Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

School of Civil and Environmental Engineering

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

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This is to certify the Thesis Prepared by **Seifu Woldemichael** Entitled as "**Applying 3D-Eco Routing Model to Reduce Environmental Footprint of Road Transports in Addis Ababa city**." Is Submitted in Partial Fulfillment of the Requirements for The Degree of Master of Science in Geodesy and Geomatics (Specialization in Geomatics) Compiles with the Regulations of the University and Meets the Accepted Standards with its Originality and Quality.

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Declaration

I hereby declare that this thesis, entitled **"Applying 3D-Eco Routing Model to Reduce Environmental Footprint of Road Transports in Addis Ababa city."** which I submit to School of Civil and Environmental Engineering of Addis Ababa University Institute of Technology in partial fulfillment of the requirement of degree of Master of Science in Geodesy and Geomatics (Specialization in Geomatics), is my original work carried out under the supervision of Daniel Alemayehu (PhD). It has not been presented for a degree in any other universities and all sources of materials used for the thesis work have been properly acknowledged.

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This MSc Thesis has been submitted for Examination with My Approval as Thesis advisor.

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Advisor Name	**Signature**	**Date**

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I would like to praise almighty God, who helped me in all stages of this work to accomplish successfully.

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Abbreviations and Acronyms

2D – Two Dimensional

3D - Three Dimensional

CF – Correction Factor

CO_2 – Carbon dioxide

CO - Carbon Monoxide

DEM – Digital Elevation Model

EEM – Emission Estimation Model

FC – Fuel Consumption

GCF – Gradient Correction Factor

GHG - Greenhouse Gas
GIS – Geographic Information System

HDV – Heavy-Duty-Vehicles

LCF – Load Correction Factor

MEET - Methodology for calculating transportation emissions and energy consumption model

NA – Network Analyst

NOx – Oxides of Nitrogen

PM - Particulate Matter

RN – Road Network

SA – Study Area

VOC - Volatile Organic Compounds

Abstract

Road Transportation is the fastest growing major contributor to global climate change, accounting for a significant share of worldwide energy-related carbon dioxide CO_2 emissions. It is therefore, this sector needs to undertake responsibilities for its environmental impact. This paper introduces a 3D Eco -Routing Model to reduce environmental footprints of road transports in Addis Ababa city for distribution vehicles, which adds one more degree of freedom to the system and allows driving routes to be optimized for minimum fuel consumption. The applied model in this study takes into account the effects of road inclination, varying velocity, and vehicle weight to evaluate the effects of road inclination on a vehicles fuel consumption and its proportional CO_2 - Emissions, the 3D -Routing-Model is applied in three different scenarios within different vehicle weight range in the city of Addis Ababa, political capital of Africa, The obtained results indicate that eco-routes can yield significant fuel and CO_2 Reduction potentials of up to 39.818% in the tested scenarios in addition from other pollutants eco routes saves emissions up to 25.650% in the tested scenarios. These numbers designate the importance of considering the topographic characteristics and fuel consumption in routing applications to reduce vehicles emission impacts on the environment. These findings have implications for future investment and policy decisions to concern eco routing strategies.

Key words: *Climate Change, CO_2 Reduction, Eco Route, Emission*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

The Transportation System is a crucial element of urban infrastructure and also the lifeline of the city. It plays a key role in the economic growth of that region. It also displays the region's economic condition as well as planner's dedication for their region. Efficient route planning and accessibility facilitate sustainable development(Herzog and Billings 2016.) However, it also brings disadvantages congestion and pollutant emissions such as Carbon monoxide(CO),Volatile organic compounds (VOCs), Oxides of nitrogen(NO_2) and Carbon monoxide(CO_2), the greenhouse gas (GHG) which are primarily responsible for global warming.

Addis Ababa city is dominantly dependent on road transport. The road network in Addis is being developed and maintained by Addis Ababa city Road Authority (AACRA). Today the city roads length reached 3324 kms the road network coverage has reached 12.21% compared with the developed area of the city. Following the rapid population growth and increased socio-economic function of the Addis Ababa City, the demand for transport has increased with unprecedented scale. In a move to respond to the ever-increasing demand for mobility, the City administration has launched large scale transport projects and they are in their development phases ("Addis Ababa city transport management office 2019"). but this development is not sustainable and to reach climate change related objectives the road transportation sector needs to account for their environmental impact by reducing its CO2-Emissions. however, by optimizing routes for the environmental externalities of fuel consumption, significant CO2-Emissions savings can be reached (Toro et al. 2016).To facilitate the approach of reducing fuel consumption and CO2-emissions by route optimization based on information systems, GIS enables respective approaches with their functionalities to capture, store, manipulate, analyze, manage and represent spatial data. GIS is widely used in the domain of logistics and transportation (The Geography of Transport systems. 2006).Utilizing GIS functionalities, routes or entire Vehicle Routing Problems can be optimized for environmental externalities (e.g. fuel consumption and CO2-Emissions) by implementing Emission Estimation Models (EEM), which account for fuel consumption influencing factors, such as varying velocities, road inclination and others (LAT/EEA 2007).

