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Energy Security in Ecuador: An Analysis Considering the Interrelationships of the WEF Nexus

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Abstract: The objective of this research was to analyze energy security in Ecuador, which is interconnected with water and food security. As a methodology, 21 indicators grouped into the following dimensions were analyzed: availability, infrastructure, energy prices, efficiency, social impact, environment and governance. For each indicator, a cross-sectional analysis was carried out with the countries of Colombia, Peru and Bolivia, along with a longitudinal analysis from 2011 to 2021. The main contribution of this study is the characterization of the Ecuadorian energy system as available, accessible, affordable and renewable in an electrical matrix but inefficient and heavily dependent on fiscal resources. The factors that may affect Ecuador's energy security were determined to be the risk of a reduction in income due to it becoming a net importer of energy, climate change, socio-environmental conflicts, poor diversification, energy subsidies and weak governance. A policy is proposed aimed at decoupling development from fossil fuels, with a systemic vision considering the complexity of interactions with other economic sectors, such as water and food, among others.

Keywords: energy security; WEF nexus; energy matrix

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1. Introduction

Energy security, along with water and food security, is a constitutive part of the WEF nexus. This approach sees our hyperconnected worlds of water, energy and food as increasingly interdependent [1]. Although this concept is not new, it emerged as a global security concern about natural resources following the financial, energy and food crises of 2007 and 2008 [1–3]. In 2011, the World Economic Forum published a correlation risk between the water, energy and food sectors, warning of the social and political instability that this can lead to [4]. The pioneering conference on the WEF nexus [5] was held in Bonn, Germany, with the premise that the impacts in one sector affect the others. This event focused not on economic security but on human security [6].

The region of Latin America and the Caribbean (LAC) has abundant natural resources, which have facilitated its economic development. This region is an exporter of water, food and energy; however, these export activities have been associated with negative impacts on the environment and social well-being, particularly for local communities. High levels of inequality, poverty and dissatisfaction with the fulfillment of human rights persist. The climate change underlying WEF nexus considerations is present as a challenge. It will affect agriculture, energy, industry and domestic use [1,7].

The Ecuadorian Constitution, characterized as progressive, implicitly recognizes an interrelation between resources. Articles 313 and 318 mention that water and energy are strategic sectors that should primarily serve food sovereignty. According to Gordillo and Méndez [8], both food security and food sovereignty emphasize the need to increase production, productivity and access to nutritious food.

It should be noted that since the origins of the WEF nexus, water has been placed on a more important plane with respect to the other two elements. However, studies, such as those by Terrapon et al. [2] Ferroukhi et al. [9] and Ochoa and Bracamonte [10], highlight the role of energy in interactions with water and food. The unavailability, inaccessibility and unaffordability of energy have direct implications in the purification, distribution and sanitation of water; in the production, processing and transportation of food; as well as at the household level, in the sanitary use of water and the storage and cooking of food.

Article 334 of the Ecuadorian Magna Carta mentions that the state will promote, among other things, energy sovereignty. According to Montesdeoca [11], this term used by the Constituent Assembly can be summarized as security of supply, competitiveness, sustainability and accessibility. These four aspects are covered by the seven dimensions of energy security, which according to Ang et al. [12] are energy availability, infrastructure, energy prices, efficiency, social impact, environment and governance.

Energy security is essential to meet the fundamental, basic and productive needs of society [13]. It has acquired a special concern due to climate change [14,15], increased demand for energy [16], socio-environmental conflicts [16], the phenomenon of energy poverty [12], the peak oil hypothesis [14], EROI theory [17] and energy dependency [18], among others. Energy security is considered one of the three relevant factors of energy policy by the International Energy Agency (IEA) [19], due to its negative externalities, growing global interdependencies and the unequal distribution of resources on the planet, specifically crude oil [20].

Ecuador has one of the largest oil reserves in LAC. However, it runs the risk of becoming a net importer of this hydrocarbon in the medium term. This scenario is concerning, because oil is the most important source of foreign exchange contributing to the financing of the state budget, and the main social investment expense in Ecuador is for fuel subsidies. According to the International Energy Security Risk Index [21], Ecuador, from 1980 to 2018, has had a worsening energy security index at an annual rate of 8%. This could trigger internal conflicts with their corresponding social, political and economic instability. So, the objective of this research was to analyze the energy security in Ecuador, which is interconnected with water and food security.

The novelty of this study is the recognition of factors that in the medium term could eventually put Ecuador's energy security at risk, such as becoming a net importer of oil, with its consequent decrease in tax revenues; the growing socio-environmental problems, motivated largely by the empowerment of the indigenous sector; climate change, due to the strong water–energy interrelationship; indiscriminate energy subsidies, which stimulate overconsumption; the state's centralized energy structure, which limits energy diversification; and weak governance that prevents achieving national agreements. For these reasons, it is suggested as a working hypothesis for future research that Ecuador is heading towards a situation of energy vulnerability.

The remaining part of this paper is organized as follows: Section 2 presents the Ecuadorian energy system, including its historical evolution, and its primary and its secondary energy sources. Section 3 presents the methodology used, which consisted of analyzing seven dimensions and twenty-one indicators through a cross-sectional comparison with its neighboring countries of Colombia, Peru and Bolivia, but also longitudinally, over time. Section 4 contains an analysis and discussion of each indicator. This analysis shows the interrelationship between energy, water and food resources in Ecuador. At the end of this document, in Section 5, the conclusions are presented. There, the Ecuadorian energy system is characterized, implications for energy security are presented, and public policies are proposed.

2. Ecuadorian Energy System

The use of energy sources, their process of transformation, transportation and use, is interconnected with political, economic, social, and cultural elements that together make up an energy system. According to Castro [22], energy systems explain the development of societies, their collapse, internal conflicts, the role of intermediaries, the irrationality of economic systems and the connection between financial processes, culture and decision making [22]. In this chapter, the evolution of the energy sector, primary energy, and secondary energy are analyzed.

2.1. Evolution of the Energy Sector

Since 1972, oil has undoubtedly been the most important product and subject of disputes in the Ecuadorian economy and society, not only to meet the domestic demand for fuels and electricity generation but also due to the revenues derived from exports, which have been part of the government's fiscal resources. In the same year, the Hydrocarbons Law came into effect, and the newly created Ecuadorian State Oil Corporation (CEPE) took control of the areas in production [23]. In 1973, Ecuador began oil exports in an international context marked by sustained increases in oil prices [24]. It joined OPEC and became the second-largest hydrocarbon producer in South America, consolidating the external sector as the main component of its economic dynamics [23].

Historically, a part of the oil benefits has been invested in developing other energy areas, particularly the electricity sector [25]. Ecuador had ranked among the lowest in electrification in Latin America, and firewood was the most widely used final energy source [26]. In 1970, the National Electrification Fund was created, funded by the royalties the government received from oil production. Between 1976 and 1987, the Ecuadorian Electrification Institute (INECEL, its initials in Spanish) built hydroelectric and thermal power generation projects. In Latin America and the Caribbean (LAC), the construction of large infrastructure works such as dams, power generation plants and power grids was a characteristic of the 1970s and 1980s, when governments were interested in promoting economic development through the extension of energy supply [27].

The oil boom resulted in generous subsidy policies and fueled rapid growth in public spending, which led to increasing indebtedness. This led to a significant reduction in agriculture, turning Ecuador into a food-importing country and predominantly urban, which brought about rural-to-urban migration and the formation of poverty belts on the outskirts of cities, especially in Guayaquil. This led to clear symptoms of the so-called Dutch disease [28].

Starting in 1986, oil prices fell dramatically, causing severe disruptions in various years (1982–1983, 1986, 1997–1998) [29], which resulted in recurring devaluations and an increase in the price of domestic fuels, leading to strikes and commotions. The economy experienced long-lasting stagnation, and social conditions deteriorated, accompanied by accelerated deforestation and other environmental impacts. The crisis also affected the electricity sector as royalties from oil were frozen, while electricity tariffs remained practically fixed, leading to a deterioration in INECEL's capacity. From 1992 to 1997, there were continuous electricity rationing measures [30]. State production of light crudes declined from 1993 due to Petroecuador's limited reinvestment in secondary and tertiary recovery in old fields [23].

Starting in the year 2000, Ecuador dollarized its economy, coinciding with an upward trend in international oil prices. This translated into a significant increase in importations, among which fuels and automobiles have stood out. The deficiencies of the productive system were exacerbated by the loss of local competitiveness resulting from the exchange rate appreciation under the dollarization scheme [31].

In 2008, a new Constitution was approved, strengthening the role of the state and rejecting the privatization policies implemented in the 1990s. It declared the energy sector, both hydrocarbons and electricity, as strategic, with the right to manage, regulate, control and administer it. Petroleum reforms were implemented to reclaim control over natural resources [24,32]. Changes were introduced in the electricity sector, promoting a central role for the state in generation, transmission and distribution, in investment for the expansion and integration of activities, and as guarantors of a single tariff and subsidies.

By 2005, the electricity system not only faced vulnerability from long periods of drought but also had a high dependence on fossil fuels and imported electricity, accounting for 44% and 11%, respectively. In late 2009 and early 2010, the country experienced power rationing again. This trend did not change significantly until 2016, when hydroelectric energy accounted for 57.6% of total capacity, thanks to the contribution of new hydroelectric plants such as Coca-Codo-Sinclair with 1500 MW and Sopladora with 487 MW [33].

The petroleum sector continued to be a relevant aspect of the Ecuadorian economy, especially for the central government, as it represented a significant source of income, averaging USD 8 billion between 2000 and 2019 [34]. Ecuador entered a phase of unprecedented economic growth driven by high oil prices and other commodities. It launched an ambitious program of investments in road infrastructure, the energy matrix and social policies, which led to an expanding economy and the emergence of a middle class. However, the collapse of oil prices in 2014 had a severe adverse impact on public finances and the balance of payments [35].

On 26 June 2007, the execution of a project for the construction of a new refinery with a capacity of 300,000 barrels per day was approved through a strategic alliance between Petróleos de Venezuela S.A. and Petroecuador. This project established the creation of the Refinery Complex in the Ecuadorian Pacific, in the province of Manabí. The deadline for starting operations was initially set for 2013 but was later extended to 2015 and finally to 2017, pending the injection of capital by the Chinese state-owned company China National Petroleum Corporation [36], which never materialized. In 2017, President Lenín Moreno requested its dismissal due to the absence of investors [37].

To strengthen energy security and achieve an efficient substitution of petroleum derivative imports, the National Development Plan (Senplades, 2009), called the National Plan for Good Living 2009–2013, prioritized the use of biofuels. The goal was to achieve an effective substitution of petroleum derivative imports and strengthen energy sovereignty in light of the depletion of oil reserves [38]. In 2015, the progressive substitution of all "Extra" gasoline with a blend called "Ecopaís" was established. This fuel is a mixture of gasoline and ethanol made from sugarcane juice or molasses.

In 2014, with the aim of reducing LPG imports, Ecuador implemented, according to Nolivos [39], the largest program in the world to switch to electric stoves. This program aimed to introduce 3 million induction cookers in an equal number of households, which also involved parallel investments in household connections and incentives for users who opted for this option. By the end of 2017, a little over 700,000 units had been sold [35].

The discretionary price controls for fuels introduced during the oil price boom ended up becoming a problem for the governments in power. Attempts to reduce them led to indigenous uprisings in October 2019 and June 2022, which were significantly violent, involving road blockades, disruption of public services, damage to public infrastructure, injuries and fatalities [40–44]. According to the Central Bank of Ecuador (BCE), the economic impact of the October 2019 events amounted to a total of USD 821.68 million, mainly affecting the productive sector [45]. By June 2022, the BCE estimated that the economic impact reached USD 1115.4 million, with the energy and hydrocarbon sector being the most affected [45–47].

