

# Emissions and exergy profile associated with electricity generation in Argentina, Brazil and Colombia

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## Abstract:

South America exhibits highly heterogeneous electricity transition pathways, shaped by differences in resource endowments, generation infrastructure, institutional frameworks, and national policy priorities. Within this regional context, Colombia, Argentina, and Brazil constitute three representative cases. Hence, this study verified the energy and electricity-sector structure of Colombia using official Unidad de Planeación Minero Energética (UPME) sources, mainly the Colombian Energy Balance and the 2020–2024 statistical bulletin, and compared its generation and emissions profiles with those of Argentina and Brazil for the year 2024 using the information provided by the Sistema de Información Energética de Latinoamérica y el Caribe (SIELAC). Based on annual electricity generation by technology, the equivalent input energy requirement was estimated using representative exergy efficiencies, enabling comparable profiles across countries. For thermal technologies, fuel-specific fossil emission factors on a heating value basis reported by the Intergovernmental Panel on Climate Change (IPCC) were applied, while zero operational fossil emissions were assumed for hydropower, solar, wind, and nuclear energy. In the case of bioenergy, fossil CO<sub>2</sub> was considered zero under IPCC conventions, with the biogenic fraction recorded separately. In exergy terms, Argentina reached 308,280 GWh<sub>B</sub>; Brazil reached 1,723,426 GWh<sub>B</sub> and Colombia reached 146,840 GWh<sub>B</sub>. In emission terms, Argentina totaled 35.72 MtCO<sub>2</sub>; Brazil reached 134.23 MtCO<sub>2</sub> and Colombia reached 15.05 MtCO<sub>2</sub>. Within the bioenergy category, Argentina's emissions were split into solid biomass (0.894 MtCO<sub>2</sub>) and biogas (0.335 MtCO<sub>2</sub>); Brazil's into sugarcane bagasse (59.240 MtCO<sub>2</sub>), black liquor (31.80 MtCO<sub>2</sub>), biogas (1.248 MtCO<sub>2</sub>), and other biomass (2.8 MtCO<sub>2</sub>); and Colombia's into bagasse (1.01 MtCO<sub>2</sub>) and biogas (0.029 MtCO<sub>2</sub>). Although the 2024 analysis does not constitute a direct assessment of the Nationally Determined Contributions (NDC) compliance, the results show that the three countries still face significant challenges in aligning the expansion of their electricity sectors with their climate commitments.

## Keywords:

Energy profile, Electricity generation, Exergy, CO<sub>2</sub> emissions, Colombia, Argentina, Brazil.

## 1. Introduction

South America's electricity transition is highly heterogeneous, with over 80% renewable generation in some areas while others heavily rely on fossil fuels, driven by diverse resource endowments and policy gaps. Comparative studies for Latin America and the Caribbean have shown that countries in the region do not follow a single decarbonization trajectory; instead, they display markedly different combinations of hydropower, fossil fuels, and emerging non-conventional renewables. This heterogeneity makes cross-country comparisons especially relevant for identifying structural contrasts in electricity generation and for evaluating how technology choices condition environmental performance [1].

Within this region, Argentina, Brazil, and Colombia represent three particularly interesting cases. Argentina has historically maintained a stronger dependence on thermal generation, especially natural gas, and long-term scenario analyses continue to identify decarbonization of its energy sector as a major challenge [2]. Brazil, in contrast, is commonly recognized for its large renewable participation, historically anchored in hydropower, although the literature also warns that continued fossil-based expansion may erode this advantage [3]. Colombia represents an intermediate configuration: its power system is largely hydro-based, but its operational

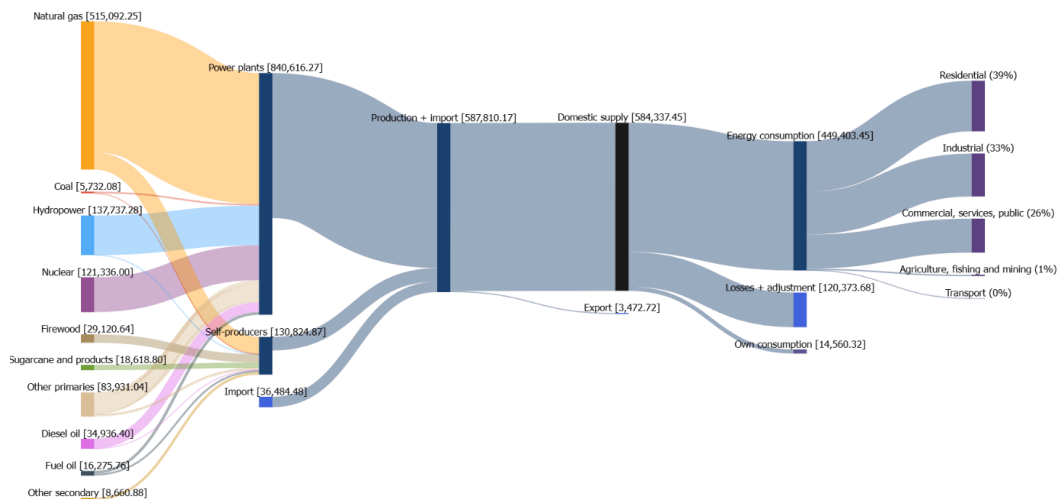
reliability remains conditioned by hydrological variability and by the availability of thermal backup during dry periods [4].

