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The Role of Renewable Energies for the Sustainable Energy Governance and Environmental Policies for the Mitigation of Climate Change in Ecuador

Flavio R. Arroyo M. [1,2,*] and Luis J. Miguel [1,3]

1 Systems Engineering and Automatic Control, School of Industrial Engineering, Paseo del Cauce s/n, University of Valladolid, 47011 Valladolid, Spain; ljmiguel@eii.uva.es
2 Faculty of Engineering, Physical Sciences and Mathematics, Av. Universitaria, Central University of Ecuador, 170129 Quito, Ecuador
3 Research Group on Energy, Economy and System Dynamics, School of Industrial Engineering, Paseo del Cauce s/n, University of Valladolid, 47011 Valladolid, Spain
* Correspondence: flavio.arroyo@gmail.com

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Abstract: This article presents a comparative analysis of energy governance with respect to renewable energy sources in Ecuador. The use of renewable energy sources increases energy security and enables countries to achieve their climate mitigation goals. Ecuador's energy mix is dominated using fossil fuels and produces only 7.8% of its energy supply from renewable energy. The scenario analysis suggests that using the example of international renewable energy policies will achieve sustainable energy development in Ecuador. Relying less on fossil fuels and decentralizing the electricity sector from the use of thermoelectric plants is the great challenge for the country. Using the enormous water potential that Ecuador has and taking advantage of the sources of solar, biomass and wind energy available in the country will reduce the forecast of 60,233.70 KT CO_2 by 2030 that would be reached if current consumption conditions and energy mix are maintained, while designing a long-term energy planning with a greater participation of renewable energies would forecast a CO_2 emission of 41,232.30 KT, that is, a reduction of 31.5% in emissions.

Keywords: energy governance; climate change; energy policy; economic growth; energy consumption; CO_2 emissions

1. Introduction

The scant results of different climate summits are just a sample of how far the world is from the necessary transition towards a system that provides energy services safely and sustainably. The key role of energy in global problems is clear. About two-thirds of greenhouse gas emissions causing climate change can be traced back to the use of fossil fuels. A new struggle over oil is raising fears of a new generation of geopolitical conflict. Global economic instability is strongly correlated to the volatility of the price of energy. Economic development is mostly defined by the process of overcoming energy poverty, although 1.6 billion people still lack access to even the most basic energy services [1].

Global primary energy consumption grew rapidly in 2018, led by natural gas and renewable energy. However, carbon emissions increased at their highest rate in 7 years. Primary energy consumption grew 2.9%, almost double the 10-year average of 1.5% per year and the fastest since 2010 [2]. The impacts of climate change continue to exert considerable costs on the global economy, especially for least developed countries, with little adaptability and resilience [3,4]. Energy-related carbon emissions grew 2.0%, again the fastest expansion in many years, with an increase in emissions of around 0.6 gigatons.

The energy sector is continuously affected by rapid changes, including multilateral innovations. In the run-up to the COP21 climate conference in Paris in December 2015, more than 160 countries submitted national plans on how they intended to contribute to the objectives of the convention on climate change in the post-2020 period [5]. The new global energy governance agenda now overlaps with global environmental governance and the poverty alleviation agenda [6].

The protection of the environment and climate change promote the use of renewable energy. Renewable energy technologies could offer competitive cost options for the delivery of modern energy services in remote areas, while innovation and scale merit continue to achieve cost savings [7]. A robust dialogue on the nature, scope, and challenges of energy and climate governance must be initiated. Energy governance encompasses regulation and enforcement that aims to overcome collective action problems related to energy supply and use [8].

The concept of energy governance is highly context dependent. It generally includes policy-related attributes [9], such as international interactions, coordinated and interactive agreements, institutionalized rules and, finally, a complex and diverse range of stakeholder groups [10]. Energy governance is a process of coordination between public-private institutions in order to decide how to provide energy services [11]. It is understood as a system of regulation of energy-related interactions between the State, society and the economy [12].

Energy as a field of politics is an almost classic cross-cutting theme, closely related to climate policies, but also to development cooperation, research and innovation, trade, and foreign and security policies [13]. One of the key factors brought together by the study of global environmental policy and energy research is the threat of climate change [14].

Problems caused by fossil fuels, including widespread air pollution and climate change, have led governments, companies, investors and the public to recognize the need to decarbonize the world economy. Climate change poses an existential threat to humanity and the Earth's ecosystems. Unless urgent steps are taken to decarbonize the energy sector, the world comply with the Paris Agreement [15].

Most pathways to a low carbon economy would require a rapid deployment of renewable energy and doubling energy efficiency, given that the energy sector accounts for two thirds of global emissions [16]. Ref. [17] has shown that implementing renewable energy combined with an improved energy efficiency provides the most cost-effective way to achieve 90% reduction in energy related emissions. Energy efficiency enables economic growth with lower energy inputs. In the 20th century, the average growth rate of energy demand was 3%, almost equal to the growth rate of world GDP. In recent decades, improvements in energy efficiency have overcome this correlation. The demand for primary energy is forecast to grow 1% annually until 2040 [18].

Energy transition implies a profound economic, industrial and social transformation. It could affect prosperity, employment and social organization as much as the first Industrial Revolution. Renewable energies bring several macroeconomic advantages. For example, by 2050, the cost of energy could go from 5% of world GDP to just over 2% of a much larger world economy [19]. The promotion of renewable energy and energy efficiency are popular ways for countries to achieve their energy and environmental goals and for decarbonization and decontamination in the future energy matrix [20].

Studies carried out by [21] propose a long-term energy and climate planning that includes two strategic elements and processes: the National Integrated Energy and Climate Plan with a ten-year perspective, and the strategies for long-term low emissions with a fifty-year perspective. Energy and climate change policies must not be complicated; clean energy must be supplied at a competitive cost aimed at reducing emissions [22].

Based on their situations and concerns regarding energy, different countries may adopt different policies and legal measures for energy transition. To reduce the effects of the environmental problem, governments must develop and implement energy conservation policies [23]. The investigations of [24–26] conclude that energy consumption often affects economic growth. The studies of the European Union have proposed policies for an energy transition that can be summarized in three key elements: reduction of emissions, development of renewable energies and energy efficiency. These three elements are intertwined and should be considered a priority [24]. Several studies have been carried out on energy efficiency and renewable energy as a problem of global energy governance [25,26].

Ref. [27] studied the compatibility of combining economic growth with the control of climate change. The relationships between the various indicators of economic growth and productivity were tested using two different ways to calculate carbon intensity. High carbon intensity sectors show absolute growth in terms of production and associated emissions. Green growth will require radical change or huge technological improvements.

Ecuador is currently undergoing a massive change in the energy sector. The country is shifting from heavy dependence on fossil fuels to almost complete self-sufficiency through renewable energy, especially hydroelectric power. The country is also improving its energy transfer infrastructure to allow massive loads to be transported more efficiently at high voltage.

Ecuador is a country with some important aspects when analyzing the energy sector. A remote oil-producing region limited financial resources and lack of infrastructure are just some of the great challenges that the country must face when exploring its natural resources, while guaranteeing its diverse and unique Amazon ecosystem [28].

Ecuador's economy operates around the supply of non-renewable natural resources: mainly crude oil and, to a lesser extent, gas and other minerals. Ecuador has a high economic vulnerability due to dependence on oil exports and its fluctuating price [29], oil production approaching its maximum peak, fossil fuel prices being highly subsidized [30], significant potential for the use of hydroelectric energy and/or other renewable energy sources [31].

A key moment for Ecuador's energy policy was 1979, when, after a decade of military dictatorship, Ecuador returned to a nominally democratic system. National strategic resources, including the exploitation of primary energy resources and the generation of electricity, were privatized. The electricity sector pursued a combination of hydrothermal electricity, consisting of large-scale hydroelectric power plants and fossil fuel-based thermoelectric plants [31]. In 2008, a new constitution was drafted. The new approach aimed at reverting to a state-controlled natural resource management system, and the country set out to making its energy matrix cleaner and more environmentally sustainable. The control of the energy sector shifted from a mainly privately-owned system to a centralized State-owned system. The period from 2008 to 2014 has generally been characterized by economic prosperity as a result of high oil prices and increased production from mature oil fields in the Amazon [32].

The government implemented policies to promote hydroelectric energy and unconventional renewable energy, which have not reached the expected performance. Energy subsidies remained among the highest in the world, which has led the transport sector to become the fastest growing sector of the economy in terms of energy consumption [33]. Ecuador exports crude oil and imports fossil fuels, which causes a significant imbalance in the national economy.

In 2013, the Ministry of Electricity and Renewable Energy introduced the concept of "change of energy matrix" or "energy transition" in order to legitimize a new energy policy based mainly on the use of renewable energy. This commitment to clean energy was mainly intended to be implemented by the electricity sector. It would contribute to greater environmental care and would begin a post-oil period by reducing fossil fuel-based thermoelectric plants and investing in eight new hydroelectric plants.