2.2. Primary Energy

For a country, having a wide range of primary energy resources confers a series of strategic and economic advantages, including reducing dependence on energy imports, decreasing vulnerability to price fluctuations in the global market and the possibility of strengthening internal energy security. This section examines the different sources of primary energy present in Ecuador, emphasizing resources such as oil, which has played a leading role in the country's economy, hydroelectric power and biomass, among other primary sources.

2.2.1. Oil

Only a few countries in Latin America and the Caribbean are net exporters of crude oil, natural gas and fuels. In 2019, only Bolivia, Colombia, Ecuador, Trinidad and Tobago, Venezuela, Brazil and Peru exported more oil, natural gas and fuels than they imported [48].

Oil production in 2007 marked a turning point as it began to decline, primarily due to the depletion of the mature fields Shushufindi-Aguarico and Libertad-Atacapi [33]. Nashawi et al. [49] identify this year as the peak of oil production in Ecuador, a concept developed by geophysicist King Hubbert, who predicted that once it reaches its highest point, it rapidly declines due to the energy required for its exploitation [50].

According to Parra et al. [51], the energy return rate (EROI) for medium oil blocks is in a ratio of 36:1, and for heavy oil blocks it is 18:1. This is understandable from a technical point of view since processes in extraction become more energy-intensive as the API gravity increases, but also in terms of water consumption. Ecuadorian oil is classified as Oriente crude and Napo crude, the former with an average API gravity of 23 degrees and sulfur content of 1.45%, and the latter between 18 and 21 degrees API with a sulfur content of 2.10% [52]. In Ecuador, as conventional oil reserves run low over time, government statistical figures suggest a gradual shift from light and medium to heavy oil production [51,53]. See Figure 1.

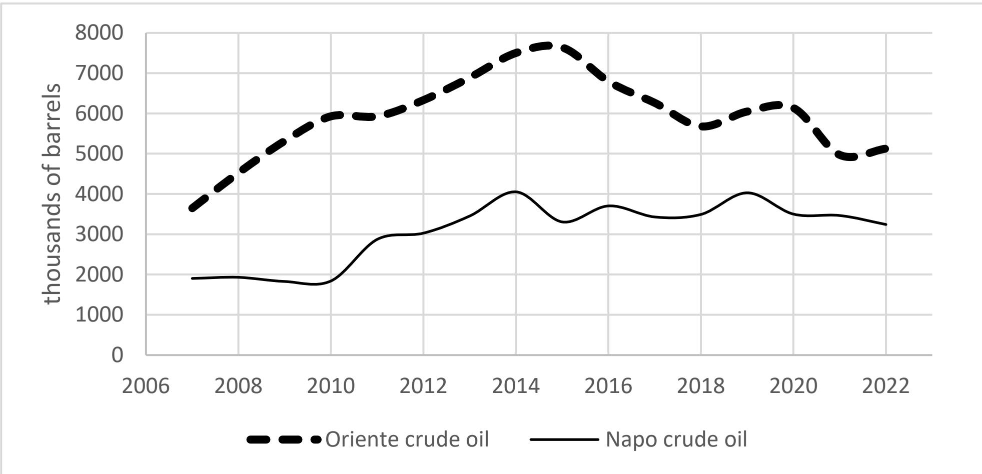

Figure 1. Ecuadorian exports broken down by Oriente and Napo crude oil. Elaboration based on data from BCE [54].

2.2.2. Hydroelectric Power

Table 1 provides an overview of the largest hydroelectric power plants located in Ecuadorian territory. This information facilitates an understanding of the geographical distribution and hydroelectric power generation potential of the country. Until the first decade of this century, 90% of the hydroelectric energy supply in Ecuador was concentrated in four large plants: Paute, Agoyán and Pisayambo-Pucará located in the Amazon region, and the Marcel Laniado plant located in the Guayas Province. In the 2010s, there was significant progress in this type of generation.

Table 1. Expansion of hydroelectric power generation.

Name	Year	Province	River	Power (MW)
Pucará	1977	Tungurahua	Yanayacu	70
Paute-Molino	1983	Morona Santiago	Paute	1100
Agoyán	1987	Tungurahua	Pastaza	156
Marcel Laniado	1999	Guayas	Daule	213
San Francisco	2004	Tungurahua	Pastaza	230
Mazar	2015	Cañar	Mazar	170

Table 1. *Cont.*

Name	Year	Province	River	Power (MW)
Manduriacu	2015	Imbabura–Pichincha	Guayllabamba	65
Sopladora	2016	Azuay–Morona Santiago	Paute	487
Coca Codo Sinclair	2016	Napo	Coca	1500
Delsitanisagua	2018	Zamora	Zamora	180
Minas-San Francisco	2019	Azuay–El Oro	Jubones	275

Elaboration based on data from MERNNR [55].

2.2.3. Biomass

Between 2011 and 2021, the production of energy from sugarcane bagasse increased from 1423 kBOE to 2006 kBOE, while the production from firewood decreased from 2197 kBOE to 1565 kBOE. In 2021, these represented 1.1% of the electricity matrix. Sugarcane bagasse was used for industrial purposes (68%), electricity generation (20.3%) and distilleries (11.7%) [56].

During the period from 2011 to 2021, the use of molasses increased from 6224 tons to 52,496 tons, and the use of sugarcane juice increased from 42,301 tons to 356,768 tons. They experienced an annual growth rate of 24.3% between 2011 and 2021 [56]. These are inputs for ethanol production, which is a component of the gasoline called "Ecopaís".

Since 2016, data have been collected from two biogas generation plants, internal combustion engines located at the Inga landfill in Quito and the Pichacay landfill in Cuenca, with capacities of 5 MW and 1.2 MW, respectively. In 2021, they represented 0.1% of the electricity matrix.

2.2.4. Other Primary Sources

Intermittent renewable energies such as solar and wind as well as other biomass sources are classified as other primary energy sources. They have had an annual growth rate of 58.7% from 2011 to 2021. However, in 2021, they only represented 0.3% of the electricity matrix [56]. Ecuador had the lowest installed solar capacity in Latin America and the Caribbean in 2021 [57].

Pinion oil is used for electricity generation on Floreana Island in the Galapagos to replace diesel and promote the agro-industrial development of the existing pinion oil (*Jatropha curcas*) hedges in the province of Manabí [58]. However, it has experienced an annual decline of 13% from 2011 to 2021 [56].

2.3. Secondary Energy

In 2021, the main energy sources consumed were diesel with 29,199 kBOE, gasoline with 26,376 kBOE, electricity with 16,910 kBOE, LPG with 9872 kBOE, and fuel oil with 3218 kBOE [56].

2.3.1. Petroleum Derivatives

Throughout 2021, the refined petroleum products most in demand were diesel, gasoline and LPG, as shown in Table 2. The transportation sector stands out as the most important consumer of diesel and gasoline, accounting for 83.0% and 82.3%, respectively. As for LPG, the residential sector is the largest consumer, representing 70.4% of the total consumed in the country.

Table 2. Consumption of petroleum derivatives by sector, expressed in percentages.

	Diesel	Gasoline	LPG
		%	
Transport	83.0	82.3	1.0
Industry	12.4	0.7	7.3
Commercial	2.7	-	4.2

Table 2. *Cont.*

	Diesel	Gasoline	LPG
		%	
Residential	-	-	70.4
Agriculture, fishing and mining	-	3.5	1.9
Others	1.9	13.3	15.2
Annual change in total demand	1.8	2.3	2.3
Imports	69.5	60.9	88.0
Annual variations in imports	4.5	3.6	3.2

Elaboration based on data from the National Energy Balance [56].

2.3.2. Electricity

In 2021, the electricity consumption was 26,969 GWh, with the following breakdown of sources: hydroelectric power 74.63%; thermal power 23.89%, which comes from plants distributed in various provinces (see Table 3); biomass 1.05%; wind power 0.18%; biogas 0.13%; and photovoltaic 0.12% [59]. From 2011 to 2021, it had an average annual growth rate of 3.9%. Considerable consumers are the industrial and residential sectors, accounting for 42% and 30%, respectively. The remaining 28% is for the commercial sector and other users [56].

Table 3. Main thermal power plants in Ecuador.

Name	Province	Power (MW)
Jaramijó	Manabí	149.2
Gonzalo Zeballos Foil	Guayas	146.0
Machala Gas	El Oro	138.6
Machala Gas 2	El Oro	136.8
Esmeraldas	Esmeraldas	132.5
Trinitaria	Guayas	133.0
Edén Yuturi	Orellana	119.6
Anibal Santos	Guayas	113.3
Enrique García	Guayas	102.0
Esmeraldas 2	Esmeraldas	96.0
Santa Elena 2	Santa Elena	90.1
Santa Rosa	Pichincha	71.1
Quevedo 2	Los Ríos	47.6
Sistemas Insulares	Galápagos	24.3

Elaboration based on data from ARCERNNR [59].

2.3.3. Fuel Oil

Fuel Oil is the most used fuel for electricity generation in Ecuador, although it has experienced an annual reduction of 9.9% from 2011 to 2021 [56], primarily due to the incorporation of new hydroelectric power plants and renewable energy sources [59].

3. Methodology

In this research, a cross-sectional and/or longitudinal analysis of twenty-one indicators of the following seven dimensions was used: availability, infrastructure, energy prices, efficiency, social impact, environment and governance. These indicators are commonly used in long-term energy security studies, although not all studies incorporate all indicators [12,60–62].

In the cross-sectional analysis, as in Castro et al. [63] and Fontaine [64], these indicators were compared with those of neighboring countries such as Colombia, Peru and Bolivia, which share the same geographical and historical context, have similar productive structures and have comparable sizes. Sometimes, these comparisons were expanded to the Andean and LAC regions. Longitudinally, the trends of these indicators were compared over time, usually from 2011 to 2021. These indicators were acquired from OLADE, BIEE, IEA and the National Energy Balance 2021. See Table 4.

Table 4. Dimensions of energy security and indicators used.

Dimension	Indicator
Availability	Per capita primary energy supply and final energy consumption Scope of proven oil and gas reserves Energy self-sufficiency Diversification Renewability in the primary supply Dependence on petroleum derivatives for transportation
Infrastructure	Fuel infrastructure Hydroelectric infrastructure
Energy prices	Liquefied petroleum gas priceElectricity energy price Gasoline and diesel prices
Efficiency	Energy intensity Sectoral energy intensity Efficiency indicators in transportation Electrical losses
Social impact	Electric coverage
Environment	Forest coverage Water availability Per capita carbon dioxide emissions Per capita sulfur dioxide emissions
Governance	Worldwide governance rating

In the specific case of diversification within the availability indicator, the Shannon–Weaver Index (SWI) was used for analysis. It considers "source species" of each of the different primary energy sources present in the energy matrix of each country in Latin America and the Caribbean; data collected from SIELAC [63] are included. The primary sources (i) considered are oil, natural gas, coal, hydro, geothermal, nuclear, firewood, sugarcane and other primary sources, with the total energy supply expressed in kBOE. Once the "species" are defined with their respective energy values, the following formula is applied:

$$SWI = -\sum_{i=1}^{j} p_i ln(p_i)$$

where p_i corresponds to the portion that the source has in the total primary energy supply. This value is calculated for a total of nine primary sources (j).

4. Analysis and Discussion of Indicators

This section focuses on the analysis and discussion of key dimensions and indicators that make it possible to assess various facets of Ecuador's energy security. The dimensions analyzed were availability, infrastructure, energy prices, efficiency, social impact, environment and governance.

