Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America

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Highlights

- Renewable energy policy is at the heart of decarbonisation strategies
- The choice of the policy instruments is crucial particularly for developing countries
- Policy effectiveness is evaluated thought a panel dataset covering 50 countries
- Support policies are the main drivers of RE diffusion in Europe and Latin America
- Policy effectiveness differs across regions and instruments.

Abstract

Renewable energy (RE) technologies for electricity generation are a central pillar of energy sector decarbonisation strategies worldwide. Public policies to promote their diffusion have been in place in developed economies since 1980, and, since the 2000s, a growing number of emerging countries began implemented such policies. The Latin American countries have been proactive in this promotion, but few attempts have been made to evaluate the results. This article proposes an econometric analysis of the effectiveness of renewable energy policies, based on panel data for 20 Latin American and 30 European countries, over 20 years. The results converge for the influence of promotion policies in general: they have a positive and statistically significant effect on RE investment, being the principal determinant in both regions. Nevertheless, on their own, tax incentives are insufficient to assure the deployment of RE technologies. This article also highlights specificities in policy approaches and motivations across both regions and explains why auction became the main instrument in Latin American countries.

Keywords: renewable energy, decarbonisation, electricity, Latin America, Europe, panel data, auctions.

Word count: 7514.

List of abbreviations

AUC: Auctions

EU: European Union

FE: Fixed-effects model

FIT: Feed-in Tariffs

PV: Photovoltaic

RE: Renewable Energy

RPS: Renewables Portfolio Standards.

1. Introduction

A substantial increase in the share of Renewable Energy (RE) sources in the energy mix is crucial to achieving a level of anthropogenic CO_2 emissions compatible with the Paris Climate Agreement. Thus, RE technologies for electricity generation are considered one of the fundamentals of global energy sector decarbonisation strategies (1). Public policies to promote their diffusion were implemented in the developed countries from the 1980s, within a niche market strategy, and, since the 2000s, a growing number of emerging and developing countries have also introduced support policies (2) . Following a sharp drop in the cost of several RE technologies, especially wind and solar photovoltaic (PV) (3), these policies aim to promote their large-scale diffusion to achieve a dominant share of the electricity mix. However, there are several open questions regarding the effectiveness, economic efficiency, and equity of selected promotion policies and, especially, in emerging and developing countries where empirical evidence is scarce.

Europe was a pioneer in the implementation of policies to promote RE, which were first introduced at the end of the 1980s in Denmark. The numerous policy adjustments and reforms in Europe combined with different country-level approaches, provide valuable data for an economic analysis that considers differences in socio-economic contexts and should help design and implement similar policies in other world areas.. There is a growing body of literature assessing RE policies based on cross-country analyses (4-11), case studies (12-16), and, more recently, econometrics (17-25).

Among the emerging and developing economies, those in Latin America have been proactive in promoting RE since the 2000s. However, very little research has aimed at evaluating the results of these policies. There are some valuable cases studies (26-30), but no attempts to perform broader statistical or econometric analysis representative of the Latin American region. Among the few studies that include some countries in Latin America is Pfeiffer and Mulder's (2013) study (31) of 108 developing economies. Moreover, European and Latin-American countries have implemented the same kind of instruments, which facilitates comparisons between both regions.

The objectives of the present article are, firstly, to perform an original ex-post assessment of the effectiveness of the support policies implemented in Latin America, comparing them with the European experience, and, secondly, to analyse the influence of energy-system and macroeconomic determinants on RE diffusion. We conducted an econometric analysis based on panel data of 50 countries (30 in Europe and 20 in Latin America) during the period 1995-2015. The criterion of effectiveness is understood as the policy's capacity to trigger new investment in RE which is the primary objective of such measures (7).[1] To consider a comparable and homogeneous unit of effectiveness, we selected the annual increase in installed capacity (in MW/inhabitant) of RE technologies as the dependent variable of our econometric model.

This article contributes to the literature on energy policy assessment by integrating an econometric analysis based on panel data that includes most of the Latin American countries, a region sparsely studied despite its ambitious objectives concerning RE deployment. The model

[1] We also consider the definition in Mitchell et al. (2011): effectiveness is ‘the extent to which intended objectives are met, for instance the actual increase in the output of renewable electricity generated or shares of renewable energy in total energy supplies within a specified time period’

allows us to test novel variables to capture the effects of energy-related and economic factors on RE diffusion. The results of this econometric analysis are then compared with previous case studies to understand the effects of policies in different contexts. From a political point of view, a comparison between different decarbonisation pathways in Europe and Latin America should facilitate future cooperation in energy and climate matters, an objective of the European Commission, the Mercosur, and other multilateral organizations.

The rest of this article is structured as follows. Section 2 reviews the existing literature about RE investment determinants and allows selection of the main explanatory variables included in our model. Section 3 describes the data and the econometric model. Section 4 presents and discusses de results, and finally, Section 5 summarises the main conclusions and policy implications.

2. The multiple drivers of renewable energy investment

Analysis of international experiences shows that RE diffusion is a complex process involving several elements (32). In addition to support policies, other technical, economic, and socio-political variables may have a significant impact on the diffusion rate of RE technologies. A growing corpus of econometric work is investigating the effects of different drivers. However, only a few (18, 19, 31, 33) include in their analyses the developing and emerging countries although these economies account for more than half of total RE investment[2] (2).

2.1 Contrasting results on the impacts of support policy

Given the cost gap between RE and conventional sources, investments in green energy have relied heavily on the implementation of support policies. These policies, traditionally, fall into two broad categories: price-based and quantity-based (34) Among price-based initiatives, guaranteed purchase or Feed-in Tariffs (FIT) and Feed-in Premiums (FIP) are intended to ensure return on investment in a stable and predictable framework. The second type of initiative includes quantity-based policies that set targets for the integration of RE into the energy mix and rely on Auctions (AUC) or Renewable Portfolio Standard (RPS) schemes, which include flexibility mechanisms such as green certificates (35-38). Recently, the "quantity" instruments, especially auctions, tend to replace the "price" instruments in both regions. Tax incentives are also used to complement price or quantity-based instruments, but the cases in which they represent the main (the only) support policy are scarce.

Although from a theoretical perspective, price and quantity instruments may be equivalents (39), numerous case studies and cross-country analyses show that, in practice, the effectiveness of policy instruments can differ substantially. Evaluation of European RE policy suggests that effectiveness and efficiency are higher in countries using price instruments than in those that have implemented quantity instruments (9, 10, 40, 41). Nevertheless, the effectiveness of these policies depends heavily on each technology's maturity and the specific “design elements” of each policy instrument (42).

[2] The recent development in RE investment has varied by regions, rising in China, Latin America, and the Middle East and Africa while falling in Europe, the United States, Asia-Oceania (excluding China), Japan, and India (REN21, 2018).

The number of countries that have implemented policies and the hindsight on these actions is sufficient for econometric studies to provide additional analytical elements. These studies differ in their methodology and their findings for policy effectiveness. Popp et al. (43) analysed the influence of the ratification (or not) of the Kyoto Protocol. According to the authors, although ratification is not in itself a direct incentive for investment, it can serve to signal a country's commitment to climate policy and, hence, to future carbon prices. Their model, that included data from the OECD countries between 1991 and 2004, showed a positive and significant relationship between the ratification of the Kyoto Protocol and investment, but no significant influence of direct support policies.

