Hindawi
Modelling and Simulation in Engineering
Volume 2023, Article ID 1874418, 20 pages
https://doi.org/10.1155/2023/1874418

Research Article

Evaluation of Electric Vehicle-Dependent Strategy in Addis Ababa, Ethiopia Transport System

Tesfamichael Chala Eticha[1] **and Yonas Minalu Emagnu**[2]

[1]*Department of Civil Engineering, College of Engineering, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia*
[2]*School of Civil and Environmental Engineering, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia*

Correspondence should be addressed to Tesfamichael Chala Eticha; tesfamichaelc@gmail.com

Received 2 June 2023; Revised 15 August 2023; Accepted 13 September 2023; Published 7 October 2023

Academic Editor: Paolo Iodice

This paper assesses the transport system of Addis Ababa, Ethiopia, taking factors such as the number of vehicles, roadway width, speed of vehicles, longitudinal grade, and proportion of both fuel and electrical vehicles by dividing vehicles into seven classes, namely, car, minibus, small bus, coach, small truck, heavy truck, and truck trailer, to determine CO_2 emission, CO emission fuel consumption, and electric consumption in addition to the percent to replace ICE vehicles. After selecting eight representative road sections in Addis Ababa city, input data was collected from both primary and secondary sources. Simulation of urban mobility (SUMO) is used to model the existing road transport system and two other scenarios, cases being 20% and 40% replacement of internal combustion engine vehicles by electric vehicles. Among the vehicle types studied under this paper, the SUMO results show that coaches are with the highest CO_2 emission, releasing an average amount of 28.442 grams of CO_2 every time step, while cars are with the lowest CO_2 emission value of 6.542 grams. Minibuses are the top CO emitters, releasing an average of 0.420 grams of CO every time step, and truck trailers emit the smallest CO emission, 0.025 grams. Regarding electric consumption, the truck trailer is the vehicle type with the highest electric consumption, with a value of 2.282 kwh (watthour) consumption every time step, and cars are the least electricity-consuming vehicles, with a value of 0.151 kwh. The fourth point is fuel consumption; besides the high CO_2 emission, coaches' consumption of fuel is leading by 8.946 grams, and cars use 2.087 grams of fuel every time step. Totally, public transport vehicles are responsible for higher emissions and huge fuel consumption. Therefore, if our transport system encourages the penetration of electric vehicles into the road transport system, a healthy and energy-efficient environment is reserved. Again, from a financial and environmental standpoint, the replacement of 40% of ICE vehicles by EVs enhances us with reduced costs and a green environment.

1. Introduction

Ethiopia has experienced substantial urbanization in recent decades because of the increased migration of rural people to cities in search of the best economic opportunities. Rapid urbanization and increased automobile use suggest increased economic actions in the area. However, it has exacerbated concerns related to transportation such as air pollution, traffic accidents, and congestion as well as having a detrimental impact on the overall liveability of cities. Furthermore, in the presence of sunlight during the daytime, emissions such as CO_2, NOx, HC, CO, and particulate matter undergo a chemical transition resulting in ground-level ozone (O_3) and aerosol particles (fine and ultrafine particles), both of which are damaging to the human respiratory system. In 2015, vehicle exhaust emissions were responsible for around 380,000 premature deaths worldwide [1].

Ethiopia's capital, Addis Ababa, is aiming to build a resilient, green, and safe city for its citizens. The city is mainstreaming climate change and air quality policy into the city's urban planning as part of this effort. These mainstreaming techniques will assist Ethiopia in consistently meeting the national air quality standards and achieving its national goal of decreasing GHG emissions to 64% below baseline levels by 2030 [2]. Therefore, supporting the use of a green and active mode of transportation will aid in the development of continual urban communities with higher levels of public health.

A transportation system is a method of moving people or goods from one location to another. Inputs, processes, outputs, and feedback are all part of transportation systems. [3]. An electric vehicle (EV) on the other hand is a vehicle powered by either one or more electric motors. EVs can be powered by a collector system, extravehicular electricity, or a battery (often charged by solar panels, or by converting fuel to energy using fuel cells or a generator). EVs, combined with other emerging automotive technologies like linked vehicles, autonomous driving, and shared mobility, represent a future mobility vision called linked, shared, autonomous, and electric (CASE) mobility [4].

Besides the emission, another reason to discourage the use of old-modelled ICE vehicles is the significant increase in the price of fuel oil. To counteract the rise in the cost of fuel, our government has been doing different tasks. According to the Ministry of Finance of Ethiopia, electric vehicles are exempted from VAT, excise, and surtaxes. According to a statement shared by the ministry, the import tax for electric vehicles has been reduced. The ministry's new regulation reduces the tax rate on completely imported electric vehicles to 15%, while only 5% on semiassembled vehicles. The ministry's decision is expected to encourage investment in electric car assembly and import. It is also expected that it will benefit the final consumers by allowing them to have affordable vehicles.

According to [5], not less than 80% of vehicles exported to poor nations, including greater than 50% of those transported to Africa, fail to meet minimum requirements of safety and environmental health. Between the years 2015 and 2018, around 14 million cars, whose standards are below the least required, were supplied to developing countries from Europe, Japan, and the United States. Moreover, half of these were allocated to Africa. According to the survey, the continent's air pollution is worsening due to the age and condition of automobiles. Surprisingly, many of the cars were with removed valuable vehicle elements, such as airbags and antilock brake systems, adding to a spike in traffic accidents.

According to the Ministry of Transport's most recent report, the total number of vehicles registered by the authority at both the federal and regional levels has surpassed 1.2 million [6]. According to the data, a total of 1,200,110 automobiles have been registered nationwide through the fiscal year ending July 7, 2020, with around 630,440 vehicles registered in Addis Ababa.

The alarming and concerning issue of the twenty-first century on our planet is the continued use of fossil fuels, which produce CO_2 and other GHG emissions and contribute to global warming. Climate scientists are pushing for the world community to change the outdated CO_2 emission rules and replace them with improved ones that could reduce their content in the atmosphere. Transitioning the highest amount of the world's energy demands from these nonrenewable sources to renewable sources is a potential option for lowering CO_2 emissions [7]. Thus, in terms of reduction in emission and improvement of air quality, it looks apparent that switching the transportation sector to an EV-dependent strategy is profitable, for electric vehicles have zero emission to the environment compared to combustion vehicles.

Furthermore, fuel stocks are depleting daily, and gasoline prices are rising far faster than power prices around the world. When it comes to our own country, fuel subsidies in Ethiopia have been cut by 75%, according to the Trade Ministry. This therefore resulted in a higher cost of fuel and a burden on users. The country's government has then wasted over 24.05 billion birr (more than $608.5 M) on fuel cost subsidies in the last two years. The subsidy for gasoline price stabilization has escalated by more than 1.5 billion birr in December 2020, according to the ministry. As a result, the elimination of subsidies is executed for better achievement [8].

According to the most recent Global Burden of Disease study, air pollution is the second leading cause of disability and death in Ethiopia. Poor quality of air is expected to contribute to 21% of nonaccidental deaths in 2017, accounting for 2,700 deaths in the city. Without action to reduce air pollution, this figure is expected to rise to 6,200 by 2025, accounting for 32% of all deaths [2].

The current transportation system therefore relies on these internal combustion engine vehicles, whose models are outdated, whose energy consumption is higher, having higher operational and maintenance costs, and making increased emissions to the atmosphere. In response to these problems, this research has set the objectives of evaluating the switching of the current transportation system from conventional gasoline vehicles to an electric vehicle-dependent strategy to reduce the abovementioned drawbacks.

2. Literature Review

Patil et al. [9] conducted a comparison of the total ownership cost of electric and motorized two-wheelers from an Indian viewpoint. They listed four components under the total ownership cost (TOC): (1) acquisition costs (AC), (2) operating costs (OC), (3) maintenance costs (MC), and (4) resale value (RV). Then, they established certain assumptions about categorizing electric and motorized two-wheelers into two categories: category A—low-performance two-wheelers, and category B—high-performance two-wheelers. For a period of ten years beginning in 2021, the factors considered for comparison are average daily distance travelled (ADDT), efficiency of battery charging (€), inflation rate (IR), unit rate of electricity (URE), unit rate of gasoline (URG), frequency of battery replacement (f), depreciation (D), and method of purchase. The superior energy efficiency of electric two-wheelers and the cheap price of a unit of electricity compared to a litre of gasoline were credited to the model, projecting electric two-wheelers to be a more cost-effective form of transportation than motorized two-wheelers.

Kebede and Gebresenbet [10] mapped out the benefits of a night delivery system and identified the existing limits of traffic congestion and exhaust emission from freight vehicles within Addis Ababa city. They classified vehicle count based on loading capacity, trip time, and travel length between the origin (freight gates) and destination places in the city centre, and direct tailpipe emission measurement of CO and CO_2 emissions from freight vehicles based on their age group as a key input. It was finally determined that air pollution is assumed to be high due to the prevalence of old vehicles and substandard road infrastructure.

They mentioned in their work measuring the energy impact of plug-in hybrid electric vehicles that an accurate assessment of the impact of PHEVs (plug-in hybrid electric vehicles) on petroleum and electricity consumption is a vital step towards successful policy [11]. The paper examines the origin and relevance of the estimation of fuel and electricity use through graphical illustration, mathematical derivation, and empirical study.

