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Greenhouse Gas Emission Scenarios and Vehicle Engine Performance in a Main Urban Road in Northwestern Mexico

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Featured Application: A methodology to estimate vehicular GHG emissions and project them, whilst considering vehicle performance improvements, which are applicable to help urban planners or decision makers to improve vehicular flow on urban roads and to mitigate the CO_2e generated.

Abstract: Transport is one of the sectors with the highest greenhouse gas emissions (GHG) that is imperative to reduce in order to decrease global warming. Although modern vehicles and arterial roads have adopted technological and structural improvements to enhance fuel use efficiency, the emission of greenhouse gases (GHG) into the atmosphere by the transport sector has been increasing in different Mexican cities. In generating mitigation strategies, modeling scenarios of decreased equivalent carbon dioxide, CO_2e emissions, may be useful as an evaluation tool. In this study, the aim was to model a trend scenario and a scenario, including improvements with a projection to the year 2039 on one of the main urban roads of the border city of Mexicali, Mexico. In order to create a dynamic emission model of GHG, including emission factors, the main variables for the simulation were vehicle volume, travels, motor performance, and fuel consumption. These last two parameters were the most important for vehicular emissions estimations and for the projection of them in this period. As a result of the projections, CO_2e was observed to increase in a trend scenario, while modeled improvement actions resulted in emission reductions of up to 5%. The model showed that the key variable to achieve this reduction is vehicle engine performance (Pf), whose increase factor was 1.1% per year. Replicating this methodology to evaluate and mitigate the GHG emissions on different city roads or in other cities, can be a contribution for the urban designers, authorities, and involved institutions.

Keywords: vehicle transport; engine performance; emissions; greenhouse gases; projection

Citation: Ibañez-Acevedo, Y.A.; Cruz-Sotelo, S.E.; Flores-Jiménez, D.E.; Santillán-Soto, N.; Santos-Gómez, M.d.l.Á.; Ojeda-Benitez, S. Greenhouse Gas Emission Scenarios and Vehicle Engine Performance in a Main Urban Road in Northwestern Mexico. *Appl. Sci.* **2022**, *12*, 12502. https://doi.org/10.3390/app122312502

Academic Editor: Wenming Yang

Received: 14 October 2022
Accepted: 29 November 2022
Published: 6 December 2022

1. Introduction

Over the past decades, global warming concerns have increased throughout the world due to the rise in GHG emissions, resulting from activities carried out by the energy [1], transport [2,3], agriculture [4], construction [5], waste management [6], and afforestation and reforestation sectors [7], to name a few. According to the International Energy Agency (IEA), the transport sector is the second most significant source of carbon emissions [8]. The main GHG emissions produced by vehicles are N_2O (nitrogen oxide), CH_4 (methane), and CO_2 (carbon dioxide), which are also expressed as CO_2 equivalent (CO_2e) [9].

Therefore, reducing the emissions caused by transport activities is a global target among the climate change mitigation goals [10]; these activities are one of the main sources of the environmental CO_2 released into the atmosphere and they are responsible for three quarters of these emissions worldwide [11]. In this regard, the assessment of urban roads and the exposure to pollutant emissions as a result of vehicular traffic addresses different economic, social, and environmental agendas, which are especially important in developing countries [12].

Carbon dioxide emissions are exacerbated by the large increase in the number of cars and the indiscriminate desire to use them (seeking comfort or status), especially in developing countries, which exerts a growing pressure on the capacity of existing urban road networks. The negative impacts of vehicular congestion [13], both immediate and long-term, require multidisciplinary efforts to be kept under control, mainly through the design of appropriate measures, for example, improvements in transportation technology and adaptation of road infrastructure [14]. Congestion is defined as the high traffic volume of urban roads by vehicles, that is, a high density of vehicles in an area of the city; urban mobility involves the creation of comprehensive transportation habits (improvements) that reduce energy costs, environmental pollution, and traffic accidents [15].

However, given its considerable weight in the problem, the transport sector has an enormous potential for developing environment-friendly solutions; therefore, different alternatives to reduce its emissions should be studied. For example, Zhan, L. [16] decoupled urban road traffic CO_2 emissions estimations from economic growth and developed an inventory of greenhouse gases by city in China. For their part, Sun, L. [17] focused on strategies to reduce vehicular congestion and traffic density using a dynamic modeling method considering an urban transport service space-time network.

Velepucha and Sabando [18], used a quantitative approach and a quasi-experimental design to determine the gas emissions generated by vehicles; dynamic tests were used to determine whether the analyzed cars were within the parameters, and static tests showed out-of-range values (4.03–4.05%) for carbon monoxide (CO) emissions, representing an excess percentage of 0.54% above the maximum allowed parameter of 3.5%, as determined by the NTE (Ecuadorian Technical Standard) [19], which is ascribable to engine maintenance and performance. Gebisa [20], reported that COPERT 5 software overestimates CO by 131.9% and NO_x by 63% when compared to direct measurements.

Concerning the case of Mexico City, Solís and Sheinbaum [21] presented an energy consumption and emissions classification focused on motor transport for 1990–2010, showing that private passenger vehicles are the main gasoline consumers (34% of the sector's CO_2 emissions in 2010), followed by light cargo vans (26%). In addition, the authors projected CO_2 emissions in the transport sector for 2010–2050, identifying a trend scenario and a mitigation scenario in which different technological options and changes in the growth structure of the transport system were analyzed.

Considering the variables evaluated in the aforementioned studies, it is important to focus the research on GHG emissions. The transportation sector has received plenty of attention in recent years due to efforts to find control/reduction solutions for these gases based on the greatest-impact variables and factors, such as emission levels, vehicle performance, and fuel consumption, among others, as a basis for generating emission mitigation strategies in different scenarios [22].

Thus, emissions studies using simulations to create and evaluate scenarios revealing increasing trends in the use of transport services and energy have been carried out [23], and there are many software-based simulation tools to estimate these trends and envision alternatives. Another example is a study on vehicular traffic pollution in Calabria, a region in southern Italy, based on the Corinair (AIR Information Coordination) methodology, developed by the EEA (European Environment Agency) to quantify, and analyze total and vehicle emissions by area unit (km^2) and by citizen [24]. The Simapro 8 software [25] was used in a life-cycle analysis of transport in the European Union, which included 27 countries in 2010. In Lima, greenhouse gas (GHG) emissions resulting from urban road network improvement activities, as well as from regular traffic, were analyzed using the CarbonROAD software, version 1.0 [26]. Global energy systems [27] is another technique used to evaluate high-impact variables, such as fuel consumption; this technique assumes stable CO_2 emissions and the paper suggests transition scenarios seeking improvements.

The aim of the present study was to generate a trend and an improvement in simulated scenarios to address the problem of GHG emissions. One of the main urban roads of the border city of Mexicali, Mexico, was selected and its GHG emissions were estimated, considering the impact variables, such as vehicle engine performance, fuel consumption, and kilometers traveled. In second place, continuous flow effects were analyzed and projected to 2039. The model proposed by the IPCC, which uses emission factors endorsed worldwide, was adapted to estimate GHC emissions. An encouraging result obtained was a reduction in GHG emissions closely linked to vehicle motor performance.