Marques and Fuinhas (23) included a broader range of policy variables to evaluate RE effectiveness in a set of 23 European countries from 1990 to 2007. First, the authors constructed a variable for the number of policy measures in each country (the accumulated Number of RE Policies and Measures). They then tested the influence of different types of policies according to the general classification proposed by the IEA Global Renewable Energy Policies and Measures Database: Information and Education Policies, Economic Instruments (including FIT, FIP, etc.), R&D, Regulatory Instruments (including quotas, standards, etc.), Voluntary Approaches and Policy Support. Their results showed a positive and significant impact of public policies in general. However, if considered individually, only subsidies and policy support (e.g., strategic planning and creation of institutional frameworks) showed a major influence. Overall, Marques and Fuinhas found that regulatory instruments and all other types of policies were not significant for promoting RE.

Aguirre & Ibikunle (44) whose approach was similar to that followed by Marques & Fuinhas (2012), analysed the OECD and BRIC countries from 1990 to 2010. They found a low level of effectiveness of promotion policies and even a negative relationship between tax incentive policies and diffusion of RE. However, the studies by both Marques & Fuinhas (2012) and Aguirre & Ibikunle (2014) included all RE sources, including biomass (in all its forms) and large hydroelectric power plants. These last two traditional RE sources are generally not targeted by support policies and, therefore, their estimation results may have been possibly biased.

Pfeiffer & Mulder (31)took again a different approach based on dummy variables to assess a panel of 108 developing countries between 1980 and 2010. Their results indicated that the likelihood of investing in RE was 10% higher after the Kyoto Protocol and even 30% higher in countries with support policies. Regarding policy effectiveness, countries that implemented economic or regulatory instruments showed respectively a 27% and 52% higher likelihood of investing in RE. In terms of amount invested, Pfeiffer and Mulder found a more significant effect where regulatory instruments were used compared to economic instruments, which contrasts with most of the findings for these aspects (see, e.g., (9)).

Cadoret and Padovano (20) measured two other policy variables in a panel that includes 26 European countries from 2004 to 2011. The first reflects the country’s level of commitment (as a percentage) to the 2020 European RE targets.[3] The second variable concerns environmental taxes,

[3] According to Directive 2009/28 / EC

as a percentage of environmental duties in total tax revenues, according to the Eurostat classification. They found no statistically significant influence from this second variable, which, they believe, might be because environmental tax revenues are not intended for environmental protection or the dissemination of new technologies, but are budgetary instruments.

Polzin et al. (22)used ordinal variables to represent the different policies in place in the OECD countries between 2000 and 2011. They highlighted the importance of a reliable policy framework with clear medium- and long-term objectives and found that tax and economic incentives (FIT, FIP) are the most relevant measures for investors based on an evident reduced risk associated with such projects. Other indirect instruments, including tradable CO_2 emissions permit systems, seem to have a positive impact, but only for the most mature technologies.

The Kilinc-Ata (21) study used data from 1990 to 2008 from Europe and the US. They showed that FITs, tenders and tax incentives are effective for boosting the deployment of RE, while quotas are not. Finally, Kim and Park (33) included a single policy variable: FIT. The results of the various models they tested showed a positive and significant influence of FIT.

In summary, econometric studies tend to agree on the effectiveness of policies in general but are less conclusive on the differences between specific instruments. More empirical evidence is required, considering a more recent sample that includes developing countries.

2.2. Influences of the structure and dynamics of energy markets

Beyond the incentive policies, context-specific variables can have a significant effect on RE diffusion. However, the empirical evidence is inconclusive on several points. In this section, we focus on variables related to the structure, functioning, and evolution of the energy sector (and particularly the electricity subsector).

a) The energy mix: competition or complementarity between technologies

The existing electricity mix may condition the dissemination of RE technologies in several ways. On the one hand, countries with high proportions of hydropower and nuclear-based electricity in their energy mix may be less concerned with developing new low-carbon technologies (43). Similarly, power generation that is concentrated on a particular source (e.g., nuclear) may reflect a situation of technological lock-in[4] and the possible influence of lobbying to maintain their market share (31). On the other hand, countries with high percentages of hydroelectricity have the necessary storage capacity to help to balance the intermittency of solar and wind power. From this perspective, new RE and hydroelectric plants are complementary rather than competing technologies. Therefore, the link between these sources of electricity generation is difficult to predict.

b) Electricity prices and the relative costs of RE and conventional energy sources

RE compete with other sources of electricity generation. Thus, the availability of cheap domestic fossil fuel resources for electricity production, particularly gas and coal, can affect the

[4] Learning effects and economies of scale can lead to reductions in the cost of a specific technology in some countries (e.g., nuclear power in France)

attractiveness of RE. The higher the price of any competing sources, *ceteris paribus*, the more attractive will investments in RE be (43). Simultaneously, several authors (24) have discussed the importance of electricity prices: the higher the price of electricity, the more investors will be encouraged to invest in RE. Chang et al. (45) found a positive and significant relationship between energy prices and the contribution of RE to energy supply in regions with high economic growth, although this was not significant for low-growth economies.

It would be optimal to include in our model the costs of the electricity produced by the different sources in each country. However, the only data available are the overall electricity prices by country. These are endogenous since they include the cost of electricity produced by RE. Therefore most previous models included proxy variables such as per capita gas and coal production and, if available, the prices of these sources for each country.

c) The energy dependence rate

Countries dependent on external energy supply need further to develop local sources of production, including RE. Reducing energy dependence is an energy policy objective and one of the main arguments for increasing RE in both developed and developing economies (44). As Marques and Fuinhas (23) pointed out, the expected theoretical relationship between these two variables is positive: the higher the country's dependence on external supply, the greater will be the incentive to deploy RE.

d) Power sector dynamics: the annual rate of consumption growth

The more electricity demand increases or, the higher the prospects for its growth, the more a country will need to invest in new power capacity, including RE. Besides,, the need for new investments in the electricity sector is linked to the average age of existing plants. When fossil fuel plants reach the end of their useful lives, they must be replaced by equivalent new capacity (except in the case of an equal drop in demand). Although a dynamic power sector should positively influence the spread of RE, the empirical evidence concerning that link is not conclusive.

e) The level of CO_2 emissions from fuel combustion

Fighting climate change by reducing energy-related GHG emissions is one of the main reasons for developing RE. Hence, the need for a control variable that captures the emission levels in each country. Most studies include a variable for CO_2 emissions (from the energy sector) per capita. Aguirre et al. (44) recall the well-known fact that environmental concerns should stimulate investment in RE.

2.3 Macroeconomic determinants

The better the country's macroeconomic situation, the higher the investment level in RE, *ceteris paribus*. Economies have specific characteristics that make them more or less attractive for investment generally, and in new technologies in particular. These features include, among others, the existence of highly skilled workers, good quality infrastructure, and legal and financial security (24). Access to project financing sources at reasonable interest rates is also fundamental and, especially, concerning high initial capital-intensive investments.

a) Income per capita

Several studies (23, 44) included GDP per capita in their models. The underlying assumption is that high-income countries are more likely to deploy RE because they can more easily bear the costs of developing these technologies and encourage them through economic incentives. The heterogeneity in our sample of countries is essential for this variable, given the large gap between low-income nations, such as Bolivia or Honduras, and countries with significantly higher incomes such as Norway and Luxembourg.

b) Access to funding

One of the most significant barriers to RE deployment is the high initial investment cost. The RE sector's capital intensity is higher than for fossil fuel energy and requires a proportionately higher initial investment before production can begin. Using panel data for 30 countries for the period 2000-2013, Kim & Park (33) examined the relationship between the development of financial markets and RE deployment on a global scale. Their results suggest that RE technologies are diffusing rapidly in countries with well-developed (both equity and credit) financial markets.

c) The openness to international trade

Pfeiffer & Mulder (31) tested the influence of foreign direct investment and the level of openness to international trade. Contrary to their initial hypotheses, they found a negative relationship between both variables and the level of RE generation. From a theoretical point of view, the influence of economic openness on new energy technologies can follow contradictory rules. In principle, trade openness should foster the diffusion of new technologies through lower costs (due to increased competition), removal of barriers, international agreements, etc. (46). However, greater openness to international competition also requires additional efforts to lower domestic product costs, which, in turn, might lead countries to develop cheaper sources of energy. Therefore, the role of international trade in RE depends on several economic and political factors specific to each country, which are difficult to represent using a single variable.