These structural differences are relevant not only from an energy-planning perspective but also from the standpoint of climate mitigation. Power systems with a higher participation of thermal generation tend to concentrate larger direct operational CO<sub>2</sub> emissions, whereas systems with large shares of hydropower and variable renewables generally exhibit lower operational emissions but may face reliability constraints associated with seasonality, droughts, storage requirements, and reserve margins. Recent regional analyses further suggest that aligning electricity expansion with decarbonization targets requires country-specific strategies rather than uniform prescriptions [1]. In this sense, comparing generation structure, equivalent input exergy requirements, and technology-specific emissions provides a useful basis for assessing how current electricity systems relate to broader transition and NDC-oriented discussions.

### 1.1. Energy and power-sector structure in South America (Argentina, Brazil and Colombia)

Argentina, Brazil, and Colombia display markedly different electricity-sector configurations within South America. Argentina is characterized by a predominantly thermal system in which natural gas plays a central role in electricity generation; accordingly, the literature identifies the decarbonization of gas-based generation as one of the main long-term challenges of the Argentine energy transition [2]. Brazil, by contrast, has historically relied on a large hydropower base and has progressively incorporated wind, solar, and bioenergy. However, this comparatively favorable renewable energy structure does not eliminate environmental trade-offs, as previous studies have warned that increased fossil fuel use may compromise sustainability gains [3]. Colombia, in turn, remains strongly dependent on hydropower, while coal- and gas-fired plants continue to provide operational support, particularly under conditions of hydrological stress [4].

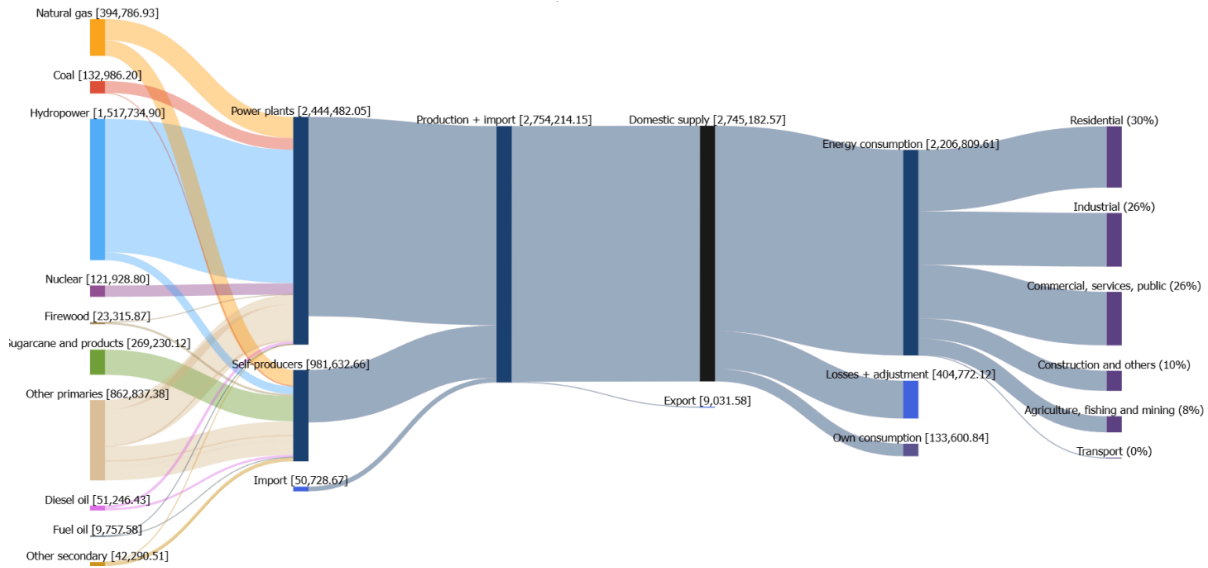
This contrast justifies the comparative focus adopted in this study. Rather than representing isolated national cases, these three countries reflect distinct patterns of electricity development in the region: a gas-centered structure in Argentina, a renewable-diversified structure in Brazil, and a hydro-dominated system with thermal backup in Colombia [1-3]. Argentina (Figure 1) is characterized by a significant participation of thermal technologies, with natural gas as the main fuel for electricity generation [5], 511.674 (TJ). Brazil (Figure 2) has the most robust hydropower matrix, complemented by growing contributions from solar, wind, and bioenergy [5] 2.704.807 (TJ). Colombia (Figure 3) maintains a structure strongly supported by hydroelectric power plants, but with thermal backup from coal, natural gas, and petroleum derivatives to a lesser extent [6] 298.557 (TJ).



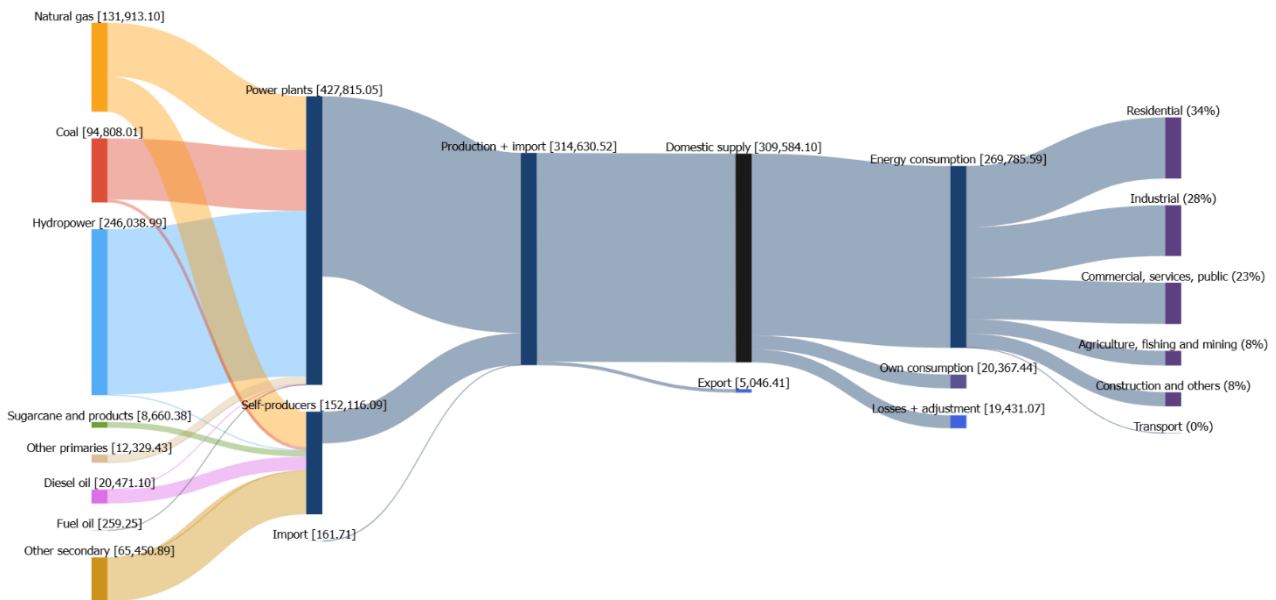
**Figure 1.** Sankey diagram of energy production and end-use distribution by sector in Argentina [5].