This article is organized sequentially. After the introductory section, we present materials and methods, including the selection of a main urban road for the study, information gathering and analysis, transport emissions model, emissions model simulations, projected scenario, and simulated planning of urban road improvement actions. Subsequently, we present results for vehicle volume measurement (VVM), travels, equivalent CO_2 emissions in each VVM point, and the projected equivalent CO_2 emissions. Conclusions are presented in the last section.

2. Materials and Methods

The methodological framework of this study began by selecting the study area and obtaining and analyzing field data for the emissions model. Subsequently, the simulation of the trend scenario was generated, as well as the scenario incorporating the improvement actions (Figure 1).

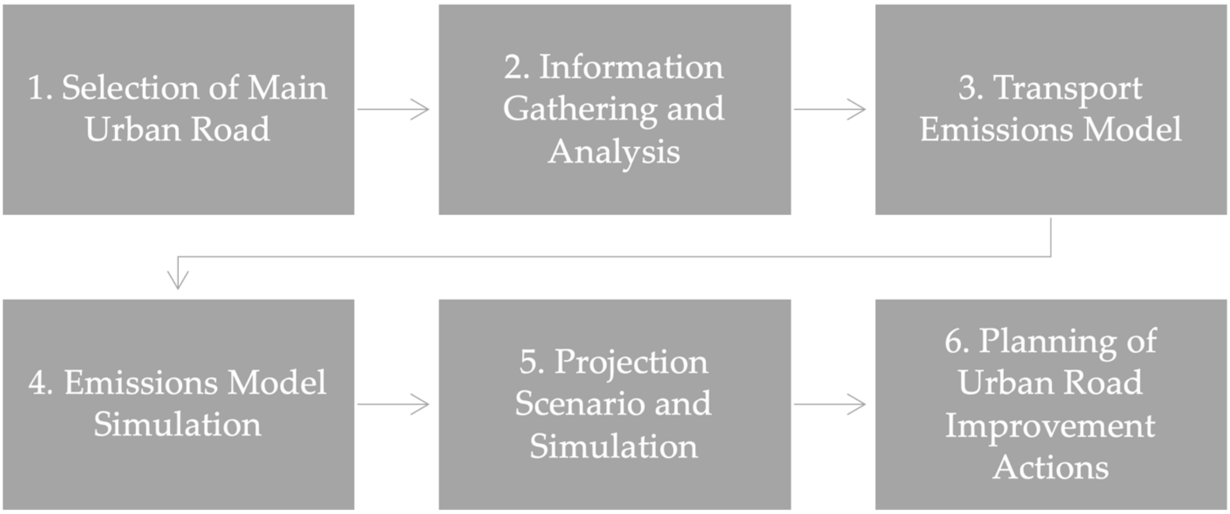

Figure 1. Flowchart of methodological framework.

This study was conducted in the city of Mexicali, located in the Mexico–United States of America border. Mexicali is the capital of Baja California, and its topography is flat. Its geographic coordinates are 32.55° N, 115.47° W and it is 4 m above sea level [28] (Figure 2). The population of the city of Mexicali is 1,049,792 inhabitants [29].

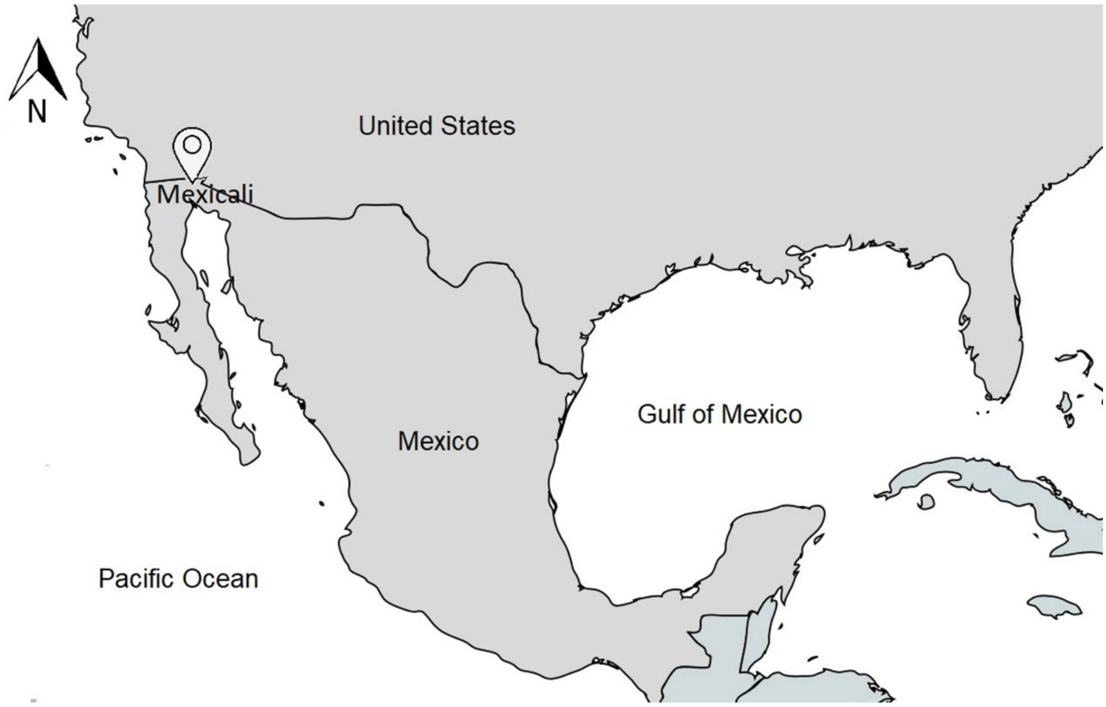

Figure 2. Geographic location of Mexicali, Baja California, Mexico. Source: Google Maps.

2.1. Selection of Main Urban Road

The city's road infrastructure was developed from the historic center and international border crossing; primary roads connect this area with population nuclei to the south, east, and west, following a semi-concentric pattern of urban organization. Three primary roads were identified: Adolfo Lopez Mateos Boulevard (BLM), which has a daily vehicular demand of 48,661 units (annual daily average) and crosses the city from northwest to southeast; Manuel Gomez Morin road (formerly Periferico Oriente), with a vehicular demand of 25,598 units, which encircles the city; and Lazaro Cardenas Boulevard (BLC), with a vehicular demand of 68,013 units, that is another important road that connects the city in the east—west and west–east directions, which also has the highest vehicular flow [30,31].

The main study road was selected based on the following criteria:

1. Being a primary urban road;
2. High vehicular volume in relation to other roads;
3. Presenting a variability in terms of vehicle classification;
4. Presenting connectivity with other primary and secondary urban roads, as well as with a variety of urban land uses;
5. Being susceptible to infrastructure and operation changes.

Based on these criteria, we selected BLC and established 11 vehicle volume measurements (VVM) along an 11.4 km line (Figure 3). The points were not placed at intersections but at intermediate points, representing vehicular flow in selected BLC segments.