2.4 Political and institutional determinants

In recent years, some theoretical and empirical studies have focused on the political factors influencing the design and effectiveness of energy and environmental policy. They have highlighted two sets of political determinants: governance quality, including the institutional framework in which these policies are implemented, and the ideology (political orientation) of the government in power. Several articles (47-51) suggested that political factors can influence both energy and environmental policies. Nevertheless, none of these studies refers specifically to RE diffusion.

Cadoret and Padovano (20) is one of the first papers investigating the influence of purely political factors on RE diffusion. The authors studied the determinants of RE’s share in final energy consumption based on panel data for 26 European countries over the period 2004-2011. Their results showed that industry lobbies have a negative influence on the deployment of RE and that left-wing governments tend to favour the deployment of RE compared to their right-wing counterparts. They also showed a positive effect of governance quality on the deployment of RE

Other political or geographical factors that can influence RE diffusion include population density (related to the space available to install solar and wind parks), wind strength, solar radiation, etc.

These variables might have a strong effect on the diffusion of a particular technology but are less relevant when we study general RE policy, independently of technology. Therefore, we exclude them from our model.

3. Data and method.

Our dataset covers 50 countries (i=1,…,i=50) and 20 years (t=1995,…,t=2014) and is balanced[5]. In this section, we explain our choices concerning the explained variable (3.1), the explanatory variables, including a brief description of RE policy in Europe and Latin America (3.2 and 3.3), and the econometric model (3.4).

3.1 The dependent variable

This study seeks to explain the RE diffusion determinants and, accurately, the level of investment in RE technologies over the 20 years to 2014. The literature review showed that several different definitions of the dependent variable had been proposed: a) amount invested in new RE capacity (for country x for year t); b) RE generation in kWh per capita (31); c) share of RE in the electricity mix, as a percentage (44, 52); d) ratio of total RE capacity to total electricity generation (53); e) newly installed RE capacity per inhabitant (MW/1 million inhabitants) (22, 43). In our case, investments in new RE are measured not in monetary terms, but as physical quantities (MW). We use indicators of capacity since they are the most accurate proxy for technology deployment. We define net investment per capita in technology *j*, of country *i*, in year *t* as:

$$\frac{\left(CAP_t^{i,j} - CAP_{t-1}^{i,j}\right)}{POP_{ij}} \qquad (1)$$

$$\forall i = 1, \dots, 50; j = 1, \dots, 4; t = 1995, \dots, 2014$$

CAP is the total installed capacity at the end of each year; *POP* is the population.

The RE technologies included in the dependent variable are wind, solar, geothermal, and biomass. Large hydropower plants are excluded because hydropower is a more mature technology that is not promoted by the support policies we are evaluating. Small hydropower plants could be included because they tend to be targeted by promotion policies. However, most countries' data do not distinguish reliably between small and large hydropower plants. Thus, we exclude all of them from our analysis. The data also do not include small generation plants that are not connected to the grid since they are affected by other policies, beyond the scope of this study.

Finally, this study includes thirty European and twenty Latin-American countries, two regions using similar policy instruments to promote RE growth. The list of countries is available in Appendix 1. Some countries of these regions were excluded because of the lack of reliable data.

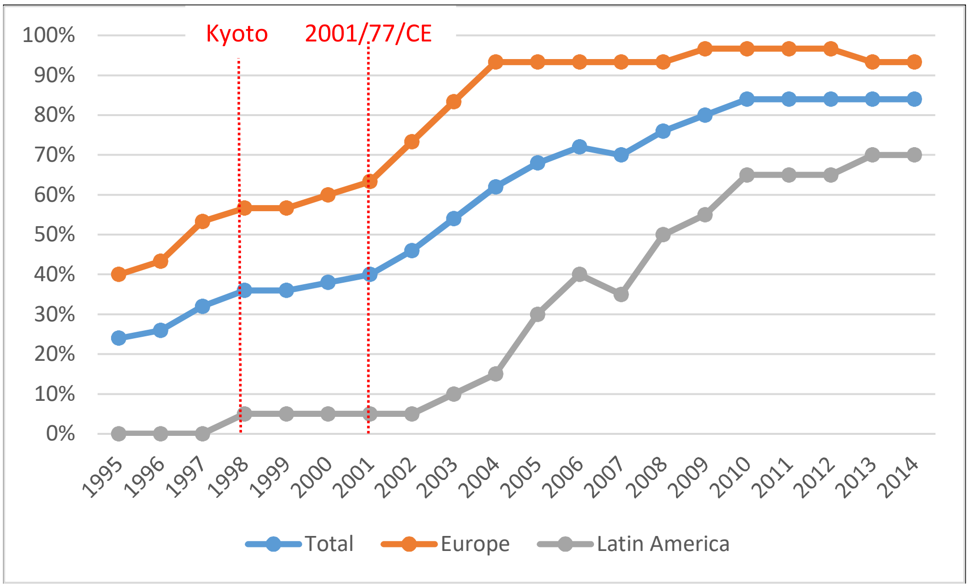
[5] There are no missed observations for any country and any year.

3.2 Support policies in Europe and Latin America

The main explanatory variables included in our model are Ex_pol, which denotes the existence or not of support policy, and four variables for the type of instrument. We consider the main support instruments: Feed-in Tariff and Feed-in Premium (FIT), the auction system (AUC), the quota obligations with negotiable green certificates or Renewable Portfolio Standards (RPS), and the fiscal -tax- incentives (FIS). We do not include instruments implemented for short periods, such as voluntary agreements or green pricing. The selected variables reflect the intensity and diversity of the policies implemented in the two regions studied.

We exploited several data sources: IRENA/IEA (Joint Policies and Measures database), European RE-Shaping projects (54), and data from (55) and (56)Since we are interested in investments in new technologies for electricity generation, we focus on policies specific to the electricity sector. Our database contains 1,000 observations indicating the existence or not of a policy in the country *i* in the year *t,* and the type of instrument. These observations were transformed into binary variables.