4.1. Availability

Ecuador is one of the few countries in the Latin America and Caribbean region that is a net exporter of oil, as already indicated in Section 2.2.1. The hydrocarbon autarky of Ecuador in the year 2021 was 1.95 [63].

Ecuador significantly relies on oil exports to finance its national budget [64]. According to figures from the Central Bank (BCE), in the period between 2011 and 2014, Ecuador experienced a notable economic influx through oil exports, reaching revenues of over USD 10 billion, with an average of 136 million barrels exported. The heyday of this period was observed in 2013, when revenues amounted to USD 12,578 million. This figure resulted from the international sale of 140 million barrels of oil, considerably supported by the high oil prices that prevailed at that time.

However, in 50 years of oil exports, Ecuador has not been able to escape underdevelopment. This contradiction can be understood in light of the theory of dependency, which reveals a historical–structural difference between the productive, social and institutional specificities of developing countries, referred to as the periphery, in contrast to the economies of developed countries, referred to as the center. The limited dynamism of global demand for primary products originating from the periphery contrasts with the high demand of the periphery for industrial products produced in the center. This results in a deficit balance of payments that has adverse effects on the dynamism and stability of economic growth with social and political implications [65]. This instability is curiously reflected in its energy matrix as, despite its abundance of natural resources, Ecuador imports half of the energy it consumes, as will be seen in Section 4.1.3.

To reflect the availability dimension, five metrics were used: per capita primary energy supply and final energy consumption, the scope of proven oil and gas reserves, energy self-sufficiency, diversification and the proportion of renewable energy in the total primary energy supply.

4.1.1. Per Capita Primary Energy Supply and Final Energy Consumption

The primary energy supply per capita in Ecuador is 0.88 tons of oil equivalent (tep) per person, similar to that of Colombia and higher than that of Bolivia and Peru. Between 2011 and 2021, in Ecuador, this indicator decreased by an annual average of 0.5%, due to the incorporation of new hydroelectric generation plants, which grew by 87.6% in the same period. See Table 5.

Table 5. Primary energy supply and final energy consumption per capita.

	Primary Energy Supply per Capita		**Final Energy Consumption per Capita**	
	Average 2021	**Annual Variation 2011–2021**	**Average 2021**	**Annual Variation 2011–2021**
	Toe/Capita	**%**	**Toe/10^3 Capita**	
Bolivia	0.75	1.2	595.06	1.8
Colombia	0.89	0.1	653.37	0.4
Ecuador	0.88	−0.5	742.99	0.4
Peru	0.72	0.1	605.14	−0.1
Andean zone	0.84	−2.9	618.04	−3.1
LAC	1.22	−1.2	912.01	−0.9

Elaboration based on data from SIELAC [63].

In 2000, Ecuador and Peru had similar per capita final energy consumption of 470 toe/1000 people, while Colombia had 567 toe/person, representing a 21% difference. However, by 2021, Ecuador's energy consumption was 14% and 23% higher than that of Colombia and Peru, respectively. See Table 5 and Figure 2. According to Castro et al. [66], the higher energy consumption in Ecuador compared to the other analyzed countries was due to transportation.

Throughout the period from 2011 to 2021, fossil fuels were the main source of energy. In 2021, oil, gas, hydroelectricity and other primary sources represented 71%, 5%, 19% and 5%, respectively.

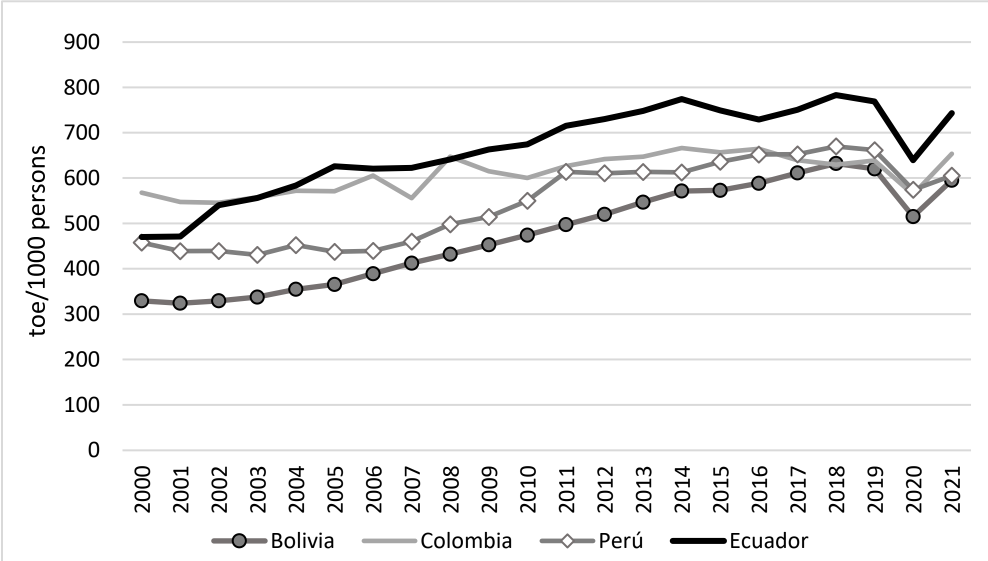

Figure 2. Final energy consumption in Bolivia, Colombia, Ecuador and Peru. Elaboration based on data from SIELAC [63].

4.1.2. Scope of Proven Oil and Gas Reserves

Venezuela, Argentina, Colombia, Mexico and Ecuador have the largest proven onshore reserves in LAC, with 302.8, 2.8, 1.8, 1.7 and 1.3 Gbbl, respectively. The scope of Ecuador's proven oil reserves is 7.7 years, similar to Colombia and Peru. Ecuador's proven oil reserves have decreased significantly, at an annual rate of 8.8% from 2011 to 2021, faster than those of neighboring countries [63]. See Table 6. Oil production also has been declining, at an annual rate of 0.6% from 2011 to 2021 [56].

Table 6. Scope of proven oil and natural gas reserves.

	Oil		Natural Gas	
	Average 2021	Annual Variation 2011–2021	Average 2021	Annual Variation 2011–2021
	Years	%	Years	%
Bolivia	12.75	−2.0	14.94	−1.3
Colombia	6.76	0.0	4.42	−1.1
Ecuador	7.70	−8,8	3.03	−0.1
Peru	8.01	−3.5	15.31	−4.2

Elaboration based on data from SIELAC [63].

Ecuador is on the way to becoming a net importer of oil due to (i) the growing proportion of heavy crude oil, which reduces energy efficiency; (ii) the restrictions on the expansion of the oil frontier in the Amazon, for both environmental and social reasons; and (iii) the growth in demand and imports of petroleum derivatives [32,67–69].

Natural gas production in Ecuador comes from the Amistad Field in the Gulf of Guayaquil and oil exploitation in the eastern part of the country, where a significant portion of the produced gas is vented. The scope of proven gas reserves in Ecuador is 3.03 years, lower than those of Colombia and Peru. Ecuador and Colombia have balanced supply and demand for natural gas, while Peru is an exporter [70].

Between 2011 and 2021, there was a decrease of 0.2% in the production of associated and non-associated natural gas. See Table 6. Regarding associated gas, since 2015, a portion of the vented gas has been used to replace diesel oil in electricity generation for oil field operations [56,70]. Non-associated natural gas is utilized for power generation at the Bajo Alto thermoelectric plant in the El Oro province, with a capacity of 277 MW. Additionally, this energy resource is supplied to the industrial sector as liquefied natural gas, transported by cryogenic tankers from a liquefaction plant located in the Bajo Alto area. However, the installation has experienced land subsidence issues and there is a decline in gas pressure [71–74].

4.1.3. Energy Self-Sufficiency

Bolivia, Colombia, Ecuador and Peru are among the countries with higher energy self-sufficiency indices in the Latin America and Caribbean region, along with Venezuela, Brazil and Guyana [63].

Ecuador has an energy self-sufficiency index of 1.79, which has been decreasing at a rate of 1.1%. The external energy dependence is −78.67%, and between 2011 and 2021, Ecuador became more dependent at an annual rate of 2.3%. To achieve energy sovereignty, as mentioned in Ecuador's Constitution, the ideal scenario would be to depend less on imports, as Peru has done at an annual rate of 8.8%. See Table 7.

Table 7. Energy sufficiency and foreign energy dependence.

	Energy Sufficiency		Foreign Energy Dependence	
	Average 2021	Annual Variation 2011–2021	Average 2021	Annual Variation 2011–2021
		%	%	%
Bolivia	1.97	−2.4	−97.47	−4.2
Colombia	2.27	−4.6	−139.58	−4.7
Ecuador	1.79	−1.1	−78.67	−2.3
Peru	1.27	−0.2	−15.28	8.8
Andean zone	1.99	−3.4	−101.67	−5.0
LAC	1.12	−1.5	−5.76	−14.0

Elaboration based on data from SIELAC [63].

After dollarization, the economy became addicted to imports [75]. Among the items with the highest demand were vehicles and transportation equipment, accounting for 4% and 8% of the value of imports between 2000 and 2021, respectively. This significant growth in the vehicle fleet led to increased imports of petroleum derivatives, which accounted for 17% of the value of imports from 2000 to 2021 [31,76]. It is worth mentioning that, being a dollarized economy, the results of the external sector are crucial for the liquidity of the financial system. Therefore, among other measures, reducing imports is desirable [34]. See Figure 3.

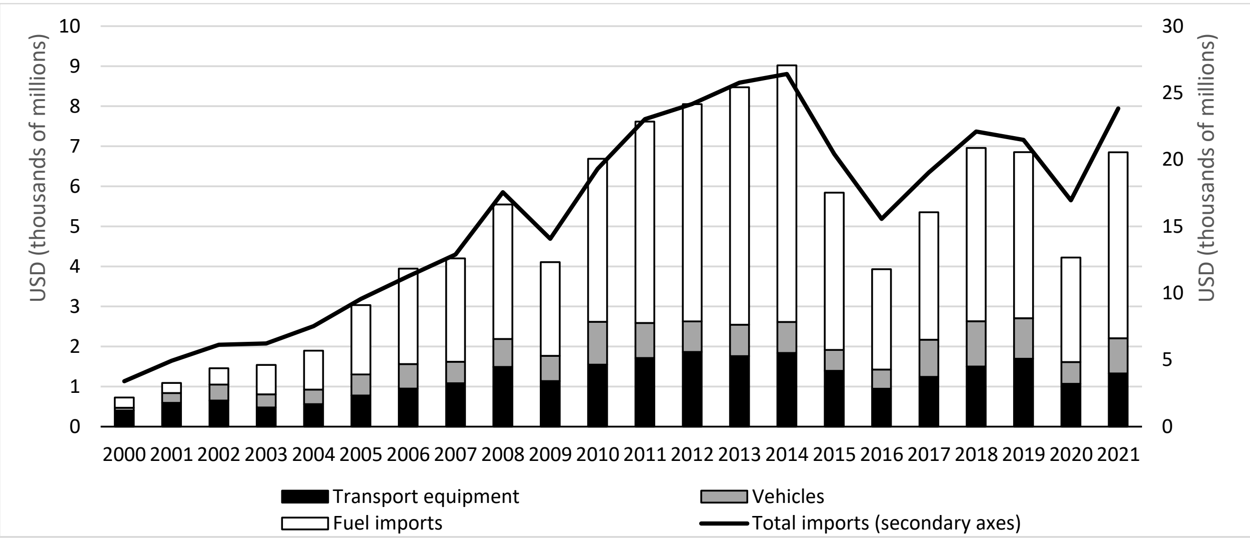

Figure 3. Amounts of total imports of vehicles and fuels. Elaboration based on data from BCE [77] and CEPALSTAT [78] for vehicles.

