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Dynamic Simulation of Energy Scenarios in the Transition to Sustainable Mobility in the Ecuadorian Transport Sector

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Abstract: In Ecuador, the growth of the transportation sector has significantly increased greenhouse gas emissions. According to experts, this sector currently contributes to 49.8% of total greenhouse gas emissions in this country. This poses significant challenges for environmental sustainability, emphasizing the urgent need for effective strategies to mitigate these emissions and promote environmentally friendly practices. Therefore, this study focuses on developing a dynamic simulation of energy scenarios for the year 2035 in the transportation sector, with the goal of transitioning to sustainable mobility, as fossil fuels are the main pollutants in the country. This study proposes system dynamics models using VENSIM 6.0b software to estimate the total energy demand and pollutant emissions in the transportation sector. The results suggest that if Ecuador aligns with global mobility trends and implements public policies promoting the use of electric vehicles, total CO_2 emissions could potentially decrease from 50,161,432 kilobarrels of oil equivalent (kBOE) to 20,589,720 kBOE by the year 2035.

Keywords: dynamic simulation; energy demand; pollutant emissions; transport sector; sustainable mobility

Citation: Atiaja, J.; Arroyo, F.; Hidalgo, V.; Erazo, J.; Remache, A.; Bravo, D. Dynamic Simulation of Energy Scenarios in the Transition to Sustainable Mobility in the Ecuadorian Transport Sector. *Sustainability* **2024**, *16*, 6640. https://doi.org/10.3390/su16156640

Academic Editors: Shuofeng Wang, Wenbin Yu, Qinghe Luo, Du Wang and Socrates Basbas

Received: 5 May 2024
Revised: 13 July 2024
Accepted: 31 July 2024
Published: 3 August 2024

1. Introduction

At present, one of the main sectors responsible for CO_2 emissions is the transportation sector, surpassing both the energy and industrial sectors. Between 1970 and 2017, CO_2 emissions increased by 70%, and transportation emissions account for 24% of global CO_2 emissions, contributing significantly to global warming. Experts suggest that limiting the rise in ambient temperature to 1.5 degrees Celsius could help mitigate the environmental impact. This target is in line with international agreements like the Paris Agreement, which aims to keep global warming well below 2 degrees Celsius above pre-industrial levels. However, projections indicate that by mid-century, temperatures could increase by as much as 2.7 degrees Celsius. This underscores the urgent need to reduce emissions by 6% annually between 2020 and 2030, which is crucial to combatting climate change. This goal is even more important as the global population is expected to reach 9.7 billion by 2050. With more people, there will likely be increased demand for energy and resources, making emission reduction even more critical [1–3]

In Ecuador, the transport sector is a major generator of greenhouse gas emissions, accounting for 50.1% of total emissions in the country in 2019 [3]. This high proportion of emissions is mainly due to the use of individual, local, and interprovincial transport based on petrol or diesel, as well as the use of old transport models and the lack of efficient transit systems. Despite having a relatively modern vehicle fleet, Ecuador has the worst fuel quality in the region, which contributes significantly to the increase in CO_2 emissions and other polluting gases in the transport sector [4]. The lack of innovation and sustainable mobility design in the Ecuadorian transport sector has generated environmental pollution and health problems in the population. Respiratory, lung, and cancer diseases have been identified as consequences of exposure to these pollutant emissions [5]. Even though Ecuador has managed to reduce emissions by 18.7% in 2020, external factors such as the COVID-19 pandemic have influenced this decrease [6]. The implementation of new technologies and sustainable mobility approaches through industrial design is proposed as a solution to mitigate the environmental impact and improve the quality of transport in the country. The application of sustainable mobility and industrial design in the transport sector in Ecuador is scarce compared to other countries, which highlights the need to adapt to new situations and needs of the Ecuadorian population [7].

In search of solutions to address the environmental impact generated by the transportation sector, several countries, such as Spain, Colombia, Singapore, among others, have incorporated sustainable mobility into the industrial design of new transportation systems, besides achieving sustainable changes in the sector. Their objective is to create future scenarios of low environmental impact, efficiency, safety, intelligence, and inclusion, considering aspects such as product production, quality, life cycle, and user experience [8]. Regarding the last point, several research studies have been developed around the world to provide strategies to mitigate environmental problems. For instance, Månsson et al. (2016) [9] developed a study based on several scenarios where the influence of external factors on energy security is analyzed, focusing on passenger and freight transport on Swedish roads. Four exogenous scenarios are developed using cross-impact balance analysis, finally showing the results of strategies that reduce energy use in the transport sector.

On the other hand, Talbi et al. (2017) [10] conducted a study examining the impact of fuel energy consumption, economic growth, urbanization, and fuel utilization rate on CO_2 emissions. The Vector Autoregressive (VAR) model was applied to analyze the factors influencing the transport sector in Tunisia from 1980 to 2014. This study concludes that fuel energy efficiency plays a significant role in reducing CO_2 emissions. It also notes that improving energy efficiency is achieved with new energy vehicles, consideration of biofuels and fuel blends, and promoting the use of hybrid and electric vehicles. The study carried out by Wolfram et al. (2017) [11] addressed the transition and life cycle analysis of light-duty vehicles that use electric energy from renewable sources. This study developed a hybrid model called EIO-LCA (Economic Input–Output Life Cycle Assessment), which considers both the materials and the energy resources necessary for economic and environmental activities. This methodology, supported by Carnegie Mellon University (EIOLCA, n.d.), integrates various scenarios related to electricity generation and transportation. In addition to analyzing different scenarios, this research assessed environmental impacts, specifically in terms of carbon footprint, throughout the life cycle of electric vehicles. According to the results obtained, by using renewable energy, as in the case of Australia, a significant reduction of 66% in the carbon emissions associated with the use of these vehicles can be achieved.