They provided the whole approach of a transportation system in their research study: a sustainable transport system employing renewable energy and efficient electric automobiles [12]. The paper described a novel approach for optimizing the efficiency of induction motor drives, reported on practical evaluations of an electric vehicle drive under controlled laboratory conditions, and related the application of renewable sources of electrical energy to the transportation sector. The findings indicate that a sustainable transportation system based on efficient electric vehicles and renewable energy sources is achievable.

The study "Impact of road grade on vehicle speed-acceleration distribution, emissions, and dispersion modelling on freeways" [13] investigates the influence of incorporating grade and the grade-SAJD (speed-acceleration joint distribution) correlation on modelling of emissions given explicit descriptions of the impact of grade on the operations of roadways. A case study of a 9.5-mile motorway corridor was conducted to explore the potential implications of the modelling of PM2.5 dispersion near roads. To compare, emissions are calculated for three different scenarios: one that considers grade and the correlated changes in operating conditions (observed conditions), one that ignores grade but uses observed operating conditions, and one that considers grade but ignores changes in operating conditions caused by grade.

Traffic congestion worsens air pollution by prolonging commute times, but ecologically efficient modes of transportation can reduce it. According to the UN, the population of cities grew from 751 million in 1950 to 4.2 billion in 2018. This is related to rapid urbanization and a rise in the global population. The number of cities has increased, as have their inhabitants. The growth in city size and environmental contamination appear to be causally associated. Furthermore, as urban population density increases, so do pollutant emissions and air pollution. As a city grows, so does the number of motor vehicles. Traffic-related pollutants have increased considerably in their contribution to air pollution, and they are now a significant source of pollution [14].

The possibility of using ethanol as an alternative transportation fuel, global ethanol production, possible sources, and ethanol production technologies are all discussed in this study [15]. Furthermore, the physicochemical parameters of ethanol and gasoline are evaluated to assess their influence on combustion efficiency and NOx exhaust emissions. Ethanol production and use as an alternative fuel in spark ignition (SI) engines have been extensively studied, and it has been demonstrated that gasoline/ethanol blends, like other oxygenated fuels, can significantly reduce CO and HC exhaust emissions in SI engines when compared to neat gasoline. However, there are significant anomalies in accounting for NOx emissions, and a basic understanding of this subject remains acceptable. As a result, there are few review studies on the effect of cold-start transient, compression ratio, and engine load on NOx emissions in SI engines driven by ethanol/gasoline mixes; this review article seeks to address that need. The research on NOx exhaust emissions related to the usage of ethanol/gasoline fuel mixes in last-generation SI engines under real operating conditions is fully evaluated and critically analysed in this review paper. And this paper has examined NOx emissions associated with the usage of ethanol/gasoline blends in SI engines, offering a thorough literature analysis on the status of ethanol combustion in SI engines to explain the observed contradictions. Thus, the key achievements of this work are as follows:

(i) Because gasoline/ethanol blends have a higher latent heat of vaporization and a lower heating value than commercial gasoline, NOx emissions from SI engines fall as ethanol concentration increases in ethanol/gasoline blends

(ii) It can also be argued that because ethanol has a lower carbon number than gasoline, NOx emissions in blended fuels drop as the ethanol percentage increases

(iii) NOx emissions should rise as compression ratios rise, especially at high engine loads due to greater combustion temperatures

(iv) In rich-mixture operating conditions, ethanol's quicker flame speed than gasoline plays a crucial role in accomplishing more complete combustion. At the same time, increasing engine loads results in an increase in NOx emissions

The primary goal of this analytical-experimental study was to propose hybrid-electric propulsion for motorcycle applications to reduce engine-out emissions in urban settings (see [16] and/or [17]). Because exhaust emissions and fuel consumption are highly sensitive to changes in vehicle instantaneous speed and acceleration, fresh experimental results were employed to identify the kinematic factors that generate increased HC and CO emissions. To meet this goal, an analytical-experimental investigation was conducted using roller-test bench measurements to detect CO and HC emissive levels in the exhaust emissions of a motorbike equipped with a four-stroke SI engine and a three-way catalyst. The study then offered a minimally intrusive alternative based on an electric motor directly installed on the wheel hub, which can help the thermal engine during transient phases, i.e., during acceleration phases, to lessen the environmental effect of the tested motorcycle. A procedure based on both observed exhaust emissions and the kinematic parameters of the driving dynamics obtained during experimental tests was used to determine power requirements and the grade of electrical assistance in various driving scenarios. Finally, an environmental analysis was carried out to compare the tested thermal motorcycle with a similar one that has the same technical characteristics as the tested vehicle and is equipped with an electric motor directly installed on the wheel hub (the configuration proposed in this study). Because the environmental analysis was carried out under the same driving conditions, it was possible to estimate the percentage of CO and HC emissions that could be avoided by using a hybrid motorbike instead of a traditional thermal motorcycle. The share of saved CO and HC emissions on the distance travelled of 44.8 km (equivalent to the autonomy of the battery) was then computed using the experimental values of CO and HC emissions measured on the conventional motorcycle. The major findings of this environmental analysis were then shown as percentage reductions in emissions, and CO is reduced by 40.9% while HC by 25.5%.

3. Materials and Methods

3.1. Study Area. The Ministry of Transport, in its latest report in 2020, revealed that Addis Ababa has more than 630,440 vehicles; likely, this figure is more than half of the total vehicles owned and driven on the roads of the city, and it is by far greater than vehicles in the rest of the states. Therefore, the research study area is selected as Addis Ababa.

Regarding the selection of corridors for study, representative road sections are selected considering several engineering factors such as traffic congestion, longitudinal grade of road, and speed. Subcity divisions have also been taken into account in shortlisting representative corridors.

3.1.1. Traffic Congestion. By lengthening commute times, traffic congestion makes air pollution worse. Thus, traffic congestion is expected to be among the factors that contribute to the increased road traffic emissions. The data we have found from the Addis Ababa City Administration Traffic Management Agency lists the highly congested areas in the city as Jackross, Ayertena, African Union/Sarbet, Salite Mihret to Megenagna, Meskel Square, Saris, Torhayloch, Atlas, Lebu, and Sholla.

3.1.2. Road Grade. Road grade is a critical variable that affects the engine load, as when the vehicle is moving uphill, the gravitational load acts against the vehicle and increases engine load, fuel consumption, and emissions. Therefore, road grade is the other factor contributing to increased traffic-related emissions. The areas with severe slopes in the city are selected by the process.

Addis Ababa city road network data was taken from the Addis Ababa Plan and Development Commission, and 12.5-resolution digital elevation model (DEM) data was downloaded from the Alaska Satellite Facility. Using ArcGIS software, the data files from the two sources were processed to filter road sections with a relatively steeper slope within the city. Therefore, major roads in the city are identified by their elevation as per Figure 1.

Based on longitudinal grade, traffic congestion, subcity classification, and other factors, the routes selected for study are listed in Table 1.

The shortlisted eight study areas representing eight of the eleven subcities in Addis Ababa are shown in Figures 2 and 3, divided into two sections.

3.2. Analysis with the Simulation of Urban Mobility (SUMO). A simulation is modelled for both internal combustion engines and electric vehicles to observe their performance with respect to environmental aspects, i.e., emission of greenhouse gases and energy consumption.

Steps for simulation [18]:

Step 1. Search and download OpenStreetMap.

Step 2. Convert the map into the SUMO network [19].

Step 3. Including elevation data to the network.

Step 4. Modifying the network.

Step 5. Traffic assignment zone (TAZ) definition.

Step 6. Trips generation.

(i) All vehicles are internal combustion engine (ICE) vehicles

(ii) 20% of ICE vehicles replaced by EVs

(iii) 40% of ICE vehicles replaced by EVs

Step 7. Route assignment.

(i) Vehicle type definition

  (a) For ICE vehicles

  (b) For electric vehicles

(ii) Maximum acceleration/deceleration

(iii) Maximum speed [20]

Step 8. Set up the SUMO configuration file and run.

Step 9. SUMO output (emission and energy consumption).

3.3. Evaluation of the Transport System. Different scenarios are being evaluated by replacing the ICE vehicles with EVs based on the considered parameters. Finally, an optimum strategy is selected.