The capacity, characteristics and obsolescence of Ecuador's refineries do not allow it to meet the domestic demand for petroleum derivatives. The existing refineries were not designed to process the heavy crudes that the country is increasingly producing and which constitute the majority of its reserves [79].

According to the Energy Balance [56], Ecuador imported 12.73% and 48.71% of its consumed energy in 2000 and 2021, respectively, indicating an average annual consumption growth rate of 3.1% [56].

In 2021, Ecuador had to import 65% of its diesel, 62% of its gasoline and 85% of its LPG to meet the high demand for petroleum derivatives. About 67% of the supply of these energy products is imported. From 2011 to 2021, there has been a growth of 156% in diesel imports, 142% in gasoline imports and 132% in LPG imports, while the GDP grew by 13.4% [56].

4.1.4. Diversification

Regarding the ability of the region's energy systems to respond and adapt, one important dimension is their diversification. The Shannon–Weaver Index (SWI) has been used as an indicator for this type of analysis, where a higher value indicates a better balance and diversity of the energy matrix [80]. Ecuador and Bolivia exhibit low diversification, while Colombia and Peru show a greater variety in their primary energy sources. See Table 8.

Table 8. Shannon–Weaver Indicator.

	SWI (Average 2021)
Bolivia	1.15
Colombia	1.56
Ecuador	0.88
Peru	1.56
Venezuela	1.07
LAC	1.77
Andean zone	1.43

Elaboration based on data from SIELAC [63].

According to Fontaine [81], the modes of energy governance influence the diversification of the energy matrix. On one hand, Venezuela, Ecuador and Bolivia, with a centralized governance style focused on the state, exhibit low diversification of energy sources. On the other hand, Colombia and Peru, with a decentralized and market-oriented governance style, have greater participation in other energy sources.

4.1.5. The Proportion of Renewable Energy in the Total Primary Energy Supply

In 2021, Ecuador's renewable energy index was 17.45% [56], which was lower than that of Colombia and Peru. See Table 9. According to CEPAL [82], along with Mexico, Argentina and Bolivia, Ecuador has one of the lowest renewable energy indexes in the region. However, the growth rate of the renewable energy index, at 4.6% annually, has been the highest in the LAC region. This significant increase can be attributed to the integration of hydroelectric power plants into the country's energy system, as indicated in Section 2.2.2.

The Andean region, with a percentage of 75.46%, has the highest proportion of renewable energy in its electricity matrix, primarily through hydroelectric generation [83]. Colombia and Ecuador stand out with percentages of 83.42% and 81.00%, respectively. Between 2011 and 2021, Ecuador experienced a growth of 3.8% in this aspect. Ecuador, with 80%, is second only to Venezuela, with 97%, in LAC in terms of its dependence on hydroelectric power among the renewable energy sources [63]. See Table 10. According to SENAGUA (the National Water Secretariat of Ecuador, by its initials in Spanish) [84], 80.5% of water concessions are for electricity generation. For this reason, it is relevant to analyze the issues within this sector, which represents a particular interrelation of the water–energy nexus.

Table 9. Comparison of renewability indicators.

	Renewability Index	
	Average	Annual Variation 2010–2021
	%	%
Bolivia	14.71	−0.7
Colombia	25.00	−1.6
Ecuador	17.45	4.6
Peru	28.78	0.4
Andean zone	22.78	1.3
LAC	29.84	1.6

Elaboration based on data from SIELAC [63].

Table 10. Indicators of the percentage of renewables in the electricity matrix of the Andean countries and the LAC region.

	Percentage of Renewables		Hydroelectric Dependency	
	Average	Annual Variation 2011–2021	Average	Annual Variation 2011–2021
	%	%	%	%
Bolivia	38.25	1.1	21	1.2
Colombia	83.42	0.0	53	0.3
Ecuador	81.00	3.8	80	2.0
Peru	61.17	0.8	50	2.2
LAC	58.97	−0.2	26	−2.8
Andean zone	75.46	1.1	62	0.0

Elaboration based on data from SIELAC [63].

In order to reduce the risks of excessive dependence on hydroelectric generation, IRENA [10] proposes implementing other renewable energy sources, even if they are intermittent. According to OLADE [83], regional experience shows that intermittent renewable energy can be complemented with hydroelectric generation, utilizing the storage provided by hydropower plants.

Ecuador has a modest performance regarding non-hydropower renewable energy [85]. This contrasts with its privileged location on the equatorial line, which gives it a significant reception of solar radiation. According to the National Renewable Energy Laboratory (NREL) [86], on a scale of 3.0 to 6.5, Ecuador registers, on average, between 4.5 and 5.5 kWh/m^2/day of global horizontal radiation, with the insular region concentrating the higher radiation levels.

Regarding biomass, the most appropriate agricultural residues for electricity generation are African palm and banana, both export crops, and rice and sugar cane, which are subsistence crops [87]. In the ideal case, proposed by Calderón et al. [87], they would produce 19 GWh (our own calculation based on data from Calderón et al. [87]). The distributed nature of many of these renewable energy technologies means that they can offer solutions and generate benefits across the WEF nexus sectors. Examples include solar food drying, photovoltaic power generation, solar cooling and refrigeration, solar or wind water pumping, and the use of biomass residues for on-site power generation [10]. However, the presence of energy subsidies presents barriers to their implementation [87].

According to H2LAC [88], there are countries in the region with large-scale projects for green hydrogen production, such as Chile, Colombia, Brazil and Costa Rica. However, Ecuador currently lacks a regulatory framework or related studies in this regard.

4.1.6. Dependence on Petroleum Derivatives for Transportation

According to Campos and Pérez [89], increasing the usage of innovative energy carriers such as biofuels could reduce dependence on petroleum derivatives for transportation. A special link between the three elements of the WEF nexus occurs in the case of biofuel production. However, according to Terneus and Viteri [90], in 2019, the cultivated area used for ethanol production was about 135 km^2, which made it one of the main crops in Ecuador. It should be noted that this country depends on imports of wheat and corn, which are two of its three most consumed food products. Ethanol was also the product with the ninth largest use of land suitable for agriculture and had the seventh largest irrigated area. The required irrigation volume was 58 Mm^3, in an area of critical vulnerability to conflicts due to water scarcity. In addition, it presents a risk of aquifer contamination.

In Ecuador, biofuels account for only 0.2% of fuel [82], despite Ecopaís gasoline with a 45% market share being the most demanded, followed by Extra with 41% and Super with 14% [91].

4.2. Infrastructure

In the context of energy supply and its contribution to a country's economic and social development, the crucial importance of robust and adequate infrastructure to ensure the uninterrupted availability of energy resources is emphasized [12]. This section provides an overview of the energy infrastructure in Ecuador to meet its domestic energy demand, focusing specifically on the areas of fuel and hydroelectricity. The following indicators are analyzed: fuel infrastructure, hydroelectric infrastructure, electricity transmission and distribution infrastructure.

4.2.1. Fuel Infrastructure

Ecuador has three refineries: La Libertad, Shushufindi and Esmeraldas [92]. The daily refining of barrels of oil decreased by 7.7% from 2011 to 2021. In 2021, an average of 156,000 barrels of oil were refined daily, with 57.9%, 23.8% and 12.4% corresponding to the Esmeraldas, La Libertad and Shushufindi refineries, respectively. The remaining 6% represented the usage in topping plants in the initial refining stage [56].

There are four maritime terminals: Tres Bocas, La Libertad, Monteverde and Balao. A pipeline network transports gasoline, diesel and liquefied petroleum gas (LPG), connecting refineries and maritime terminals with fuel terminals. The pipelines include Shushufindi–Quito, Esmeraldas–Santo Domingo–Pascuales, Quito–Ambato, Libertad–Manta, Libertad–Pascuales, Monteverde–El Chorrillo, Tres Bocas–Fuel Oil, Tres Bocas–Pascuales, Ambato–Riobamba, Pascuales–Cuenca and Esmeraldas–Santo Domingo–Quito. The fuel terminals include El Beaterio in Pichincha, Santo Domingo, Ambato, Riobamba, Cuenca, Pascuales, El Chorillo, Barbascallo, La Troncal and Oyambaro. There are two fuel depots, La Toma and Baltra Island. Regarding LPG, the Monteverde–El Chorrillo gas pipeline facilitates the storage, transportation and distribution of liquefied petroleum gas in the southern region of the country [93]. This infrastructure is showing premature deterioration and its contracting has been the subject of several complaints about corruption [94].

According to Zambrano et al. [95], Ecuador's oil pipelines have a significant potential for accidents due to natural and climatic conditions, political instability, technical problems and lack of maintenance. This has led to a sustained increase in accidents. It should be noted that fuel transportation is carried out by tanker trucks to the eastern provinces and those located on the northern and southern borders, among others.

4.2.2. Hydroelectric Infrastructure

According to the Electricity Master Plan 2016–2025 [96], Ecuador has an economically feasible hydroelectric power capacity of 22,000 MW, of which only 5109 MW were installed by 2021 [56]. The biggest plant, called the Coca Codo Sinclair, is located in the province of Napo and Sucumbíos. Its construction began in July 2010 and it was inaugurated on 18 November 2016. According to Villavicencio, it has construction flaws and has been plagued by cases of corruption.

According to SIELAC [63], Ecuador has utilized 23.3% of its hydroelectric capacity, while the average for the Andean region is 15.6%. In fact, the Electricity Master Plan 2016–2025 includes several projects for expanding hydroelectric generation. The Paute

Cardenillo project in the Méndez canton, with a capacity of 596 MW, is considered a high priority. The Santiago project, located at the confluence of the Zamora and Namangoza rivers in the Morona Santiago province, is planned in four phases, each with a capacity of 600 MW [96].

However, increasing temperatures [97], fluctuating rainfall patterns [98] and the melting of glaciers in Antisana [99], Cotopaxi [100], Chimborazo [101], Cayambe [102] and Cotacachi [103], can impact this type of generation by increasing variability in seasonal flows [104]. There are different studies on this matter, with varied results.

The study carried out by Hasan and Wyseure [105] on the Jubones River (the Jubones River is located in the provinces of Azuay and El Oro, where the Minas San Francisco hydroelectric project with a generating capacity of 275 MW is located) concluded that climate change could alter the seasonal flow regime and the resulting hydroelectric potential. According to Samaniego et al. [106], projections for Ecuador indicate an average temperature increase of up to 3 °C and a precipitation increase of 5.5 mm/day nationwide by the end of the century. In the same way, the IEA [107] and Peñil et al. [104] project an increase in the hydroelectric capacity factor for the Andean region. In contrast, Zaballa et al. [108] project a 5% reduction in the hydroelectric potential for the same subregion.

4.2.3. Electricity Transmission and Distribution Infrastructure

The National Transmission System operates transmission lines at voltage levels of 500 kV, 230 kV and 138 kV. The 500 kV system allows for the transportation of electricity from the Coca Codo Sinclair hydroelectric plant to the Chorrillos substation on the Ecuadorian coast [6]. As for the sub-transmission system, by the end of 2018, Ecuador had 385 distribution infrastructures with a cumulative capacity of 6628 MVA operating at voltage levels of 46 kV, 69 kV and 138 kV.

The Andean Electrical Interconnection System (SINEA), created in 2011, is a strategic initiative aimed at promoting energy security, greater utilization of complementary renewable resources, better prices and increased resilience of the electrical systems among Bolivia, Colombia, Chile, Ecuador and Peru [109]. Through this infrastructure, Ecuador exported a total of 255.6 GWh of energy in 2018, with 91.3% and 8.7% going to Colombia and Peru, respectively [110]. In the same year, Ecuador imported 106.07 GWh of electricity from the Colombian energy system. The country's distribution system includes approximately 101,759 km of medium-voltage networks, 93,122 km of low-voltage networks and 324,776 distribution transformers.

