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Article

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International Journal of Energy Economics and Policy

IJEEP

INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY

EJ EconJournals ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2018, 8(3), 197-208.

EJ EconJournals

The Data Envelopment Analysis to Determine Efficiency of Latin American Countries for Greenhouse Gases Control in Electric Power Generation

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ABSTRACT

The objective of this research is to determine the efficiency of Latin American countries for the control of greenhouse gas (GHG) emissions due to the generation of electrical energy using the Data Envelopment Analysis. A positivist epistemic position is assumed, and a methodology of evaluative character is used, comprising five (5) phases. The results show that the countries that are located on the efficient frontier have common police like the increase in the share of renewable energies, and diversification of the energy matrix, which means a better control of GHG emissions. It is possible to determine the efficiency of the public policies established by the countries of Latin America for the control of GHG emissions. In conclusion, the countries that are located on the efficient frontier are those that generate electricity with predominantly renewable sources or, at least, use natural gas as a fuel in greater proportion.

Keywords: Greenhouse Gases, Efficient Frontier, Data Envelopment Analysis
JEL Classifications: C1, Q4, Q5

1. INTRODUCTION

The dependence on traditional energy sources has stimulated the discussion about the limited and final realization of the traditional energy sources and the fossil fuels, the adverse environmental impact, and the global warming due to greenhouse gas (GHG) emissions (Mahmoodi, 2017). The control of GHG is the concern of both developed and developing countries, which suggests the creation of mechanisms to mitigate the effects of climate change, and advance towards a sustainable development. According to the investigations carried out by the Intergovernmental Panel on Climate Change (IPCC), anthropogenic action is the main cause of the temperature average increase on the Earth (IPCC, 2001), (IPCC, 2007a) and (IPCC, 2014a). Among the activities that stand out for generating the highest GHG emissions are: Industrial production, agriculture, transport and electric power generation.

To try to slow the effects of climate change, the world is moving toward a development with low carbon emissions, paying special attention to the areas with the highest GHG emission levels, as the energy supply sector, specifically in the form of generation. This sector, in conjunction with the industry sector, due to the burning of fossil fuels, emits the largest proportion of GHGs to the atmosphere (IPCC, 2014b). For this reason, governmental national plans for climate change mitigation mostly include a section related to the generation of electric power.

At the Paris Summit held at the end of 2015, each country of the world consigned a document known as Intended Nationally Determined Contributions (INDC), where they set out their public policies aimed at various sectors to mitigate climate change (UNFCCC, 2015). In the case of Latin American countries documents submitted contain general policies related to two (2) scenarios: The first of these would be the results to obtain using only the resources of each of the countries. The second scenario contemplates the results that can be obtained with economic aid and/or technology transfer on the part of developed countries and international organizations with competence (UNFCCC, 2015).

In this regard, consistent with (CEPAL, 2007), Tanaka (2011), (CEPAL, 2015), Thapar et al. (2016), it is necessary the evaluation of the policies of the energy sector in Latin American countries, which contributes to control GHG emissions produced by the power generation. This allows the countries to monitor the effect of the policies established (UNFCCC, 2015), which could be improved, changed, or maintained in the program, depending on the results obtained.

On the other hand, it is known that the Data Envelopment Analysis (DEA) is a versatile and widely used tool for the determination of relative efficiencies of units (countries, companies, departments, among others) in diverse areas of interest in both industrial sector and the academic-scientific field (Coll & Blasco, 2006), which has been used previously by the authors at Viloria et al. (2009) and Sánchez et al. (2017).

The assessment the efficiency of public policies created by the energy sector to control GHG emissions in Latin America allows countries to measure their performance at a national and international level in order to verify if they are efficient in the control of such emissions without ceasing to be productive in the generation and rational use of energy, and maintaining or increasing the quality levels in the provision of electric service to citizens.

For all the above, the objective of this research is to determine the relative efficiencies of Latin American countries in the control of greenhouse gas emissions due to the generation of electrical energy, using the DEA as a tool.

2. LITERATURE REVIEW

2.1. Global Warming and Electric Power Generation

According to the IPCC, the last two (2) decades of the 20th century and the first decade of the 21st century have been successively warmer on the surface of the Earth (IPCC, 2013a) than any previous from 1850. According to the IPCC (IPCC, 2013a), global warming is unequivocal. The atmosphere and the ocean have warmed up, the volumes of snow and ice have decreased, the sea level has risen, there has been an accelerated melting of the glaciers (since 1970), essentially the intertropical ones which have lost between the 20% and the 50% of its ice mass. In addition, the number and strength of climatic events have increased with large-scale human and economic losses, growth of the frequency of torrential rains that later became landslides and flooding. According to the IPCC (IPCC, 2013b), this is the result of the increase of GHG concentrations in the atmosphere.

The projections of the IPCC regarding global warming, far from being conservative are dramatic. It is urgent that international agreements can be made where countries are committed to reduce GHG emissions to offset the increase in global temperature and its effects on the environment. The impact generated by GHGs is now visible and will raise over time if the threshold of 2°C is exceeded by the end of the century (Bono, 2008). The most studied and referenced effects are: Less agricultural productivity due to the salinization and desertification of agricultural land, increased water insecurity, greater exposure to coastal flooding, extreme climatic conditions, and increased health risks (Bono, 2008). Coral reefs and regional fisheries will also be affected and will cause displacement in the location of schools of fish in the South, and East Pacific (Conde & Saldaña-Zorrilla, 2007). Since the effects of GHG emissions on the environment are extensive, a comprehensive review should refer to the IPCC document (IPCC, 2007b).

To face the disastrous consequences of climate change described in (IPCC, 2007b), it is necessary to establish measures that allow the control of GHG emissions from the individual actions of the countries. A first approach to mitigate climate change was published by the IPCC in 1996 in its report called "Technologies, policies, and measures to mitigate climate change" (IPCC, 1996). This document involves all productive sectors, the field of residential, commercial, and institutional buildings, transport, industry, agriculture, forestry sector, and environmental treatment through the elimination of solid waste and wastewater, and the energy supply sector.