Bioenergy constitutes a structurally relevant component of the electricity mix in all three countries, with economic and agro-industrial dimensions that extend beyond the power sector. In Argentina, electricity-oriented bioenergy relies on solid biomass and biogas, both linked to the country's extensive agricultural sector and its agro-industrial residue base [7]. In Brazil, the segment is more diversified and deeply embedded in the national economy: bioenergy from sugarcane and other sources represented the leading renewable contribution to the country's energy mix in 2024, with sugarcane bagasse and black liquor as the dominant sub-sources [8]. In Colombia, bioenergy is structurally anchored in the sugarcane agroindustry of Valle del Cauca and Cauca, where bagasse-based cogeneration feeds surplus electricity into the national grid and constitutes one of the most economically significant agro-industrial sectors in the country [9]. The bioenergy feedstocks considered in this study: solid biomass and biogas for Argentina; sugarcane bagasse, black liquor,

biogas, and other biomass for Brazil; and bagasse and biogas for Colombia. This reflects both the technical configurations of each power system and the broader agro-industrial contexts in which these sources operate.



**Figure 2.** Sankey diagram of energy production and end-use distribution by sector in Brazil [5].



**Figure 3.** Sankey diagram of energy production and end-use distribution by sector in Colombia [5].

Representative exergy efficiencies were assigned to each electricity-generation technology in order to estimate the equivalent input exergy associated with the reported electricity output. This approach is consistent with using exergy as a more meaningful metric for comparing power technologies, since electricity is a high-quality energy form and simple energy balances may conceal important differences in thermodynamic performance. Because exergy efficiency depends on plant configuration, system boundaries, and operating conditions, the values adopted in this study were not intended to represent plant-specific performance; instead, they were selected as representative values within ranges reported in the literature for each technology [10].

## 2. Methodology

### 2.1. Research design and framework

The research was developed under a quantitative, descriptive, and comparative approach. Its purpose was to verify the electricity generation structures in Argentina, Brazil, and Colombia, using 2024 as the base year, and to verify compliance with the traceability proposed in each nation's NDC. The analysis focused on two main

variables: the exergy profile of generation technologies and the CO<sub>2</sub> emission factors associated with the fossil fuels used in the electricity sector.

Figure 4 presents the methodological workflow used in this study. Electricity generation data were collected from UPME for Colombia and from SIELAC for Argentina and Brazil. The technologies were classified as renewable or non-renewable, and the processing stage was evaluated based on electricity generation and exergy efficiency. Fossil and bioenergy technologies were assessed on an LHV basis, while low-carbon renewable systems were analyzed separately.