According to Fuentes et al. [111], the countries with the best reliability of their electrical systems, understood as the ability to access energy resources and provide a stable and uninterrupted supply of electrical energy, are Argentina, Colombia, Ecuador, Costa Rica, El Salvador, Paraguay, Panama, Nicaragua, Uruguay, Guatemala and Belize.

4.3. Energy Prices

Energy prices determine the affordability of energy supplies and are critical to achieving energy security. In this dimension, the price and stability of residential electricity, LPG, gasoline and diesel were analyzed, as well as energy subsidies.

4.3.1. Residential Electricity Price

Regarding electricity tariffs, Ecuador, like other countries in Latin America and the Caribbean, provides various subsidies primarily to mitigate the impact of electricity payments on household income and to promote a culture of payment among consumers. According to SIELAC [63], Ecuador has a lower residential electricity price than the regional and Latin American averages. See Table 11.

Table 11. Electricity tariffs.

	Electricity
	Tariff 2021
	USD/KWh
Bolivia	0.09
Colombia	0.15
Ecuador	0.10
Peru	0.16
Venezuela	0.04
Andean zone	0.11
LAC	0.16

Elaboration based on data from SIELAC [63].

These subsidies are mainly supported by direct contributions from the government. According to Canese [112], most countries benefit from having a larger population than those living below the poverty line, especially Jamaica, Ecuador and Peru. Inadequate pricing signals encourage inefficient energy use, and in this regard, differentiated subsidies play a fundamental role [113].

A tariff, called the dignity tariff, is applied to residential users whose electricity consumption is up to 110 kWh in the Sierra region and up to 130 kWh in the Coast, Amazon and Insular regions [114].

Through a cross-subsidy, subscribers who consume between 1 and 130 kWh/month receive a discount. On the other hand, those who consume more than a certain amount receive a 10% increase in the consumption bill [115]. According to Contreras [113], Ecuador is the only country in Latin America that explicitly allows the existence of cross-subsidies to favor low-income consumers.

The benefit for the elderly is applied to individuals aged 65 or older and provides a 50% discount on the first 138 kilowatt hours (kWh) of electricity consumption at their place of residence. The benefit for people with disabilities applies to individuals who can provide evidence of their disability, or this is performed by their legal representative, and they also can benefit from a 50% discount on their monthly energy consumption. These benefits are established in Article 13 of the Organic Law for Older Adults and Article 79, numeral 2, of the Organic Law for Persons with Disabilities. Additionally, there are laws in favor of residents in the influence zone of the Tungurahua volcano [116].

4.3.2. LPG Price

In Ecuador, 92.6% of the population uses LPG for cooking [78]. The cost of a 15 kg gas tank is USD 1.61, equivalent to 27.53 USD/bbl and approximately four times cheaper than in neighboring countries like Colombia and Peru, due to a widespread subsidy provided by the government [117]. See Table 12. According to Nolivos [39], Ecuador provides the highest subsidy for LPG used for cooking, which is the highest subsidy granted worldwide.

Table 12. LPG price and firewood consumption.

	LPG	Firewood Consumption	
	Price 2021	Average 2021	Annual Variation 2011–2021
	USD/bbl	Ton/Capita	%
Bolivia	28.39 (2015)	0.02	−6.70
Colombia	98.38 (2015)	0.12	−3.42
Ecuador	27.53 (2023)	0.03	−6.70
Peru	101.61 (2015)	0.16	−3.97
Venezuela	12.71 (2011)	0.01	−10.40
Andean zone	53.72	0.09	−3.61
LAC	109.00	0.23	0.00

Elaboration based on data from SIELAC [63].

Nolivos [39] also states that the low price of LPG has contributed to Ecuador having one of the lowest rates of residential firewood use at 0.03 t/capita. This is below the averages for the Andean and LAC regions, which are 0.09 and 0.23 t/capita, respectively. This is also found in Table 12. It is essential to note that firewood, used for cooking in certain areas of the region, is less efficient and more harmful to health, particularly for women [118–120], which is why it is considered a case of energy poverty [80].

There is a clear relationship between energy and food at the level of domestic needs [80]. This relationship has been surrounded by social conflicts, which in January 2000 led to the dismissal of the President of the Republic, due to the increase in the price of the LPG tank among other reasons [121].

According to Urquiza and Billi [80], Ecuador has the lowest proportion of household expenditure on cooking fuels among 14 surveyed countries in LAC, with 1.8%. It is worth noting that Ecuador has the highest percentage of residential use of LPG at 52.9%. In comparison, the residential LPG use in Colombia and Peru is 8.6% and 24.3%, respectively.

It is estimated that 80% of household LPG consumption is used for cooking [122,123]. The remaining percentage is used for water heating, for which the subsidy is not supposed to be used. According to Guamán et al. [124], Ecuador employs one of the most expensive and polluting systems for water heating worldwide.

In Ecuador, the low price of LPG and the absence of regulations surely influenced the shift from solar water heating, which was available in the 1990s, to the LPG water heaters that exist today. This shift occurred while the global capacity of solar water heaters worldwide increased from 89 million m^2 in 2000 to 746 million m^2 in 2021 [125]. According to IRENA [126], this solar water heating technology is associated with local capacity building and employment in manufacturing these devices.

4.3.3. Gasoline and Diesel Prices

Due to widespread fuel subsidies, in 2022, Ecuador along with Colombia, Bolivia and Venezuela had the lowest gasoline prices in Latin America and the Caribbean at 0.67, 0.61, 0.55 and 0.02 USD/L, respectively. The price of gasoline in neighboring countries such as Colombia and Peru was 2.2 and 3.5 times higher than in Ecuador between 2010 and 2022. See Figure 4.

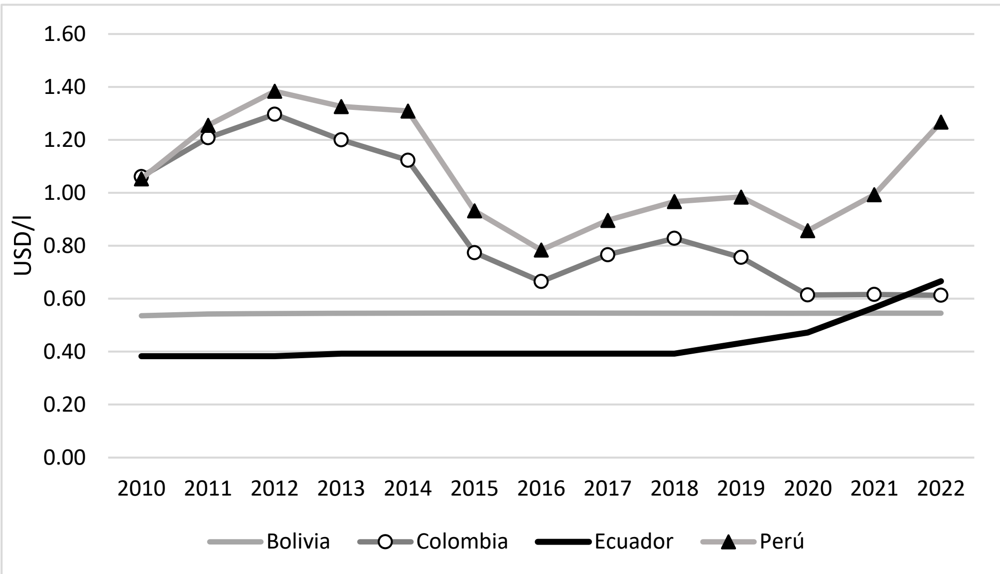

Figure 4. Gasoline price. Elaboration based on data from CEPALSTAT [78].

Regarding diesel, Ecuador and Venezuela had the lowest diesel prices in the region at 0.50 and 0.02 USD/L, respectively [63]. The price of diesel in neighboring Colombia and Peru was 2.9 and 3.5 times higher than that in Ecuador between 2010 and 2022. See Figure 5.

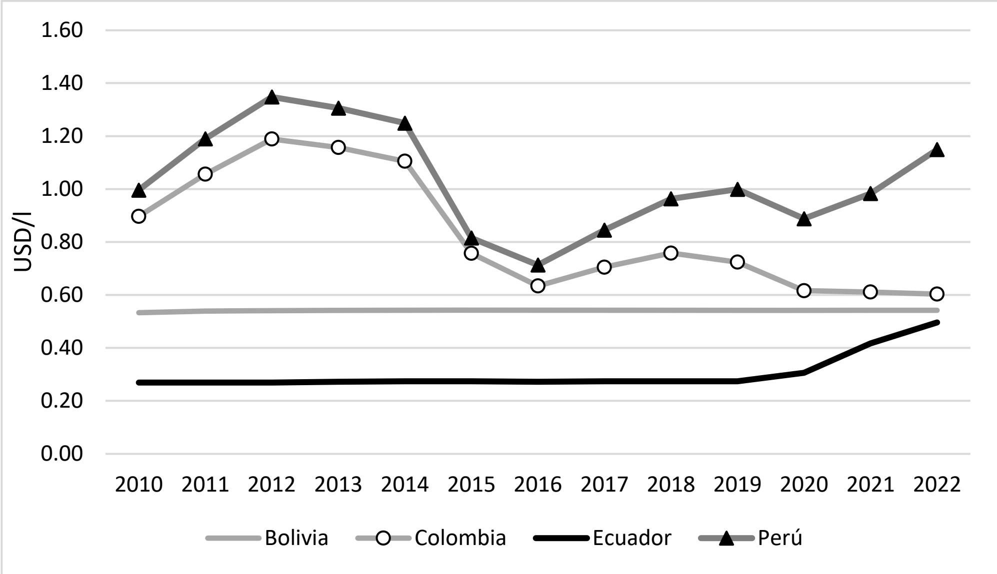

Figure 5. Diesel price. Elaboration based on data from CEPALSTAT [78].

4.3.4. Energy Subsidies

According to the Ministry of Economy and Finance [127], the fuel subsidy stands out for its high fiscal weight and because, over the years, it has become a regressive subsidy. For the year 2023, an amount of USD 2667 million is planned [127]. This social compensation represents around 10% of the state's general budget and 22% of oil export revenues [128].

A key element in Ecuador's energy matrix is energy subsidies [129]. Figure 6 illustrates the energy subsidies per capita per year. Between 2007 and 2021, the percentages of the total subsidy amount were 47%, 30%, 20% and 3% for diesel, gasoline, LPG and electricity, respectively.

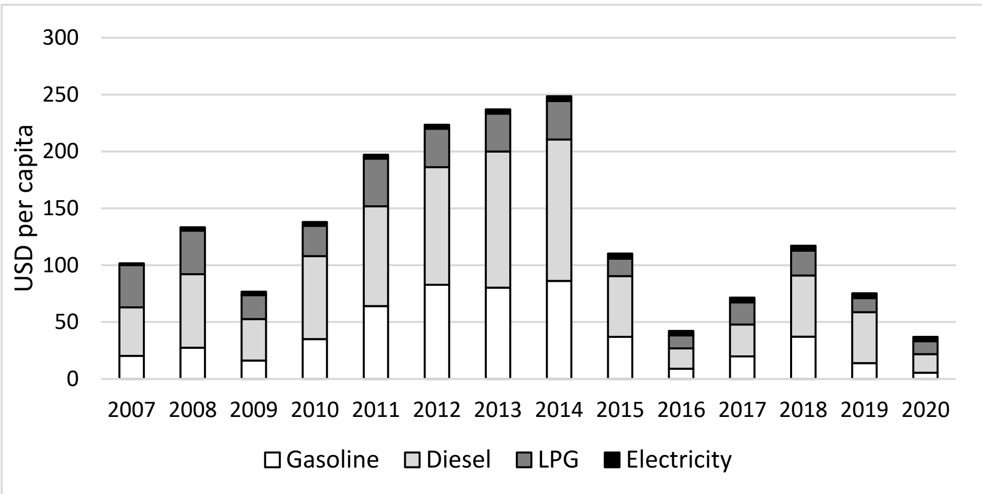

Figure 6. Per capita amounts of energy subsidies, per year. Elaboration based on data from BCE [54].

