Applying 3D-Eco Routing Model to Reduce Environmental Footprint of Road Transports in Addis Ababa City

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Abstract

Climate change has emerged as a very important threat to economic development, atmosphere, and public health. One of the driving factors for global climate change was road transportation. therefore, this sector needs a responsibility of reducing its effect on the environment. this study finds ways to mitigate climate change impacts on environment especially greenhouse gas emissions and other selected air pollutants by anew navigation concept called eco route by applying a 3D Eco -Routing Model to reduce the environmental footprints of road transports in Addis Ababa city for distribution vehicles. The applied model in this study considered the road gradient, varying velocity or speed of vehicles, and weight of vehicles to evaluate gradient effects on consumption of fuel, CO 2 and also other air pollutants emission, the model is applied in three scenarios within different vehicle weight range and three different cases in the city of Addis Ababa, political capital of Africa,

The attained results imply eco-routes emission Reduction potentials up to 39.81% from fuel and CO 2 and 25.65% from other air pollutant in the tested scenarios. The results showed that Eco Routes have the ability of reducing Fuel consumption, CO 2 and other air pollutant emission rate.

Such potentials of eco routes make them an ecological solution for a future sustainable transportation in Addis Ababa City. This study recommends the use of Eco Routes, rather than Fastest and Shortest Routes, where significant road gradients exist.

1. Background

The road transportation system is a crucial element in city infrastructure and it displays the economic growth of cities. Effective road transport planning and also its accessibility for users enable sustainable growth (Arora and Pandey 2011). However, it also brings disadvantages to congestion and emission of air pollutant (i.e. Particulate matter (PM), Volatile organic compounds (VOCs), Oxides of nitrogen (NO_x) Carbon monoxide (CO), and Carbon dioxide (CO_2), the greenhouse gas (GHG) which are primarily responsible for global warming.

Road transportation is the most dominant transportation mode in Addis Ababa City. Roads in the city constructed and maintained by Addis Ababa City Road Authority (AACRA). Today the city roads length reached 3324 km the road network coverage has reached 12.21% compared with the developed area of the city. Following the rapid increment of the population, the transportation demand was increased. In order to answer the ever-increasing mobility demand, the Addis Ababa City administration has launched large transport projects and that they are in their expansion phases. However, this road network development doesn’t consider its impact on the environment. to fulfill the sustainability of the environment the road sector must be responsible for its impact. however, Substantial Carbon dioxide emission saving can be obtained by optimizing routes for fuel consumption at the minimum (Toro et al. 2016). To enable optimization for the purpose of fuel and emission minimization this study uses a Geographic information system (GIS), it is widely applicable in transportation network analysis (The Geography of Transport systems 2006). Utilizing GIS functionalities, optimization can be done by introducing Emission Estimation Models, which considers Speed of Vehicle, Gradient or ups, and downs of road, the weight of vehicles as a factor fuel consumption. (LAT/EEA 2007).

Eco-routing algorithm is a strong fuel consumption model that helps to identify low energy routes when vehicles travel from origin to destination and vice versa. Rather than fastest and shortest routes eco routes are obtainable as vehicles reduce their fuel consumption consequently their emission level. To quantify the environmental footprints or impacts of eco routing strategies, fuel consumption and its corresponding emissions must be assessed or expected. (Minett et al. 2011).

Numerous authors have examined eco routing tactics (Coloma et al. 2017) used drivers' behavior in a small city to reduce emission. in this study for driver's performance evaluation vehicle speed, time, acceleration and deceleration and also vehicle number of stops considered for the purpose of finding eco routing and driving effects on emission based on field-based traffic data. Also, in (Jovičić et al. 2010) The purpose of the research was to estimate and reduce fuel and CO_2 for communal vehicles. moreover, the fuel-efficient routes are compared considering time and distance with the corresponding route. (Andersen et al. 2013) used eco-weights to a study area road network based on can bus trajectories fuel consumption and Global positioning system data to enable eco routes. based on the generated data the authors compared eco routes to the shortest and fastest routes. more over (Huang and Peng 2018) extends the above authors by using Autonomies to calculate fuel consumption in the study area road network, eco routes are again compared with shortest and fastest routes as well. The results showed that eco-able to reduce fuel consumption. In waste management case studies (Tavares et al. 2009) proposed 3D route model for waste transportation aiming to minimize fuel consumptions. and also (Li et al. 2014) used method by applying engineering system, for the collection of waste in cities major urban central area aiming to reduction of fuel consumption and emission from vehicles.

Meanwhile, routing models need to use spatial data such as geographic information systems (GIS). GIS is intelligent in data input, management and displaying geospatial information.as reported by Keenan (1998) and M. Schröder and Cabral (2019) proposed a model by using geographic information systems (GIS) to provide a comparative result in routing applications.

As presented above, influencing factors such as time and distance are commonly used for the optimization of vehicles and also real-time traffic and speed of vehicles have been considered in a specific range of the vehicle. However, vehicle engine productivity on emission and fuel consumption affected by road gradients, vehicle fuel consumption is higher on higher gradients and vice versa. Therefore, it would be valuable to address gradients and includes abroad range vehicle weights in order to find more accurate fuel consumption, in addition to increase the percentage of eco routes fuel saving potential and emission estimation. Such a method is innovative and would deliver realistic fuel consumption and emission estimation.

This paper focuses on the role of eco routing which depends on the road gradient extracted from the digital elevation model of the study area in the city road network system. Furthermore, it uses an emission estimation model, the model considers different vehicle weight ranges and speeds of vehicles.to enable fuel consumption and emission minimization this study Uses GIS network analyst as a tool and other open-source data.

2. Materials And Methods

2.1 Study Area Description

Addis Ababa city is the African political capital and the capital city of Ethiopia. The study area was located in the country of a man of origin. detailed location and map description are shown below in table 1 and figure 1 respectively.

Table 1:Location Description

Addis Ababa City	
Coordinates	38°44′24″E 9°1′48″N
Climate	Subtropical highland Climate
Area(total):	519.482 km^2
Elevation	2,355 m
Time zone	Universal Time Coordinated (UTC+3)

2.2 Road transportation in the city

In the city of Addis Ababa, the dominant public transportation modes are automobiles and dry cargo. standard city buses and mini-bus taxis are the dominant and affordable means of public transportation for the majority of the residents. and within a city, there are private limited companies and governmental road freight transportations which give delivery to the customers and a total of 596084 different types of vehicles available until 2019.a great challenge for Addis Ababa city for the establishment of a reliable and sustainable transportation system in the city for proper movement of vehicles.

There is a project in progress in the city for heavy-duty distribution vehicles and public buses to traverse in selected lanes to improve the transport management systems. It is expected that the current research will help in choosing a road network for distribution vehicles in an environmentally friendly manner, which takes into account the gradient and other environmental factors into consideration.

2.3 Data and Data Acquisition

Data used in this study were obtained from different sources. Road network data mainly digitized from google earth image of 2019 on the study area at the spatial resolution of 10m ,and ortho photos were used to georectify the digitized road networks .Advances Land observing satellite (ALOS) Phased array L band synthetic aperture radar (PALSAR) of 12.5 spatial resolution was used to as digital elevation model for the study area obtained from Alaska satellite facility .GPS Coordinates of origin - destination locations were collected using actual measurement in the field. Emission data related data's were obtained from MEET emission estimation model and other literatures.

2.4 Methods

Primarily this paper establishes methodology whereby to find optimal eco route networks that reduce the consumption of fuel and its related CO_2 additionally other air pollutants emission for transporting different types of goods from origin to destination locations and vice versa. the model application was done in four steps: (1) establishment of 3D-RN ;(2) Fuel consumption and pollutant emission estimation by using Emission estimation Model; (3) Road network data set development and (4) optimization for different scenarios and other attribute calculations are done by utilizing visual basic script options.

The following figure 2 shows general Work flow and procedure are adopted in this study and forms the basis for deriving Eco-Route of the study area and subsequently the overall findings.

2.4.1. Connecting 2D road Network with DEM

In this stage the 2D road segment consists of 40886 polyline records with functional class [motorway, principal arterial, sub arterial, collector and local streets] were preprocessed by adding speed attributes to fit study area speed limit based on Addis Ababa city road authority (AACRA)Standard [80 for Motorway,70 for Principal arterial,60 for Sub arterial and collector,30 for Local Streets] and also Street Hierarchy tabulated Based on AACRA Street Hierarchy based on its functional classes Standard [1 for Motorway,2 for Principal arterial, 3 for Sub arterial, 4 for collector,5 for Local Streets] also worked on 2D Road Network. Finally, ALOS PALSAR DEM [12.5m resolution] is used to convert 2D road Networks to 3D Road Network. To obtain gradients of a street network ArcMap was used on the first step feature vertices to points on centerline feature class twice once for start and once for end was generated, secondly, values are extracted to points on the start and end features classes finally by adding new fields and gradient was gained by subtracting start elevation from end elevation values and the divided by segment length and multiplied by hundred, The study area faces with many undulating trains especially on local streets. due to DEM resolution on some parts of local street gradient values are unrealistic. To overcome these gradient values for the generated street segments within study boundary higher than permissible maximum restriction for road slopes are reduced according to (Bartlett 2015) however in this study the implemented scenarios cases not exceed the permissible Road Slopes.

