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Renewable Energy Consumption and its Main Drivers in Latin American and Caribbean Countries: A Robust Analysis Between Static and Dynamic Panel Data Models

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Abstract
This study examines the potential drivers of renewable energy consumption for 22 Latin American and Caribbean countries during 2005–2014. I use the sys-GMM method to deal with the presence of endogeneity, country-specific components and serial correlation within observations. Results confirm the dynamic behaviour of green energy consumption. Moreover, GDP per capita and CO_2 emissions per capita are the determinants of this clean energy source. The positive effect of per capita GDP implies that a non-depleting alternative source has been used to satisfy an increasing energy demand, which was experienced due to the acceleration of economic growth in the region. On the other hand, the negative effect of per capita CO_2 emissions reflects the weight that fossil fuels have in the energy mix. Because of some of the analysed countries' oil-producer nature, oil prices rise is not enough for a switch response.
Keywords: Renewable energy; Latin American and Caribbean countries; CO_2 emissions; panel data models
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Introduction

Before 1973–1974, energy consumption rose at increasing rates in industrialised countries. After that, this factor's consumption growth evolved into moderate levels in virtue of the shock in real oil prices and the gradual decrease of global capitalist economies' economic growth rate. This phenomenon developed an interest in academia to start studying energy effects. First contributions are attributed to Hudson and Jogerson (1974) and Berndt and Wood (1975), who found that energy, as a production factor, substitutes labour while complements capital. Nevertheless, other scholars manifest that energy substitutes capital in the long-run (Griffin & Gregory, 1976). These debatable results gave foundation about the study of energy's performance in the economy. However, research has been more appealed to find causal relationships between energy and growth to comprehend whether energy conservation policies could affect economic levels. Following Kraft and Kraft (1978) seminal contribution, the debate about growth, conservation, neutrality, and feedback hypothesis emerged. Energy economics' research was guided toward that issue until in the last few decades, with the evidence of the hole in the ozone layer, climate change, global warming and the contribution of human activities in the generation of greenhouse gases (GHG), scholars developed an interest in renewable energy topics.

Since energy plays a fundamental role in economic development, and likewise, it has detrimental contributions to the environment through dirty emissions, adopting clean energy sources is indispensable. This decision can draw a path to sustainability in the following aspects: 1) Combating GHG emissions, 2) Giving support to the no-depletion of natural resources such as oil, natural gas and coal, 3) Lessening the impact of oil price volatility, 4) Offsetting the foreign exchange proportion due to oil imports, 5) Improving the living conditions of rural areas and job creations (Cardoso & Fuinhas, 2011; Ackah & Kizys, 2015). Therefore, understanding which factors drive renewable energy deployment is substantial. Empirical research has contributed to explaining the influence of economic growth, carbon dioxide (CO_2) emissions and oil prices, mainly. Most of the literature has focused on developed and industrialised countries. There are few studies about the determinants of green energy consumption in Latin America and the Caribbean (LAC) countries. To my knowledge, there is no research exploring this topic in the whole region.

Inspecting LAC context is appealing. Its environment could convince that renewable sources' share would exceed non-renewable ones. Nevertheless, its important role as oil producer makes this fuel as the main source of total primary energy supply (46 per cent), followed by natural gas (25.8 per cent), coal (6.9 per cent) and hydro-energy (6.2 per cent); other sources accounts for 15.1 per cent (CEPAL, 2019). Oil principal use is from transport and industrial sector, while its participation in power generation has been replaced by natural gas. By sub-region, energy mix differs in weight but, overall, oil predominates.

On the other hand, hydropower is highly employed in electricity. During the last decades, power generation has increased its contribution to the total final energy consumption (IRENA, 2016a). Its historical dependency on hydropower to produce electricity and the lower use of coal on it, which is the main fuel generator of CO_2 gases, set up LAC as the lowest fossil fuel-based global carbon emitter (IDB, 2000). However, hydropower generation has diminished in the response of droughts and natural gas expansion, positioning the latter as second in the power mix.

Transport and industry are the sectors with higher total final energy consumption (TFEC): 39 per cent and 35 per cent, respectively. Since 80 per cent of its population lives in cities, road transport demand has risen at increasing rates (IRENA, 2016a). As a result, dirty emissions continue growing since vehicles are mainly feeding by oil or natural gas. Furthermore, industries are significant for the region: During 2016, its contribution to GDP represented 32 per cent (IRENA, 2016a). From this sector, extractive industries are transcendent in LAC. The region is home to about 20 per cent of the proven world's oil reserves, with Venezuela and Brazil as the main endowed countries (IRENA, 2016a). If non-renewable sources remain to have a high share in TFEC structure, CO_2 emissions will continue growing. Dismayed by the environmental problems these would carry out, policymakers have intensified the implementation of low-carbon measures to promote renewable energy use since 2004. Hence, this question arises: Do CO_2 emissions trigger the consumption of renewable energy significantly?

Energy plays a vital role in the development of the region. Since the 2000s, its demand in LAC has risen at increasing rates due to rapid economic growth and increased population. Some countries have not been able to cover those requirements, challenging fossil fuels and power generation. Therefore, the necessity of diversifying traditional energy sources with renewables has heightened. Hence the following question arises: Does economic growth drive renewable energy consumption significantly in LAC?

Another point that may benefit renewables expansion is related to fossil fuel prices volatility. For instance, Central America has adopted renewable energy sources to deal with oil prices shocks. It conducts to question: Do fossil fuel prices determine renewable energy demand significantly in LAC?

Regarding green energy consumption, it excelled the global average in 2013, reaching participation of 27 per cent (IRENA, 2016a). Its favourable amounts have been due to the share of hydro-energy. However, it has been declining as mentioned. Expectations about other renewable energy sources are mainly related to resources endowments that some countries have — for instance, wind in Brazil, Argentina and Mexico, and biomass in Brazil. Regarding the first renewable case, its technology has been expected to be costly. However, costs have fallen due to auctions. This regulatory instrument has translated reductions in renewable prices in some countries, motivating to question: Do auctions significantly impact clean energy adoption, enhancing its consumption? It is worth mentioning that some studies (Vergara et al., 2013) suggest that green technology costs can be competitive with fossil fuels ones. However, others argue that renewable costs are more effective than non-renewable ones in the long run (Lazard, 2017).

Unquestionably, this energy's deployment is related mainly to policies to attract private investment since capital-intensive. LAC countries exposed to higher investment levels reveal liberalisation characteristics (i.e., Brazil, Chile, Costa Rica, Uruguay). Being opened allows the country to take advantage of technological transfer. Since technologies are transferrable, countries can acquire the *know-how* to innovate after that (Pueyo & Linares, 2012). Moreover, trade openness may represent benefits in energy supply/consumption due to the possibility of interconnection between countries. Therefore, this brings us to ask: Does trade openness generate a significant effect on LAC's renewable energy consumption?

Previous and other queries will be responded in this application, which aims to determine the factors that have significantly impacted the consumption of clean energy in LAC countries during the period 2005–2014. I execute a robust analysis between static and dynamic panels models to achieve this. The remainder of this study follows this structure: Section 2 reviews theoretical and empirical literature about energy consumption and renewable energy consumption, and announces my contribution to the literature; Section 3 exposes data and variables employed in the empirical model, discusses their respective hypothesis, and comments about the methodology; Section 4 evaluates results; Section 5 concludes, suggests about policies which might be implemented to stimulate green energy consumption, discloses about limitations, and ends recommending future works.

Literature Review

Theoretical Framework

It is fundamental to address the literature about conventional energy and its consumption to comprehend which factors may be related to renewable energy consumption.

Energy and production factors.

The relationship between economic growth and energy consumption has been covered widely. In the beginning, the aim was to discover whether there is substitutability or complementarity between the factors of production and energy. Initially, Hudson and Jogerson (1974) and Berndt and Wood (1975) led the research on this topic, finding that energy has a substitute effect on labour and a complementary effect on capital.

Because of methodological aspects, these results were questioned by Griffin and Gregory (1976). Assuming a twice-differentiable aggregate production function with capital (K), labour (L), energy (E) and materials (M) as inputs, and weakly separability condition [(K, L, E), M] due to unavailable information about material prices, scholars find short-run substitutability between energy, labour, and material, and complementarity between energy and capital. Yet in the long run, energy and capital substitution effects emerge.

Griffin and Gregory (G-G hereafter) justification relies on "(…) *in the long run, the use of new equipment to achieve higher thermal efficiencies in an industry may represent substantial capital costs*" (p. 846). Judging the previous argument as misleading due to the omission of material inputs in the model, Berndt and Wood (1979) reconfirm the complementarity between capital and energy. They show that they have not controlled for the material explains biased conclusions from G-G since results indicate "*gross substitution elasticities instead of net elasticities*" (p. 349).

Previous investigations gave insight into the role of energy. However, the focus in energy economics literature has been causal relationships between energy consumption and economic growth. Since profound implications could be derived from the direction of the relationship between energy consumption and economic growth, it has originated interest in the literature to be documented theoretically and empirically. If a predicted causal effect from energy consumption to economic growth is corroborated, any repercussion in energy could generate social welfare issues. The previous assumption results from the *growth hypothesis*, and it continues being the reason for several debates in energy economics.

The growth, conservation, neutrality and feedback hypothesis.