According to data obtained from the 2010 Census of Population and Housing in Ecuador, an average of 3.78 people per household was determined. These data mean that, in the period between 2007 and 2020, each family, hypothetically, would have received the amount of USD 488 annually in energy subsidies. According to Mejía and Pinos [130], the

Ecuadorian state, in the period 2009–2019, except in 2011, incurred an unsustainable debt, due to the bulky public spending [130].

The artificially low prices of LPG, gasoline and diesel in Ecuador have been identified as one of the causes of the following phenomena:

(a) Overconsumption of energy, as widely mentioned by Vallejo [131], Espinoza and Guayanlema [132], Puig et al. [133] and Terneus et al. [134].
(b) Quito and Guayaquil are considered the third and seventh most congested cities in South America [135]. It is worth mentioning that the effect of speed on fuel consumption takes the form of a U-shaped curve: very low and very high speeds result in higher consumption [136].
(c) Fuel smuggling to neighboring countries and to international vessels, ranging from 5% to 30% [137], and causing significant damage at the national level, is estimated at around USD 400 million annually [138]. It is carried out by a section of the population, often backed by organized criminal groups and drug trafficking organizations [139–143]. It should be noted that the media have reported numerous cases of fishermen captured for drug or fuel smuggling [144,145].

4.4. Efficiency

Energy efficiency is considered an important component of ensuring energy supply, improving competitiveness and reducing greenhouse gas (GHG) emissions [146]. One of the three principles of the WEF nexus, "Creating more with less", refers to increasing the overall efficiency in the use of resources [5]. Article 413 of the Ecuadorian Constitution states that Ecuador will promote energy efficiency. In 2019, the Organic Law on Energy Efficiency (LOEE) [147] passed, declaring the efficient, rational and sustainable use of energy to be a matter of national interest and an essential element in the development of a society that is solidary, competitive in production and concerned about economic and environmental sustainability. However, a long history of fuel subsidies has not allowed Ecuadorians to develop a desirable energy-saving habit [131]. The following metrics were used in this study: primary and final energy intensity; sectoral energy intensity in industry, service, agriculture–fishing–mining and transport; and efficiency indicators in transportation and electrical losses.

4.4.1. Primary and Final Energy Intensity

Energy intensity depends on the productive structure of each country [131]. Under the SE4ALL (https://www.seforall.org/ accessed on 9 January 2023) framework, the rate of improvement of primary energy intensity was defined as a proxy for energy efficiency, with the objective of doubling this rate by 2030 [148].

Ecuador has the second highest primary energy intensity among the analyzed countries, behind only Bolivia. Colombia and Peru have 77% and 73% of Ecuador's energy intensity, respectively. It is worth mentioning that these three countries share a similar geography, climate and productive structure. Ecuador had the lowest rate of reduction among the analyzed countries.

Ecuador's final energy intensity is above the average for the Andean region and LAC [48]. The desirable trend is its reduction, as is happening in LAC and the world as a whole, due to the adoption of energy-efficient technologies and changes in end-user behavior. However, in Ecuador, from 2011 to 2021, the sectors of the economy experienced a growth in energy intensity at an average annual rate of 0.7%. See Table 13.

Table 13. Primary and final energy intensity.

	Primary		Final	
	Average 2021	Annual Variation 2011–2021	Average 2021	Annual Variation 2011–2021
	Koe/USD2011PPA	%	Koe/USD2011PPA	%
Bolivia	0.09	−0.6	0.07	0.0
Colombia	0.06	−1.5	0.04	−1.2
Ecuador	0.08	−0.2	0.07	0.7
Peru	0.06	−1.7	0.05	−1.9
LAC	0.08	−1.2	0.06	−0.9
Andean zone	0.07	−2.5	0.05	−2.6

Elaboration based on data from BIEE [82].

4.4.2. Sectoral Energy Intensity

The sectors analyzed were industry; services; agriculture, fishing and mining; and transport. These sectors represent the main segments of production and comprise the majority of final energy use. In Figure 7, the relative position of Ecuador compared to other countries in the LAC region can be easily seen. This indicator is defined as the ratio of energy consumption in the sector relative to the value added in that sector. For the transportation sector, the indicator proposed by the BIEE was considered, which is the energy consumption of the sector divided by the total GDP. For the analysis, the information from the BIEE [82] for the year 2017 was considered.

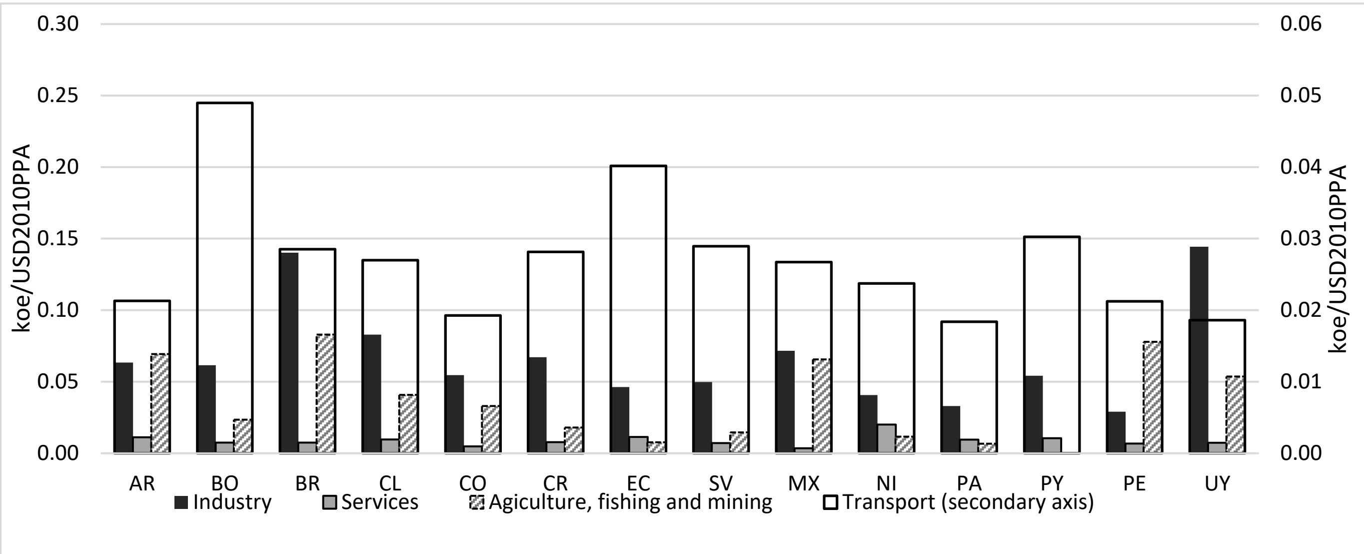

Figure 7. Sectoral energy intensity 2017, in selected LAC countries. The sectors considered were industry; services; agriculture, fishing and mining; and transportation. Elaboration based on data from BIEE [82].

Energy Intensity of Industrial and Service Sectors

The energy intensity of the industrial sector in Bolivia, Colombia, Ecuador and Peru is 0.067, 0.05, 0.045 and 0.030 koe/USD2010PPA, respectively. Uruguay, Brazil, Costa Rica, Mexico and El Salvador have significant industrial energy consumption due to energy-intensive industries such as paper, cement, chemicals and/or steel [149]. In contrast, Ecuador has one of the lowest percentages of industrial energy consumption in LAC, at 16%.

The services sector comprises trade, tourism, education, health and general administration. The energy intensity of this sector in Bolivia, Colombia, Ecuador and Peru is 0.007, 0.005, 0.011 and 0.007 koe/USD2010PPA, respectively.

Energy Intensity of Agriculture, Fishing and Mining Sector

The energy intensity of the agriculture, fishing and mining sector in Bolivia, Colombia, Ecuador and Peru is 0.023, 0.033, 0.008 and 0.078 koe/USD2010PPA, respectively. It is worth noting the low energy intensity of Ecuador in this sector, considering that, along with Uruguay, Chile and Colombia, it is one of the major food producers in LAC [150].

It should be noted that in Ecuador, access to resources is different between large agro-industrial groups and peasant family farming [151]. According to INEN [152,153], 75.9% of the cultivated area does not have irrigation. The gravity irrigation method, which requires low investment, at 48.4%, is the most used technique. Pressurized irrigation methods are widely used in export crops. On the other hand, regarding the use of machinery for land preparation, only 52.4% of farming used a tractor.

Regarding fishing and aquaculture, the fuel use is indicated in Table 14. The consumption of diesel and gasoline in this sector with respect to the total consumption of each type of fuel is 12.2 and 3.7%, respectively. This is an indicator of the strong energy–food nexus that exists in this sector, which is preferably export-oriented.

Table 14. Dispatch of fuel for the fishing and aquaculture sector in 2019.

Sector	Diesel (KBOE)	Gasoline (KBOE)
Shrimp	2062	28
Tuna	1083	1
Other fisheries	454	0
Artisanal fisheries	0	1005 [a]
Total	3599	1033

[a] Gasoline for two-stroke engines. Elaboration based on data from Terneus and Viteri [154].

According to Avadi [155], the low fuel price is partly a cause of the high energy consumption in tuna fishing. Furthermore, shrimp production is an energetically intense process, mainly due to pumping water and mechanical aeration [156,157]. Diesel consumption for tuna and shrimp, for 2019, was 3.9 and 2.8 boe/t, respectively. In addition, artisanal fishing uses a significantly large amount of gasoline for two-stroke engines [158]. However, there is no information on the landings of artisanal fishing, so it is hard to establish indexes of energy productivity or consumption.

An energy–food relationship is evident. On the one hand, there is diesel, which is mostly imported, and on the other hand, there is fishing and aquaculture, preferably oriented to the international market. This relationship is a source of conflict. In 2022, shrimp farms of more than 30 hectares stopped receiving fuel subsidies, due to pressure from the dialogue tables (the dialogue tables are spaces created by the agreement that ended the protests of June 2022; their purpose is to reach consensus between the government and the social movements, with respect to various issues raised by the latter) [159–161]. In 2023, an increase in the sale of diesel for automotive use in certain gas stations was detected and attributed to the shrimp sector [162,163].

Energy Intensity in Transportation Sector

Transportation energy intensity in Bolivia and Ecuador, at 0.05 and 0.04 koe/USD2010PPA, respectively, is the highest in LAC. In those countries, this indicator is nearly double that in Peru and Colombia, which have 0.022 and 0.019 koe/USD2010PPA, respectively. In terms of the annual rate of increase of this indicator between 2010 and 2018, Ecuador stands out with 2.0%. The rates of increase in Bolivia, Colombia and Peru were 1.4%, 0.7% and 1.8%, respectively [82]. In Ecuador, the percentage of energy consumption in this sector relative to total consumption was 55% in 2021, one of the highest in the LAC region. According to Terneus and Viteri [154], in Ecuador food consumes 41% of the energy used in transportation. This is an interrelation between energy and food which is especially sensitive, as demonstrated by the social disturbances of October 2019 and June 2022 [154,164].

4.4.3. Efficiency Indicators in Transportation

According to the BIEE [82], Ecuador stands out as the highest consumer of road transport per equivalent car, with 1.8 toe/eq-car, among the analyzed countries. Peru and Colombia have consumption levels of 1.16 and 1.10 toe/eq-car, respectively. The per capita energy consumption in transportation, at 0.43 toe/capita, is the highest among the analyzed countries. See Table 15.