2.4.2. Calculation of Fuel Consumption and Pollutants Emission Estimation

for this study, the method proposed in Methodologies to Estimate Emissions from Transport (MEET) Based on (Demir, Bektaş, and Laporte 2014) and (EEA 1999) was used. All calculations and estimations are done using the data available on MEET vehicle weight ranges (i.e. 3.5 up to 32 tones) for three scenarios and each scenario tested with three cases.

The basic fuel consumption and other pollutants expressed for speed only, in (g/ km), which was obtained from MEET Model given below:

Scenario (1):

For V 5 – 60 $1425.2V^{-0.7593}$ (1)

For V 60 – 100 $0.082V^2 - 0.0430V + 60.12$ (2)

Other Pollutants

CO For V 5 – 100 $37.280V^{-0.6945}$ (3)

NOx For V 5 – 50 $50.305V^{-0.7708}$ (4)

For V 50 – 100 $0.0014V^2 - 0.1737V + 7.5506$ (5)

VOC For V 5 – 100 $40.120V^{-0.8774}$ (6)

PM For V 5 – 100 $4.5563V^{-0.707}$ (7)

Scenario (2):

For V 5 – 60 $1068.4V^{-0.4905}$ (8)

For V 60 – 100 $0.0126V^2 - 0.6589V + 141.2$ (9)

Scenario (3):

For V 5 – 60 $1595.1V^{-0.4744}$ (10)

For V 60 – 100 $0.0382V^2 - 5.163V + 399.3$ (11)

Based on the vehicle’s category, corrections could also be applied to consider the gradient of street and load of vehicles' effects on the emissions.

Gradient factor

Uprising or down rising of the road has the effect of ascending or descending the vehicle's fuel consumption and emission (EEA 1999). For street gradient class, the gradient correction factor calculated using The MEET model provides gradient correction factor for a range of (-6 % to 6 %) of gradient .to include abroad range of gradient classes in a city road network the given equations are adjusted to fit an exponential function. The equations (12-14) used also for other pollutants as the road gradient correction factor and expressed by the following equation where RG represents the road gradient in percentage.

For scenario 1: $G_{CF} = 0.213e^{0.165RG}$ (12)

For scenario 2: $G_{CF} = 0.419e^{0.180RG}$ (13)

For scenario 3: $G_{CF} = 1.0458e^{0.187RG}$ (14)

Vehicle Load factor

The higher the vehicle weight the higher its fuel consumption and emission and also the same for vice versa (Tavares et al 2009).

50% of the load for emission factor is corrected to tolerate different load conditions, is corrected with the use of the following equation (15).

[Please see the supplementary files section to access this equation.]

(15)

where,

L_{cf} = emission factor corrected of the fuel consumption in [g/km]

lp = 0 for empty load vehicle and lp = 100 for fully load

cf = load correction factor of the FC which is 0.18

for Loaded vehicles Lcf of 1.18 and for unloaded Vehicles Lcf of 0.82 was applied

the above equation (15) also used to consider vehicle load for other pollutants emission estimation calculations. The actual Load factor for pollutants is given in MEET and applied for this study and load correction applied for pollutants is given below in the table (2) load factor and (3) the load correction factor respectively.

Table 2:Pollutants and its Load factor

Pollutant	Load Factor(lp)
CO	0.21
NOx	0.18
VOC	0
PM	0.08

Table 3:Pollutants Load Correction Factor

	Load Correction Factor (Lcf)	
Pollutant	**Empty Load**	**Complete Load**
CO	0.79	1.21
NOx	0.82	1.18
VOC	1	1
PM	0.92	1.08

MEET Suggests the Total Fuel Consumption in gram as in equation (16) and for all pollutants, (i.e. CO, NOx, VOC, PM) the total Emission per Road length is calculated as in gram as in equation (17)

$$FC = Fcv * G_{CF} * L_{cf} * D \qquad (16)$$

$$\text{Total Emission of Pollutant} = Pv * GCF * Lcf * D \qquad (17)$$

Where: Fcv = Speed factor for Fc , P_V = Pollutants speed factor , G_{CF} = Gradient Correction Factor , L_{cf} = Load Correction Factor , D = Distance in km

For real application, fuels in grams are converted to Liters [L]

Diesel for automotive use is around 832gm/liter

Therefore: [See supplementary files.] (18)

The calculated fuel consumption values are used as an impedance to find eco routes in a network. For comparison, the road networks are completed with time attribute, Length and allowed road functional class velocity expressed as equation 19.

[See supplementary files.] (19)

L[km] = 3D Distance used for Short Routes

Moreover, CO_2 emissions rates are estimated based on fuel consumption only for each scenario. The following equation 20 is applied from the MEET methodology.

Weight of CO2 = 44.011 (wight of fuel/(12.011 + 1.008 . rH/C)) (20)

Where: rH/C = hydrogen to carbon ratio in the fuel (~2.0 for diesel)

2.4.3. Road Network Data Set Development

Transport networks are mostly done in a GIS environment by the Network dataset. Network datasets are made of network elements. Network elements are created from point or line features to create the network dataset. network elements contain attributes that change navigation over the developed network. Network attributes help to regulate traverse ability over the network. in this study, a one-way restriction was applied while solving the analysis. The hierarchy was given according to the road functional class how drivers generally select the level of a street to travel. More predictable that drivers choose high order roads rather than low order roads. for this study vertex connectivity was selected. And finally, Elevation fields considered that helps to improve the connectivity at line ends. They contain elevation information to consider effectively vehicles to pass overpasses underpasses and normal streets in the network.

2.4.4. Optimization

The route optimization was done with ArcMap Network Analyst. In this study, route optimization primarily focuses on minimizing the fuel to find eco-routes in a network that connects origin-destination points. Additionally, time and distance attributes are added to be used as cost attributes of the network**.** This study mainly aims to reduce vehicle environmental footprints, therefore, reduction in fuel is not questionable.

In this study, three scenarios were introduced to test different routing conditions, which include different ranges of vehicle weight classes that are available in the city of Addis Ababa. Each scenario contains three cases with different loading and routing conditions. The overall implementations are tabulated in table 4.

Table 4:Scenario Implementation

Scenarios	Cases	Engine Type	Weight Class [Ton]	Loading Condition	Routing	Relationship	Description
1	1	Diesel Vehicles	3.5-7.5	Loaded	Simple	One to One	Loaded Vehicles travels from one origin to one Destination
	2			Loaded	Full Distribution	One to Many	Loaded Vehicles travels from one origin to Many Destination
	3			Unloaded	Back Haul	Many to One	Unloaded Vehicles travels from Many Destinations to One Origin
2	1	Diesel Vehicles	7.5 -16	Loaded	Simple	One to One	Loaded Vehicles travels from one origin to one Destination
	2			Loaded	Full Distribution	One to Many	Loaded Vehicles travels from one origin to Many Destination
	3			Unloaded	Back Haul	Many to One	Unloaded Vehicles travels from Many Destinations to One Origin
3	1	Diesel Vehicles	16 -32	Loaded	Simple	One to One	Loaded Vehicles travels from one origin to one Destination
	2			Loaded	Full Distribution	One to Many	Loaded Vehicles travels from one origin to Many Destination
	3			Unloaded	Back Haul	Many to One	Unloaded Vehicles travels from Many Destinations to One Origin

3. Results

At this stage, the route results are compared with different criteria, including travel time, fuel consumption and distance. Additionally, CO_2 Emission estimation for all scenarios and air pollutants emission for scenario 1 was estimated for routes moreover the fuel cost was estimated.

3.1 Scenario 1

This scenario pretends the supply of Bottled water to the market, which is utilized by the Aqua Addis Bottled Water supplier.

3.1.1 Case 1

case 1 under scenario 1 tests the fuel and emission levels for origin to a single supermarket. routes are separately generated for fuel consumption, Time and Distance. The resulting of three routes are displayed in fig 3 below.

As shown in Figure 3 the shortest and fastest routes, overlaps which are mainly utilizing Principal Arterial and Sub arterial streets for long distances because of the routes are not optimized for fuel consumption. In contrast, eco routes optimized for fuel consumption prefers lower gradients.