The energy supply sector refers to all the stages related to the generation, transport, and consumption of electricity. However, the one that emits the greatest proportion of GHG is the generation of electric power with fossil fuel-based plants (IPCC, 2014b). CO_2 emissions from burning fossil fuels and industrial processes contributed to the 78-80% increase in total of GHG emissions from 1970 to 2010 (IPCC, 2014b).

It is truly alarming that the IPCC establishes (IPCC, 2014b) that about half of the accumulated emissions of CO_2 between 1750 and 2010 have occurred in the last 40 years. In this way, the cumulative emissions of CO_2 from the burning of fossil fuels, cement production and, flare combustion since 1750 were 420 ± 35 $GtCO_2$; In 2010, this accumulated total tripled to 1300 ± 110 $GtCO_2$.

Annual anthropogenic GHG emissions have increased by 10 GtCO2eq between 2000 and 2010, an increase that corresponds directly to the sectors of energy supply (47%), industry (30%), transport (11%) and the buildings (3%). Of the 49 (± 4.5) GtCO2eq issued in 2010, 35% (17 GtCO2eq) of GHG emissions were released from the energy supply sector, 24% (12 GtCO2eq, net emissions) in AFOLU (Agriculture, Forestry, and other Land Uses), 21% (10 GtCO2eq) in industry, 14% (7.0 GtCO2eq) in transport and 6.4% (3.2 GtCO2eq) in buildings. The emissions derived from electricity and thermal production are attributed to the sectors that use the final energy, that is, indirect emissions, the proportions of the sectors of industry and buildings to the global emissions of GHG increase to 32 and 19%, respectively.

In this regard, the IPCC proposes the following technology improvements to reduce GHG emissions in the energy supply sector: More efficient conversion of fossil fuels; the shift to low carbon fossil fuels; the decarbonization (reduction of carbon intensity) of fuels and exhaust gases, the storage of CO_2, the change to nuclear energy, and the change to renewable energy sources (IPCC, 1996).

2.2. The DEA

DEA is a tool that emerges from previous studies by Farrell (1957), in which a measure of productive efficiency is made on US agricultural production by means of the resources used (inputs) (Coll & Blasco, 2006). After Farrell, between 1962 and 1968, several contributions were made to this tool (Seiford, 1996), allowing it to consolidate as a wide-ranging technique in the measurement of efficiencies in various areas.

According to Coll & Blasco (2006), technical efficiency is the ability of an individual firm (country, company, etc.) to obtain the maximum outputs from a given set of inputs and is obtained by comparing the observed value of each individual firm with the optimal value that is defined by the estimated production boundary, which is obtained by the DEA. This mathematical programming tool allows to obtain an enveloping surface, frontier of efficiency or empirical production, from the available data of the homogeneous units from a set of inputs and outputs (Coll & Blasco, 2006).

The DEA is a deterministic, non-stochastic, and non-parametric tool that allows a multidimensional treatment. Table 1 shows these characteristics and their description.

On the other hand, the DEA is classified according to the type of efficiency measure, the orientation of the model, and the type of yields to scale, shown in Table 2.

In the present research, a measure of efficiency is carried out in a radial, input-oriented way. Constant (DEA-CCR) and variable (DEA-BCC) yields are used. Both are applied to compare the efficiency obtained by any types, as shown by two (2) of the authors in Sánchez et al. (2017).

3. METHOD

3.1. Epistemic Posture

The research assumes the positivist approach as was adopted by Gómez (2016) in the analysis of the variation of the efficiency in the production of biofuels in Latin America using the DEA as a tool.

From the ontological point of view (what and how is the reality being studied) the positivist approach considers that there is a single objective reality that operates according to predetermined cause-effect laws.

According to the epistemology (what scientific knowledge can be built and how the researcher relates to the object studied), the positivist assumes there is no relationship between the knower and the knowledge, between the evaluator and the reality, remaining as independent entities.

From the methodological point of view (how knowledge is constructed), the positivist research uses conventional methodology based on discovery and verification; that is, the research departs from a first stage where the hypothesis emerges. This is the most creative stage of the process, where the theory to be proved, corroborated, or refuted is established. In this stage, a variety of methods (fundamentally statistical) are applied using deductive knowledge to formulate cause-effect laws with general application.

3.2.Data

The data used in the DEA was extracted from the portal of the Energy Information System of Latin America and the Caribbean (SIER-OLADE, 2017), using the values from 2006 to 2013 for the following indicators: GHG emissions by generation of electric power (ton/GWh), total electricity generation (GWh), and total final electricity consumption (Kbep). The first of these indicators corresponds to the input for the DEA, while the last two (2) are the output, that is, one (1) entry and two (2) outputs, for a total of three (3) variables.

The need to use three variables is based on the fact that it was necessary to divide the countries of Latin America into two (2) clusters; the first one consisting of 11 countries (cluster A) being these the most emitters and the second one of 9 countries (cluster B) corresponding to those that have less GHG emissions by electricity generating. In this sense, it is necessary to be careful with the rules to determine the appropriate proportion between the number of variables (inputs + outputs) and the countries as production units. The rules were summarized by (Caceres et al., 2014). In the present research, the three rules are satisfied by using one (1) input and two (2) outputs, as shown in Table 3.

According to the above, it is evident that the DEA is applied separately to the data of each cluster of countries, as shown in Tables 4 and 5.