In Ecuador, several policies have been incorporated to promote the use of non-conventional renewable energy. The 1998 Constitution of the Republic already established that the State will promote its use, while in the 2008 Constitution strengthened this principle and incorporated the concept of energy efficiency [34]. In 2000, Ecuador ratified the Kyoto Protocol, and therefore can participate in the application of the Clean Development Mechanism (CDM).

Given its geographical conditions, there is significant potential to apply technologies with renewable energies. Hydroelectric energy will prevail in the short and medium term in the country, since the country still has great potential and in full use. Ecuador requires other energy sources to diversify generation and reduce the vulnerability of the electricity system, avoiding the increase in high-cost and high-impact thermoelectric generation.

2. Materials and Methods

Strategic energy forecasting consists of determining and analyzing the most probable future scenarios for a given energy system and constitutes an indispensable tool to develop the most appropriate strategic options. Projections of future energy demand and composition have implications for policy decisions [35]. Energy system models are important methods used to generate a range of knowledge and analysis of energy supply and demand. Regardless of how power systems modeling develops, policymakers and analysts who support them should focus on understanding the assumptions included in any modeling output [36].

This research mainly has a two-part methodology that includes literature review and evaluation and scenario analysis using system dynamics (SD). Systems dynamics methodology has been widely used to model complex systems in which feedbacks, delays, and nonlinearities are frequent [37,38]. Some of these applications have been aimed at modelling energy and environmental systems [39–41], as well as integrated evaluation models [42,43]. These models represent the relationships between the main variables using flows and stocks in an easily understandable way. From all the analyses of the literature review, it is understood that the promotion of renewable energy and energy efficiency will help Ecuador achieve its objectives in the energy field.

This research mainly has a two-part methodology that includes literature review and evaluation and scenario analysis using system dynamics (SD). From all the analyses of these reviews, it is understood that the promotion of renewable energy and energy efficiency will help Ecuador achieve its objectives in the energy field. The evaluation in this document seeks to clarify "which are" the current energy policy instruments related to renewable energy and energy efficiency in Ecuador, comparing the situation to the rest of the world. It also seeks to identify what should be considered in the future, considering Ecuador's economic sectors. After the evaluation process, it was determined that the possible future challenges of energy policy will show and emphasize how future policies should be designed in Ecuador by decision makers in the last part of the discussion section.

2.1. Summary of the Energy Sector in Ecuador

2.1.1. Characterization of the Supply and Demand of Energy

Ecuador's primary energy matrix has been dominated by oil production since the beginning of its exploitation in the Amazon (Figure 1). Renewable energies have had little participation, however, the production of hydraulic energy in the last fifteen years has grown significantly, reaching an important participation in the national energy matrix. Other renewable energy sources such as wind and photovoltaic continue to be of little importance and specific low-generation projects are promoted [44].

Total secondary energy production has remained at levels close to 70 MBOE between 2003 and 2015, with fuel oil as the main source of secondary energy produced in the country, followed by diesel until 2011, becoming the second most produced secondary source electricity and almost on par with fuel oil in 2012 (Figure 2).

In Ecuador, the final energy consumption is mainly distributed in six economic sectors, as shown in Figure 3. In 2016, the transport sector further increased its energy demand, reaching growth of 74% compared to 2000, while the industrial sector grew 54% and the residential sector 45%. The industrial sector reduced its energy consumption by 6% compared to 2015 [44].

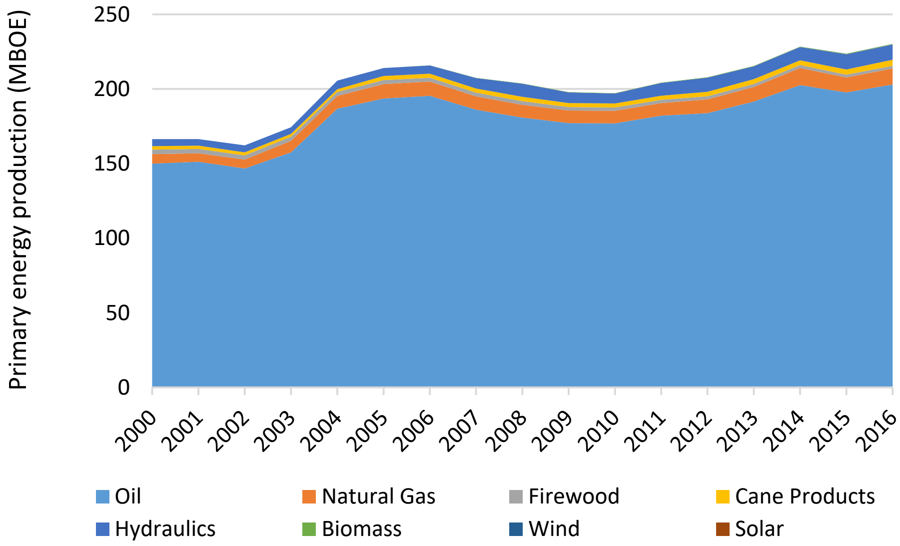

Figure 1. Primary energy production in Ecuador according to energy type [44,45].

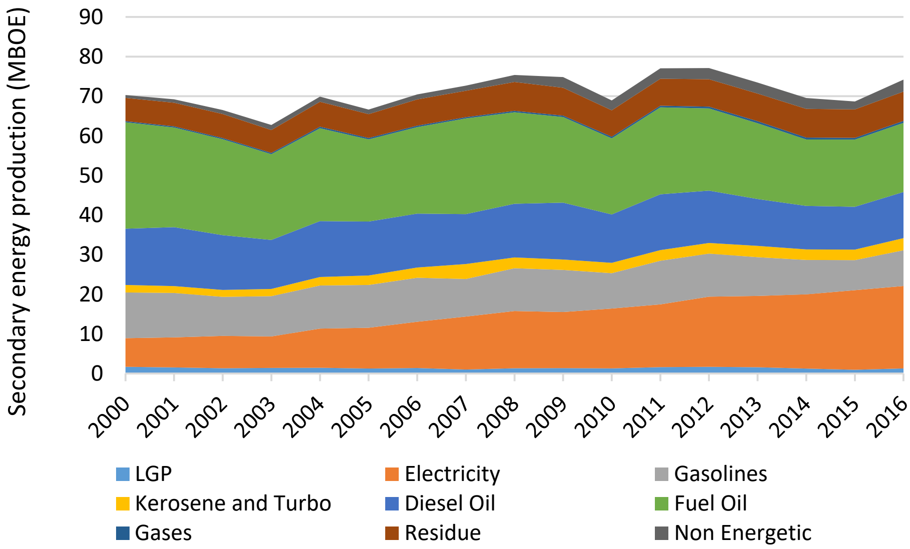

Figure 2. Total secondary energy production in Ecuador for different sources [44,45].

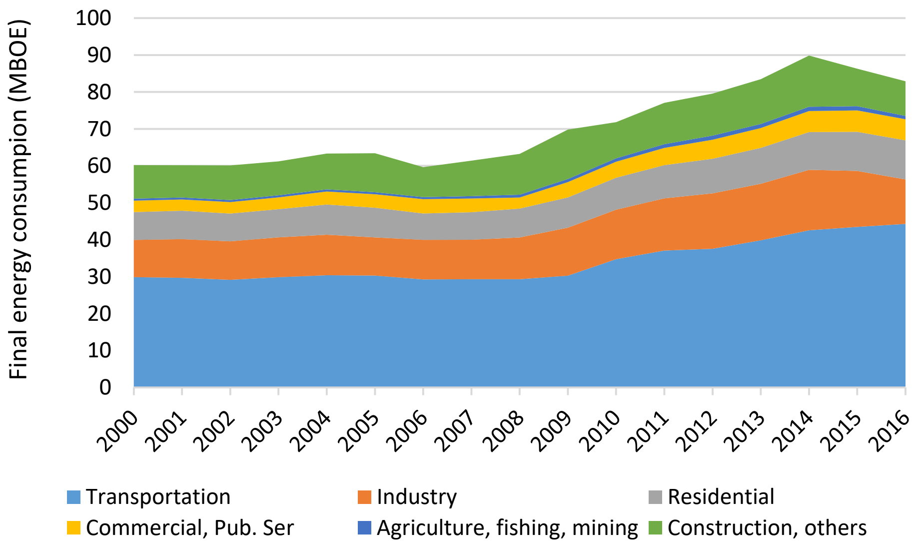

Figure 3. Final energy consumption in Ecuador according to productive sector [44,45].

