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Research article

Renewable energy in Latin America

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Abstract: Since the signing of the Paris Agreement in 2015, signatory countries have been adopting commitments to promote the use of renewable energy. Among the signatory countries, those of Latin America have stood out for the high percentage of renewables in their energy mix and their commitment to continue advancing towards energy decarbonization. This commitment implies the need to adequately recognize the starting point of renewable energy consumption in the region, and its relationship with the population and regional production. This study analyzes the evolution of renewable energy consumption in the Latin American region and its member countries, in relation to the Worldwide position, from 1993 to 2018. For this, the direct consumption of renewable energies and the energy used to generate electricity and heat, have been considered. These values are analyzed in Worldwide per capita and per unit production terms. The results show that the Latin American region has a higher percentage of renewables in its energy mix than Worldwide, with this percentage being even higher when considering only the consumption of renewable energies of indirect origin. Brazil stands out for the share of its renewable consumption. In terms of per capita renewable energy consumption, Latin America presents higher values than those achieved Worldwide, with a growing trend throughout the studied period. The renewable energy intensity is also higher in Latin America, with a decreasing trend, as experienced Worldwide.

Keywords: energy consumption; renewable energy consumption; direct renewable energy; indirect renewable energy; energy economics; Latin America

1. Introduction

At the signing of the Paris agreement in 2015, 195 countries worldwide committed to reducing

their CO_2 emissions to prevent a global temperature rise above 1.5 ºC, compared to pre-industrial values [1]. Among these countries, 18 from Latin America signed this agreement, sending their Intended Nationally Determined Contributions (INDCs) documents, in the following years, specifying the targets for reducing greenhouse gas emissions and the dates to achieve them.

Washburn and Pablo-Romero [2] detail these targets, by country, showing that to achieve them many of these countries have made commitments linked to energy and electricity consumption, as a source of harmful emissions. The authors highlight two issues regarding energy consumption in the region. Firstly, its growth is linked to economic expansion. Secondly, its growth is associated with an increase in fossil fuels consumption, although this does not displace the countries of the region from the top of the renewable energy users ranking. In fact, four Latin American countries are among the top ten in the share of renewables in their electricity production [3]. The recent energy consumption evolution in Latin America has led 10 countries in the region to commit, within the framework of the United Nations Conference held in Spain in 2019, to work towards the regional goal of 70% of electricity production from renewable energies by 2030, encouraging other countries in the region to adhere to this commitment. Thus, recently in 2021, another three countries have joined this commitment.

The increase in renewable energy is seen as an opportunity to make Latin American society less polluting and less dependent on fossil fuels [4]. As stated in Zhang et al. [5], this is a fundamental piece of energy and climate change policy, and an opportunity to contribute to the growth of the region, making energy more accessible to the entire population [6] and increasing the energy security [7]. Thus, in the Latin American region, as well as in other developing countries, public policies have been introduced to support renewable energies within a niche market strategy, especially since the late 1990s [8,9].

This different perspective on the role of renewable energies in the region, and how to achieve its objective, has aroused the interest of the scientific community. On the one hand, some researchers have focused their research on the link between renewable energies and economic growth. Among these, some authors, such as Al-Mulali et al. [10], have analyzed the role of electricity consumption generated with renewable energy on growth in Latin American countries, while others, such as Koengkan et al. [11], have more recently focused on analyzing the effect of renewable energy incentives on economic growth in the region. On the other hand, others have focused their interest on the effects of such energies on CO_2 emissions and climate change. Additionally, the studies by Fuinhas et al. [12] and the recent study by Koengkan and Fuinhas [8], explore the effect of renewable energies on CO_2 emissions in the region, the latter concluding that the energy transition process can mitigate environmental degradation in LAC countries. Finally, few others have analyzed what public policies are being implemented to incentivize renewable energies and their effectiveness. Among them, some authors have focused on the analysis of specific measures, such as the study by Jacobs et al. [13] on feed-in tariff incentives and Washburn and Pablo-Romero [2] analyzed renewable energy promotion measures for electricity production. Finally, others have analyzed the effectiveness of renewable energy incentives from an econometric point of view. In this line, Pfeiffer and Mulder [14] have analyzed this effect in a sample of 108 developing economies, including some Latin American countries, and Bersalli et al. [15], have econometrically evaluated the effectiveness of different RE policy instruments applied in Europe, and in Latin America. The authors conclude that public policies had a positive effect on RE investment, but the effectiveness of these policies was lower in the Latin American region.

From different points of view, these studies share the general positive effect of an increase in renewable energies on the environment, the economy and society. These, therefore, share the idea of

the benefit that an increase in the participation of this type of energy in the energy mix can bring to the region. However, despite the interest in increasing the share of renewable energy, and the interest in research on its benefits for the environment and the economy, few studies focus on analyzing its status and evolution in the region. Among these, it is worth highlighting the IRENA report [16] that reviews the evolution of renewable energies by sources in five large areas of the region, and analyzes the investments made in six Latin American countries during the period 2005–2015, highlighting the role of hydropower. Additionally, the REN21 report [17] referred to the global context, highlights the relevant role of some Latin American countries in certain energies, although it does not offer an analysis of the region. Together with these reports, some institutions offer databases and interactive maps, from which the situation and evolution of the installed capacity, or consumption of renewable energies by specific sources, can be determined (for example, Enerdata [3] and IRENA [18]), although they do not offer an analysis of these data or their evolution). Finally, there are a few studies which include a review of renewable energy consumption in the region, focused on electric power [2], or on specific technologies [19,20] or specific areas or countries in the region (for example, [21–24]).

To the best of our knowledge, no study exists that analyzes total renewable energy consumption trends in Latin American countries, in a recent period, and which considers their importance in relation to the population, or the productive capacity of the country. Therefore, the aim of this paper is to provide a concise analysis of total renewable energy consumption trends, in absolute and relative terms, in the Latin American region and countries, for the period 1993–2018. The analysis of total renewable energy consumption is novel, since previous reports and studies do not offer a total value of this variable, only partially, in the form of biofuels consumption and electricity, or heat consumption from renewable energies. This analysis is interesting in the context of emissions reduction, economic recovery, and rising prices of fossil fuels, as many of the policies established for these purposes are aimed at increasing the share of renewable energies within the energy consumption mix.

In order to be able to assess the status and evolution of the use of renewable energies in the region, which allow progress in the general objective of reducing greenhouse gas emissions, this paper analyzes the evolution of the use of renewable energies, both directly and indirectly through electricity and heat consumption, in Latin American countries, from 1993 to 2018. For this purpose, the total consumption of renewable energies is calculated and analyzed, in total values, and in per capita and per unit of production terms.

After this introduction, Section 2 details the data used, and the methodology employed. Section 3 analyzes the Worldwide situation and evolution of renewable energy consumption in Latin America. Section 4 analyzes this situation and evolution in per capita terms. Section 5 shows the energy intensity analysis, with its value for renewable energies being detailed. Finally, Section 6 concludes.

2. Data and methodology

2.1. Data

This paper analyzes the situation and evolution of renewable energy consumption in 17 Latin American countries, in those countries as a region, and Worldwide. The Latin American countries analyzed are Mexico, six Central American countries (Costa Rica, El Salvador, Guatemala, Honduras, Panama and Nicaragua) and 10 South American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay and Venezuela), for which there is sufficient statistical information.

The analyzed period is from 1993 to 2018.

Energy consumption and electricity and heat generation data, from the International Energy Agency (IEA) [25] database, are used. As the data offered in the Balances sub-base is expressed in Ktoe, those related to the electricity generation in GWh, and those referring to heat in TJ have been converted into Ktoe. Additionally, population and production data, from the World Bank database [26], were used to relativize the energy consumption values. Specifically, total population and GDP in constant 2010 US$ were used. Both indicators are expressed in per million terms.