3.1.2 Case 2

case 2 under scenario 1 tests the fuel and emission levels for origin to each supermarket. routes are separately generated for fuel consumption, Time and Distance. The resulting one hundred forty-seven routes are displayed in fig 4

3.1.3 Case 3

case 3 under scenario 1 tests the fuel and emission levels for destination market to origin to consider returning trucks from the market. routes are here again separately generated for fuel consumption, Time and Distance. The resulting one hundred forty-seven routes are displayed in fig 5.

3.2. Scenario 2

This scenario pretends the supply of a Soft Drinks (i.e, Sprite, Mirinda,7up, Pepsi, Cool gas water, and etc) to the market, which is utilized by Moha Soft Drinks from summit plant supplier on a demand-based schedule.

3.2.1 Case1

In this scenario 2 of case 1, the same principles were applied as that of scenario 1 case 1, as such This case under scenario 2 works for origin to a single supermarket. routes are separately generated for fuel consumption, Time and Distance. The resulting of three routes are displayed in fig 6 below.

At the beginning and end distances the shortest and fastest routes are overlapped with each other as they are mainly utilizing Principal Arterial and Sub arterial streets which prefer the Summit-Salhite-Mihret road at initial. However, eco routes at those locations prefer lower gradients as shown in figure 6.

3.2.2 Case 2

This case under scenario 2 applied for the supply of soft drinks to each market location with a completely loaded. each market place is supplied by a single truck. routes are separately generated for fuel consumption, time and distance. The resulting total of 150 routes is displayed below in Figure 7.

3.2.3 Case Study 3

case 3 under scenario 2 applied for backhauls destination market to origin to consider returning trucks from the market. routes are here again separately generated for fuel consumption, Time and Distance. The resulting total of 150 routes is displayed below in Figure 8.

3.3 Scenario 3

This scenario pretends the supply of a vehicle Gas (i.e., Diesel and gasoline) to the service station, which are utilized by Oilibiya private limited company. Which distributes fuel from Gotera area depot to service stations on a demand-based schedule. The vehicle range incorporated in this scenario is HDV 16 -32 tons.

3.3.1 Case 1

In this scenario 3 of case 1, the same principle applied as that to scenarios 1 and 2 of case 1, as such routes are separately generated for fuel consumption, Time and Distance. The resulting three routes are displayed in Figure 9 below.

The fastest route tends to jump on motorways (ring road) and the shortest routes mainly utilize principal arterial streets which are not optimized for FC, however, eco routes utilize initially at Gotera overpasses and tend to use sub arterial streets and local streets as shown in figure 9 above. all three routes partially overlapping at initial and destination kilometers. However, and eco routes prefer lower gradient of a street network.

3.3.2 Case 2

This case 2 worked under scenario 3 for the supply of Fuel to each Service station locations (i.e the depot to 27 service stations) with a completely loaded. each service station is supplied by a single truck. The three routes are generated for fuel consumption, time and distance the resulting total of 81 routes is displayed below in Figure 10.

3.3.3 Case Study 3

This case applied for the backhaul to account for empty returning trucks. The three routes are generated for fuel consumption, time and distance. The resulting total of 81 routes is displayed below in Figure 11.

3.*4 Parameter comparison results for three Scenarios*

Table 5: Eco routes Fuel Saving potential

[illegible]	% Fuel Savings From Fast	% Fuel Savings From Short	Shortest Route			Fastest Route			Eco Route		
			Distance [Km]	Time [Hr.]	Fuel [L]	Distance [Km]	Time [Hr.]	Fuel [L]	Distance [Km]	Time [Hr.]	Fuel [L]
[illegible]	39.81	35.91	12.78	0.22	1.44	12.82	0.19	1.54	17.23	0.39	0.92
[illegible]	35.43	29.50	386.15	6.05	54.49	393.42	6.05	59.11	473.62	10.91	38.16
[illegible]	27.08	23.93	379.06	6.32	34.43	382.59	6.027	35.92	443.53	9.985	26.19
[illegible]	10.72	13.91	22.47	0.329	2.57	22.66	0.32	2.48	24.89	0.46	2.21
[illegible]	13.20	11.22	737.03	11.80	81.23	750.18	10.71	83.07	816.22	13.93	72.11
[illegible]	8.96	9.81	746.00	11.12	54.44	753.61	10.76	53.93	796.29	13.64	49.09
[illegible]	19.48	16.28	9.97	0.145	4.49	10.39	0.141	4.67	10.31	0.15	3.76
[illegible]	12.79	19.32	176.99	2.84	92.04	179.71	2.63	85.14	192.83	3.08	74.25
[illegible]	8.38	12.61	180.80	2.89	41.43	185.26	2.68	39.52	189.50	3.07	36.21

Table 6:Eco routes CO_2 Saving potential

Routing Scenario	Vehicle Weight Range and cases	% CO_2 Emission Savings From Fast	% CO_2 Emission Savings From Short	Shortest Route		Fastest Route		Eco Route	
				CO_2 [Kg]	Cost [$]	CO_2 [Kg]	Cost [$]	CO_2 [Kg]	Cost [$]
Scenario 1	3.5-7.5 ton (C1)	39.78	35.88	743.962	0.92	792.16	0.98	477.02	0.59
	3.5-7.5 ton (C2)	35.43	29.96	27991.40	34.87	30364.87	37.83	19604.46	24.42
	3.5-7.5 ton (C3)	27.08	23.93	17689.08	22.04	18451.50	22.99	13454.62	16.76
Scenario 2	7.5-16 ton (C1)	10.73	13.89	1321.69	1.64	1274.80	1.58	1138.00	1.41
	7.5-16ton (C2)	13.20	11.22	41722.13	51.98	42671.03	53.16	37037.95	46.15
	7.5-16ton (C3)	8.96	9.81	27962.18	34.84	27700.64	34.51	25216.77	31.42
Scenario 3	16-32 ton (C1)	19.48	16.27	2309.35	2.87	2401.62	2.99	1933.61	2.40
	16-32 ton (C2)	12.79	19.32	47276.36	58.90	43735.45	54.49	38139.80	47.25
	16-32 ton (C3)	8.39	12.61	21284.08	26.52	20303.11	25.29	18599.39	23.17

The above table 5 and 6 comparison results showed that eco routes ability in reducing fuel consumption and CO_2 emission up to 39.81%. therefore, in the tested scenarios, Eco routes fuel and emission saving high on scenario one, moderate on scenario 2 and lowest on scenario three averagely.

3.5 Other Pollutants Result for Scenario 1

In many urban area’s road transportations was the main source of air pollution. for this study Emissions of pollutants from generated routes focused on carbon monoxide (CO), Particulate matters (PM), Oxides of nitrogen (NOx) and, Volatile organic compounds (VOC), and similar to fuel consumption and CO_2 emission on this stage different pollutants obtained from the shortest and fastest routes compared with eco routes results are presented below.

3.5.1 Scenario 1 Pollutant Result

In this scenario, the results are accumulated from the scenario (1) which is generated for fuel consumption and CO_2 emissions. Emission rate results are presented below for each case.

Table 7:Scenario 1 Case 1 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	2.306	4.327	7.717	9.4023
From Shortest Route	12.193	16.295	14.685	19.050

The three route results shown in figure 12 dramatically use the same trend, in this scenario case 1, PM has the lowest emissions. In the shortest routes causes the total high emission of CO. but eco routes show significant emission saving potential at CO. moreover that eco routes have significant emission saving potential with respect to its alternative in all pollutants.

Table 8:Scenario 1 case 2 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	0.304	22.845	14.086	16.863
From Shortest Route	1.177	8.423	3.833	6.580

The three route results shown again in figure 13 dramatically use the same trend, in this scenario case 2, PM has the lowest emissions. Fastest of CO has high emission, but eco routes show significant emission saving potential in VOC. this case implies again eco routes has emission saving potential with respect to its alternative.

Table 9:Scenario 1 Case 3 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	22.070	25.650	17.597	20.538
From Shortest Route	5.776	7.889	4.410	6.474

The three route results show the same trend in figure 14, in this scenario case 3, PM has the lowest emissions with respect to the other three pollutants. The Fastest Route is a factor for high emissions, Fastest of CO has again high emission, but eco routes show significant emission saving potential in VOC with respect to others.

Therefore, eco routes in all tested scenarios are more environmentally friendly, implies eco routes has emission saving potential with respect to its alternative.

4. Discussion

The calculated results showed that Fuel and emission Reduction in all tested scenarios. This study used to MEET emissions factors because they better reflect the characteristics of the Addis Ababa diesel fleet.