Case I

(a) If all the vehicles driven in the city are internal combustion engine, the amount of pollutant (greenhouse gas) emitted

(b) If all the vehicles driven in the study section are internal combustion engine, the amount of energy consumption, i.e., fuel

Case II

(a) If 20% of ICE vehicles are banned and replaced with EVs, the amount of pollutant (GHG) emitted

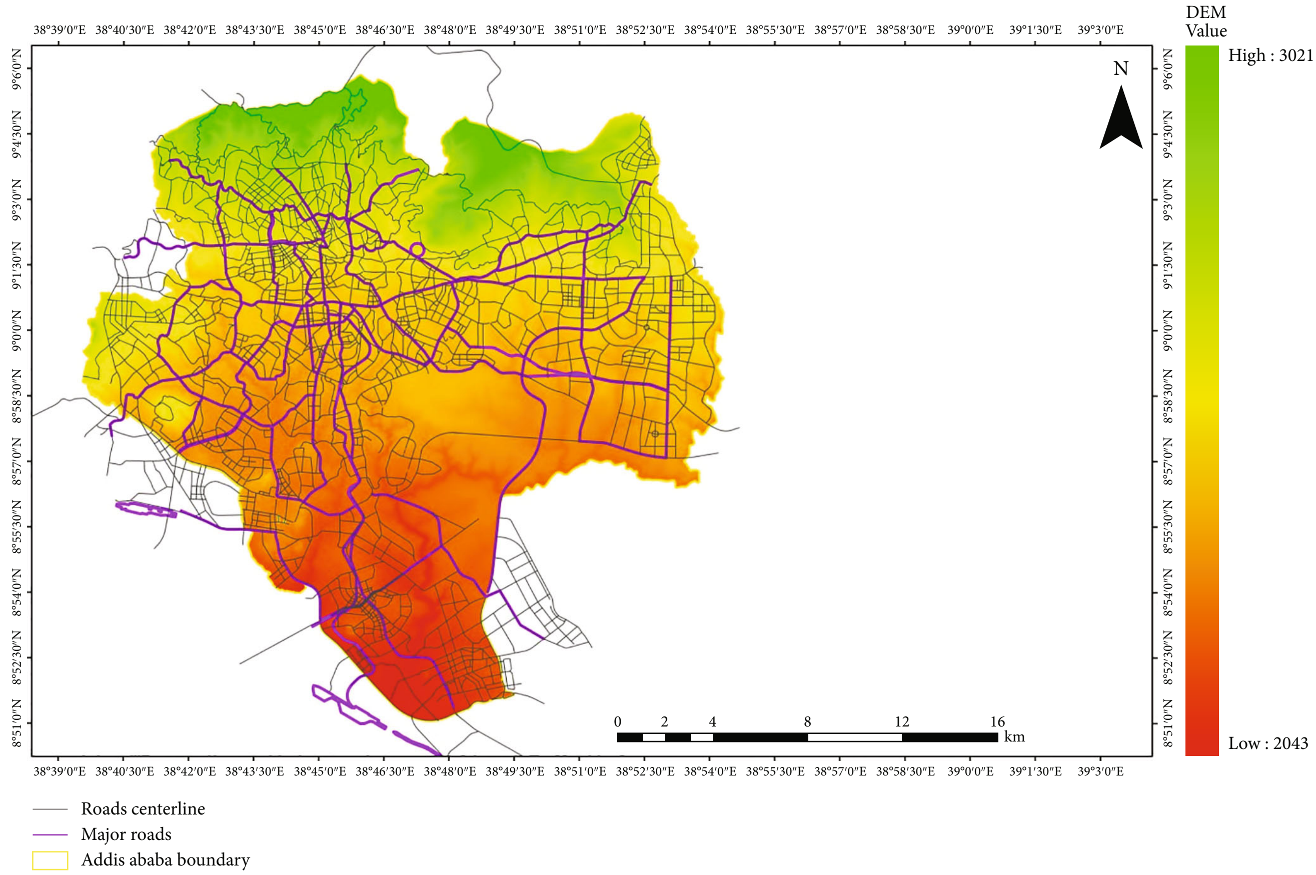

Figure 1: Road network map of Addis Ababa city integrated with DEM data.

Table 1: List of study areas.

No.	Corridor name	Subcity
1	Zenebewerk to Total	Kolfe Keranio
2	Legehar to Meskel Square	Kirkos
3	Shola to Megenagna	Yeka/Bole
4	Afincho ber to Yekatit 12 square	Arada
5	Mariif Int’l School to Ferensay Gurara Biret Dildiy	Yeka
6	Semien Hotel to Sheger Park	Gulele
7	Gelan Condominium – Hyundai Motors – Sefera	Nifas Silk-Lafto
8	Kality Maseltegna to Saris Abo	Akaki Kality

(b) If 20% of ICE vehicles are banned and replaced with EVs, the amount of energy consumption, i.e., fuel and electricity

Case III

(a) If 40% of ICE vehicles are banned and replaced with EVs, the amount of pollutant (GHG) emitted

(b) If 40% of ICE vehicles are banned and replaced with EVs, the amount of energy consumption, i.e., fuel and electricity

4. Results and Discussion

4.1. Results [21]. As shown in Figure 4, the carbon dioxide emission results from the SUMO analysis are shown. The amount of average carbon dioxide emitted into the atmosphere is expressed for all seven vehicle types studied under this paper. Coaches are the vehicle types with the highest CO_2 emission value of 28.44 grams, while cars have the lowest CO_2 emission value of 6.5 grams at every time step. Three of the truck types do have a closer CO_2 emission value close to one another ranging from 19.88 grams to 22.12 grams. The rest two types of vehicle minibus and small bus

Figure 2: Study areas I.

Figure 3: Study areas III.

have a CO_2 emission value of 7.04 grams and 22.25 grams, respectively.

The other type of greenhouse gas emitted from vehicles into the atmosphere is CO. As shown in Figure 5, unlike the CO_2 emissions, the lighter vehicles are responsible for increased CO emissions, and minibuses release the highest amount, 420 grams every time step, while cars follow by 149.9 grams. The buses and all the trucks emit a smaller amount of CO ranging from 25.19 grams to 31.3 grams.

It can be inferred from Figure 6 above that coaches are among the vehicle types consuming the highest amount of fuel. Next to coaches, the other public transportation vehicles which are small buses have increased fuel consumption. Like the above cases, the truck types again have a closer value of fuel consumption of 6959.22 mg, 6597.99 mg, and 6253.8 mg for small trucks, heavy trucks, and truck trailers. The lighter vehicles, minibuses and cars, do not use much fuel relative to the others, as the numbers show. They consume 2086.91 mg and 2230.9 mg, respectively, every time step.

By replacing the ICE vehicles with EVs by 20% and 40% for cases II and III, respectively, the electricity consumed by those vehicles had been analysed. As per Figure 7, truck trailers consume the highest electric amount, while cars consume the least electric amount. Minibuses again consume

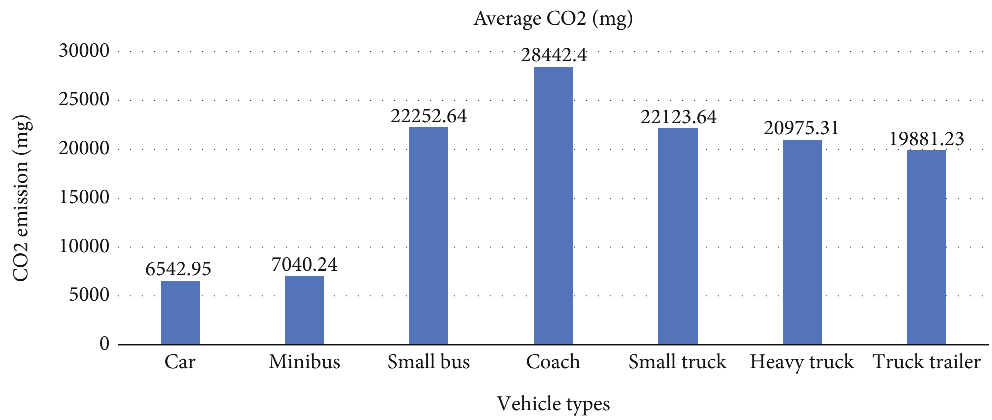

FIGURE 4: CO_2 emission by vehicle types.

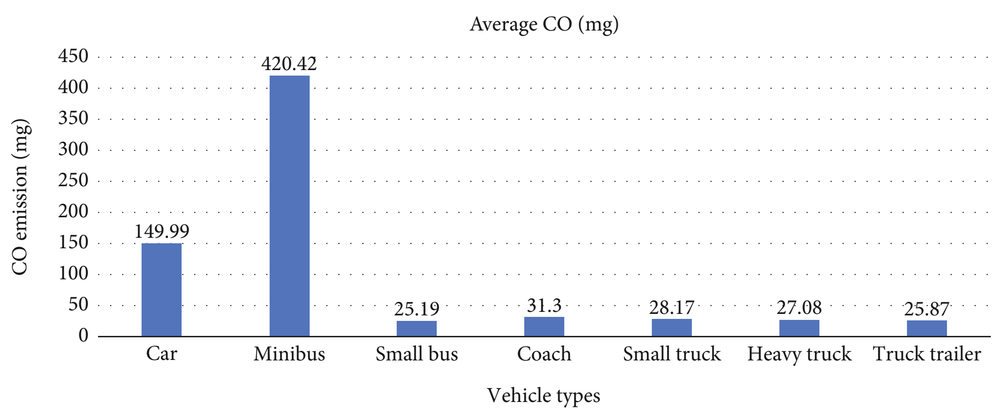

FIGURE 5: CO emission by vehicle types.

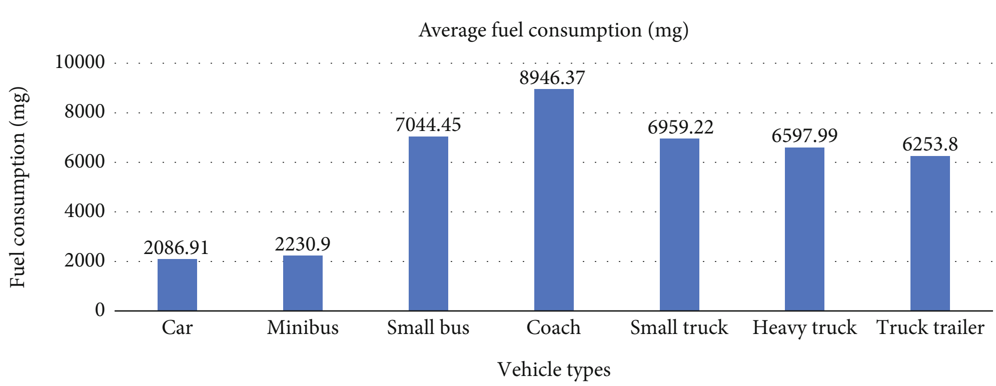

FIGURE 6: Fuel consumption by vehicle types.

less, 177.55 wh, and small buses consume around 511.95 wh every time step. Heavy trucks and coaches' electric consumption is 1875.75 wh and 1970.54 wh, respectively. The other vehicle type, a small bus, takes 746.19 wh of energy.