Since the late 70s, scholars have explored the relationship between energy consumption and the level of economic activity. Kraft and Kraft (1978) realised a seminal study about this concern. Having inspected the US context for the post-war period 1947–1974 and applying Sims' causality test (1972), they conclude about unidirectional causality from the gross national product (GNP) to gross energy consumption (GEI), and not from GEI to GNP. That means, an economic activity might influence on energy consumption, but not vice-versa. Evidencing a *conservation hypothesis*, authors argue that energy conservation policies may not endanger the country's economic activity since the economy is not energy-dependent. Upon the Granger-causality framework, the *conservation hypothesis* is evidenced when real GDP increases cause increases in energy consumption (Payne, 2010). Hence, any adverse shock on GDP may negatively impact energy consumption.

Given Kraft and Kraft (1978) judgement, other scholars were interested in evaluating previous conclusions. Akarca and Long (1980) question the period employed by Kraft and Kraft (K-K hereafter) since it does not include meaningful events, as the two World Wars, which may impact US economic condition. Moreover, Akarca and Long (1980) argue that during 1973–1974 there was an acceleration in energy prices because of the oil embargo. Changing by two years the data used by K-K, researchers conclude no causal relationship between GNP and GEI. With this, another scenario results: the *neutrality hypothesis*. In this scheme, energy consumption would not generate significant economic growth impacts since this factor is a small component of real GDP (Payne, 2010). Hence, expansive or conservative energy policies do not produce repercussions in economic growth since they do not influence each other (Ozturk, 2010). The *neutrality hypothesis* holds when no-causal relationships between real GDP and energy consumption is evidenced.

Two opposite findings open the debate about whether economic level influences energy consumption, or in fact, there is no short-run association. To contribute to that, Yu and Hwang (1984) review the causality from GNP to GEI, using US updated data for the same K-K analysis period. Although both variables are highly correlated, causality tests produce evidence of no-causal linkage within the US context. Likewise, Yu and Choi (1985) support the *neutrality hypothesis* in the US. However, other countries analysed evidence causal linkage: from GNP to total energy consumption in South Korea, and from total energy consumption to GNP in the Philippines. The literature references this latter causality as the *growth hypothesis*.

Regarding growth hypothesis, energy consumption has a key role in economic growth directly, and indirectly as a complement of production factors (Ozturk, 2010; Payne, 2010). Hence, energy deficiencies may affect economic growth, while improvements may enhance it. Testing for the *growth hypothesis* is fundamental because policymakers need to know whether a specific policy will threaten the economy. Upon the Granger-causality framework, the *growth hypothesis* is evidenced when energy consumption increases cause increases in real GDP. Thus, if energy consumption Granger-causes economic growth, stringent policies which seek to protect the environment might discourage the economic level, another theorem, the feedback hypothesis, indicates that energy consumption and economic growth influence each other and might perform as complements. (Payne, 2010).

A final re-examination about the causal relationship between GNP and energy consumption in the US was done by Abosedra and Baghestani (1989). They reconfirm unidirectional causality from GNP to GEI, rejecting observations from Akarca and Long (1980), Yu and Hwang (1984), Yu and Choi (1985). Authors work with the same period used by previous scholars. According to Abosedra and Baghestani (1989), their conclusions are mistaken due to a possible methodological error.

Some research continued extending (Erol and Yu, 1989; Yu et al., 1988). Nevertheless, the literature has not attained a consensus. One explanation about the discrepancy of the results lay on the econometric techniques. Most of the estimations were conducted applying OLS, making inferences without contemplating the data's time series properties (Huang et al., 2008). Therefore, spurious regressions could prevail, producing misleading results (Granger and Newbold, 1974). The empirical literature has reinforced the hypothesis test of relationships between energy consumption and economic growth with the improvement of statistical methods in time series and panel data.

Empirical Literature

Energy consumption.

Although advanced econometric tools have improved results, it does not evidence consensus about the causality direction. The economic development within countries can explain the remained divergence in conclusions, energy consumption (EC hereafter) patterns, periods analysed, model specifications, methodologies and omitted variables problems (Payne, 2010; Apergis & Tang, 2013).

For instance, Chontanawat et al. (2008) continued working with bivariate models, employing the Johansen-Juselius technique to study 100 countries during 1976–2000. They find long-run causality from energy to per capita GDP for most OECD-developed countries compared to non-OECD-developing countries. Hence, energy-conservation policies may affect more OECD-developed countries growth than non-OECD-developing countries growth. Similarly, Soytas and Sari (2003) use Johansen-Juselius to study the relationship between EC and GDP per capita in G7 countries and top 10 emerging markets (excluding China), during 1950–1992. Unlike Chontanawat et al. (2008), their results confirm long-run unidirectional causality from EC to GDP per capita for Turkey and France. Additionally, they identify long-run unidirectional causality from per capita GDP to EC for Italy and Korea; and long-run bidirectional causality for Argentina.

To lessen omitted variable bias issues, scholars started working with trivariate models. Salim et al. (2008) cover six non-OECD Asian countries to evaluate the dynamics between EC, GDP and a proxy of energy prices. From their results, Bangladesh does not evidence any causal linkage while Malaysia exhibits long-run bidirectional causality between GDP and EC; India and Pakistan have long-run causality from EC to GDP while Thailand from GDP to EC. Controlling for the same factors, Asafu-Adjaye (2000) finds long-run causality from EC to GDP per capita in India and Philippines; no long-run effect on EC in Indonesia; long-run bi-directional causality between EC and GDP per capita in Thailand. On the other hand, Mishra et al. (2009) control urbanisation since EC may increase due to connections to the grid. Taking the Pacific Island countries as an economic framework and using dynamic ordinary least square (DOLS) estimator, scholars show that per capita GDP and urbanisation have positively influenced EC for the whole panel. I predisposed empirical literature to apply time series approach to examine relations between EC and GDP per capita. However, most studies work with samples size around thirty, which has low statistical testing power (Huang et al., 2008). Hence, inconsistency could be contemplated, and with that, the disparity in conclusions. For that reason, recently, scholars have proposed implementing alternative techniques such as dynamic panel data. Moreover, they have contemplated financial variables as potential determinants of EC.

Sadorsky (2011) and Çoban and Topcu (2013) indicate that EC could be fostered by financing factors through credits, for example. In Sadorsky's model, financial development is discriminated between banking and stock market variables. He uses four banking and three stock markets regressors to capture their partial effect on the predicted variable. Contrarily, Çoban and Topcu (2013) apply the Principle Component Analysis to detect banking and stock markets' aggregate effects. Sadorsky (2011) finds that EC is strongly determined by its previous level, and — unexpectedly — that GDP per capita does not influence it.

Regarding banking covariates, liquid liabilities, financial system deposits, and deposit money bank assets impact EC. However, the stock market turnover ratio is the unique stock regressor which enhances EC in his sample of nine Central and Eastern European countries. On the other hand, Çoban and Topcu (2013) do not achieve significant effects from financial indicators when they analyse the model for EU countries as a whole. Significance from banking and stock markets regressors are acquired when authors divide the model into old and new EU members. For old members, lagged-energy consumption, GDP per capita and both financial indicators evidence positive causal effect on EC. For new members, banking and stock markets variables do not present significant impacts. Hence they estimate non-linear relationships. This latter confirms that the stock index is not a driver for EC in EU countries.

Renewable energy consumption and its drivers.

The empirical literature has explored EC extensively since the 70s. Nevertheless, the determinants of renewable energy have been studied narrowly. The causal analysis for renewable energy consumption (REC hereafter) has intensified during the last decades due to the global warming problem's awareness. According to "Mitigation of Climate Change" Report (IPCC, 2007), "*the energy* *supply sector is the responsible for the largest growth of GHG emissions, with increments of 145% between 1970–2004"*. Stern (2006) states that adopting clean energy technologies is necessary to counterbalance GHG emissions effects. Otherwise, there would be repercussions in economic growth. These judgements guided researches to green energy consumption evaluations.

The literature started testing causal relationships between REC and economic growth using bivariate/trivariate models. Sadorsky (2009a) gives one of the leading contributions. Working with G7 countries, researcher finds mostly similar estimators applying fully-modified ordinary least square (FMOLS) and DOLS. Specifically, rising 1 per cent GDP per capita generates increments about 8.44 per cent and 7.25 per cent in REC according to FMOLS and DOLS, respectively. Moreover, CO_2 emissions per capita evidence similar significant elasticities among techniques. However, the effect of oil price is small-negative but significant in DOLS while insignificant in FMOLS. From the error correction model (ECM), his main conclusion is that the time to return to the equilibrium can diverge considerably among countries. In another study, Sadorsky (2009b) predicts the relationship between REC and GDP per capita, in eighteen economies (some LAC countries such as Argentina, Brazil, Chile, Colombia, Mexico, Peru, are considered). For countries with available information about electricity prices, he also analyses its long-run association with REC. Likewise, GDP per capita is a highly important predictor. Therefore, modest adjustments on it might generate substantial impacts on REC. Furthermore, ECM estimations expose that GDP per capita responds to adjustments back to the equilibrium level, while electricity prices do not.