Fig 1: Percentage of countries that have adopted at least one support policy

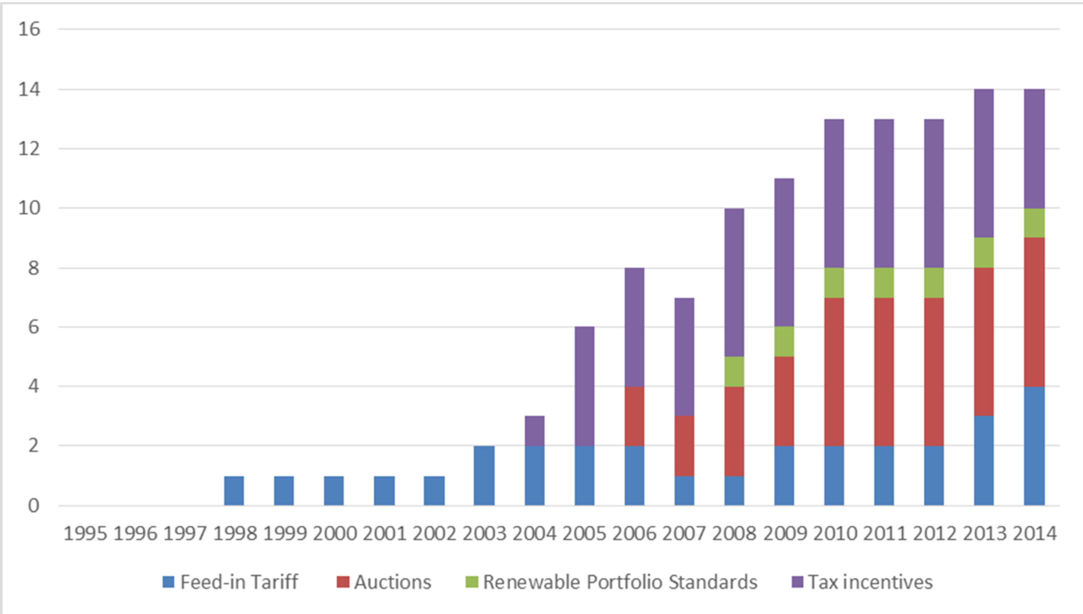


Note: Directive 2001/77/EC on the promotion of electricity produced from RE sets indicative targets for each Member State. Following the enlargement of the EU in 2004, a new target for the EU-25 has been set: the production of 21% of electricity from renewable energy sources. (http://.europarl.europa.eu/)
Source: the author, IRENA data.

Figure 1 depicts the percentage of countries that implemented at least one support policy in the electricity sector. In 1995, 40% of European countries had a policy in place. The number of countries increased significantly after the signing of the Kyoto Protocol (December 1997) and especially after the European Commission published Directive 2001/77/EC. This increase illustrates two central features of RE support policies in the Old Continent. First, they emerged in the context of climate policies and, especially, the need to reduce greenhouse gas emissions from the energy sector. Second, European institutions have played and continue to play a central role in this area through specific regulatory frameworks and common long-term objectives. Thus, the RE development objectives of European Union member states are set at the European level, although the choice of policy instruments to achieve them are chosen nationally.

In Latin America, promotion policies have followed a different logic. These countries were much less concerned about climate policies in the 1990s and 2000s: per capita emissions were significantly lower due to lower energy consumption and the existence of high levels of hydroelectric production in most countries. Figure 1 shows that the first policies were put in place only in the late 1990s and early 2000s. They seek to diversify electricity production by attracting private investment needed to meet growing demand. There is also no coordinated planning of the energy sector in this region. The role played by regional institutions, such as *Mercosur* or *Comunidad Andina*, is somewhat limited in all but the Central American countries where energy integration is stronger (56).

Fig. 2: Policy instruments in Latin America



Source: the author, data from IRENA and (56).

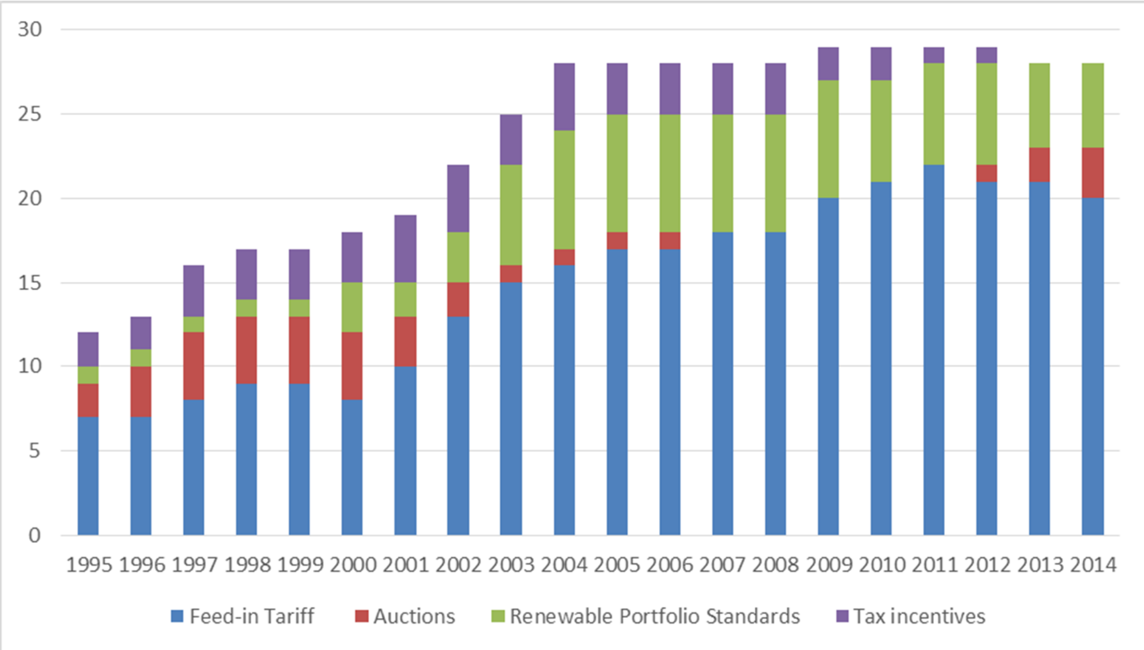
Figure 2 depicts the diversity of policy instruments in Latin America. A specific characteristic of the region is the dominance of quantity instruments based on auctions, used by five states in 2014: Argentina, Brazil, Uruguay, Peru, and Nicaragua. Four smaller economies - Bolivia, Ecuador, Dominican Republic, and Honduras - chose FIT. A quota system has been in place in Chile since 2008. Six countries - Colombia, Venezuela, Paraguay, Costa Rica, Jamaica, and Belize - have no economic or regulatory support policies while Mexico[6], Guatemala, El Salvador, and Panama offer only tax incentives.

Figure 3 shows the evolution of support policies in Europe. The price-instruments have tended to dominate, although, in recent years, several countries have reformed their support systems and introduced Feed-in Premiums to replace Feed-in Tariffs (Denmark, Estonia, Germany). The quota

[6] Mexico implemented a RPS in 2015.

system is in place in several countries, although Italy and the UK recently decided to withdraw it. It should be noted that auctions, which had almost disappeared, are being used again in Italy, France, the Netherlands or Russia. Also, most countries use the same instrument to promote all types of RE technologies, although with differentiated levels of support. Only a few EU member states apply instruments specific to a technology. For example, in 2014, Italy had auctions for wind and biomass and FIT for solar PV, and Denmark had auctions for offshore wind and FIP for other technologies.

Fig. 3: Policy instruments in Europe



Source: the author, data from IRENA and (7).

In our model, the influence of support policies is estimated in two stages. First, we included the variable Ex_pol, which indicates the existence or not of a support policy (regardless of the type of instrument) in each country at the end of each year. Only direct promotion policies are considered. Thus, regulatory frameworks in the electricity sector, strategic plans and other similar policies that do not include direct diffusion instruments are excluded. Ex_pol is a binary variable, which takes the value 0 if none of these policies are in effect and 1 otherwise. Second, we included four variables for the type of policy tool. If a country *i* has the value 1 for the variable Ex_pol (for a year t) this means it has applied one of the following instruments: FIT, RPS, AUC or FIS. Similar measures for RE policy have been used in previous studies, including (52), and (25).

3.3 Other explanatory variables

According to our theoretical framework, we included several control variables in our model, accounting for the influence of the structure and dynamics of the energy system and the main macroeconomic determinants of RE diffusion. Table 1 presents the name, the definition, the expected influence of each variable to the dependent variable, and also the data sources.