In the same research field, Raugei et al. (2018) [12] carried out a comprehensive assessment of the impact of electric vehicles on reducing environmental pollution. This study was based on the combination of a mathematical model covering the entire life cycle of a compact battery electric vehicle (BEV) together with a detailed energy analysis of various power supply alternatives during the development and use phase of the vehicle. Furthermore, Barisa and Rosa et al. (2018) [13] presented results of the DTReM-LV (Dynamic Transport Emission Model) model, which analyzed CO_2 emissions and designed mitigation policies in the transport sector in Latvia. This academic article generates scenario studies up to 2030, proposing reference scenarios and recommending the implementation of a package of policies that promote the use of vehicles with alternative fuels to improve the acceptance of public transport. Finally, Declercq et al. (2020) [14] propose an energy and environmental transition with potential scenarios for Spain's transportation sector until

2030. They also evaluate the technological, economic, and environmental consequences of the sector by employing the global business as usual (BaU) scenario.

Due to the above, the present study focuses on developing a dynamic simulation of energy scenarios for the Ecuadorian transport sector by 2035. This aims to facilitate a transition toward sustainable mobility, given that fossil fuels are the primary pollutants in the country. Additionally, this study emphasizes the significance of implementing public policies regarding the use of electric vehicles. This initiative seeks to enhance mobility and reduce pollutant emissions, particularly CO_2, which contributes to global warming and adversely impacts the health of the population. By addressing these challenges and proposing strategies for sustainable transportation, this study contributes to the ongoing efforts to create a cleaner and healthier environment for present and future generations in Ecuador and the world.

The importance of the model implemented in this study lies in its potential to serve as a foundation for decision-making aimed at reducing greenhouse gas emissions, decreasing the use of fossil fuels, enhancing energy security, implementing sustainable technologies, and improving public health by reducing air pollutants and associated diseases. Dynamic simulation of energy scenarios allows for more effective planning, anticipating challenges, and optimizing the transition to a sustainable transportation system. This transition can positively contribute to mitigating climate change, boosting local economic development, creating jobs, and reducing long-term operational costs.

2. Methodology

2.1. Identification of Key Parameters

For the present study, a series of parameters were taken into consideration that are directly related to sustainable mobility, energy efficiency, as well as technology and innovation. These parameters have been proposed according to previous studies [15–27] and are presented in Table 1, grouped into three categories.

Table 1. Key parameters influencing sustainable mobility.

Categories	Parameters	Id.
Energy efficiency and sustainability	Energy	1
	Decarbonization	2
	Electrification	3
Industrial Design	Design and redesign of alternative mobility products	4
	Consumption, utilization, reuse, and repair	5
	Product life cycle analysis	6
	Mobility Design	7
	Reduction in CO_2 emissions	8
	Use of technology	9
	Ecological transportation	10
Technology and innovation	Fuel Optimization	11
	Intelligent Transportation Systems	12
	Smart and Sustainable Cities	13
	Sustainable Infrastructure	14

2.2. Selection of Key Parameters

To carry out the analysis of the key factors, a MIC–MAC matrix is used that considers the parameters presented in Table 1. The MIC–MAC matrix was chosen to better understand the structure and dynamics of the proposed complex system, as well as to identify key areas for intervention or change. To mitigate subjective errors in the weighted scoring of key factors, experts were engaged to assign weights to the variables; objective criteria were established for weight assignment, and an iterative review process was implemented to minimize biases. In this matrix, influence is classified as verticality and dependence horizontally, evaluating each variable in relation to the others. For the weighting of values, the following questions are asked: To what extent do industrial design trends influence mobility trends? These questions are used to determine the level of influence of each variable. To perform the weighting, the following values are considered: 0 = null; 1 = wake; 2 = moderate; 3 = strong. The matrix evaluation was performed taking into account the experience and criteria of the authors. The schematic representation of the MIC–MAC matrix is shown in Figure 1.