Because of cross-sectional dependence and structural breaks, Salim and Rafiq (2012) apply Westerlund cointegration technique to identify a long-run relationship between the same variables examined by Sadorsky (2009a). According to FMOLS and DOLS results, income elasticities, in the long run, are 1.23 per cent and 0.20 per cent, respectively, and carbon-dioxide elasticities are 0.03 per cent and 0.13 per cent, respectively. Unlike other studies, authors apply ARDL technique individually to examine short-run causality for Brazil, China, India, Indonesia, Philippines, and Turkey. They conclude that CO_2 emissions per capita are a determinant of REC in almost all countries, excepting for Philippines and Turkey. However, in these countries, income is the principal long-run determinant of REC. Regarding oil prices, it does not evidence significant influence in any examination.

Studying six Central American countries, Apergis and Payne (2011) analyse REC, GDP, gross fixed capital formation and labour, identifying positive long-run relationships between the variables.[1] Authors also find short-run and long-run bidirectional causality between REC and GDP. Similarly, in another study of eleven South American economies, Apergis and Payne (2015) reveal bidirectional causality between REC and GDP per capita in the short and long run. Additionally, they detect a positive long-run relationship between GDP per capita, CO_2 emissions per capita, oil prices and REC.

Besides standard factors such as CO_2 emissions per capita and fossil fuel prices, scholars start evaluating other possible predictors. Moreover, the literature considers additional econometric techniques. For instance, Marques et al. (2010) employ fixed effects with vector decompositions methodology to avoid drops of country-specific components such as geographic dimension. This variable is relatively time-invariant since its size does not change drastically year by year. Besides, it is expected to impact the use of renewable energy according to the country's production potential. That means the geographically extensive the country is, the more production potential and use of renewables.

Additionally, they control for energy import dependency. Estimating three models (all countries, non-EU members and EU members), their main finding is that CO_2 emissions per capita have significant negative impacts on renewable energy usage, in all outputs. Moreover, energy import dependency presents a direct effect in almost all the models; GDP impacts positively in EU members, but negatively in the non-members; oil prices encourage the consumption of nonrenewables for EU members instead of driving the use of renewable energy while in non-EU members it has a non-significant impact. Finally, natural gas prices positively affect renewable energy usage in all countries.

[1] Gross capital formation is applied as proxy of capital stock.

One of the limitations to exploit clean energy sources is technology costs during the initial stage. However, costs have been diminished with the support of some regulatory instruments such as feed-in-tariff and auctions, or by financial aid from governments in the R&D phase. According to Johnstone et al. (2010), public policies enhance renewable energy innovations. Moreover, technology improvements may close the cost gap between renewable and non-renewable, making it feasible to develop clean energy sources. Because of this, Popp et al. (2011) examine the impact of the innovative process through feasible generalised least squares technique. Using the OECD patent database as a measure of the technological frontier to evaluate its influence on renewable energy investment and control other non-standard factors such as feed-in-tariff, renewable energy certificates and Kyoto ratification, authors find that innovations have a positive but small effect. Indeed, Kyoto commitment evidences a larger impact on renewable investment in 26 OECD countries during 1990–2004.

Furthermore, researchers have applied econometric techniques dealing with endogeneity produced by variables which were not strictly exogenous. Since it has been evidenced empirically that current EC levels are influenced by its past levels (Sadorsky, 2011; Nayan et al., 2013), literature has assessed renewable drivers upon a dynamic approach. For instance, Cardoso and Fuinhas (2011) control several factors that potentially determine renewable energy contribution in 24 European countries. Besides the usual variables, energy consumption, nuclear power share to electricity generation, and energy import dependency are controlled. They estimate three dynamic models (diff-GMM, sys-GMM and least squares dummy variable corrected), with outputs not differing substantially by estimation. Results from these variables are: 1) renewable energy use from previous period determines the current one, 2) increases in energy consumption forces to exploit alternative energy sources to satisfy energy needs, 3) nuclear power as inputs of energy production lessen the development of renewable energy because of lobbying effect, and 4) high energy imports reduce renewables commitments since countries have lower resources available to develop clean sources. Moreover, GDP, fossil prices and CO_2 emissions per capita evidence unexpected results: the formers present non-significant effects on the predicted variable while the latter negatively impact renewable energy contribution.

Omri and Nguyen (2014) continue studying the standard determinants of REC but incorporating trade openness as control variable since it can drive REC through income improvements. As part of robustness analysis, they segregate their sample between high-income, middle-income and low-income groups. Their model is estimated in growth form due to the non-stationarity of their data. Sys-GMM results suggest that CO_2 emissions per capita are the main driver of REC, being positive significant in four models (global panel and the three income level panels). Moreover, current REC is influenced by its previous value. Other predictors vary according to the model. For example, oil price presents significant negative effects in middle-income and global panel. Simultaneously, per capita GDP and trade openness are positive in the high and middle-income panel, and low-income and global panels, respectively. In another study, Omri et al. (2015) contrast the estimations between static and dynamic panels, showing that the former approach is not suitable due to autocorrelation in residuals. Likewise, their model is estimated in growth form. Under dynamic panel data methodology, they discriminate between diff-GMM and sys-GMM. The lagged-variable confirms a persistent effect in REC.

Unlike their previous paper, oil prices do not evidence a relevant effect in most panels. Trade is only significant in low- and middle-income and the global panel. CO_2 emissions per capita and GDP per capita are the main drivers, presenting significant positive effects in their four models. Akar (2016) apply sys-GMM to explore the determinants of REC in the Balkans. Unexpectedly, the author finds that per capita GDP has a negative highly significant impact on REC, which suggests that Balkans development does not lead to the higher costs of technology that require the adoption of clean energy. Trade openness and natural gas prices influence positively on REC. Moreover, the dynamic effect of REC is corroborated.

Elements that boost economic growth may contribute to the deployment of green energy. For instance, capital stock and labour force are input factors that might affect the predicted variable through GDP.[2] Therefore, controlling for them is rational, as Ackah and Kizys (2015) have done. Seeking to determine the causal effect on REC in African countries, they also include human capital and energy depletion as predictors. More educated people are more aware of environmental issues, and energy deficits would seek alternative sources, respectively. Their results from contrasting between random effect and sys-GMM do not diverge: the main drivers for REC are per capita carbon-dioxide emissions and energy depletion. An excellent outcome is produced by capital since its effect changes from positive to negative when this variable is regressed jointly with the other regressors. A plausible explanation is that other determinants lessen its impact. Furthermore, dynamic regressor is significant in the model.

From the previous causal studies performed on this topic (Berk et al., 2018), two novelties have to be recognised. Firstly, the inclusion of FDI inward stock regressor in the model. Controlling for this indicator is reasonable given that FDI may prompt the predicted variable through allowances on financial capital, which might support investments in renewables. Secondly, the convergence speed analysis of renewables has not been considered in previous REC literature. Authors contrast between unconditional and conditional convergence examination. That means, regressing the lagged variable on the predicted variable (unconditional), and regressing the predicted variable against the lagged and control variables (conditional). Having control for all predictors (FDI inward stock, CO_2 emissions per GDP in the previous period, electricity prices) authors find that the magnitude of the lagged-value coefficient is reduced, which means a fast convergence of renewables share in primary energy consumption in European countries. Although not all the control variables are significant jointly, the result lays on the strength that additional regressors produce on the sys-GMM instrument set (Hoeffler, 2002).

Contribution to the Literature

The empirical literature has advanced gradually applying different tools to determine which factors influence on REC. It has evolved from panel cointegration techniques to static panel data, and ultimately dynamic panel data. Nevertheless, there are still some improvements that must be done upon the latter approach. Most of the studies conclude the validity of their results after testing for no-autocorrelation and over-identifying restrictions.

However, information about the number of instruments, and the instrument variables selected with their respective number of lags, are not usually reported. Some researchers present their choices between static panels and dynamic panels, but a minority exhibits their discrimination between one or two-step estimation, or among diff-GMM and sys-GMM. According to Roodman (2006), these details must be shown to reduce false-positive results. Therefore, my main contribution to this application is to perform a robust analysis, following previous advice.

Moreover, the tendency to determine causal relationships/effects on REC is distinguished: explore usual factors (GDP, CO_2, oil prices); segregate between high, middle, low-income countries; work with European, OECD or industrialised countries as the framework. In this study, I also contemplate to contribute with these aspects: 1) Using LAC countries as economic context, and 2) controlling for additional factors which have not been examined widely in previous literature.

Data and Variables, and Methodology

Data and Variables

Data description.

In this study, a balanced panel of 22 LAC countries is used. It contains information about renewable energy consumption, real GDP per capita, real oil price, real natural gas price, CO_2 emissions per capita, trade openness, real gross capital formation (GCF) per capita, auctions adoption, and Kyoto commitment.[3]

Real oil and natural gas prices were constructed deflating the West Texas Intermediate (WTI) and Henry Hub spot price by US consumer price in-

[2] Scholars use gross capital formation as proxy of capital stock.

[3] The available free data of renewable energy consumption of LAC countries express this variable in percentage terms. Literature (Carley, 2009; Marques et al., 2010; Akar, 2016) has worked with the dependent variable in that unit of measurement. GDP and GCF are measured in constant 2010 USD. GCF is a flow variable; it does not represent capital stock (Lee et al., 2008). Following Akar (2016), trade openness sums up total exports and imports, measured as share of GDP.

dex (2010 = 100).[4] WTI prices are used since the framework of this study is LAC countries. Besides, it has been employed extensively in previous research to represent world crude prices. Since all the economic variables are measured in dollar USD, the country's conversion to specific oil and natural gas prices is not compulsory. Furthermore, GCF is converted to per capita terms dividing it by the respective population.