2.2. Methodology

The methodology used in this study is based on that by Pablo-Romero et al. [27]. Total energy consumption, by a country or region (TC), is divided into renewable energy consumption (R), and non-renewable energy consumption (NR). In turn, R is divided into the direct consumption of renewable energy (DR), and the indirect consumption of renewable energy, by consuming electricity or heat generated from renewable sources (IR). Likewise, the total energy consumption TC can be divided into total direct energy consumption (TCD) and total indirect energy consumption (TCI). The first is the sum of the direct consumption of non-renewable energy (DNR), plus DR. The second is the sum of the indirect consumption of non-renewable energy (INR), plus IR. Annual changes, energy intensity and per capita energy consumption have been studied. Likewise, the value and/or evolution of different ratios, which are shown throughout the study, have been calculated and analyzed.

TC is directly offered by the IEA [25]. NR is calculated as the sum of the final consumption of coal, petroleum products and natural gas (DNR), and the non-renewable energy consumed indirectly (INR). R is calculated from the sum of the direct consumption of biofuels and waste and solar, wind and other renewables (DR), and by the indirect consumption of renewable energy (IR). DNR and DR are offered by the IEA [25], while INR and IR are calculated from the data provided by the IEA [25], in the Electricity and Heat sub-base. IR is the sum of indirect consumption of renewable energy, by consumption of electricity produced from renewable energies (IRE), and indirect consumption of renewable energy by consumption of heat, produced from renewable energies (IRH). INR is the sum of indirect consumption of non-renewable energy, for consumption of electricity produced from non-renewable energies (INRE), and indirect consumption of non-renewable energy, for consumption of heat produced from non-renewable energies (INRH). These indicators (IRE, INRE, IRH, and INRH) are calculated as follows in Eqs (1) to (4), respectively:

$$IRE = TE * re \tag{1}$$

$$INRE = TE * nre \tag{2}$$

$$IRH = TH * rh \tag{3}$$

$$INRH = TH * nrh \tag{4}$$

where TE is the electricity final consumption, TH is the heat final consumption, and re, nre, rh and nrh are calculated as follows in Eqs (5) to (8), respectively:

$$re = \frac{\text{REL}}{\text{EP+EI}} \tag{5}$$

$$nre=\frac{\text{NREL}}{\text{EP+EI}} \tag{6}$$

$$rh=\frac{\text{RH}}{\text{HP+HI}} \tag{7}$$

$$nrh=\frac{\text{NRH}}{\text{HP+HI}} \tag{8}$$

where REL is the sum of electricity generated from biofuels and waste, hydropower, geothermal, solar photovoltaic and solar thermal, wind, ocean, municipal waste, and other waste. NREL is the sum of electricity generated from coal, oil, natural gas, nuclear and others. RH is the sum of heat produced from biofuels and waste, hydropower, geothermal, solar photovoltaic and solar thermal, wind, ocean, municipal waste, and other waste. NRH is the sum of heat produced from coal, oil, natural gas, nuclear and others. EP is the total electricity produced, EI is the electricity imports, HP is the total heat produced and HI is the heat energy imports.

3. Situation and evolution of renewable energy consumption in Latin America and worldwide

3.1. Energy and renewable consumption in Latin America in 2018

Table 1 shows the total energy consumption Worldwide, in Latin America and in the region's countries, in 2018. The total energy consumption is presented in its total value and divided into total consumption from renewable and non-renewable sources. Renewable energy consumption is also shown divided into direct and indirect renewable energy consumption. Several relative values are offered.

Worldwide energy consumption in 2018 amounted to 9,585,255 Ktoe, while its value in Latin America was 566,888 Ktoe, this represented 5.9% of the total Worldwide value. Brazil and Mexico stand out as countries with the highest energy consumption, while the lowest values were registered in El Salvador and Nicaragua.

In terms of total energy consumption from renewable sources, column 5 shows that this amounted to 16% Worldwide, while the Latin American region reached a much higher value, equal to 29%. It is worth highlighting the high percentage of energy consumption from renewable sources in Guatemala, with 63%. Other countries also exceeded the 50% threshold in that year: Honduras, Nicaragua, Paraguay, and Uruguay. At the opposite end of the spectrum, Mexico and Bolivia stand out for having below 10% of energy consumption from renewable sources.

The renewable energies consumption is divided into direct or indirect values. In the Latin American region, the indirect consumption comes entirely from the consumption of electricity, generated by renewables energies (mostly hydropower). Column 8 shows the percentage of indirect renewable energy consumption over the total renewable energy consumption. Worldwide, this was 31%, this was below the value for Latin America, which stood at 37%. Ecuador and Venezuela accounted for the highest proportion of this value, while Guatemala barely reached 7%.

Finally, the last two columns in Table 1 show the total indirect energy consumption and the percentage of renewable energy consumption in this indirect consumption. Worldwide, this value amounted to 26%, much lower than the 57% in Latin America, values somewhat higher than those presented in the IRENA [16] report for 2013, but which also show that the share of renewables in

power generation in Latin American is far larger than in other regions. However, both values considerably exceed the percentage of renewable energies in the total energy consumption. In other words, most of the renewable energy consumed comes from the electricity consumption generated from renewable sources. Paraguay, Costa Rica, and Uruguay show values very close to 100%, while Mexico barely reaches 16%. In line with these data, Costa Rica has recently been highlighted as an example of a Latin American country with positive evolution towards a renewable-based energy sector, due to its adequate use of energy potential, and adequate public policies [23]. Likewise, in Uruguay there has been a clear political intention to move towards a renewable energy model [25].

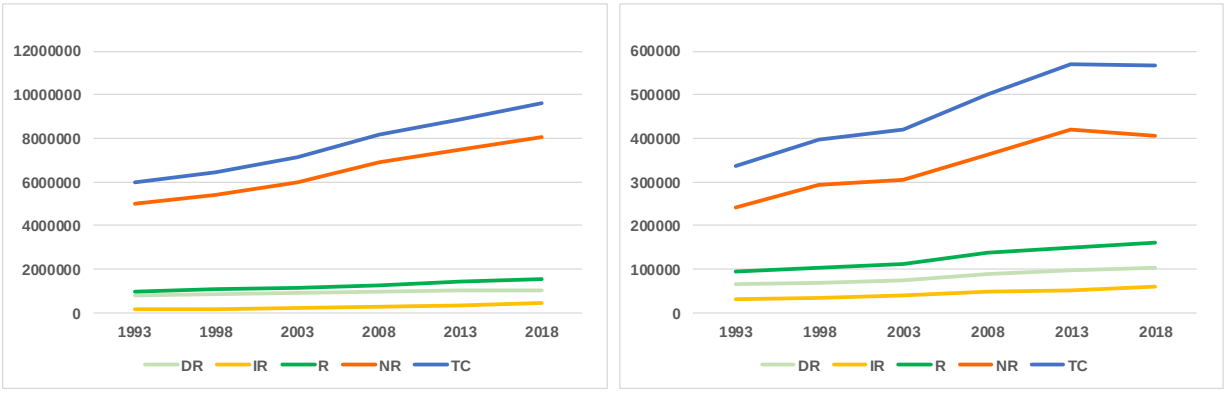
Table 1. Total energy consumption and direct and indirect renewable energy Worldwide and in Latin America: 2018 (Ktoe).

	TC	R	NR	R/TC	DR	IR	IR/R	TCI	IR/TCI
Worldwide	9585255	1542010	8043246	0.16	1060696	481314	0.31	1867627	0.26
Latin America	566888	161946	404942	0.29	102139	59807	0.37	105727	0.57
Costa Rica	3940	1344	2596	0.34	537	807	0.60	818	0.99
El Salvador	2460	494	1966	0.20	183	311	0.63	400	0.78
Guatemala	11657	7365	4292	0.63	6850	515	0.07	830	0.62
Honduras	4407	2193	2214	0.50	1810	383	0.17	570	0.67
Mexico	124309	11494	112815	0.09	7566	3928	0.34	24064	0.16
Nicaragua	2605	1290	1315	0.50	1109	181	0.14	307	0.59
Panama	3533	852	2682	0.24	233	619	0.73	797	0.78
Argentina	56465	5469	50996	0.10	2963	2506	0.46	10377	0.24
Bolivia	6490	488	6002	0.08	268	220	0.45	726	0.30
Brazil	222221	97357	124864	0.44	63404	33953	0.35	41264	0.82
Chile	28114	6968	21146	0.25	4063	2905	0.42	6280	0.46
Colombia	28952	8632	20320	0.30	4551	4081	0.47	5310	0.77
Ecuador	12552	2006	10546	0.16	457	1549	0.77	2134	0.73
Paraguay	6561	3851	2710	0.59	2776	1075	0.28	1075	1.00
Peru	20087	5522	14565	0.27	3001	2521	0.46	4149	0.61
Uruguay	4777	2827	1951	0.59	1865	962	0.34	986	0.98
Venezuela	27757	3795	23962	0.13	503	3292	0.86	5639	0.58

Source: Own elaboration from the IEA [25].

3.2. Energy and renewable energy consumption in Latin America: 1993–2018

Figure 1 shows the evolution of energy and renewable energy consumption, Worldwide and in Latin America, from 1993 to 2018, as well as the origin of the renewable energy.



Worldwide Latin America

Figure 1. Energy and renewable energy consumption in Latin America: 1993–2018 (Ktoe). Source: Own elaboration from the IEA [25].

Figure 1 shows that total energy consumption Worldwide has been growing steadily over time, with greater intensity since 2003. Non-renewable energy consumption shows a very similar trend to total energy consumption, with a slight attenuation from 2008 and onwards. In all years, non-renewable energy consumption considerably exceeds renewable energy consumption. On the other hand, renewable energy consumption tends to increase over time, with greater intensity in recent years. The consumption of direct renewable energy is higher than indirect consumption, throughout the period, although in recent years there has been a trend towards these values equalizing. While direct renewable energy consumption has remained fairly stable, in recent years, since 2008, indirect renewable energy consumption has tended to grow significantly.

In Latin America, the evolution of energy consumption has not been equal to that of the Worldwide picture. For, despite the positive total growth throughout the entire period, energy consumption shows a downward trend from 2013, especially notable in the case of energy from non-renewable sources. On the other hand, the consumption of renewable energies shows a positive evolution, throughout the period, although its value is much lower than the consumption of non-renewable energies over the whole period. Within the consumption of renewable energies, there are also differences with respect to Worldwide performance. Thus, while at the Worldwide level there is a convergence between the consumption of renewable energy from direct and indirect sources, in Latin America, its value tends to diverge slightly at the end of the period under study. However, both types of renewable energy show a sustained growth, over time. Finally, it should also be noted that the difference between renewable and non-renewable energy consumption is relatively lower in Latin America than Worldwide, throughout the study period. As with the Worldwide scenario, this difference tends to widen at the end of the period, despite the sustained growth of renewable energy consumption.

Table 2 shows the evolution of total energy consumption and the consumption of renewable and non-renewable energies, in terms of growth rates. It also shows the evolution of direct and indirect renewable energy consumption. Growth rates are shown for the period 1993 to 2018, as well as 1993 to 2008, and 2008 to 2018.

It is worth noting the growth of energy consumption, at the Worldwide and Latin American levels, throughout the entire period. The Latin American region growth rate was slightly higher than that Worldwide over the whole period (68 and 60%, respectively). Nevertheless, the growth rate from 2008

to 2018 was higher Worldwide. The countries in the region with the highest energy growth rates, over the entire period, were Guatemala and Bolivia, with growth rates of 1.66 and 1.65%, respectively. Likewise, these countries had high relative growth rates between 2008 and 2018. The countries with the lowest growth in energy consumption were El Salvador and Honduras, with rates below 10% for the whole period. Additionally, it is worth highlighting the negative energy consumption growth in Venezuela, a fact that occurred due to its negative growth between 2008 and 2018. According to Pietrosemoli and Rodríguez-Monroy [23], this energy crisis is associated to structural problems and related to a political model that does not favor competitiveness and economic independence.

Regarding renewable energy consumption, it is noteworthy that the Latin American region also had higher growth than that Worldwide (70 to 55%). However, once again, the growth of these energies was higher Worldwide from 2008 (22% to 17%). The countries with the highest growth rates in renewable energy consumption were Uruguay and Guatemala, at 209% and 111%, respectively. On the contrary, Bolivia and El Salvador showed a negative growth in said consumption.

The growth rates of non-renewable energy consumption are quite similar to those of total energy consumption, in all the periods analyzed, both in the Worldwide economy and in Latin America. However, this pattern is not observed in all countries of the Latin American region. The highest growth in non-renewable energy consumption is found in Bolivia, Guatemala, Paraguay, and Panama. All these countries had growth rates of over 200% during the whole period. Likewise, these are the countries that had the highest growth rates of this energy consumption, from 2008 to 2018. The lowest growth in non-renewable energy consumption occurred in Venezuela, with a negative rate of 6%. It is also worth noting the small growth in non-renewable energy consumption in Honduras, at just 8%, from 1993 to 2018.

The last columns in Table 2 show the renewable energy consumption growth rates, according to their direct or indirect origin. The growth of direct renewable energy consumption is positive, both Worldwide and in the Latin American region. However, all the periods and sub-periods considered have lower growth rates than those recorded for renewable energy consumption. It is also noteworthy that many countries in the sample show negative growth rates for direct renewable energy consumption. Specifically, this variable decreases in El Salvador, Mexico, Panama, Bolivia, Ecuador, and Venezuela. In contrast, it is worth noting the strong growth experienced in Uruguay, whose growth rate for the whole period was 238%.

Finally, regarding the evolution of the indirect consumption of renewable energies, it is worth noting the strong growth observed during the whole period, both Worldwide and in Latin America. However, it was higher at the Worldwide level, with a growth rate of 176%. This strong momentum occurs between 2008 and 2018, when it distances significantly from that of Latin America. By country, a strong growth of indirect consumption of renewable energies is observed in Ecuador, Paraguay, and Panama, with growth rates above 300%. In contrast, Venezuela presented the lowest growth rate, with only 5%. It is also worth noting the small growth of this type of energy consumption in Argentina and Mexico, whose overall growth rates did not exceed 70%, compared to the region's growth of close to 100%. The slower growth of indirect renewable energies in Mexico was already highlighted in the OECD report [29], which even showed a certain setback, during the period from 2000 to 2010. However, it is also curious that, at least for some years, it has been the second Latin American country with the highest investment in renewable energies, especially in wind energy [30].

Table 2. Total energy consumption, renewable and non-renewable energy, and direct and indirect renewable energy growth rates (Worldwide, Latin America and Latin American countries): 1993–2018.

	TC			R			NR			DR			IR		
	1993–08	2008–18	1993–18	1993–08	2008–18	1993–18	1993–08	2008–18	1993–18	1993–08	2008–18	1993–18	1993–08	2008–18	1993–18
Worldwide	0.36	0.17	0.60	0.27	0.22	0.55	0.38	0.16	0.61	0.21	0.07	0.29	0.54	0.79	1.76
Latin America	0.48	0.13	0.68	0.45	0.17	0.70	0.50	0.12	0.67	0.39	0.13	0.57	0.57	0.25	0.96
Costa Rica	0.93	0.14	1.20	1.16	−0.02	1.11	0.79	0.26	1.26	1.09	−0.25	0.57	1.25	0.21	1.73
El Salvador	0.05	−0.03	0.02	−0.44	−0.37	−0.65	0.74	0.13	0.95	−0.59	−0.65	−0.86	0.98	0.17	1.32
Guatemala	0.83	0.45	1.66	0.74	0.39	1.42	1.04	0.59	2.23	0.71	0.38	1.36	1.39	0.48	2.53
Honduras	0.01	0.10	0.10	0.04	0.09	0.13	−0.02	0.11	0.08	0.02	−0.02	0.00	0.26	1.26	1.85
Mexico	0.35	0.06	0.44	0.05	0.06	0.12	0.40	0.06	0.48	−0.04	−0.01	−0.05	0.36	0.25	0.69
Nicaragua	0.38	0.24	0.71	0.10	0.15	0.26	0.95	0.34	1.61	0.09	0.06	0.15	0.32	1.49	2.29
Panama	0.61	0.50	1.42	−0.06	0.59	0.49	1.05	0.47	2.02	−0.41	−0.06	−0.45	0.92	1.16	3.14
Argentina	0.49	0.08	0.61	0.14	0.53	0.74	0.53	0.04	0.60	−0.15	1.25	0.91	0.41	0.11	0.57
Bolivia	0.67	0.61	1.67	−0.19	−0.33	−0.46	1.17	0.81	2.92	−0.31	−0.50	−0.66	0.65	0.19	0.96
Brazil	0.66	0.16	0.92	0.65	0.17	0.94	0.66	0.14	0.90	0.69	0.14	0.92	0.58	0.25	0.97
Chile	0.67	0.25	1.09	0.47	0.05	0.55	0.77	0.33	1.36	0.49	−0.11	0.33	0.44	0.41	1.03
Colombia	0.16	0.25	0.44	0.02	0.30	0.33	0.22	0.23	0.50	−0.22	0.29	0.01	0.57	0.31	1.06
Ecuador	0.57	0.47	1.31	0.09	0.61	0.74	0.69	0.45	1.46	−0.30	−0.16	−0.41	0.89	1.20	3.15
Paraguay	0.26	0.68	1.11	0.15	0.49	0.71	0.53	1.06	2.15	0.03	0.34	0.38	1.17	1.09	3.55
Peru	0.66	0.42	1.36	0.50	0.18	0.78	0.75	0.54	1.70	0.38	−0.05	0.31	0.84	0.67	2.07
Uruguay	0.42	0.53	1.17	0.46	1.12	2.09	0.39	0.09	0.51	0.69	1.00	2.38	0.10	1.42	1.66
Venezuela	0.29	−0.27	−0.05	0.54	−0.34	0.01	0.25	−0.25	−0.06	0.45	−0.42	−0.16	0.55	−0.33	0.05

Source: Own elaboration from the IEA [25].

3.3. Relative share of renewable energy consumption in Latin America

The evolution of the different growth rates mentioned above means that the relative weight of total energy consumption, of both renewable and non-renewable, and of direct and indirect consumption of renewable energy, has been changing over time. Table 3 shows the evolution of the weight of the value of the Latin American variables over the Worldwide total.

Table 3. Relative share of Latin America's energy consumption within the Worldwide total: 1993–2018.

	1993	1998	2003	2008	2013	2018
TC	0.056	0.061	0.059	0.061	0.064	0.059
R	0.096	0.097	0.099	0.109	0.106	0.105
NR	0.048	0.054	0.051	0.053	0.056	0.050
DR	0.079	0.078	0.080	0.091	0.093	0.096
IR	0.175	0.183	0.186	0.177	0.145	0.124

Source: Own elaboration from the IEA [25].

In 2018, Latin America's energy consumption represented 5.9% of Worldwide consumption. This value, higher than that observed in 1993, has been oscillating slightly during the study period, it registered its highest value in 2013, equivalent to 6.4% of the Worldwide total. The weight of renewable energy consumption in Latin America, over the Worldwide total, is considerably higher than the weight of total energy consumption. In 2018, this value accounted for 10.5%, with an increasing trend from 1993 to 2018, and some stagnation since then. In contrast, the share of non-renewable energy consumption is quite similar to that of total energy consumption, with a pattern also similar in the oscillations observed throughout the period.

Regarding the share of renewable energies in the Worldwide total, according to whether it is direct or indirect consumption, it should be noted that the two types of consumption show a different trend. While the weight of direct renewable energy consumption tends to rise throughout the period, reaching 9.6% at the end of this period, the weight of indirect consumption follows a decreasing trend from 2003, with 12.4% in 2018. Again, it becomes evident that, although the consumption of renewable energy in Latin America tends to rise slightly in relative terms, with respect to total Worldwide consumption, the share of its consumption through the indirect effect, mainly electricity consumption, does not follow the Worldwide evolution. The recent Enerdata report [31] highlights the strong growth of wind and solar power generation, from the early 2000s, in the USA, China, India and Japan, without highlighting the importance of such growth in the Latin American region, during the same period. In fact, the study by Washburn and Pablo-Romero [2] indicated that, during the 2005–2015 period, the increase in the percentage of solar and photovoltaic power generation Worldwide stood out, which in turn contrasted with the relatively low value and growth in Latin America.

In terms of countries, some notable differences are observed among them. Figure 2 shows the share of total, renewable and non-renewable energy consumption, of each country in Latin America, in 1993, 2008 and 2018. Meanwhile, Figure 3 shows the share of direct and indirect renewable energy consumption of each country within the region.

In general terms, a few countries in the region account for more than 75% of total energy consumption and non-renewable energy consumption. Specifically, Brazil, Mexico, Argentina, and Venezuela account for more than 75% of the total energy consumed in Latin America. Although

Venezuela's share decreased at the end of the period, Brazil, Chile, and Peru increased their share. It is also important to highlight the weight of Brazil and Mexico in this energy consumption. Throughout the entire period, they represent more than 60%. An almost identical pattern can be observed, in the share of each country, in the total non-renewable energy consumed, and in its evolution. Again, Brazil, Mexico, Argentina, and Venezuela together consume more than 75% of the region's non-renewable energy, with Venezuela's share decreasing, and Brazil's increasing.

This distribution of participation is different for renewable energy consumption. In this case, Brazil stands out, with more than 50% of the renewable energy consumed. Its evolution also increased between 1993 and 2008, when it reached a value of 60%. Brazil's high weight is in line with its great abundance of renewable resources for wind, solar and hydroelectric power generation and its capacity for biodiesel production [24]. The weight of Mexico and Venezuela also stands out, although their share is decreasing. In this regard, the high dependence of these two countries on their fossil resources should be considered [22].

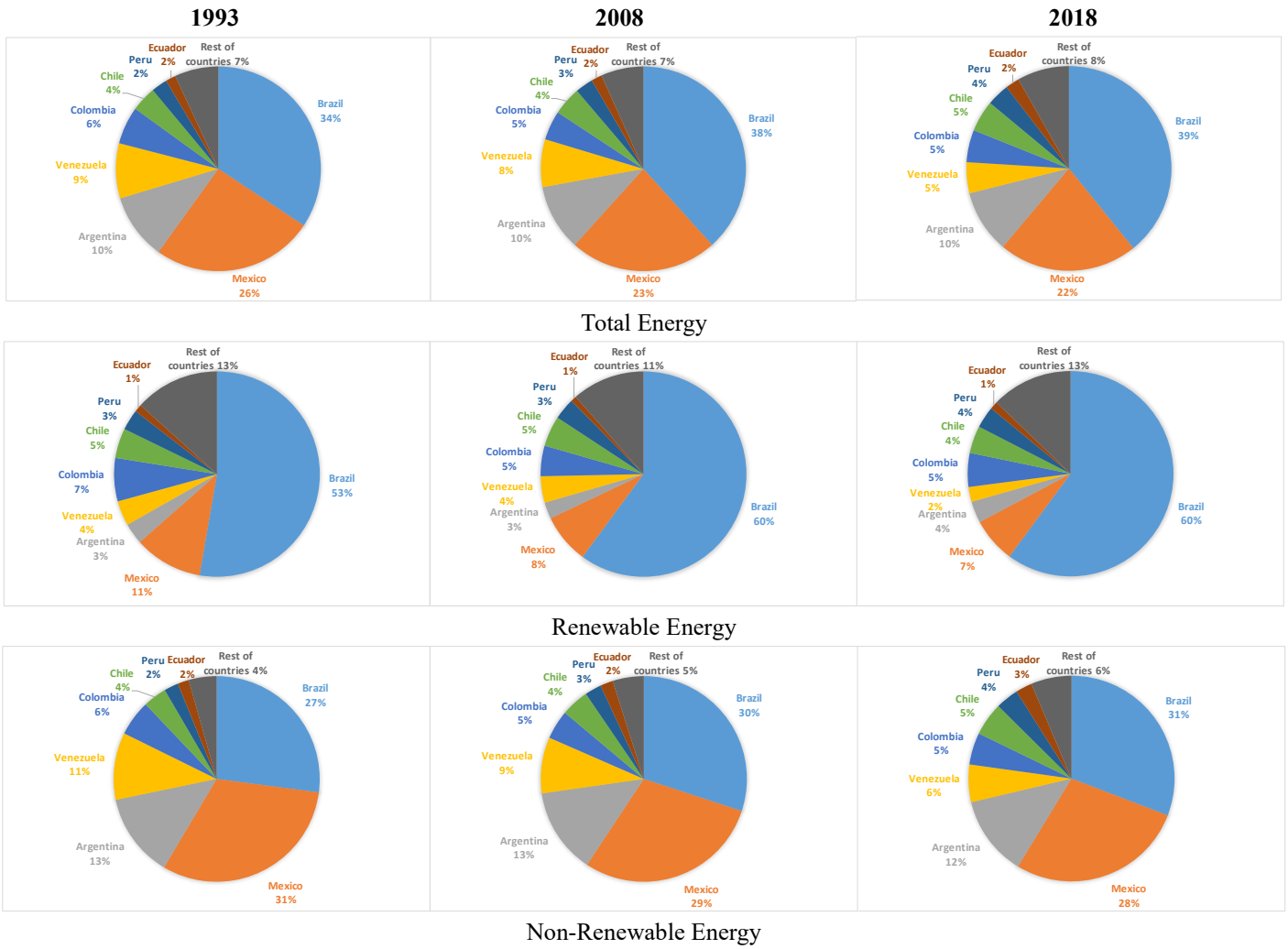


Figure 2. Total, renewable and non-renewable energy consumed: share by country over the region. Source: Own elaboration from the IEA [25].

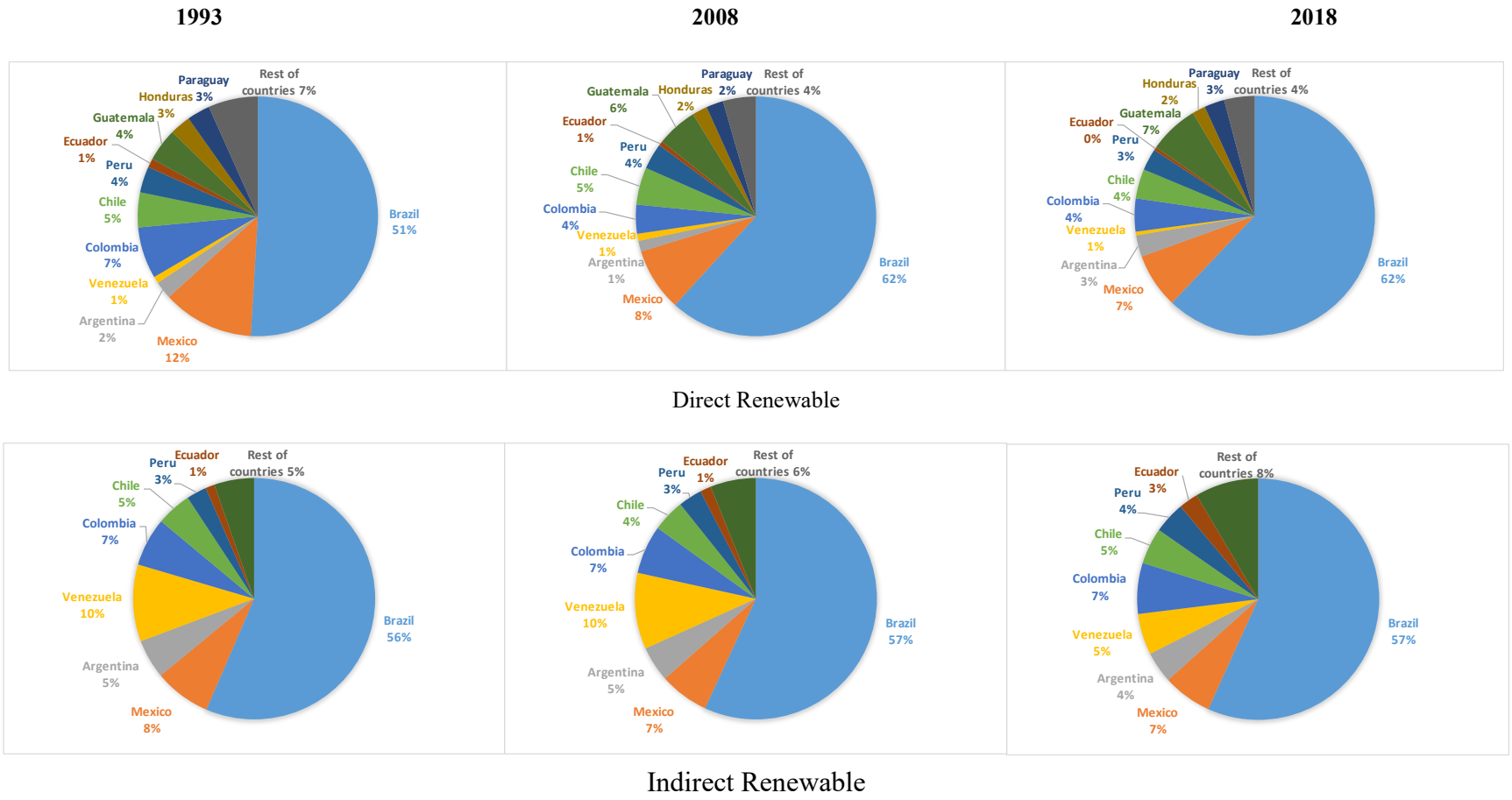


Figure 3. Direct and indirect renewable energy consumption: share by country over the region. Source: Own elaboration from the IEA [25].

Figure 3, once again, shows the large weight of Brazil and Mexico in the renewable energy consumed directly in the region. Brazil presents an increasing trend, reaching 62% of the total, and Mexico a decreasing trend, from 12% to 7%. In fact, Brazil is one of the largest producers of biodiesel in the world [24]. The rest of the countries have a relatively similar share, with a significant weight reduction in Colombia, and an increase in Guatemala, which reaches a similar weight to Mexico at the end of the period.

Finally, it is worth noting the high share of Brazil in the indirect renewable energy consumption, with an almost constant share of approximately 57% of the regional total. However, it should also be noted that this share is lower than that of direct renewable energy consumption. In this regard, it is worth noting that, in recent years, Brazil has undergone a process of change in the generation of its energy mix, since, for climatic reasons, it has reduced its hydroelectric power generation capacity, compensating it with investments in solar and wind energy [24]. With a much lower share, Mexico and Colombia stand out at the end of the period, with 7%. Finally, Ecuador shows a notable increase, from 1% to 3% of the regional total.

To show the relative significance of some Latin American countries in the evolution of renewable energy consumption, Figure 4 shows the share of each country's renewable energy consumption, over its total energy consumed, and the indirect renewable energy consumption, over its total renewable energy consumption. Figure 4 shows the relative importance of renewable energy consumption in Latin America compared to the Worldwide total, both in terms of renewable energy over total energy consumed and as a percentage of indirect renewable energy consumption over total renewables. However, it should be noted that the Worldwide evolution of the latter is much greater than in Latin America. Consequently, at the end of the period both values tend to converge.