TENDENCY				DEPENDENCY														
				T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12	T13	T14	TOTAL
Energy.	1	INFLUENCE	T01		1	2	2	2	0	1	2	2	2	2	1	1	1	**19**
Decarbonization	2		T02	1		1	2	2	2	2	1	2	3	3	1	1	1	**22**
Electrification	3		T03	3	1		3	1	0	1	3	1	2	2	1	1	1	**20**
Design and redesign of alternative mobility products.	4		T04	3	2	3		2	1	1	3	2	1	2	1	1	1	**23**
Consumption utilization, reuse. and repair.	5		T05	3	0	3	3		3	2	1	3	1	1	1	1	1	**23**
Product life cycle analysis.	6		T06	1	0	2	3	3		3	1	1	1	2	2	2	2	**23**
Mobility Design	7		T07	2	2	3	3	2	1		1	3	1	2	2	2	2	**26**
Reduction of CO2 emissions	8		TOB	3	3	3	3	1	2	3		1	3	3	2	2	2	**31**
Use of technology	9		T09	3	2	3	2	2	2	2	2		2	1	3	3	1	**28**
Ecological transportation	10		T10	3	3	3	2	1	1	3	3	2		2	2	2	2	**29**
Fuel Optimization.	11		T11	2	3	3	2	1	2	3	3	2	3		2	2	2	**30**
Intelligent Transportation Systems.	12		T12	2	1	2	2	2	1	2	3	3	3	3		1	1	**26**
Smart and Sustainable Cities.	13		T13	2	1	2	2	2	1	2	3	3	3	3	3		0	**27**
Sustainable Infrastructure	14		T14	1	1	2	2	2	1	2	2	2	2	3	2	2		**24**
TOTAL				**29**	**20**	**32**	**31**	**23**	**17**	**27**	**28**	**27**	**27**	**29**	**23**	**21**	**17**	

Figure 1. MIC–MAC Matrix.

On the other hand, for segmenting the parameters, an influence and dependency matrix was created, as depicted in Figure 2, illustrating the behavior of the aforementioned parameters.

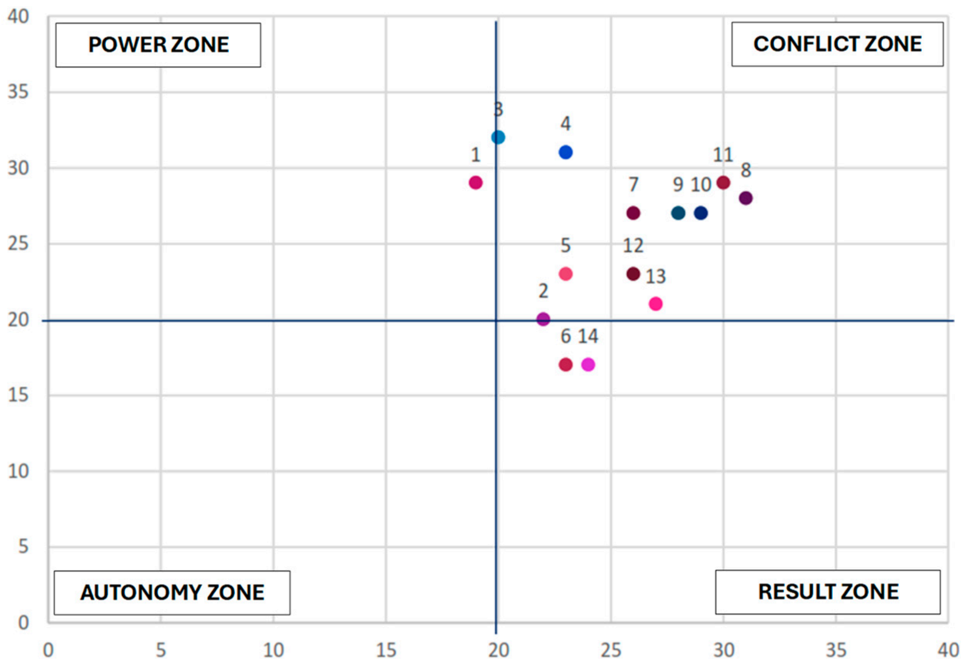

Figure 2. Influence–dependency matrix.

Figure 2 is called Influence-dependency matrix, and it is divided into four zones: Power Zone, Conflict Zone, Autonomy Zone, and Result Zone. Each key parameter is reresented by a numbered, colored point to enhance visibility in the scatter diagram.

According to Figure 2, it is established that variable (1) "energy" is in the power zone, which indicates that it has high influence and low dependence. Therefore, the winning variable is determined, as it influences the other trends and is easy to develop. On the other hand, it can be visualized that most of the parameters are found in the conflict zone, as they have high influence and dependence. These parameters serve as support for the development of the research; however, the parameters that are closest to the power zone will be considered, which in this case are the parameters (3), (4), and (5): "electrification"; "design and redesign of alternative mobility products"; and "consumption, use, reuse, and repair". Within the result zone are parameters (6) and (14), which will not be considered since they are in an area known as a "dead location" due to their low influence and high dependence.

Table 2 shows the variables with the most influence that will be used to generate energy scenarios.

Table 2. Variables with the most influence in energy scenarios.

Categories	Variable	Id.
Energy efficiency and sustainability	Energy Electrification	1 3
Industrial Design	Design and redesign of alternative mobility products Consumption, utilization, reuse, and repair	4 5

2.3. Generation of Energy Scenarios

This methodology for scenario generation was established through a series of steps. Initially, the scope for scenario construction was defined, involving the identification of the scenario field, key actors, and key factors. Subsequently, the process of scenario generation commenced, encompassing subjective elements that allowed for diverse interpretations. Scenario generation is essential for predicting the evolution of variables, particularly in promoting sustainable mobility within the transportation sector and mitigating CO_2 emissions.