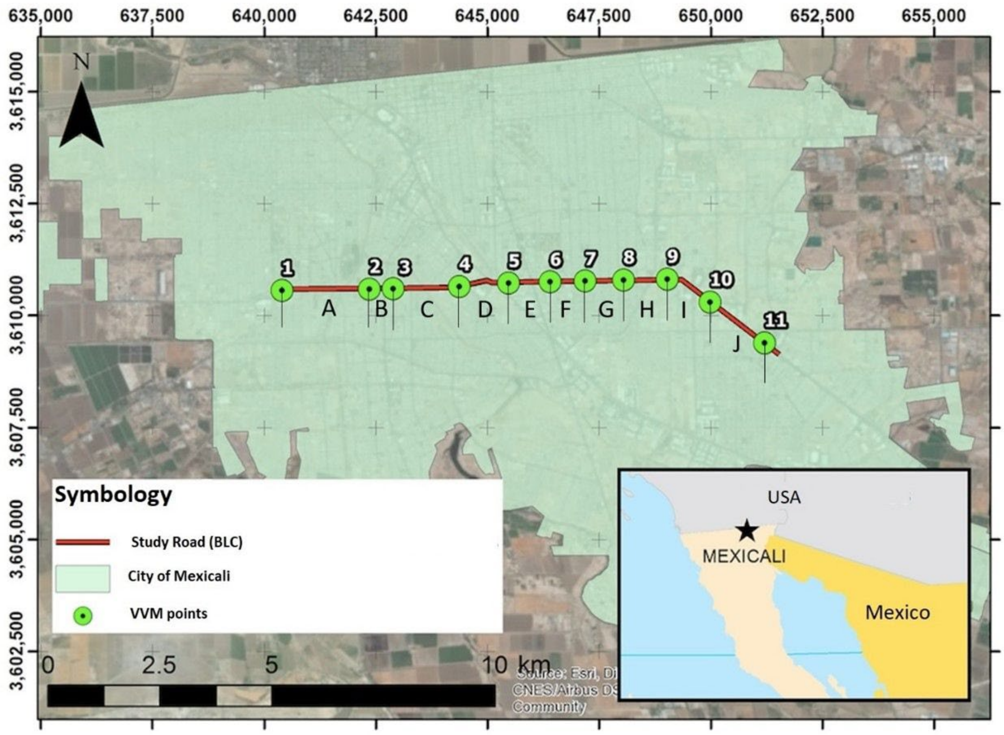

Figure 3. Location of vehicle volume measurement (VVM) points. Each segment between points is defined by vertical lines and represented letters from A to J. Elaborated by the authors (ARCGIS 10.3).

Congestion in BLC is largely due to its main function of connecting commercial, industrial, residential, and school areas. The activities in the area are related to jobs, housing, education, and culture, among others, as reported by monitorization studies on nine Mexican cities for which air quality data are systematized and analyzed. These cities have the highest levels of air pollutants in the country, exceeding official standards. Comparable pollutant levels are reported for Mexico City, Guadalajara, and Mexicali since their main emission sources are combustion processes, such as vehicle emissions and agricultural burning [32]. Land use and vehicles also favor the emissions generated by tire friction and tire erosion due to the unpaved urban roads. These cities present intense cargo vehicle traffic, especially those in arid regions; similar arterial road problems can be observed around the world [33].

2.2. Information Gathering and Analysis

During this stage, the VVM was carried out using a 4 digit analog manual counter [34]. The period was from 1 February 2018 to 31 January 2019, which will be referred to as P0218–0119; 12 months of information was recorded. The VVMs were taken every 15 min for one hour in each circulation direction (east–west and west–east) at three times: morning, afternoon, and evening. Measurements were taken on the same day of each month to obtain representative data on business days over one year. The schedules in the three periods were: 08:00–10:00, 12:00–14:00, and 17:00–19:00. These periods were identified as those with the greatest demand for vehicular movement. The VVMs obtained are presented in the results section and were utilized as input data to the base line and projections.

2.3. Transport Emissions Model

As part of the aim of this model, it is important to take into account the following considered and not considered criteria for the variables and for the model.

- Considered criteria:
  1. The model worked only for GHG vehicle emissions, (as proposed in the methodology);
  2. The emission factors proposed by the IPCC were used for road transport models;
  3. Within the emissions, CO_2, CH_4 y N_2O are already quantified and are presented as CO_2e, considering their respective global warming potentials and the respective types of vehicles;
  4. No adjustments were made to the uncertainties of GHG emission factors (EF) stipulated by the IPCC;
  5. Regarding the field information used to calculate the activity data (DA), a statistical error of 1% was considered in such a way that the *p*-value calculation was smaller than that error.
- Not considered criteria:
  1. The model does not consider other polluting sources, besides the GHG specified by the IPCC methodology, for example, criteria pollutants for smog-control measurements, which were carried out in closed enviroments.

The transport model used in this research is presented in Figure 4, for the estimation of GHG emissions based on the IPCC methodology; Table 1 presents the equations associated with the model. This was applied to each of the BLC segments, considering their specific length data (L).

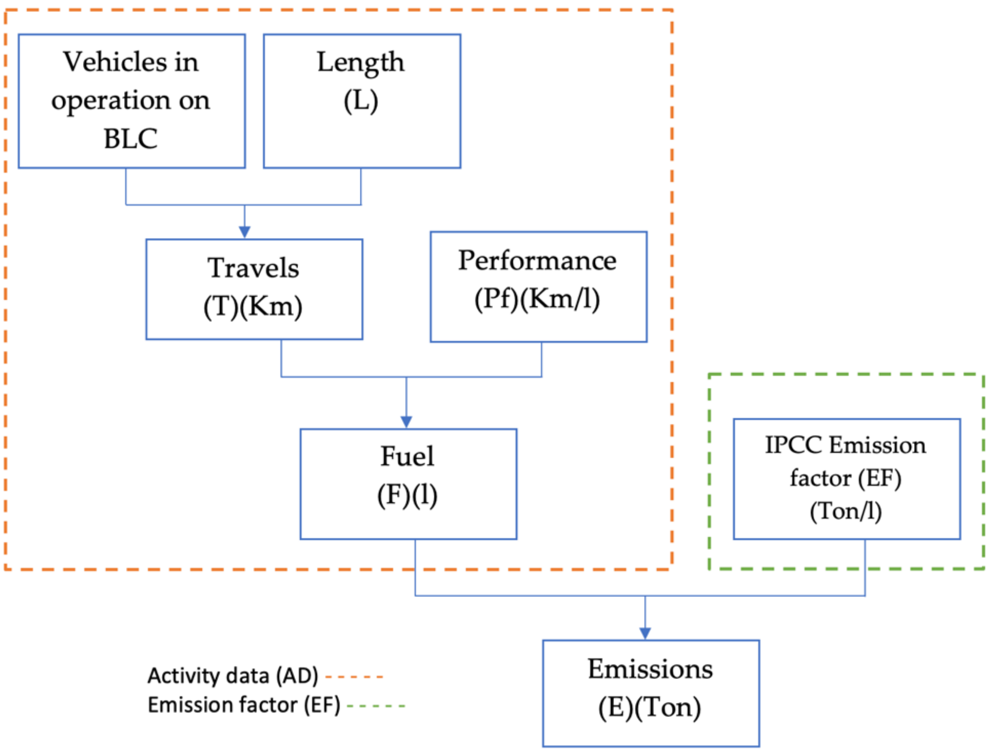

Figure 4. Emissions estimation model (own elaboration) based on IPCC [35].

Table 1. Equations associated with Transport and GHG Emissions model variables.

Dependent Variable	Formula/Data
Vehicles in operation on BLC (V)	40,748,850
Length (L)	L (every segments from A to J)
Travels (T)	$T = V \times L$
Performance (Pf)	7.53 Km/L
Fuel (F)	$F = T/Pf$
Emissions (E)	$E = EF \times AD$

*Trip Length (L), Performance of BLC (Pf), Emission Factor (EF), Activity Data = Fuel (AD)). The data corresponds to the reference period P0218-0119.