When analyzing the weight of renewable energy consumption over the total, it is worth noting that only three countries are below the Worldwide average, at the end of the period analyzed: Mexico, Argentina, and Venezuela (approximately 10%). Nevertheless, these countries have a high relative importance in energy consumption, as shown in Figure 3. It should be noted that while Venezuela and Mexico are oil producers and exporters, Argentina is dependent on fossil fuels. Its low penetration of renewable energy is due to the traditional lack of investment in the development of renewable energy technologies, and the need to import large quantities of oil, to manage its energy demand. Recently, however, investment in renewable energy has increased [32].

In contrast, Paraguay, Nicaragua, and Guatemala stand out as those with the highest relative values of renewable energy consumption, at approximately 60%. However, while those first two countries show a decreasing trend, Guatemala stands out for its stability. It is also worth noting Uruguay's strong positive trend, reaching 60% at the end of the period.

The right graph in Figure 4 shows the indirect renewable energy consumption over total renewable energy consumed. The greatest weight is recorded in Venezuela, which maintains a stable value of over 80%. At the end of the period, Costa Rica, El Salvador, Panama and Ecuador, were above 60%, with the last three showing significant growth. Guatemala, Nicaragua and Honduras, with values of approximately 10%, have the smallest share. However, solar and wind generators are not prevalent throughout Guatemala [33]. This introduction is also scarce in Nicaragua and Honduras, where there have been very few sustainable energy policies to promote the development of these energies [34,35].

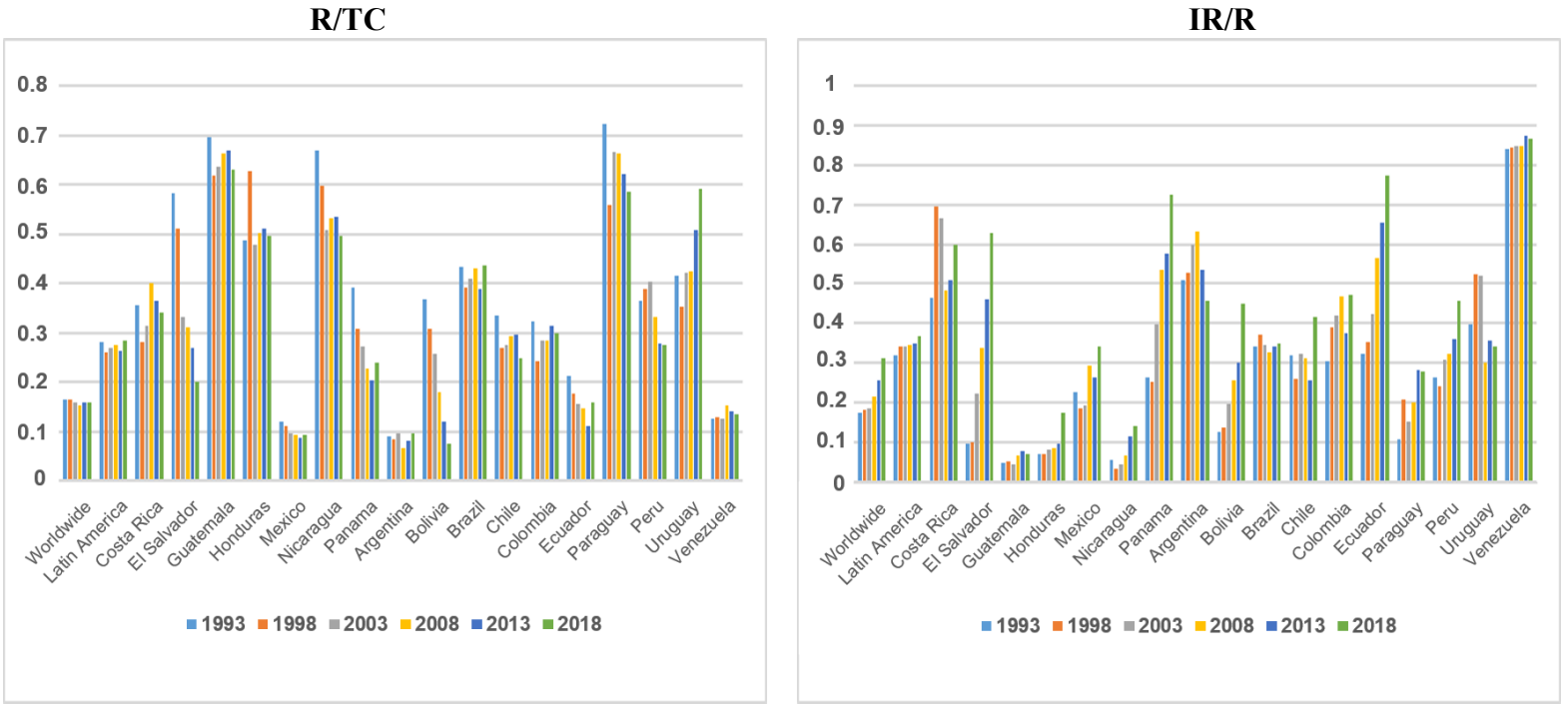


Figure 4. Renewable energy consumption on total energy consumption and indirect renewable energy consumption on renewable energy: 1993–2018. Source: Own elaboration from the IEA [25].

3.4. Direct and indirect renewable energy consumption

Figure 5 shows the evolution of the percentage of direct and indirect renewable energy consumption, over total direct and indirect energy consumption, respectively. In both cases, these percentages are higher in Latin America than Worldwide. However, the evolution of these relative magnitudes differs. In Latin America, the share of indirect renewable energy in the total indirect energy consumed, is decreasing until 2013, when it begins to recover its value. However, it did not reach the values of 2008. Worldwide, the evolution of this variable is slightly decreasing until 2003, starts to increase from then, with this growth being more pronounced from 2008. The percentage values are, however, considerably lower Worldwide, than those achieved by Latin America at the end of the study period, with a difference of almost 30 percentage points. It is important to note that, although Latin America benefits from rich hydropower resources, and hydroelectricity is a major contributor to this region's energy mix, climate change may already be reducing the generating capacity of its hydropower plants [36]. Therefore, if the adoption of other renewables continues to be slower than in the rest of the world, its indirect renewable capacity will tend to decline over time.

In the case of the share of renewable energies in direct energy consumption, Figure 5 also shows that Latin American values are higher than Worldwide values, with a stable trend in the first case, and a slightly decreasing trend in the second. At the end of the period, the difference between Latin American and Worldwide values is not as wide as in the case of indirect energy (slightly more than 5 percentage points).

