable energy sources in a group of nineteen countries from the LAC region between 2001 and 2017. This investigation is in the initial stages of maturation, where it will supply a solid foundation for second-generation researchers regarding this topic. This study is a kick-off about the advancement of new renewable energy sources in the LAC region. This empirical research has been based on economic principles to construct a model that provides an accurate explanation of the results that were found in this study.

This empirical investigation utilised as a method the Canay model estimation to realize the following analysis. The results from the preliminary tests pointed to the non-presence of normal distribution and that the variables are on the borderline between the I (0) and I(1) orders of integration. Indeed, both two results agree with the literature that approached this group of countries.

The Canay model estimation results showed that the independent variables renewable energy finance flows, economic globalisation index, and carbon dioxide emissions positively affect our dependent variable named change in non-hydroelectrical renewable installed capacity. It is worth remembering that this empirical investigation opted to choose from the Canay model estimation because it can capture the variations between countries (i.e., cross-sections). That is, the results found by this empirical investigation can answer the research question that arose.

As mentioned before, the possible explanation for the positive impact of renewable energy finance flows on change in non-hydroelectrical renewable installed capacity could be related to the increase of capital inflow caused by financial liberalisation and that consequently reduced the financing costs and encouraged the development and investments in new renewable energy technologies (e.g., marine, wind, solar, geothermal, solid biofuels and waste and liquid biofuels). That is, the reduction of financing cost made the new renewable energy technologies more attractive than the hydropower plants in the LAC region. Moreover, another factor could be related to this positive impact is the existence of efficient renewable energy financial policies that encouraged public and private financing in new renewable energy projects.

The positive impact of the economic globalisation index could be related to the process of deep financial, trade, and foreign investment liberalisation, as well as the privatisation of significant portions of the public sector, and the reduction of import barriers caused by the restructuring plans that were adopted by some LAC countries that encouraged the economic activity and so the energy demand. However, to attend to the energy demand will be necessary to carry out new investments in alternative energy sources. Moreover, this liberalisation process in Latin American economies also encouraged the import of new renewable energy technologies to increase productivity and reduce the consumption of non-renewable energy sources.

Moreover, the positive impact of CO_2 emissions on change in non-hydroelectrical renewable installed capacity could be related to the increase of environmental, political, and social pressure regarding the increase of environmental degradation caused by the growth in these emissions that encouraged the new investments in renewable energy technologies, as well as could be related to the own capacity of consumption of new renewable energy sources to mitigate these CO_2 emissions in the LAC region.

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Highlights

- Assessment of evolution of non-hydroelectrical renewable installed capacity
- Nonlinearities controlled by quantile regressions econometric technique of Canay
- Renewable energy finance flows impact non-hydroelectrical renewable capacity
- Carbon dioxide emissions impact non-hydroelectrical renewable installed capacity
- Environmental degradation encourages investments in renewable energy technologies

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: