Greenhouse Gases Emissions and Electric Power Generation in Latin American Countries in the Period 2006–2013

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Abstract. The objective of this study is to classify the group of countries that contributes to the emissions of GHG gases in relation to their electric power generation. The data used for this classification are those reported by OLADE during the period from 2006 to 2013. The results show that they were organized in four (4) clusters, dividing them into efficient and inefficient levels. In the highest efficient level is Brazil, while in the lowest efficient level are Colombia, Costa Rica, El Salvador, Panama, Paraguay, Peru, Uruguay, and Venezuela. Argentina and Mexico are in the highest inefficient level, while the rest of the Latin American countries are in the lowest inefficient level. The countries located at the efficient and inefficient levels were labeled as *most emitting countries* and *least emitting countries*.

Keywords: Latin America · Power generation · Greenhouse gases
More emitters · Less emitters

1 Introduction

Currently, the effects of global warming due to greenhouse gas (GHG) emissions are eminent. Since 1996, the investigations carried out by the Intergovernmental Panel on Climate Change (IPCC) [1] indicate that the anthropogenic action is the main cause of the average temperature increase in the planet. Although initially there was discrepancy with this hypothesis by the group known as Skeptics [3], the reports of the IPCC demonstrate that this change is *unequivocal* [2]. In this sense, among the sectors that stand out for generating the highest GHG emissions are industry, transport, and electric power generation due to the burning of fossil fuels.

The effects of GHG emissions vary in the different regions and countries of the world. Among the effects of these emissions are the lower agricultural productivity due to

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salinization and desertification of the land; extreme weather conditions and reduced availability of water; increased exposures to coastal flooding; and health risks [4]. Unlike other regions of the world, the effects recorded in Latin America have dramatically deepened in recent years, so the analysis of the causes is needed in order to compel the countries in this region to implement measures for slowing their GHG emissions down.

In most of the Latin American region there is an increase of 0.5 to 3 °C of the average temperature between the years 1901 and 2012 [2], with highest increases observed in the tropical zone of South America. The projections suggest that South America will undergo an average warming of 4 °C (range 2 to 5 °C) by the end of the 21st century, while the Central America average will be of 2.5 °C (range 1.5 to 5 °C). Additionally, both regions will experience reductions of 15% and 10% [2], respectively, in the annual average rainfalls, with a decrease in rainfall during the summer. Additional effects such as the vulnerability of the power plants during the drought periods are included since this region generally depends on the generation of hydroelectric energy, condition that affects the stability of the electrical systems. An example of these effects are the electric power outages in Venezuela during the year 2009 [5].

Therefore, it is extremely important that these countries set measures and take individual actions to control and reduce GHG emissions in order to face the consequences of climate change described in [1, 3, 4, 6]. A first approach on the way to mitigate the consequences of the problem was published by the IPCC in 1996 [1], covering all sectors including the one related to the electric power generation. In this sense, the mentioned document proposes the following conditions to reduce emissions in this sector: (i) a more efficient conversion of fossil fuels, (ii) the shift to low-carbon fossil fuels, (iii) decarbonization (reduction of carbon intensity) of fuels and exhaust gases, (iv) the storage of CO_2, and (v) the change to nuclear energy and renewable energy sources.

At the same time, energy is a key indicator of economic development of regions and countries in the absence of explicit macronomic indicators [7]. For this reason, the mission of the Latin American Energy Organization (OLADE, Organización Latinoamericana de Energía) is "to contribute to the integration, sustainable development, and energy security of the region" [8] keeping records and monitoring the main energy indicators of the countries. Consequently, Latin American countries, like other regions in the world [9], have designed and implemented policies to achieve control of and reduce their GHG emissions [9–15] and help to slow down the effects of climate change [11].

Therefore, the purpose of this paper is to classify the group of countries that present GHG emissions related to the electric power generation with the aim of establishing associations that help in the diagnoses of critical points, and the design of statistical models for carrying out further studies. To achieve this objective, the methodology pretends to create conglomerates for the 20 Latin American countries, correlating the GHG emission by electric power generation (ton/GWh), and the electric power generation (GWh), using, in both cases, the average of the data during the period 2006–2013.