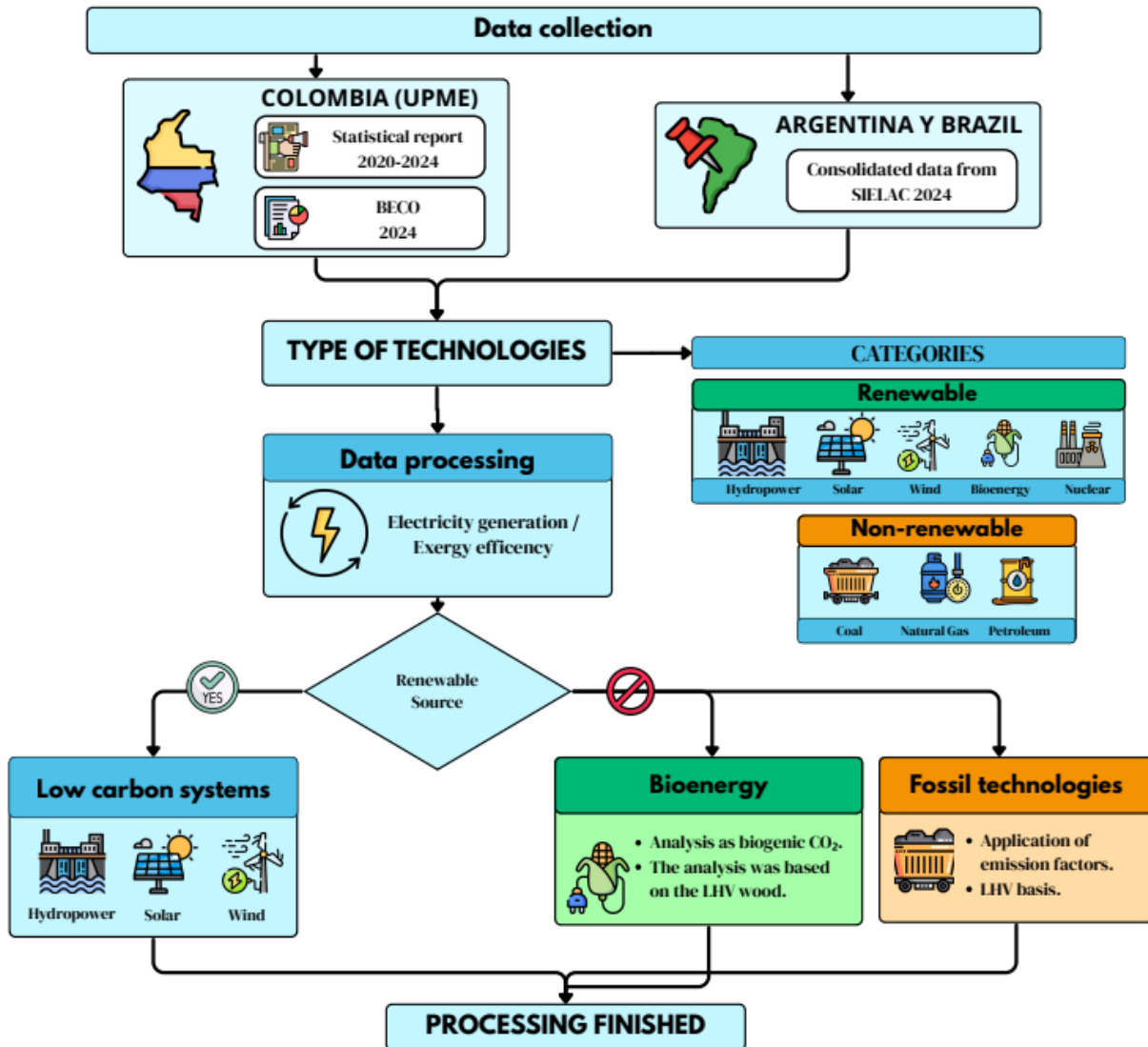


Figure 4. Data processing flowchart.

## 2.2. Data acquisition and pre-processing

For Colombia, the main sources were used from official national records available at UPME-*Unidad de Planeación Minero Energética*, particularly the BECO [6] and the 2020-2024 Statistical report [9]. For Argentina and Brazil, a consolidated electricity generation profile from the Latin-American Energy System [5], organized by technology, was used. Subsequently, the technologies were standardized into comparable categories: hydropower, solar, wind, coal, natural gas, petroleum or derivatives, bioenergy, and nuclear.

In the pre-processing stage, electricity generation in GWh was taken as the base variable. A representative exergy or conversion efficiency was assigned to each technology, allowing the calculation of the equivalent fuel energy required to produce the reported electricity. For fossil technologies, specific emission factors in t CO<sub>2</sub>/TJ were applied, using an LHV basis [11]. For non-combustible technologies, operational fossil fuel emissions were assumed to be zero [12]. For bioenergy, it was analyzed as biogenic CO<sub>2</sub> based on the LHV value reported. [11]. For the pre-processing stages, the reported electricity output in GWh for each generation technology was used as the base input. First, electricity generation was converted into TJ (Equation 1).

$$1 \text{ GWh}=3,6 \text{ TJ} \quad (1)$$

Then, a representative conversion efficiency was assigned to each technology in order to estimate the equivalent input exergy required to produce the reported electricity (Equation 2).  $B_{xi}$  is the input exergy in TJ,  $E_{el,i}$  is the electricity generation in GWh, and  $\eta_i$  is the efficiency of technology  $i$ .

$$B_{xi} = \frac{E_{el,i} \times 3,6}{\eta_i} \quad (2)$$

In this framework, hydropower was assigned a representative exergy efficiency consistent with the high thermodynamic performance commonly attributed to hydroelectric systems in comparative exergy assessments [13]. For solar photovoltaic generation, a representative efficiency within the range reported in the literature was adopted, consistent with case-study exergy efficiencies reported for photovoltaic systems under different operating conditions [14].

For thermal technologies, the use of representative efficiencies is consistent with the exergy literature, particularly for gas-fired and coal-based systems, whose performance is strongly influenced by plant configuration and conversion scheme [15]. Table 1 summarizes the representative exergetic efficiencies adopted in this study for each electricity-generation technology [16], for coal, oil products, natural gas, nuclear and wind.

**Table 1. Exergetic efficiency for technology.**

Technology	Adopted $\eta$
Hydropower	0.80
Solar	0.12
Wind	0.45
Natural gas	0.46
Coal	0.46
Petroleum	0.40
Nuclear	0.32

Representative exergy efficiencies for bioenergy-based electricity generation were assigned individually to each biofuel type considered in this study, rather than using a single aggregated value, given the significant thermodynamic differences among conversion technologies. For sugarcane bagasse, a representative efficiency of 0.28 was adopted, consistent with values reported for bagasse-fired cogeneration systems operating under conventional steam Rankine configurations [17, 18]. For solid biomass and other biomass, a value of 0.30 was selected [16], in line with efficiencies reported for dedicated biomass combustion plants using dry feedstocks [19]. For black liquor, a value of 0.12 was adopted, reflecting the low electricity conversion efficiency — reported in the range of 9–14% — characteristic of conventional Tomlinson recovery boilers, which remain the dominant technology in the pulp and paper industry [20]. For biogas, a representative efficiency of 0.30 was selected based on exergy analyses of internal combustion engine-based power generation systems fueled with biogas [21]. Table 2 summarizes the adopted efficiencies and their corresponding sources.