In this study, the applied model, which can be previously presented adds values from the work of other authors' in several ways. This work encompasses four steps: (1) establishment of 3D-RN ;(2) Fuel consumption and pollutant emission estimation by using Emission estimation Model; (3) Road network data set development and (4) optimization for different scenarios and other attribute calculations are done by utilizing visual basic script options for different types of Distribution vehicles for minimization of fuel consumption, Distance, and time and finally the results were compared.

Whereas in the contradictory Zsigraiova, Semiao, and Beijoco (2013) introduced a methodology to estimate and reduce cost and emission. In this study Vehicle speed and weight are considered for influencing factors. However, optimization was not done for fuel consumption, the author compared the emission levels in terms of distance and time only. The gradient effects on fuel consumption were also not considered. And also, in Pan, Ballot, and Fontane (2013) proposed logistical mutualization at the strategic level was assessed from the environmental point of view. the study was able to predict the effect on reducing CO_2 emissions by the integration of supply chains. In addition, road, and rail transports are considered in this paper. The conclusions arrived at in the paper show that CO_2 emission reduced by logistic mutualization approach. Whereas the effect of road gradient or inclination was also neglected.

In connection to the current study M. Schröder and Cabral (2019) introduced a methodology, to estimate and reduce fuel consumption and CO_2 emissions, the authors considered factors such as gradient, vehicle load, and vehicle speed. Vehicle ranges incorporated in this study were < 16ton and HDV > 32-ton. Obtained Results showed eco-friendly routes saved fuel and emission up to 20% in the tested cases. Whereas Scora, Boriboonsomsin, and Barth (2015) described eco-routing strategies that used emission models that account for a factor like a gradient, speed of vehicle-based on field measurement and weight. The study results showed eco routes saved fuel consumption by up to 7.5%. Also, Tavares et al. (2009) proposed a methodology for transportation of waste, the introduced model was optimized for fuel consumption. road inclination and vehicle weight were considered as well. The vehicle range incorporated in this study was HDV 7.5–16ton, the results indicate eco routes fuel-saving potential up to 12% from its alternative distance.

The current study estimates and reduce fuel consumption and emissions in the tested scenario areas in the Addis Ababa road network characterized by a gradient range of around − 8–8%. However, the calculated gradient values show in exact values in the study areas of residential streets which are mainly constructed with cobblestones and gravel road, the utilized ALOS PALSAR DEM (12.5 m) used for slope generation. In addition, the model can be extended by adding different vehicle weight ranges which used to identify in which range of vehicles significantly increases fuel consumption and Pollutant emissions. Also, some restrictions were given to road networks as restrictions for vehicle to turn, for to use the street based on its functional importance which means to use street hierarchy, in addition to this Elevation was considered to consider overpasses, underpasses and normal street networks to smoothly drive along delivery street and also company’s distribution schedules considered. Accordingly, fuel consumption and emission rates are higher in the heavy-duty vehicle range of (16–32 tons) compared to heavy-duty vehicles (< 16 tons). However as discussed above, authors used a specific range of vehicles, whereas this study methodology is applied to three scenarios with three different vehicle weight range cases.

As a result, the current study methodology calculated FC, CO_2 emission and air pollutants emission estimates for road-segment by considering Variable [Gradient, Speed, Vehicle Weight (3.5–32 tons)] using MEET Model. Finally, Eco-Routes identified having FC and CO_2 saving potential of 8.39% to 39.81% to its alternatives. The cost calculation is based on fuel costs only. therefore, the eco-route in all scenarios saves a fuel cost, being up to 39.86% fuel and emission reduction potential. Therefore, obviously, these findings imply eco routes are better solutions for the future sustainable road transport and also for the environment.

5. Conclusion

This study decisively addresses climate change and brings significant benefits to Addis Ababa City and also helped to avoid the runaway costs of climate change by the application of the model. The study model was applied in three scenarios each scenario contains three case studies. This study confirmed the method used was capable of the reduction of the environmental footprint of vehicles in Addis Ababa City.

Emission saving gained when changing the optimizer to the lowest 3D fuel consumption from the 3D distance and 3D Time. In the tested scenarios, substantial differences were detected among the shortest, fastest and eco routes under the same criteria .in the tested scenarios, Eco routes showed Fuel and CO_2 emission reduction potential observed up to 39.82% from its alternatives.

Eco Routes were found to be the most influential route in reducing Fuel consumption, CO_2 emissions and also air pollutants emission. Such potentials of eco routes make them an ecological solution for a future sustainable environment in Addis Ababa City. This is supported by the 3D eco route model.

This study provided baseline information on carbon emissions in Addis Ababa City and explored the implications of transportation activities with respect to Emissions in a new manner that has not been previously undertaken. The current study suggested the ways that the transportation sector might adjust its transport investment activities to reduce carbon emissions by utilizing Eco routes. It is very much expected that the proposed eco-route Model can contribute to the development of a low-carbon transportation system in Addis Ababa City.

Abbreviations

FC: Fuel Consumption; GCF: Gradient Correction Factor; HDV: Heavy Duty Vehicle; Lcf: Load Correction Factor; Lp: Load factor; RG: Road Gradient

Declarations

- Acknowledgements

Not Applicable

- Ethics approval and consent to participate

Not Applicable

- Consent for publication

We have agreed to submit for Environmental Systems Research journal and approved the manuscript for submission

- Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

- Competing interests

The authors declare that they have no competing interests

- Funding

No funding was received

- Authors' contributions

Seifu Woldemichael Busho has conceived of the study and made contributions in design, data collection, analysis, interpretation of results and draft the manuscript. Daniel Alemayehu has participated in the sequence alignment and critical commenting of the manuscript. Both authors read and approved the manuscript

