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Article

Environmental and energy indicators in Latin America and the Caribbean: An evaluation from multivariate techniques on sustainability

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Abstract: In the current context of concern about the environmental impacts of human activity, the focus on sustainable development and environmental impact assessment (EIA) has gained prominence. The Brundtland Commission highlights the importance of meeting present needs without compromising future ones, leading to international treaties and public policies to address the environmental crisis. Moreover, the Latin American and Caribbean Initiative for Sustainable Development (ILAC) seeks to promote sustainable development in key areas in Latin America and the Caribbean. Among them, energy efficiency and destination are crucial for sustainable use of energy resources and emission reduction. The aim of this article is to examine the evolution of variables and countries regarding installed capacity to produce electricity, renewable primary energy supply share, and fossil-fuel subsidies through Dynamic biplots and multivariate analyses. Trends in the increase of renewable energy production capacity are shown. In contrast, the correlation between the share of fossil fuel subsidies and the share of renewable primary energy supply presents a weak inverse relationship. Therefore, although progress has been made toward using cleaner energies and the consumption and subsidization of fossil fuels have decreased, some countries still depend significantly on non-renewable sources. It is concluded that even when environmental information presents challenges, analyzing indicators and conceptual models contributes to understanding environmental dynamics and progress toward sustainable development in the region, especially through creating and implementing public policies.

Keywords: sustainable development; environmental indicators; renewable energy; multivariate methods; Latin America

1. Introduction

Among the significant problems afflicting humanity today are the negative effects on the environment caused by human intervention. The catastrophic consequences of climate change, such as the decrease in water availability, the increase in ecological vulnerability, and the continuous deterioration of the natural environment—resulting in air, soil, and water pollution—have led to greater visibility within the public debate of the imminent risk of an environmental crisis (Miranda Cuéllar and Fonden Calzadilla, 2019).

This context has undoubtedly led to a series of international treaties to create public policies to lead States toward sustainable development. The Brundtland Commission, constituted by the General Assembly in 1983, in its report "Our Common Future" (CMMAD, 1987), defines the term "sustainable development" as development that meets the needs of present generations without compromising the ability of future generations to meet their own needs. It also considers addressing the demands of an environmental protection agenda and ensuring the development of countries with lower levels of progress (Araya and Correa, 2023).

One of the most promoted global policies to prevent environmental degradation is the Environmental Impact Assessment (EIA) mechanism promoted by the United Nations Conference on Environment and Development in 1992 (CNUMAD, n.d.). To date, 191 countries of the United Nations have incorporated this process in their political agendas, being an essential tool of environmental public policy (Perevochtchikova, 2013).

The mechanism requires the integration of environmental policy goals into sectoral public policies, as well as relevant concepts and repercussions. Therefore, one of the main aspects in which it is considered imminent to work is the elaboration of environmental information, useful for the political process (Manteiga, 2000). Thus, it is necessary to develop a standard conceptual structure based on an agreement of concepts and definitions. The Organization for Economic Co-operation and Development (OECD) and its member countries must formulate, identify, and define indicators and provide a guide for their use in articulation with environmental performance assessment (OCDE, 2006).

In Latin America and the Caribbean, the Latin American and Caribbean Initiative for Sustainable Development (ILAC) was adopted on 31 August 2002, at the First Meeting of the Forum of Ministries of the Environment of that region. It is considered the main instrument for the promotion of sustainable development and consists of six goals divided into six areas: Biological diversity; water resources management, vulnerability, human settlements, and sustainable cities; social issues (health, inequity, and poverty), economic aspects (competitiveness, trade, production, and consumption patterns) and institutional issues (PNUMA, 2011).

In order to carry out this type of study, primary information obtained through environmental monitoring networks is required, which is simply and concisely understood as environmental indicators that will then be transmitted to the civil population and decision-makers (Perevochtchikova, 2013). Environmental indicators describe and make visible the states and the central environmental dynamics (Quiroga Martínez, 2009). Despite this tool, it is understood that environmental information contains complexities related to its nature, thus challenging national statistical systems. This is why, when approaching environmental dynamics in their breadth and difficulty, understanding their constant and dynamic change, the arduous task of dimensioning and measuring them over time can be noted (Quiroga Martínez, 2009).

Despite the peculiarities that must be considered to measure the environment's state, some authors have delved into it, using different types of indicators in their studies and models to systematize the information, such as the Pressure-State-Response Model (PSR) developed by Friend and Rapport (Pino Neculqueo, 2002) and the Driving Force-Pressure-State-Impact-Response (DPSIR) model, developed by the European Environment Agency (EEA) (Aguirre Royuela, 2002). Both models enable the promotion of indicator systems that fully contemplate the environmental problems studied. Other indicators related to the environmental crisis are those related to energy efficiency, which refers to optimizing energy use to reduce resource consumption and minimize the environmental impacts of energy production and use.

This research aims to examine environmental indicators, specifically the variables concerning the production and consumption of energy in Latin America and the Caribbean. The general objective of the paper is to analyze the evolution of variables and countries regarding installed capacity to produce electricity, renewable primary energy supply share, and fossil-fuel subsidies through dynamic biplots and multivariate analyses. This methodology has not been detected in other studies of the region.

The study provides valuable insight into the evolution of renewable energy supply and consumption in Latin America and the Caribbean. Furthermore, due to the biological diversity and vulnerability to environmental changes, conducting a study focusing solely on this region is crucial. The paper highlights the achievements and future challenges the region faces in its quest for more sustainable energy.

2. Theoretical framework

The ecological critique of contemporary economics has pointed out that the economy considers nature as an objective variable, i.e., an unlimited space and territory. Therefore, it justifies the extensive exploitation of resources without considering their exhaustibility or the social and cultural impact. The consequence of this form of natural resource extraction has generated adverse effects on the environment, which has led to the creation and implementation of various answers to address the environmental crisis (Georgescu-Roegen, 1996). Studies have examined various regions and countries to compare and analyze environmental indicators, including energy efficiency. The following subsections describe two models used to establish environment indicators. Afterwards, a literature review on energy efficiency and destination is presented.