Table 15. Energy consumption per equivalent vehicle and transportation energy consumption per capita.

	Energy Consumption per Vehicle 2018		Transportation Energy Consumption per Capita 2018	
	Average	**Annual Variation 2010–2018**	**Average**	**Annual Variation 2010–2018**
	Toe/Eq-Car	**%**	**Toe/Capita**	**%**
Bolivia	1.06	2.7	0.33	4.8
Colombia	1.10	0.2	0.25	3.2
Ecuador	1.76	0.5	0.43	3.4
Peru	1.16	0.4	0.27	4.9

Elaboration based on data from BIEE [82].

These indicators speak negatively about the energy efficiency of transportation, which can be explained by the low fuel prices, as indicated by the IEA [165], smuggling [141,142,166,167], oversupply and lack of control in heavy transportation [164] and almost nonexistent vehicle fuel consumption standards [168].

Considering the poor efficiency indicators in the transportation sector, one might assume that there would be special attention given to this sector, but it seems to be quite the opposite. There is a lack of coordination among state agencies related to this sector, existing databases are incomplete, inconsistent and disconnected, and there is evidence of limited and lax control by authorities [134].

As of 2021, Ecuador was 64% urban [169], creating opportunities to meet a significant portion of the population's needs through the use of mass public transportation.

4.4.4. Electrical Losses

The relationship between losses and electricity supply is the indicator used to measure the efficiency of the electricity sector [48]. See Table 16.

Table 16. Comparison of electricity loss indicators between Andean countries and the LAC region.

	Average	Annual Variation 2010–2021
	%	**%**
Bolivia	9	−2.5
Colombia	6	−6.6
Ecuador	14	−2.1
Peru	12	2.0
Venezuela	19	−4.1
Andean zone	12	−5.0
LAC	13	−1.6

Elaboration based on data from SIELAC [63].

According to SIELAC [82], Ecuador, at 14%, is above average for LAC, which in turn is higher than the international reference of 8% [113]. Between 2006 and 2014, Ecuador achieved an admirable performance by reducing its total electrical losses from 21% to 13% [63]. Between 2011 and 2021, it had a reduction rate of 2.1%.

This indicator shows that distribution facilities do not have adequate investment and maintenance, resulting in higher technical losses or the presence of widespread illegal connections [148]. In 2022, non-technical losses, referring to unauthorized electricity use by the population, accounted for 7.0% [59].

4.5. Social Impact

Some authors include social aspects as part of energy security [60,170,171]. Two aspects were analyzed in this study: the population's access to basic energy services, as part of social welfare, and the acceptance by neighboring communities of energy projects that could eventually affect their living environment.

With respect to accessibility, in 2022, the national electricity coverage was 97.29%, and the electricity consumption per capita was 1231 kWh/capita [59]. Electricity coverage in Ecuador is above average for the Andean and LAC regions. See Table 17. According to CEPAL [118], the proportion of the population without access to electricity in Ecuador is 1.4%, while the regional average for LAC is 4.8%. From 2012 to 2021, the increase in electricity coverage in the Sierra, Costa, Amazon and Insular regions was 0.79%, −0.56%, 5.36% and −0.02%, respectively. Ecuador has made significant efforts to achieve universal access to electricity. Provinces with lower coverage are typically those with more difficult access, including Esmeraldas, Morona Santiago, Santa Elena, Pastaza and Napo, with coverage rates of 86.2%, 89.1%, 90.3%, 91.1% and 92.1%, respectively [59]. However, the rate at which people gain access to electricity is lower than the regional and national averages, and it is decreasing. From 2011 to 2021, the annual variation rate was 0.13%, and from 2020 to 2021, it was 0.09%. If current growth rates continue, it will be challenging to achieve the target of universal electricity coverage set for 2030 by the Sustainable Energy for All (SE4ALL) initiative and established in the 2030 Agenda for Sustainable Development [148].

Table 17. Electricity coverage and growth rates in Andean countries and the LAC region.

	Average 2021	Annual Variation 2011–2021
	%	%
Bolivia	94.10	1.56
Colombia	96.81	0.11
Ecuador	97.29	0.13
Peru	97.00	1.39
Venezuela	99.00	0.01
Andean zone	96.84	0.61
LAC	95.02	0.54

Elaboration based on data from SIELAC [63].

From the perspective of the energy–food nexus, this indicator is relevant, considering that access to electricity is crucial for food preservation and therefore is an important variable in achieving food security for the population [13,80,119].

Regarding the acceptability of energy projects in LAC, the relationship between nature and economic development has been a constant source of conflicts for communities, indigenous peoples and various civil society groups [172]. These events are global phenomena that make energy policies increasingly difficult, slow and expensive, due to socio-cultural aspects and internal politics that must be taken into account [173].

The Ecuadorian government's development strategy regarding energy policy is increasingly in conflict with the conservation objectives defended by both the Confederation of Indigenous Nationalities of Ecuador (CONAIE, by its initials in Spanish), a politically influential indigenous organization, and conservationist groups. This includes oil extraction projects and the development of hydroelectric energy, which face serious opposition due to the negative environmental externalities, which is closely related to the negative history of the oil sector [121,174]. Tensions with CONAIE have been increasing since 1994 when the first indigenous uprising in Ecuador was recorded. They have transitioned from being social subjects to becoming active political actors.

There are several conflicts related to oil exploitation, often revolving around environmental impact, biodiversity protection and the rights of communities and indigenous peoples. In some cases, demonstrations have succeeded in preventing the continuation of oil activities, resulting in the termination of exploitation contracts [175,176].

One of the most well-known conflicts was the case of Chevron-Texaco, which operated in the Ecuadorian Amazon from 1964 to 1990; this case reached international tribunals. According to the Ministry of Foreign Affairs and Human Mobility [177], this company caused severe environmental damage that was never remedied and has resulted in irreparable harm to the inhabitants of an area in the Ecuadorian Amazon region.

According to Martín and Justo [178], oil exploitation is one of the main causes of socio-environmental conflicts, but so are hydroelectric projects. These are clear indicators of the water–energy interaction [6]. Regarding hydroelectric projects, there have been cases such as Angamarca-Sinde, Abanico and the Piatúa River.

The first one sparked dissatisfaction among the inhabitants of Moraspungo and the Juntas, in the Pangua canton. In September 2007, after a failed attempt to share the results of the environmental impact study with the community, an intense collective mobilization took place, including blocking access to the area, closing the municipality and destroying the machinery room of the Calope hydroelectric project. The community demanded a cessation of activities and immediate abandonment by the hydroelectric companies operating in the area. The residents expressed their discontent due to the non-compliance with the socio-environmental guidelines of previous hydroelectric projects and the potential reduction of water flow that would directly affect their agricultural activities. Additionally, the lack of efficient mechanisms for disseminating and accessing technical information increased their distrust, culminating in the indefinite suspension of the project [179].

The second project is located in the southeastern region of Ecuador, 15 km from the city of Macas, the capital of the Morona Santiago province. It is a run-of-the-river hydroelectric power plant without a reservoir. It was built in two stages, the first one with 15 MW and the second one with 22.5 MW, resulting in a total power capacity of 37.50 MW [180]. According to residents of the Jimbotono community, in the General Proaño parish, this project caused flooding of crops and farms, due to the increased flow of the Jurumbaino River, which collects water from the Abanico River through the release of water held in the reservoir [181]. The organizations opposing the construction included the Popular Peasant Coordinator of Morona Santiago and Zamora Chinchipe, Shuar groups (an ethnicity descended from pre-Hispanic nationalities, originating from the Amazon region of Ecuador and Peru), municipalities, parish councils and the Ombudsman's Office, among others. Mobilizations, strikes, and violent confrontations occurred between residents, Hidroabanico guards, the National Police and the armed forces [181,182]. The agreements for the completion of this project included compensatory works for the community, monitoring and maintenance of the Balaquepe and Jurumbaino rivers' courses, as well as the hiring of local personnel.

The third project led to strikes, complaints and lawsuits against the state. The plaintiffs argued that prior consultation, free and informed, was not conducted, and they adhered to the rights of nature, health, water, food and work. The affected individuals, belonging to the Kichwa nationality (an ethnic group descended from pre-Hispanic nationalities located in the north-western part of the Ecuadorian Amazon region, now settled in the upper area of the Province of Napo, Sucumbíos), considered that the collective rights of the indigenous peoples involved, living in the Santa Clara de Pastaza canton, were violated. The Provincial Court of this province decided to suspend the hydroelectric project on the Piatúa River, revoking the authorization for the use and exploitation of the water flow and revoking the environmental license issued by the Ministry of the Environment [183–185].

4.6. Environment

Ecuador is considered one of the most biodiverse countries in the world [151], which has granted it access to significant strategically important natural resources. The exploitation of these resources has been closely linked to its history and integration into the global economy, but with a high socio-environmental cost. Tensions exist between conservation objectives and extractives policies, as well as between resource nationalism and foreign participation [121]. The 2008 Constitution grants rights to nature, defining it as the space that allows for a healthy environment and the sustainable exploitation of its resources for a dignified life.

The environment has increasingly become part of the consideration for energy security [12]. It is reflected in four metrics: deforestation and land use change; access to piped water, highlighting the water–energy nexus; CO_2 emissions related to energy per capita, recognized as the main greenhouse gas (GHG) attributed to human activities; and SO_2 per capita which is characterized as a colorless gas of irritating nature formed mainly by the burning of fossil fuels such as oil and coal [186].

4.6.1. Forest Coverage

According to the Ministry of Environment, Water and Ecological Transition, Ecuador registered 12.5 million hectares (ha) of native forest until 2018. The biggest forests are located in the Amazon region and the north of Esmeraldas [187]. In the Amazon region is 70% of this forest, 26% is in the Coast region, and a smaller amount is in the Sierra, especially in the eastern foothills of the Andes [188].

Ecuador is one of the countries in South America with the highest deforestation rates [189]. According to the Food and Agriculture Organization of the United Nations (FAO) [190], annual deforestation was 1.5% between 1990 and 2000 and increased to 1.7% between 2000 and 2005, reaching a total of 1980 km^2 of forest lost per year.

Among the main causes behind forest reduction in Ecuador is the usage of land for agricultural purposes. African palm plantations have occupied about 246,574 hectares in the Amazon and on the coast, where other crops such as rice, cocoa, sugar and various tropical fruits are also grown [191,192]. In addition, pastures cultivated for livestock represent another significant factor [193]. Infrastructure also plays an important role in this problem; the expansion and construction of roads for hydrocarbon and mining exploitation, both legal and illegal, and for the construction of hydroelectric plants, have also contributed to the loss of forest areas [193,194]. Deforestation continues due to the lack of control and public policies to curb this environmental economic phenomenon.

In 2023, it was approved to hold a popular consultation on keeping oil underground in a zone of the Yasuní National Park. According to the government, if the 'Yes' vote prevailed, the economic implications would be catastrophic. On the other hand, social collectives argued that the government itself had indicated that oil extraction in one of these zones is not economically profitable due to its high viscosity [195]. Almost 60% of the population voted in favor of stopping oil exploitation at this site.

The Yasuní ITT Initiative was created in 2007 by former President Rafael Correa to mark a milestone in biodiversity protection, environmental impact mitigation and the safeguarding of ancestral communities located in the Aguarico and Arajuno cantons of the Orellana and Pastaza provinces, respectively. However, after six years of unsuccessful efforts to maintain this initiative, on 15 August 2013, the same president issued Executive Decree 74, which gave the green light for oil extraction in the region. This event catalyzed the creation of the Yasunidos collective, a group motivated by the defense of the rights of nature and indigenous communities [196].