Using GIS as a tool and open source Data, this paper focuses on the role of 3D Eco-Routing Model which accounts for road inclination by utilizing elevation for the study area in the city road network system. Furthermore, it implements an emission estimation model (EEM) for different vehicles which considers varying velocities and load factors for different road segments along a route was provided to enable the method of reducing fuel consumption and CO_2 Emissions by route optimization based on information systems.

1.2 Statement of the problem

Road transport, delivers many benefits to our society. It allows the movement of people and goods; it supports economic growth and it provides employment. However, despite these benefits the road transport sector is a major contributor to emissions of greenhouse gases (GHGs) and other pollutants like, particulate matter, volatile organic compounds, carbon monoxide and oxides of nitrogen. it harms human health, the environment or both. Such harmful impacts caused by road transport pollution cause real economic costs to the community. International Energy Agency indicated that the Transportation sector is the main source for emitting CO2. At the moment, Transportation is the fastest growing major contributor to global climate change, accounting for 23% of energy-related carbon dioxide(CO_2) emissions (Brief 2010).

Current roadway GPS navigation can determine a shortest-distance or a fastest-time route for any trip. These navigation lead to carbon and global carbon dioxide emissions linked to pollution, respiratory and irreversible climate change with increased use the effects on soil, water, and air quality will continue to worsen (Earthava 2019).

In developing countries, like Ethiopia emissions from vehicles not well understood related to its environmental impact, it makes them critical for air quality management planning. in Addis Ababa city the road transportation planning based on emission reduction from vehicles in the city could not be adopted and no roadway navigation was based on emission reduction for their environmental impacts by the transport program management office and also not studied by any researcher.

Therefore, the above problems should be clearly identified and fixed through a scientific approach to gain an eco-friendly future environment. finally, this study develops a new navigation concept called "eco-routing," which finds a route that requires the least amount of fuel and/or produces the least amount of emissions.

1.3 Objectives

1.3.1 General objective

The objective of this study is to apply a 3D-Eco Routing Model to reduce environmental footprint of road transports in Addis Ababa City, as well as to show the effects of road inclination on fuel consumption and CO_2-Emissions.

1.3.2 Specific Objective

The specific Research objectives by using Geospatial techniques are:

- To analyze Fuel consumption estimates and to evaluate probable CO_2 Emmision.
- To Evaluate the relationship between Fuel consumption and CO_2 Emission
- To Estimate Other pollutant Emmisions Such as:
    - Carbon Monoxide (CO) - Volatile Organic Compounds(VOC)
    - Oxides of Nitrogen (NOx) - Particlute Matter (PM)

1.4 Research questions

In order to assess the stated problem and objectives, the study attempted to answer the following scientific questions:

- What percentage of fuel and carbon dioxide saved over the study area scenario results?
- What correlation do fuel consumption and carbon dioxide results?
- What percentage of pollutant emissions reduced over the study area scenario results?

1.5 Significance of the study

Climate change has emerged as a very important threat to economic development, atmosphere, and public health. This study finds ways to mitigate the impact of climate change especially that linked to GHG emissions by anew navigation concept called eco route. The study result will help for long term strategic framework for scaling up “support for environmentally sustainable development, including projects to reduce carbon dioxide emissions and to address climate change”. It also emphasizes a commitment to help not only Addis Ababa city but also the nation to move their economies onto low carbon growth paths by modernizing road transport management systems. The study result finally highlights the reduction of the environmental footprint of Addis Ababa City road transport, this was used as a base for future studies. moreover, this study will help for active monitoring of GHG emissions.(Rosenqvist et al. 2007)

1.6 The scope of the study

The scope of this research is applying 3D Eco-Routing Model to reduce environmental footprint of road transports in Addis Ababa city. however the study didn’t recognize the process of how emissions formed and harm the environment; the study uses macroscopic emission estimation model (MEET Emission Estimation Model) and the factors that govern emission incorporated in this study are Gradient of streets, 3.5-32tons of vehicle weight range, vehicle speed and vehicle travel distance in a street segment of Addis Ababa city. It mainly covers mapping of Routes namely Eco, short, and fast routes and also include fuel consumption and CO_2 estimations, in addition pollutants (PM, VOC, NOx, and CO) emission estimation incorporated in Addis Ababa city.