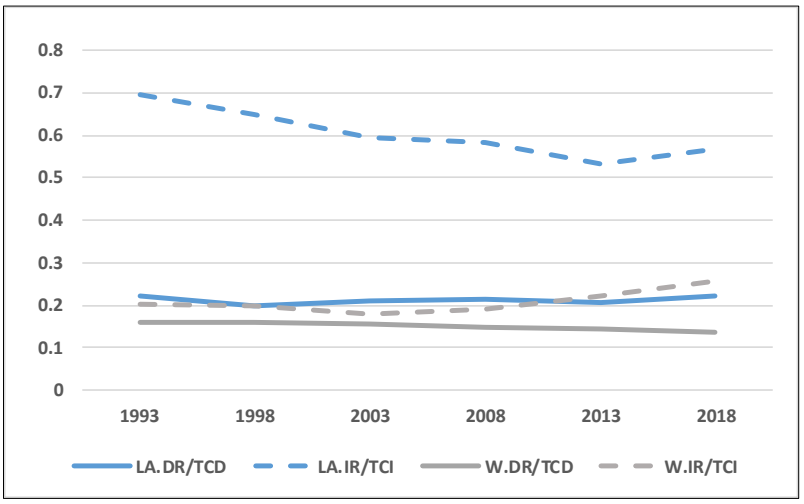


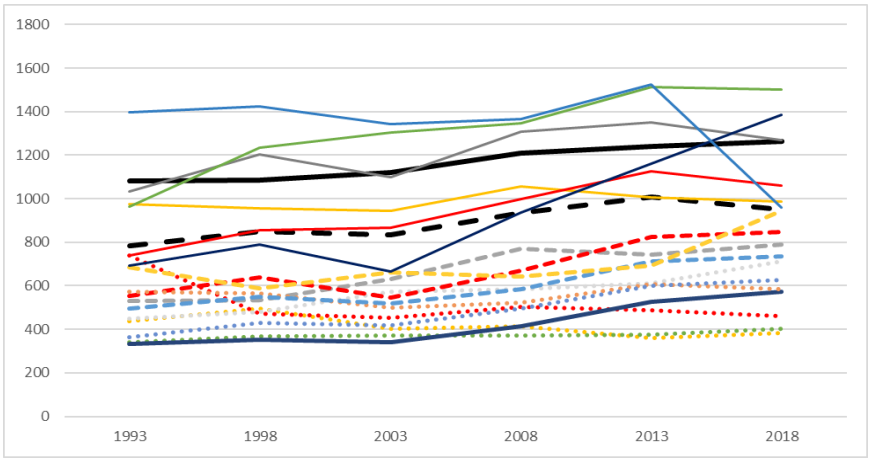
Figure 5. Renewable energy shares on direct and indirect energy consumption in Latin America and Worldwide: 1993–2018. Source: Own elaboration from the IEA [25].

4. Renewable energy consumption per capita in Latin America

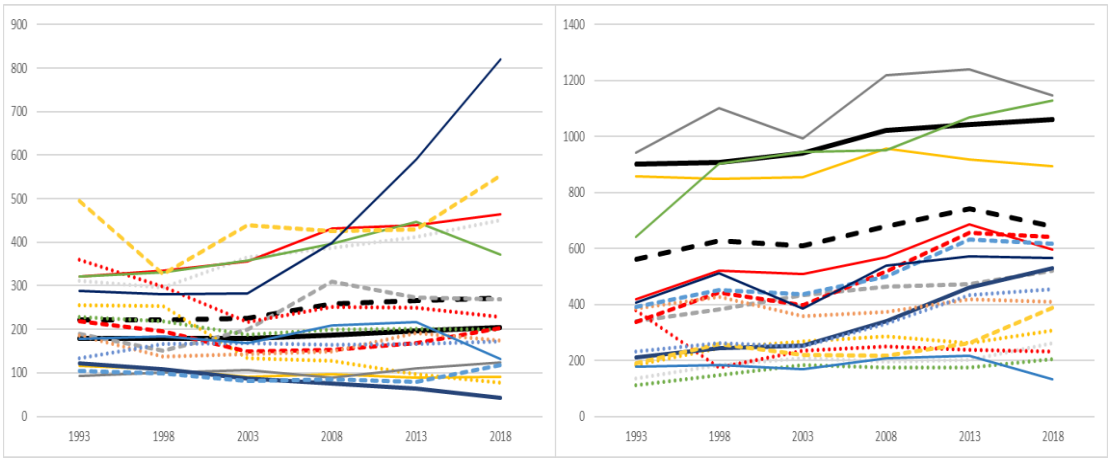
Figure 6 shows the evolution of the energy consumption per capita consumed in Latin American countries, during the period 1993–2018. The top graph shows the evolution of total energy consumed per capita. The thick black line and the thick dashed line show the evolution of that variable, at the Worldwide level, and in Latin America, respectively. The evolution of per capita energy consumption

is positive in both, with lower values in Latin America. However, since 2013, Latin America has presented a decreasing trend, which increases the distance with respect to Worldwide.

Throughout the period, only three countries have had per capita consumption values higher than Worldwide: Argentina, Venezuela and Chile, although Venezuela has a pronounced decline at the end of the period. Along with these countries, in 2018, Uruguay presents values higher than Worldwide, after presenting a very pronounced positive evolution from 2003. Among the Worldwide and Latin American lines are Mexico and Brazil, both countries with an overall positive trend, except at the end of the period. The rest of the countries are below the regional value, with most of them showing a positive per capita consumption trend. These include Paraguay, Panama, Ecuador, Bolivia, and Peru.



Total per capita energy consumption



Renewable per capita energy consumption Non-renewable per capita energy consumption

Figure 6. Total, renewable and non-renewable per capita energy consumption in Latin America: 1993-2018 (Ktoe/million inhabitants). Source: Own elaboration from the IEA [25] and World Bank [26].

The lower part of Figure 6 shows the evolution of renewable energy consumption per capita (lower left graph), and non-renewable energy consumption per capita (lower right graph). Renewable energy consumption per capita is always higher in Latin America than Worldwide. The evolution is slightly positive in both cases, although the growth is somewhat higher in Latin America. The countries with the highest values are Uruguay, Paraguay, Brazil, Chile, and Guatemala, with a very significant growth in Uruguay from 2003. The introduction of renewable energies has been carried out in Uruguay mainly for two reasons. The high dependence on fossil fuels, and the difficulty of supplying gas, since 2004, and the decisive action of the main political parties to adopt a green policy, which was reinforced after the development of the 2008 energy plan [28]. The countries with lower values are Bolivia, Mexico, Ecuador, Argentina, and El Salvador, with Bolivia showing a continuing downward trend. Finally, Venezuela shows a pronounced decline in the last five years.

In the lower right graph of Figure 6, it can be observed that non-renewable energy consumption per capita Worldwide, is much higher than in Latin America, with a positive evolution up to 2013, when a significant drop begins. It can be observed that Mexico, Chile and Argentina have values approximately equal to those Worldwide, with the continued growth of Chile standing out. The rest of the countries have values below the regional level. Almost all show an upward trend until the last five years, except for Bolivia and Paraguay, which maintain their upward trend. Finally, the low values of Nicaragua, Honduras and Venezuela are notable.

5. Renewable energy consumption and energy intensity in Latin America

Figure 7 shows the evolution of total energy intensity, renewable and non-renewable, in Latin American countries. The top graph shows the evolution of the total energy intensity. The thick black line and the thick dashed line show the evolution of this variable Worldwide and in Latin America, respectively. Both trends are slightly negative, with Worldwide energy intensity remaining higher than Latin America, without significant changes in the relationship of this magnitude between regions, pointed out by Sheinbaum-Pardo and Ruiz [37] in their study.

At the end of the period, the global intensity stood at 0.14 Ktoe per constant 2010 US$ million, approximately, while this value was 0.1 Ktoe/US$ million in Latin America. Honduras and Nicaragua stand out with values well above those recorded Worldwide, although they show a markedly downward trend. On the contrary, Bolivia, Chile and Uruguay stand out as the countries with the lowest intensity, at the end of the period, approximately 0.07 Ktoe/US$ million. It is also worth noting the strong decrease in intensity presented by Panama.

The evolution of energy intensity from renewable (lower left graph) and non-renewable energy (lower right graph), is shown at the bottom of Figure 7.

Renewable energy intensity in Latin America is higher than that Worldwide, with a decreasing trend in both cases. It is worth highlighting the growth of renewable energy intensity in Uruguay, with a value, at the end of the period, higher than the regional average. Also noteworthy is Brazil's value, which is above the regional average. With respect to non-renewable energy intensity, the higher Worldwide value than the regional level, throughout the period, is noteworthy, with a negative trend in both cases, but more accentuated at the Worldwide level. Uruguay, Chile and Brazil are the countries with the lowest non-renewable energy intensity, with a slight downward trend. Panama and Venezuela also stand out for their decreasing trend throughout the analyzed period.