- Scenario 1. BaU (business as usual): The first scenario, termed BaU (business as usual), depicts a projection based on current trends and assumes no implementation of sustainable mobility policies in the future. This scenario serves as an intervention-free simulation, reflecting what would happen if the current trajectory persisted;
- Scenario 2. Mobility Policies in Ecuador: The second scenario, named Mobility Policies in Ecuador, integrates all proposed mobility policies by the current government. This scenario considers various documents such as the following: Urban Mobility Plan (PNMU) [28]; Strategic Mobility Plan 2013-2037 (PEM) [29]; Strategic Vision and Objectives for Sustainable Urban Mobility in Ecuador by 2030 and 2050 [30]; The Role of Renewable Energies for Sustainable Energy Governance and Environmental Policies to Mitigate Climate Change in Ecuador [31]; and Low-Carbon Energy Governance: Scenarios for Accelerating the Energy Matrix Change in Ecuador [32]. These policies serve as a basis for projecting potential outcomes based on planned interventions. In conducting the research for future projections, we considered all mobility policies proposed by the current government;
- Scenario 3. Global Mobility Trends: The third scenario, Global Mobility Trends, incorporates global sustainable mobility trends. This scenario envisions a shift toward clean energy sources and enhanced energy efficiency, aligning with trends outlined in reports by such entities as the International Energy Agency (IEA). Additionally, a range of documents was consulted to inform this scenario, further enriching the analyses and projections [30–33].

2.4. Modeling of Energy Scenarios

For the development of Scenarios 2 and 3, we employed the system dynamics modeling approach based on the World Limits Model (WoLiM). The WoLiM model serves as a tool for integrating and simplifying data within a transparent framework [34–41]. In this study, we utilized the VENSIM 6.0b software to implement this model, which is specifically designed to estimate the final energy demand in the transportation sector up to 2035. We considered the energy sources of Ecuador, as depicted in Figure 3, during the course of this research.

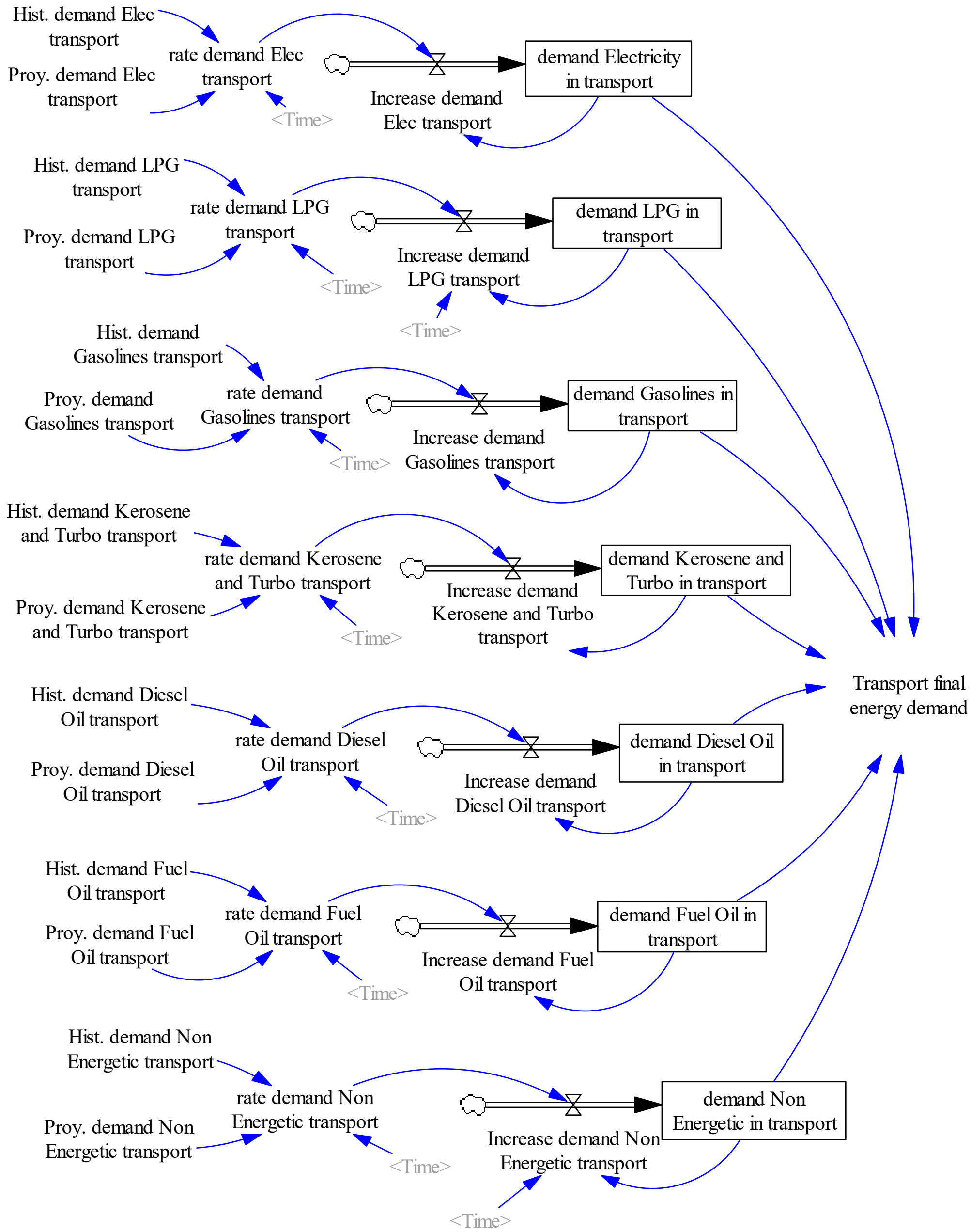

Figure 3. System dynamics of the transport sector in Ecuador. VENSIM 6.0b software.