The proposed model in Figure 4 was adopted from the IPCC methodology for GHG calculations ($E = EF \times AD$), designed for open environments and consisting of the application of the defined emissions factors for each GHG [35]. The variable "activity data" (AD) utilizes parameters to quantify emissions, which were obtained from field information, such as travels (T) and vehicle performance (Pf) and were used to obtain fuel consumption (F); the EF variable is based on a previous study [36].

The IPCC model contains three application tiers, which depend on available information. This case study considers Tier 3 [35], which requires highly specific activity data and emission factors, as well as kilometers traveled and vehicle efficiency.

Based on the previous description and using weighted average volume by type of vehicle, a 20 year GHG emissions projection was made, considering historical vehicle data from 1980 to 2019. One of the simulation's essential variables was vehicle engine performance (Pf), which is a function of the capacity, age, and mechanical conditions of each type of vehicle [36].

2.4. Emissions Model Simulation

In this part of the study, the simulation was carried out in Stella 9.0.3, which allows for dynamic modeling and presents estimation processes and graphic results. The designed model uses this software to estimate the emissions generated by each type of vehicle. The basic structure of this computer program is a graphical interface with icons that represent variables and processes. In Figure 5, stocks contain the iterative results for each time-differential (TD); arrow connectors indicate relationships between variables; flows represent input and output data for stocks, and converters contain the algorithms. This program has prebuilt functions to define the algorithms, verifying them in order to make sure that their syntax is correct.

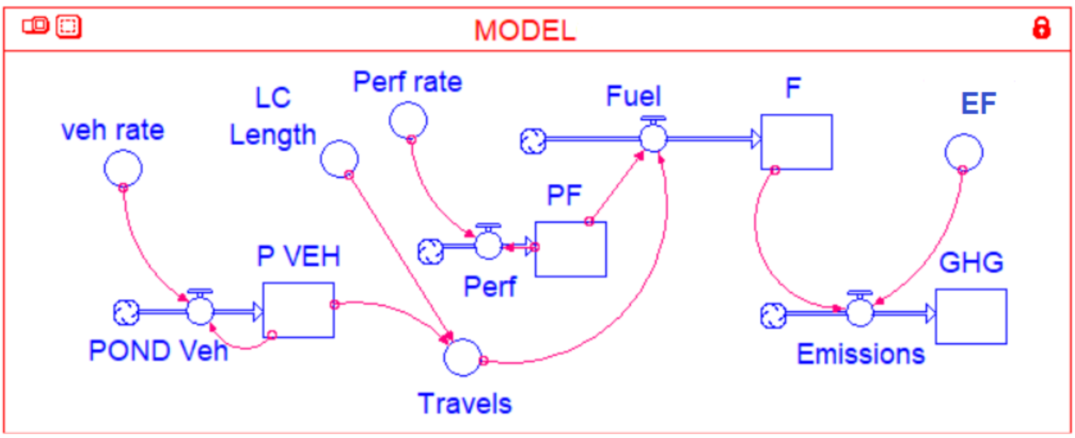

Figure 5. Emissions Model in Stella 9.0.3. ("Stocks" are represented by rectangles, "converters" by circles, and "flows" by valves). Abbreviated symbols Fuel (F), Performance (PF), Vehicle Weighted Average (P VEH), Emission Factor (EF).

The dynamic of the model was structured based on the order that the variables carry within their respective algorithms. Thus, vehicle behavior was measured first and expressed as a weighted vehicle rate based on the by-point segmentation of the urban road length and contrasted with the number of vehicles circulating on each section to obtain BLC travel. Performance (Pf) was measured next, expressed as a performance rate calculated using historical data and the current performance to obtain fuel consumption. Finally, the amounts of emissions were quantified together with the emissions factor.

For the simulation stage, the Stella software, whose version is 9.0.3, provides three numerical methods to solve equation systems: Euler, Runge–Kutta, and second-order Runge–Kutta. The chosen method depends on the type and behavior of the model, for example, the software's authors recommend Euler for models with discrete variables and Runge–Kutta for discrete behavior or oscillatory systems. The Euler method [37] was selected for the present study.

An important aspect of the simulation process is the time-differential (TD), which represents a fraction of the time unit (TU) in which the simulation will be carried out; to refine the results, Stella performs calculations in periods shorter than the TU. This variable can take values from zero to one; the lower the TD value the more time required by the model to perform the calculations [37].

The simulation process consisted of two stages: initialization, where a list of equations was created, the order for their evaluation was established, and the initial state variables or cumulative variables (stock) were calculated; the second stage corresponded to the iteration process, in which the change values corresponding to each TD are estimated and new stocks totals were obtained. With these data, the values in the flows (where the storage variables increase or decrease and their characteristic equations must be described) and converters (element of the model where the equation is described and the calculation is performed) are recalculated (Figure 5). This process is repeated for each TD until the requested simulation period ends [38].

2.5. Projection Scenario and Simulation Planning of Urban Road Imrpovement Actions

The projection and simulation model was created using a database of vehicular data using 40 historical years (1980 to 2019) and taking the performance direct variable (Pf) published in the official document PEACC [36] as an initial reference. Based on the historical data of this variable, the weighted average vehicle performance on the BLC for 2019 was equal to 7.53 Km/L.

Regarding projected scenarios, the first considered a trend resulting from a situation where no changes were made, while the second scenario assessed improvement proposals based on actions, bearing in mind urban development, to analyze the effects on CO_2e emissions. The actions considered were:

1. Road infrastructure improvements (lane adequacy and smart traffic lights);
2. Urban road recarpeting;
3. Continuous flow (no crossings with other arterial roads).

As Díaz, C. and Sosa, M., [39] have indicated, an important aspect of sustainable mobility strategies are actions to improve the technology, operations, and design of infrastructure and vehicles. These improvement actions can be incorporated into the Stella 9.0.3 software through the vehicle travel (Tv) and fuel consumption (F) algorithms (Table 1) since both parameters have a direct impact on GHG emissions.

Based on the travels and the increase factor for the weighted performance previously obtained in a time series, iterations were carried out with the Euler method on emissions for the P0218-0119 period in order to create projections that serve to identify its behavior over time, setting a 20 year period (2019–2039) for the trend scenario and the improvement scenario.

3. Results and Discussion

This section presents the results for the impact variables contained in the model, specifically number of vehicles and total travels. Emissions are shown by type of vehicle, considering their relationship with performance, fuel consumption, and the emission factor. The estimated emissions in the trend scenario and the scenario including the improvement proposals are also presented in this section.

3.1. Vehicle Volume Measurement (VVM)

Figure 6 shows the number of vehicles per VVM point, considering the east–west (EW), west–east (WE), and EW + WE directions. As can be appreciated, the highest concentration of vehicles was located in the central VVMs, that is, 4–10, with the maximum at point 5. This figure presents the average values for each VVM, therefore, the maximum and minimum values of traffic during peak hours are not shown, and similar values were obtained for both directions.