Table 1: Explanatory variables

NAME/CODE	DEFINITION/INDICATOR	EXPECTED INFLUENCE
Electricity demand growth (ele_agr) *	Growth rate of electricity consumption over the last 5 years.	(+) countries facing rapid growth of electricity demand need to invest in new generation capacity, including RE.
Share (%) of nuclear in the electricity mix (nuk_shr)*	Share of nuclear energy in the total gross electricity production.	(-) a high share of nuclear, i.e., low-carbon electricity, provides less incentive to invest in RE.
Share of hydropower in the electricity mix (hyd_shr)*	Share of hydropower in the total gross electricity production.	(-) a high share of hydro, i.e., low-carbon electricity, provides less incentive to invest in RE.
Energy dependence rate (ind_shr)*	Share of primary energy consumption covered by domestic primary energy production.	(-) a low level of energy independence can encourage countries to further invest in RE.
CO_2 emissions (CO_2_pcp)*	CO_2 emission from fuel combustion per capita (tCO_2/capita).	(+) high CO_2 emission levels can encourage countries to invest in low-carbon energy sources.
Coal production per capita (coa_pcp)*	Gross annual coal production per capita (Mt/capita).	(-) higher coal production can discourage RE investment.
Gas production per capita (gas_pcp)*	Gross annual gas production per capita (Mm3/capita).	(-) higher gas production can discourage RE investment.
Income per capita (gdp_pcp)*	GDP US$ at constant price and exchange rate (2005) per capita.	(+) it is easier for high-income countries to invest in RE.
Access to domestic credit (cdt_shr)**	Share of financial resources provided to the private sector by the banking sector and other financial corporations (% of GDP)	(+) well developed local financial markets can facilitate RE investment.

Source of data: *ENERDATA; **World Bank WDI

3.4 The econometric model

To assess the effects of RE policies on RE generation, we specified our model as follows:

$$\mathbf{Y_{it} = X_{it}\,\beta + \alpha_i + \varepsilon_{it}} \qquad \text{for } t = 1,\ldots,20 \text{ and } i = 1,\ldots,50 \quad (2)$$

where Y_{it} is the dependent variable (annual new RE capacity) observed for country *i* at year *t*, X_{it} is the time-variant 1 x k regressor matrix, β is the vector of coefficients α_i is the unobserved time-invariant country effect and ε_{it} is the error term.

Our analysis encompasses several steps. We first analysed the characteristic of our data, and we especially confirmed the absence of multicollinearity through the variance inflation factor (VIF) indicator. The next steps consisted of choosing between a fixed or a random-effects model. Using a fixed-effects (FE) model, we assume that specific unobserved characteristics of individuals (in our case countries) can have an impact or a bias on the explanatory variables of our model, and we, therefore, seek to control this. The random-effects assumption is that the individual-specific effects are uncorrelated with the independent variables. The opposite is valid for a FE model, which removes the effect of these time-invariant characteristics, allowing us to assess the explanatory variables' net effect on the dependent variable. Given the characteristics of the data and the literature review, our panel should correspond to a FE model. We tested this hypothesis through the Hausman test (57). The null hypothesis implies that the preferred model is the random-effects model, and the alternative hypothesis leads to a FE model. The test rejected the null hypothesis, and in the following, we consider the FE model.

Then, we conducted several tests to analyses heteroscedasticity and correlation. Firstly, we tested for cross-sectional dependence/contemporaneous correlation, through the Pesaran cross-sectional test of independence (see (58)) where the null hypothesis is that residuals across entities are not correlated. The test did not reject the null hypothesis, and we conclude that the data have not contemporaneous correlation. Secondly, we tested for serial correlation, applying a Breusch-Godfrey test (see (59, 60)) where the null hypothesis is that there is no serial correlation. The test rejected the null hypothesis, and we conclude that the data have a possible problem of serial correlation. Thirdly, we tested for heteroscedasticity through the Breusch-Pagan test (see (61)), where the null hypothesis is that there is homoscedasticity. The test rejects the null hypothesis, and we conclude that there is heteroscedasticity in the data. Finally, to take into account both heteroscedasticity and serial correlation for a fixed-effects model, we applied the Arellano's correction (62).

Some previous analyses (22, 23) applied the Panel Corrected Standards Error (PCSE) method. This technique is well suited to estimating model parameters in the presence of heteroscedasticity and correlation at panel level. However, the estimation of the variance-covariance matrix in PCSE depends on large T, which is not the case for our sample (T=20). Thus, we did not privilege this method.

In summary, after applying several tests, we have chosen a fixed-effects model with Arellano correction. Then we compare the results with those obtained using the random-effect and the PCSE models. We conducted the different steps described here first for the entire sample (50 countries) and then separately for Europe and Latin America.

4 Results and discussion

This section presents the results of the regressions, first on the whole sample: 1,000 observations corresponding to 50 countries over 20 years; and, second, for the European and Latin American countries separately. Also, we discuss the motivation and effects of RE policy in both regions.

4.1 General Results

Table 2 summarises the results of our primary model (fixed-effects with Arellano correction), comparing them with two alternative models (PCSE and random-effects models). The three models are significant, according to the Wald statistic. Several variables are statistically significant, given the probability attributed to them. Three of our public policy variables appear to be statistically significant: feed-in tariffs, renewable portfolio standards, and auctions. In contrast, the variable representing "fiscal incentives" is not statistically significant in any model.

We also estimated a model in which the four policy-instrument variables are replaced by the single variable "Ex_pol' which indicates the existence or not of a promotion policy in year t for country x, regardless of the instrument adopted. It allows us to test our primary hypothesis about the effectiveness of RE energy policy when controlling by the macroeconomic and energy-related determinants. The results of this model show a positive and significant influence of Ex_pol on the dependent variable. Therefore, considering a sufficiently large sample of countries and years, as in our study, promotion policies appear to be the first determinant for RE investment. These results are in line with those in (21, 22, 31), but contrasts with the findings of (43, 44) which found no positive effects of RE policies.

Besides, the relationship between growth in electricity consumption and the dependent variable is significant but negative. It indicates that countries with higher demand growth have not invested more in RE, but have relied on other, less expensive electricity sources. For instance, countries like Bolivia and Honduras have had averaged a 6% growth in electricity demand but almost no RE investment. Likewise, countries that have invested the most in RE have simultaneously implemented ambitious energy efficiency policies, which have influenced demand. This is the case of several EU countries like Denmark and Sweden, which have had high RE investment per capita, while the electricity demand stagnated. Popp et al.(43) found similar results in a sample of 26 OECD countries.

Our model's outputs also show that a high share of nuclear power in the electricity mix has a negative relationship with investment in RE. This result can be explained by the fact that countries with high shares of nuclear power (like France) have been less concerned with the rapid development of RE because they already have a decarbonised electricity mix. The coefficient for hydroelectricity is also negative but no significant. This finding confirms the fact that the complementarity or opposition between RE and hydropower is country-specific. On the one hand, a high share of hydroelectricity facilitates the integration of intermittent technologies (wind and solar) thanks to the storage capacity. On the other hand, countries with a high share of hydropower in the electricity mix (a low-carbon source) may be less concerned about the rapid deployment of other RE sources.

Concerning the influence of coal and gas production, the results are different. Contrary to our hypothesis, a high level of coal production per capita has a positive influence (statistically non-

significant, however) on RE diffusion. The explanation for this finding might be that some countries with a high share of carbon in the electricity production have substantially invested in RE as a form to decarbonize the mix or replace nuclear (that is especially true for Germany). The result is negative for gas: a high gas production would be, contrary to coal, a disincentive to develop RE fast. This inverse relationship may be because many countries started to replace coal with natural gas during the 1980s or 1990s to reduce pollution what created a lock-in in these technologies. However, the decarbonisation of the electricity mix is reflected in some countries by the development of RE and gas simultaneously: they phase-out coal and, at the same time, use gas to preserve the grid balance, while intermittent electricity increases.
Results in Table 2 show a clear positive and significant relationship between income per capita (GDP per capita) and the dependent variable. That reflects that RE has deployed more rapidly in high-income countries, where the economic and institutional conditions are more favourable to the early diffusion of new technologies. This result is in line with the findings of (43, 53). Finally, the availability of credit does not appear as statistically significant. Further analysis that includes additional refined variables is needed to understand the relationship between the development of equity and credit markets and RE deployment.