The dataset, which covers the period 2005–2014, was set up with information acquired mainly from World Bank Development Indicators (WDI), except for oil and natural gas prices, auctions and Kyoto, whose statistics were collected from Bloomberg terminal, IEA/IRENA Joint Policies and Measures database, and United Nations Treaty Collection website, respectively.[5]

The sample contains the following LAC countries (Table 1): Argentina, Bahamas, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay and Venezuela. Because of lack of data, Barbados, Grenada, Guyana, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Trinidad and Tobago were omitted from the analysis.

Table 2 displays the descriptive statistics of the variables across countries over time. Regarding the share of REC, the sample average is 33 per cent roughly. Its dispersion is by 20 per cent around the mean, varying from consumption levels from 0.84 to 83.16 per cent. About GDP per capita, it indicates an average of 7,088.23 USD. The economic performance heterogeneity is reflected in the region, varying from 665.63 USD to 31,632.45 USD. Another indicator that evidences a meaningful distance between the highest and lowest value is GCF, ranging from a minimum amount of 168.27 USD to a maximum of 11,679.63 USD, with a deviation from the mean of 2,026.82 USD on average. As reported by emissions, LAC countries show an average of 2.34 metric tons per capita over time, without vast disparity across countries. Due to the global recession, the fall in oil price is documented in the dataset, being the minimum value (45.17 USD per barrel).

Table 1
*Classification of countries**

Sub-Region	No. Countries	Countries
Central America	8	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama
Caribbean	4	Bahamas, Cuba, Dominican Republic, Haiti
South America	10	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, Paraguay, Uruguay, Venezuela

* Although Mexico belongs to North America geographically, some states are located in Central America region.

Moreover, real natural gas does not deviate substantially from their mean, with approximately 3 USD. About trade openness ratio, it seems that some areas of the region have been more integrated into the world economy than others. Overall, it suggests that LAC countries have been exposed to international trade. Ultimately, auctions' policy variable shows that it was not widely implemented in LAC (29 per cent on average). In comparison, the commitment to environmental performances has been ratified by 81 per cent of the sample.

Intending to inform which LAC countries lead some analysis factors during 2005–2014, Table 3.3 exhibits a ranking according to the average of each variable by country. Bahamas shows high levels of per capita GDP, CO_2 emissions and GCF.

However, it presents the lowest demand for REC over the period.[6] These results may suggest a limited relationship with REC. Paradoxically, Haiti and Paraguay, which were the countries with higher REC are listed as the lowest CO_2 emitters, anticipating an indirect relationship between these factors. Regarding trade openness, it does not hint about its relation with REC.

[4] CPI data was acquired from WDI.

[5] Initially, the time of analysis was decided from 2000 to 2016. However, the time horizon was narrowed due to the unavailability of data for all the countries.

[6] Venezuela ranked as the second highest GDP per capita in the region is due to the period of analysis, which is before its economy contraction. This country intensified its economic crisis with the fall in oil prices during 2014 (OPEC, 2019).

Table 2
Summary statistics

Variables	Mean	Std. Dev.	Min.	Max.
Renewable energy consumption (% total final energy consumption)	32.875	20.059	0.844	83.161
GDP per capita (constant 2010 USD)	7,088.228	6,163.889	665.627	31,632.450
CO2 emissions (metric tons per capita)	2.336	1.582	0.213	7.427
Real oil price (USD per barrel)	77.654	18.663	45.170	100.939
Real natural gas price (USD per million BTU)	5.568	2.846	2.661	12.533
Real gross capital formation per capita (constant 2010 USD)	1,782.666	2,026.821	168.267	11,679.630
Trade openness (% GDP)	70.726	29.960	22.106	166.699
Auction (dichotomous)	0.286	0.450	0	1
Kyoto (dichotomous)	0.814	0.390	0	1
No. Observations	220	220	220	220

Source: WDI, Bloomberg terminal, IEA/IRENA Joint Policies and Measures database, United Nations Treaty Collection website.

Variables and hypothesis.

This study's variables are included due to economic theory, previous literature, and data availability.

Renewable energy consumption (REC): Historically, LAC has utilised considerable amounts of hydropower to produce electricity. Nevertheless, its share has diminished over time, while fossil fuel share has increased, and emissions levels have increased. Furthermore, energy consumption has expanded during the last decades due to population growth and the development of its economy, exceeding even the quantities demanded from OECD countries (IDB, 2000). These facts develop a concern about the relevance of promoting regenerative energy sources. This variable is regressed against a vector of explanatory/control variables to determine which factors may influence renewable consumption. In this study, REC is measured as the percentage of total final energy consumption.

Continuous consumption of renewable energy (REC_{t-1}): As suggested by Cardoso and Fuinhas (2011), the use of renewable energy is a continuous process since it depends on meaningful investments done to supply it. Moreover, the production of energy would require a stable level of demand. Hence, I expect that REC_{t-1} has a positive and significant impact on the dependent variable. The hypothesis to be tested is:

H_1 – *Renewable energy consumption is positive affected by its previous value*

GDP per capita (Y): GDP is commonly implemented in this literature since it keeps the relationship with energy consumption, is a proxy of income and a growth measurement. Scholars have found that increases in per capita GDP positively affect the consumption of clean energy since countries have more resources to afford the higher technology or regulatory costs (Sadorsky, 2009b; Apergis & Payne, 2011). Furthermore, economic growth implies more demand for energy, leading to the use of renewable sources to satisfy it. For that reason, I expect a significant positive relationship between per capita GDP and the dependent variable. The hypothesis to be tested is:

H_2 – *GDP has a positive significant effect on renewable energy consumption.*

It is worth mentioning that this regressor is not strictly exogenous because of the following reasons: Literature has proved that GDP determines renewable energy consumption (i.e. Omri et al., 2015; Akar, 2016). Likewise, literature has evidenced that renewable energy consumption drives economic growth (i.e. Inglesi-Lotz, 2016; Amri, 2017).

Carbon-dioxide emissions per capita (CO_2): During the process of energy production, fossil fuels are burned, emitting toxic gases to the environment like CO_2, which is the main responsible for

Table 3
Ranking of countries according to indicators, period 2005–2014

Country	REC	Country	GDP	Country	TO	Country	CO2	Country	GCF
Haiti	78.402	Bahamas	29,517.94	Panama	145.438	Venezuela	6.210	Bahamas	9,832.539
Paraguay	65.216	Venezuela	14,083.45	Belize	122.305	Bahamas	5.282	Venezuela	3,230.321
Guatemala	61.545	Chile	12,939.34	Honduras	121.947	Argentina	4.499	Panama	3,146.191
Nicaragua	52.318	Uruguay	11,546.97	Nicaragua	98.082	Chile	4.343	Chile	2,971.688
Honduras	51.298	Argentina	10,046.00	Bahamas	84.575	Mexico	4.141	Uruguay	2,315.518
Uruguay	46.032	Mexico	9,494.83	Bolivia	77.917	Cuba	2.826	Brazil	2,253.547
Brazil	45.743	Panama	8,243.70	Costa Rica	76.240	Ecuador	2.415	Mexico	2,123.628
Costa Rica	40.992	Costa Rica	8,085.31	Paraguay	75.752	Panama	2.378	Argentina	1,716.798
El Salvador	33.910	Colombia	6,392.25	El Salvador	75.655	Uruguay	2.134	Costa Rica	1,567.036
Belize	33.422	Cuba	5,583.82	Chile	70.804	Brazil	2.126	Colombia	1,371.858
Chile	30.102	Dom. Rep.	5,417.49	Haiti	65.227	Dom. Rep.	2.115	Dom. Rep.	1,339.856
Peru	29.334	Peru	4,964.75	Guatemala	62.434	Costa Rica	1.698	Ecuador	1,309.569
Colombia	27.615	Ecuador	4,755.33	Mexico	60.772	Peru	1.660	Peru	1,105.523
Panama	23.702	Belize	4,415.92	Ecuador	60.242	Colombia	1.603	Belize	896.985
Bolivia	20.080	Bolivia	4,339.11	Dom. Rep.	58.559	Bolivia	1.580	Paraguay	887.660
Cuba	18.436	Paraguay	4,193.83	Uruguay	55.747	Belize	1.572	Cuba	609.209
Dom. Rep.	17.826	El Salvador	3,025.50	Venezuela	53.339	El Salvador	1.066	El Salvador	585.255
Venezuela	13.646	Guatemala	2,840.76	Peru	51.825	Honduras	1.040	Honduras	509.290
Ecuador	12.978	Brazil	1,959.87	Cuba	40.906	Guatemala	0.887	Guatemala	468.511
Mexico	9.491	Honduras	1,910.72	Colombia	37.707	Nicaragua	0.803	Nicaragua	454.411
Argentina	9.427	Nicaragua	1,557.75	Argentina	35.483	Paraguay	0.772	Bolivia	340.650
Bahamas	1.735	Haiti	703.17	Brazil	25.008	Haiti	0.233	Haiti	182.610

REC = renewable energy consumption; TO = trade openness; GCF = gross capital formation. *Source:* WDI.

global warming. Because of the apprehension about climate change, and the necessity to diminish pollution and contribute to sustainable development, countries could be triggered to adopt pro-environmental actions such as promoting clean energies. From empirical studies, it has been found that CO_2 emissions per capita drives green energy consumption (i.e. Sadorsky, 2009a; Salim & Rafiq, 2012; Omri & Nguyen, 2014). Nevertheless, Marques et al. (2010) and Cardoso and Fuinhas (2011) have found negative impacts, concluding that higher emissions levels lessen its use. However, I expect a positive effect from this explanatory variable. The hypothesis to be tested is:

$H_3 -$ CO_2 *has a possitive significant effect on renewable energy consumption*.