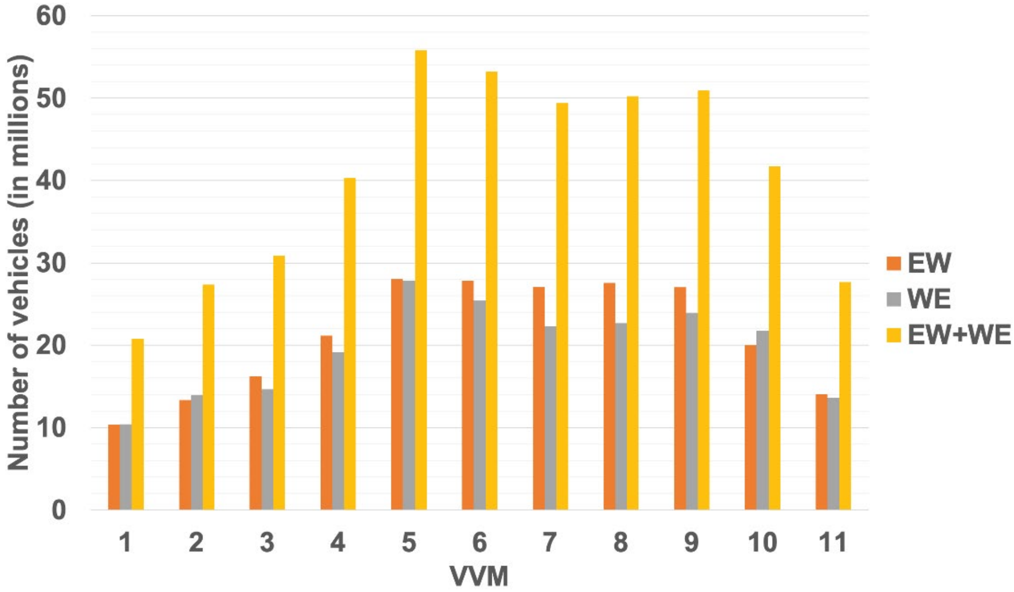

Figure 6. Number of vehicles in each vehicle volume measurement (VVM) point.

3.2. Travels and Equivalent CO_2 Emissions in Each VVM Point

Figure 7 shows the travels per segment, considering the 11 VVMs, where it can be observed that the travels are distributed above and below the mean value (46,387,837 Km/yr), with a standard deviation of 16,404,516 km/yr.

This variable is very important since it is directly related to the amount of fuel consumed and emissions generated (Table 1 and Figure 7).

The main urban road under study was divided into segments from A through to J (Figure 7). Segments B, C, D, and E (associated with VVM points 2, 3, 4, and 5) present a positive slope due to a series of intersections in segments B and C that increase their densities, creating arterial road congestion [40]; in segment H, which is the peak of the slope, there are two important intersections characterized by heavy traffic, which, together with the length of the segments, increases the number of travels. Segments A, I, and J (associated with VVM points 1, 2, 9, 10 and 11) present a negative slope that indicates a decrease in the number of travels.

Considering the different types of vehicles (cars, motorcycles, buses, and light and heavy cargo vehicles) and applying the weighted average GHG emission factors, CO_2e emissions were obtained for each VVM point, since its variability in each one has a direct impact on the total amount of said parameter per VVM point (Figure 8). This same figure shows that point five presents the maximum values of CO_2e, considering all types of vehicles (202,666 ton/year). This is associated with the high vehicular flow, which represents a high number of travels (636,244,430 km/year).

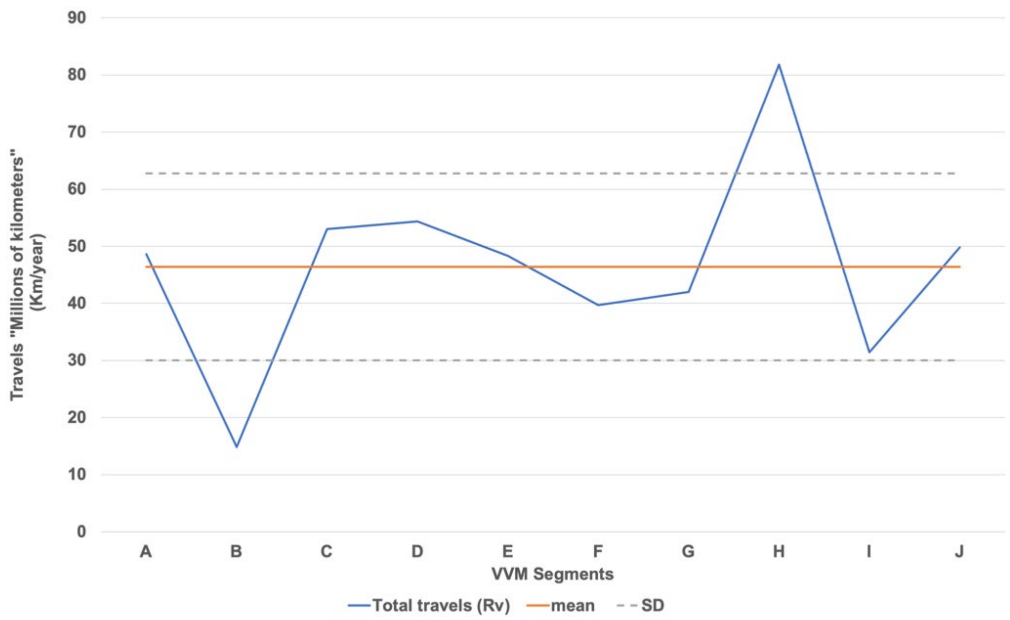

Figure 7. Travels by segment.

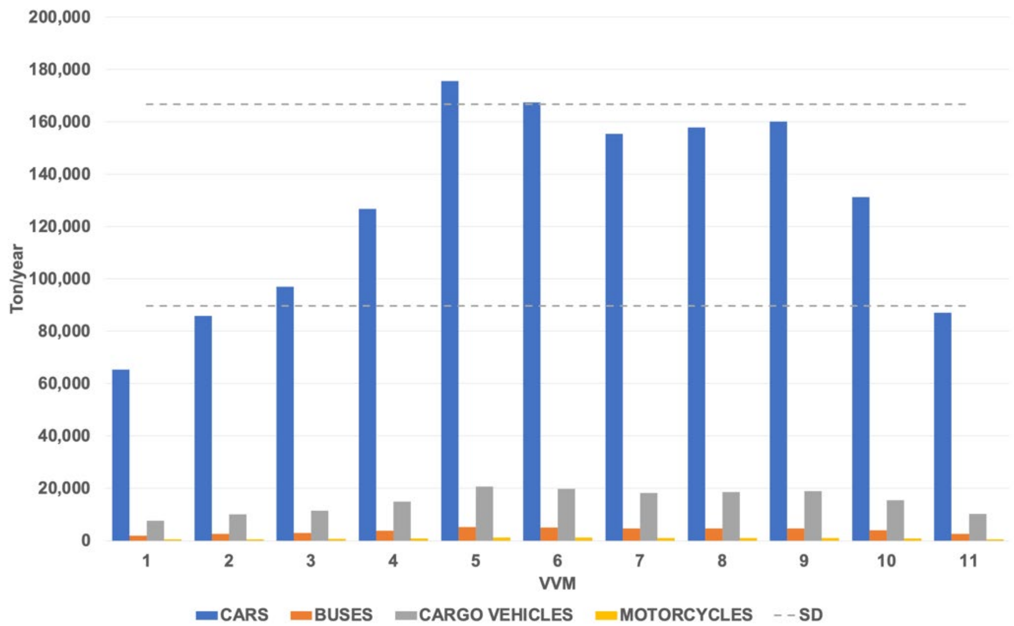

Figure 8. CO_2e emissions by type of vehicle in each VVM.