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Figures

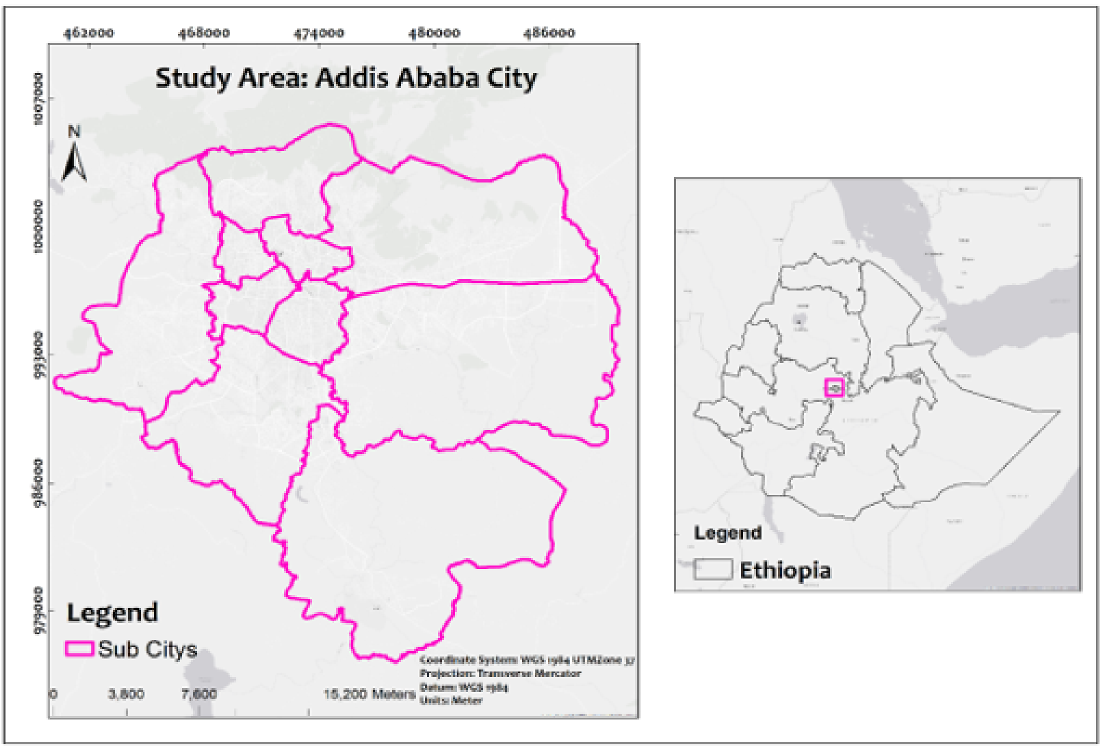

Figure 1

Addis Ababa City Map

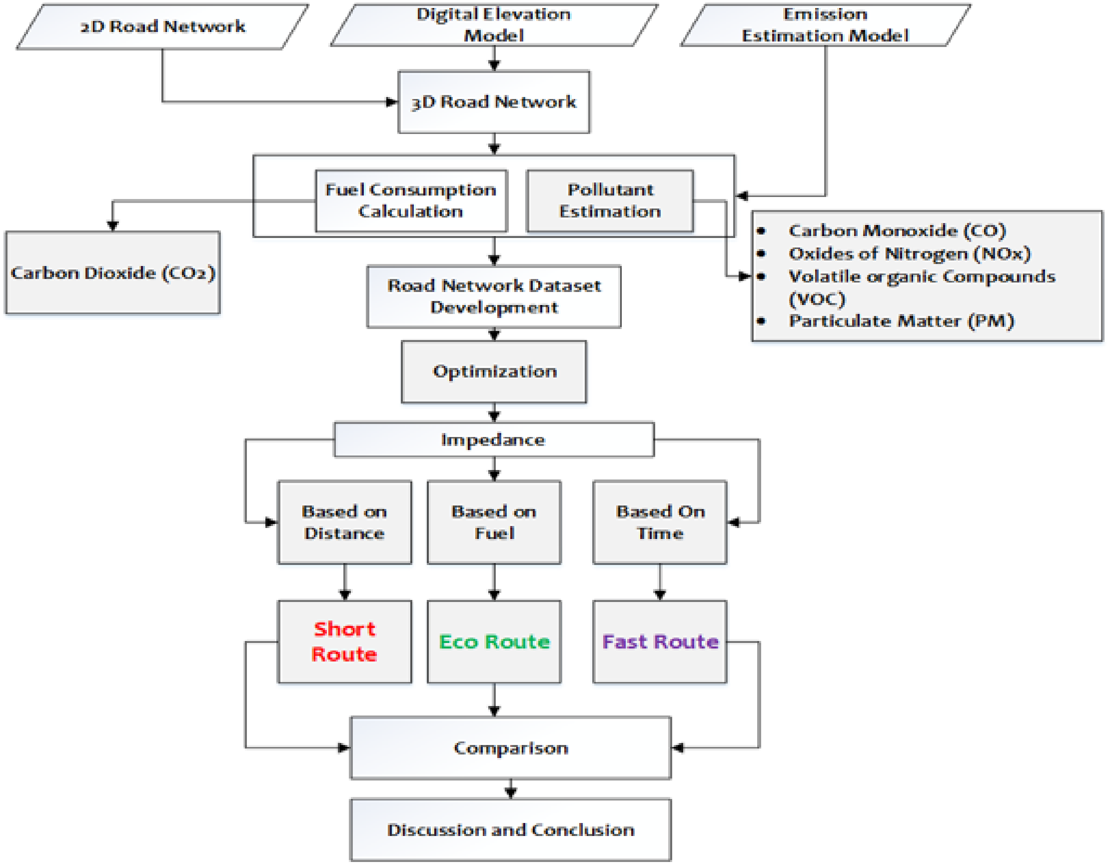

Figure 2

General Work flow of the Study

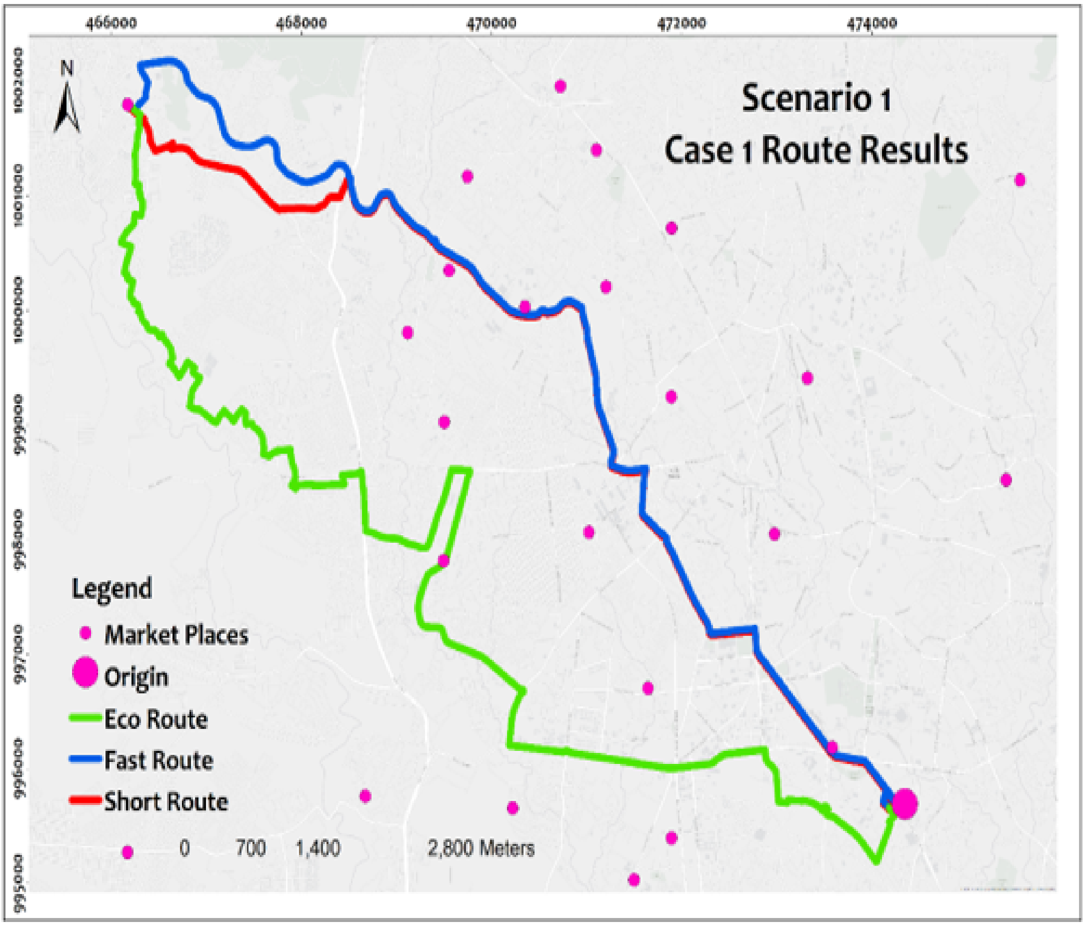

Figure 3

Scenario 1 case 1 Route Results