Moreover, the empirical literature has evidenced that renewable energy affects significantly carbon-dioxide emissions (i.e. Shafiei & Salim, 2014). Therefore, CO_2 is judged to produce endogeneity in the model.

<u>Oil price</u> (ROP), <u>Natural gas price</u> (RGP): Oil and natural gas are categorised by IEA such as non-renewables because they arise from the buried remains of plants and animals. Renewable sources are considered substitutes of non-renewables in the production of energy. Furthermore, prices of energy produced by fossil fuels are lower than the price of renewable energy because the formers do not internalise social damage. It would be expected that increments in fossil fuel prices could influence to reduce their use and promote renewable energy demand, ceteris paribus. However, a consensus has not been evidenced since some literature confirms a significant positive influence of oil prices (i.e. Apergis & Payne, 2015) while others state negative or non-significant effect (i.e. Sadorsky, 2009a; Omri & Nguyen, 2014). The two respective hypothesise to be tested are:

$H_4 -$ ROP *has a possitive significant effect on renewable energy consumption.*

$H_5 -$ RGP *has a possitive significant effect on renewable energy consumption*.

Since quantities and prices emerge from the equilibrium of demand and supply, outcomes arise from the dynamic market process. Changes in fossil fuel prices generate changes in renewable energy consumption. Changes in the demand for renewable energy could contribute to adjustments in fossil fuels' price due to future demand expectations. Hence both covariates are judged to produce endogeneity.

Trade openness (TO): Renewable energy technologies are transferrable across countries (IRENA, 2016b). Being exposed to international trade allows the country to the possibility of technological transfer, which may represent improvements in renewable energy deployment. Furthermore, foments in economic growth due to being opened could represent opportunities to attract more foreign investment (FDI) and develop renewable energy sources. Therefore, I expect a positive impact on the dependent variable. Indeed, there is confirmation about its positive influence on green energy consumption (i.e. Omri et al., 2015). The hypothesis to be tested is:

$H_6 -$ TO has a possitive significant effect on renewable energy consumption.

This regressor could be a source of endogeneity because of the omission of a variable correlated with TO and determines clean energy use, for instance, energy conservation policies. This factor could affect trade openness in two ways: 1) by export side: conventional energy is required during the process of production and transportation of goods, hence promoting the reduction of energy modifies operative mechanisms which could shrink exportable amounts, 2) by import side if foreign commodities are energy-intensive (Sadorsky, 2012). Further, energy conservation policies could impact the dependent variable. Given that conventional energy consumption is lowered, they induce the adoption of alternative sources to satisfy the increasing energy demand.

Investment in capital per capita (GCF): This explanatory variable may trigger the adoption of renewable energy consumption since it could positively affect the production capacity of this energy source. Ackah and Kizys (2015) have found that increases in gross capital formation promote clean energy consumption when this variable is regressed individually on renewable energy consumption. When renewable energy consumption is regressed against the gross capital formation and other covariates, the effect is negative. Nevertheless, I anticipate a positive effect on the predicted variable. The hypothesis to be tested is:

$H_7 -$ GCF has a possitive significant effect on renewable energy consumption.

Capital investment might keep relation with renewable energy consumption growth or expectations about its future demand. Given that investors need confidence before investing, they may evaluate demand's evolution to seek whether consumption levels justify the respective higher risks and costs. Hence it would not be expected that consumption affects investment during the same year. Therefore, I assume that GCF does not produce endogeneity in the model.

Furthermore, *auctions* and *kyoto* variables are considered as part of robustness. As reported by IRENA (2015), auctions are the most applied regulatory instrument in LAC to promote renewable energy.[7] Its implementation has created economic benefits like price competitiveness, local employment and industry development, and technologies. Moreover, the study exposes that Latin America is a pioneer and innovator in the design of auctions. Hence, this variable is included in the robustness process to explore whether it significantly impacts renewable energy consumption. It is treated as a dichotomous variable, taking the value of one when the policy was established. The hypothesis to be tested is:

$H_8 -$ auctions have a possitive significant effect on renewable energy consumption.

According to Johnstone et al. (2010), policies that induce innovations for developing renewable technology are enforced in some OECD countries because of Kyoto Protocol commitment. Moreover, Popp et al. (2011) find that renewable energy has risen after signing the Kyoto Protocol. OECD countries that invest more in technology are due to their commitment. Therefore, I consider Kyoto commitment as a part of the robustness exercise to verify its partial effect on renewable energy consumption. This regressor is a dummy variable, which takes the value of one when the country has ratified, accepted, acceded or approved the protocol. It is remarkable to comment that the first stage finished in 2012, however, some countries like Honduras, Mexico and Peru accepted in 2014 the Doha Amendment.

[7] The process of auctions is the following: project developers present a bid withelectricity price per unit. Governments take a decision upon some criterias such as prices, environmental requirements, technologies implemented. The winner signs a contract to be the renewable generator over a time period (IRENA, 2015, p. 12).

Therefore, these countries take the value of one in 2014. The hypothesis to be tested is:

H_9 – *kyoto has a possitive significant effect on renewable energy consumption*.

Methodology

In this study, static and dynamic approaches are employed to produce a robust comparison and verify their estimations' accuracy. Since dynamic panel models expunge the bias generated from the association between the lagged-dependent variable and the error and also deals with regressors which are not strictly exogenous, therefore, some authors implemented them recently to examine the determinants of renewable energy consumption (i.e. Omri et al., 2015; Cardoso & Fuinhas, 2011).

Static panel model.

Based on previous literature (Omri et al., 2015; Ackah & Kizys, 2015; Akar, 2016), Equation 1 is expressed as a function of the following variables:

$$REC = f\left(Y, CO_2, ROP, RGP, GCF, TO\right) \quad (1)$$

where REC indicates the consumption of renewable energy, Y GDP per capita, CO_2 carbon-dioxide emissions per capita, ROP real oil price, RGP real natural gas price, GCF gross capital formation per capita are measures of capital investment and TO trade openness.

Equation 1 is written in panel form as follows:[8]

$$\begin{aligned} \log REC_{it} &= \alpha + \beta_{i1} \log Y_{it} + \\ &+ \beta_{i2} \log CO_{2_{it}} + \beta_{i3} \log ROP_{it} + \\ &+ \beta_{i4} \log RGP_{it} + \beta_{i5} \log GCF_{it} + \\ &+ \beta_{i6} \log TO_{it} + \mu_i + \varepsilon_{it}, \end{aligned} \quad (2)$$

where $i = 1, \ldots, N$ denotes the country, and $t = 1, \ldots, T$ the periods, μ_i captures country-specific non-observable effects, and ε_{it} represents the disturbance.

Variables in Equation 2 are converted in logarithm form since that helps deal with any issue arisen from the data's dynamic properties (Bhattacharya et al., 2016). Following Marques et al. (2010), a normality test for REC_{it}. It is measured in percentage terms and executed, indicating a skewed distribution (Appendix). Hence, it is recommendable to transform the regressor in logarithm to avoid biased and inconsistent results (Cameron & Triverdi, 2009).

To estimate Equation 2, I employ static panel data techniques. The country-specific non-observable effects μ_i could be fixed or random. If μ_i is assumed to be fixed, the correlation between this factor and regressors are presumed. It will generate biased results due to omitted variable issues. However, it is possible to obtain consistent estimators applying fixed effects (FE) model. FE disposes of those risks, operating such as transformation to dropping the regression's noisy component. If μ_i is assumed to be random, zero correlation between this factor and regressors are presumed. Under this approach, estimating Equation 2 by FE produces inconsistent results. The suitable is to apply random effects (RE) technique.

Although the model's feature could decide whether performing FE or RE, scholars generally apply both methods and select one of them after conducting a formal examination. Hausman (1978) developed a test to seek whether the coefficients of the time-varying variables evidence statistically significant differences. If the assumption sustained by RE about no correlation between the country-specific components and the regressors fails, this estimator will be inconsistent. FE is not affected because it does not rely on the previous assumption. A rejection of the null hypothesis states that both estimators are consistent, and being in favour of the alternative will be the conclusion, suggesting that FE is more suitable.

Dynamic panel model.