1.7 Limitations of the Study

The present study was attempted with all possible efforts in acquiring required inputs in the form of primary and ancillary data collection, analysis and interpretation. However, the study has encountered certain limitations. The most challenging limitations of this research work are resource limitations, unavailability of high-resolution digital Elevation Model. in addition, the study encounter unavailability of direct fuel and CO_2 emissions measuring devices hinders for more accurate validation of the study results.

1.8 Structure of the thesis

This thesis is organized into five chapters as follows: The first Chapter introduces introduction, statement of the problem, objectives of the study, research questions, the scope of the study, the significance of the study and limitations of the study. Chapter two concentrates on literature review related to this study that used to develop and adopt different methodologies and grasps information about different emission models, and related works were briefly presented in general. The third chapter focuses on a description of the study area. the general methodology followed, the data and material used in the study and Chapter four explain the data analysis, the results, which presents the detailed results from collected data. In this section, the three different routes were mapped and comparison of their fuel and emission presented. Moreover, evaluating the relationship between fuel consumption and Co2 values presented and interpreted as well. also presents the discussion part, the study discusses in terms of other studies findings in general. the last chapter five presents conclusions and recommendations. In this section, key findings and critical points that need further treatment has been forwarded as a recommendation for decision-makers and for future research.

CHAPTER TWO

2. REVIEW OF LITERATURE

2.1 GPS route types

2.1.1 Short Routes

This route style is the one that people often confuse the most. Shortest, which means the route which can tick the least number of digits on your odometer. When adding up the distance the route will take to drive, ignoring how long it will take you the shortest route is that the one with the smallest amount distance traveled. Note that the shortest route can typically take you on slower "back roads" and on routes of any vital distance can seldom get you there within the least of your time.

2.1.2 Fastest Route

The fastest route is a route picked that may seemingly get you there within the least amount of time. While the shortest route is fairly objective, the fastest route is somewhat subjective. The GPS can and account for things just like the estimated travel speed on certain roads, how long it might take to travel through certain intersections, etc. GPS devices can be fairly smart and, in some cases, will recognize that in general right turns are faster than left turns since you don't have to cross against traffic. This is the route style most people pick when they use a GPS.

2.2 The Role of GIS for Transportation

Geographic Information System (GIS) represents a new paradigm for the organization of information and design of information systems, the essential aspect of which is the use of the concept of location as the basis for the structuring of information systems. The application of GIS has important to transportation due to the essentially spatially distributed nature of transportation related data, and the need for various types of network level analysis, statistical analysis, and spatial analysis and manipulation.

Most transportation effects are spatial at GIS platform, the transport network information is usually extended by integrating several sets of its attribute and spatial data through its linear referencing system. Moreover, GIS will facilitate the integration of all other socioeconomic data with transport network database for a wide variety of planning functions.

An important advantage of a GIS-based network in contrast to graph theory is the geographic elements of shape or length. Length is essential for calculating travel time (Curtin 2014). The use of GIS for network analysis is essential for improving emergency response routing based on travel time information (Alivand, Alesheikh, and Malek 2008). (Curtin 2014) thought network analysis was one of the most significant research and application areas in GI Science while (Sensing et al.

2015) mentioned network analysis is a powerful tool in the GIS environment for solving the optimal path in a network.

2.3 Network Analysis

Background familiarity of a network can be advantageous to the understanding of transportation network analysis. A network is essentially a set of lines known as segments or edges connected or joined by a set of vertices known as nodes or junctions. A GIS stores these edge and junction options with their attributes. Spatio-temporal networks are networking whose topology and parameters change with time. These networks are significant to applications such as emergency traffic planning and route finding (Winn and Winn 2014). The routing of vehicles in the domain of road transportation is a well-examined research domain based on the work by Dijkstra and his well-known shortest path. Originated in the domain of operations research and graph-theory, routing optimization has been adapted and continuously extended into the domain of logistics where it represents one of its essential tasks (The Geography of Transport Systems. 2006).