Although the data used in the research were published in the OLADE Report [12] including the amounts of each gas emitted, it was necessary to calculate the amount of GHG using the Global Warming Potential (GWP) of the following gases: methane (CH_4), carbon dioxide (CO_2), and nitrogen oxide (N_2O), which are responsible for 98%

of the emissions. Once the correlation matrix is obtained, the dispersion chart is made [13], and finally, the clusters are formed [16–18].

This research is important since the clusters obtained from the 20 Latin American countries are regrouped into just two large groups of countries, the *most emitters* and the *least emitters*, with the aim of establishing associations to suggest statistical models, and for diagnosis purposes.

The following sections of the paper address to issues related to GHG emissions due to electric power generation, the applied methodology, results and discussions, and finally, the references.

2 GHG Emissions from Electric Power Generation

In general, the sources of electric power generation are classified according to their primary energy into categories named *renewable*, *non-renewable*, and others. Among these categories, the non-renewable sources are the ones using oil, coal and its derivatives for generating power, and are the main responsible for emitting GHG, particles in suspension, and nuclear waste. The rest of technologies are only responsible of the emissions resulting from the construction, which in some cases can be significant considering that these gases are not emitted in their generation phase [5]. In this sense, Table 1 shows the emissions of GHG gases per unit of production.

Table 1. GHG depending on the type of technology used to generate electricity (ton/GWh).

SOURCE	CO_2	NO_2	$S0_2$	Par	CO	Hid	Nuclear waste	Total
Carbon	1,058.2	2.986	2.971	1.626	0.267	0.102	–	1,066.0
Natural gas	824	0.251	0.336	1.176	*	*	–	825.8
Nuclear	8,6	0.034	0.029	0.003	0.018	0.001	3.641	12.3
Photovoltaic	5.9	0.008	0.023	0.017	0.003	0.002	–	5.9
Biomass	0	0.614	0.154	0.512	11.361	0.768	–	13.4
Geothermal	56.8	*	*	*	*	*	–	56.8
Wind power	7.4	*	*	*	*	*	–	7.4
Solar thermal	3.6	*	*	*	*	*	–	3.6
Hydraulic	6.6	*	*	*	*	*	–	6.6

*Traces

3 Methodology

The analysis of the clusters is a tool that helps to generate conglomerates with a high degree of similarity between their elements with the purpose of establishing structures and associations to suggest statistical models, make diagnoses, and with other purposes [15–17]. In order to conform the clusters of 20 Latin American countries, the emission values of the CO_2, CH_4 and N_2O gases are extracted from the OLADE document taking

into account the electric power generation (ton/GWh), and the annual electric power generation (GWh) reported by each country during the period of 2006–2013, both inclusive [14]. After obtaining the values emitted of each gas and their respective Global Warming Potential (GWP), the GHG value is calculated per year from 2006 to 2013 to get an average of the results. At the same time, the values of generated electric power (GWh) during the same period (2006–2013) are taken from the OLADE, calculating the average of the data (Table 2).

Table 2. Correlation matrix and P-value

		Electric power generation GWh)	GHG/electric power generation (ton/GWh)
Electric power generation (GWh)	Pearson correlation	1	0.596*
	Sig. (2-tailed)		0.006
	N	20	20
GHG/electric power generation (ton/GWh)	Pearson correlation	0.596*	1
	Sig. (2-tailed)	0.006	
	N	20	20

*Correlation is significant at the 0.01 level (2-tailed)

The clustering method is carried out by the following procedure: on the one hand, the dispersion chart is generated with the variable named *GHG emissions by electrical generation (ton/GWh)* on the axis *x*, while the variable *total electric power generation (GWh)* is located on the axis *y*. In this graph, two lines are drawn corresponding to the average values of all countries per each of the variables mentioned above. This procedure leads to obtaining four zones, each representing a group of countries, for a total of four groups of countries.

On the other hand, the research presents the correlation matrix between the variables supported by the SPSS® statistical software, which provides a significant positive correlation of +0.596, as can be observed in Table 1.

4 Results and Discussions

As shown in Table 3, the Dominican Republic, Cuba, and Chile present the highest GHG emissions per unit of energy, reporting an average of approximately 586, 503, and 460 tons/GWh in the period under study. At the other end, Paraguay, Costa Rica, and Brazil emit the lowest proportion of these emissions with approximately 0.02 and 78 ton/GWh, noting that since the total energy matrix of Paraguay is hydroelectric, supported by the Binational Itaupí, its GHG emission of 0.02 is the lowest value of all.