Nayan et al. (2013) explained that the current energy consumption level tends to follow the pattern of consumption from the previous period. Since the production process would require a continuous demand level, it could be expected an interdependence of renewable energy consumption. It implies a dynamic feature in the model. To represent it, Equation 2 is rewritten in the following form:

$$\begin{aligned} \log REC_{it} &= \alpha + \beta_i \log REC_{it-1} + \beta_{i1} \log Y_{it} + \\ &+ \beta_{i2} \log CO_{2_{it}} + \beta_{i3} \log ROP_{it} + \\ &+ \beta_{i4} \log RGP_{it} + \beta_{i5} \log GCF_{it} + \\ &+ \beta_{i6} \log TO_{it} + \mu_i + \varepsilon_{it}, \end{aligned} \quad (3)$$

[8] Auctions adoption and Kyoto commitment are considered as part of robustness analysis.

where REC_{it-1} provides the impact of the one-period lagged value of renewable consumption in the model. The existence of the lagged-dependent variable displays the dynamic structure of the system. To estimate Equation 3 under a dynamic framework, the first step is to remove μ_i by first-differencing procedure:

$$\Delta y_{it} = \delta \Delta y_{i,t-1} + \Delta x'_{it}\,\beta + \Delta v_{it}; \qquad (4)$$

where $\Delta v_{it} = \left(\varepsilon_i - \varepsilon_{i,t-1}\right)$; y_{it} is the dependent variable and x'_{it} is a vector of regressors

Country-specific effects were eliminated because of the first-difference process. However, the transformation of the residual $\left(\varepsilon_i - \varepsilon_{i,t-1}\right)$ is by construction correlated with $\left(y_{i,t-1} - y_{i,t-2}\right)$ due to the association between $y_{i,t-1}$ and $\varepsilon_{i,t-1}$.

To estimate Equation 4, the difference and system generalised method of moments (diff-GMM and sys-GMM, respectively) can be implemented. Both procedures are devised to work accurate, dealing with: 1) lagged-dependent variable as the predictor, 2) independent variables which are not strictly exogenous, 3) fixed-effects components, 4) heteroscedasticity, 5) serial correlation within observations (Roodman, 2006, p. 4).[9]

Diff-GMM, introduced by Holtz-Eakin et al. (1988) and continued by Arellano and Bond (1991), considers the endogeneity arisen in Equation 4. Likewise, an endogeneity could emerge from the association between other regressors that are not strictly exogenous and $\varepsilon_{i,t-1}$. Hence, the utilisation of instruments is necessary to solve the problem. Since the method contemplates the challenge of finding good external instruments, it exploits internal instruments acquired using the levels of the regressors of Equation 4, lagged, as instruments. The crucial assumption for GMM estimators' validity is that those instruments must be exogenous, and that is satisfying because lagged variables are orthogonal to the disturbance (Roodman, 2006).

A shortcoming of the diff-GMM is related to unbalanced panel data. Since in that type of panels, not all the units are observed, differencing the data intensifies the gaps. Nevertheless, it does not occur in this study since my panel is strongly balanced. Another deficiency is originated when the dependent variable is highly persistent, and when the period is small. It could generate small sample bias due to weak instruments, making diff-GMM estimator inefficient (Blundell & Bond, 1998; Roodman, 2006; Cardoso & Fuinhas, 2011). Upon weak instrumentation, the employment of an alternative estimator improves the results. Sys-GMM was developed by Blundell and Bond (1998) to increase efficiency and produce more robust instruments. Behaving as a system of two simultaneous equations, sys-GMM combines the moment conditions of the data in levels and the transformed model (Roodman, 2006). The equation in levels implements lagged-first-difference variables as instruments, and the differenced equation uses lagged-level variables as instruments. Given that my time dimension is small and that sys-GMM produce more efficient estimators, I estimate Equation 4 by this approach.

By the construction of the second equation, additional instruments can be encountered. When too many instruments are implemented, the endogeneity could not be expunged, and the joint validity of the instruments produced by the Hansen test could present suspicious high p-values. Literature generally does not advise about the number of instruments. Therefore, the decision is guided by researcher criteria or empirical works.[10] Instruments proliferation can be overcome, restricting the number of lags, collapsing instruments, or using the previous tools jointly (Çoban & Topcu, 2013).

The overall validity of the instruments is tested by Hansen, where the null hypothesis states that the instruments as a group are exogenous. Hence, with high p-values, there is no statistically valid evidence to reject the null, giving support to the set of instruments applied. Nevertheless, p-values close to one produce doubtful about exogeneity conclusions.[11] Under this scenario, a proliferation of instruments results and a finite-sample bias is derived (Roodman, 2009).

Another diagnostic for the consistency of the estimators is conducted by the test for serial correlation of the idiosyncratic error ε_{it} (Arellano & Bond, 1991). This test is implemented to the differenced residuals to set aside μ_i. Overall, the

[9] Each category of GMM estimator has two versions: one step and two steps.

[10] Another option is to test the robustness of the results until reduce the p-value of Hansen test (Windmeijer, 2005).

[11] According to Roodman (2006), p-values higher than 0.60 needs attention.

test's mechanic looks for autocorrelation of order l in levels by inspecting serial correlation of order $l+1$ in differences (Roodman, 2006, p. 34). Hence, the AR(2) test in first differences is more informative than AR(1) test. A rejection of its null hypothesis suggests a serial correlation in the error term, implying endogeneity.

Results

Static Panel Results

FE and RE carry out the static models' estimation; robust POLS is presented as a benchmark model. Unlike Omri et al. (2015), the unit-roots test was not executed due to the dataset's small-time horizon. Scholars have emphasised that the appliance of unit roots tests in finite samples has arbitrarily low power and could produce misleading results (Schwert, 1987; Lo & MacKinlay, 1989; Cochrane, 1991).

Table 4 displays the results of the two models. In model 1, the standard empirical model is estimated, while in model 2, *auctions* and *kyoto* regressors are incorporated to examine their partial effect on the use of renewable energy.[12] Hausman test is conducted to test the null hypothesis about no-correlation between unobserved effects and regressors. As reported, there is statistically evidence against the null at 1% level, implying that the FE model generates consistent estimators. Thus, the analysis will be done, taking into account this method.

As reported in model 1, CO_2 is the variable with the highest impact on REC, in absolute value. Nevertheless, the negative sign is unanticipated since some studies predict a positive relationship among the factors (i.e., Salim & Rafiq, 2012; Apergis & Payne, 2015). The result indicates that keeping the other variables fixed when countries face more levels of emissions per capita, their response to the use of green energy decreases instead of being promoted. GDP per capita evidences a positive and significant effect at 5 per cent level, implying that income increases may induce to consume renewable energy, ceteris paribus. This result is expected, and it is in line with findings from Sadorsky (2009b) and Omri et al. (2015). Typically, a 1 per cent increase in income per capita raises renewable energy consumption by 0.420 per cent.[13] Regarding RGP, this factor has a positive partial effect on the dependent variable, suggesting that there exists a switch response when its prices increase. This outcome does not contradict the results of Marques et al. (2010).

In model 2, I control two policies induced in LAC countries: *auctions* and *kyoto*. When these regressors are incorporated in the equation, FE estimators do not change dramatically: GDP, CO_2 and RGP continue being statistically significant at the same levels. Moreover, the negative sign of carbon-dioxide emissions remains. Regarding the included covariates, *auctions* is unique with a statistically significant effect. Keeping other variables constant, it seems that adopting *auctions* causes increments in REC. On the other hand, *kyoto* shows the expected sign but is non-significant even at 10 per cent level.

It is worth mentioning that previous estimations may have produced naïve conclusions. Results are jeopardised because of non-strict exogeneity of regressors. Furthermore, it has been evidenced by the literature that the consumption of energy is strongly related with past observations (i.e., Sadorsky, 2011; Nayan et al., 2013; Çoban & Topcu, 2013). Besides, Wooldridge AR(1) test has detected the presence of serial correlation in the idiosyncratic disturbance in both models (Table 4), which imply biased standard errors, not efficient estimators and misleading outcomes.[14] Therefore, the static approach is not accurate.

Dynamic Panel Results

In this study, the sys-GMM framework is preferred over the diff-GMM since it is more efficient and avoid small sample bias (Blundell & Bond, 1998; Cardoso & Fuinhas, 2011). One of the prerequisites of this framework to produce relevant results is that the cross units might be higher than the time horizon. For this reason, the sample cannot be segregated to evaluate the drivers by sub-regions (see Table 3). Following Roodman (2006) recommendations, one and two-step estimations are conducted in both models.

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[12] The lagged dependent variable is not included as predictor in static models since it induces endogeneity.

[13] Given the log-log transformation, outcomes could be interpreted as elasticities. However, this interpretation is not meaningful due to the measurement of the dependent variable.

[14] Drukker (2010) demonstrates that Wooldridge test for serial correlation in RE, FE models with small samples have good power properties.

Table 4
Static panel output

Variables	Model 1						Model 2					
	Pooled OLS		Random effects		Fixed effects		Pooled OLS		Random effects		Fixed effects	
	Coefficient	Std. Errors	Coefficient	Std. Errors	Coefficient	Std. Errors	Coefficient	Std. Errors	Coefficient	Std. Errors	Coefficient	Std. Errors
$logY_{it}$	−0.275*	0.093	0.003	0.150	0.420**	0.195	−0.253*	0.087	0.006	0.152	0.454**	0.200
$logCO_{2_{it}}$	−0.638*	0.123	−0.595*	0.101	−0.509*	0.106	−0.662*	0.119	−0.582*	0.100	−0.491*	0.105
$logROP_{it}$	−0.038	0.143	−0.033	0.031	−0.035	0.031	−0.052	0.139	−0.039	0.031	−0.047	0.031
$logRGP_{it}$	−0.0002	0.078	0.056**	0.023	0.099*	0.025	0.065	0.089	0.075*	0.024	0.113*	0.026
$logGCF_{it}$	0.027	0.083	0.106	0.068	0.015	0.075	0.027	0.085	0.114***	0.068	0.018	0.074
$logTO_{it}$	−0.125***	0.067	−0.057	0.090	0.014	0.095	−0.129**	0.062	−0.018	0.091	0.050	0.095
$auctions_{it}$							0.278*	0.077	0.089*	0.034	0.085**	0.034
$kyoto_{it}$							0.016	0.114	0.017	0.025	0.037	0.025
Constant	6.465*	1.340	3.113	1.222	−0.222	1.567	6.166*	1.253	2.810**	1.236	−0.727	1.595
Prob > F		0.000		0.000		0.000		0.000		0.000		0.000
R-squared		0.583						0.602				
N. Groups				22		22				22		22
N. Observations		220		220		220		220		220		220
Breusch-Pagan LM test: p-value						0.000						0.000
Hausman test: p-value						0.005						0.046
Wooldridge test AR(1): p-value						0.000						0.000

Significant at *1%, **5%, ***10% level. Model 1 is the standard equation; Model 2 includes $auctions$ and $kyoto$ covariates for robustness.