4. RESULTS AND DISCUSSIONS

In Table 6 the cluster A shows that Mexico is located at the frontier during all the years considered and calculated by the two (2) models: DEA-CCR and DEA-BCC. According to data from OLADE (SIER-OLADE, 2017), between 2006 and 2013, this country issued an average of 1,338 ton/GWh and generated

Table 1: Characteristics of the DEA tool

Characteristic	Description
Deterministic	It means that all individual firms share the same frontier and the differences between their behavior and the frontier are attributed to inefficiencies, ignoring, or ruling out the possibility that the normal development of an individual firm may be affected by factors that are out of control, e.g., adverse weather conditions (Canay, 2002).
No Stochastic	It considers as inefficient any individual firm that is not on the production frontier (Canay, 2002).
Non-parametric	It considers that the distribution of errors is free, being less prone to specification errors (Canay, 2002).
Multidimensional treatment	It allows a multidimensional treatment both on the side of the supply of inputs (inputs) and products (outputs), without this implying dealing with multiple crossed indicators, in such a way that it is ideal for evaluating the comparative behavior of individual firms and provide a systemic and integral vision (CEPAL, 2007)

Source: Own realization From (Canay, 2002) And (ECLAC, 2007). DEA: Data envelopment analysis

Table 2: Classification of DEA

Classification according to	Description
The type of efficiency measure	
Radial (proportional)	They measure the maximum equiproportional reduction of all the inputs that would be compatible with the same level of production or, alternatively, the greatest equiproportional increase in the outputs that could be obtained using the inputs in the same quantity (García, 2002). This type of measure presents an important problem for not detecting all the possible situations in which there is technical inefficiency, since this may be due to excessive use of certain inputs, not all of them (García, 2002).
No radials	With these type of measure, all possible situations of technical inefficiency are identified, although they have an important disadvantage compared to the radial measures because non-radial measures are usually sensitive to changes in the units of measurement used. This means that radial measures win the battle in the empirical field and are used in most efficiency studies (García, 2002).
The orientation of the model	
Input oriented	It aims towards the maximum proportional reduction of inputs without increasing outputs, in addition to remaining on the production or efficiency frontier (Coll & Blasco, 2006).
Output oriented	It aims at the maximum proportional increase in outputs without increasing the level of inputs, in addition to remaining on the production or efficiency frontier (Coll & Blasco, 2006).
The type of yields to scale	
Constant	DEA-CCR, its name derives from the authors who developed it, Charnes et al. (1978). It measures radial efficiencies and low constant-scale yields (Coll & Blasco, 2006).
Variables	DEA-BCC, developed by Banker, Charnes, and Cooper (1989). The latter is an extension of the DEA-CCR model and is characterized because it relaxes the assumption of constant scale yields, which, in many cases, is excessively restrictive and, therefore, unreal, allowing the typology to be variable, that is, constant, increasing or decreasing (Coll & Blasco, 2006).

Source: Self-realization from (Coll & Blasco, 2006) and (García, 2002). DEA: Data envelopment analysis

Table 3: Clusters and rules to determine the proportion between the variables and the producing units

Cluster	Countries	Number of countries (n)	Rules to determine the proportion of variable-producing units (Caceres et al., 2014)	Rules met in this research
A	Argentina, Bolivia, Chile, Cuba, Ecuador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, and the Dominican Republic.	11	Golany & Roll (1989) n≥2*(E+S) Charnes et al. (1994) n≥3*(E+S) Murias Fernández (2005) n≥E*S Key n=number of countries, E=number of inputs S=number of outputs	Golany & Roll (1989) n≥2*(E+S) n≥2*(E+S) n≥2*(1+2)≥4 Charnes et al. (1994) n≥3*(E+S) n≥3*(1+2)≥9 Murias Fernández (2005) n≥E*S≥1*2≥2 (Where n is equal to 9 or 11)
B	Brazil, Colombia, Costa Rica, El Salvador, Panama, Paraguay, Peru, Uruguay, and Venezuela.	9		

Source: Own elaboration

283,320 GWh, so that although it produced more energy, it emitted less GHG, locating the country at the efficient frontier.

In this same group of countries, Argentina, Cuba, Guatemala, Haiti, and Honduras are located at the frontier at least one (1) of the years, calculated with the DEA-BCC model. It must be remembered that the results of the efficiencies are relative, that is, the DEA compares the countries among them and, additionally, the DEA-BCC model is less restrictive than the DEA-CCR (Coll & Blasco, 2006). Besides, in the DEA-BCC model, each production unit (country) is compared to those of its size and not with all the units of the problem (Saborido-Bermejo, 2013), which means that through this model, a larger number of countries locate in the frontier.

Table 7 shows that, as a result from DEA-CCR and DEA-BCC, Paraguay, in cluster B, is in the efficient frontier during all the years studied. This is not surprising since this country generates 99, 9% of its electricity through hydroelectric power plants (Espinaza et al., 2017), having zero GHG emissions (SIER-OLADE, 2017). Brazil and Venezuela stand out when located on the frontier in some years. Venezuela is only located on the frontier by using the DEA-BCC model. The rest of the countries in the cluster have the lowest efficiencies because these are relative to each other. In addition, Paraguay is included in the group, as a country that has zero GHG emissions due to its matrix with 100% renewable or green energy. In this sense, the relative measures of the rest of the countries are inefficient

Table 4: Data input and output for the DEA (cluster A)