In order to estimate CO_2 emissions in Ecuador's transportation sector, we constructed a model based on WoLiM. This model employs a sequential framework within the context of scenarios up to 2035, facilitating the calculation of net CO_2 emissions in the sector. We considered the main energy sources used, namely, electricity, LPG, gasoline, fuel oil, diesel, and kerosene (as shown in Figure 4).

As part of this analysis, a tank-to-wheel (TtW) model was used because this model accounts for the emissions produced directly from fuel combustion in vehicles and their subsequent emissions during operation.

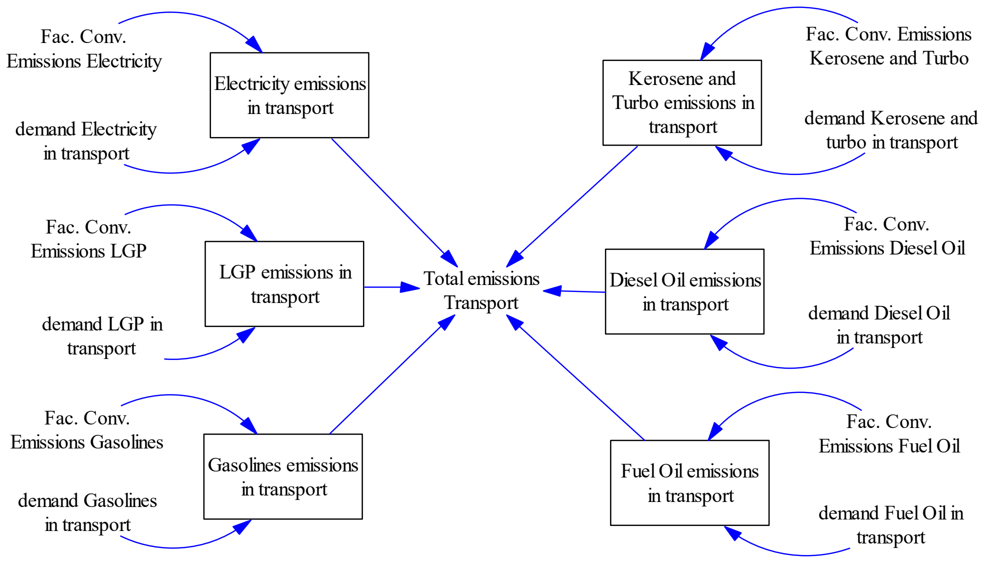

Figure 4. Dynamics of systems for the estimation of CO_2 emissions. VENSIM 6.0b software.

2.5. Validation of the Simulation Model

In the development of scenarios, traditional energy resources in the Ecuadorian transportation sector have been included. For the construction of the BaU scenario. The validation of the model to test its predictive power and robustness was carried out in the first instance by comparing the official data from the calculation of the Mean Absolute Percentage Error (*MAPE*), which aims to compare the official data from 2000 to 2020. This formula is defined as follows:

$$MAPE\ (\%) = \frac{1}{n}\sum\left|At - \frac{Ft}{At}\right| \times 100 \tag{1}$$

where At is the actual value, and Ft is the forecast value.

To determine whether a system dynamics model meets its stated purpose, non-technical, informal, and qualitative processes are necessary. Furthermore, in simulation models, and consequently in system dynamics models, it is necessary to validate the internal structure of the model in order to carry out its complete validation. Barlas established a logical sequence of formal tests to validate system dynamics models. Two types of tests can be distinguished to analyze the internal structure of the model: direct structure tests and structure-oriented behavioral tests.

To increase the credibility of the model, experts were asked to carry out independent verification and validation; they concluded that the model was valid, and the results of the model were valid. All simulations carried out for validation tests follow a business as usual (BAU) scenario, in which the main energy and environmental trends are maintained. Direct structure tests are carried out in the model development process by checking its parameters, equations, and units. These tests have been carried out on all the subsystems of the model, allowing for the errors to be corrected and modifications to be made to the structure. To show the validation process with direct structure tests, we will focus on the part related to energy demand through energy intensities since it is a submodule that occupies an important part in the development of the research.

Energy consumption depends on energy intensity and economic variables, and, in turn, it is shown how energy consumption is fed back by energy scarcity from three negative loops. These three negative loops tend to stabilize the model when there is a shortage. Analyzing the equations, it can be seen how both variables depend on the stock, confirming the first-order negative feedback loop:

- Inertial_rate_energy_intensity_TOP_DOWN = Evol_final_energy_intensity_by_secto r_and_final_energy × Efficiency_energy_aceleration x available_improvement_efficiency;

- Variation_of_intensity_due_to_energy_substitution_TOP_DOWN = Max_yearly_ch ange × Evol_final_energy_intensity_by_sector_and_final_energy × Pressure_to_change_energy_technology.