Table 3. Emmision of GHG by average electric power generation (ton/GWh), and total electric power generation (GWh) during the period 2006–2013 [14].

Country		Electric power generation GWh)	GHG/electric power generation (ton/GWh)
Argentina	AR	128,609.80	308.96
Bolivia	BO	7,062.50	348.12
Brazil	BR	513,575.40	78.13
Chile	CL	64,616.20	459.53
Colombia	CO	66,128.20	189.54
Costa Rica	CR	9,737.50	31.52
Cuba	CU	18,037.20	502.81
Dominican R	DO	16,156.90	585.55
Ecuador	EC	20,574.60	352.77
El Salvador	SV	5,949.60	185.13
Guatemala	GT	9,263.00	343.26
Haiti	HT	833.70	437.06
Honduras	HN	7,295.20	343.83
Mexico	MX	283,319.50	442.80
Nicaragua	NI	3,794.80	3,421.74
Panama	PA	7,865.20	282.13
Paraguay	PY	56,121.80	0.02
Peru	PE	37,448.10	229.33
Uruguay	UY	10,249.10	10,165.62
Venezuela	VE	122,588.60	247.96

The average of all the countries in the variable *GHG emissions by electricity generation* is 825 tons/GWh, while the average in the *generation of total electric power* is

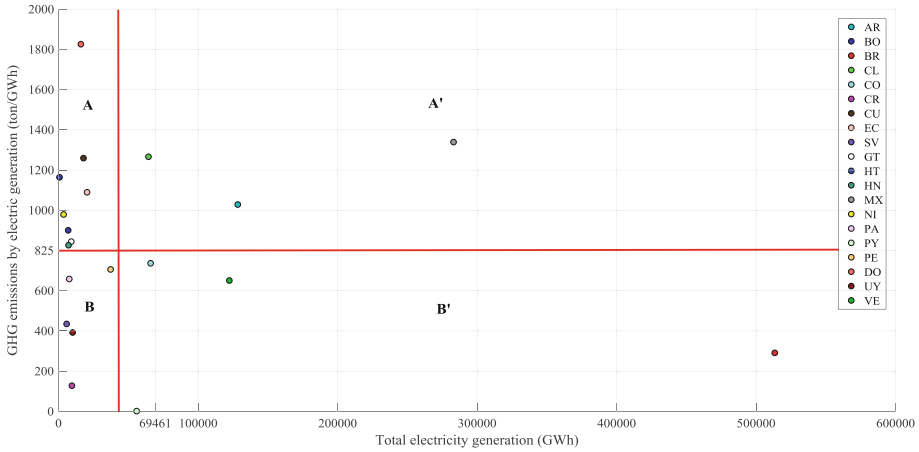

Fig. 1. Scatter chart

69,462 GWh. On these points of the scatter chart shown in Fig. 1, two lines are divided into four (4) groups or clusters of Latin American countries.

Clusters A and A′, labelled as *most emitting countries* and comprised by the countries of Argentina, Bolivia, Chile, Cuba, Ecuador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, and the Dominican Republic, report the highest GHG emissions (ton/GWh) per unit of electricity production (GWh), and an electric power generation of 40% of the region. As an average for the period under study in these countries, emissions of 1,137.10 ton/GWh are reported, for an interval between 825.03 and 1,824.52 ton/GWh. The highest value is reported by the Dominican Republic, whose energy matrix entirely depends on fossil fuels (Table 4).

Table 4. Distribution of countries by cluster.

Cluster	Description	Countries	Num. Countries	Tag
A	***Lower Inefficient Level*** Countries with a total electric power generation lower than 69,492 GWh, and GHG emissions higher than 825 ton/GWh	Bolivia, Chile, Cuba, Ecuador, Guatemala, Haiti, Honduras, Nicaragua Dominican Republic	09 (45%)	*Most emitting countries*
A′	***Higher Inefficient Level*** Countries with a total electric power generation greater than 69,492 GWh, and GHG emissions higher than 825 ton/GWh	Argentina Mexico	02 (10%)	
B	***Lower Efficient Level*** Countries with a total electric power generation less than or equal to 69,492 GWh, and GHG emissions lower than 825 ton/GWh	Colombia, Costa Rica, El Salvador, Panana, Paraguay, Peru, Uruguay and Venezuela	08 (40%)	*Least emitting countries*
B′	***Higher Efficient Level*** Countries with a total electric power generation higher than 69,492 GWh, and GHG emissions lower than 825 ton/GWh	Brazil	01 (5%)	

Cluster B, comprised by Colombia, Costa Rica, El Salvador, Panama, Paraguay, Peru, Uruguay, and Venezuela, reports lower GHG emissions (ton/GWh) per unit of electric power generation (GWh), for the period under study, with an average electric power generation of 23%. The average of GHG emissions is 462.15 ton/GWh, for an interval between 0.04 and 735.12 ton/GWh. The lowest value is reported by Paraguay, whose energy matrix entirely depends on the hydroelectric power plant.