2.1.2. Renewable Energy and Generation Potential

The past decade has seen strong growth in the deployment of renewable energy technologies, with the electricity sector leading the way thanks to sharp cost reductions for solar photovoltaic (PV) and wind power. The development of new technologies is a key requirement for expanding the use of renewable energy sources. Since renewable resources vary so much by region, state and local efforts could play a useful role in promoting their development [46].

The 2013–2022 Electrification Master Plan details the energy potential for hydroelectric, geothermal, solar and wind resources. The calculated theoretical hydroelectric resource amounts to 90,976 MW; however, 21,903 MW are considered technically and economically usable [47]. In the case of geothermal energy, a hypothetical potential of 6500 MW is available [48]. Regarding solar resources, in 2008, National Electricity Council (CONELEC) published the first Solar Atlas. This has allowed locating local power generation projects: 2.8 MW, under construction, in addition to 907.94 MW from other potential projects [49]. In 2013, the Wind Atlas was published, which determined that Ecuador's gross wind potential is 1671 MW with an average energy production of 2869 GWh/year [50].

Ecuador has an enormous diversity of biomass source to produce energy and other products. Although important steps have been taken to encourage the use of biomass for energy purposes, hard work is still required to achieve a greater participation of this renewable energy source in the national energy matrix [44]. Ecuador is a country that has a high potential for water resources. For the water system of continental Ecuador, a water potential measured in flow equal to 16,500 m^3/s is estimated; of which 11,715 m^3/s correspond to the Amazon slope, and 4785 m^3/s to the Pacific slope [34]. The (CONELEC) has studied the country's potential for hydroelectric generation; and as a result of these studies and investigations, a potential of 2255.94 (MW) and an average annual energy of 11,837.29 (GWh/year) have been determined [51].

2.1.3. Economic and Energetic Context

The debate on the economic impact on the environment today is wide. Two scenarios can be defined: optimistic and pessimistic. Optimists argue that, as resources run out, the economy will replace them with others. Sustained economic growth will produce a less polluted world. On the other hand, pessimists claim that, if the current trend of economic growth persists, the world will become more polluted and the supply of certain essential resources will decrease or can even be forever lost, without the possibility of finding substitutes. The extraction, conversion and use of energy have a considerable influence on the environment and external costs. While replacing fossil energy with renewable energy technologies can often reduce greenhouse gas emissions and, to some extent, other environmental effects and external costs, these technologies may also impact the environment and external costs, according to the energy source and technology used [52].

The current population of Ecuador is approximately 17.35 million inhabitants, the GDP per capita in 2018 was 6344.87 (current USD). The oil sector of the country continues to be the main source of foreign exchange, but it has strongly reduced its participation in national GDP, from 13.2% in 2011 to 4.8% in 2017, according to the World Trade Organization (WTO). The poverty rate fell from 29.6% in 2011 to 24.5% in 2018. External debt rose to $39.5 billion at the end of 2017, when in 2011 it amounted to c. Sending remittances amounted to $2840 million in 2017. Energy is a fundamental input in the quality of life of the population and in the productivity of a society.

Although the production of renewable energy since 2005 has increased by almost 100% in 2016, its participation barely reaches 5% of the total primary energy produced in Ecuador [39,40,45,47]. The participation of renewable energies in the energy matrix of Ecuador considers the following aspects; electricity generation, using natural resources in hydroelectric, wind, biomass (co-generation) and solar (photovoltaic) projects. Projects have been implemented to use biofuels for transportation, through the consumption of extra gasoline with ethanol (pilot project in the city of Guayaquil). On the other hand, in several homes solar water heating systems have been installed. The indicators considered are those suggested at the regional level by the methodological guide of the study Energy and Sustainable Development in Latin America and the Caribbean [53] (Figure 4).

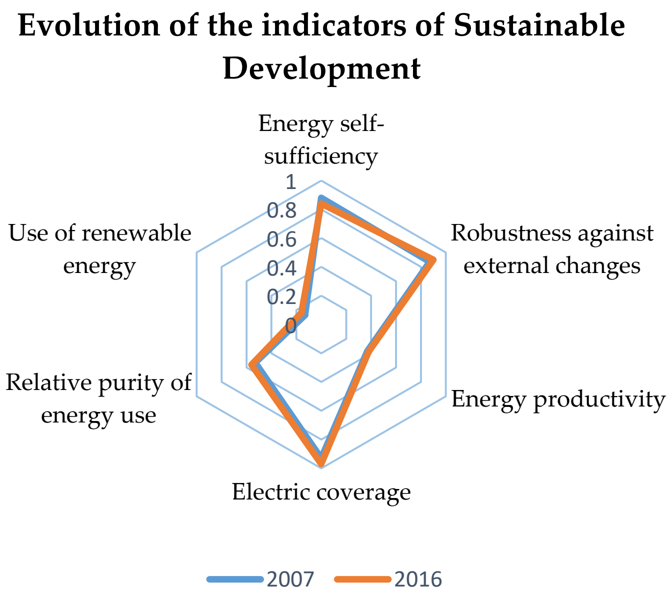

Figure 4. Evolution of sustainable development indicators (Minister of Electricity and Renewable Energy [44].

2.2. *Scenario Analysis*

The construction of scenarios allows exposing a set of alternatives regarding the future, it can be defined as the creation of multiple possible futures to support strategies [54]. Scenarios are descriptions of trips to possible futures that have different assumptions about how current trends develop, how critical uncertainties develop, and what new factors may change over time leading to strategic planning. In this case, the energy prospect and the CO_2 emissions in Ecuador is to be identified. The settings necessarily include subjective elements and are open to various interpretations. Three scenarios were developed to consistently describe the relationships between energy supply and demand and emissions in the country. The formulation of the scenarios is necessary to predict the evolution of the main variables, which can promote energy generation policies, and to project consumption and mitigation of CO_2 emissions.

Our methodology considers three scenario approaches: SCERARIO1 The Business As Usual (BAU) scenario projects the current trends identified by each nation. It assumes that past trends will continue in the future and that no new energy saving, nor environmental protection policies will be implemented [55]. SCENARIO2 (The National Policies) includes the government plans and strategies that have been established for the coming years in Ecuador in terms of energy production and consumption. The following documents are considered: National Energy Agenda 2014–2040, National Energy Balance 2015–2017, National Energy Efficiency Plan 2016–2035, Electricity Master Plan 2016–2025, Electrification Master Plan 2013–2022, Analysis of R&D&I opportunities in Energy Efficiency and Renewable Energies in Ecuador, National Strategy for Climate Change of Ecuador 2012–2025. Finally, SCENARIO3 (Global policies and trends), considering the environmental dimension of the objectives of sustainable development, global environmental governance, multilateral environmental agreements and global macroeconomic perspectives for sustainable development. Replacement plans for clean energy and energy efficiency will serve as the basis, or the trends in the reports of organizations such as the Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA), BP, among others.

The model combines different sectors through feedback mechanisms to capture the complexity of the behavior of the economic-climatic system. The matrix of productive sectors in this study consists of six sections: (I) transport, (II) industry, (III) residential, (IV) commercial, services and public administration, (V) agriculture, fishing and mining, (VI) construction and others. The constant energy matrix of the following primary energy sources: oil, natural gas, hydroelectric energy, cane products, and other primary products. The final energy sources are electricity, LGP, gasoline, kerosene and air fuel, diesel, fuel oil, gases, reduced and non-energy crude oil. Renewable energies not included include photovoltaic, wind, biomass, biogas and biofuels [56]. This structural approach allows for a more scientific representation of feedback relationships. The simulation model is structured in three main modules: economy, energy demand and emissions. The main characteristics of each module are:

Economy: The economy is modeled assuming the monetary value of the final goods and services produced by an economy in each period. The volume of economic activity during the study period is analyzed and considered considering the dynamic integration of regional and global input-output data.

Energy Demand: Final energy demand by sector is estimated through projection of sectoral economic production, efficiency improvements, and energy replacements driven by national, regional, and global policies.

Emissions: the global model calculates the production of CO_2 emissions is set based on the consumption and type of energy considering the three scenarios proposed as a reference.

2.3. Modeling and Simulation

The proposed model was simulated using Vensim software, a modeling tool commonly used to build, simulate, and analyze dynamic model systems based on causal loops or stock and flow diagrams. The model was designed to estimate economic growth, energy substitution and the CO_2 emissions in Ecuador in 2030. To achieve the research objective, Ecuador's traditional energy resources and possible renewable energy resources were considered. Consideration is being given to examining the impact of economic growth on energy consumption and the CO_2 emission system. Figure 5 shows the summary flow diagram of the Economic—Energy—Emissions system, the model analyzes the CO_2 emissions that come from the energy demand of the different economic sectors of the country. There are three stocks in the proposed SD model including Final energy demand, GDP, Population. Total energy demand is the sum of the demand for different types of energy for each of the six economic sectors of Ecuador. Total CO_2 emissions are the sum of the emissions by type of energy that each economic sector demands.