**Table 2. Exergetic efficiency for biofuel type.**

Biofuel type	Adopted $\eta$
Solid biomass	0.3
Biogas	0.3
Sugarcane bagasse	0.28
Black liquor	0.12
Other Biomass	0.3

For fossil-based technologies, direct  $CO_2$  emissions were calculated by multiplying the equivalent input exergy by the corresponding emission factor (Equation 3), where  $EF_i$  is the emission factor in  $\frac{tCO_2}{TJ}$ .

$$CO_{2,i} = B_{xi} \times EF_i \quad (3)$$

Table 3 presents the emission factors (EF) adopted in this study for each technology and summarizes the assumptions used to estimate the technology-specific  $CO_2$  emissions profile [11]. For hydropower, solar, wind, and nuclear technologies, operational fuel emissions were assumed to be zero.

**Table 3. Emission factor for technology.**

Technology	EF
Natural gas	56.1
Coal	94.6
Petroleum	74.1

The following table presents the EF assigned to the biofuels considered in this study. These factors were selected according to the specific bioenergy composition adopted for Argentina, Brazil, and Colombia, namely solid biomass, sugarcane bagasse, black liquor, biogas, and other biomass sources. Their use allows the aggregated bioenergy category to be treated according to the actual biofuels represented in each country rather than as a single undifferentiated source. The emission factors correspond to IPCC default values [11] on a net calorific value basis and were used consistently throughout the estimation of biogenic CO<sub>2</sub> emissions.

**Table 4. Biofuels emission factor.**

Biofuel type	EF <sub>bio</sub>
Solid Biomass	100
Sugarcane bagasse	100
Black Liquor	95.3
Other Biomass	100
Biogas	54.6

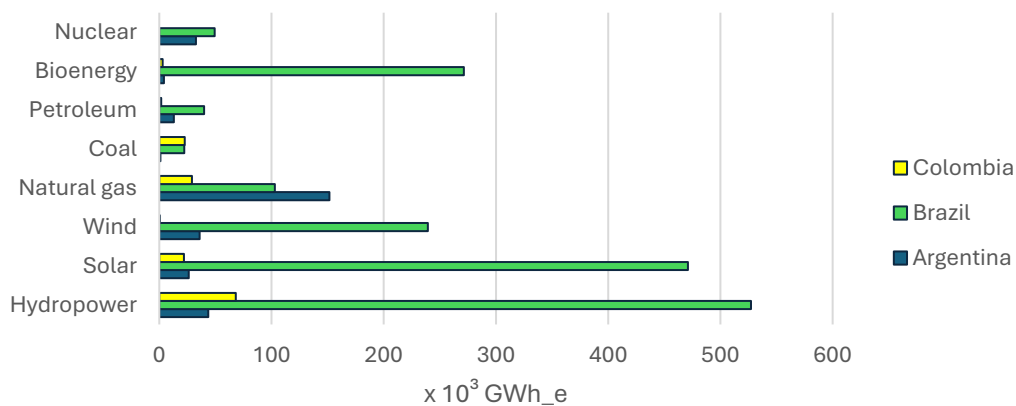
### 3. Results and discussion

#### 3.1. Exergy profile per technology and country

Table 5 and Figure 5 (a) and (b) summarize the electricity generation profile by technology for Argentina, Brazil, and Colombia. Together, they provide a comparative overview of the contribution of renewable and non-renewable sources to the power sector in each country, highlighting the relative importance of hydropower, solar, wind, natural gas, coal, petroleum, bioenergy, and nuclear generation in the 2024 electricity mix. Meanwhile, Figure 6 is the total exergy by country taking into account 2024 as a year of reference.

**Table 5. Power generation by technology on exergy basis.**

Technology	Argentina (GWh <sub>B</sub> )	Brazil (GWh <sub>B</sub> )	Colombia (GWh <sub>B</sub> )
Hydropower	43,671	527,249	68,130
Solar	26,275	471,098	21,976
Wind	35,919	239,231	331
Natural gas	151,607	103,012	29,069
Coal	1,042	22,276	22,716
Petroleum	12,923	39,947	1,645
Bioenergy	4,190	271,342	2,973
Nuclear	32,653	49,271	-



(a)

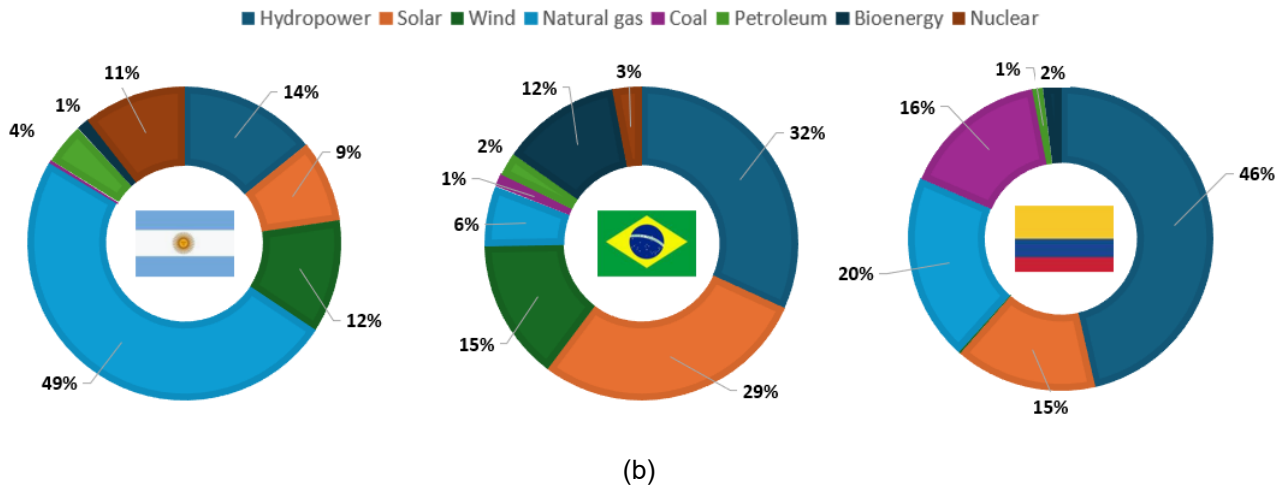


Figure 5. Exergy-based electricity generation by technology in Argentina, Brazil, and Colombia.