Table 2: Summary of results - global model

Variables/model	Fixed-Effects				PCSE				Random-Effects			
Y= new RE capacity	Coeff.	SE			Coeff.	SE			Coeff.	SE		
Feed-in Tariffs	7.04	3.45	(+)S	**	7.41	3.15	(+)S	**	9.50	2.00	(+)S	***
Portfolio Standards	16.55	4.36	(+)S	***	12.68	5.28	(+)S	**	15.20	2.91	(+)S	***
Auctions	7.31	3.12	(+)S	**	5.92	3.64	(+)S	*	6.44	2.83	(+)S	**
Fiscal incentives	3.25	3.04	(+)NS		3.64	2.98	(+)NS		0.52	2.68	(+)NS	
Demand growth	-0.63	0.27	(-)S	**	-0.49	0.22	(-)S	**	-0.80	0.20	(-)S	***
Share nuclear	-0.50	0.25	(-)S	**	-0.32	0.11	(-)S	***	-0.13	0.06	(-)S	**
Share hydropower	-0.12	0.10	(-)NS		0.00	0.08	(+)NS		-0.08	0.05	(-)S	*
Energy dependence	0.42	0.23	(+)S	*	0.51	0.19	(+)S	***	0.06	0.05	(+)NS	
CO_2 per capita	-4.20	1.56	(-)S	***	-2.76	1.68	(-)S	*	-3.48	0.58	(-)S	***
Coal production	4.86	3.91	(+)NS		7.12	2.57	(+)S	***	3.66	0.78	(+)S	***
Gas production	-0.02	0.01	(-)S	*	-0.02	0.01	(-)S	**	-0.00	0.00	(-)NS	
GDP per capita	1.81	0.62	(+)S	***	1.40	0.41	(+)S	***	1.05	0.13	(+)S	***
Credit access	0.04	0.08	(+)NS		0.06	0.07	(+)NS		0.07	0.03	(+)S	**
Observations	50 X 20 = 1000				50 X 20 = 1000				50 X 20 = 1000			
R^2	0.23				0.35				0.24			

Notes: Significance levels: *** (1%), ** (5%), * (10%); (S): Statistically significant, (NS): Non-significant.

4.2 About RE policy effectiveness in Latin America and Europe

We performed specific analyses for the Europe and Latin America samples to identify possible policy effectiveness differences between both regions.

Firstly, we evaluated the significance of our main explanatory variables (the RE promotion policies) through a t-test. The results in Table 3 show that the existence of a promotion policy (observations from group 1) increased the mean of the dependent variable significantly (p-value <0.05). Furthermore, the policies have a positive and significant impact in both regions but with different relative effectiveness. In Europe, for years and countries with incentive policies (observations from group 1) the additional RE capacity is ten times higher than cases without policy (group 0); the ratio is 5 in Latin America. The standard deviation in group 1 observations is also significant, suggesting differences in policy effectiveness within countries.

Table 3. Effect of policies on RE investment - Student's t-test by continent.

	Europe			Latin America		
Group	Obs.	Mean	SE	Obs.	Mean	SE
0: Without policy	129	2.19	6.5	282	1.07	3.94
1: With policy	471	23.32	30.9	118	5.33	13.78
Combined	600	18.7	28.9	400	2.33	8.39

Secondly, we estimated the model with a binary "existence of RE policy" variable. The impact of support policy was positive and significant for both Europe and Latin America. Finally, we introduced the four specific policy instruments in our model. As in Section 4.1, we base our analysed in the fixed-effects model with Arellano correction and compare them with the two alternative models (Tables 4 and 5).

The three main policy instruments applied in Europe -FIT, RPS, and auctions- show a positive and significant influence. These results confirm what the review of energy policies for RE in Europe shows. The public policies implemented by the Member States at the European Commission's initiative in favour of the development of RE have been very effective. This is confirmed by the mid-term progress assessment report[7], which states that the EU Member States are on track to meet the renewable energy targets for 2020, i.e., 20% renewable energy in gross energy consumption[8]. To this end, the European Union's policy has been based on several successive directives setting quantitative objectives for Member States (2010, 2020, 2030) but

[7] European Commission, 2015, Report from the Commission to the European Parliament, the Council, the European economic and social Committee and the Committee of the regions, Renewable energy progress report.

[8] Climate 2020 Energy Package.

leaving each of them free to choose the means to be used to achieve them. The very marked opposition during the 2000s between price and quantity instruments has evolved towards the clear domination of the former. Since then, incentive mechanisms have been adapted to take into account technological progress and cost trends. Again under the impetus of the European Commission, support schemes have evolved in recent years. Indeed, to allow better integration of renewables into the electricity market, quantity control, and competitive pressure between producers, the financial incentives will have to be gradually allocated by competitive auctions. This evolution of incentive schemes is too recent to appear in the model. However, it is in line with the results observed in Latin America and more broadly throughout the world, with a substantial increase in the auction system as an effective RE supply scheme. This evolution of promotion policies has been accompanied by a very marked dynamic of cost reduction over the last 20 years: while the first feed-in tariffs that enabled the PV sector to take off exceeded €500/MWh (55), the average prices of the 2019 tenders for ground-based PV installations in Germany were below €50/MWh.

Table 4: Summary of results - Europe

Variables/model	Fixed-Effects				PCSE				Random-Effects			
Y= new RE capacity	Coeff.	SE			Coeff.	SE			Coeff.	SE		
Feed-in Tariffs	12.25	4.38	(+)S	***	11.67	4.42	(+)S	***	14.39	3.12	(+)S	***
Portfolio Standards	23.51	5.06	(+)S	***	18.22	6.58	(+)S	***	19.68	4.20	(+)S	***
Auctions	10.95	3.32	(+)S	***	8.77	5.71	(+)NS		7.42	5.09	(+)NS	
Fiscal incentives	8.35	7.37	(+)NS		9.66	6.10	(+)NS		7.83	5.40	(+)NS	
Demand growth	-1.77	0.46	(-)S	***	-1.50	0.50	(-)S	***	-2.06	0.43	(-)S	***
Share nuclear	-0.66	0.26	(-)S	**	-0.42	0.15	(-)S	***	-0.22	0.09	(-)S	**
Share hydropower	-0.52	0.22	(-)S	**	-0.26	0.18	(-)NS	**	-0.21	0.10	(-)S	**
Energy dependence	0.61	0.32	(+)S	*	0.61	0.31	(+)S	*	0.10	0.10	(+)NS	
CO_2 per capita	-4.02	1.91	(-)S	**	-2.45	1.84	(-)NS		-3.53	0.86	(-)S	***
Coal production	4.53	3.82	(+)NS		6.61	2.78	(+)S	**	3.16	1.18	(+)S	***
Gas production	-0.02	0.01	(-)S	**	-0.02	0.01	(-)S	**	-0.00	0.00	(-)NS	
GDP per capita	1.25	0.66	(+)S	*	1.01	0.43	(+)S	**	1.00	0.18	(+)S	***
Credit access	0.03	0.09	(+)NS		0.06	0.07	(+)NS		0.05	0.04	(+)NS	
Observations	30 X 20 = 600				30 X 20 = 600				30 X 20 = 600			
R^2	0.26				0.34				0.25			

Notes: Significance levels: *** (1%), ** (5%), * (10%); (S): Statistically significant, (NS): Non-significant.