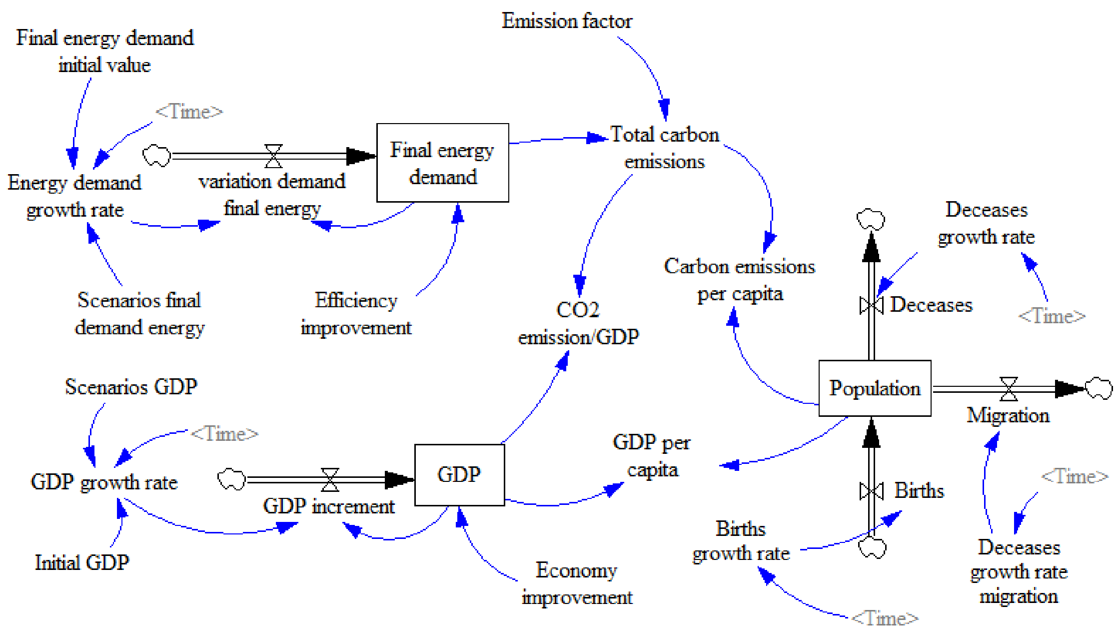

Figure 5. Economic—energy—carbon emissions system flow diagram in Ecuador (adapted from [56]).

3. Results

Below are some of the most relevant results of modeling scenarios for the Ecuador energy system. For each of the productive sectors, the substitution of fossil energy for renewable energy has been proposed.

3.1. GDP per Capita

The simulation of GDP per capita based on the projection of the three scenarios SCENARIO1, SCENARIO2 and SCENARIO3– shows a positive economic projection until 2030 (Figure 6): Economic growth would be between 35% and 37% in the first two scenarios, while there would be an increase reaching 60% compared to the year 2000 in SCENARIO3. Although the simulation shows economic growth, it is necessary to indicate that for the next decade the Economic growth is not very encouraging, so Ecuador's GDP per capita would continue to be one of the lowest in Latin America [57], which could be attributed to high population growth and moderate economic growth [58]. Politically, a structural change in the Ecuadorian economy has been proposed, focusing on sustained and equitable economic growth in the long term [59].

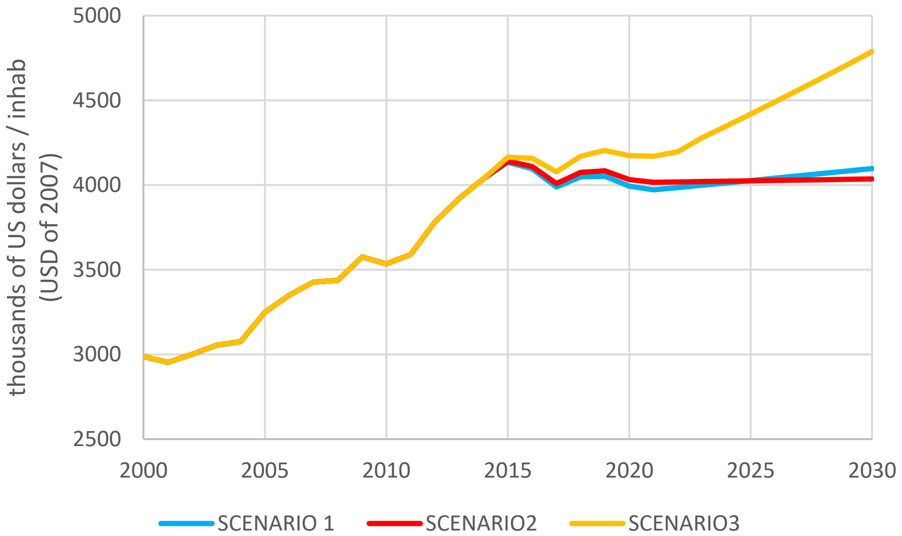

Figure 6. GDP per capita projection in thousands of US dollars/inhab (USD of 2007).

3.2. Final Energy Demand

Figure 7 shows the scenarios of the final energy demand of the transport sector. The energy demand of this sector shows an upward curve in the case of the SCENARIO1, while in the case of SCENARIO2 and SCENARIO3, the energy demand stabilizes, and the increase is greater at the end of the evaluation period. This is mainly due to the substitution of fossil energy for renewable energy, which in the case of Ecuador would be hydropower. Energy efficiency and renewable energy policies can reduce the demand for, and supply of energy generated from fossil fuels [60]. The reduction in energy demand is associated with energy policies that seek to replace energy sources and improve its efficiency. The change in the energy mix will improve the efficiency of a sector that has traditionally been very inefficient energy wise. The projection of SCENARIO2 predicts a reduction of 25% in energy demand by the year 2030 if the current conditions of consumption and energy mix were maintained. Proposing policies of developed countries would forecast a further reduction, reaching 35% of the SCENARIO1 projection.

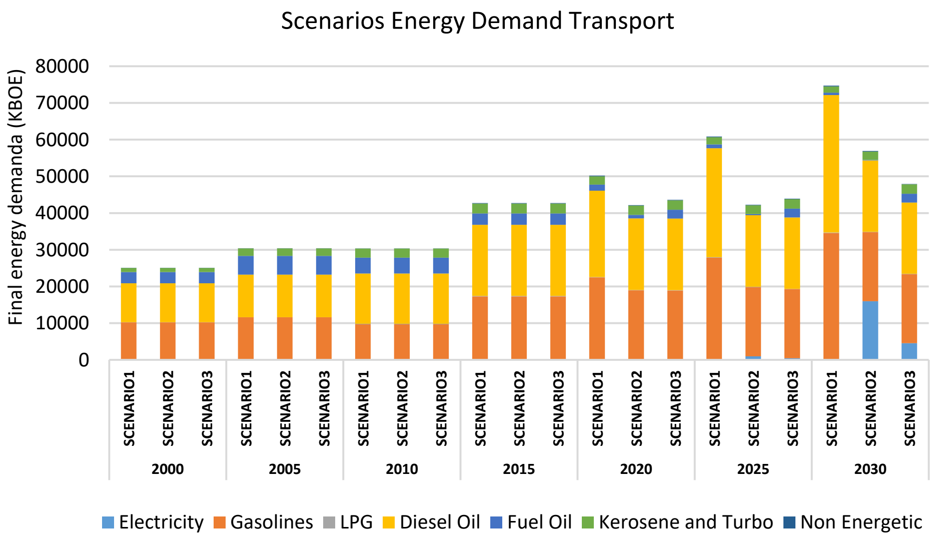

Figure 7. Final energy demand scenarios in the transport sector.

In the case of the industrial sector, the simulation of the scenarios shows an increase in energy demand for the three scenarios. The most significant increase occurs in SCENARIO2, where energy demand grows 140% regarding the simulation's baseline (Figure 8). This is mainly due to government policies that promote the industrial sector. The dependence on oil in the national economy fosters change in the productive matrix by developing new industries such as refining, petrochemicals, steel, shipyards and others [61]. SCENARIO2 proposes an increase in the use of renewable energy. For the industrial sector, an energy mix would be proposed with a 50% share of renewable energy, mainly hydropower, improving the energy efficiency of this sector and reducing CO_2 emissions. On the other hand, SCENARIO3, which promotes global policies, projects an increase of no more than 4% due to energy efficiency and the use of renewable energy in this sector [62].