Subsequently, in VVM 7, travels and emissions decrease by 12%, with respect to maximum emission values; in VVM 8, the values increase to 572,469,060 km/year in travels and 182,351 ton/year in CO_2e emissions due to traffic volume, although this remains below the highest values registered in VVM 5. In VVM 10, CO_2e emissions decreased by 25% (151,568 ton/year) with respect to the maximum value; this point was located at the end of the urban road, where vehicular traffic is less intense.

Emissions by private vehicles (considering that cars are the main form of transportation) are clearly different in each VVM (Figure 8), with an average of 128,152 and a standard deviation of 38,509 ton/year for vehicles; 3816 and 1147 ton/year for buses; 15,123 and 4544 ton/year for cargo vehicles; 880 and 265 ton/year for motorcycles. Private cars are the most significant category since it represents 87% of the total studied vehicles (Table 1). This is mainly due to the city's population, which is currently 1,049,792 inhabitants and grew at a rate of 1.2% from 2015 to 2019, as reported by the National Institute of Statistics and Geography [29], as well as the 60.2% increase in the number of registered vehicles, which notably exceeded population growth. Clearly, the city must consider other transportation alternatives, such as intelligent transportation systems, electric and hybrid vehicles, or autonomous vehicles, among others [41].

Finally, Table 2 presents the results of the main variables of the model for Tier 3 of the IPPC during the P0218-0119 period. Total distance traveled (464,536,891 km/year) and weighted performance for 2019 (7532 km/L) stand out. These two parameters are used to calculate fuel consumption, which was found to be 61,669 × 10^6 L/year. Applying the corresponding emission factor, we obtained total CO_2e emissions (147,971 tons/year). The content of this table was used to carry out the emissions projections, which are presented in the following section.

Table 2. Base year emissions by type of vehicle (P0218-0119).

Emissions by Vehicle Type			Travels	Performance	Fuel	Emission Factor *	CO_2e Emissions
Type	%	Units	Km/Year	Km/L	L/Year	ton/L	ton/Year
Cars	94.00	38,303,919	436,664,678	7.821	55,832,333	0.0022	128,152
Buses	0.91	370,815	4,227,286	3.673	1,150,940	0.0033	3816
Cargo vehicles	3.91	1,593,280	18,163,392	3.982	4,561,374	0.0033	15,123
Motorcycles	1.18	480,836	5,481,535	44.000	124,580	0.0070	880
Total			464,536,891				147,971

* Weighted emissions factor for each type of transport.

3.3. Projection of Equivalent CO_2 Emissions

Two simulated scenarios over a 20 year period (2019–2039) were proposed. The first of them was based on the information presented in Table 2 (P0218-0119). This projection, the trend scenario, considered no urban road improvement or mitigation actions, assuming that the conditions remain unchanged over the 20 year period. This projection shows an annual increase in CO_2e emissions that results in a total of 5,037,728 ton/year in 2039, which is the end of the scenario. The behavior of these increases is illustrated by the red bars in Figure 9.

The second scenario uses engine performance (Pf) as a main variable for data activity (DA) to estimate CO_2e emissions and its annual increase factor was set at 1.1%, supported by the20 year period of historical data [36]. This leads to a proportional increase in emissions due to an increase in vehicle efficiency and a higher vehicle demand since performance (Pf) is a function of the vehicle's average age and mechanical conditions.

Additionally, improved road infrastructure could promote continuous vehicular flow, avoiding traffic jams, interruptions, and improving the behavior of the performance variable (Pf), which is directly related to fuel consumption and, consequently, a higher performance due to lower CO_2e emissions. In the 2039 projection, incorporating the mentioned improvement and changes, the decrease in CO_2 emissions is of up to 5% (green bars, Figure 9). As can be appreciated in the modeling, the emissions behavior is exponential, revealing growth in the trend scenario and a differentiated decrease in the modified scenario. In addition, despite the expected impact of a population growth and an increased motorization index in the future, which will increase vehicle volume and, presumably, CO_2e values, the total emissions projected until 2039 in the modified scenario remained below those of the base period P0218-0119. This demonstrates that improvement actions focused directly on vehicles and urban planning will result in effective GHG mitigation in the sector.

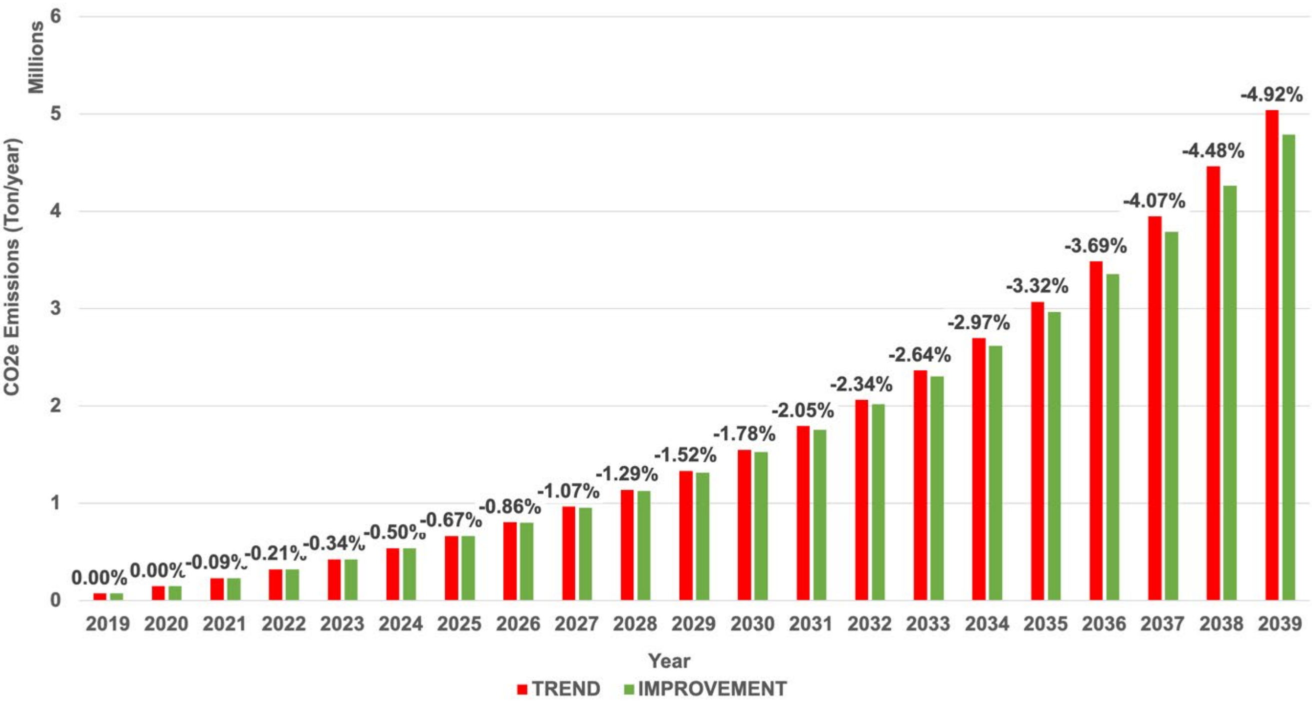

Figure 9. Total CO_2e emissions on the BLC from 2019 to 2039; trend scenario and modified scenario CO_2e emissions by type of vehicle in each VVM.