2.1. Models related to environment indicators

As stated above, one of the main models used to systematize the information regarding environment indicators is the Pressure-State-Response Model (PSR) (Pino Neculqueo, 2002) created at the end of the 1980s, which was adopted and disseminated by the OECD. It explains that human activities, directly and indirectly, exert “pressures” on the environment, which affect the quality and quantity of available natural resources “state”. The population responds to these pressures by adopting environmental, economic, and sectoral policies becoming aware of the actions taken, which translates as “responses”. The model serves as an advantage to identify the pressures, states, and responses on behalf of decision-makers and society, even though there is a direct proportion between the environmental actions carried out in terms of their impact, as well as the link between environment and economy (OECD, 1993).

This model has been adapted according to the degree of precision and particular characteristics of environmental settings. As an example, the driving force-state-response model used by the United Nations (United Nations, 2001) is considered, using sustainable development indicators (Polanco, 2006).

The European Environment Agency (EEA) created a slightly more complex analysis framework than the previous OECD model called the Driving Force-Pressure-

State-Impact-Response (DPSIR) model (Aguirre Royuela, 2002). It is based on a sequential evolution in which social and economic development generates pressures on the environment, which give rise to different changes in the state of the environment. The consequence of these changes is the impact on health, availability of resources, and natural ecosystems, among others. This provokes society to seek answers from decision-makers and public authorities to improve economic and social management, in addition to the reduction of pressures, in order to restore and recover the environment and correct the impact caused on it. Thus, the model incorporates environmental and social economic agents as responsible (driving forces) in conjunction with the harmful effects on the health and development of human beings, the environment, society, and the economy (impacts).

Consequently, both models mentioned above enable promoting indicator systems that fully contemplate the environmental problems studied. This is through the relationships between causes, effects, and/or consequences (Aguirre Royuela, 2002).

2.2. Energy efficiency and destination

Energy efficiency refers to optimizing energy use to reduce resource consumption and minimize the environmental impacts of energy production and use. On the other hand, energy destination refers to the way in which energy is used, i.e., for what it is used. For example, energy use can be residential, commercial, industrial, and transportation, among others. Energy efficiency and destination are essential to achieve sustainable use of energy resources and reduce greenhouse gas emissions (Fornillo, 2017). In Latin America, there are sustainability certifications related to energy efficiency, and it is suggested that governments in the region consider the existence of public certifications in this area. In addition, it is mentioned that an opportunity for governments in the region is to negotiate agreements for the homologation of national certifications with international certifications accepted in export destination markets, which should include certifications related to energy efficiency and destination (Araya and Correa, 2023).

Studies such as Carpio and Coviello (Carpio and Coviello, 2013) and Inter-American Development Bank (Banco Interamericano de Desarrollo, 2017) attempt to show the progress in the policy framework on the subject, highlighting the new key actors in energy efficiency and their effective role; resources and financing mechanisms for energy efficiency programs; programs and their results; the barriers that remain in place, both general and specific to each country of study; and lessons learned in the development of national programs and/or activities in energy efficiency.

Regarding the environmental crisis and sustainable development, the use of renewable energies has been promoted to generate electricity and reduce CO_2 emissions (Bersalli et al., 2020). As stated by Bersalli et al. (2020), Europe pioneered the implementation of policies that encourage the incorporation of renewable energies, and nowadays, there are strong policies that encourage the use of these kinds of energies. On the contrary, the authors indicate that Latin America has a more recent approach to the creation of policies in renewable energies, which have been introduced to the region due to the decrease in the costs of technology needed to implement renewable energy (Bersalli et al., 2020). Furthermore, because of its relative novelty, the researchers identify a gap in evaluating those policies in Latin America, highlighting the importance of data-based studies that contribute to these evaluations.

Also, it should be noted that even when renewable energies are increasing in different countries, CO_2 emissions are still a significant issue in environmental degradation (Kartal, 2022; Sadiq et al., 2023), especially considering nations that maintain high levels of CO_2 emissions. Therefore, to understand the effect of different energy sources in this matter, such as fossil fuels and renewable sources, Kartal (2022) has conducted a study in the top five countries with the highest levels of CO_2 emissions., i.e., USA, China, India, Japan, and Russia. The author concluded that the use of fossil fuels (coal, oil, and natural gas) and the high production of carbon in these countries determine the emissions of CO_2. To reverse this effect, Kartal proposes encouraging the use of renewable energy sources.

In other regions, such as South Asian countries, Sadiq et al. (2023) found a relation between the increment of the Gross Domestic Product, the globalization index, and the use of non-renewable energy. The researchers state that there is a relationship between economic growth and the use of this kind of energy, which impacts environmental degradation. In the case of South Asian nations, it seems that economic growth depends on "industrialization, globalization, and trade liberalization", which implies the use of fossil fuels. This situation has had a negative impact on the environment in the region, highlighting the need to implement policies that control CO_2 emissions (Sadiq et al., 2023).

As can be seen in the articles described (Bersalli et al., 2020; Kartal, 2022; Sadiq et al., 2023), although renewable energies are developing, non-renewable energies and fossil fuels still impact CO_2 emissions. A specific analysis of each country and region is necessary to understand the reasons for using non-renewable energies. Focusing on the reality of each region can contribute to the design and implementation of policies that diminish environmental damage.

3. Materials and methods

Several databases extracted from the Economic Commission for Latin America and the Caribbean (ECLAC) were available for the area of production and consumption of energy from renewable and non-renewable resources in Latin America and the Caribbean. The measurements, during the period from 2015 to 2020, involve:

- Share of renewable primary energy supply. 4898 records were analyzed and measured as percentage.
- Energy intensity by economic activity. 3137 records were analyzed and measured in Tons of oil equivalent per thousands of constant 2010 dollars.
- Installed capacity to produce electricity by source. 2659 records were analyzed and measured in megawatts.
- Renewable proportion primary energy supply. 1438 records were analyzed and measured as a percentage.
- Renewable share of primary energy supply (REN_PRIM).
- Renewable non-combustion shares of primary energy supply (REN_NC_PRIM).
- Renewable share of total energy supply (REN_OF_TOT).
- Renewable share of renewable energy in total final energy consumption

(REN_CON_TOT).
- Fossil fuel subsidy (SUBS_FOS).