4.2. The Effect of Grade, Proportion of Vehicle Type, Speed, and Number of Lanes on Greenhouse Gas Emissions and Energy Consumption. The effect of all the independent variables on carbon emissions and energy consumption is shown in the tables for all cases I to III. The correlation values are also calculated and explained.

The effect of grade, proportion of vehicle type, speed, and number of lanes on carbon dioxide emission, carbon monoxide emission, and energy consumption under case I are shown in Table 2.

The correlation values between the independent variables and each other and with the dependent variables are shown by a square matrix summarised in Table 3.

As inferred from the tables, the number of vehicles ranging from an hourly volume of 679 vehicles being the smallest to 3568 vehicles being the highest tends to have a strong positive correlation with all the CO_2 emission, CO emission,

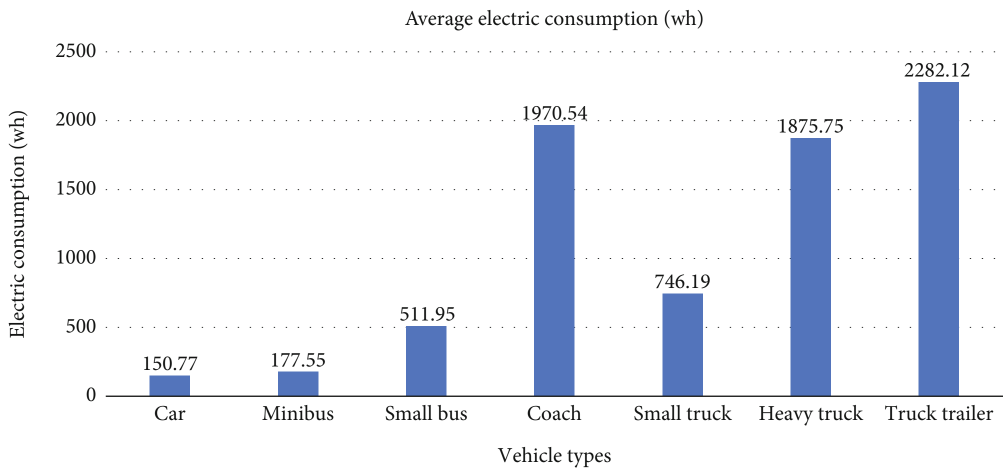

Figure 7: Electricity consumption by vehicle types.

and fuel consumption, in which the correlation values are 0.83, 0.6, and 0.83, respectively. Therefore, as the number of vehicles in general increases, the dependent values are expected to increase as well.

The longitudinal grade is the other independent variable, having an average slope range of 1.7% for the Legehar-Stadium Road section to 7% for the Sefera-Gelan road section. For the eight road sections studied under this paper, the correlation values of 0.013, -0.043, and 0.01 for greenhouse gas emission and fuel consumption imply that grade has a nearly zero relation. Thus, future works need to study the effect of grade by considering the higher number of corridors.

Speed, among the explanatory variables, ranges from 30 km/hr for heavy vehicles in congested areas to 50 km/hr for areas of lighter traffic and ring roads. When we see the correlation values for speed, they are 0.77, 0.92, and 0.76 for CO_2 emissions, CO emissions, and fuel consumption, respectively. Thus, we conclude that speed has a strong positive relationship with all the dependent variables, especially for carbon monoxide emission.

Even if the total number of vehicles is noticed to have an effect on the dependent variables, examining the impact of the proportion of each vehicle type on greenhouse gas emission, and energy consumption is necessary.

The effect of grade, proportion of vehicle type, speed, and number of lanes on carbon dioxide emission, carbon monoxide emission, and energy consumption under case II are shown in Table 4.

The correlation values between the independent variables and each other and with the dependent variables are shown by a square matrix summarised in Table 5.

The number of vehicles is not changed in this case II, but rather has been replaced by 20% electric vehicles, and only the proportion of vehicle type is manipulated, thus it keeps having a strong positive correlation with all the carbon dioxide emission, carbon monoxide emission, fuel consumption, and electric consumption as it had in case I in which the correlation values are 0.83, 0.6, 0.83, and 0.86, respectively. Therefore, it can be noted that as the number of vehicles in general increases, the dependent values for case II are expected to rise as well.

The longitudinal grade as well is kept the same as for case I since the road infrastructure is itself and the correlation values are not changed from 0.013, -0.043, and 0.01 for greenhouse gas emissions and fuel consumption, but since we have a 20% electric vehicle proportion, we have a 0.115 correlation value between electric consumption and longitudinal grade which is again a weak relation.

Speed, among the explanatory variables, was ranging from 30 km/hr to 50 km/hr for case I, and it is still considered the same for the newly inserted 20% electric vehicles. Due to the 20% replacement, the correlation values for speed have shown a 0.01 increment for the first three relations, from 0.77 to 0.78, from 0.92 to 0.93, and from 0.77 to 0.78 for CO_2 emissions, CO emissions, and fuel consumption, respectively, leading to a conclusion of a strong positive relationship between them. The newly achieved correlation is between speed and electricity consumption, which is 0.53, it can be noted that they have a fair positive relation but not as strong as the first three dependent variables.

The main explanatory variable that was being manipulated from the situation in case I is the proportion of each vehicle. Besides the impact of the total vehicles, the impact by altering the proportion of each vehicle type on greenhouse gas emission and energy consumption is shown.

The effect of grade, proportion of vehicle type, speed, and number of lanes on carbon dioxide emission, carbon monoxide emission, and energy consumption under case III are shown in Table 6.

The correlation values between the independent variables and each other and with the dependent variables are shown by a square matrix summarised in Table 7.

The table above shows the combined case III carbon dioxide emissions, carbon monoxide emissions, fuel consumption, and electricity consumption results due to their respective characteristics, i.e., independent variables. As inferred from the tables, the number of vehicles has a strong effect on the amount of electricity consumed. The electric consumption value can be predicted from the number of vehicles together with other independent variables.

The number of vehicles unlike the above cases has been 40% replaced by electric vehicles; thus, it keeps having a

Table 2: Summary output for case I.

Location	Cases	Grade	No. veh	Speed	Lanes	Independent variables								Dependent variables			
						Proportion of fuel vehicles							Proportion of Evs				
						Car	Minibus	Small bus	Coach	Small truck	Heavy truck	Truck trailer	EV	CO_2 emission	CO emission	Fuel consumption	Elec consum
Afinchober	Case I	5.40%	1790	35	3	36.31%	39.22%	4.47%	6.37%	9.05%	3.91%	0.67%	0.00%	14,182,864.28	211,397.82	4,483,256.14	0.00
Legehar	Case I	1.70%	3568	35	3	67.68%	22.03%	2.86%	3.34%	2.66%	1.09%	0.34%	0.00%	24,100,146.84	397,380.64	7,647,383.59	0.00
Maarif	Case I	6.90%	679	35	3	35.79%	47.42%	2.80%	9.28%	3.24%	0.88%	0.59%	0.00%	5,803,454.00	108,175.83	1,835,702.99	0.00
Maseltegna	Case I	4%	3438	55	4	50.84%	34.15%	1.80%	1.05%	6.57%	4.36%	1.22%	0.00%	52,504,481.82	2,065,074.54	16,658,463.52	0.00
Sefera	Case I	7%	3577	35	3	35.95%	38.80%	2.07%	3.27%	11.69%	4.98%	3.24%	0.00%	36,648,529.44	677,399.71	11,586,459.95	0.00
Semenh	Case I	4.50%	2302	35	3	50.30%	36.75%	0.35%	3.39%	4.69%	3.30%	1.22%	0.00%	17,423,631.94	328,349.82	5,517,571.44	0.00
Zenebewerk	Case I	4.80%	2738	50	3	46.38%	38.46%	3.98%	5.04%	3.21%	1.97%	0.95%	0.00%	34,289,142.55	1,048,408.57	10,867,862.74	0.00
Shola	Case I	2.20%	1528	35	3	61.58%	34.16%	0.85%	1.18%	1.44%	0.52%	0.26%	0.00%	8,701,517.36	167,336.96	2,763,285.79	0.00

Table 3: Correlation values for case I.