Finally, when comparing the improvement scenario with the trend scenario, emissions decrease under 1% over the first eight years. A gradual decrease begins in 2027, which continues until 2039, when the percentage is almost 5%.

4. Conclusions

The aim of this study was to propose a scenario of reduced CO_2e emissions. Therefore, the impact of GHG emission mitigation strategies in the transport sector was modeled, and the proposal was found to be favorable. Using the emissions trend model projection, proposed, and based on the IPCC methodology, and considering improvement adjustments, a decrease of up to 5% was obtained for 2039, when compared to a no-adjustment scenario.

The model and its simulation showed positive results in terms of GHG reduction, when considering a 1.1% annual factor in vehicle performance (Pf). In this regard, a proportional decrease in emissions would be expected each year; however, this estimation is limited by the convergence of factors, such as population and vehicular growth and the complex influence of urban dynamics.

It should be noted that, to accomplish the IPCC level 3 in the methodology, it was necessary to collect specific information on the study area, which was achieved by field work to obtain the activity data (travels, categorization, and performance) required in the IPCC for estimate emissions. Few studies in Latin America have carried out this type of research when considering growth rates and different weighted values to achieve a finer projection of the model's results; therefore, characterizing the main road in segments refines the analysis scale to address the problems of the study area and prioritize improvement actions more efficiently.

It is recommended that, to achieve or enhance the 1.1% factor in the performance previously mentioned, it is necessary to make road improvements as well as reducing the average age of vehicles. In addition, if in countries, such as Mexico, the economic resources are not enough for the incorporation of additional lanes, which can contribute to improving the vehicular flow, this could be mitigated by minor actions, such as applying periodic maintenance to road surfaces. The methodology proposed in this research, may be easy to implement for transportation engineers and researchers, since in addition, continuous vehicular flow would be improved. Therefore, the novelty of this research is that the proposal methodology is practical enough to be applied in a road network.

As additional future actions, it is recommended that urban designers, authorities, and the city's stakeholders design action plans for road infrastructure improvement, such as adequate traffic lanes and bridges, installation of intelligent traffic lights, recarpeting using quality pavements, promoting the use of public transportation or other transportation modes, updating the GHG emissions factors regarding the use of other types of fuel, and promoting cleaner technologies for vehicle propulsion systems.

Finally, this methodology can be replicated to evaluate GHG emissions on urban roads in other cities, in order to mitigate these emissions as long as databases, containing specific information about the model variables, are available.

Author Contributions: Y.A.I.-A., S.E.C.-S., D.E.F.-J., N.S.-S., M.d.l.Á.S.-G. and S.O.-B. contributed to conceptualization; Y.A.I.-A. and M.d.l.Á.S.-G. contribute to simulations and emission estimations; Y.A.I.-A., D.E.F.-J., N.S.-S. and M.d.l.Á.S.-G. contributed to validation resources, methodology, formal analysis, investigation, writing, original draft preparation, and visualization; Y.A.I.-A., S.E.C.-S., D.E.F.-J., N.S.-S., M.d.l.Á.S.-G. and S.O.-B. contributed to writing-review, editing and project administration. 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: Not applicable.

Acknowledgments: The authors are grateful to the Engineering Institute of Autonomous University of Baja California for the support given to conduct this project and to the Nation Council of Science and Technology (CONACYT) for financial support for Yidanes Alejandra Ibañez-Acevedo.

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

References

1. Klemm, C.; Wiese, F. Indicators for the optimization of sustainable urban energy systems based on energy system modeling. *Energy Sustain. Soc.* **2022**, *12*, 3. [CrossRef]
2. Sajede, A.; Mohsen, S.; Fahime, M.; Borna, A. Factors affecting the emission of pollutants in different types of transportation. *Energy Rep.* **2022**, *8*, 2508–2529. [CrossRef]
3. Menendez, M.; Ambühl, L. Implementing Design and Operational Measures for Sustainable Mobility: Lessons from Zurich. *Sustainability* **2022**, *14*, 625. [CrossRef]
4. Guo, Y.; Ma, Z.; Ren, B.; Zhao, B.; Liu, P.; Zhang, J. Effects of Humic Acid Added to Controlled-Release Fertilizer on Summer Maize Yield, Nitrogen Use Efficiency and Greenhouse Gas Emission. *Agriculture* **2022**, *12*, 448. [CrossRef]
5. Fang, D.; Mueller, C. Mortise-and-tenon joinery for modern timber construction: Quantifying the embodied carbon of an alternative structural connection. *Arch. Struct. Constr.* **2021**, 1–14. [CrossRef]
6. Górka, M.; Bezyk, Y.; Sówka, I. Assessment of GHG Interactions in the Vicinity of the Municipal Waste Landfill Site—Case Study. *Energies* **2021**, *14*, 8259. [CrossRef]
7. Stubenrauch, J.; Garske, B.; Ekardt, F.; Hagemann, K. European Forest Governance: Status Quo and Optimizing Options with Regard to the Paris Climate Target. *Sustainability* **2022**, *14*, 4365. [CrossRef]
8. IEA (International Energy Agency). Data and Statistics: "CO_2 Emissions by Sector, World 1990–2019". Available online: https://www.iea.org/data-and-statistics/data-browser?country=WORLD&fuel=CO2%20emissions&indicator=CO2BySector (accessed on 10 April 2022).
9. ProAire. Programa Para Mejorar la Calidad del Aire en Mexicali 2011–2020. Available online: https://www.gob.mx/cms/uploads/attachment/file/69289/12_ProAire_Mexicali.pdf (accessed on 22 February 2022).
10. Zhang, H.; Mu, J.E.; McCarl, B.A.; Yu, J. The impact of climate change on global energy use. *Mitig. Adapt. Strat. Glob. Chang.* **2022**, *27*, 9. [CrossRef]
11. Garrido, P. CO_2 Emissions arising from the displacement of the population in private transport mode in Gran Santiago. *Rev. Geogr. Espac.* **2013**, *3*, 69–86. [CrossRef]