Period	Country	Output	Output	Input
		Electricity Generating (GWh)	Final Energy Consumption (Kbep)	GHG Emissions by Electric generation (ton/GWh)
2006	AR	113419.00	354287.31	843.90
	BO	4962.00	26473.71	793.15
	CL	55320.00	165442.39	280909.68
	CU	15992.00	46502.47	2042.51
	EC	15116.00	63413.60	1130.65
	GT	8163.00	51439.86	948.30
	HT	570.00	19706.59	686.71
	HN	5983.00	25086.81	582.32
	MX	256386.00	808393,18	1403.97
	NI	3150.00	14023.60	1156.52
	RD	14478.00	38969.11	2084.53
2007	AR	113525.00	376641.38	1008.81
	BO	5412.00	28371.56	806.90
	CL	58510.00	175154.90	285004.44
	CU	17113.00	44552.84	2033.13
	EC	17337.00	64864.88	1094.99
	GT	8755.00	52277.25	954.02
	HT	779.00	20722.67	693.63
	HN	6313.00	26711.47	901.67
	MX	263415.00	836221.33	1318.15
	NI	3221.00	14834.20	1176.04
	RD	15018.00	39756.75	2048.04
2008	AR	121905.00	385744.36	1055.11
	BO	5913.00	30207.48	839.80
	CL	59704.00	177593.64	294765.54
	CU	17170.00	54607.58	1966.19
	EC	18609.00	68077.95	933.59
	GT	8717.00	50747.12	903.59
	HT	779.00	20842.58	693.63
	HN	6537.00	27383.52	879.36
	MX	269469.00	863860.29	1208.91
	NI	3397.00	14338.11	1058.45
	RD	15076.00	39192.36	2006.01
2009	AR	122326.00	361638.52	1014.75
	BO	6216.00	31749.24	881.68
	CL	59690.00	173849.50	307183.09
	CU	17709.00	74593.70	617.38
	EC	18265.00	73632.07	1171.85
	GT	9040.00	57559.15	876.32
	HT	536.00	20904.44	855.74
	HN	6880.00	28350.06	733.78
	MX	267922.00	822294.74	1708.33
	NI	3457.00	14222.85	1124.74
	RD	14088.00	39372.42	1766.50
2010	AR	125992.00	392046.72	1054.81
	BO	7067.00	34924.27	937.04
	CL	59456.00	178916.19	323594.11
	CU	17396.00	76899.32	972.47
	EC	19510.00	75693.92	1272.65
	GT	8832.00	67047.76	738.16
	HT	649.00	20777.33	784.51
	HN	7014.00	27586.52	719.81
	MX	275740.00	856948.87	1279.80
	NI	3650.00	14542.88	1021.92
	RD	15073.00	41339.69	1740.42
2011	AR	129483.00	404398.81	1107.12
	BO	7277.00	38288.67	981.41
	CL	65037.00	193008.10	336751.03
	CU	17754.00	70593.92	1070.85
	EC	20544.00	80906.72	1099.26
	GT	8147.00	67749.48	765.64
	HT	687.00	21395.64	893.55
	HN	7352.00	31661.15	818.91

(Contd...)

Table 4: ***(Continued)***

Period	Country	Output	Output	Input
		Electricity Generating (GWh)	Final Energy Consumption (Kbep)	GHG Emissions by Electric generation (ton/GWh)
	MX	292327.00	886715.10	1266.34
	NI	3831.00	14788.93	1038.66
	RD	16113.00	41238.71	1760.10
2012	AR	136034.00	406254.00	1081.50
	BO	7756.00	39799.51	959.16
	CL	69729.00	190093.53	330186.25
	CU	67801.00	72442.78	1043.79
	EC	22848.00	83836.38	992.65
	GT	9403.00	67442.78	680.99
	HT	1162.00	21202.61	1758.64
	HN	7668.00	33482.89	775.21
	MX	296582.00	876296.02	1320.07
	NI	4018.00	15732.24	909.19
	RD	17214.00	44149.78	1614.79
2013	AR	139441.00	426665.49	1018.23
	BO	8163.00	43504.35	880.89
	CL	72957.00	200065.99	307043.19
	CU	19156.00	69903.25	966.33
	EC	23260.00	87621.45	1071.68
	GT	9197.00	67123.12	708.88
	HT	1105.00	21765.52	1708.43
	HN	7841.00	32852.35	841.00
	MX	297304.00	881769.20	1303.86
	NI	4202.00	16002.39	741.65
	RD	18389.00	43706.94	1549.68

Source: (SIER-OLADE, 2017). Legend: AR: Argentina, BO: Bolivia, CL: Chile, CU: Cuba, EC: Ecuador, GT: Guatemala, HT: Haiti, HN: Honduras, MX: Mexico, NI: Nicaragua, RD: Dominican Republic

compared to Paraguay and, to a lesser extent, compared to Brazil and Venezuela.

Table 8 shows the ranking of Latin American countries in the control of GHG emissions by electricity generation for each of the clusters, and was prepared taking the efficiencies of 2013, as it is the year closest to the current one. The efficiencies shown are those obtained by DEA-BCC because, as mentioned above, this model is less restrictive than the DEA-CCR (Coll & Blasco, 2006), which means that a greater number of countries are in the efficient frontier.

The results of applying the DEA provides information about the more and less efficient countries in the control of GHG emissions by generating electricity in each cluster (A and B). Cluster A countries have the highest GHG emissions when generating electricity, being Mexico, Guatemala, and Argentina the countries that occupy the first, second and third place, respectively. On the other hand, the least efficient are Chile, Haiti, and the Dominican Republic. In this group of countries, it is interesting that Guatemala has been in the efficient frontier when compared to the rest of the countries. Guatemala has a great potential for renewable energy, but unfortunately uses only 23%, however, it leads the energy capacity in Central America (Gándara, 2015).

Cluster B corresponds to the countries with the lowest GHG emissions. When applying the DEA to these nine (9) countries, the most efficient ones in controlling their emissions while generating electricity are Paraguay, Brazil, and Venezuela, while the least efficient are Panama, El Salvador, and Uruguay. No surprise in the outcome of countries that are located on the frontier, since they have a generation level >64% from clean energy.

As previously mentioned, the DEA-BCC determines the relative efficiencies among the similar units, for which it was necessary to group the countries into GHG emitters. The countries classified as "most emitting" but located in the efficient border are; Mexico and Guatemala, in first and second place, respectively. When located at the efficient frontier, they indicate that within this group of countries (cluster A) they have performed best (in this group) in the control of GHG emissions.