	Grade	No. veh	Speed	Lanes	Car	Minibus	Small bus	Coach	Small truck	Heavy truck	Truck trailer	EV	CO_2 emission	CO emission	Fuel consumption	Elec consum
Grade	1															
No. veh	-0.23738	1														
Speed	-0.0327	0.355461	1													
Lanes	-0.11735	0.371947	0.763763	1												
Car	-0.96763	0.301374	-0.04834	0.091664	1											
Minibus	0.84936	-0.64275	0.002436	-0.12611	-0.86105	1										
Small bus	0.260883	-0.0312	0.343384	-0.1683	-0.38245	0.142955	1									
Coach	0.621207	-0.60449	-0.24942	-0.45248	-0.63296	0.640527	0.584632	1								
Small truck	0.613829	0.367585	0.067767	0.143478	-0.65187	0.240349	0.192578	0.006279	1							
Heavy truck	0.466026	0.505209	0.338255	0.40591	-0.50212	0.136562	0.016448	-0.21567	0.907410691	1						
Truck trailer	0.597602	0.501481	-0.0078	0.068078	-0.49791	0.222838	-0.14756	-0.16171	0.796905562	0.754506231	1					
EV	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1				
CO_2 emission	0.012717	0.83005	0.769966	0.716466	0.020643	-0.26394	0.029882	-0.5069	0.403162638	0.617657916	0.51252405	#DIV/0!	1			
CO emission	-0.04306	0.607823	0.923778	0.882221	0.045677	-0.14934	-0.00841	-0.46954	0.205323735	0.480167559	0.270116371	#DIV/0!	0.929445703	1		
Fuel consumption	0.010708	0.829777	0.771114	0.717693	0.022563	-0.2651	0.029447	-0.50762	0.40103419	0.61613201	0.510329668	#DIV/0!	0.999996206	0.930174657	1	
Elec consum	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1

Table 4: Summary output for case II.

Location	Cases	Grade	No. veh	Speed	Lanes	Independent variables: Proportion of fuel vehicles							Proportion of Evs	Dependent variables			
						Car	Minibus	Small bus	Coach	Small truck	Heavy truck	Truck trailer	EV	CO_2 emission	CO emission	Fuel consumption	Elec consum
Afinchober	Case II	5.40%	1432	35	3	29.05%	31.37%	3.58%	5.09%	7.24%	3.13%	0.54%	20.00%	11,413,790.32	170,504.69	3,607,991.71	108,784.35
Legehar	Case II	1.70%	2854	35	3	54.15%	17.62%	2.29%	2.67%	2.13%	0.87%	0.27%	20.00%	19,367,397.02	315,585.94	6,145,430.18	201,283.73
Maarif	Case II	6.90%	543	35	3	28.63%	37.94%	2.24%	7.42%	2.59%	0.71%	0.47%	20.00%	4,637,652.62	87,737.92	1,467,024.66	52,984.88
Maseltegna	Case II	4%	2750	55	4	40.67%	27.32%	1.44%	0.84%	5.26%	3.49%	0.98%	20.00%	42,049,737.09	1,644,559.65	13,340,277.98	368,021.37
Sefera	Case II	7%	2862	35	3	28.76%	31.04%	1.66%	2.62%	9.35%	3.98%	2.59%	20.00%	29,481,188.35	540,662.47	9,320,313.00	337,294.59
Semenh	Case II	4.50%	1842	35	3	40.24%	29.40%	0.28%	2.71%	3.75%	2.64%	0.97%	20.00%	14,150,445.63	260,323.58	4,480,521.10	115,101.50
Zenebewerk	Case II	4.80%	2190	50	3	37.11%	30.77%	3.18%	4.03%	2.57%	1.58%	0.76%	20.00%	27,394,808.90	851,099.89	8,682,870.60	162,912.47
Shola	Case II	2.20%	1222	35	3	49.27%	27.33%	0.68%	0.94%	1.15%	0.42%	0.21%	20.00%	7,079,134.35	137,334.83	2,247,886.76	40,000.00

Table 5: Correlation values for case II.

	Grade	No. veh	Speed	Lanes	Car	Minibus	Small bus	Coach	Small truck	Heavy truck	Truck trailer	EV	CO_2 emission	CO emission	Fuel consumption	Elec consum
Grade	1															
No. veh	-0.23714	1														
Speed	-0.06906	0.389728	1													
Lanes	-0.11735	0.371808	0.768958	1												
Car	-0.96763	0.301157	0.041682	0.091664	1											
Minibus	0.84936	-0.6426	-0.03234	-0.12611	-0.86105	1										
Small bus	0.260883	-0.03131	0.144985	-0.1683	-0.38245	0.142955	1									
Coach	0.621207	-0.60443	-0.30135	-0.45248	-0.63296	0.640527	0.584632	1								
Small truck	0.613829	0.367843	-0.03207	0.143478	-0.65187	0.240349	0.192578	0.006279	1							
Heavy truck	0.466026	0.505446	0.250491	0.40591	-0.50212	0.136562	0.016448	-0.21567	0.907410691	1						
Truck trailer	0.597602	0.501752	0.02813	0.068078	-0.49791	0.222838	-0.14756	-0.16171	0.796905562	0.754506231	1					
EV	$1.44E-16$	0	0	0	$-3.1E-16$	$-1.3E-16$	$-1E-16$	$2.33E-16$	$9.84713E-17$	$-1.00664E-16$	$-1.51969E-16$	1				
CO_2 emission	0.011939	0.831952	0.779036	0.715786	0.021811	-0.2658	0.025374	-0.51029	0.405337356	0.620245244	0.515386222	0	1			
CO emission	-0.04225	0.605965	0.930367	0.878541	0.044424	-0.14668	-0.00344	-0.46711	0.202336462	0.476888904	0.268652882	$1.77E-16$	0.927921422	1		
Fuel consumption	0.009944	0.831686	0.780142	0.716979	0.023716	-0.26696	0.025	-0.51098	0.403208346	0.618703266	0.513195957	$1.54E-16$	0.999996263	0.928645611	1	
Elec consum	0.114712	0.861627	0.529894	0.64091	-0.05556	-0.27702	-0.02411	-0.46752	0.592838828	0.710993052	0.67066706	$1.27E-16$	0.93198943	0.782959589	0.931462506	1

Table 6: Summary output for case III.

Location	Cases	Grade	No. veh	Speed	Lanes	Independent variables: Proportion of fuel vehicles							Proportion of Evs	Dependent variables			
						Car	Minibus	Small bus	Coach	Small truck	Heavy truck	Truck trailer	EV	CO_2 emission	CO emission	Fuel consumption	Elec consum
Afnchober	Case III	5.40%	1074	35	3	21.79%	23.53%	2.68%	3.82%	5.43%	2.35%	0.40%	40.00%	8,594,403.61	129,390.62	2,716,987.91	219,632.95
Legehar	Case III	1.70%	2141	35	3	40.61%	13.22%	1.72%	2.00%	1.60%	0.66%	0.20%	40.00%	14,563,037.20	235,240.61	4,620,765.26	396,829.23
Maarif	Case III	6.90%	407	35	3	21.47%	28.45%	1.68%	5.57%	1.94%	0.53%	0.35%	40.00%	3,432,968.63	63,353.12	1,085,892.63	102,631.88
Maseltegna	Case III	4%	2063	55	4	30.51%	20.49%	1.08%	0.63%	3.94%	2.62%	0.73%	40.00%	31,582,866.94	1,252,959.60	10,019,917.40	739,022.17
Sefera	Case III	7%	2146	35	3	21.57%	23.28%	1.24%	1.96%	7.01%	2.99%	1.95%	40.00%	22,093,053.55	403,390.60	6,984,450.55	651,358.25
Semenh	Case III	4.50%	1381	35	3	30.18%	22.05%	0.21%	2.03%	2.81%	1.98%	0.73%	40.00%	10,634,170.97	197,189.81	3,367,157.95	224,516.02
Zenebewerk	Case III	4.80%	1643	50	3	27.83%	23.08%	2.39%	3.02%	1.93%	1.18%	0.57%	40.00%	19,128,771.46	597,673.76	6,062,819.44	311,455.27
Shola	Case III	2.20%	917	35	3	36.95%	20.50%	0.51%	0.71%	0.86%	0.31%	0.16%	40.00%	5,290,787.84	101,757.29	1,679,939.93	80,000.00

TABLE 7: Correlation values for case III.

	Grade	No. veh	Speed	Lanes	Car	Minibus	Small bus	Coach	Small truck	Heavy truck	Truck trailer	EV	CO_2 emission	CO emission	Fuel consumption	Electric consumption
Grade	1															
No. veh	-0.23763	1														
Speed	-0.06906	0.390058	1													
Lanes	-0.11735	0.37201	0.768958	1												
Car	-0.96763	0.301577	0.041682	0.091664	1											
Minibus	0.84936	-0.6429	-0.03234	-0.12611	-0.86105	1										
Small bus	0.260883	-0.03115	0.144985	-0.1683	-0.38245	0.142955	1									
Coach	0.621207	-0.60462	-0.30135	-0.45248	-0.63296	0.640527	0.584632	1								
Small truck	0.613829	0.36741	-0.03207	0.143478	-0.65187	0.240349	0.192578	0.006279	1							
Heavy truck	0.466026	0.50507	0.250491	0.40591	-0.50212	0.136562	0.016448	-0.21567	0.907410691	1						
Truck trailer	0.597602	0.501263	0.02813	0.068078	-0.49791	0.222838	-0.14756	-0.16171	0.796905562	0.754506231	1					
EV	$1.44E-16$	0	0	0	$-2E-16$	$-8.7E-17$	$2.17E-16$	$-5.6E-17$	$3.28238E-16$	$-6.71094E-17$	$-6.07876E-17$	1				
CO_2 emission	0.007796	0.836871	0.760655	0.732396	0.026375	-0.27699	0.002243	-0.5243	0.422810463	0.63614314	0.522705365	$2.63E-16$	1			
CO emission	-0.04628	0.604627	0.919136	0.89553	0.047713	-0.15232	-0.02256	-0.47725	0.212642892	0.487758624	0.269059183	$1.17E-16$	0.924138317	1		
Fuel consumption	0.005792	0.836588	0.761795	0.733624	0.02828	-0.27814	0.00188	-0.525	0.420666523	0.634599858	0.520479556	$-2.1E-16$	0.999996155	0.924898284	1	
Electric consumption	0.10059	0.856389	0.539956	0.663465	-0.04612	-0.28398	-0.02644	-0.47465	0.586584981	0.710540008	0.651240276	$-3.5E-16$	0.946963427	0.800552364	0.946493265	1

strong positive correlation with all the carbon dioxide emission, carbon monoxide emission, fuel consumption, and electric consumption as it had for case II in which the correlation values are 0.83, 0.6, 0.83, and 0.86, respectively. As the number of vehicles in general increases, the dependent variable values for case III rise as well.