These are some examples of the many structure confirmation tests that have been performed on all submodules of the proposed model.

3. Results

The accuracy and reliability of simulation results have been ensured by inputting real-world data into the simulation, thereby guaranteeing precision. In the future, sensitivity analysis, ongoing model refinement, and cross-validation will be necessary.

Table 3 details the three scenarios analyzed in this study, focusing on the transportation sector: business as usual (BaU); Scenario 1; and Scenario 2. The business as usual (BaU) scenario has a lower electricity usage, whereas the other two scenarios propose sustainable mobility policies for the sector.

Table 3. Scenarios analyzed in this study.

Actions	2020	2030	2050
Scenario 1			
BaU	BaU	BaU	BaU
Scenario 2			
Substitution of diesel and gasoline in transport	1%	20%	50%
Electrification of vehicles and public transport fleets	0%	50%	100%
Electrification of heavy load transport (merchandise)	0%	50%	100%
Application of industrial design in the sector, such as the design and use of bicycles	1.42%	50%	100%
Electric motorcycles	1%	50%	100%
Electric scooters	1%	50%	100%
Scenario 3			
Electrification of vehicles (cars):	5%	64%	100%
Electrification of 2- and 3-wheel vehicles	40%	85%	100%
Bus Electrification	3%	60%	100%
Vans Electrification	0%	72%	100%
Heavy truck electrification	0%	72%	100%
Biofuels	5%	13%	14%
Micromobility	0%	50%	100%

In Scenario 1, electricity tries to be part of the road transport sector in Ecuador, providing 25% of energy usage by 2035 compared to 1% in 2020. This shows that electricity is in its nascent phase in the transportation sector when applied to sustainable mobility using electric fleets, scooters, bicycles, and cars. As the use of fossil fuels shifts to electricity, the demand for electrical energy in this sector will contribute to efficiency improvements. It is expected that starting from 2025, with the execution of the Quito Metro, CO_2 emissions will be reduced while transporting a larger number of people using electric systems. In Scenario 2, a rapid transition moves away from oil being the leader in the transportation sector, with electricity taking over and contributing to 75% of energy usage by 2035. Considering these results, electricity will become one of the dominant fuels in the transportation sector worldwide by 2030, representing 50% of energy consumption compared to 10% in 2020. This is caused by actions implemented by international governments toward sustainable mobility. To achieve this, the design and use of micromobility are proposed. In addition, the electrification of light and heavy vehicles, as well as urban fleet electrification, are suggested, along with the use of biofuels.

Scenario 1 (BaU) projects the highest growth in energy demand, reaching 103,016.188 kBOE by 2035. In contrast, scenarios based on mobility policies in Ecuador and global sustainable mobility trends show lower energy demand, reaching values of 49,020.1875 kBOE and 44,197.5273 kBOE, respectively, as evidenced in Figure 5.

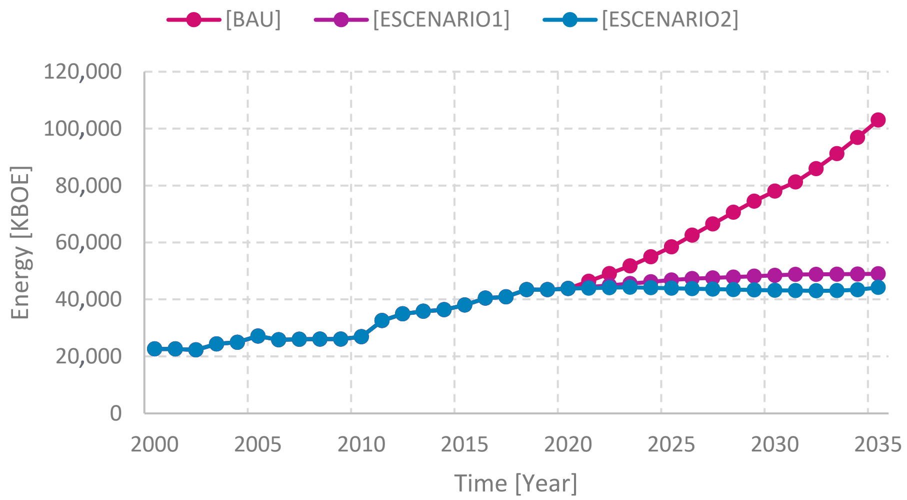

Figure 5. Scenarios of energy demand in the transport sector of Ecuador.

On the other hand, Figure 6 shows the evolution and projection of total CO_2 emissions in the country's transport sector between 2000 and 2035 under three different scenarios: BAU (business as usual); Scenario 1; and Scenario 2. From 2000 to approximately 2020, CO_2 emissions increased similarly across all scenarios. Starting in 2020, the scenarios began to diverge significantly. In the BAU scenario, emissions continue to rise steadily, reaching approximately 55,000,000 KBOE by 2035. In Scenario 1, emissions grow at a more moderate rate, reaching around 30,000,000 KBOE by 2035, reflecting the implementation of some mitigation policies. Lastly, in Scenario 2, emissions start stabilizing in 2020, remaining around 20,000,000 KBOE until 2035 due to the adoption of more effective political and technological measures according to government proposals.