The records of countries with missing data in no more than two analysis periods were considered, imputing the missing data by linear regression. Thus, a dataset was constructed with 24 countries in the Proportion of renewable primary energy supply, 28 in energy intensity by economic activity, 21 in installed capacity to produce electricity by source, and 28 in Renewable Proportion of primary energy supply by type.

In addition, figures from the Renewable Energy Statistics 2023 of the International Renewable Energy Agency (IRENA) were used, involving the following regions: Africa, Asia, Central America and the Caribbean, Eurasia, Europe, Middle East, North America, South America, and Oceania. The following variables were considered:

- Installed capacity of electric power production by type of source. It is measured in MW.
- Electrical energy production by type of source. It is measured in GWh.
- Calculated efficiency measured in percent.

Statistical methodology

1) Multivariate analysis

Within the analyses, the treatment of multivariate data was considered through biplot methods, visualizations capable of showing more than two variables and multiple individuals in a two-dimensional graphical representation based on the principal components established in the decomposition matrix that is decided to be used (Gabriel, 1971).

In these displays, the variables are represented by vectors or arrows pointing in the direction of growth of the variable. The length of the variable represents its variability, thus indicating that angles close to 0° or 360° present strong direct correlations, those close to 180° present strong inverse correlations, and angles close to 90° present independence. In addition, individuals will be better represented by a variable as they are closer to the vector that represents it, and the orthogonal projections to them can give a reference of the value above or below the mean in terms of the proportion of the standard deviation.

Depending on the factorization performed in the decomposition of the multivariate data, a better quality of representation of the variables or individuals in the graphical representations can be obtained. Galindo developed the HJ-Biplot method, which is based on maximum quality of representation for variables and individuals in the same visualization (Galindo-Villardón, 1986).

Using the R package 'dynBiplotGUI,' we can access an interface for applying the Biplot methods dynamically, allowing us to establish data in three ways (variable, individual, and moment) that allow us to represent the trajectories and evolution of variables or individuals at different stages of an analysis period with the visualization of the period that we estimate as a reference. For this study and by default of the tool, the latest data of our study dataset will be used (Egido Miguélez, 2015).

As shown in **Figure 1**, we will be able to identify trajectories of variables or individuals in the periods of analysis, establishing which variables best represented an individual over time.

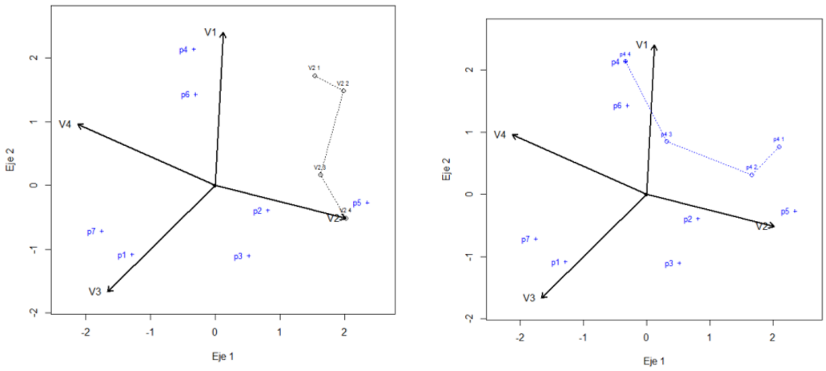

Figure 1. Dynamic biplots, trajectories of variables and individuals.

Static biplots, in essence, are an excellent tool for visualizing multivariate data. Thus, if a reasonable variance is explained, robust and visually interpretable conclusions can be drawn from larger volumes of data and variables. On the other hand, adding the dynamics over specific data periods also allows us to visualize how the variables and movement of individuals behave over time under the set of analysis measures, with reliable and interpretable three-way (variable, individual, and period) visualizations. Biplots were chosen considering the relationships and comparisons sought in the analysis variables, considering the evolution through specific periods of nations and regions regarding sustainability.

2) Normality test

The Shapiro-Wilk test presents as a null hypothesis the behavior according to a normal distribution of a variable, being the test statistic

$$W = \frac{\left(\sum_{i=1}^{n} a_i\, x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{1}$$

where

$x_{(i)}$ is the number occupying the *i*-th position in the sample ordered from smallest to largest.

$\overline{x}$ represents the average of the variable or sample mean.

The variables a_i are calculated

$$(a_1, \dots a_n) = \frac{m^T V^{-1}}{(m^T V^{-1} V^{-1} m)^{1/2}} \tag{2}$$

where $m = (m_1, \dots, m_n)$ where $m_1, \dots, m_n$ are the mean values of the ordered statistic of independent and identically distributed random variables sampled from normal distributions, and V denotes the covariance matrix of that order statistic.

The hypothesis of normality will be rejected if the value of the statistic is too small (Shapiro and Wilk, 1965).

3) Correlation analysis

Depending on the fulfillment of the assumptions of normality for our variables of analysis, it is prudent to use Spearman’s correlation coefficient for variables that do not reject normality (Martínez Ortega et al., 2009). This coefficient interprets strong direct correlations when it is close to 1 and strong inverse correlations when it is close to −1, in the same way that when the coefficient is close to 0, it is evidence of independence between variables. The statistic is calculated using the formula

$$r_s = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \tag{3}$$

4. Results and discussion

Figures 2 and **3** show the share of renewable primary energy supply by type of source. They explain 73% of the variance of the data using 2019 as the baseline structure, marking an excellent quality of representation in the period.