The longitudinal grade as well is kept the same as for cases I and II since the road infrastructure is itself, and the correlation values are decreased from 0.013 to 0.008, from -0.043 to -0.046, and from 0.01 to 0.0058 from case II to case III for greenhouse gas emissions and fuel consumption, but since we have increased electric vehicle replacement, the 0.115 correlation value between electric consumption and longitudinal grade is changed to 0.1006 which is a much weaker relation.

Speed, due to the 40% replacement, the correlation values for speed are changed from 0.78 to 0.76, from 0.93 to 0.919, and from 0.78 to 0.76 for CO_2 emissions, CO emissions, and fuel consumption, respectively, which has a slight reduction but still leads to the conclusion of a strong positive relationship between them. The other correlation left is between speed and electricity consumption, which was 0.53 for case II and increased very slightly to 0.54 for case III, a fair positive but a little reduced relation compared to the first three dependent variables.

The main explanatory variable that was being manipulated from the situation in cases I and II is the proportion of each vehicle. Besides the effect of the total number of vehicles, the impact of altering the proportion of each vehicle type on greenhouse gas emission and energy consumption is also shown. The total fuel vehicles which are 60% are divided into seven classes, and there is a 40% electric vehicle.

4.3. Sensitivity Analysis. Sensitivity was determined by observing variations in output. One-factor-at-a-time (OFAT) is employed in this study to do sensitivity analysis because of practical reasons. This looks like a logical strategy because any change in output will be explicitly attributed to the one variable modified. Furthermore, by modifying one variable at a time while maintaining the other variables at their core or baseline levels, this improves the comparability of the results (all "effects" are computed with reference to the same central point in space) and reduces the likelihood of computer program crashes, which are more common when multiple input factors are altered at the same time. In the event of a model failure under OFAT analysis, the modeler quickly understands which input factor is to blame [22].

4.3.1. Speed. The required changes in speed are specified by adding and subtracting 10 km/h and 20 km/h speeds from the baseline or recorded speed so that their effect is analysed on carbon emissions and energy consumption.

As can be seen from Figure 8, as the value of speed increases, the amount of carbon dioxide emitted increases directly for all the vehicle types. From 30 km/h to 60 km/h, the slope is steep, and emission increases at a faster rate; however, above 60 km/h, the rate is significantly decreased.

As inferred from Figure 9, vehicle types of car and minibus carbon monoxide emissions are high as speed is increasing; however, the other vehicle types, small bus, coach, small truck, heavy truck, and truck-trailer, are susceptible to a small increment of carbon monoxide emissions because of variation in speed.

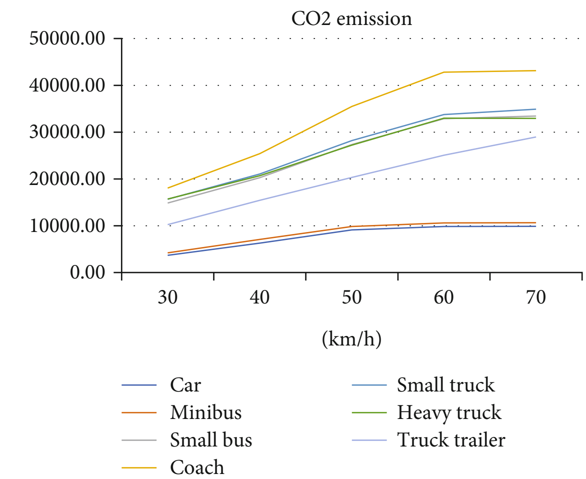

Figure 8: CO_2 emission varying the speed.

As Figure 10 indicates, as the value of speed increases from 30 km/h to 70 km/h, the consumption of fuel is likely to increase. However, the increment rate is higher for the range of 30 km/h to 60 km/h, while the rate is decreased for a speed above 60 km/h.

When we see the effect of speed increment on electricity consumption, Figure 11 shows that for the speed ranges up to 55 km/h, all the vehicle types are nearly consuming higher electricity. However, coaches and truck trailers tend to use less electricity beyond 60 km/h, while heavy trucks' electricity consumption keeps using the same increased amount for speeds greater than 60 km/h. In cars, minibuses, small buses, and small trucks, electricity consumption rises at a smaller rate by increasing the speed.

4.4. Summary of Results of Evaluation of Each Case

4.4.1. Case I

(i) CO_2 emitted to the atmosphere

$$\text{Total amount of } CO_2 \text{ released to the atmosphere} = \frac{16 = 16{,}286\ \text{kg (day)}}{5{,}850.5\ \text{ton (year)}},$$
$$\text{Total amount of } CO_2 \text{ in 10 years} = 10^{*}5{,}850.5 = 58{,}505\ \text{ton}. \tag{1}$$

(ii) CO emitted to the atmosphere

$$\text{Total amount of CO released to the atmosphere} = \frac{406.7\ \text{kg (day)}}{146.1\ \text{ton (year)}},$$
$$\text{Total amount of CO in 10 years} = 10^{*}146.1 = 1{,}461\ \text{ton}. \tag{2}$$

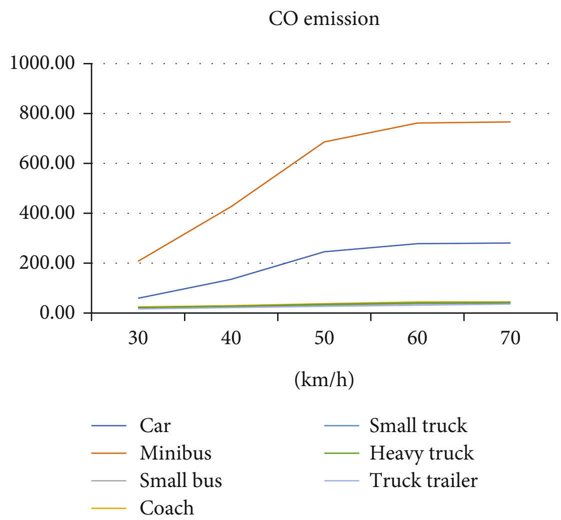

Figure 9: CO emission varying the speed.

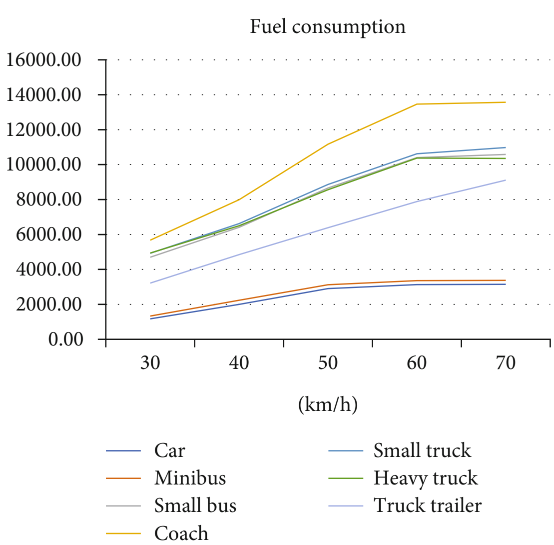

Figure 10: Fuel consumption varying the speed.

(iii) Cost of fuel + electricity

$$\text{Total cost of energy (fuel + electricity)} = \frac{5{,}779{,}620.12\ \text{ETB (day)}}{2.11\text{B ETB (year)}},$$
$$\text{Total cost of energy in 10 years} = 10^{*}2.11 = 21.1\text{B ETB} \tag{3}$$

(iv) Car ownership cost

As per the survey conducted in different car markets around the city, the average market price for the different vehicle types is summarised in Table 8.

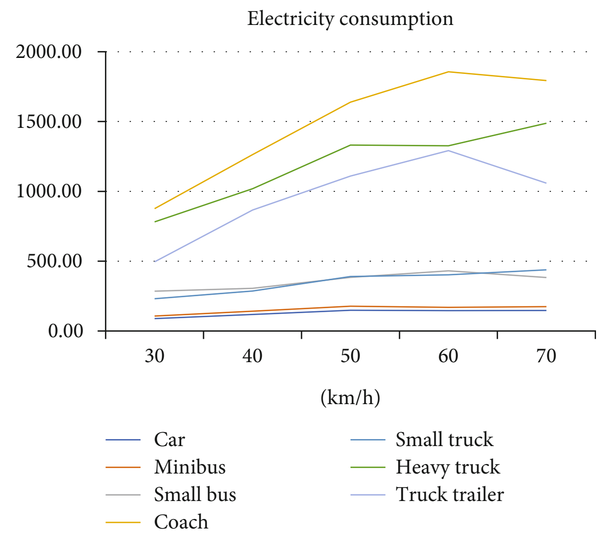

Figure 11: Electricity consumption varying the speed.