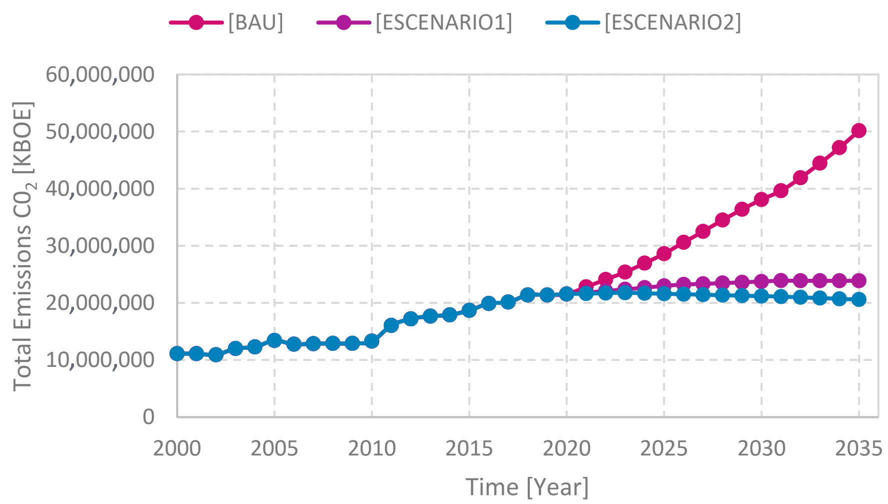

Figure 6. CO_2 Emissions Scenarios in the transport sector of Ecuador.

4. Discussion

It should be noted that electrification is the primary option for reducing CO_2 emissions in the transport sector. Sustainable mobility, driven by advancements in technology and industrial design, is transforming the market with the deployment of electric vehicles and alternative transportation methods. These alternatives include bicycles, electric motorcycles, and electric scooters, as well as several sustainable prototypes currently under development.

The projections indicate that if current energy sources are maintained, CO_2 emissions will continue to rise, as illustrated in the BAU (business as usual) scenario, which projects emissions reaching approximately 55,000,000 kBOE by 2035. However, scenarios that incorporate a mix of energy sources and increased use of electricity show a significant reduction in emissions. Specifically, Scenario 1 projects emissions of approximately 30,000,000 kBOE, while Scenario 2, which assumes the adoption of more effective measures, stabilizes emissions around 20,000,000 kBOE by 2035.

The observed increase in CO_2 emissions of approximately 10,000,000 kBEP between 2000 and 2020 can be attributed to several key factors as follows:

a. Population Growth and Urbanization: During this period, Ecuador experienced significant population growth and urbanization. This led to an increase in the number of vehicles on the road, both for personal and commercial uses, contributing to higher fuel consumption and CO_2 emissions;
b. Economic Development: Economic growth and development resulted in greater industrial activity and higher energy demand, especially in the transport sector. As the economy expanded, so did the logistics and transportation needs, leading to increased emissions;
c. Limited Adoption of Cleaner Technologies: Between 2000 and 2020, the adoption of cleaner and more efficient technologies in the transport sector was limited. Most vehicles continued to rely on fossil fuels, and there were minimal incentives or infrastructure to support alternative energy sources such as electric vehicles;
d. Policy and Regulatory Environment: During this period, there were fewer stringent environmental regulations and policies targeting emission reductions in the transport sector. The lack of robust policies to curb emissions allowed for continued reliance on fossil fuels.

For the BAU scenario from 2020 to 2035, the projected increase of approximately 30,000,000 kBEP in CO_2 emissions is based on the assumption that the factors driving emissions growth will continue and possibly intensify without significant policy intervention or technological advancements. Specifically, the following factors are considered:

a. Continued Economic and Population Growth: It is anticipated that economic and population growth will persist, leading to further increases in vehicle numbers and transportation needs;
b. Increased Energy Consumption: With ongoing economic development, energy consumption in the transport sector is expected to rise, particularly if there are no substantial shifts toward more sustainable energy sources;
c. Insufficient Implementation of Emission Reduction Measures: The BAU scenario assumes that current policies and measures to reduce emissions will remain inadequate. This includes slow progress in adopting electric vehicles, renewable energy sources, and other technological innovations that could mitigate emissions.

For Ecuador, the implementation of sustainable mobility practices is crucial for achieving substantial reductions in CO_2 emissions. The projections for CO_2 emissions in Ecuador's transport sector are 50,161,432 kBOE under the BAU scenario, 23,885,272 kBOE under Scenario 1, and 20,589,720 kBOE under Scenario 2. This underscores the impact that sustainable mobility can have in reducing CO_2 emissions both locally and globally.

The strategies for the transport sector should focus on minimizing the environmental impact of products throughout their life cycle. This includes considering the raw materials used, pollution generated during manufacturing and delivery, the amount of energy consumed, and the waste produced when disposing of products. Integrating eco-design into research and development strategies is essential for effectively measuring and limiting environmental impact at each stage of the product life cycle. Eco-design must quickly become a central solution for sustainable transport. To address the challenges of sustained population growth, increasing traffic, and the environmental impact of transport in Ecuador, national policies must prioritize eco-design processes, including circular economy aspects that extend the lifespan of transport systems while improving comfort and services.