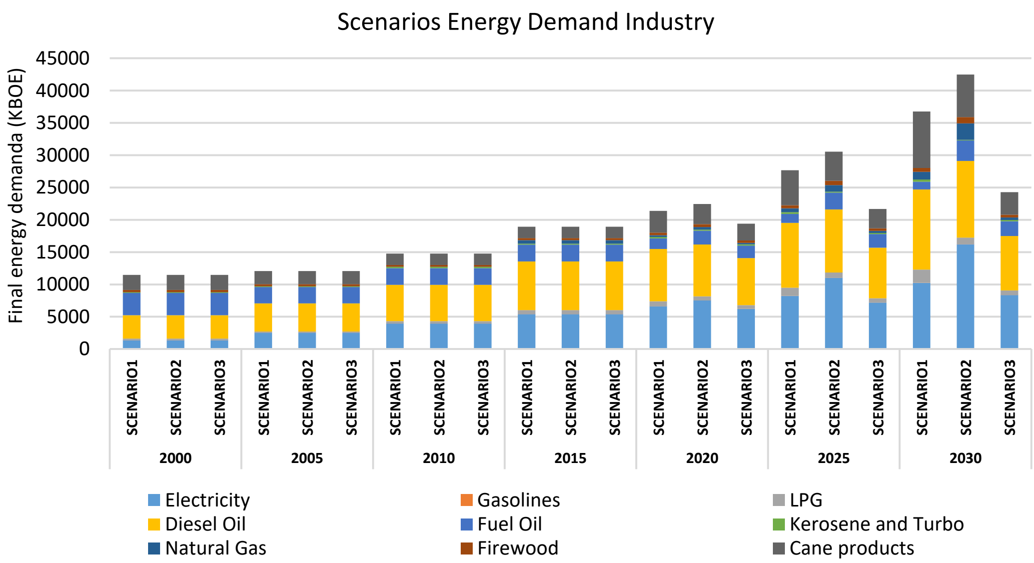

Figure 8. Final energy demand scenarios in the industry sector.

Figure 9 shows the simulation of energy demand in the residential sector. SCENARIO2 projects the highest growth, reaching 160% of the value at the start of the simulation in 2016. In this scenario, a change in the consumption structure can be observed in favor of the increase in the share of renewable energy. The plan to replace the LGP by electric cooking is one of the main factors for the mentioned change. Government policies propose the right that Ecuadorians must access electrical energy and the need for the sector to improve its energy efficiency. The growth in energy demand projected in SCENARIO3 is 42%, which is the lowest percentage of growth. This is based on energy efficiency plans and policies for the use of renewable energy proposed by developed countries.

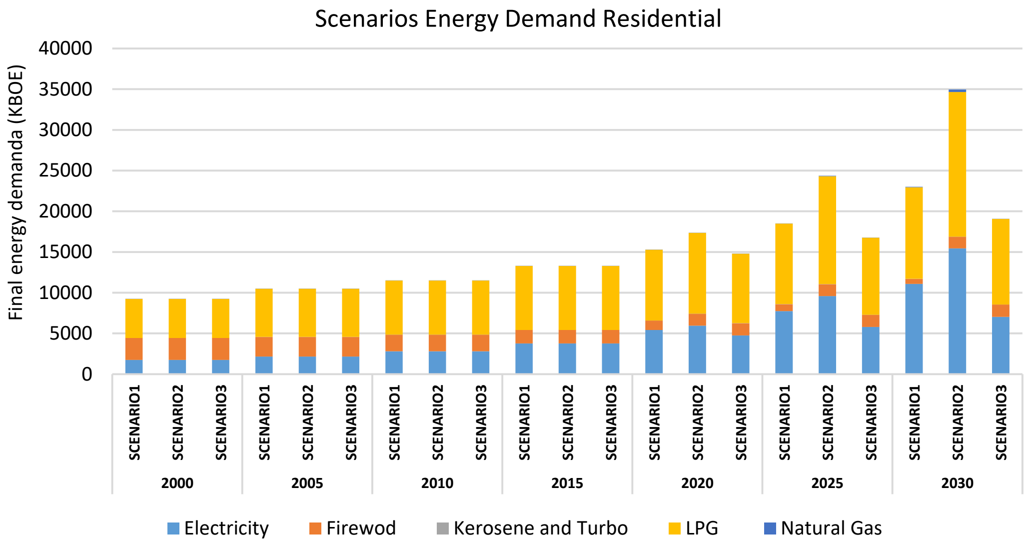

Figure 9. Final energy demand scenarios in the residential sector.

Regarding the commercial sector, Figure 10 shows the evolution of energy demand. The demand of the residential sector presents a similar behavior to the demand of the residential sector. Scenario1 that contemplates government policies shows a steeper upward curve, by 2030 it will reach 12,989 KBOE, the substitution of sources and technologies is presented as the main measure; which would generate significant changes in the consumption matrix of the commercial sector. The demand-population growth relationship would cause the growth of total consumption at the end of the study period. Electricity would continue to be the predominant source in the sector. The decrease in energy demand forecast by SCENARIO3 is due to energy efficiency policies that have been implemented in the last decade by developed countries.

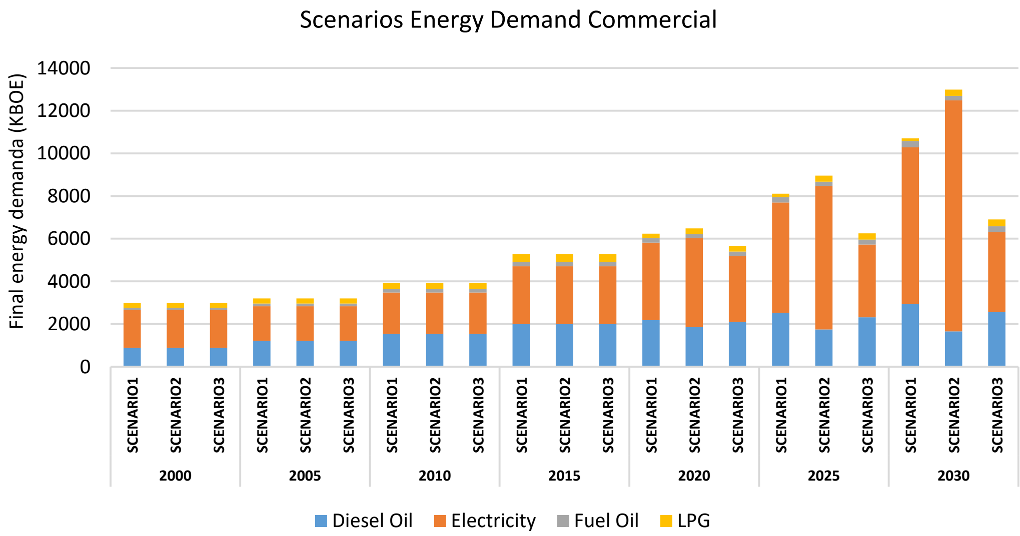

Figure 10. Scenarios demand final energy commercial sector.

In the agriculture, fishing and mining sector, the three scenarios project an increase in energy demand as shown in Figure 11. Within national policies, the state has made the decision to promote mining activity in all its phases, the increase in energy demand projected by SCENARIO2 is sustained by the implementation of large-scale mining projects, which will require energy and will reach 426.66 KBOE by 2030. The energy efficiency and substitution by clean energy sources contemplated in SCENARIO3 projects a lower energy demand 325.10 KBOE.

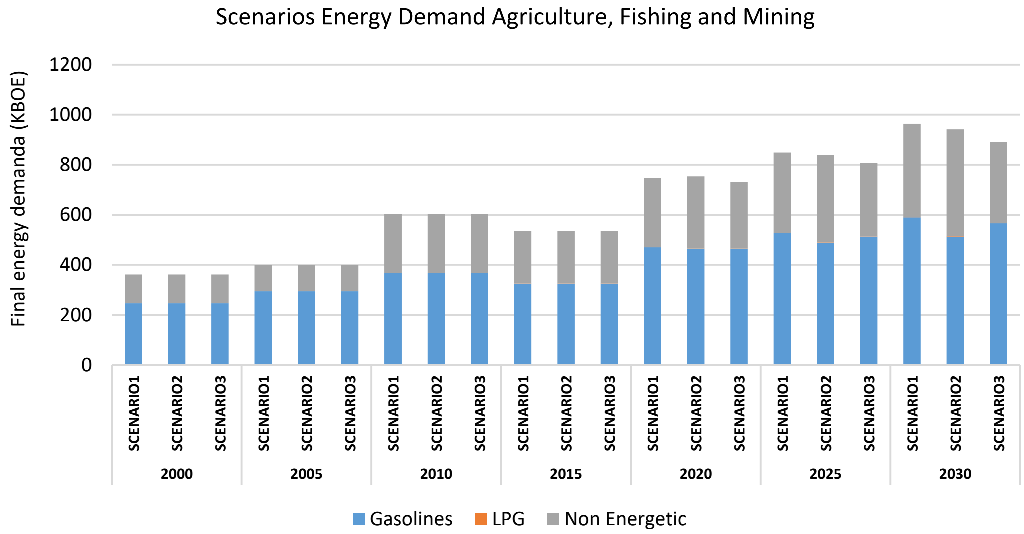

Figure 11. Scenarios demand final energy sector agriculture, fishing and mining.