The fixed-effects model for Latin America shows a positive and significant influence of auctions and RPS, while FIT is not significant. We observe a “sub-performance” of feed-in tariffs in Latin America compared to the European experience, where it was a central instrument. In Latin America, only a few countries applied feed-in tariff and feed-in premium, with quite poor results. It was the case in Argentina between 1998 and 2006: public policy based on feed-in premium failed to help RE to take off, affected by an unfavourable macroeconomic and regulatory context (63). Brazil applied FIT for a few years and then changed for an auctions system. Since 2010 auctions became the main policy instrument with, in general, positive results in countries like Brazil, Uruguay, and, more recently, Argentina.

The auction scheme has several advantages that explain its implementation in Latin American countries: i) It provides a stable and well-known ex-ante revenue stream once projects have been awarded, which facilitating project funding; ii) It stimulates competition among producers, facilitates the externalization of RE costs and allows control of the total cost of the policy; iii) It is adaptable to promote technologies with different degree of techno-economic maturity; iv) Besides costs, it allows the introduction of other selection criteria (like jobs creation) among the tenders submitted according to the objectives of the public policy. Most importantly, auctions scheme fits well with the institutional design of the electricity system in most Latin-American countries (42). Nevertheless, the downside of auctions is that it favours “big” existing actors to the detriment of new and smaller producers to enter the markets. Thus, this instrument should be complemented by specific policy targeting small and decentralized RE projects. In recent years, several countries of that region have moved in that direction.

RE policies in Latin America were introduced later and started to be effective when the cost of technology was affordable enough to allow private investments while controlling the cost of the policies. The primary motivation of RE policy was concerns about energy security and the diversification of the electricity mix. Most Latin American countries have an electricity system concentrated in fossil fuels (Chile, Mexico, Argentina) or hydroelectricity (Brazil, Paraguay, Uruguay). A power mix concentrated in a few sources raises risks considerably: a succession of dry years or problems with the supply of imported gas or coal can affect electricity production and its cost substantially. For that reason, countries tried to diversify the electricity mix, and nuclear power and renewables have represented the main options. However, nuclear power exists only in three countries (Argentina, Brazil, and Mexico), and is a sophisticated technology that requires enormous investment and expertise. Renewables were relatively expensive, but the substantial cost decrease and their modularity made them an increasingly attractive option during the 2000s. Even if some RE technologies are currently cost-competitive in Latin America, public policies still play an essential role in reducing the risk of such investments.

Table 5: Summary of results - Latin America

Variables/model	Fixed-Effects				PCSE				Random-Effects			
Y= new RE capacity	Coeff.	SE			Coeff.	SE			Coeff.	SE		
Feed-in Tariffs	0.43	1.87	(+)NS		1.15	1.24	(+)NS		1.72	1.63	(+)NS	
Portfolio Standards	6.37	2.28	(+)S	***	3.75	2.98	(+)NS		8.52	3.70	(+)S	**
Auctions	7.05	3.02	(+)S	**	3.97	2.80	(+)NS		9.52	1.55	(+)S	***
Fiscal incentives	-0.08	1.27	(-)NS		-1.20	1.02	(-)NS		0.21	1.47	(+)NS	
Demand growth	-0.09	0.04	(-)S	**	-0.05	0.08	(-)NS		-0.11	0.10	(-)S	
Share nuclear	0.93	0.55	(+)S	*	-0.11	0.50	(-)NS		-0.31	0.33	(-)S	
Share hydropower	0.09	0.06	(+)NS		0.18	0.07	(+)S	**	0.03	0.02	(-)S	
Energy dependence	0.25	0.26	(+)NS		0.31	0.17	(+)S	*	-0.01	0.02	(+)NS	
CO_2 per capita	0.89	1.02	(+)NS		-1.27	1.74	(-)NS		-1.04	0.62	(-)S	*
Coal production	-0.86	1.03	(+)NS		-3.22	1.73	(-)S	*	-1.13	1.59	(+)S	
Gas production	-0.00	0.00	(-)S		0.00	0.00	(+)NS		-0.00	-0.00	(-)NS	
GDP per capita	2.87	1.69	(+)S		4.45	1.65	(+)S	***	1.23	0.37	(+)S	***
Credits acces	-0.04	0.10	(+)NS		0.01	0.09	(+)NS		-0.01	0.03	(+)S	
Observations	20 X 20 = 400				20 X 20 = 400				20 X 20 = 400			
R^2	0.19				0.24				0.19			

Notes: Significance levels: *** (1%), ** (5%), * (10%); (S): Statistically significant, (NS): Non-significant

5. Conclusion and Policy Implications

This paper's primary purpose was to evaluate the effectiveness of different RE policy instruments implemented in Europe and, more recently, in Latin America, while controlling by other determinant factors. We first performed a review of the literature on econometric evaluation of RE policy. The determinants explaining the different levels or RE diffusion across countries can be classified into four categories: support policy, factors related to the structure and dynamics of energy markets, macroeconomic factors, and political and institutional determinants. We identified several conflicting points and lacunas in the econometric literature. We then developed a model which is the first to integrate a significant sample of Latin-American countries. Our results converge for the influence of promotion policies in general: public policies had a positive and statistically significant effect on RE investment. However, the effectiveness of these policies seems stronger in Europe than in Latin America, partially explained by the different temporality in policy implementation. Also, some differences appeared concerning the type of instrument: auctions have consolidated as the main instrument in Latin America, where the institutional conditions felicitate their implementation.

We conclude on the effectiveness of the main policy instruments to promote RE, in both Europe and Latin America. Instruments like feed-in tariff or the auction scheme are essential to reduce the risk associated with RE investment, even when some technologies like wind and solar PV are already cost-competitive in several markets. On the opposite, tax incentives, on their own, are not sufficient to incentivize RE deployment, and countries should not base their technology policy only on such instruments.

RE generation is increasing in both regions. In Europe, the share of renewables in electricity production (excluding hydropower) was 1% in 1995, 14.6 % in 2014, and 19.5 % in 2018[9] . In the beginning, the incentive policies, especially subsidies like feed-in tariffs, were paramount due to the cost gap between fossil fuel and RE projects. In Latin America, RE (excluding hydro) represented 2.5% of total electricity production in 1995, 6.42% in 2014, and 11% in 2018. The countries of this region started to introduce RE policy later than the Europeans one and, thanks to a substantial drop in the costs of RE technologies and favourable natural conditions, most RE projects in Latin America do not need direct subsidies anymore. Currently, that region benefits from one of the greenest electricity mixes in the world thanks to a strong base of hydroelectric power and an increasing share of solar and wind energy. Indeed, Latin America is the first region in the world in terms of the share of RE generation if we include hydroelectricity (the share is around 58% in Latin America, while 36% in Europe, and 25% in the world average). The public policies implemented since the 2000s have had a significant influence on the development of wind, solar, and biomass energy sources. However, the decarbonisation, first, of the electricity sector and then of the whole energy sector, has revealed various problems and requires sustained public policies over time. Several European countries have accumulated vast experience in the implementation of RE policy, including potential adverse effects. Stronger cooperation among the policymakers in both regions would help to boost energy transition. One specific area of plausible collaboration is the decentralised RE solutions (like home-based solar and wind technologies) that could enhance energy access in many rural areas of Latin America.

Our econometric analysis has some limitations and several possible extensions. First, the available data did not allow us to estimate the influence of some determinants identified in the literature, such as the cost of other sources of power generation, the real potential for different RE sources, and political factors. Similarly, more detailed consideration of the variables for access to financing (e.g., changes in the cost of available financing) would improve our model's explanatory power.. Finally, effectiveness is not the only criterion relevant to an evaluation of energy policies. Other factors, such as static and dynamic efficiency (42, 64) and the equity of such policies, are also relevant and should be considered in future research.