In **Figure 2**, we can observe that the annual trajectory of the sources does not present significant variations concerning the representation by country. Nevertheless, it presents a strong inverse correlation between the share of renewable energy from firewood and hydro-energy, which in turn presents remarkable independence with the source of sugarcane and derivatives.

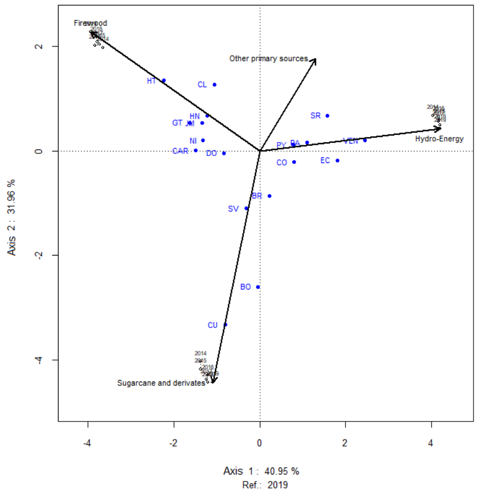

Figure 2. Share of renewable primary energy supply (requiring or not requiring combustion) by type of source (Var).

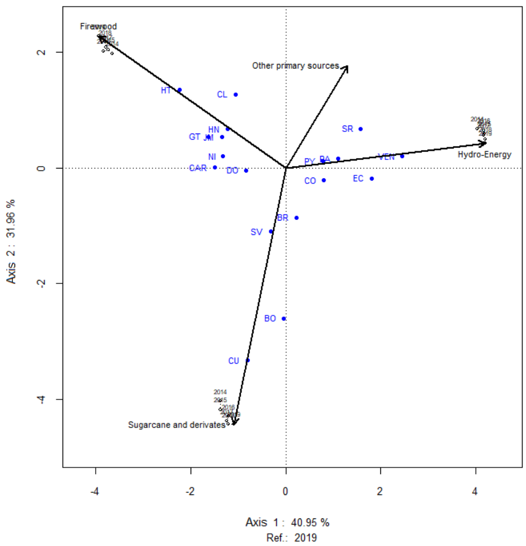

Figure 3. Share of renewable primary energy supply (requiring or not requiring combustion) by type of source (Country).

In **Figure 3**, we can observe the trajectories of the shares by source for each country, noting that in the period 2014 to 2019, most countries with a filter greater than 50% of inertia do not present significant variations except for Jamaica. This country has presented a notable variation from the sugarcane source to firewood in the years of the analysis.

It should also be noted that the countries that predominate in sugarcane and derivatives as primary renewable energy supply are Cuba and Bolivia, which are better represented in this variable.

Figures 4 and **5** present the Energy Intensity by economic activity under the unit of tons of oil equivalent per thousands of constant 2010 dollars (Final energy consumption/Aggregate value of economic activity in constant 2010 dollars). They explain 66% of the variance of the data equally distributed in factorial components one and two, ensuring a good representation and considering an inertia filter of 60%.

In **Figure 4**, we can observe the trajectory of the variables in the period 2015 to 2019, where it is observed that the energy intensity of the commercial activity and industry has suffered notable positive variations in the period of analysis. Likewise, the energy intensity of the activities of agriculture, fishing, and mining suffered positive variations. On the contrary, in the transport activities, the energy intensity has not had significant fluctuations according to the context of countries.

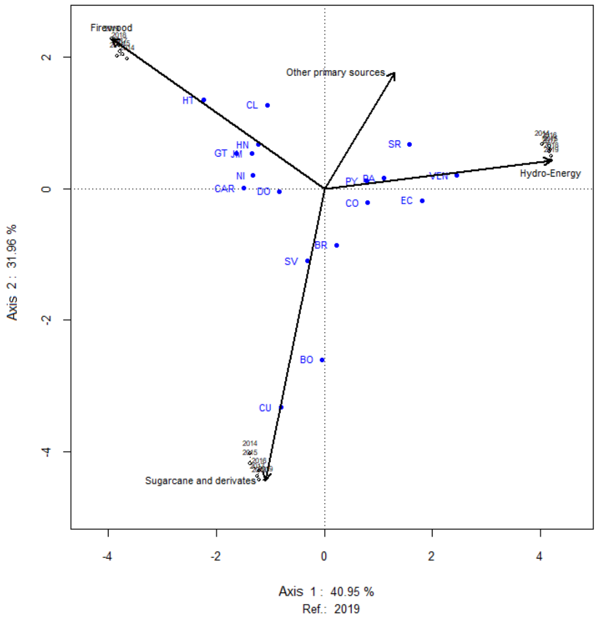

Figure 4. Energy intensity by economic activity (VAR).

Figure 5 shows the trajectory of the energy intensity of the activities by country, where we can observe an intense movement of Venezuela towards the industrial and commercial sector, dominating in these activities. In addition, Jamaica is well represented in the agriculture, fishing, and mining variables, and Guyana has undergone slight variations in energy intensity in the transport activity towards the commercial and industrial.

Within the group of countries, there are no major variations other than those mentioned. Latin America and the Caribbean, in general, are not presented in the graph given the inertia filter, so they do not present significant variations in the analysis period.

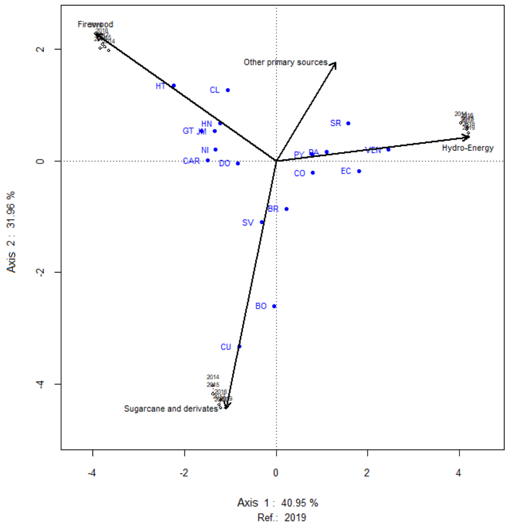

Figure 5. Energy intensity by economic activity.