On the other hand, although Argentina is not located in the efficient frontier, this country obtained an efficiency of 0.9603 which is very close to the unity, occupying the third (3) place in the ranking of the Table 6. From this fact, the following question emerges: What have the governments of Mexico, Guatemala and Argentina done in terms of their public policies in the electricity sector to be the first three (3) countries in the ranking about the control of GHG emissions in Cluster A? The answer to this question is not simple or unique, it must be borne in mind that these countries are part of the "most emitting countries", however, below are some considerations that show why these countries, although being part of the "more issuers" are in the efficient frontier:

4.1. Mexico

According to (Espinaza et al., 2017), the share of fossil fuels in total energy consumption was 91%.55% of the total corresponding to liquid fuels, 30% to natural gas, and 6% to coal.

Table 5: Data entry and exit for the DEA (cluster B)

Period	Country	Output	Output	Input
		Generation of electricity (GWh)	Final Energy Consumption (Kbep)	GHG Emissions by Electric Generation (ton/GWh)
2006	BR	419337.00	1284599.66	249794.81
	CO	59268.00	179111.20	680.30
	CR	8702.00	24356.88	124.03
	GL	5597.00	24420.93	572.54
	PA	6077.00	19734.91	684.21
	PY	53774.00	26466.95	0.01
	PE	27370.00	85728.46	522.96
	UY	5595.00	18262.37	652.28
	VE	110644.00	285098.04	480.52
2007	BR	445094.00	1362882.86	298608.79
	CO	60621.00	171372.40	635.99
	CR	9055.00	26938.53	160.54
	GL	5806.00	22090.48	474.39
	PA	6468.00	21489.46	709.67
	PY	53715.00	26490.76	0.01
	PE	29943.00	89287.40	554.63
	UY	9380.00	19995.55	240.16
	VE	113697.00	293081.48	444.31
2008	B-R	463120.00	1408077.09	312311.54
	CO	61442.00	202317.90	596.96
	CR	9480.00	28142.12	97.89
	GL	5960.00	21243.62	362.62
	PA	6427.00	20564.79	607.57
	PY	55456.00	28400.12	0.01
	Int.	32443.00	99916.35	644.65
	UY	8770.00	23153.35	686.14
	VE	119317.00	355763.53	678.47
2009	BR	466158.00	1374944.71	300365.25
	CO	63353.00	189739.33	780.35
	CR	9296.00	26476.52	89.95
	GL	5788.00	20172.28	263.69
	PA	6953.00	22548.36	671.13
	PY	54940.00	29415.99	0.01
	Int.	32945.00	105147.96	781.38
	UY	8667.00	24294.94	580.00
	VE	124844.00	354091.07	721.36
2010	BR	515799.00	1496703.31	312223.99
	CO	64765.00	184084.06	855.68
	CR	9583.00	26818.01	125.19
	GL	5980.00	20255.98	185.28
	PA	7419.00	20093.42	669.26
	PY	54066.00	31292.82	0.01
	Int.	35908.00	113087.66	780.64
	UY	10734.00	25892.25	182.68
	VE	116716.00	416824.00	710.95
2011	BR	531758.00	1548202.38	327706.55
	CO	66341.00	195019.59	669.20
	CR	9831.00	26734.49	142.68
	GL	5763.00	20277.57	213.80
	PA	7858.00	21419.94	826.94
	PY	57625.00	31770.54	0.01
	Int.	38786.00	121850.19	814.29
	UY	10346.00	26666.84	441.86
	VE	122898.00	339550.76	630.30
2012	BR	552498.00	1655671.39	320124.09
	CO	67801.00	201982.41	707.99
	CR	10164.00	26693.32	109.05
	GL	6106.00	18521.31	529.60
	PA	8606.00	22730.71	652.01
	PY	60235.00	31772.34	0.06
	PE	39928.00	122631.71	806.29
	UY	10597.00	27068.20	614.48
	VE	127854.00	375312.14	712.97

(Contd...)

Table 5: ***(Continued)***

Period	Country	Output	Output	Input
		Generation of electricity (GWh)	Final Energy Consumption (Kbep)	GHG Emissions by Electric Generation (ton/GWh)
2013	BR	570025.00	1684055.68	301396.19
	CO	69985.00	206493.61	756.31
	CR	10234.00	27014.70	178.82
	GL	6268.00	17349.18	568.15
	PA	8958.00	22852.02	592.17
	PY	60381.00	32335.83	0.06
	Int.	43330.00	129084.21	706.10
	UY	11659.00	28488.38	277.32
	VE	132683.00	345501.48	686.10

Source: (SIER-OLADE. 2017). Legend: BR: Brazil, CO: Colombia, CR: Costa Rica, SV: El Salvador, PA: Panama, PY: Paraguay, UY: Uruguay, VE: Venezuela

Table 6: Efficiencies of cluster A countries in the control of GHG emissions by electricity generation by DEA-CCR and DEA-BCC