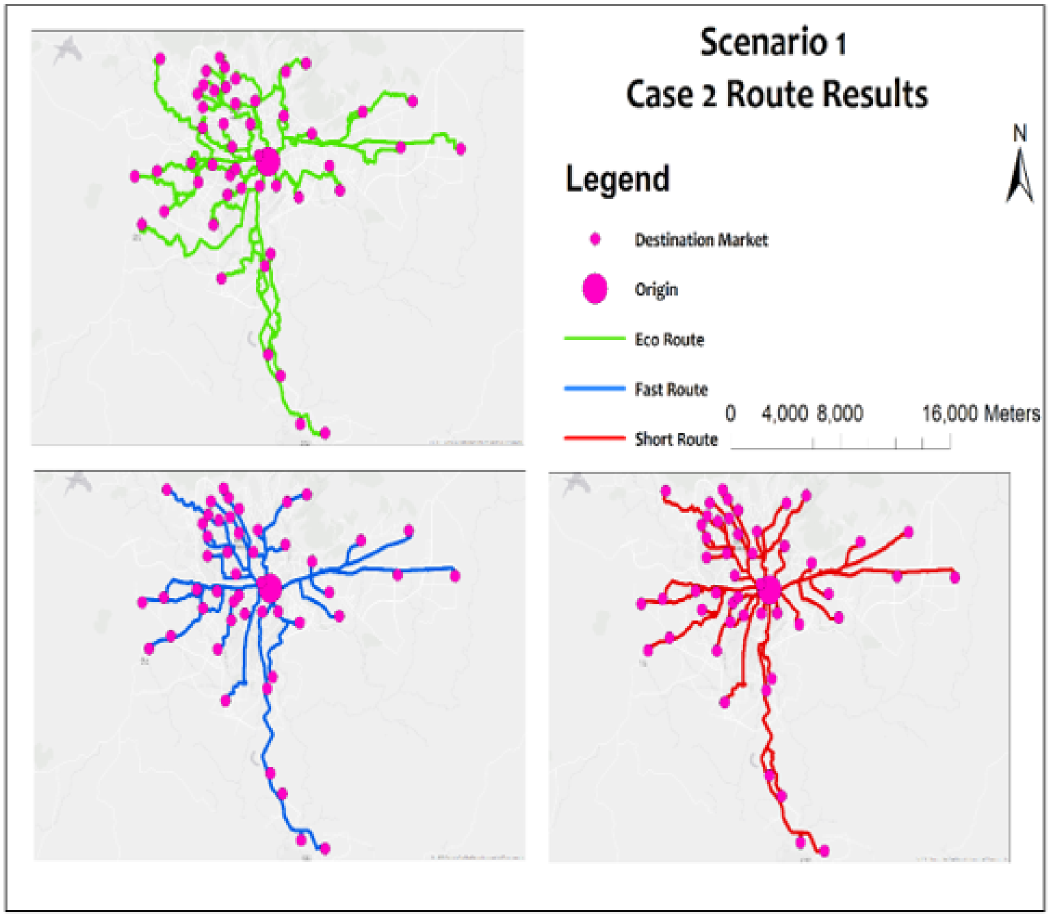

Figure 4

scenario 1 cases 2 Route Results

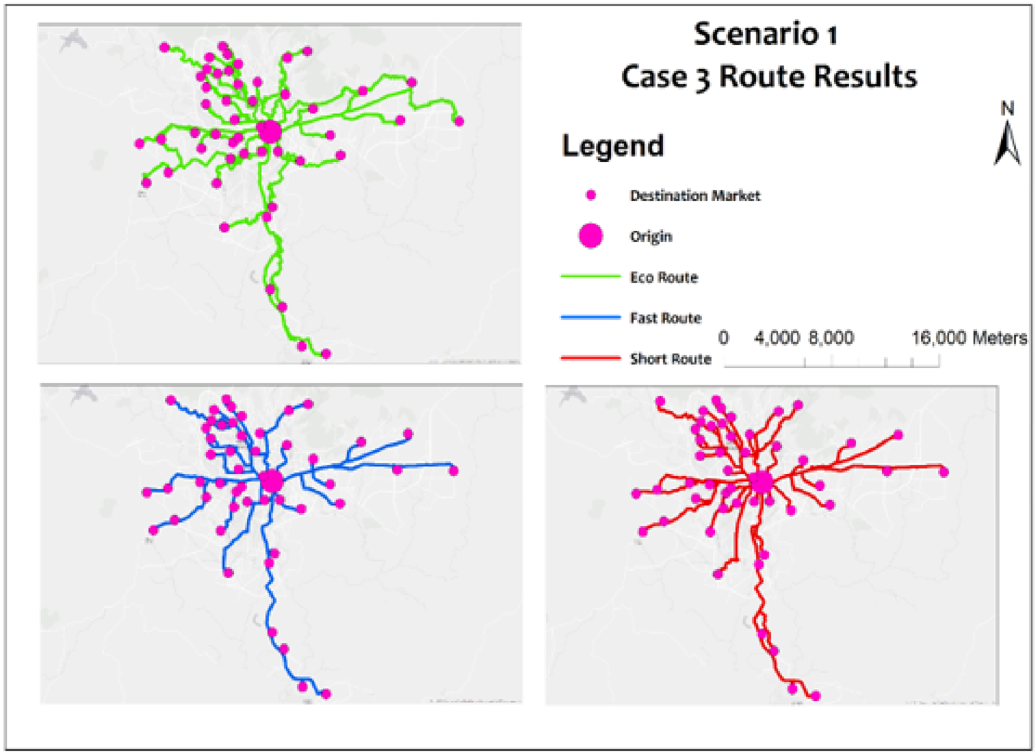

Figure 5

Scenario 1 Case 3 Route Results

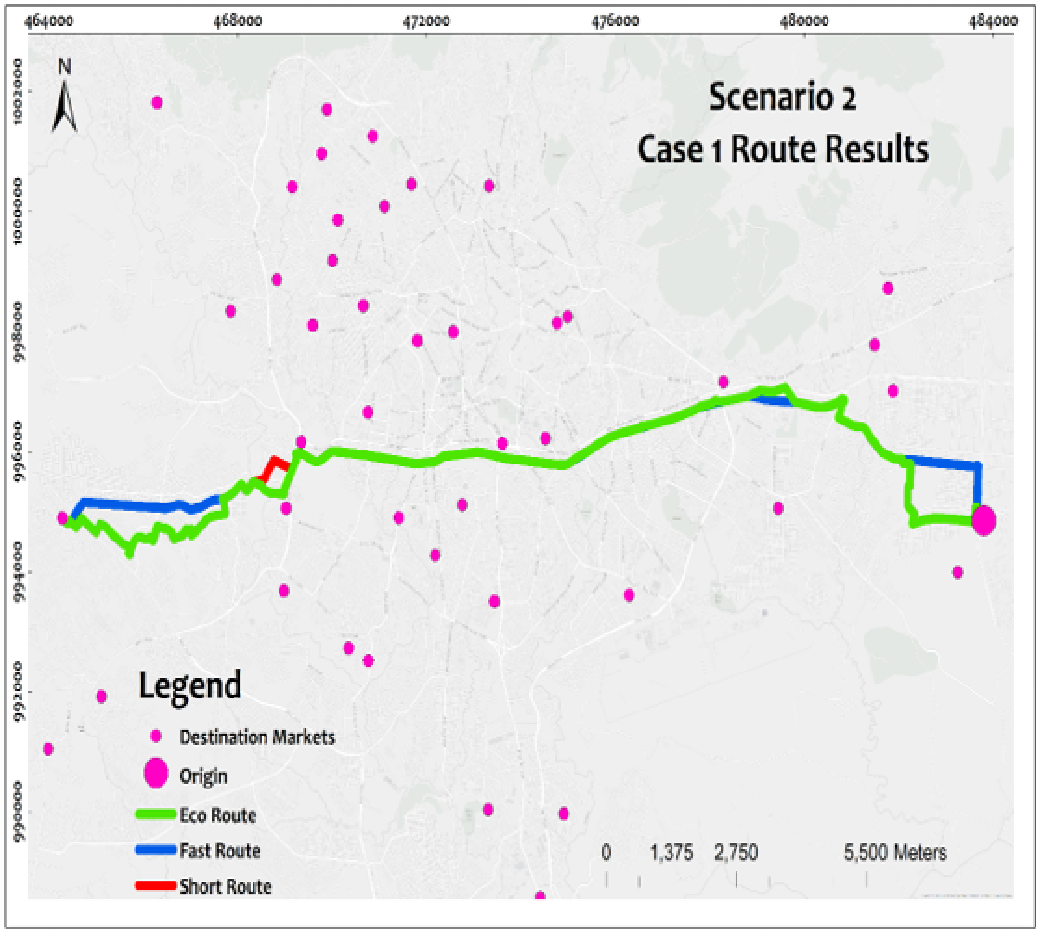

Figure 6

Scenario 2 Cases 1 Route Results

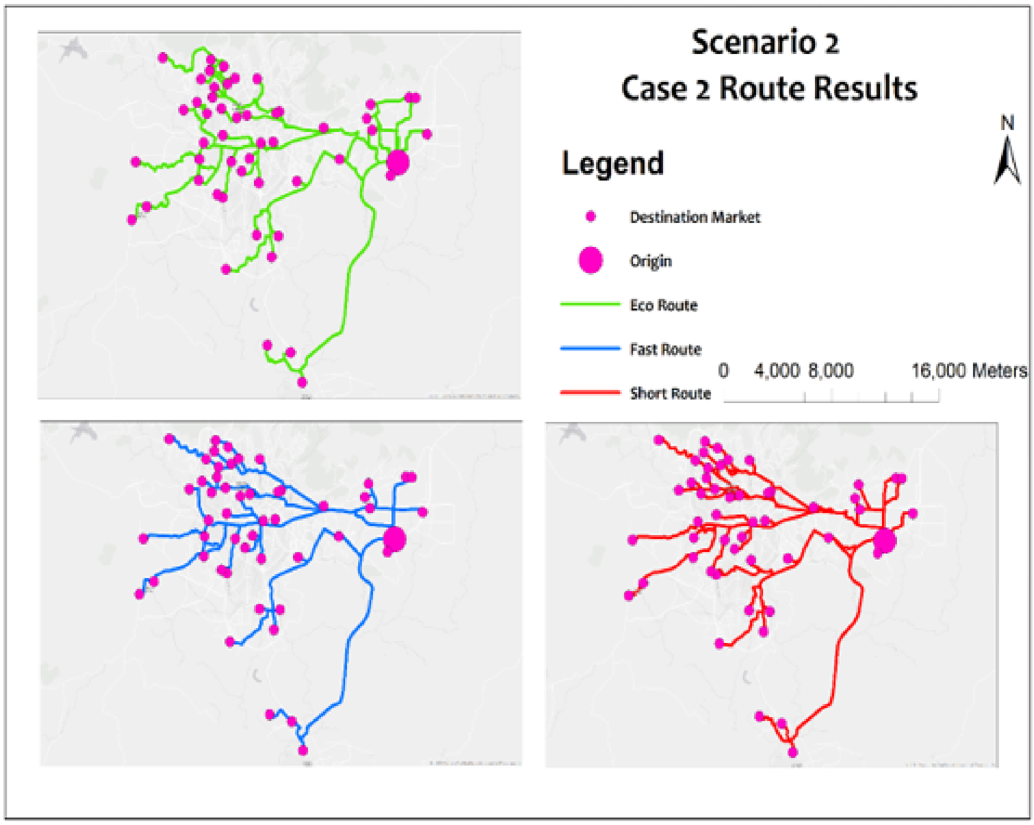

Figure 7

Scenario 2 Case2 Route Results