Consistency of estimators is validated when the following conditions are satisfied: 1) no-autocorrelation in the error term evidenced by AR(2) test, 2) validity of instruments reported by Hansen test, 3) no instruments proliferation. As reported in Table 5, those conditions are fulfilled in one-step and two-step sys-GMM in model 1.

Regarding the Arellano-Bond test, the p-value provides little evidence against the null hypothesis of the absence of second-order autocorrelation in residuals. Hansen test verifies the joint validity of the instruments. As it is shown, the p-value is not implausibly large. Furthermore, the rule of thumb that the number of instruments must be smaller or equal than the number of cross-sections is achieved. Hence there is no proliferation of instruments, and with that, finite sample bias was avoided (Table 5).

Moreover, the coefficient of REC_{t-1} has a value lower than the unit. Therefore, a convergence or steady-state assumption suggested by Roodman (2009) is satisfied.[15] Its statistical significance at 1 per cent level indicates that the consumption of renewable energy is strongly and positively affected by its previous value, confirming H_1 and is in line with the literature (Ackah & Kizys, 2015; Omri et al., 2015; Akar, 2016).

Although one and two-step estimations are presented in both models, it is recognised that the two-step approach is preferable since it generates more efficient estimators than one-step approach (Roodman, 2009). Hence the next results will be analysed under the two-step approach. In addition to the lagged variable in model 1, per capita GDP evidences a positive and significant effect at 5 per cent level, ceteris paribus. This finding is consistent with Apergis and Payne (2015), Omri et al. (2015). H_2 has been confirmed: GDP per capita enhances the consumption of renewable energy in LAC countries, implying that economic growth has influenced to afford for regenerative sources to satisfy the result in increasing energy demand that the region has experimented since the 2000s.

The negative impact of CO_2 on the adoption of green energy is reinforced at the 10 per cent level, indicating that increments in emissions per capita diminish the demand for renewable sources. It implies that social pressure about environmental concerns is insufficient in LAC countries to increase the consumption of a clean energy source in a short-run scenario. The suspicious about this indirect effect is verified, and H_3 is rejected because of the sign (Section 3.1.2). Although this variable's sign contradicts some empirical evidence (i.e., Omri & Nguyen, 2014; Omri et al., 2015; Berk et al., 2018), other scholars (Marques et al., 2010; Cardoso & Fuinhas, 2011) have found similar results. A rationale for this result could be related to the share of fossil fuels in LAC. This sector is very influential in the region, with higher energy mix participation. Although some countries like Mexico are promoting environmental regulations, they continue strengthening policies that support fossil fuel sector since its private investment enhances their economy. Therefore, there are no strong incentives to reduce gains to benefit the environment. Moreover, the main source of dirty emissions in LAC comes from transport and industry, which use oil as the principal resource.

ROP does not evidence to determine green energy adoption, rejecting H_4. Its small negative magnitude is consistent with findings of Sadorsky (2009a), and its insignificant impact is in line with Cardoso and Fuinhas (2011), and Salim and Rafiq (2012) who manifest that the short period of analysis could be an explanation of the results. Although fluctuations in oil prices bring disadvantages to the energy mix, it is not significant for switching to green systems, unexpectedly. A possible justification might be related to resource endowments and cost savings in a short-run scenario. The region is highly dependent on oil products due to the disposal of large reserves from Venezuela, Brazil, and Mexico. Given that renewable electricity projects require grants or subsidies for starting to be operative, they are not attractive for competing directly with projects that use oil as input. In terms of monetary cost savings, it may be more convenient to use other low-priced energy sources like natural gas when prices run up at the expense of continuing deteriorating the environment (Omri & Nguyen, 2014). Furthermore, OPEC's presence may influence the delay of renewable energy deployment. Upon a free-market approach, its scarcity would be warned by its high price due to higher extraction costs. It could induce a switch response because

[15] The steady state assumption suggests that any deviation from the long-term value must not be systematically correlated with individual-specific effects (Çoban & Topcu, 2013).

renewables become more attractive, as Cardoso and Fuinhas (2011) explained. However, that is not taking place since the cartel controls the price, and it is not set too high to mitigate replacements.

On the other hand, RGP expose a substitute response as expected, being in line with Akar (2016). However, its effect is non-significant (it differs from static panel results). Thus, H_5 is rejected. The sign could be associated with the swap that some LAC countries have done from hydropower to natural gas due to the former's shortages and the latter's abundancy. Currently, LAC experiments a positive natural gas trend as the power generator input because of its efficiency and trading. Also, natural gas is considered as a clean alternative source for electricity.[16]

GCF does not explain changes in REC, rejecting H_7. This result is not consistent with Apergis and Payne (2011) findings who predict a positive linkage among these variables in six Central America countries. A potential justification is that outcome differs because of the analysis period and the methodology applied. Nevertheless, Ackah and Kizys (2015) detect a negative effect from this predictor, concluding that other factors lessen its impact. Although this result is unexpected, a hint about its indirect was anticipated by me. I judge that the negative and non-significant effect of this variable could be related to the increments on tax bases levied on companies oriented to investments, as reported by ECLAC (2004). These policies constrain the expansion of renewable energy projects since they need more investment per unit of installed capacity.

Regarding TO, the sign is analogous to findings from Omri et al. (2015) and Akar (2016), implying that barriers discharges reinforce transfers of goods, services, knowledge, and technologies, which could give advantage to the production of this energy and with that, triggers its consumption. However, this factor does not reflect a significant impact, rejecting H_6. It could be explained by the regulations, taxes and other distortions applied from LAC governments to control the energy sector, which depress the market trade. According to WTO, governments can apply regulations to pursue any policy objective even though the market is liberalised.[17] Furthermore, as Yépez et al. (2011) stated, trade-related with electricity is limited in LAC in absolute magnitude and overall demand.

When *auctions* and *kyoto* regressors are controlled in model 2, sign and significance of REC_{t-1}, CO_2 and GDP are robust to previous results. Moreover, ROP and RGP become significant at the 10 per cent level.

Despite Popp et al. (2011) report that ratifying *kyoto* has a significant impact on renewable energy investment, in this study this commitment has not evidenced a causal effect on REC, rejecting H_9 (Section 3.1.2). This result is not abrupt. Literature discloses that the first phase of this international agreement was ineffective in achieving its target due to weak incentives of enforcement and cooperation (Barret, 2010). According to Mathys and Melo (2010), not using trade as an enforcing mechanism of control and sanction among signatories and non-signatories is related to pessimistic results. Moreover, a report (IDB, 2000) mentions that LAC countries did not succeed in identifying the inventories of their GHG emissions during Kyoto. Finally, *auctions* present statistically significance at 5% level indicating that this regulatory policy has a positive effect on REC, and confirming H_8.

The aim to include the two latter variables in model 2 lays on robustness examination since previous empirical work has not controlled them to explore their influence on REC. Nevertheless, these results are not suitable because a bias could have been generated due to the proliferation of instruments. Although the techniques emphasised by Roodman (2009) were applied, the number of instruments exceeds the number of groups (Table 5). That may happen because many variables held in this model. Consequently, the p-value of the Hansen test gets a high value, representing a warning signal and reduction of power in the overidentification test. Therefore, conclusions from these estimations could be suspicious and not reliable.

Conclusions, Policy Recommendations, Limitations and Future Work

Conclusions

In this study, I analyse the potential drivers of REC in LAC countries, over the period 2005–2014. Applying two econometric techniques (static and dynamic panels), I verified the estimated parameters' sensitiveness. Using two-step

[16] This assumption relies on the fact that natural gas is lower carbon-dioxide emitter than oil.

[17] Information obtained from World Trade Organization website.