Country	AR	BO	CL	CU	EC	GT	HT	HN	MX	NI	RD
2006											
CCR	0.7360	0.0580	0.0011	0.0429	00974	0.0942	0.0498	0.0748	1.000	0.0211	0.0380
BCC	1.000	0.7356	0.0025	0.2970	0.5420	0.6362	0.8480	1.000	1.000	0.5035	0.2893
2007											
CCR	0.5885	0.0554	0.0084	0.0421	0.0934	0.0864	0.0471	0.0467	1.000	0.0199	0.0367
BCC	0.9578	0.8733	0.0030	0.3603	0.6694	0.7524	1.000	0.7839	1.000	0.5947	0.3552
2008											
CCR	0.5183	0.0503	0.0102	0.0392	0.1020	0.0786	0.0421	0.0436	1.000	0.0190	0.0337
BCC	0.8776	0.8377	0.0027	0.3688	0.7796	0.7879	1.000	0.8013	1.000	0.6601	0.3594
2009											
CCR	0.7686	0.0748	0.0012	0.2510	0.1305	0.1365	0.0508	0.0803	1.000	0.0263	0.0509
BCC	1.000	0.7002	0.0025	1.000	0.5286	0.7045	0.7215	0.8414	1.000	0.5489	0.3495
2010											
CCR	0.5551	0.0557	0.0064	0.1181	0.0888	0,1357	0,0396	0.0572	1.000	0.0213	0.0402
BCC	0.9175	0.7718	0.0027	0.7701	0.5893	1.000	0.9175	1.000	1.000	0.7044	0.4232
2011											
CCR	0.5217	0.0557	0.0036	0.0941	0.1051	0.1264	0.0342	0.0552	1,000	0.0203	0.0397
BCC	0.8847	0.7801	0.0028	0.7308	0.7164	1.000	0.8568	0.9349	1.000	0.7371	0.4430
2012											
CCR	0.5659	0.0625	0.0012	0.2891	0.1272	0.1492	0.0182	0.0651	1.000	0.0261	0.0474
BCC	0.8902	0.7100	0.0026	0.7769	0.7162	1.000	0.3872	0.8785	1.000	0.7490	0.4325
2013											
CCR	0.6196	0,0730	0.0082	0.1070	0.1209	0.1400	0.0188	0,0578	1.000	0,0319	0.0520
BCC	0.9603	0.8047	0.0029	0.7549	0.6886	1.000	0.4320	0.8429	1.000	0.9558	0.4697

Source: Own elaboration, Legend: AR: Argentina, BO: Bolivia, CL: Chile, CU: Cuba, EC: Ecuador, GT: Guatemala, HT: Haiti, HN: Honduras, MX: Mexico, NI: Nicaragua, RD: Dominican Republic

The dominance of fossil fuels in total energy consumption has remained at levels like those observed in the periods 1984-1987 and 1999-2002. However, in 2013 oil and its derivatives decreased their relative contribution by 11 points (from 65% to 54%) compared to the period 1999-2002, and by six points (from 60% to 54%) compared to the period 2005-2008. This reduction is due to the increase in the relative share of natural gas, which went from 19% of total energy consumption for the period 1999-2002 to 24% for the period 2005-2008, until reaching 30% in 2013 (Espinaza et al., 2017).

Renewable energy sources have little participation within the energy matrix of Mexico. During 2013, they supplied 308,000 equivalent barrels of oil per day (bopd), equivalent to 7.5% of the total primary energy supplied during that year. On the other hand, renewable energy sources reduced their relative share in total energy consumption by two points (from 10% to 8%) compared to the periods 1999-2002 and 2005-2008 (Espinaza et al., 2017).

In 2013, Mexico was the second largest electricity producer in Latin America, with a 19.63% share of the total electricity generated in the region. During that year, electricity production reached 297,079 GWh, a figure that reflects an increase of 17% over the period 2002-2012 and represents an annual growth rate of 2.9% (Espinaza et al., 2017).

4.2. Guatemala

Guatemala has a great potential for renewable energy, of which barely uses 23%, and leads the energy capacity in Central America (Gándara, 2015). Thus, the 2013-2027 Energy Policy of Guatemala (Ministerio de Energía y Minas, 2017), as one of its operational objectives, promotes the diversification of the electricity generation matrix through the prioritization of renewable sources, with which it intends to achieve 80% of the generation of electric power from these resources in the long term (Ministerio de Energía y Minas, 2017). Guatemala generated 66.21% of its electricity from renewable energy in 2013.

Table 7: Efficiencies of Cluster B countries in the control of GHG emissions by electricity generation through DEA-CCR and DEA-BCC

Country	BR	CO	CR	GL	PA	PY	PE	UY	VE
2006									
CCR	0.0087	0.0001	0.0001	0.0000	0.0000	1.000	0.0001	0.0000	0.0003
BCC	1.000	0.4169	0.0001	0.0000	0.0000	1.000	0.2106	0.0000	1.000
2007									
CCR	0.0069	0.0001	0.0001	0.0000	0.0000	1.000	0.0001	0.0000	0.0003
BCC	1.000	0.3797	0.0047	0.0000	0.0000	1.000	0.1887	0.0000	1.000
2008									
CCR	0.0086	0.0001	0.0001	0.0000	0.0000	1.000	0.0001	0.0000	0.0002
BCC	1.000	0.6038	0.0001	0.0000	0.0000	1.000	0.2299	0.0000	1.000
2009									
CCR	1.000	0.0001	0.0001	0.0000	0.0000	1.000	0.0001	0.0000	0.0002
BCC	1.000	0.4565	0.0001	0.0000	0.0000	1.000	0.2154	0.0000	1.000
2010									
CCR	1.000	0.0001	0.0001	0.0001	0.0000	1.000	0.0001	0.0001	0.0003
BCC	1.000	0.3293	0.0001	0.0001	0.0000	1.000	0.1932	0.0001	1.000
2011									
CCR	0.0088	0.0001	0.0001	0.0000	0.0000	1.000	0.0001	0.0000	0.0003
BCC	1.000	0.4996	0.0001	0.0001	0.0000	1.000	0.2266	0.0000	1.000
2012									
CCR	1.000	0.0005	0.0004	0.0001	0.0001	1.000	0.0003	0.0001	0.0009
BCC	1.000	0.4990	0.0005	0.0001	0.0001	1.000	0.2339	0.0001	1.000
2013									
CCR	0.0111	0.0005	0.0003	0.0001	0.0001	1.000	0.0003	0.0002	0.0009
BCC	1.000	0.5045	0.0003	0.0001	0.0001	1.000	0.3002	0.0002	1.000

Source: Own elaboration. Legend: BR: Brazil, CO: Colombia, CR: Costa Rica, SV: El Salvador, PA: Panama, PY: Paraguay, UY: Uruguay, VE: Venezuela

Table 8: Ranking of Latin American countries in the control of GHG emissions by electric generation