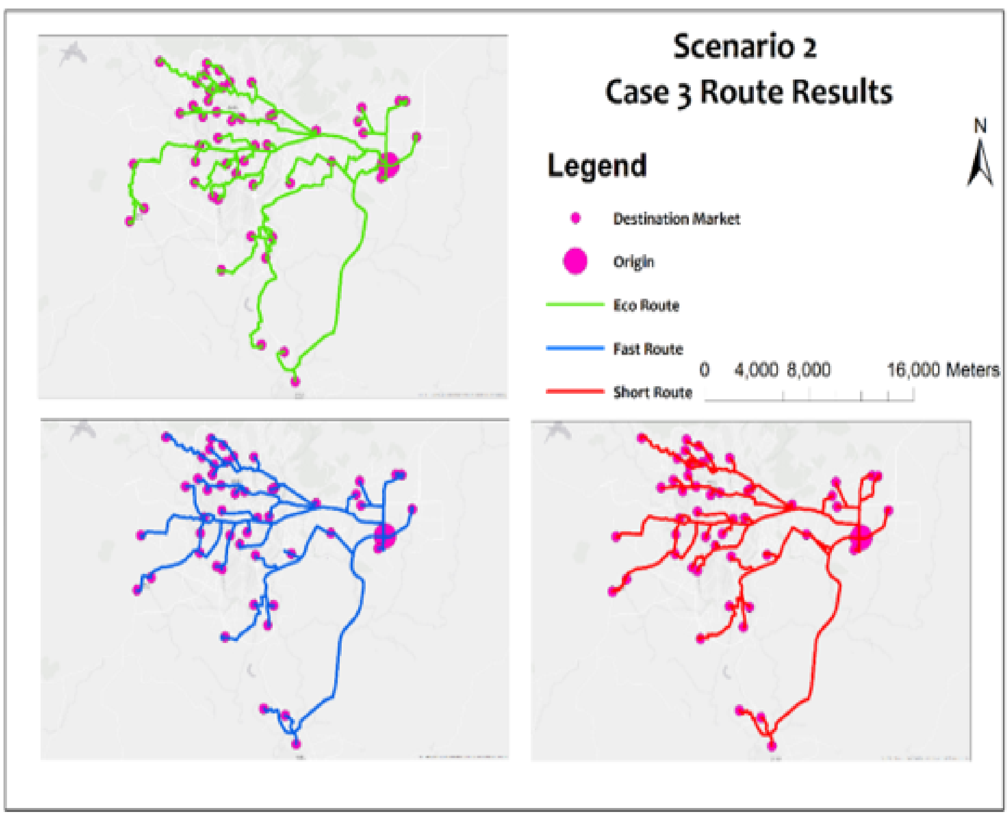

Figure 8

Scenario 2 Case 3 Route Results

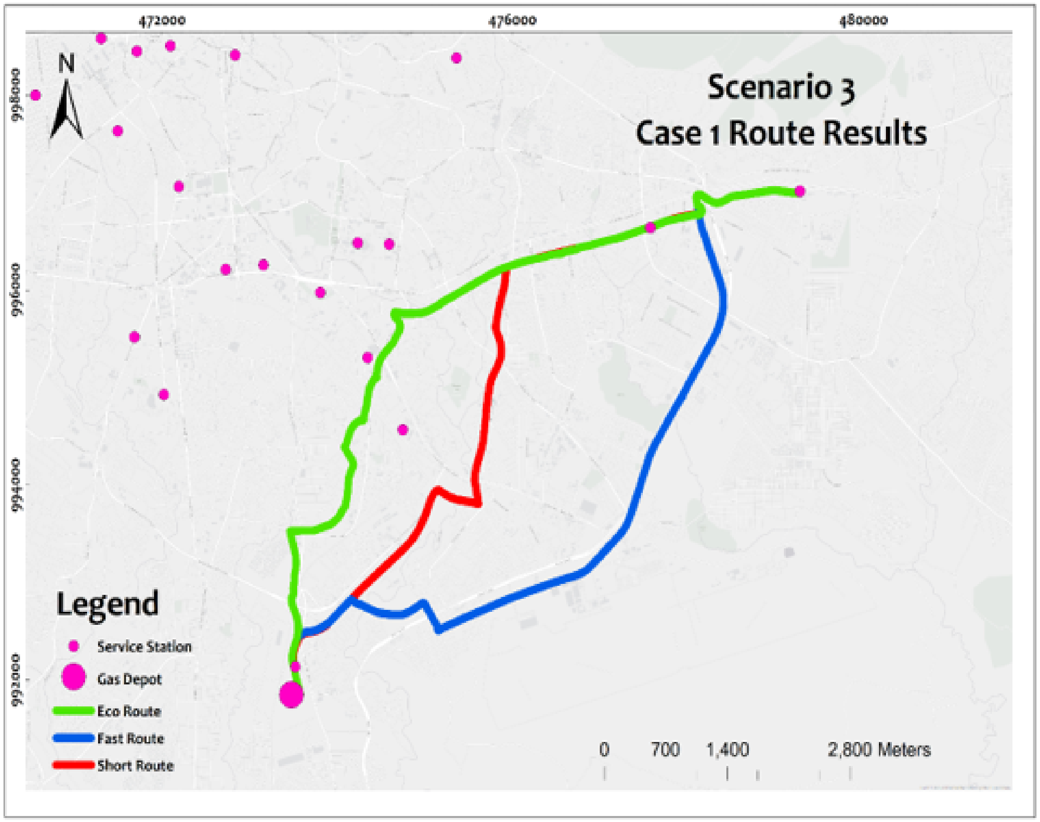

Figure 9

Scenario 3 Case 1 Route Results

Figure 10

Scenario 3 Case 2 Route Results

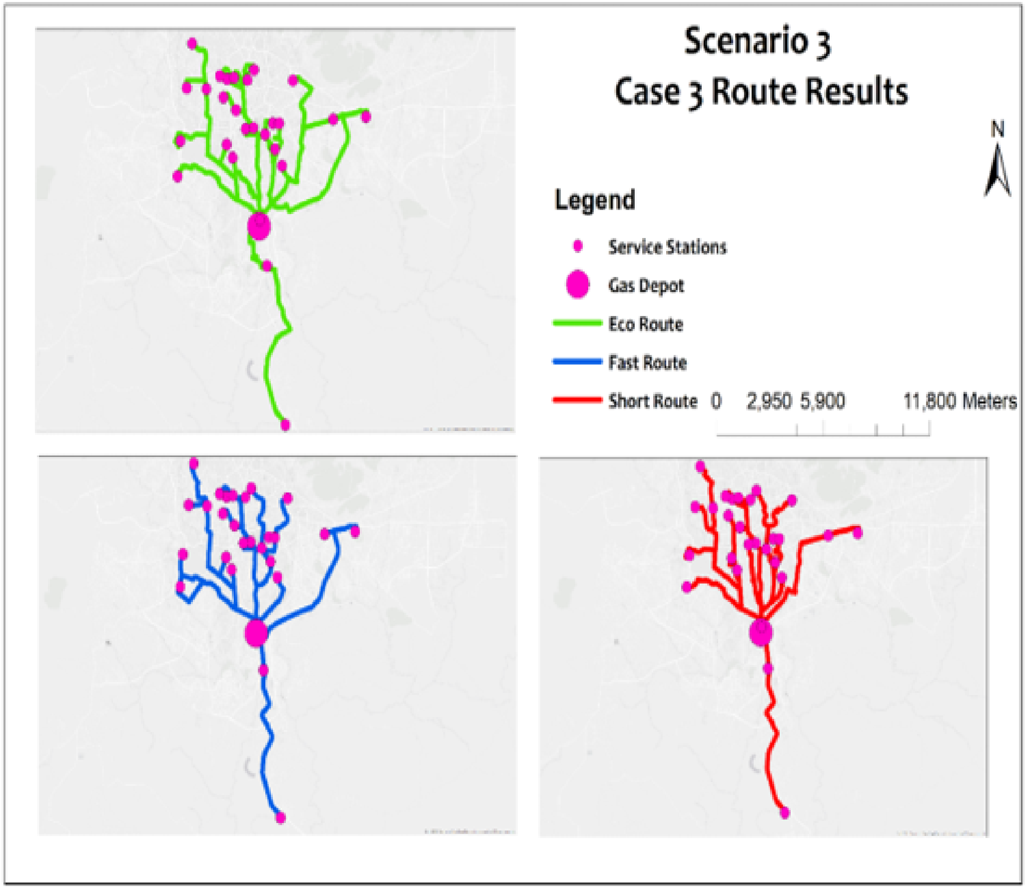

Figure 11

Scenario 3 Case 3 Route Results