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[9] ENERDATA, 2019

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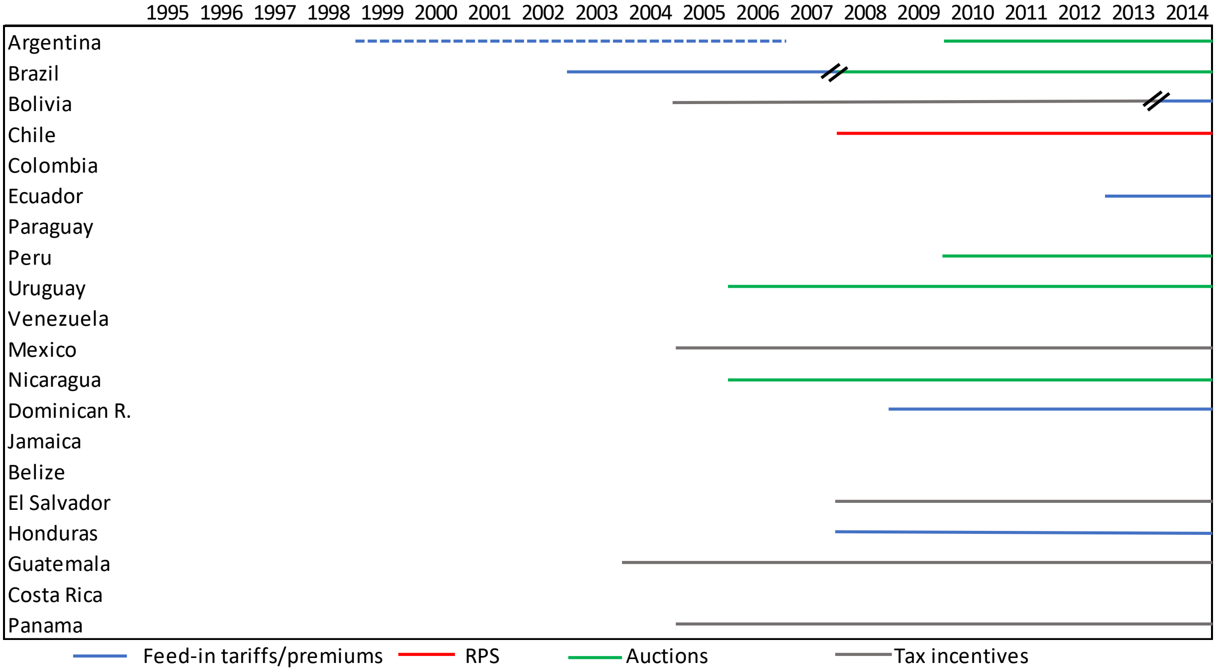
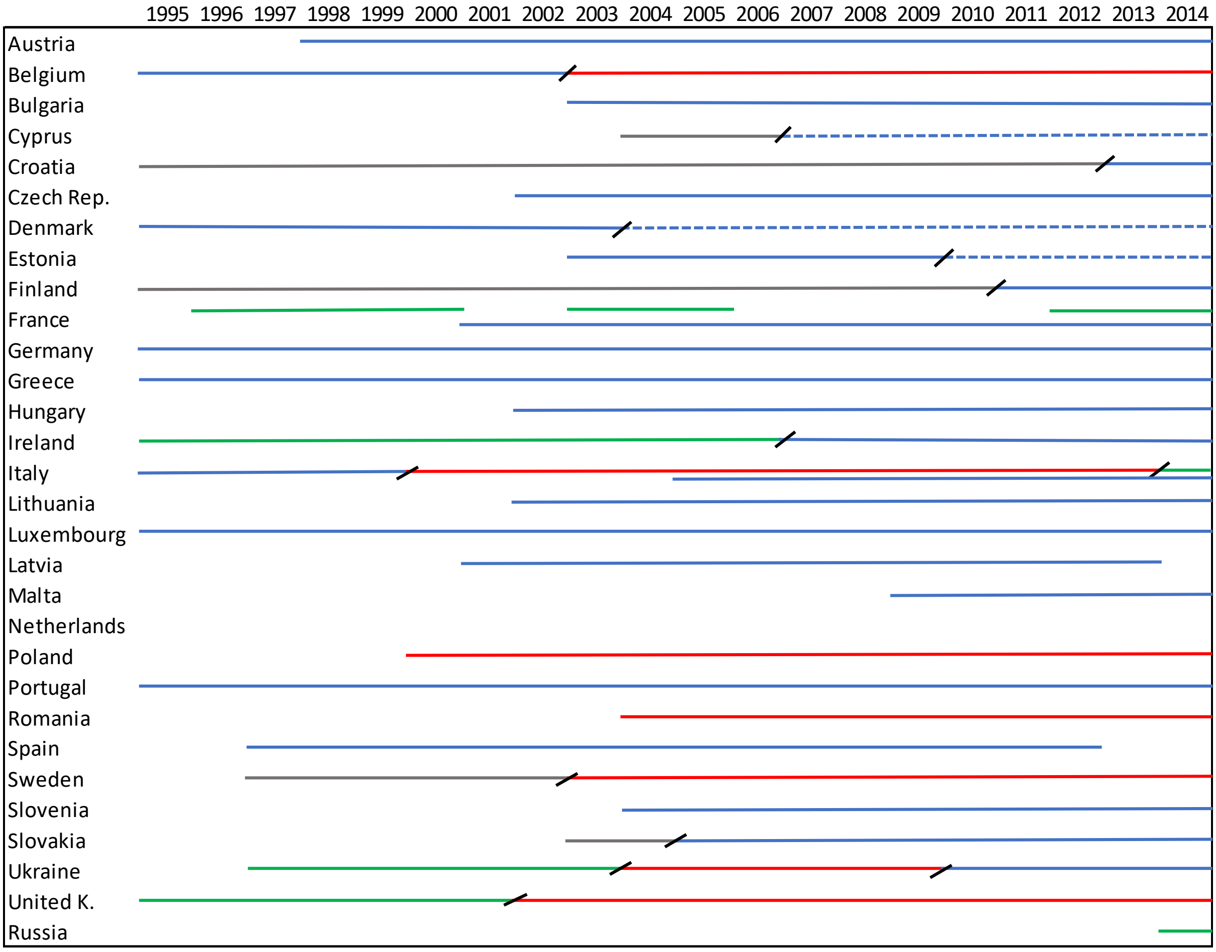
Appendix 1: Policy instruments in Latin America & Europe.



Source: the author, data from IRENA and BCIE/PNUD (2015



Source: the author, data from IRENA and Held et al., (2014).

Appendix 2: Descriptive statistics.

Variable	Observ.	Mean	Std. Dev.	Min	Max
cap_ad	1000	12,197	24,398	-57,059	184,202
ex_pol	1000	0,589	0,492	0	1
fit	1000	0,336	0,473	0	1
RPS	1000	0,096	0,295	0	1
AUC	1000	0,072	0,259	0	1
FIS	1000	0,096	0,295	0	1
ele_agr	1000	2,897	3,631	12,299	31,586
nuk_shr	1000	12,391	20,427	0	85,056
hyd_shr	1000	30,216	28,796	0	100
part_fos	1000	52,111	27,915	0	100
ind_shr	1000	54,813	30,909	0	100
CO2_pcp	1000	5,580	3,998	0,534	24,293
coa_pcp	1000	0,951	2,100	0	16,124
gas_pcp	1000	376,233	947,427	0	6189,361
GDP_pcp	1000	15,656	16,538	0,915	87,771
cdt_shr	1000	59,191	41,886	0,186	23,563