4.6.2. Water Availability

According to Sovacool [61], the purpose of this indicator is to highlight the link between water and energy, which is especially crucial in Ecuador. On the one hand, there is an 80% dependence on hydropower, and on the other hand, there has been a significant increase in groundwater use authorizations, from 2342 to 9841 L/s from 2006 to 2016 [84]. The largest flows are destined to plantain, sugar, shrimp and rice farms [154]. It is worth mentioning that the low price of energy in this country can lead to the overexploitation of aquifers [197,198]. This is a typical example of the interrelationship between WEF nexus resources [6].

In Ecuador, water availability is 5018 and 77,584 m^3/capita/yr for the Pacific and Amazon watersheds, respectively [199]. Although there is a progressive reduction in water availability, in general, there is an important water wealth that exceeds by several times the world average [84]. The water availability in the Pacific basin exceeds 1700 m^3/capita/yr [197], which is considered a condition of water stress. However, in some coastal areas, whose rivers are not fed by snowmelt, water availability values are below this level, especially during the drought periods. These are the hydrographic systems of Jama, Portoviejo, Jipijapa and Arenillas in Manabi, and Zapotal in Guayas.

In 2021, the average national drinking water service coverage indicator was 78.8% [200], although there are cantons in the country that have a worrisome shortage of the resource, particularly in municipalities of the Coastal region and areas such as the provinces of Chimborazo, Cotopaxi and Tungurahua [201]. In Ecuador, water used for human consumption averages 230 L per person per day [202,203], while an optimal level would correspond to an endowment of 100 to 150 L per person per day to meet consumption and hygiene needs [204]. This may be due to the fact that only 28% of households use water-saving practices [205]. In addition, 55% of water is wasted from the potable stage until it reaches human consumption [206].

It is worth mentioning that water pollution is a major problem in Ecuador, mainly due to the discharge of wastewater from most cities, artisanal mining activities, hydrocarbon activities and diffuse pollution from the use of large quantities of agrochemicals in agriculture, which contaminate not only surface water but also groundwater. This leads to water scarcity due to poor water quality [207,208].

4.6.3. Per Capita Carbon Dioxide Emissions

In the Ecuadorian context, 74.51% of GHG emissions correspond to CO_2, which is equivalent to 0.1% of global emissions of this gas [209]. According to CEPALSTAT data [78], 2.26 tons of CO_2 emissions per capita were recorded in 2019, attributed to energy. Ecuador has the highest emissions per capita compared to Bolivia, Colombia and Peru, but is lower compared to the LAC region as a whole. With respect to CO_2 emissions per USD 1000 of GDP (Table 18), Ecuador is above the regional average and has about 45% more than its neighbors Colombia and Peru. Ecuador has participated in the Paris Agreement [210] and has implemented projects such as the National Climate Change Adaptation Plan [211].

Table 18. CO_2 emissions per capita and per USD 1000 of GDP.

	Tons of CO_2/Capita	Tons of CO_2/1000 USD GDP
Bolivia	1.94	546.29
Colombia	1.61	250.81
Ecuador	2.26	363.46
Peru	1.75	248.53
LAC	2.53	289.74

Elaboration based on data from CEPALSTAT [78].

The technical commission in charge of determining GHG emission factors (CTFE) [212] stated that emissions from the electricity sector in the country were 5.9 and 1.2 Mt of CO_2 in 2014 and 2021, respectively, due to the incorporation of new hydroelectric plants in the National Interconnected System (SIN) [110]. This trend is consistent with the data provided by the Energy Information System of Latin America and the Caribbean (SIELAC) [213]. On the other hand, the transportation sector experienced an increase of 5.5 Mt of CO_2 between 2000 and 2019, as reported by Muentes et al. [214].

The Green Future Index 2023, regarding energy transition, examined the latest available data on the carbon emission levels of each country and how they have changed over the last half decade, ranking Ecuador, Peru, Honduras and Paraguay as the most laggard countries in Latin America and the Caribbean with scores of 4.14, 3.97, 3.57 and 3.55, respectively [215].

4.6.4. Sulfur Dioxide (SO_2) Emissions per Capita

Despite the lack of concrete data on SO_2 emissions per capita in Ecuador, monitoring is carried out through a network of 26 automatic, semi-automatic and passive air quality monitoring stations located in the cities of Quito, Guayaquil and Cuenca [216].

According to the Ministry of Environment, Water and Ecological Transition [216], in 2013, an annual average concentration of 130.01 ug/m^3 of SO_2 was detected at the monitoring station in downtown Guayaquil. This value, the highest recorded between 2005 and 2018, exceeded the annual average limit of 60 ug/m^3 set by the country's Air and Environment Quality Standard (NCAA) [217]. During the same period, there were only three specific years (2008, 2011 and 2016) with values below the specified national standard.

4.7. Governance

The six indicators proposed by the World Bank [218] provide insight into the functioning of a government and its interaction with citizens. They assess the political dimensions, which refer to the process by which individuals are chosen and replaced in government positions in a country; the economic dimension, which pertains to the government's ability to formulate and implement policies; and the institutional dimension, which concerns the citizens and the state's respect for their institutions.

According to data from the World Bank [218], in the case of Ecuador, there was a considerable adverse impact of −0.7 in regulatory quality in 2021, followed by a lack of control of corruption in the public sector, with a score of −0.6. The indicators for political stability and rule of law obtained a score of −0.3, and the perception of government effectiveness was −0.2. See Table 19.

Table 19. Governance indicators for Ecuador, Colombia, Peru and LAC for 2021.

		Ecuador	Colombia	Peru	LAC
Policy	Voice and accountability	0.1	0.1	0.2	0.1
	Political stability	−0.3	−0.9	−0.4	−0.1
Economic	Government effectiveness	−0.2	0.0	−0.3	−0.4
	Regulatory quality	−0.7	0.2	0.1	−0.3
Institutional	Rule of law	−0.3	−0.5	−0.5	−0.5
	Control of corruption	−0.6	−0.3	−0.6	−0.4

Elaboration based on data from World Bank [218].

As a significant issue for governance, it should be noted that in the most violent conflicts in the history of Ecuador, the link between fuels and food has been present. The removal of the subsidy on LPG [219], which is predominantly used for cooking, was related to the removal of President Jamil Mahuad. Given the fall in oil prices of 2014, and in order to comply with international creditors, President Lénin Moreno eliminated subsidies for fuels used in the transportation sector at the beginning of October 2019. This produced a social uprising, in which the possible impact on the price of food was present [220]. Similarly, the June 2022 strike was due to (i) the progressive rise in fuel prices, according to international prices, and (ii) inflation in food prices [221].

5. Conclusions and Policy Recommendations

The objective of this study was to analyze energy security in Ecuador, which is interconnected with water and food security. For this, seven dimensions and 21 indicators were analyzed that allowed characterizing its energy system, identifying implications for energy security and recommending policies.

5.1. Characterization of the Energy System

Ecuador has an abundance of hydrocarbon and hydropower resources, as well as solar and biomass. It produces twice the amount of hydrocarbons it consumes. Three quarters of the energy consumed in Ecuador is fossil. In the 2010s, it made significant efforts to diversify the energy supply, mainly with hydropower generation; for that reason, between 2011 and 2021, it had a better performance in the decreasing trend of total energy supply. At 80%, it is one of the countries in Latin America and the Caribbean with the highest percentages of renewables in its electricity matrix.

Ecuador's energy consumption, to produce a unit of wealth, is high compared to its neighbors, which share the same geography, have similar productive structures and have comparable sizes. The primary energy intensity of Colombia and Peru is around three quarters that of Ecuador. Moreover, it is growing, contrary to the desirable global trend of reducing it. The transportation sector in Ecuador stands out in the region for its high energy intensity and low efficiency.

The dollarization of the economy has driven the growing consumption of foreign oil derivatives, to the point that, in 2021, these constituted half of the energy consumed in this country. In order to reduce fuel imports, biofuels were created in Ecuador; however, their contribution is only 0.2% and, furthermore, this is one of the products that uses the most agricultural land and that also has wide availability of irrigation. In this clear nexus between resources, it is energy that puts pressure on water and land, which could affect food production.

There is solar and biomass potential to be exploited at different scales in Ecuador. Their use at a deconcentrated level can provide clear benefits for water and food resources. However, there are obstacles to their use, among which is the artificially low price of energy.

The generalized fuel subsidy has characterized the energy matrix of Ecuador and is identified as one of the causes of (i) fuel smuggling, (ii) low efficiency, (iii) low development of alternative energies, (iv) vehicle congestion and (v) low energy productivity, among others. Additionally, and with a clear relationship to the WEF nexus, it represents a risk to the quantity and quality of groundwater sources.

It can be said that Ecuador has one of the lowest energy poverty rates in the region, because it has one of the highest rates of electricity coverage, one of the lowest firewood consumption rates and some of the lowest LPG, gasoline, diesel and electricity prices in the region. However, the sustainability of this social benefit depends strongly on revenues for the fiscal treasury.

5.2. Implications for Energy Security

According to several authors, Ecuador is on the way to becoming a net importer of oil. Some of the reasons mentioned are the 7.70 and 3.03 years of proven oil and natural gas reserves; the greater proportion of heavy crude oil, which requires greater energy, water and economic resources for its exploitation; the restrictions on oil expansion due to socio-environmental conflicts, among which the Yasuní National Park case is particularly mentioned; and the annual increase of 3.1% in fuel imports in the period 2000–2021. This situation can compromise Ecuador's trade balance, and with this its ability to maintain public spending, where the largest item corresponds to fuel subsidies.

Ecuador has a strong water–energy relationship; therefore, climate change may affect the reliability of its electrical system. Currently, it has exploited a quarter of its hydroelectric capacity, which means that in the future it could have more renewable and endogenous electrical energy. However, socio-environmental conflicts can alter the exploitation process or eventually prevent it.

Ecuador has the least diverse energy sources among the Andean countries, which could affect its ability to respond and adapt its energy system. Furthermore, its governance structure centered on the state and the general fuel subsidy are identified as obstacles to the use of the country's abundant solar and agricultural waste resources.

Energy security can also be improved by addressing demand. However, a long history of energy subsidies has encouraged overconsumption of this resource and has not developed a desirable energy-saving behaviour. In addition, this country is characterized by weak governance, which has prevented reaching national consensuses that encourage rational and efficient energy consumption.

Although there has been progress in energy infrastructure, it is worth mentioning that some is limited, has construction flaws and/or there are corruption claims in their contracting.

As a working hypothesis for future research, it is suggested that Ecuador is heading towards a situation of energy vulnerability. For this reason, the implementation of public policies that reverse the current situation is necessary.

5.3. Policy Recomendations

In general, Ecuadorian society must begin an economic transition process based on the decoupling of fossil fuels, considering that its oil horizon is unfavorable and aggravated by the growing energy demand.

Actions taken must not be disconnected from other public objectives. Energy policy in Ecuador must be approached from a systemic perspective, considering the complexity of interactions with other economic sectors, such as water and food, among others.

Since water availability is a fundamental element for Ecuador′s energy security, a weak point is related to the drought periods exacerbated by climate change. These necessitate proper and coordinated planning processes for water and energy. Hydroelectric projects should comply with all socio-environmental requirements, in order to take advantage of this abundant resource that Ecuador possesses and which could reduce its dependence on oil.

Diversifying energy sources and transitioning towards greater energy efficiency and self-sufficiency is a security, economic, environmental and commercial strategy. It requires an active role being played by the state through a variety of energy policy mechanisms. The key one would be a review of energy subsidies, without affecting the most vulnerable population.

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