Sustainable mobility enables the creation of diverse business models by enhancing the variety of mobility modes, empowering them with new technologies, and the intelligent use of data. The critical factor for improving the transport sector in Ecuador will be how to design and integrate new modes of transport intelligently, thereby reducing individual traffic and habitual trips that currently generate a high environmental impact.

External factors, such as weather, vehicle distribution, and local demand, should be considered in real time. This includes addressing traffic jams, construction sites, and CO_2 emissions. Slower vehicles, such as scooters and cargo bikes, can increase flexibility compared to traditional options. In new residential areas, shared fleets can help implement flexible mobility concepts. Rapidly growing cities mean an increasing number of people on the move, resulting in more traffic in metropolitan areas. This introduces new challenges in terms of safety, reliability, and maintenance. There is a need for more attention to space division and physical traffic arrangements, as well as new investments in smarter, data-driven traffic control measures.

The next step beyond proposing the shortest and fastest travel options is to suggest those with the lowest carbon footprint. The automotive industry must focus on the overall life cycle emissions of its products and the direct local emissions from vehicles. It is crucial for production plants to become more sustainable and efficient. Recycling, renewable raw materials, and the use of new energy sources play central roles in the proposal of national policies.

The mobility sector in Ecuador has traditionally been seen as relatively independent. However, today, interaction with other industries and business areas is essential. This shift is evident in the move toward electric vehicles and sustainable mobility. The transition to sustainability requires a collaborative effort. Manufacturers and operators must connect and cooperate with political and scientific spheres, establishing strong economic partnerships with component manufacturers and recycling specialists. Besides suppliers of green energy, banks, insurance companies, and a network of retailers and services can contribute to this effort. Innovation in business models, such as car subscriptions, delivery services, or fast charging solutions, seen in other countries, could provide valuable alternatives.

Electrification of vehicles and public transport fleets necessitates significant investment in infrastructure, including charging stations and electric vehicles. However, this investment can pose challenges for stakeholders. Technological hurdles involve battery durability and efficiency, particularly in extreme climates or prolonged usage. Additionally, the absence of supportive policies and regulations may discourage electric vehicle adoption. Market acceptance might be slow due to a prevailing preference for conventional vehicles and resistance to change.

The findings of this study may have relevance for other cities or regions with varying demographic, geographic, and economic characteristics. However, several considerations and limitations must be considered when extrapolating these results. Contextual differences, such as population density, topography, climate, and existing infrastructure, play a significant role. Additionally, the availability of renewable energy sources, the political and regulatory environment, and varying levels of commitment to decarbonization and electric vehicle promotion in different regions should be considered. Public acceptance of electric vehicles varies, with some regions being more receptive to electric mobility due to cultural or practical preferences. Factors like the cost of electric vehicles, maintenance, and infrastructure investment also differ across regions. Battery technology, range, and durability are fundamental, and extreme climates can impact battery performance.

5. Conclusions

The transformation of the transport sector to reduce CO_2 emissions requires firm government decisions in the coming years. All governments must eliminate fossil fuel subsidies and encourage the transition to environmentally friendly and low-cost fuels.

By 2035, governments need to define clear strategies for decarbonization in the sector. Industrial design is fundamental for the electrification of vehicles, as focusing on this need makes the sector's transition more feasible. A wide variety of products that use electricity as fuel will allow users to find options in the market that suit their needs, thus promoting sustainable mobility.

Considering Ecuador's electrical potential, the transition from fossil fuels to electricity sources in the transport sector is crucial to reducing CO_2 emissions. Electrification has played an essential role in decarbonization in recent years, and the use of alternative sources to diesel or gasoline has been important globally. In Ecuador, it is necessary to comply with the proposed mobility policies that offer sustainable alternatives. The change from current energy sources to the implementation of electrical energy or natural sources is fundamental. Projects like the Quito Metro or the Tram in Cuenca are the beginning of this transition. This progression toward sustainable mobility, promoting the use of electric vehicles and alternative transport such as bicycles, motorcycles, or scooters, changes the energy demand in the sector.

The simulation of scenarios highlights the importance of changing Ecuador's energy matrix. By incorporating clean energy sources, mainly electricity, there is a significant reduction in emissions within the matrix. Energy efficiency plays a crucial role in the innovation and competitiveness of countries, being one of the most effective ways to address climate change. In Ecuador, the transport sector is one of the largest energy consumers and, consequently, the sector that generates the highest emissions. Considering the CO_2 emissions scenarios, it is observed that by achieving greater participation of electricity in the sector, improving energy efficiency, and by implementing industrial design, emissions can be significantly reduced.

In summary, the transition to sustainable mobility in Ecuador requires a combination of government policies, technological innovation, and a firm commitment to the electrification of transport. The implementation of these strategies will not only help reduce CO_2 emissions but also improve the quality of life and environmental sustainability of the country.

Author Contributions: Conceptualization, D.B.; investigation, J.A. and F.A.; writing—original draftand A.R.; writing—review & editing, V.H. and J.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to related research are being developed in a recent local project.

Conflicts of Interest: The authors declare no conflicts of interest.

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