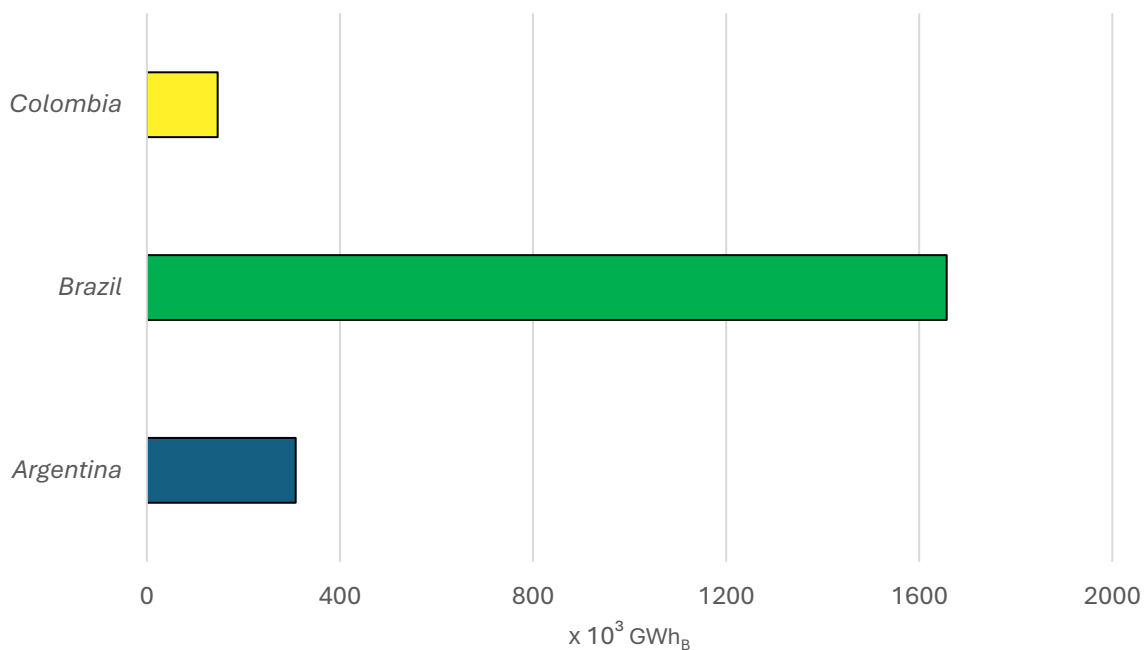


Figure 6. Total exergy flow in Argentina, Brazil, and Colombia.

Argentina remains primarily gas-centered, with natural gas (151,607 GWh<sub>B</sub>), well above hydropower (43,671 GWh<sub>B</sub>), wind (35,919 GWh<sub>B</sub>), solar (26,275 GWh<sub>B</sub>), and nuclear generation (32,653 GWh<sub>B</sub>); total 308,280 GWh<sub>B</sub> (Figure 6). These values confirm a markedly thermal structure, numerically consistent with recent country-level evidence indicating that natural gas accounted for 53.0% of Argentina's electricity generation in 2022, while hydropower contributed more than 16.0%, wind 9.7%, and solar 2.0% [22, 23].

Brazil presents the most diversified profile among the three countries. The highest values correspond to hydropower (527,249 GWh<sub>B</sub>), solar power (471,098 GWh<sub>B</sub>), wind power (239,231 GWh<sub>B</sub>), and bioenergy (271,342 GWh<sub>B</sub>), while fossil-based sources such as natural gas (103,012 GWh<sub>B</sub>), petroleum (39,947 GWh<sub>B</sub>), and coal (22,276 GWh<sub>B</sub>) play a comparatively smaller role; 1,723,426 GWh<sub>B</sub> total (Figure 6). This pattern aligns with recent international statistics showing that hydropower remained the largest source of electricity generation in Brazil in 2024, accounting for 56% of total generation, while wind and solar together accounted for 21% of the mix. [24, 25].

Lastly, Colombia remains hydro-dominated. Hydropower with the highest value (68,130 GWh<sub>B</sub>), clearly exceeding natural gas (29,069 GWh<sub>B</sub>), solar power (21,976 GWh<sub>B</sub>), and coal (22,716 GWh<sub>B</sub>), while wind remains almost negligible (331 GWh<sub>B</sub>); 146,840 GWh<sub>B</sub> total (Figure 6). This profile confirms that Colombia still

relies primarily on hydropower, although thermal generation continues to play a relevant supporting role and solar has already gained a more visible position than wind in the 2024 balance presented here. This result is also consistent with recent IEA statistics indicating that hydropower represented 58% of Colombia's total electricity generation in 2024, while natural gas accounted for 19.3%, confirming the continued relevance of thermal backup in the national power system [1, 26, 27].

### 3.2. Emissions profile per technology and country

Table 6 and Figure 7 present CO<sub>2</sub> emissions for each electricity-generation technology in Argentina, Brazil, and Colombia. These results enable comparison of the environmental implications of the generation structure in each country by identifying the technologies that contribute most significantly to direct power-sector emissions. Additionally, Figure 8 shows total emissions by country in 2024.