Figures 6 and **7** show the installed capacity to produce electricity by source measured in megawatts. They explain 98% of the variance, with an excellent quality of representation. It is worth noting that most are distributed in the first factorial axis, so that the horizontal variabilities are conclusive in the representation. However, due to the little variability absorbed in the second factorial axis, no solid conclusions can be obtained about the vertical variabilities.

Figure 6 shows the variability of the sources in the period 2015 to 2020. It can be noted a substantial increase in the installed capacity to produce energy from all of them. It presents minimal changes in the capacity from renewable thermal, non-renewable thermal, geothermal, nuclear, and hydroelectric sources, but substantial positive variations of practically one standard deviation in the sources installed capacity to produce electricity from wind and solar sources.

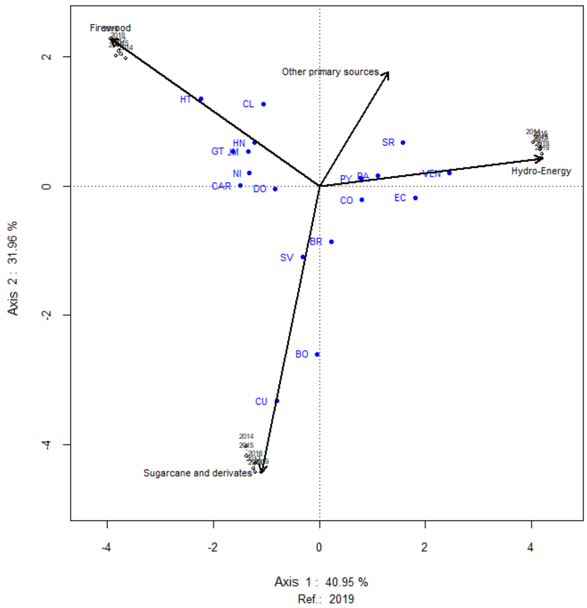

Figure 6. Installed capacity to produce electricity by source (VAR).

Figure 7 shows the trajectory in the analysis period for Latin American countries, establishing an inertia filter of 60%. In addition, **Table 1** shows a notable increase in installed capacity to produce electricity in Brazil, mainly supported by increases in solar and wind sources, which places it with wide variations in the first quadrant of the illustration.

Table 1. Installed capacity for electricity production in Brazil.

Year	Wind	Hydroelectric	Nuclear	Solar	Thermal Non-renewable	Thermal renewable
2015	7633	91,650	1990	31	26,307	13,257
2016	10,129	96,925	1990	85	27,146	14,147
2017	12,293	100,319	1990	1096	27,165	14,716
2018	14,400	104,198	1990	2360	25,737	14,824
2019	15,388	109,155	1990	4465	26,246	15,036
2020	17,146	109,294	1990	7934	27,769	15,383
Variation	124.64%	19.25%	0.00%	25,210.03%	5.56%	16.04%

Source: Own elaboration.

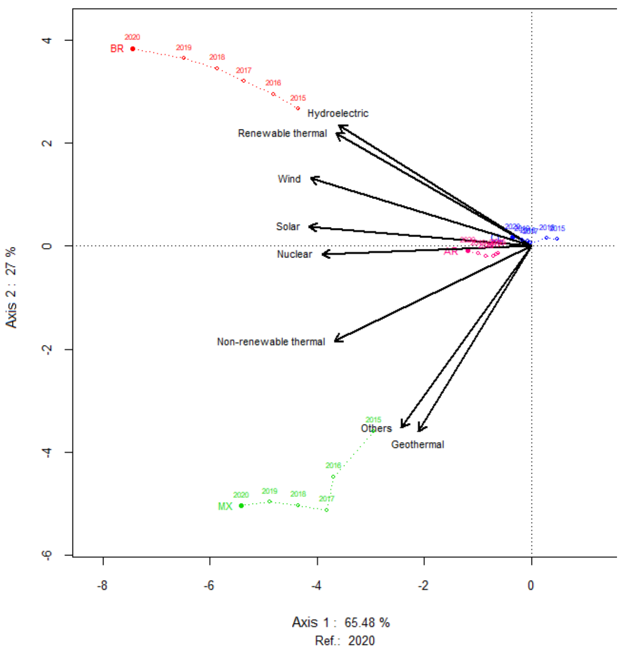

Figure 7. Installed capacity to produce electricity by source (Countries).

Similarly, **Table 2** shows a substantial growth in Mexico's capacity to produce electricity, with a predominant increase in non-renewable thermal sources, geothermal, and other sources, which, in terms of the standard deviation of the variable, are the ones that show the greatest variation in this country.

Finally, in general terms for Latin America and the Caribbean, **Table 3** shows the overall increase in installed capacity to produce electricity in practically all sources except nuclear, with significant incremental variations in wind and solar energy sources.

Table 2. Installed capacity for electricity production in Mexico.

Year	Wind	Geo thermal	Hydro electric	Nuclear	Other	Solar	Thermal Non-renewable	Thermal renewable
2015	2805	884	12,489	1510	131	56	48,801	1350
2016	3735	909	12,589	1608	262	145	52,331	1931.61
2017	3898	899	12,612	1608	374	171	47,166	1322
2018	4866	899	12,612	1608	375	1878	49,011	1709
2019	6050	899	12,612	1608	375	3646	51,547	1710
2020	6504	951	12,612	1608	378	5149	53,614	2305
Variation	131.87%	7.58%	0.98%	6.49%	188.55%	9094.64%	9.86%	70.74%

Source: Own elaboration.

Table 3. Installed capacity for electric power production in Latin America and the Caribbean.