2.4 Shortest Path Analysis

The shortest path problem is to find a path with minimum travel cost from one or more origins to one or more destinations through a network (Panahi and Delavar 2008). Shortest path analysis is important because of its extensive range of applications in transportation. The shortest path can be computed either for given start time or to find the start time and the path that leads to least travel time journeys. The classic shortest path downside and finding the simplest route for vehicle routing in static road networks supported Dijkstra's algorithmic program has been examined extensively within the literature over the years.. (Winn and Winn 2014) claimed that developing efficient algorithms for computing shortest paths in a time-varying spatial network can be challenging.

2.5 Dijkstra's Algorithm

Dijkstra's algorithm is the most frequently used route-finding algorithm for solving the shortest path (Sensing et al. 2015). Dijkstra's algorithm is occasionally called the single-source shortest path because it solves the single-source shortest-path problem on a weighted, directed graph (**G = V, E**) where V is a set whose parts area unit referred to as vertices (nodes, junctions, or intersections) and E may be a set of ordered pairs of vertices referred to as directed edges (arcs or road segments). To find the shortest path from a source **s** vertex or location to a destination location **d**, Dijkstra's algorithm maintains a set **S** of vertices whose final shortest-path weights from the sources have already been determined. Knowing that w is that the edge weight, the edge is an ordered pair (**u, v**) and assuming **w (u, v**) **≥ 0** for each edge **(u, v) ϵ E**, the rule repeatedly selects the vertex **u ϵ V – S** with the minimum shortest-path estimate, adds **u to S** and relaxes all edges departure **u** . The GIS software that was used to perform the route analysis for this study is the Esri ArcGIS Network Analyst. The route solver in GIS Network Analyst to determine the shortest path is based on Dijkstra's algorithm (Karadimas, Kolokathi, and Loumos 2007).

2.6 Eco -Routing

Eco-routing is that the identification of the foremost energy-efficient route for a vehicle to travel between two points and is obtainable as a way with in which drivers can reduce fuel consumption and consequently reduce the carbon footprint of their journeys. The Eco-Routing Navigation provides a route by determining the most fuel-efficient route for each of the pre-planned trips with consideration of roadway conditions. To identify the energy and environmental impacts of eco-routing systems, fuel consumption and emissions ought to be measured or expected. There are various models to predict fuel consumption and emission level.(Minett et al. 2011).

2.7 Environmental footprints of vehicles

The growth of travelers and freight mobility has prolonged the role of transportation as a supply of emission of pollutants and their varied impacts on the surroundings. These impacts fall within three categories:

- **Direct impacts:** The direct consequence of transport actions on the environment where the cause and effect relationship are generally clear and well understood. For example, noise and carbon monoxide emissions are acknowledged to have direct harmful effects.
- **Indirect impacts:** The secondary (or tertiary) effects of transport activities on environmental systems. They are usually of upper consequence than direct impacts, but the involved relationships are often misinterpreted and more difficult to establish. For example, particulates which are frequently the result of incomplete combustion in an inner combustion engine are indirectly linked with respiratory and cardiovascular problems since they contribute among other factors to such conditions.
- **Cumulative impacts:** The preservative, multiplicative or synergetic consequences of transport activities. They reflect the varied effects of direct and indirect impacts on an ecosystem, which are often unpredictable. Climate change, with advanced causes and consequences, is that the accumulative impact of many natural and anthropogenic factors, within which transportation plays a task. The share of transportation in global CO2 emissions is increasing. 22% of global CO2 emissions are attributed to the transport sector.

2.8 Pollutants emitted by vehicles

Road vehicles emit a variety of greenhouse gases and air pollutants. As well as actuality emitted from vehicle exhausts, certain pollutants are released from brake wear and from the evaporation of fuel. A number of different air pollutants and GHGs are emitted by road vehicles. These are

2.8.1 Carbon dioxide (CO_2)

which is the main product of fuel combustion in vehicle engines, along with water. CO2 is the most significant GHG influencing climate change, posing a threat to public health and the environment.

2.8.2 Hydrocarbons (HCs)

which are produced from either incomplete or partial combustion and which are toxic to human health. HCs, and particularly the volatile organic compounds **(VOCs),** contribute to the formation of ground-level ozone and photochemical smog in the atmosphere. Ozone irritates the eyes, damages the lungs and aggravates respiratory problems.