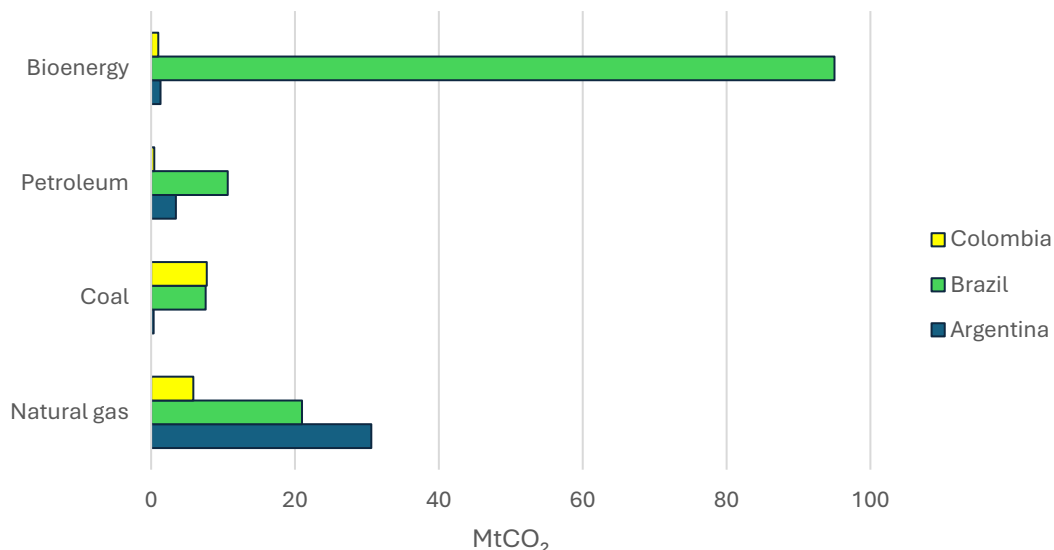
**Table 6.** Technology emission by country (MtCO<sub>2</sub>).

Technology	Argentina	Brazil	Colombia
Natural gas	30.62	20.98	5.87
Coal	0.35	7.59	7.74
Petroleum	3.45	10.66	0.44
Bioenergy	1.30	95.00	1.00

The country-level bioenergy composition applied in this study was based on MAGyP [7] for Argentina, EPE [8] for Brazil, and UPME [9] for Colombia (Table 7). Argentina was represented by solid biomass and biogas; Brazil by sugarcane bagasse, black liquor, biogas, and other biomass; and Colombia by bagasse and biogas.

**Table 7.** Biofuel emission by country (MtCO<sub>2</sub>).

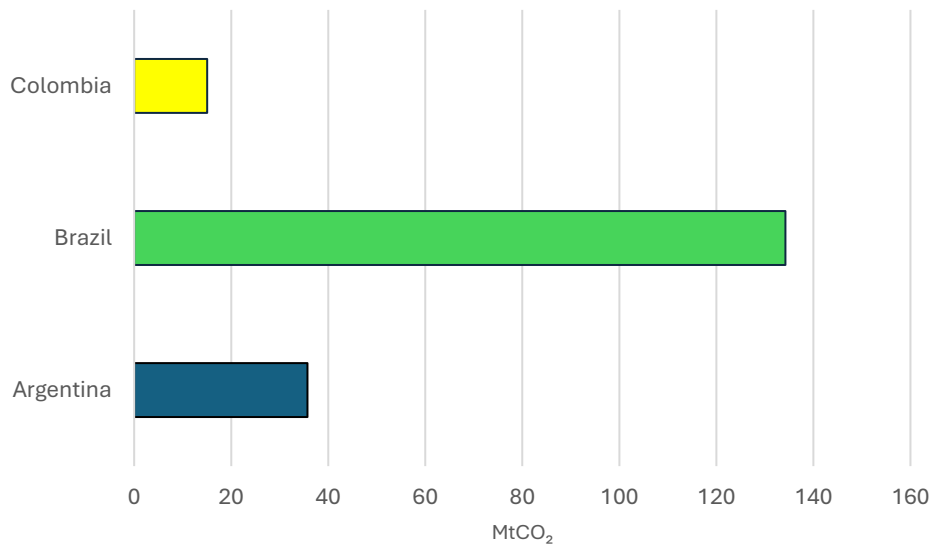
Biofuel type	Argentina	Brazil	Colombia
Solid biomass	0.89	-	-
Biogas	0.34	1.25	0.03
Sugarcane bagasse	-	59.24	1.01
Black liquor	-	31.80	-
Other Biomass	-	2.80	-



**Figure 7.** Comparison of CO<sub>2</sub> emissions by electricity-generation technology in Argentina, Brazil, and Colombia.

The most visually striking feature of Figure 7 is the magnitude of Brazil's bioenergy bar (72.05 MtCO<sub>2</sub>), which substantially exceeds all fossil-fuel contributions across the three countries. This result is a direct consequence of the large share of bioenergy in Brazil's generation mix (271,342 GWh<sub>B</sub>, see Table 5), combined with the emission factors applied to its specific biofuel composition: sugarcane bagasse, black liquor, biogas, and other biomass. However, it is essential to interpret this value within the accounting framework adopted in this study.

The CO<sub>2</sub> associated with bioenergy combustion is biogenic in origin: *it corresponds to carbon that was previously fixed from the atmosphere during the growth of the biomass feedstock*. Under IPCC guidelines, biogenic CO<sub>2</sub> is therefore reported separately from fossil emissions and is not counted as a net addition to atmospheric carbon in national greenhouse gas inventories, provided the biomass is sourced sustainably [11]. This distinction is critical: unlike fossil-fuel combustion, which introduces carbon that had been sequestered for geological timescales, bioenergy combustion operates within a short-cycle carbon loop. For this reason, the bioenergy figures reported in Table 7 and Figure 7 should not be interpreted as an environmental liability equivalent to fossil emissions, but rather as a quantification of the biogenic carbon flux associated with electricity generation from organic feedstocks in each country.