Clusters	Country	Efficiency.	Ranking	Efficiency
Cluster A	Mexico	1	1	1
	Guatemala	1	2	1
	Argentina	0.9603	3	1.041
	Nicaragua	0.9558	4	1.046
	Honduras	0.8429	5	1.186
	Bolivia	0.8047	6	1.243
	Cuba	0.7549	7	1.325
	Ecuador	0.6886	8	1.452
	Dominican R.	0.4697	9	2.129
	Haiti	0.4320	10	2.315
	Chile	0.0029	11	348.017
Cluster B	Paraguay	1	1	1
	Brazil	1	2	1
	Venezuela	1	3	1
	Colombia	0.5045	4	1.982
	Peru	0.3002	5	3.331
	Costa Rica	0.0003	6	3058.889
	Uruguay	0.0002	7	4743.686
	El Salvador	0.0001	8	9718.625
	Panama	0.0001	9	10129.440

Source: Own elaboration

This country is making efforts to consolidate its energy capacity in Central and Latin America. Guatemala has strategic plans (2013-2027) to diversify its energy matrix to achieve 80% of the generation of energy from renewable sources. In fact, as published by the National Electric Power Commission of Guatemala (CNEE, 2017) in July 2017, the energy matrix is 71.50% renewable and 28.50% non-renewable. The strategic plans of Guatemala and their efforts have resulted in the location of this country in the efficient frontier during the years 2010, 2011, 2012 and 2013.

Guatemala ranked 14th in Latin America in electricity production, with a share of 0.61% of the total electricity generated in the region.

4.3. Argentina

The installed capacity of Argentina is mostly thermal, which implies the use of fossil fuels to generate electricity and causing that 70% of its total electricity consumption is from fossil fuels. However, it is important to highlight the change in the relative composition of the use of hydrocarbons for electricity generation, where 54% comes from natural gas because this fuel has a lower price, is more efficient and less polluting (Espinaza et al., 2017).

There is still a long way to go in terms of the energy transition to sustainable development in the production of electricity since, according to Espinaza, et al. (2017) in total energy consumption in Argentina during 2013, the participation of fossil fuels was 91%, with natural gas and liquid fuels contributing 49% and 41%, respectively, evidencing the weight of these levels in the Argentine energy matrix.

On the other hand, renewable fuels, sugar cane and water sources represented the supply of 122 bopd, corresponding to 7.1% of total energy consumption. However, its relative share in total energy consumption increased from 6.5% to 7.1% over the 2005-2008 period (Espinaza et al., 2017).

Argentina was the third largest electricity producer in Latin America, with a share of 9.21% of the total electricity generated in the region. The amount of 139,171 GWh implies an increase of 23% in volume compared to the period 2002-2012 and an annual growth of 3.5% (Espinaza et al., 2017).

Considering that the energy matrix is mostly fossil, it must be observed that the higher the production, the greater the GHG emissions. This condition makes Argentina part of the cluster of more emitting countries, however, it increases the proportion of natural gas with respect to other fossil fuels and also, between 2005 and 2013, increases from 6.5% to 7.1% of total energy consumption from renewable fuels, favoring its location at the efficient frontier, indicating that, among the most emitting countries, it has a better performance at a less polluting energy transition.

On the other hand, we have Paraguay, Brazil, and Venezuela, which occupy the first three (3) places in the ranking of relative efficiency in Cluster B. In this sense, the question arises: What are the energy policies of this countries governments to make them be pioneers in the ranking and be located on the frontier of the relative efficiency measure? The answer, as in the case of Cluster A, is not simple or unique, however, here are some considerations that show why these countries are part of the "least emitters" and located in the efficient border.

4.4. Paraguay

At the end of 2013, Paraguay had an installed generation capacity of 8,816 MW, made up of 99.9% of the energy provided by hydroelectric plants and 0.1% supplied by thermoelectric plants operated with fossil fuels. Between 2000 and 2013, the country's installed electric capacity increased by 1.4 GW (19%), mainly driven by the expansion of the capacity of hydroelectric plants (Espinaza et al., 2017).

The primary energy supply (PES) reached about 147.7 kboe/day (millions of barrels of oil equivalent per day) in 2013. This energy supply was destined to transformation centers to obtain secondary energies for the final consumption of the economic sectors and for the consumption of the energy sector itself (Espinaza et al., 2017).

The renewable fuels contributed with the total of the PES: 71% came from hydraulic energy and 29% from biofuels and waste. The lack of participation of fossil fuels responds, to a large extent, to the technological endowment and the availability of water resources in the country (Espinaza et al., 2017).

During 2013, Paraguay was the seventh producer of electricity in Latin America, after Chile and Colombia. Its total production reached 60,381 GWh. This volume of production increased by 12% with respect to the period 2002-2012, which represents an average annual growth rate of 2.5% (Espinaza et al., 2017).

Paraguay is a green country par excellence, because its form of electric power generation is 100% renewable. It should also be noted that Paraguay is a country rich in natural resources; Its water richness in surface and underground waters is the largest in Latin America (Mereles & González, 2014). Paraguay has two binational hydroelectric plants, which are Itaipu shared with Brazil, and Yacyretá jointly managed with Argentina (Hydroelectric energy and its relationship with economic growth and development in Paraguay, 2014). In Paraguay, the main offer is hydroelectricity, however, it is mostly exported abroad, while the internal energy matrix is led by biomass ("Hydroelectric energy and its relationship with growth and economic development in Paraguay," 2014).

4.5. Brazil

Brazil has a high hydroelectric and wind potential. The renewables sources constitute more than 80% of the electricity generation (Escribano, 2014). This country occupies the first place in the consumption of renewable energies in Latin America, basically due to its status as the second producer of biofuels in the world, only behind the USA with more than 22% of the world production. On the other hand, the penetration of solar and wind energy has been limited until recent years (Escribano, 2014).