Table 8: Fuel vehicle ownership cost case I.

V type	Qty	Estimated price	Total price
Car	9711	1,800,000.00	17,479,800,000.00
Minibus	6793	2,500,000.00	16,982,500,000.00
Small bus	467	4,500,000.00	2,101,500,000.00
Coach	683	7,500,000.00	5,122,500,000.00
Small truck	1141	5,000,000.00	5,705,000,000.00
Heavy truck	581	7,000,000.00	4,067,000,000.00
TT	244	10,000,000.00	2,440,000,000.00
			53,898,300,000.00

(v) Maintenance and service cost

An average cost of 4,000 ETB (for automobiles)–10,000 ETB (for truck trailers) is incurred per service; vehicles are assumed to be serviced every 4 times a year (every three months), as summarised in Table 9.

(vi) Fuel station cost (2 fuel stations are assumed for each 8 study areas)

$$\text{Fuel station cost} = 2^{*}8^{*}19{,}839{,}844.82 = 317{,}437{,}517.12\ \text{ETB}. \tag{4}$$

Charging station cost – null.

TOTAL: 58,505.1 ton CO_2; 1461.1 ton CO; total cost = 75,709,543,517.12 ETB.

4.4.2. Case II

(i) CO_2 emitted to the atmosphere

Table 9: Fuel vehicles service and maintenance cost case I.

V type	Qty	Serv & maint. cost/year	Total price
Car	9711	16,000.00	155,376,000.00
Minibus	6793	20,000.00	135,860,000.00
Small bus	467	28,000.00	13,076,000.00
Coach	683	36,000.00	24,588,000.00
Small truck	1141	30,000.00	34,230,000.00
Heavy truck	581	36,000.00	20,916,000.00
TT	244	40,000.00	9,760,000.00
			393,806,000.00

$$\text{Total amount of } CO_2 \text{ released to the atmosphere} = \frac{13{,}083.8\,\text{kg (day)}}{4{,}700.16\,\text{ton (year)}},$$
$$\text{Total amount of } CO_2 \text{ in 10 years} = 10^{*}4700.16 = 47{,}001.6\,\text{ton}. \tag{5}$$

(ii) CO emitted to the atmosphere

$$\text{Total amount of CO released to the atmosphere} = \frac{337\,\text{kg (day)}}{121.06\,\text{ton (year)}},$$
$$\text{Total amount of CO in 10 years} = 10^{*}121.06 = 1210.6\,\text{ton}. \tag{6}$$

(iii) Cost of fuel + electricity

$$\text{Cost of energy (fuel + electricity)} = \frac{4{,}684{,}200.84\,\text{ETB (day)}}{1.71\text{B ETB (year)}},$$
$$\text{Total cost of energy in 10 years} = 10^{*}1.71 = 17.1\text{B ETB}. \tag{7}$$

(iv) Car ownership cost

Fuel vehicles.

In case II, the number of fuel vehicles in case I is reduced by 20% and replaced by electric vehicles. The total expense to be invested to own ICE vehicles is therefore summarised in Table 10.

To acquire the total expense for vehicle ownership under case II, the cost to own 20% of electric vehicles needs to be calculated. Thus, Table 11 shows the price for each electric vehicle and the subtotal.

(v) Maintenance and service cost

Table 10: Fuel vehicle ownership cost case II.

V type	Qty	Estimated price	Total price
Car	7,769	1,800,000.00	13,984,200,000.00
Minibus	5,434	2,500,000.00	13,585,000,000.00
Small bus	374	4,500,000.00	1,683,000,000.00
Coach	546	7,500,000.00	4,095,000,000.00
Small truck	913	5,000,000.00	4,565,000,000.00
Heavy truck	465	7,000,000.00	3,255,000,000.00
TT	195	10,000,000.00	1,950,000,000.00
			43,117,200,000.00

Table 11: Electric vehicles ownership cost case II.

V type	Qty	Estimated price	Total price
Car	1,942	2,300,000.00	4,466,600,000.00
Minibus	1,359	3,000,000.00	4,077,000,000.00
Small bus	93	5,500,000.00	511,500,000.00
Coach	137	9,000,000.00	1,233,000,000.00
Small truck	228	6,000,000.00	1,368,000,000.00
Heavy truck	116	9,000,000.00	1,044,000,000.00
TT	49	12,000,000.00	588,000,000.00
			13,288,100,000.00

Table 12: Fuel vehicles service and maintenance cost case II.

V type	Quantity	Ser & main/yr	Total price
Car	7,769	16,000.00	124,304,000.00
Minibus	5,434	20,000.00	108,680,000.00
Small bus	374	28,000.00	10,472,000.00
Coach	546	36,000.00	19,656,000.00
Small truck	913	30,000.00	27,390,000.00
Heavy truck	465	36,000.00	16,740,000.00
TT	195	40,000.00	7,800,000.00
			315,042,000.00

Since the number of fuel vehicles has decreased by 20% in case II, the cost for service and maintenance again is supposed to decrease by the same amount. Hence, Table 12 clearly shows the costs to be incurred for maintenance.

(vi) Fuel station cost (2 fuel and 1 charging station are assumed for each 8 areas)

$$\begin{aligned}\text{Fuel station cost} &= 2^{*}8^{*}19{,}839{,}844.82\\ &= 317{,}437{,}517.12\,\text{ETB},\end{aligned}$$

$$\begin{aligned}\text{Charging station cost} &= 1^{*}8^{*}9{,}429{,}638.32\\ &= 75{,}437{,}106.56\,\text{ETB},\end{aligned}$$

$$\begin{aligned}\text{TOTAL} &= 47{,}001.6\text{ ton} - CO_2\text{ ; }1210.6\text{ ton} \\ &\quad - CO\text{ ; total cost} \\ &= 74{,}213{,}216{,}623.68\text{ ETB}.\end{aligned} \tag{8}$$

4.4.3. Case III

(i) CO_2 emitted to the atmosphere

$$\text{Total amount of } CO_2 \text{ released to the atmosphere} = \frac{9{,}698.4\text{ kg (day)}}{3484.02\text{ ton (year)}},$$
$$\text{Total amount of } CO_2 \text{ in 10 years} = 10^{*}3484.02 = 34{,}840.2\text{ ton}. \tag{9}$$

(ii) CO emitted to the atmosphere

$$\text{Total amount of CO released to the atmosphere} = \frac{250.7\text{ kg (day)}}{90.06\text{ ton (year)}},$$
$$\text{Total amount of CO in 10 years} = 10^{*}90.06 = 900.6\text{ ton}. \tag{10}$$

(iii) Total cost of fuel + electricity

$$\text{Cost of energy (fuel + electricity)} = \frac{3{,}522{,}690.12\text{ ETB (day)}}{1.29\text{B ETB (year)}},$$
$$\text{Cost of energy in 10 years} = 10^{*}1.29 = 12.9\text{B ETB} \tag{11}$$

(iv) Car ownership cost

Fuel vehicles.

In case III again, the number of fuel vehicles is reduced by an additional 20% so that 40% of the total vehicles driven on the roads of Addis Ababa are assumed to be electric vehicles. The total expense to be invested to own these ICE vehicles is then summarised in Table 13.

Electric vehicles.

For case III (a combination of 60% ICE vehicles and 40% EVs), the cost to own the ICE vehicles is elaborated above, while the ownership cost for EVs is computed in Table 14.

(v) Maintenance and service cost

In case III, the expense for service and maintenance is highly reduced because the number of fuel vehicles has reduced by 40%, and Table 15 clearly shows the maintenance cost in this case.

(vi) Fuel station cost (1 fuel and 2 charging stations are assumed for each 8 areas)

Table 13: Fuel vehicle ownership cost case III.

V type	Qty	Estimated price	Total price
Car	5,827	1,800,000.00	10,488,600,000.00
Minibus	4,076	2,500,000.00	10,190,000,000.00
Small bus	280	4,500,000.00	1,260,000,000.00
Coach	410	7,500,000.00	3,075,000,000.00
Small truck	685	5,000,000.00	3,425,000,000.00
Heavy truck	349	7,000,000.00	2,443,000,000.00
TT	146	10,000,000.00	1,460,000,000.00
			32,341,600,000.00

Table 14: Electric vehicle ownership cost case III.

V type	Qty	Estimated price	Total price
Car	3,884	2,300,000.00	8,933,200,000.00
Minibus	2,717	3,000,000.00	8,151,000,000.00
Small bus	187	5,500,000.00	1,028,500,000.00
Coach	273	9,000,000.00	2,457,000,000.00
Small truck	456	6,000,000.00	2,736,000,000.00
Heavy truck	232	9,000,000.00	2,088,000,000.00
TT	98	12,000,000.00	1,176,000,000.00
			26,569,700,000.00

Table 15: Fuel vehicle service and maintenance cost case III.