**Figure 8.** Comparison of CO<sub>2</sub> total emission in Argentina, Brazil, and Colombia.

In Argentina, emissions are overwhelmingly dominated by natural gas (30.62 MtCO<sub>2</sub>), while petroleum (3.45 MtCO<sub>2</sub>), bioenergy (1.3 MtCO<sub>2</sub>), and coal (0.35 MtCO<sub>2</sub>) contribute much smaller shares, resulting in a total of 35.72 MtCO<sub>2</sub> (Figure 8). This distribution remains fully consistent with the gas-centered structure observed in the generation profile and indicates that Argentina’s electricity-related emissions continue to be structurally concentrated in fossil thermal generation [22, 27, 28]. In this study, the Argentine bioenergy contribution was disaggregated into solid biomass (59.3%) and biogas (40.7%), according to the 2024 renewable generation balance reported by MAGyP, and the corresponding emissions were estimated from that composition [7].

Brazil exhibits a different pattern. Although its generation profile is more diversified and renewable-oriented, the largest contribution in emissions corresponds to bioenergy (95 MtCO<sub>2</sub>), followed by natural gas (20.98 MtCO<sub>2</sub>), petroleum (10.66 MtCO<sub>2</sub>), and coal (7.59 MtCO<sub>2</sub>), resulting in a total of 134.23 MtCO<sub>2</sub> (Figure 8). Under the accounting framework adopted in this study, bioenergy-related CO<sub>2</sub> is treated separately from fossil emissions; however, its absolute magnitude remains significant due to the substantial share of biomass in the Brazilian electricity mix. For this reason, Brazilian bioenergy was disaggregated into sugarcane bagasse (75.0%), black liquor (18.1%), urban-waste biogas (3.1%), and other biomass sources (3.8%), following the 2024 bioelectricity balance published by EPE [8]. At the same time, the comparatively lower contribution of coal and natural gas relative to total electricity generation confirms that Brazil remains structurally less carbon-intensive than a system dominated by fossil thermal sources, which is consistent with recent work highlighting the role of hydropower and renewable diversification in the Brazilian system. [24, 25, 29].

In Colombia, emissions are shared primarily between coal (7.74 MtCO<sub>2</sub>) and natural gas (5.87 MtCO<sub>2</sub>), while petroleum (0.44 MtCO<sub>2</sub>) and bioenergy (1.0 MtCO<sub>2</sub>) remain secondary contributors, resulting in a total of 15.05 MtCO<sub>2</sub> (Figure 8). This is particularly relevant because it shows that, despite the predominance of hydroelectric power in the Colombian system in terms of electricity output, thermal backup continues to account for a substantial share of the country’s operational emissions. In the present calculation, Colombian bioenergy was approximated as bagasse (94.75%) and biogas (5.25%), using the 2024 UPME [9] distribution as a proxy for the composition of the bioelectricity segment. In comparative terms, Colombia appears less fossil-intensive than Argentina, but still more dependent on fossil fuels than Brazil’s more diversified renewable energy

structure, consistent with recent regional studies showing that the pace and depth of electricity decarbonization in Latin America depend strongly on the technological composition of each national power system. [1, 26, 27].

## 4. Conclusions

The comparative analysis carried out enabled relating the electricity generation of Argentina, Brazil, and Colombia to their respective input energy requirements and to the CO<sub>2</sub> emissions associated with generation technologies. This approach enabled complementing the conventional reading of the electricity matrix and demonstrating that the system's technological structure directly affects its environmental performance.

The results confirm that fossil emissions from the electricity sector remain concentrated in thermal technologies, especially those powered by coal, natural gas, and petroleum derivatives. Therefore, emission reductions do not depend solely on increasing the share of renewable sources, but also on reducing dependence on fossil fuels that sustain the system's operational reliability.

In relation to the NDCs of the selected Latin American emerging countries, the 2024 results should not be interpreted as a direct verification of compliance, given that national commitments are mainly defined for horizons such as 2030. However, these findings do constitute a relevant baseline for assessing whether the current trajectory of the electricity sector is consistent with those commitments. In this context, the persistence of significant fossil contributions in the three countries suggests that there are still gaps between the current generation structure and the pace of transformation required to align with national climate targets.

Finally, this work provides a reference basis for future studies focused on decarbonization pathways in the power sector, capacity expansion, and climate compliance in South America. The articulation between energy planning and NDC targets, therefore, appears as a central element for the future development of the regional power system.

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## Nomenclature

BECO: Colombian Energy Balance

Bioenergy CO<sub>2</sub>: Carbon dioxide emissions associated with biomass, reported separately from fossil emissions

IPCC: Intergovernmental Panel on Climate Change

UPME: Mining and Energy Planning Unit

NDC: Nationally Determined Contribution

SIMEC: Colombian Mining and Energy Information System

$CO_{2,i}$  Emission by technology

$E_{el,i}$  Electricity by technology [TJ]

$\eta$  conversion efficiency or representative exergy efficiency

$B_{x,i}$  Exergy by technology [GWh]

$EF$  Carbon dioxide emission factor [ $\frac{tCO_2}{TJ}$ ]

$EF_{bio}$  Carbon dioxide emission factor for bioenergy (biogenic emission) [ $\frac{tCO_2}{TJ}$ ]

GWh gigawatt-hour

GWh<sub>B</sub> gigawatt-hour equivalent of exergy

MtCO<sub>2</sub> Million tonnes of carbon dioxide

PCI / LHV lower heating value / lower heating value [ $\frac{MJ}{kg}$ ]

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