Brazil has the largest installed wind capacity in Latin America, but the figures remain well below the existing potential. The 2030 National Energy Plan estimates a potential of 258 GW for hydroelectricity, 143 GW for wind power, and 8 GW for biomass. It also has a binational hydroelectric plant (Itaipu), which is shared with Paraguay ("Hydroelectric power and its relationship with economic growth and development in Paraguay," 2014).

In Brazil, three (3) nuclear power plants operate, and this country plans to build at least four more plants by 2030 ("Hydroelectric power and its relation to economic growth and development in Paraguay," 2014).

Brazil is a large producer of electricity, and this country ranked number one (1) in Latin America in 2013, representing 37.64%. In 2011, Brazil accounted for 12% of global hydroelectricity consumption, only behind China (Escribano, 2014).

Brazil is a rising player in the international energy scene due to the variety and abundance of energy resources available, the size of its domestic market and the dynamism of demand (Escribano, 2014). In this sense, Brazil is the leading electricity consumer in Latin America and is the ninth largest energy consumer in the world and the third largest in the Americas, only behind the USA and Canada (Escribano, 2014). The diversity of renewable resources that this country has, which account for more than 80% of electricity generation, make Brazil be in the efficient frontier. Although this country is a large producer-consumer of electricity, its GHG emissions are small compared to the rest of the Latin American countries.

4.6. Venezuela

In Venezuela, a series of measures have been promoted to have a positive impact on the reduction of CO_2 eq emissions, such as:

- The development of wind farms, as in the case of the Paraguaná wind farm, which is designed to produce 100 MW through 50 turbines with 2 MW (Morales et al., 2013).
- The fuel ethanol agro-energy project, which contemplates an ambitious ethanol production plan as a substitute for the oxygenated additives of gasoline from sugarcane, rice, and cassava (Morales et al., 2013).

Venezuela ranked fourth in Latin America in electricity production, behind Brazil, Mexico and Argentina, representing 8.76% of the region's total, being the first consumer in per capita terms in Latin America (Morales et al., 2013), which should also be taken into account, since high energy consumption has an environmental impact due to carbon emissions (Setiartiti, 2018). In 2012, this country generated 64.02% of its electric power from renewable sources, specifically hydroelectric plants. This condition is the product of the country's investment in the 1960s for the construction of reservoirs, motivated by the demand for water supply and hydroelectric power (Cressa et al., 1993). However, it is enough to generate clean energy, and it is also necessary to implement the combination of energy efficiency with renewable energy sources to reduce carbon GHG emissions (Setiartiti, 2018).

From the previous comments related to each country, it is observed that the highlight in each one is their efforts to generate electricity from renewable sources (hydroelectric, biofuels, and nuclear generation) or from less polluting and more efficient fossil fuels (natural gas), leading to the diversification of its energy matrix. This is an unavoidable objective of the countries that really want to have an economic development that goes hand in hand with the planet.

The countries that generate part of their electricity through biofuels are Guatemala (13.96%), Paraguay (29%), and Brazil (21%). On the other hand, Mexico and Argentina have a low participation of renewable energies for the generation of electricity, however, they have increased the participation of natural gas which, although it is a fossil fuel, is less polluting and more efficient in the combustion process. Argentina, for its part, stands out with 4% of the generation of its electricity with nuclear energy.

In 2013, of the six (6) countries analyzed, four (4) have electricity generation mainly from clean or renewable energies, this is how Venezuela has 64.02%, Guatemala with 66, 21%, Brazil with 69.74% and Paraguay with 100%. On the contrary, Mexico and Argentina, this year, only generate their electricity with renewable sources of 11.9% and 28%, respectively.

Regardless of the cluster in question, the purpose is to relate that the countries that occupy the three (3) first places in the ranking are those that are experiencing an energy transition on the change in the production model, caused by the technical and political concern (Marin, 2014). In this way, governments and international organizations try to increase the production of energy from renewable sources and mitigate adverse environmental impacts and global warming (Mahmoodi, 2017).

Future researches can be directed to the following:

a. Analyzing which specific public policies favor more the efficiency in the control of GHG emissions and, based on the foregoing, propose a series of strategies for countries to better control their emissions. The study could cover countries in South America.
b. The DEA tool can be used to determine the efficiency of cluster B countries excluding Paraguay, which will allow determining the changes in the frontier itself by subtracting from the sample the country that leaves the rest as inefficient due to emissions from null GHG. In this way, a change will occur in the frontier and other countries (Colombia and Costa Rica) could be in it.
c. The DEA tool can be used to determine the efficiency of Latin American countries that generate electricity from biofuels, to determine the efficient countries around this condition. This is interesting since it is a policy considered by the countries at the Paris Summit (UNFCCC, 2015), which is the "substitution of fossil fuels for biofuels or an increase in biofuels compared to the former". This is evidence of a transition of the energy matrix and the advance towards the long-awaited sustainable development.

5. CONCLUSIONS

The countries that occupy the first three (3) positions of the efficiency ranking in Cluster A are: Mexico, Guatemala, and Argentina, respectively. The countries that occupy the first three (3) positions of the efficiency ranking in Cluster B are: Paraguay, Brazil, and Venezuela. However, the countries that are really located on the efficient frontier are Guatemala, Mexico (cluster A), Brazil, Paraguay, and Venezuela (cluster B), with Argentina close to the border with an efficiency value of 0.96.

Mexico (Cluster A) and Paraguay (Cluster B), keep at the border during all the years considered and by both DEA methods (CCR and BCC), indicating that these nations have maintained a production optical scale, compared to the countries in the same cluster.

6. ACKNOWLEDGMENT

The authors thank the Universidad de la Costa, based in the city of Barranquilla, Colombia for the funding of the research through the project number INV.1104-01-006-12 approved with Notification No. 328 in the Academic Council of March 23, 2017. They also recognize the unconditional support for the execution of the research by the Universidad Nacional Experimental Politécnica "Antonio José de Sucre" (UNEXPO), Barquisimeto, Venezuela.

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