Figure 12 shows the simulation of energy demand in the construction sector, the three scenarios predict an increase in energy. Maintaining the current conditions of consumption and energy mix, a demand of 17,639.21 KBOE would be forecast, on the other hand, national or global policies focused on energy efficiency and replacement of fossil fuels would be launched, the projection to 2030 would reach 16,175.35 KBOE for SCENARIO2 and 15,357.77 KBOE for SCENARIO3.

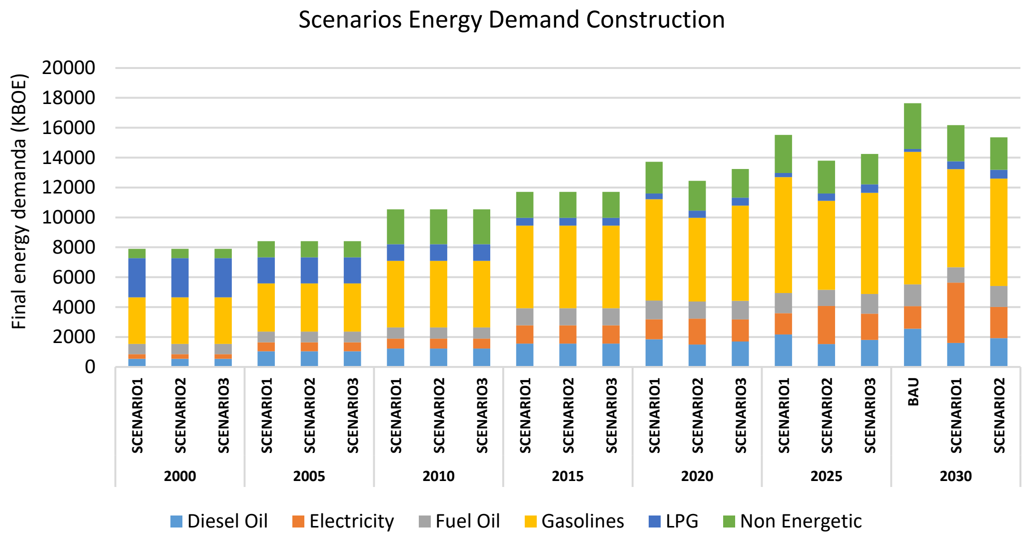

Figure 12. Scenarios demand final energy construction sector.

An increase in CO_2 emissions will continue to be observed if the country does not take urgent measures on energy consumption and, mainly, if it does not adopt the use of more efficient and less polluting energy. When comparing the SCENARIO1 and SCENARIO3 scenarios with respect to the SCENARIO1, a significant decrease in CO_2 emissions generated using energy in the different economic sectors of Ecuador is observed. In the case of SCENARIO2, where a 23% reduction is projected from the 60,233.7 KT CO_2 projected for the year 2030 in the BAU scenario. This reduction is due to the means of energy substitution, technology, energy efficiency and changes in the energy matrix proposed in government energy policies. SCENARIO3 is even more encouraging and projects an increase of just 11.5% compared to 36,978.1 KT CO_2 in 2016 (Figure 13).

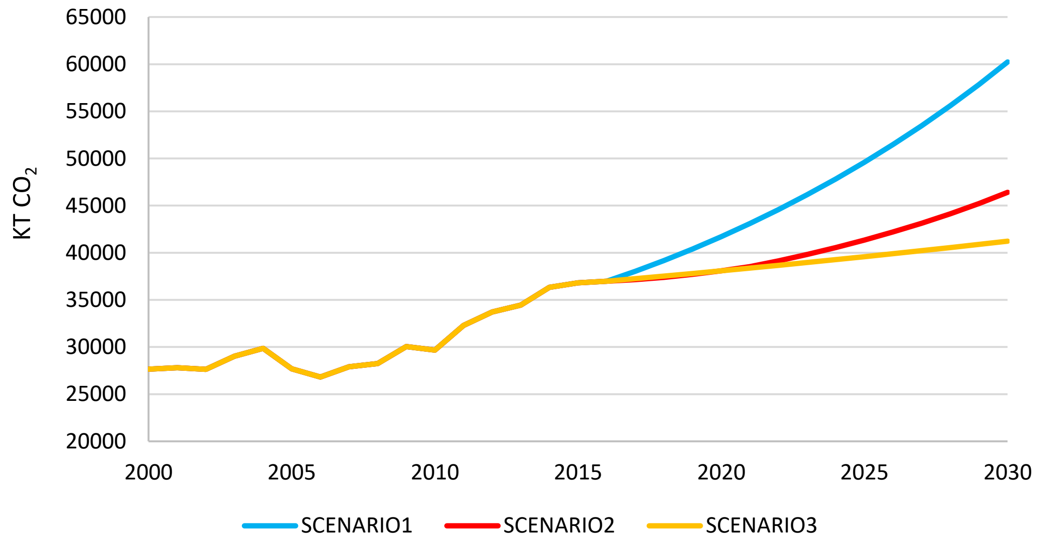

Figure 13. Projection of CO_2 emissions by total energy consumption.

4. Discussion

Based on the results obtained from the simulation of the energy variables in the SCENARIO1, SCENARIO2 and SCENARIO3 scenarios for the year 2030, energy policies could be established that are the pillar of sustainable energy governance concerned with the reduction of emissions, the improvement of energy efficiency and a sustained transition to renewable energy. The three scenarios make it possible to establish the effects of renewable energies and energy policies on energy governance in Ecuador.

The modern fossil fuel economy shows characteristics of a mature socio-technical domain, with a tight integration between the components of the hydrocarbon industry (exploration, extraction, transport, combustion, and retailing) [63]. In reviewing the main agreements, policies and reports in the area of energy governance in the world, they conclude that none of the current forms of energy governance should leave aside the care of the environment and that there are many challenges in the energy field [64]. A central aspect of the issues discussed is the observation that both politics and political processes are at the heart of governance for sustainable development. Climate change now affects all countries on all continents. It is disrupting national eco-economies and affecting lives, which is why there is an urgent need for global energy policies to address climate change, geopolitical tensions and economic vulnerability. Achieving a sustainable energy future requires a revolution in the energy system [65].

Energy is fundamental to all aspects of development, but sustainable energy is basic to improving the health and livelihoods of millions of people around the world, so there is an urgent need for progress on access to sustainable and modern energy to support the progress of nations [66]. Defining energy policies aligned with clean energy use, greater energy efficiency and responsible consumption is imperative in the effort to define sustainable energy governance.

As an oil-exporting country, Ecuador has maintained a high level of dependence on oil and its derivatives in its energy matrix, and the economy accounts for a very significant percentage of the country's total income. In recent years it has experienced a major change in energy, perhaps due to predictions that oil resources are in a phase of decline, estimating that reserves could last between 25 and 30 years [67]. The development of renewable energies has focused on hydropower, with investment in several hydroelectric projects. The Latin American Energy Organization (OLADE) has determined that Ecuador's water potential is approximately 22,520 MW.

From the high dependence on fossil fuels to an almost complete self-sufficiency through renewable energies is the main challenge of the government, policies are needed to encourage the development of new technologies focused on non-conventional clean energy sources such as solar energy, wind energy, biofuels among others. It is important to have guidelines that allow for infrastructure projects that guarantee the supply of energy while meeting high quality standards. Renewable energy promises to play an important role in reducing the generation and consumption of high-carbon energy sources [68]. The timely transition to a low carbon and renewable energy economy is key to mitigating climate change. Climate policies targeting energy-related CO2 emissions can result in short-term localized reductions in both air pollution and adverse impacts on human health [69]. Increase in the use of renewable energy would discourage the use of fossil fuel consumption and thereby mitigate carbon emissions [70].

Ref. [70] investigated the environmental impact of carbon emission mitigation to achieve sustainable economic growth, the study finds a long-term positive equilibrium relationship between renewable energy consumption and economic growth. Research has determined that there is an important relationship between the use of renewable energy and the economic growth of a country. The promotion of mechanisms for adopting the use of renewable energies fosters and stimulates the economic and sustainable growth of nations.

Energy efficiency in Ecuador plays an important role in energy planning. The adoption of energy efficiency schemes within the energy matrix will minimize energy consumption and reduce the carbon footprint. In Ecuador, sectors such as transport and industry have maintained a tendency to consume more fossil energy, producing a greater amount of CO_2 emissions. By taking into account the scenarios that propose the substitution of the energy mix and greater energy efficiency, a decrease in energy demand would be projected and a significant reduction in CO_2 emissions would be achieved compared to the scenario that projects 60,233.7 KT of CO_2 emissions if we continue as we have been acting.