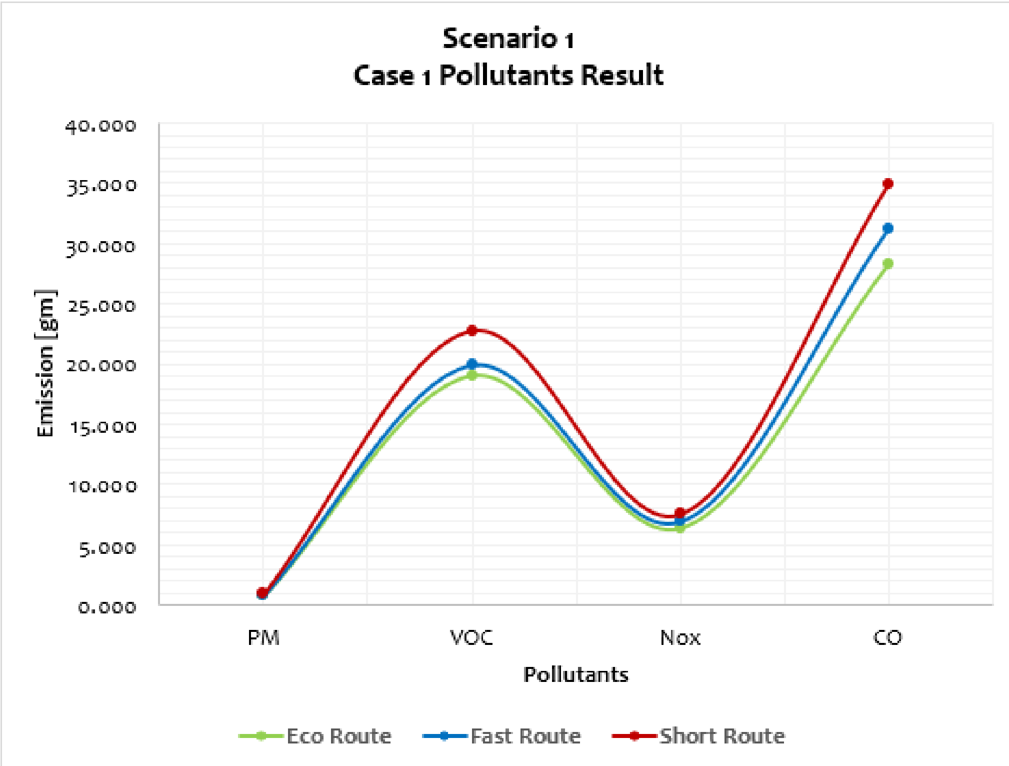

Figure 12

Scenario 1 case 1 Pollutant Result

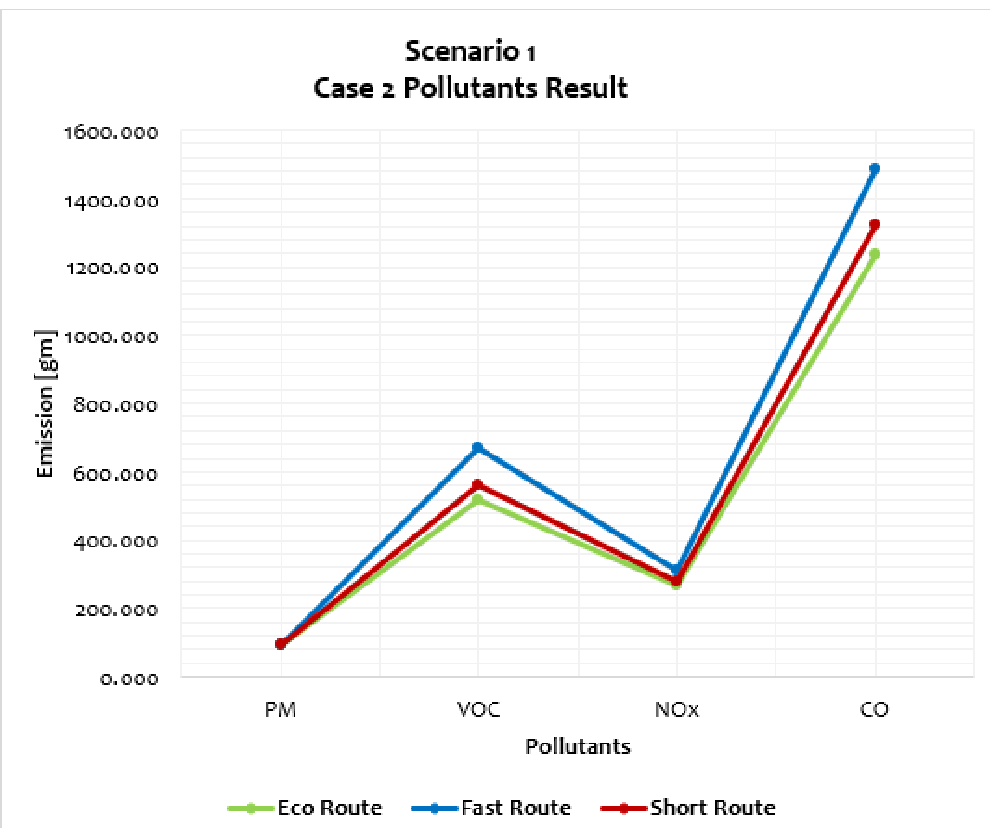

Figure 13

Scenario 1 Case 2 Pollutants Result

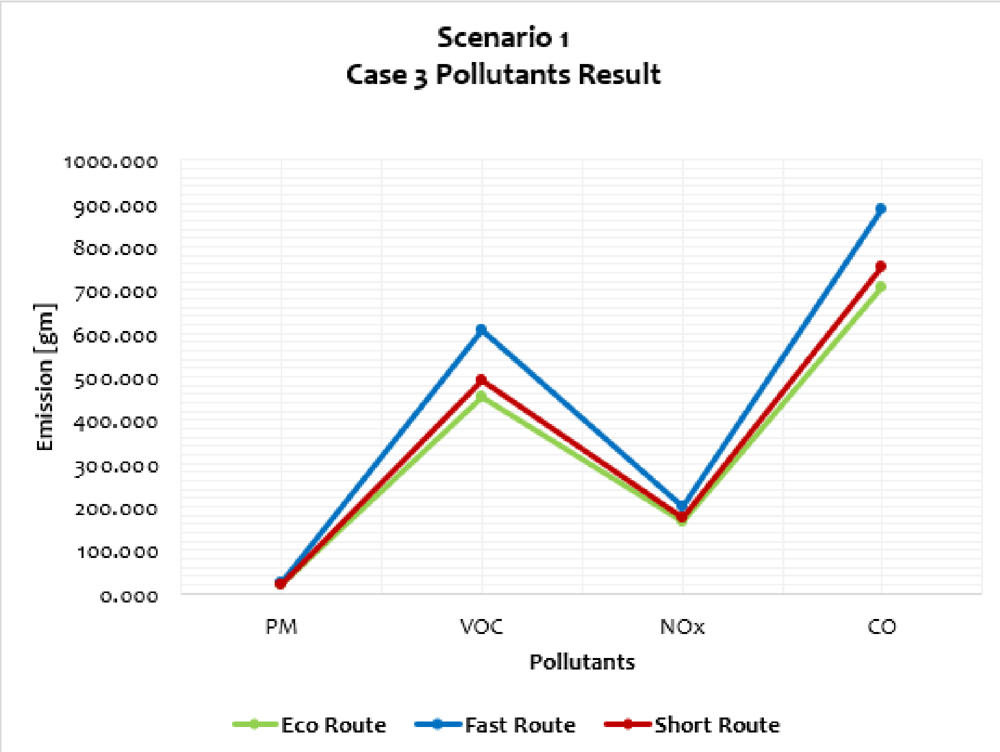

Figure 14

Scenario 1 Case 3 Pollutants Result

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