V type	Qty	Ser & main/yr	Total price
Car	5,827	16,000.00	93,232,000.00
Minibus	4,076	20,000.00	81,520,000.00
Small bus	280	28,000.00	7,840,000.00
Coach	410	36,000.00	14,760,000.00
Small truck	685	30,000.00	20,550,000.00
Heavy truck	349	36,000.00	12,564,000.00
TT	146	40,000.00	5,840,000.00
			236,306,000.00

Source: Ethiopian car market survey.

$$\begin{aligned}\text{Fuel station cost} &= 1^{*}8^{*}19{,}839{,}844.82 \\ &= 158{,}718{,}758.56\text{ ETB},\end{aligned}$$

$$\begin{aligned}\text{Charging station cost} &= 2^{*}8^{*}9{,}429{,}638.32 \\ &= 150{,}874{,}213.12\text{ ETB},\end{aligned}$$

$$\begin{aligned}\text{TOTAL} &= 34{,}840.2\text{ ton} - CO_2\text{ ; }900.6\text{ ton} \\ &\quad - CO\text{ ; total cost} \\ &= 72{,}198{,}480{,}213.12.\end{aligned} \tag{12}$$

Calculation of economic rate of return ERR:

$$\mathrm{ERR} = \frac{\text{final value} - \text{start value}}{\text{total investment}} * 100,$$

$$\mathrm{ERR}_{1-2} = 75,709,543,517.12 - 74,213,216,623.68/74{,}213{,}216{,}623.68^{*}\ 100.$$

$$\mathrm{ERR}_{1-2} = 2.02\%.$$

$$\mathrm{ERR}_{1-3} = 75,709,543,517.12 - 72,198,480,213.12/72{,}198{,}480{,}213.12^{*}\ 100.$$

$$\mathrm{ERR}_{1-3} = 4.86\%. \quad (13)$$

5. Discussion

Case III has the highest economic rate of return. It is therefore economically feasible to replace 40% of the fuel vehicles for improved economic benefits in addition to environmental benefits.

Therefore, we can conclude that to adopt a transport system containing a significant amount of electric vehicles, the ownership cost of the vehicles is more expensive than the fuel ones, while the other costs incurred as service and maintenance costs, operation costs, erection of recharging stations, and as such are in the reverse. Electric vehicles nearly have zero of these maintenance, and service costs except for the rehabilitation of the battery in eight to ten years of service; however, fuel vehicles have an average expense of 4,000 ETB to 10,000 ETB every 3-4 months. Erection of fuel stations on the other hand is an expensive task, as the comparison is indicated in the two tables. In addition, the cost to operate electric vehicles is much smaller than that of fuel vehicles.

Finally, considering these all of the analysis results which support the implementation of an electric vehicle-dependent strategy in the Addis Ababa transport system, the city's transport bureau and traffic management should encourage the penetration of electric vehicles into the city by providing a lot more charging stations in all parts of Addis Ababa. And the old-model public transport buses contributing to large carbon emissions and high fuel consumption should be replaced by electric coaches and electric trams.

6. Conclusion

This study is conducted to meet the main objective of evaluating the electric vehicle-dependent strategy in the Addis Ababa, Ethiopia, transport system. After defining the contributing factors, i.e., the independent variables, the study specifically evaluates the amount of greenhouse gas emitted into the atmosphere, fuel consumed by internal combustion engine vehicles, and electricity consumption by electric vehicles.

According to the simulation of urban mobility sumo software analysis results, the following conclusions have been made:

(i) Among the vehicle types studied under this paper, the SUMO results signify that coaches are with the highest carbon dioxide emission, releasing an average amount of 28.442 grams of CO_2 every time step, while cars are with the least CO_2 emission value of 6.542 grams. Minibuses are the top carbon monoxide emitters, releasing an average of 0.420 gram of CO every time step, and truck trailers have the smallest carbon monoxide emission, 0.025 grams. Regarding electric consumption, truck trailer is a vehicle type with the highest electric consumption, having a value of 2.282 kwh (watthour) consumption every time step, and cars being the least electricity-consumed vehicles, 0.151 kwh. The fourth point is fuel consumption; besides the high carbon dioxide emission, coaches' consumption of fuel is leading by 8.946 grams, and cars use 2.087 grams of fuel every time step

(ii) From the MLR prediction model for CO_2 emission and fuel consumption, the main factors contributing to increased CO_2 emission and fuel consumption are concluded to be speed of vehicles, the number of vehicles, width of the roadway, proportion of electric vehicles, and proportion of fuel vehicle types (passenger car, minibus, small bus, coach, small truck, heavy truck, and truck trailer)

(iii) The MLR prediction model for carbon monoxide shows that the independent variables number of vehicles, proportion of electric vehicles, and proportion of fuel vehicle types (minibus, small bus, coach, small truck, heavy truck, and truck trailer) are having a significant effect on carbon monoxide emission

(iv) From the last prediction model, the MLR prediction model for electricity consumption, number of vehicles, width of the roadway, proportion of electric vehicles, and proportion of fuel vehicle types (minibus, small bus, coach, small truck, heavy truck, and truck trailer) are the significant independent variables having a considerable effect on electricity consumption

(v) From the economic feasibility and cost comparisons, the ownership cost of electric vehicles is a bit expensive; however, the operation, maintenance, service, and infrastructure costs as erection of charging stations are much cheaper than those of fuel vehicles, besides the profit in the decrease of emissions and the reservation of green and healthy city

Data Availability

Anyone looking for any data can directly contact me via email to shorten the path. The corresponding author is very glad to share any necessary supporting files via the provided e-mail address.

Disclosure

The research is conducted as a partial fulfillment of the degree of Master of Science in Civil Engineering (Road and Transport Engineering).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The research is funded by the Addis Ababa Science and Technology University.

References

[1] Boxcar-adminblog, *New Study Quantifies the Global Health Impacts of Vehicle Exhaust*, International Council on Clean Transportation, 2019, https://theicct.org/new-study-quantifies-the-global-health-impacts-of-vehicle-exhaust/.

[2] *Addis Ababa Environment Protection and Green Development Commission.*

[3] "Transport system: elements, characteristics, types, modes," https://www.overstaytonight.com/transport-system/.

[4] "Wikipedia," *Wikipedia, the Free Encyclopedia*, 2022, https://en.wikipedia.org/w/index.php?title=Main_Page&oldid=1114291180.

[5] Earth.Orgwebsite, *Millions of Highly-Polluting Used Cars "Dumped" on Developing Countries- UN*, Earth.Org, 2020, https://earth.org/cars-developing-countries/.

[6] "The reporter, registered vehicle in Ethiopia," 2020, https://www.thereporterethiopia.com/10186/.

[7] E. E. Michaelides, V. N. D. Nguyen, and D. N. Michaelides, "The effect of electric vehicle energy storage on the transition to renewable energy," *Green Energy and Intelligent Transportation*, vol. 2, no. 1, p. 100042, 2023.

[8] "Trendsnafrica," 2021, https://trendsnafrica.com/ethiopia-cuts-fuel-subsidy-to-reduce-government-expenditure/.

[9] M. Patil, B. Bandhu Majumdar, and P. Kumar Sahu, "A comparative evaluation of the total cost of ownership between electric two-wheelers and motorized two-wheelers from an Indian perspective," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2676, no. 5, pp. 526–550, 2022.

[10] A. Kebede and G. Gebresenbet, "Mapping out goods flow to Addis Ababa city, Ethiopia, and it impact on environment," *Transportation Research Procedia*, vol. 25, pp. 1008–1020, 2017.

[11] Z. Lin and D. L. Greene, "Assessing energy impact of plug-in hybrid electric vehicles," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2252, no. 1, pp. 99–106, 2011.

[12] J. Redgate, A. Al-Habaibeh, A. Williams, and M. Kansara, "Sustainable transport system using renewable energy and efficient electric vehicles," *WIT Transactions on The Built Environment*, vol. 89, pp. 33–41, 2006.

[13] H. Liu, M. Rodgers, and R. Guensler, "Impact of road grade on vehicle speed-acceleration distribution, emissions and dispersion modeling on freeways," *Transportation Research Part D Transport and Environment*, vol. 69, pp. 107–122, 2019.

[14] J. Lu, B. Li, H. Li, and A. Ali, "Expansion of city scale, traffic modes, traffic congestion, and air pollution," *Cities*, vol. 108, 2021.

[15] P. Iodice, A. Amoresano, and G. Langella, "A review on the effects of ethanol/gasoline fuel blends on NOX emissions in spark-ignition engines," *Biofuel Research Journal*, vol. 8, no. 4, pp. 1465–1480, 2021.

[16] P. Iodice, E. Fornaro, and M. Cardone, "Hybrid propulsion in SI engines for new generation motorcycles: a numerical-experimental approach to assess power requirements and emission performance," *Energies*, vol. 15, no. 17, p. 6312, 2022.

[17] P. Iodice, E. Fornaro, and M. Cardone, "Hybrid propulsion for motorcycle application to reduce engine-out emissions: an analytical-experimental investigation," *Journal of Physics: Conference Series*, vol. 2385, no. 1, article 012065, 2022.

[18] Simulation of urban mobility (SUMO)https://sumo.dlr.de/docs/Models/Emissions.html.

[19] "Manual creation of network," https://www.youtube.com/watch?v=9MyIABer_NY.

[20] "Od matrix to trip and route generation," https://www.youtube.com/watch?v=R6v7wDkvXrk&t=108s.

[21] Sumo, 2021, https://sumo.dlr.de/docs/index.html.

[22] Wikipedia, "Sensitivity analysis," 2023, https://en.wikipedia.org/wiki/Sensitivity_analysis.