Furthermore, understanding the relationship between CO_2 emissions and economic growth would be useful for formulating energy policies and promoting the sustainable development of energy resources [71]. The significant increase in energy consumption in Ecuador has negatively affected the country's financial position, because large subsidies have been granted to energy consumption in the domestic market, and because Ecuador is an exporter of crude oil and an importer of oil derivatives. A scenario of economic growth would favor investments in scientific research that could lead to the development of new technologies related to the mitigation of CO_2 emissions; therefore, greater economic activity would have a positive impact on the environment. Economic projections do not predict an encouraging scenario and therefore, at present, they would not be a preponderant factor in reducing emissions, so policies that improve the quality of life of Ecuadorians are necessary.

5. Conclusions

The scenario simulation considers the importance of a change in the energy matrix in Ecuador. Incorporating clean energy, mainly hydroelectric energy, considering the country's water potential is one of the priorities that must be considered in national energy policies.

Increasing the participation of renewable energies in the national energy matrix plays a fundamental role in reducing CO_2 emissions. For the development of renewable energy, it is important to change the current energy landscape. Energy policies must be redesigned to promote research, implementation and use of renewable energy in the different economic sectors of Ecuador.

In the case of the transport sector, a change in its energy mix is needed. Transportation would be one of the sectors with the most CO_2 emissions and the highest energy demand by 2030 if corrective measures are not taken and current conditions are maintained. Projects such as the Metro in Quito, the Tram in Cuenca, the airway in Guayaquil, the replacement of urban transport buses by electric buses and the promotion of sustainable mobility projects would be the beginning of a decarbonization for this sector.

Considering that fossil fuels are the main source of energy consumption in Ecuador, it is necessary to propose policies and strategies that promote their rational use. Energy efficiency plays an important role in competitiveness and social aspects and is one of the most effective ways of addressing climate change. The energy required to produce a production unit is high in Ecuador. Sectors such as transport and industry have maintained the trend towards consuming more fossil-fueled energy, resulting in higher emissions and greater energy demand.

Considering the CO_2 emission scenarios, it is clearly observed that by achieving a greater participation of renewable energies and an improvement in energy efficiency, future emissions in Ecuador could be considerably reduced.

For the next few years, Ecuador's energy policies need to consider an economic recovery. Greater investment in innovation and technological development would have a positive impact on the environment. The application of more efficient technologies in energy production, the replacement of fossil fuels with clean energy and the establishment of policies focused on climate change could favor sustainable economic growth.

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Abbreviations

The following abbreviations are used in this manuscript:

BAU	Business as Usual
BOE	Barrel of oil equivalent
CDM	Clean Development Mechanism
CONELEC	National Electricity Council
GDP	Gross domestic product
GHG	Greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LGP	Liquid petroleum gas
SD	System Dynamics
USD	US Dollar
SCERARIO1	The Business as Usual
SCENARIO2	The National Policies
SCENARIO3	Global policies and trends

References

1. Florini, A. The Guardian. 12 January 2010. Available online: https://www.theguardian.com/commentisfree/cif-green/2010/jan/12/energy-governance-climate (accessed on 1 April 2019).
2. BP. *BP Statistical Review of World Energy*; BP: London, UK, 2019.
3. Claussen, E.; Peace, J. Energy Myth Twelve-Climate Policy Will Bankrupt the US Economy. In *Energy and American Society-Thirteen Myths*; Springer: Dordrecht, The Netherlands, 2007; pp. 311–340.
4. Stern, N. *The Economics of Climate Change*; Cambridge University Press: Cambridge, UK, 2007.
5. Van de Graaf, T.; Colgan, J. Global energy governance: A review and research agenda. *Palgrave Commun.* **2016**, *2*, 1–12. [CrossRef]
6. Florini, A. Global Policy. 2 November 2016. Available online: https://www.globalpolicyjournal.com/blog/02/11/2016/new-global-energy-governance (accessed on 12 February 2019).

7. Wang, Q.; Wang, Q.; Wei, Y.-M.; Li, Z.-P. Role of renewable energy in China's energy security and climate change mitigation: An index decomposition analysis. *Renew. Sustain. Energy Rev.* **2018**, *90*, 187–194. [CrossRef]
8. Sovacool, K.; Florini, A. Examining the complications of global energy governance. *J. Energy Nat. Resour. Law* **2012**, *30*, 235–263. [CrossRef]
9. Treib, O.; Bähr, H.; Falkner, G. Modes of governance: Towards a conceptual clarification. *J. Eur. Public Policy* **2007**, *14*, 1–20. [CrossRef]
10. Bazilian, M.; Nakhooda, S.; Van de Graaf, T. Energy governance and poverty. *Energy Res. Soc. Sci.* **2014**, *1*, 217–225. [CrossRef]
11. Zaman, R.; Brudermann, T. Energy governance in the context of energy service security: A qualitative assessment of the electricity system in Bangladesh. *Appl. Energy* **2018**, *223*, 443–456. [CrossRef]
12. Fontaine, G. The effects of governance modes on the energy matrix of Andean countries. *Energy Policy* **2011**, *39*, 2888–2898. [CrossRef]
13. Müller, F.; Knodt, M.; Piefer, N. Conceptualizing Emerging Powers and Eu Energy Governance: Towards a Research Agenda. In *Challenges of European External Energy Governance with Emerging Powers*; Ashgate Publishing, Ltd.: Farnham, UK, 2015; pp. 17–32.
14. Kottari, M. A new era for global energy governance? The environmental imperatives and the EU perspective. *Polit. Iapss J. Political Sci.* **2016**, *29*, 124–139. [CrossRef]
15. Global Commission on the Geopolitics of Energy Transformation. *A New World. The Geopolitics of the Energy Transformation*; International Renewable Energy Agency: Masdar, Arab, 2019.
16. IPCC. *Global Warming of 1.5 °C*; Intergovernmental Panel on Climate Change: Ginebra, Colombia, 2018.
17. IRENA. *Global Energy Transformation: A Roadmap to 2050*; International Renewable Energy Agency: Masdar, Arab, 2018.
18. International Energy Agency. *World Energy Outlook 2018*; IEA Publications: París, France, 2018.
19. DVG.GL. *Energy Transition Outlook 2018*; DVG.GL: Oslo, Norway, 2018.
20. Simsek, Y.; Lorca, Á.; Urmee, T.; Bahri, P.A.; Escobar, R. Review and assessment of energy policy developments in Chile. *Energy Police* **2019**, *127*, 87–101. [CrossRef]
21. Ringel, M.; Knodt, M. The governance of the european energy union: Efficiency, effectiveness and acceptance of the winter package 2016. *Energy Policy* **2018**, *112*, 209–220. [CrossRef]
22. Helm, D. The European framework for energy and climate policies. *Energy Policy* **2014**, *64*, 29–35. [CrossRef]
23. Chang, C.-C.; Carballo, C.F.S. Energy conservation and sustainable economic growth: The case of Latin America and the Caribbean. *Energy Policy* **2011**, *39*, 4215–4221. [CrossRef]
24. Gao, M.-Z.A.; Fan, C.-T.; Liao, C.-N. Application of German energy transition in Taiwan: A critical review of unique electricity liberalisation as a core strategy to achieve renewable energy growth. *Energy Policy* **2018**, *120*, 644–654. [CrossRef]
25. Florini, A.; Sovacool, S. Who governs energy? The challenges facing global energy governance. *Energy Policy* **2009**, *37*, 5239–5248. [CrossRef]
26. Florini, A.; Sovacool, B. Bridging the gaps in global energy governance. *Glob. Gov.* **2011**, *17*, 57–74. [CrossRef]
27. Gazheli, A.; van den Bergh, J.; Antal, M. How realistic is green growth? Sectoral-level carbon intensity versus productivity. *J. Clean. Prod.* **2016**, *129*, 449–467. [CrossRef]
28. Arroyo, F.; Miguel, L.J. Analysis of energy demand scenarios in Ecuador: National government policy perspectives and global trend to reduce CO_2 emissions. *Int. J. Energy Econ. Policy* **2019**, *9*, 364–374.
29. Svampa, M. Commodities consensus: Neoextractivism and enclosure of the commons in Latin America. *South Atl. Q.* **2015**, *114*, 65–82. [CrossRef]
30. Chavez-Rodriguez, M.F.; Carvajal, P.E.; Jaramillo, J.E.M.; Egüez, A.; Mahecha, R.E.G.; Schaeffer, R.; Szklo, A.; Lucena, A.F.; Aramburo, S.A. Fuel saving strategies in the Andes: Long-term impacts for Peru, Colombia and Ecuador. *Energy Strategy Rev.* **2018**, *20*, 35–48. [CrossRef]
31. Escribano, G. Ecuador's energy policy mix: Development versus conservation and nationalism with Chinese loans. *Energy Policy* **2013**, *57*, 152–159. [CrossRef]
32. Noboa, E.; Upham, P.; Heinrichs, H. Collaborative energy visioning under conditions of illiberal democracy: Results and recommendations from Ecuador. *Energy Sustain. Soc.* **2018**, *8*, 1–17. [CrossRef]
33. Sierra, J.C. Estimating road transport fuel consumption in Ecuador. *Energy Policy* **2016**, *92*, 359–368. [CrossRef]