Year	Wind	Geo thermal	Hydro electric	Nuclear	Other	Solar	Thermal Non-renewable	Thermal renewable
2015	13,795	1509	172,203	5255	138	1420	160,305	17,941
2016	18,037	1524	182,186	5353	269	2491	169,168	19,845
2017	21,089	1604	186,385	5353	381	5116	165,796	20,125
2018	25,229	1597	191,206	5353	382	8856	169,800	20,572
2019	28,883	1654	196,539	5353	382	13,736	172,648	21,041
2020	32,552	1704	197,020	5353	385	20,007	177,718	22,292
Variation	135.97%	12.89%	14.41%	1.86%	179.18%	1308.67%	10.86%	24.25%

Source: Own elaboration.

Figures 8 and **9** show the dynamics of biplots on the Renewable share of primary energy supply (REN_PRIM), Renewable non-combustion share of primary energy supply (REN_NC_PRIM), Renewable share of total energy supply (REN_OF_TOT) and Renewable share of total final energy consumption (REN_CON_TOT). They explain 87% of the variance, ensuring an excellent quality of representation in the first two factorial axes. In addition, an inertia filter of 60% was considered in the visual element, eliminating the countries with low variability from the visualization.

Figure 8 shows the trajectories of the variables from 2015 to 2020, which did not present an inertia filter, and it can be observed that they did not suffer significant variations in the analysis period.

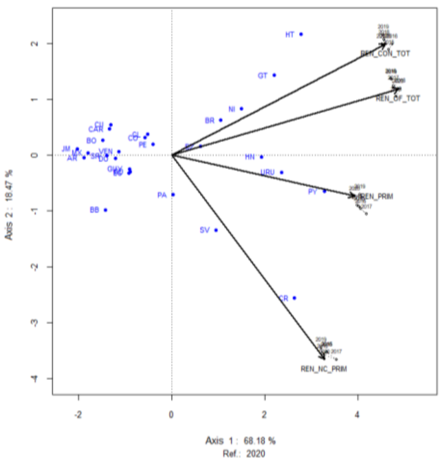

Figure 8. Renewable share of energy supply.

In **Figure 9**, we can observe the trajectories of the countries in the period of analysis, observing clear mobilities in the cases of Panama, Uruguay, and Honduras, which migrated their shares. Panama suffered a considerable decrease in the renewable share of primary energy supply that does not require combustion of more than 7 percentage points (**Table 4**).

Table 4. Change in Panama's renewable share of energy supply.

Year	REN_PRIM	REN_NC_PRIM	REN_OF_TOT	REN_CON_TOT
2016	83.2002	58.389	23.08516375	22.1
2019	40.6115	27.166	17.21027404	18.91
2015	80.6598	55.4196	23.5986572	21.9
2017	94.9678	68.9135	23.67160891	23.6
2020	48.7743	34.0453	24.90469199	28.43
2018	75.5343	56.1274	24.35517546	24.44
Variation	−7.6659	−2.2616	1.270011713	2.34

Source: Own elaboration.

Similarly, **Figure 9** shows that Uruguay suffered slight decreases in the renewable share of the total energy supply but slight increases in the other shares. The notable increase in the renewable share of primary energy supply in 2017 and subsequent regulation within the country's historical standards stand out. It would be prudent to analyze the causes of this consecutive increase and decrease of more than 20 percentage points observed in **Table 5**.

Table 5. Variation of the renewable share of Uruguay's energy supply.

Year	REN_PRIM	REN_NC_PRIM	REN_OF_TOT	REN_CON_TOT
2019	60.9322	51.9508	59.28621124	59.34
2016	59.121	49.5305	58.63346379	60.32
2015	60.9949	50.6441	57.53329204	59.4
2018	59.0878	49.429	59.12325725	60.83
2017	83.3695	70.2767	60.78135158	60.82
2020	61.1278	51.9929	59.12534996	61.09
Variation	0.1956	0.0421	−0.160861281	1.75

Source: Own elaboration.

Table 6 shows the normality tests for the variables in the following analysis, where we observe that none of the five variables meets the normality assumption, so we will calculate the correlation analysis using Spearman's coefficient.

- Renewable share of primary energy supply.
- Renewable non-combustion shares of primary energy supply.
- Renewable share of total energy supply.
- Share of renewable energy in total final energy consumption.
- Fossil fuel subsidy.

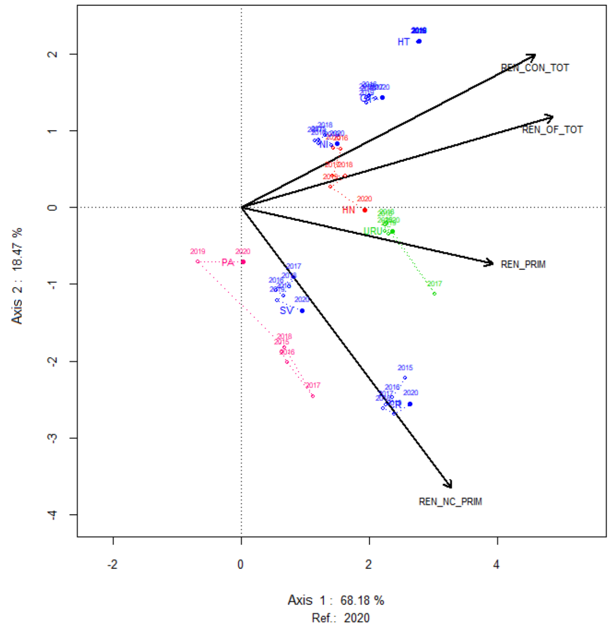

Figure 9. Renewable share of energy supply.

Table 6. Normality test.

Variable	Statistic	*p*-value
REN_PRIM	0.8243	6.07×10^{-10}
REN_NC_PRIM	0.71946	2.20×10^{-16}
REN_OF_TOT	0.89496	1.51×10^{-6}
REN_CON_TOT	0.89874	2.50×10^{-6}
SUBS_FOS	0.44623	2.20×10^{-6}

Source: Own elaboration.

Figure 10 shows the correlation graph of the variables mentioned above. It can be seen that Spearman's correlations are significant among the variables of the first analysis and show a slight inverse correlation between the percentage of GDP subsidized to fossil fuels and the renewable share of primary energy supply.