12. Obaid, M.; Torok, A. Macroscopic Traffic Simulation of Autonomous Vehicle Effects. *Vehicles* **2021**, *3*, 187–196. [CrossRef]
13. Ajay, P.; Nagaraj, B.; Pillai, B.M.; Suthakorn, J.; Bradha, M. Intelligent ecofriendly transport management system based on IoT in urban areas. *Environ. Dev. Sustain.* **2022**, *24*, 5. [CrossRef]
14. Moussa, R.R. Reducing carbon emissions in Egyptian roads through improving the streets quality. *Environ. Dev. Sustain.* **2022**, *24*, 5. [CrossRef]
15. Shokoohyar, S.; Jafari Gorizi, A.; Ghomi, V.; Liang, W.; Kim, H.J. Sustainable Transportation in Practice: A Systematic Quantitative Review of Case Studies. *Sustainability* **2022**, *14*, 2617. [CrossRef]
16. Zhang, L.; Kou, C.; Zheng, J.; Li, Y. Decoupling Analysis of CO2 Emissions in Transportation Sector from Economic Growth during 1995–2015 for Six Cities in Hebei, China. *Sustainability* **2018**, *10*, 4149. [CrossRef]
17. Sun, L.; Song, R. Improving Efficiency in Congested Traffic Networks: Pareto-Improving Reservations through Agent-Based Timetabling. *Sustainability* **2022**, *14*, 2211. [CrossRef]
18. Velepucho-Sanchez, J.M.; Sabando-Piguabe, L.F. Emisiones de gases contaminantes en vehículos livianos a gasolina. *Rev. Cient. INGENIAR: Ing. Tecnol. E Investig.* **2021**, *4*, 78–95. [CrossRef]
19. INEN. Environmental Management. Air. Motor Vehicles. Emissions Permitted Levels Produced by Road Movable Sources Using Gasoline. Servicio Ecuatoriano de Normalización. NTE INEN 2204. Segunda revision 2017-01. Quito, Ecuador. Available online: https://www.normalizacion.gob.ec/buzon/normas/nte_inen_2204-2.pdf (accessed on 30 March 2022).
20. Gebisa, A.; Gebresenbet, G.; Gopal, R.; Nallamothu, R.B. Driving Cycles for Estimating Vehicle Emission Levels and Energy Consumption. *Futur. Transp.* **2021**, *1*, 615–638. [CrossRef]
21. Solis, J.; Sheinbaum, C. Consumo de energía y emisiones de CO_2 del autotransporte en México y escenarios de mitigación. *Rev. Int. Contam. Ambient* **2016**, *32*, 7–23.
22. Heidari, E.; Bikdeli, S.; Mansouri Daneshvar, M.R. A dynamic model for CO_2 emissions induced by urban transportation during 2005–2030, a case study of Mashhad, Iran. *Environ. Dev. Sustain.* **2022**, 1–20. [CrossRef]
23. Pichlmaier, S.; Kult, M.; Wagner, U. Extension of Energy and Transport Scenario Modelling to Include a Life Cycle Perspective. *Futur. Transp.* **2021**, *1*, 188–201. [CrossRef]
24. Mazza, S.; Aiello, D.; Macario, A.; De Luca, P. Vehicular Emission: Estimate of Air Pollutants to Guide Local Political Choices. A Case Study. *Environments* **2020**, *7*, 37. [CrossRef]
25. Paulino, F.; Pina, A.; Baptista, P. Evaluation of Alternatives for the Passenger Road Transport Sector in Europe: A Life-Cycle Assessment Approach. *Environments* **2018**, *5*, 21. [CrossRef]
26. Salini, R.; Lenngren, C.A.; Bassi, L.; Baesso, D.P. Greenhouse Gas Assessment and Compensation on Brazilian Low Volume Rural Roads Using CarbonROAD—The Santa Rosa de Lima Case. *Environments* **2015**, *2*, 489–499. [CrossRef]
27. Christian, A.; Kristian, L.; Björn, A. Global energy scenarios meeting stringent CO_2 constraints—Cost-effective fuel choices in the transportation sector. *Energy Policy* **2003**, *31*, 961–976. [CrossRef]
28. García Cueto, O.R.; Santillán Soto, N.; Quintero Núñez, M.; Ojeda Benítez, S.; Velázquez Limón, N. Extreme temperature scenarios in Mexicali, Mexico under climate change conditions. *Atmósfera* **2013**, *26*, 509–520. [CrossRef]
29. INEGI Instituto Nacional de Estadística y Geografía. Censo de Población Y Vivienda 2020. Available online: https://cuentame.inegi.org.mx/monografias/informacion/bc/poblacion/ (accessed on 17 March 2022).
30. Universidad Autónoma de Baja California (UABC). *Un Espacio Urbano en la Estrategia Internacional*; Atlas de Mexicali; Universidad Autónoma de Baja California (UABC): Mexicali, Mexico, 2001; pp. 1–37. ISBN 970-9051-19-9.
31. *PMVT (Plan Maestro de Vilidad y Transorte), Sistema Municipal de Transporte de Mexicali, B.C.*; XX Ayuntamiento de Mexicali: Mexicali, Mexico, 2011; Available online: https://www.mexicali.gob.mx/sitioimip/fotos/5b26e9e0639f.pdf (accessed on 18 June 2022).
32. SEMARNAT-INE. Tercer Almanaque de Datos Y Tendencias de la Calidad Del Aire en Nueve Ciudades Mexicanas. 2007. Available online: https://sinaica.inecc.gob.mx/archivo/informes/3erAlmanaque.pdf (accessed on 24 March 2022).
33. Amézquita-López, J.; Valdés-Atencio, J.; Angulo-García, D. Understanding Traffic Congestion via Network Analysis, Agent Modeling, and the Trajectory of Urban Expansion: A Coastal City Case. *Infrastructures* **2021**, *6*, 85. [CrossRef]
34. Casa Mayers (Centro de servicios distribuidor). Categoría Y Características de Cuenta Unidades Como Instrumento de Medición. Available online: https://www.casamyers.com.mx/view/cat1:INSTRUMENTOS%20DE%20MEDICIÓN/cat2:CONTADORES/cat3:CUENTA%20BULTOS (accessed on 24 February 2022).
35. IPCC. Guidelines for National Greenhouse gas Inventories. Volume 2 Energy. 2014. Available online: https://www.ipcc-nggip.iges.or.jp/public/2006gl/spanish/index.html (accessed on 10 February 2022).
36. PEACC. *Proyecto Para Desarrollar El Programa de Cambio Climático en El Estado de Baja California*; Estudio: "Sector Transporte"; PEACC: Mexicali, BC, USA, 2013; pp. 85–97. Available online: https://biblioteca.semarnat.gob.mx/janium/Documentos/Ciga/Libros2013/CD001769.pdf (accessed on 15 March 2021).
37. Isee Systems. Technical Documentation for the Ithink & STELLA Software. 2007. Available online: https://www.iseesystems.com/store/products/stella-architect.aspx (accessed on 18 March 2022).

38. Rojas, D. Simulación de la Aplicación Del Tratamiento Mecánico Biológico a Los Residuos Urbanos. Master's Thesis, Facultad de Ingeniería, Universidad Nacional de La Pampa, La Pampa, Argentina, 2010. Available online: http://www.biblioteca.unlpam.edu.ar/rdata/tesis/i_rojsim000.pdf (accessed on 13 August 2022).
39. Diaz, C.; Sosa, M. Movilidad Sostenible: Medir El Kilometraje Recorrido Por Vehículos Mejora la Planeación Y Gestión Urbana. Banco Interamericano de Desarrollo (BID), Transporte. Available online: https://blogs.iadb.org/transporte/es/movilidad-sostenible-medir-el-kilometraje-recorrido-por-vehiculos-mejora-la-planeacion-y-gestion-urbana/ (accessed on 28 March 2022).
40. Pérez Cruz, J.R.; Lakouari, N.; Pérez Sansalvador, J.C.; Zapotecatl López, J.L. Effect of Interactions between Vehicles and Mid-Block Crosswalks on Traffic Flow and CO_2 Emission. *Appl. Sci.* **2021**, *11*, 11794. [CrossRef]
41. Chatzikomis, C.I.; Spentzas, K.N.; Mamalis, A.G. Environmental and economic effects of widespread introduction of electric vehicles in Greece. *Eur. Transp. Res.* **2014**, *6*, 365–376. [CrossRef]