34. Pelaez, M.; Espinoza, J. *Renewable Energies in Ecuador. Current Situation, Trends and Perspectives*; University of Cuenca: Cuenca, Spain, 2015.
35. Ministry of Energy Mexico. Prospects for the Energy Sector. 23 November 2018. Available online: https://www.gob.mx/sener/documentos/prospectivas-del-sector-energetico (accessed on 23 June 2019).
36. Pfenninger, S.; Hawkes, A.; Keirstead, J. Energy systemsmodelingfortwenty-first centuryenergychallenges. *Renew. Sustain. Energy Rev.* **2014**, *33*, 74–86. [CrossRef]
37. Sterman, J.D.; Dynamics, B. *Systems Thinking and Modeling for a Complex World*; McGraw-Hill Higher Education: New York, NY, USA, 2000.
38. Meadows, D.H.; Meadows, D.L.; Randers, J.; Behrens, W.W. *The Limits to Growth*; Universe Books: New York, NY, USA, 1972.
39. Ford. *Modeling the Environment*, 2nd ed.; Island Press: Washington, DC, USA, 2010.
40. Sterman, J.; Fiddaman, T.; Franck, T.R.; Jones, A.; McCauley, S.; Rice, P.; Sawin, E.; Siegel, L. Climate interactive: The C-ROADS climate policy model. *Syst. Dyn. Rev.* **2012**, *28*, 295–305. [CrossRef]
41. de Blas, L.; Miguel, J.; Capellán-Pérez, I. Modelling of sectoral energy demand through energy intensities in MEDEAS integrated assessment model. *Energy Strategy Rev.* **2019**, *26*, 100419. [CrossRef]
42. Capellán-Pérez, I.; de Blas, J.; Nieto, C.; de Castro, L.; Miguel, J.; Carpintero, Ó.; Mediavilla, M.; Lobejón, L.F.; Ferreras-Alonso, N.; Rodrigo, P.; et al. MEDEAS: A new modeling framework integrating global biophysical and socioeconomic constraints. *Energy Environ. Sci.* **2020**, *3*, 986–1017. [CrossRef]
43. Nieto, Ó.; Carpintero, L.; Miguel, J.; de Blas, I. Macroeconomic modelling under energy constraints: Global low carbon transition scenarios. *Energy Policy* **2020**, *137*, 111090. [CrossRef]
44. Ministry of Electricity and Renewable Energy. *National Energy Balance 2016*; Minister of Electricity and Renewable Energy: Quito, Ecuador, 2017.
45. Coordinating Ministry of Strategic Sectors. *National Energy Balance 2015*; Coordinating Ministry of Staging Sectors: Quito, Ecuador, 2016.
46. Asmus, P. Trends in the wind: Lessons from Europe and the US in the development of wind power. *Corp. Env. Strategy* **2000**, *7*, 51–61. [CrossRef]
47. Ministry of Electricity and Renewable Energy. *Electricity Master Plan 2016–2025*; Minister of Electricity and Renewable Energy: Quito, Ecuador, 2017.
48. Ministry of Electricity and Renewable Energy. *Plan for the Use of Geothermal Resources in Ecuador*; Minister of Electricity and Renewable Energy: Quito, Ecuador, 2010.
49. National Electricity Council. *Solar atlas of Ecuador for Electrical Generation Purposes*; CONELEC: Quito, Ecuador, 2008.
50. Ministry of Electricity and Renewable Energy. *Wind Atlas of Ecuador for Power Generation Purposes*; Minister of Electricity and Renewable Energy: Quito, Ecuador, 2013.
51. National Electricity Council—CONELEC. *Electrification Master Plan 2013–2022*; CONELEC: Quito, Ecuador, 2013.
52. Edenhofer, O.; Pichs-Madruga, R.; Sokona, Y.; Seyboth, K.; Matschoss, P.; Kadner, S. *Special Report on Renewable Energy Sources and Climate Change Mitigation*; Grupo Intergubernamental de Expertos sobre el Cambio Climático: Geneva, Switzerland, 2011.
53. United Nations-CEPAL-OLADE-gtz. *Energy and Sustainable Development in Latin America and the Caribbean*; United Nations: Santiago de Chile, Cuba, 2003.
54. Wu, Y.; Zhu, Z.Q.; Zhu, B. Decoupling analysis of world economic growth and CO_2 emissions: A study comparing developed and developing countries. *J. Clean. Prod.* **2018**, *190*, 94–103. [CrossRef]
55. Li, L.; Chen, C.; Xie, S.; Huang, C.; Cheng, Z.; Wang, H.; Wang, Y.; Huang, H.; Lu, J.; Dhakal, S. Energy demand and carbon emissions under different development scenarios for Shanghai, China. *Energy Policy* **2010**, *38*, 4797–4807. [CrossRef]
56. Arroyo, M.F.R.; Miguel, L.J. The trends of the energy intensity and CO_2 emissions related to final energy consumption in ecuador: Scenarios of national and worldwide strategies. *Sustainability* **2019**, *12*, 20. [CrossRef]
57. OCDE. *Economic Prospects of Latin America 2019: Development in Transition*; OECD Publishing: Paris, France, 2019.
58. Park, J.-K.; Ryu, D.; Lee, K. What determines the economic size of a nation in the world: Determinants of a nation's share in world GDP vs. per capita GDP. *Struct. Chang. Econ. Dyn.* **2019**, *51*, 203–214. [CrossRef]

59. National Secretariat of Planning and Development. *National Development Plan 2017–2021, A lifetime*; Senplades: Quito, Ecuador, 2017.
60. Gielen, D.; Boshell, F.; Saygin, D.; Bazilian, D.M.; Wagner, N.; Gorini, R. The role of renewable energy in the global energy transformation. *Energy Strategy Rev.* **2019**, *24*, 38–50. [CrossRef]
61. SENPLADES. *Transformation of the Productive Matrix, Productive revolution through knowledge and human talent*; Ediecuatorial: Quito, Ecuador, 2012.
62. International Energy Agency. *Energy Efficiency*; IEA: Paris, France, 2019.
63. Meadowcroft. What about the politics? Sustainable development, transition management, and long term energy transitions. *Policy Sci.* **2009**, *42*, 323–340. [CrossRef]
64. Sorrell, S. Reducing energy demand: A review of issues, challenges and approaches. *Renew. Sustain. Energy Rev.* **2015**, *47*, 74–82. [CrossRef]
65. Karlsson-Vinkhuyzena, S.I.; Jollands, N.; Staudt, L. Global governance for sustainable energy: The contribution of a global public goods approach. *Ecol. Econ.* **2012**, *83*, 11–18. [CrossRef]
66. Nerini, F.F.; Tomei, J.; To, L.S.; Bisaga, I.; Parikh, P.; Black, M.; Borrion, A.; Spataru, C.; Broto, V.C.; Anandarajah, G.; et al. Mapping synergies and trade-offs between energy and the sustainable development goals. *Nat. Energy* **2018**, *3*, 10–15. [CrossRef]
67. Gomelsky, R. *Sustainable Energy for All: Rapid Assessment Gap Analysis Ecuador*; Ministry of Electricity and Renewable Energy (MEER): Quito, Ecuabor, 2013.
68. Iskandarova, M.; Genus, A. Transforming the energy system? Technology and organisational legitimacy and the institutionalisation of community renewable energy. *Renew. Sustain. Energy Rev.* **2020**, *125*, 109795.
69. Tzankova, Z. Public policy spillovers from private energy governance: New opportunities for the political acceleration of renewable energy transitions. *Energy Res. Soc. Sci.* **2020**, *67*, 101504. [CrossRef]
70. Akadiri, S.S.; Alola, A.A.; Akadiri, A.C.; Alola, U.V. Renewable energy consumption in EU-28 countries: Policy toward pollution mitigation and economic sustainability. *Energy Policy* **2019**, *132*, 803–810. [CrossRef]
71. Mardani, A.; Streimikiene, D.; Cavallaro, F.; Loganathan, N.; Khoshnoudi, M. Carbon dioxide (CO_2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017. *Sci. Total Environ.* **2019**, *649*, 31–49. [CrossRef] [PubMed]