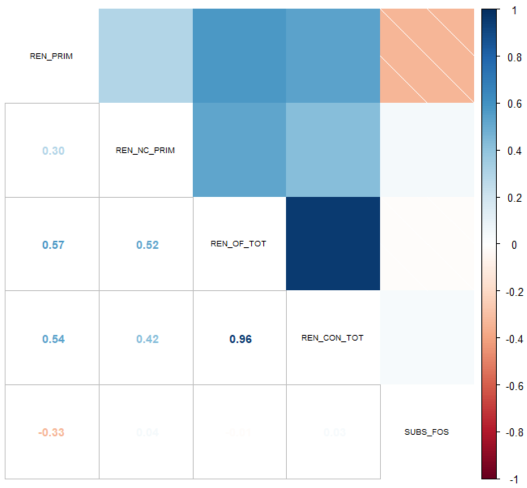

Figure 10. Correlation plot.

In **Figure 11**, we can see that this inverse correlation has become weaker over the years in the analysis period, tending slightly towards independence that could be accentuated over the years. It is important to note that the correlation of magnitude 0.3 is considered a weak but never negligible inverse correlation, which suggests an in-depth analysis considering that the energy demand grows in a general and constant manner over the years but must be directly related to the consumption of electric energy and the share of this generated by clean and non-combustion energies.

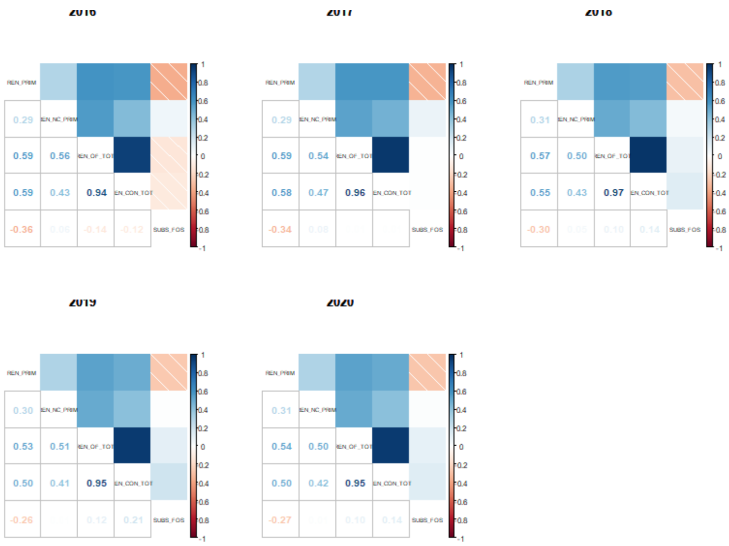

Figure 11. Correlations by year.

Table 7 shows a clear increase in the share of renewable energy that does not require combustion of the primary energy supply during the analysis period, also indicating a significant downward trend in 2020 towards the subsidy of fossil fuels.

Table 7. Variation in the share of renewable energy supply in Latin America.

Year	REN_PRIM	REN_NC_PRIM	REN_OF_TOT	REN_CON_TOT	SUBS_FOS
2015	50.820	16.386	28.551	28.830	0.512
2016	50.689	16.525	28.000	28.762	0.527
2017	53.015	18.113	28.704	29.467	0.543
2018	51.849	17.408	28.793	29.452	0.676
2019	50.845	16.375	27.900	28.426	0.686
2020	52.638	18.572	30.232	30.648	0.406
Total	51.643	17.230	28.696	29.264	0.558
Variation	1.817	2.185	1.682	1.817	−0.106

Source: Own elaboration.

With more than 96% of the variance explained, **Figure 12** provides a good quality of representation of the installed capacity to produce electricity in each region, measured in MW.

A consistent increase is observed in 2013–2021 in the installed capacity to produce electricity through renewable sources in Asia. A similar situation, in smaller magnitude and not in all sources, is observed in the case of Europe, where marine sources and bioenergies predominate.

In addition, it is observed that the installed capacity of energy production through marine sources has remained stagnant in the period, unlike bioenergy, wind, and solar sources, which have had substantial growth. On the other hand, Geothermal and Hydroelectric sources have grown to a lesser extent.

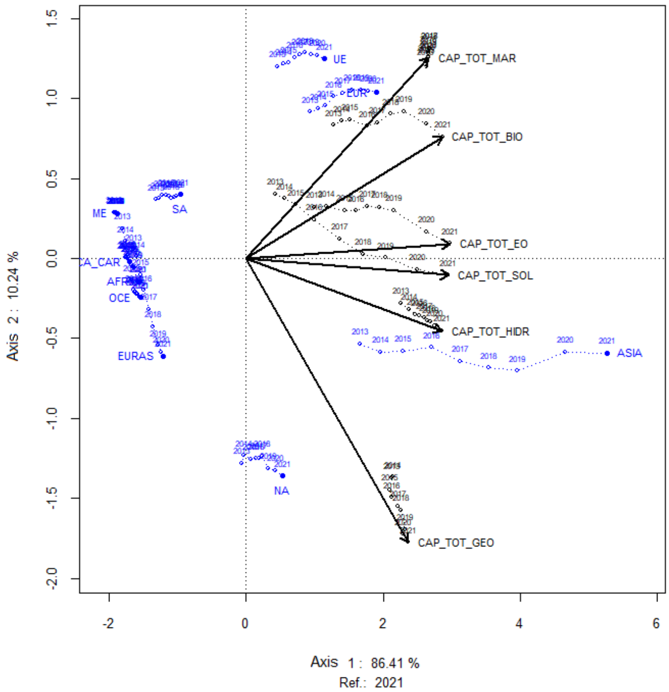

Figure 12. Installed capacity to produce electric energy (MW).

With more than 95% of variance explained, **Figure 13** shows a good quality of representation of the production of electricity from renewable sources. In the period 2013–2021, in Asia, a consistent increase in electricity production through renewable sources is observed. A similar situation is detected in the European case, but to a lesser extent and not in all sources. In this region, marine sources and bioenergies prevail.