Table 5
Dynamic panel output

Variables	Model 1				Model 2			
	One step sys-GMM		Two step sys-GMM		One step sys-GMM		Two step sys-GMM	
	Coefficient	Std. Errors (Robust)	Coefficient	Std. Errors (Robust)	Coefficient	Std. Errors (Robust)	Coefficient	Std. Errors (Robust)
$logREC_{it-1}$	0.950*	0.070	0.947*	0.067	0.942*	0.092	0.896*	0.103
$logY_{it}$	0.446	0.264	0.393**	0.188	0.494***	0.257	0.351**	0.164
$logCO_{2_{it}}$	−0.526**	0.201	−0.425***	0.222	−0.542*	0.181	−0.434*	0.134
$logROP_{it}$	−0.051	0.047	−0.033	0.037	−0.049	0.040	−0.042***	0.023
$logRGP_{it}$	0.031	0.035	0.041	0.029	0.038	0.037	0.051***	0.028
$logGCF_{it}$	−0.031	0.135	−0.030	0.117	−0.042	0.123	−0.003	0.095
$logTO_{it}$	0.090	0.217	0.017	0.145	0.133	0.188	0.001	0.143
$auctions_{it}$					0.068	0.065	0.122***	0.066
$kyoto_{it}$					0.018	0.026	0.031	0.019
Constant	−3.327	2.264	−2.718***	1.531	−3.854***	2.117	−2.348	1.407
Prob > F		0.000		0.000		0.000		0.000
N. Instruments		21		21		23		23
N. Groups		22		22		22		22
N. Observations		198		198		198		198
Arellano-Bond AR(2) test: p-value		0.499		0.461		0.425		0.308
Hansen test: p-value		0.384		0.384		0.662		0.662

Notes.
Significant at *1%, **5%, ***10% level. Following Roodman (2006), one and two-step sys-GMM estimation results are reported. Model 1 is the standard equation. GMM type variables are $logREC_{t-1}$, $logY$, $logCO_2$, $logROP$, $logRGP$, $logTO$. The standard type variable is $logGCF$. Time dummies are not included because of the aim to capture the effect of fossil fuel prices. Instruments are reduced by collapsing option and using the lags range from one to four for $logREC_{t-1}$ and $logCO_2$; from one to two for $logRGP$; from one to one for $logY$, $logROP$, $logTO$. Model 2 includes $auctions$ and $kyoto$ as standard type variables.

sys-GMM, the risks of endogeneity and serial correlation were treated, producing consistent estimators that fulfilled the conditions of no-autocorrelation in the error term, the validity of instruments, and no-proliferation of instruments. Additionally, the convergence assumption was satisfied.

The effect of REC_{t-1} was demonstrated, indicating that renewable energy consumption follows a significant dynamic process. GDP per capita and CO_2 emissions per capita were the determinants of REC throughout the analysis. That means economic growth enhances the demand for this energy source, while higher emissions levels do not induce more consumption. Both findings are in line with previous literature. Therefore, policies implementations may be mainly aligned with these factors.

On the other hand, fossil fuel prices did not evidence meaningful effects to stimulate REC. Regarding oil, the region is highly dependent because of Venezuela, Mexico, Brazil, and Colombia productions. Moreover, OPEC's existence narrows the possibility of switching to renewable sources in the short-run. Fouquet (2016) suggested that resource endowments and powerful groups' pressure could produce reactions for transitions in the energy process. Likewise, GCF and TO did not drive REC. Regulations, taxes, and other distortions applied from LAC governments are possible explanations about their insignificance.

As part of robustness, *auctions* and *kyoto* dummy variables were included. REC_{t-1}, CO_2 and GDP continued being significant. ROP, RGP and *auctions* present statistically significance, too. Nevertheless, conclusions from these estimations are misleading due to the proliferation of instruments which could fail to expunge the endogeneity (Roodman, 2009).

Policy Recommendations

According to Vachon and Menz (2006), green electricity adoption varies among geographic areas because of the incentives perceived by three different stakeholders: citizens, politicians, and lobbying groups. I consider that the LAC framework decisions are influenced mostly by the two-latter factions. As mentioned, a large fraction of the energy mix is composed of oil and natural gas. Since these industries and their partners do not face strong incentives to reduce gains, and their economic interests might be affected, they likely pressure governments. Thus, the transition process for renewable energy adoption is delayed.

Given that LAC countries are also recognised for being rich in renewable endowments such as hydroelectricity, wind and biomass resources, the possibility to attract private investment to develop those and other renewable systems might be an opportunity that national agenda needs to consider the satisfaction of increased energy demand.

Unfortunately, the macroeconomic context has not been favourable for private investment in some Latin American countries. Therefore, governments must work to strengthen the economic environment to attract investment and thereby increase private sector participation. Policies oriented to financial development should be promoted in certain countries and reinforced in others. They can manage some uncertainty and risks related to renewable technologies' investment. Financial instruments that might be applied are, for example, lines of credits, capital grants, insurances, liquidity guarantees.

The more developed is the economy's financial system, the more allowance of investment projects, which is traduced to higher incomes. With that, increments in renewable energy consumption could be expected since GDP is a relevant driver in LAC. Additionally, as recommended by IRENA (2016a), public financial institutions need to support R&D financing to no-mature renewable energy projects. During the early phase, more risks and costs are faced. Hence, public assistance will benefit private investors, given them confidence and shorten costs.

Furthermore, policy implementations might be oriented to the transport sector since this accounts for highly CO_2 emissions. Most of the population lives in cities, and they tend to use public transport. Hence fuel consumption has continued rising. For this reason, Chile has implemented environmental policies oriented to transport services. A private company specialised in electricity generation, transmission, and supply, will be responsible for supplying renewable energy to 100 electric buses that will travel around the main city.

Moreover, Chilean citizens have been able to get credits for buying electric taxis. Currently, 30 electric taxis are travelling around the cities. If other countries implement similar transport policies, it would be a win-win for the environment and clean energy usage.[18]

Finally, but not least important, the removal of fuel subsidies is a decision that governments must take. Subsidies not only affect the economy negatively but its also prompt overconsumption of dirty sources. According to the IMF (2015), gasoline and diesel prices are below the most LAC countries' social-optimal level. Although conventional energy products are taxed, the prices do not entirely internalise the externalities. Therefore, their prices are lower than the prices of renewables, disrupting clean energy deployment.

Limitations

Shortcomings are related to data. Factors such as energy depletion and innovations as a measure of technology have evidenced being drivers on REC in previous studies. However, I cannot control them because of lack of data in LAC countries. It would be interesting to examine their partial effect on the predicted variable throughout the analysis.

Comparison between income levels of countries or sub-regions in LAC was not possible to execute due to the number of observations. If the data would be subdivided, the requirement of dynamic panels that cross units must be higher than the time horizon would not have been fulfilled. Hence, the analysis was limited to a global panel. As shown by previous literature (i.e., Marques et al., 2010; Omri & Nguyen, 2014; Omri et al., 2015), results vary when the sample is subdivided. According to subcategories, Robustness verifies sensitiveness of variables was not possible to implement here.

Finally, it would be convenient to measure the variables in comparable terms. In this study, the dependent and one control variable have a different scale from other regressors. Because of free data unavailability, renewable energy consumption's raw data is in percentage terms. Following Cameron and Triverdi (2009), Marques et al. (2010) and Bhattacharya et al. (2016), it was log-transformed due to the skewed distribution exposed. Although the interpretation of a log-log model is in elasticities, it seems to be not so meaningful in this case.

Future work

Possibilities for future studies: 1) Extension of the time horizon since some events have arisen recently, for instance, Paris Agreement. According to Roman and Morales (2018), this agreement could be a new mechanism to enhance green energy deployment, 2) Use CPI as a proxy for energy price or deflate fossil fuel prices by countries. It would allow the inclusion of time dummies suggested by Roodman (2006), 3) Control for social and political factors.

[18] Information obtained from ElectroMOV website.

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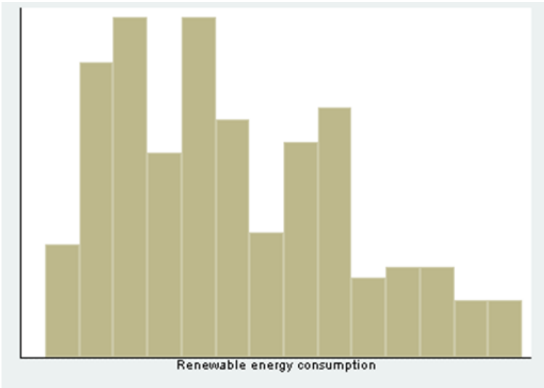
Appendix

Skewness and kurtosis test for normality

Variable	Skewness	Kurtosis	Chi-squared	p-value
Renewable energy consumption	0.002	0.032	12.390	0.002



Потребление возобновляемой энергии и его основные движущие мотивы в странах Латинской Америки и Карибского бассейна: анализ надежности между статическими и динамическими моделями панельных данных

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Аннотация. В статье представлены результаты исследования предпочтений и движущих мотивов потенциальных потребителей возобновляемой энергии в 22 странах Латинской Америки и Карибского бассейна в 2005–2014 гг. Для того чтобы учесть наличие эндогенности, специфичных для конкретной страны компонентов и серийной корреляции в наблюдениях, автор использует метод sys-GMM. В результате исследования подтвердилось динамическое поведение потребителей «зеленой энергии». Определяющими факторами потребления этого чистого источника энергии являются показатели ВВП и выбросы CO_2 на душу населения. Положительный эффект ВВП на душу населения означает, что неистощаемый альтернативный источник использовался для удовлетворения растущего спроса на энергию, который наблюдался из-за ускорения экономического роста в данном регионе. В свою очередь, отрицательный эффект выбросов CO_2 на душу населения отражает вес ископаемого топлива в структуре энергопотребления. Поскольку ряд стран региона являются производителями нефти, существующий уровень нефтяных цен не мотивирует их на переход к возобновляемым источникам энергии.

Ключевые слова: энергия; Страны Латинской Америки и Карибского бассейна; ВВП на душу населения; выбросы CO_2 на душу населения; выбросы парниковых газов; модели панельных данных