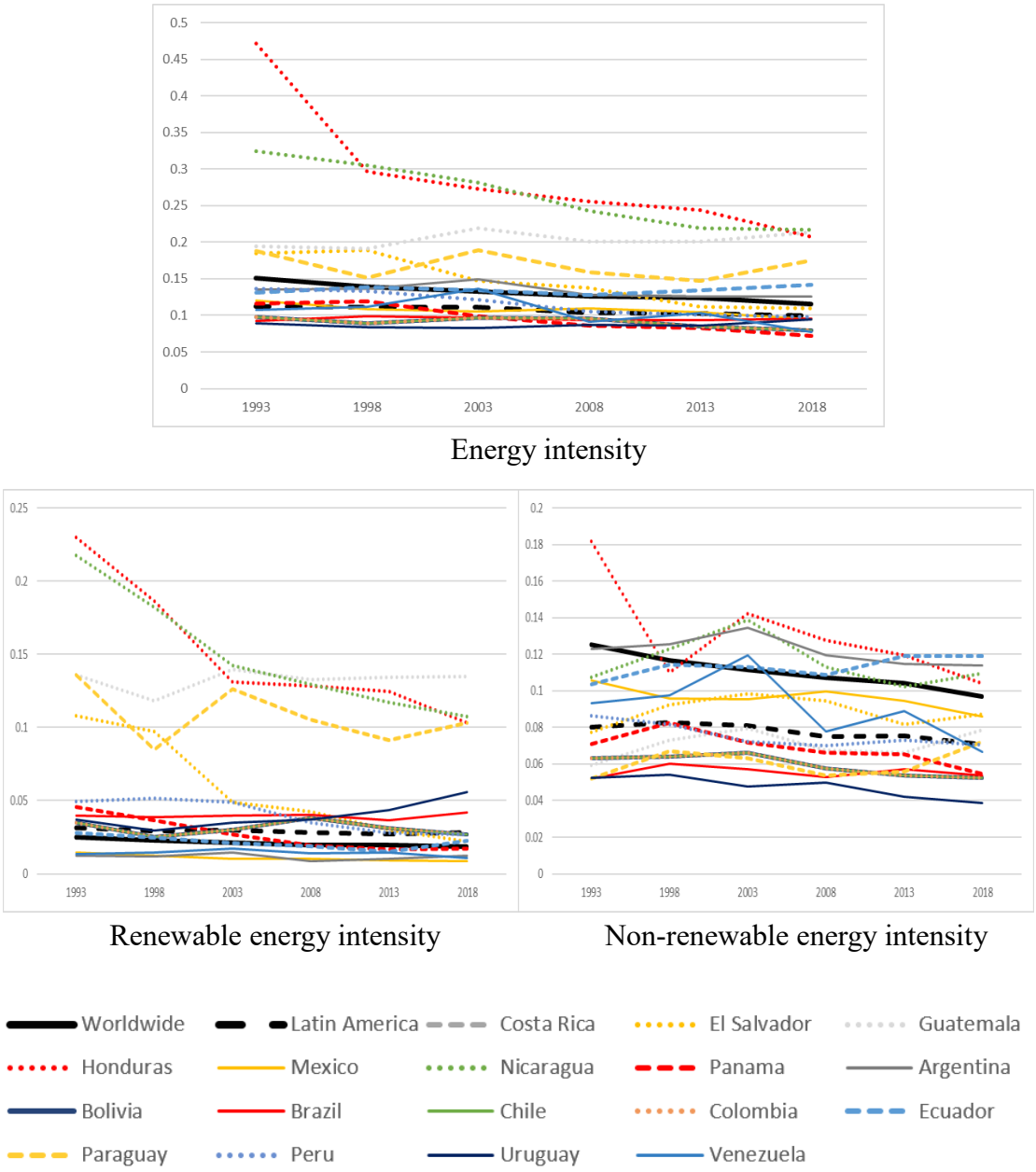


Figure 7. Total, renewable and non-renewable energy intensity in Latin America: 1993–2018 (Ktoe/ millions of 2010 US$). Source: Own elaboration from the IEA [25] and World Bank [25].

6. Limitations and future recommendation

This study is limited to offering an analysis of the situation and evolution of renewable energies, in the Latin American countries and region, to highlight the magnitude of the energy change that has been taking place in recent years, compared to that which is occurring Worldwide. It is not, therefore, intended to explain its causes, but only to put its value into context. The interest that this energy change may have on the environment, economic growth, and energy security, may make it advisable for other works to be developed, in the future, that go further and look for the specific causes, behind the behavior of the countries of the region.

7. Conclusions and policy implications

Climate change, economic growth and energy security have intensified the energy transition of many countries towards the use of renewable energies. Among them, a group of Latin American countries have recently understood the need to intensify actions, to achieve more ambitious goals, in the whole region. This paper analyzes the status of renewable energy consumption in 17 Latin American countries in 2018, and its evolution since 1993. Renewable energy consumption is studied in its totality and, by dividing its value between direct and indirect renewable energy consumption, both in absolute and relative terms.

The results of the study show that, at the end of the period, the percentage use of renewable energy, both direct and indirect, in Latin America is more than that Worldwide. Furthermore, it is observed in both that the use of renewable energies is more intense in the production of electricity and/or heat, than in direct energy consumption.

The evolution study shows that the Latin American region has not had an evolution of total energy consumption, similar to that Worldwide. In comparison to the continued Worldwide growth, from 2013, Latin America shows a decreasing trend. However, throughout the entire period, its growth was higher than that Worldwide. In Latin America and Worldwide, renewable energy consumption is lower than non-renewable energy consumption, although the difference is smaller in Latin America. In both, the evolution of renewable energy is growing, with a higher intensity in Latin America. This growth is mainly due to the increase in indirect renewable energy consumption in both regions. Nevertheless, the consumption of indirect renewable energy is growing more intensively Worldwide.

In relative terms, the consumption of renewable energies in Latin America outweighs the weight of total energy consumption in the region, which is explained by the high consumption of renewable energies through the indirect effect, in other words, the use of renewable energies in the production of electricity.

By country, it should be noted that more than 75% of total energy consumption and non-renewable energy consumption, is in Brazil, Mexico, Argentina, and Venezuela. In the case of renewable energy, the weight of Brazil and, to a lesser extent Mexico, continues to stand out, but the distribution of the other countries is more dispersed. It is also worth noting Brazil's high share of indirect renewable energy consumption, with an almost constant weight of approximately 57% of the regional total.

In per capita terms, total energy consumption is lower in Latin America than Worldwide, with a similar positive trend in both, except at the end of the period, when it decreases in Latin America. Three countries have had higher per capita consumption levels than Worldwide: Argentina, Venezuela, and Chile. Renewable energy consumption per capita is higher in Latin America than Worldwide, with a slightly higher growth in the region. However, there is a differentiated behavior of direct and indirect renewable energy because, while direct energy consumption per capita is similar to the Worldwide level, indirect energy consumption per capita is much higher in Latin America.

Regarding energy intensity in Latin America, the results show lower values than Worldwide, with a similar decreasing trend. The intensity of renewable energy consumption is higher in the region and its trend is the same as that Worldwide, decreasing. Indirect renewable energy intensity shows a certain stability, with an increasing trend since 2008, higher at the global level than at the regional level.

In general terms, Latin America has been on a slower growth path in indirect renewable energy consumption, than the rest of the world, which may be associated with a slower development of wind and solar energy. Given the possible negative impact of climate change on the capacity of hydroelectric

power, it may be advisable to strengthen investments in these non-traditional renewable energies, which can also be adduced within the global context of rising oil and natural gas prices.

Some countries have shown a positive trend in renewable energy consumption, such as Costa Rica, Uruguay, and Brazil, with a clear political willingness to change. On the contrary, other countries, such as Venezuela, Argentina, Nicaragua, and Honduras, stand out for their low consumption, which has been associated with a low desire for change, among other reasons. The willingness of society and politicians to change can therefore be the first step for the development, implementation, and increased consumption of renewable energies.

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Conflict of interest

The authors declare no conflict of interest.

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