Moreover, it is observed that the production of energy through marine sources has remained at a standstill during the period, unlike wind and solar sources, which have grown substantially. Regarding bioenergy, geothermal, and hydroelectric sources, they have grown to a lesser extent.

Regarding the Asian continent, the comparison between **Figure 12** and **13** shows that the increase is greater in energy production than in installed capacity, which suggests that in the period under analysis, the Asian continent has made efforts to improve its energy efficiency.

With more than 75% of variance explained in 2021, **Figure 14** shows a high efficiency of Bioenergy and Marine sources in the regions of the European Union, Europe, Asia, and Oceania, compared to the average of the continents.

In addition, efficiency in wind and solar sources is highlighted in the case of Central America, Eurasia, Africa, North America, and South America, which stand out compared to average efficiency.

Concerning hydroelectric and geothermal sources, all continents are observed to be close to the average. These results suggest that, in terms of energy efficiency, all continents are similar.

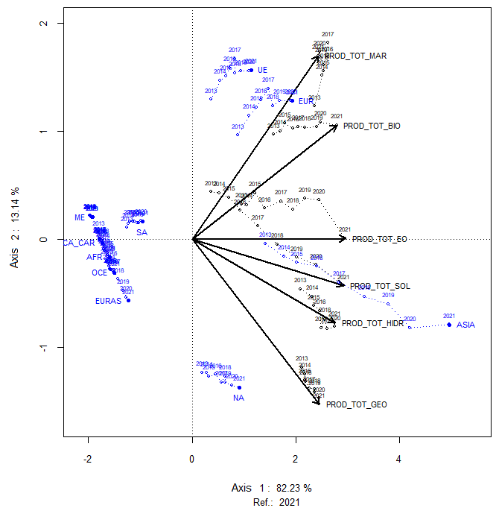

Figure 13. Energy production by type of source and region (GWh).

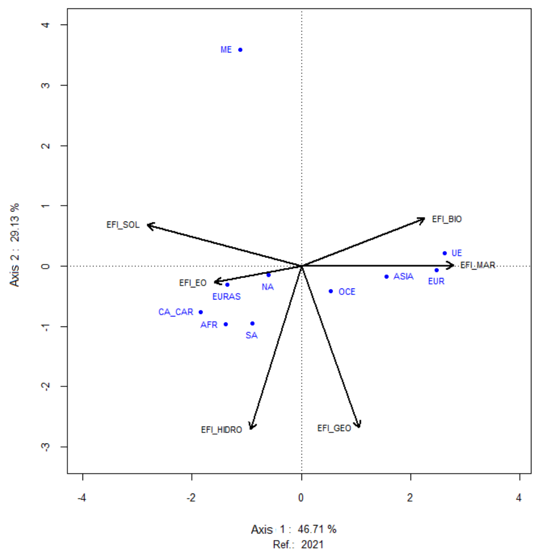

Figure 14. Energy efficiency by type of source and region.

5. Conclusions

According to the dynamic analysis of principal components and the correlations presented in terms of subsidy percentages and renewable share of energy supply, it is observed that in the period of analysis in Latin America there has been a migration from primary renewable energy sources to clean and renewable energies, such as hydroelectric power, subtly but steadily displacing combustion energies. This trend can be justified by the 136% growth in installed capacity to produce electricity through wind energy and a 1309% growth through solar energy. In addition to this, there have been considerable but smaller increments in the production of electricity through geothermal and thermal sources.

In addition, there has been a strong increase in the energy intensity of agricultural, fishing and mining activities, as well as industry, even when these are inversely correlated. This evidence the profound growth in energy consumption, mainly electricity, at the Latin American level. The situation supports and demands a profound effort in the studies and analyses that must be considered in terms of clean and renewable energies for a sustainable future.

It should also be noted that, within the shares of renewable energy consumption, the share of renewable energy that does not require combustion of the primary energy supply is the one that shows the highest percentage increase in recent years, evidencing a subtle trend toward an inverse correlation with the subsidy to fossil fuels in percentage terms of GDP. The above shows the trends in Latin America, in general terms, towards the consumption of clean energies and the decrease in the consumption and subsidy of fossil fuels for energy production.

Finally, it is concluded that:

- Renewable energy has experienced significant growth in the Latin American and Caribbean region, with an emphasis on sources such as wind and solar. This kind of energy grew by 136% and 1309%, respectively, in the installed capacity during the period under analysis.
- Although the supply of renewable energy has grown, some countries still have a significant dependence on non-renewable sources. These sources accounted for more than 70% of the energy supply in the period under analysis.
- Energy intensity in different economic sectors has varied over time, with increased consumption in sectors such as industry and commerce.
- Installed capacity for electricity production has raised considerably in the region, reflecting a growing focus on diversification of energy sources.
- Correlations between renewable energy shares and fossil fuel subsidies indicate a complex and changing relationship between these factors. Moderate inverse relationships are observed with indicators of −0.33.
- Despite the growth in renewable energy, it is essential to continue monitoring and promoting its development to achieve greater energy sustainability in the region.

Overall, these results provide valuable insight into the evolution of renewable energy supply and consumption in Latin America and the Caribbean, highlighting the achievements and challenges the region faces in its quest for a more sustainable energy future. Although progress has been made toward using cleaner energies and the consumption and subsidization of fossil fuels have decreased, some countries still have a significant dependence on non-renewable sources.

The evolution of renewable energy supply and consumption in the region highlights the need to continuously monitor and promote its development to ensure greater energy sustainability. This change in the energy matrix is crucial for the sustainable development of the region and to mitigate the negative environmental impacts of human activities, aligning with ILAC's goals and global efforts for environmental sustainability.

Moreover, multivariate data analysis, such as the one presented in this article, can contribute to developing public policies and international treaties related to environmental crises since it deeply analyzes ecological dynamics and regional sustainability. Future studies should research the topic of energy efficiency indicators through an interdisciplinary approach that includes not only statistical analysis but also public policy evaluation.

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