Cluster B′, with only Brazil as representative, shows GHG emission values of 289.66 ton/GWh, much lower than the average of Cluster B, despite being the country in the region that represents 37% of the total electric power generation. This result demonstrates the diversity of the Brazilian energy sources, and non-dependence to the exclusive use of one type of primary energy. So, Clusters B and B′ are labeled as the *least emitting countries*.

The Fig. 2 shows the Ranking of Latin American countries and the GHG emissions accumulated in the region during the period 2006–2013.

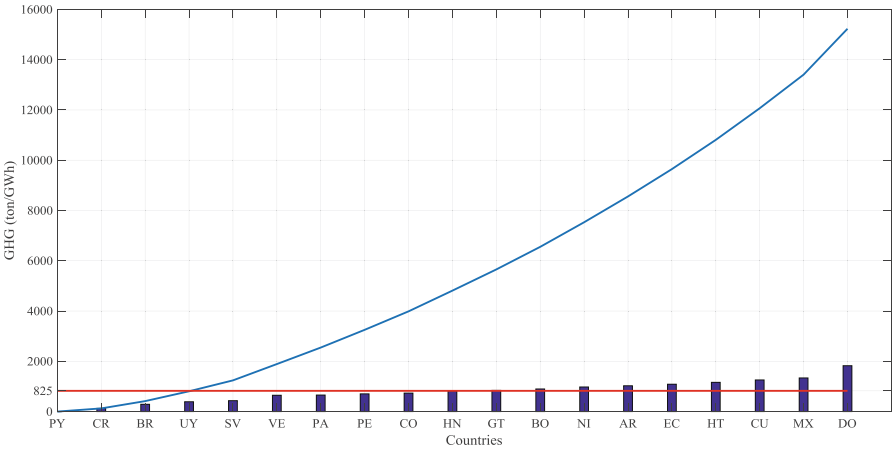

Fig. 2. Ranking of Latin American countries in terms of GHG emissions.

Figure 2 shows that the accumulated emissions in the region reach an average of 15,230 ton/GWh in the period from 2006 to 2013, both inclusive. Additionally, the first places of the countries that produce less GHG emissions are Paraguay, Costa Rica, and Brazil. On the other hand, the countries in the last positions of this ranking are Cuba, Mexico, and the Dominican Republic.

5 Conclusions

The purpose of this research is to classify the group of countries that contribute, to a greater or lesser extent, to GHG emissions, in relation to their electric power generation, with the aim of establishing associations to suggest statistical models and making diagnoses. With this purpose, a clustering is carried out for the 20 Latin American countries, correlating the GHG emission by electric power generation (ton/GWh), and electric power generation (GWh) in the period 2006–2013, both inclusive.

Four (4) clusters are obtained, divided into the efficient and inefficient levels. At the higher efficient level is Brazil, which for the period under study reported an average GHG per unit of generation of 289.66 tons/GWh, despite being the country in the region that highlights for generating 37% of the total electric power. Additionally, Colombia, Costa Rica, El Salvador, Panama, Paraguay, Peru, Uruguay, and Venezuela are at the

lower efficient level, generating 23% of electric power in the region, with GHG emissions of 462,15 ton/GWh. Countries located at the efficient level (higher and lower) are labeled as *least emitting*.

Finally, the countries located at the higher inefficient level are Argentina and Mexico, while those located at the lower inefficient level are Bolivia, Chile, Cuba, Ecuador, Guatemala, Haiti, Honduras, Nicaragua, and the Dominican Republic. The countries at the inefficient level (higher and lower) were labeled as *most emitting countries*, characterized by generating 40% of the energy in the region, and having a GHG emissions average of 11,137.10 ton/GWh, much higher than the *least emitting countries.*

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