2.8.3 Carbon monoxide (CO)

a product of incomplete combustion, which occurs when the carbon in the fuel is only partially oxidized, forming CO and not CO2. It is colorless and odorless but highly toxic. Direct exposure to CO reduces the flow of oxygen in the bloodstream and is particularly dangerous to people with heart disease. Like HCs, CO also contributes to the formation of ground-level ozone and smog.

2.8.4 Particulate matter (PM)

which is a product of incomplete combustion and a complex mixture of both primary and secondary PM. 'Primary' PM is that the fraction of PM that’s emitted directly into the atmosphere, whereas 'secondary' PM forms with in the atmosphere following the discharge of precursor gases (mainly Sulphur dioxide (SO2), nitrogen oxides (NOX), ammonia (NH3) and some VOCs). In terms of its potential to harm human health, PM is one of the most important pollutants, as it penetrates into sensitive regions of the respiratory system and can cause or aggravate cardiovascular and lung diseases and cancers.

2.8.5 Nitrogen oxides (NOx)

Nitrogen emissions from motor vehicles, which constitute a group of different chemicals that are all formed by the reaction of nitrogen the most abundant gas in the air with oxygen. NOx comprises colorless nitric oxide (NO) and the reddish-brown, very toxic and reactive nitrogen dioxide (NO2). NOx emissions also lead to the subsequent formation of 'secondary' PM and ground-level ozone in the atmosphere, and cause harm to the environment by contributing to the acidification and eutrophication of waters and soils. ("Explaining road transport emissions 2019".)

2.9 Transportation Emissions Related Models

Models used to estimate the emissions produced from the transportation system can be classified into:

- Static models
- Dynamic models.

Static Models rely principally on datum associated with transport systems specification, type, and amount of fossil-fuel consumed by these systems, whereas dynamic models rely principally on the elaborated specifications of the transport fleet, its instantaneous speed, and also the road class. Dynamic models may be pure emission model or it can use the transportation microcomputer simulation models (PARAMICS, VISSIM) to get the operation characteristic of the transport systems like the speed distributions road way characteristics, vehicle type, traffic volume, and urban traffic control systems.

2.9.1 Static Models

Static emissions models also are referred to as top-down or macro-scale models. It tends to develop a global emission model regardless of the detailed activities of the emission source. Static models develop emission and fuel consumption factors supported macroscopic activity, like transport productivity or Vehicle Travel Kilometers (VTK). This type of models is mostly utilized in case of modeling emissions of transportation systems on a large-scale strategic level, like national road network or regional scale. Static emission models may conjointly turn out inputs for associate air quality model applied in associate urban region, but additional information would be required to increase accuracy (Borge et al. 2009). This approach doesn't include specific information that would allow planners to compare the effects of different scenarios (Greenhouse, Emissions, and Assessment 2018). Moreover, a bonus of this kind of modeling is that it simply is often utilized in national emission inventories. Static models are classified to Average speed models and Aggregate emission issue models. An advantage of these models is that they are easy to use, and there is a reasonably close correspondence between the required model inputs and the data available to users. The Aggregate emission issue models operate with one emission issue being used on a large spatial scale to represent a very broad class of vehicle and a general driving condition (urban roads, rural roads, and Highway). It neglects the technology used in vehicle and vehicle specifications. Aggregated emission issue models generate emission factors supported on Vehicle Traveled Kilometer (VTK), Transport productivity or amount of fuel consumed. Therefore, this approach cannot be used to determine emissions for the situation which are not explicitly defined.

2.9.2 Dynamic Models

It is also called Bottom-up or micro-scale models. An advantage of dynamic models is, it permits transportation planners to investigate the results of various designing situations within the modeling space. On the opposite hand, it is onerous to use the technique of dynamic models in national emission inventories. The reason is that this would require an immense amount of data which can be hardly found and be reconciled for a complete country (No, EEA Report 2016). Dynamic models can be classified according to the type of parameters used in the modeling process. Thus, it are often categorized to *Traffic situation models* and Instantaneous models. The traffic situation models incorporate the effects of traffic dynamics on an aggregated link level and distinguish different road types; it incorporates both speed and traffic situation into emission estimation. Traffic situations are outlined in line with varieties; and traffic conditions (e.g. urban free flow, urban congested, stop-and-go). Good samples of this kind embrace HBEFA and ARTEMIS models. The speed used for calculating emission in the latest versions of COPERT.A disadvantage of the traffic situation of models is that it needs detailed statistics about speed and corresponding traffic situation. *Instantaneous models* are proposed to offer a more detailed explanation of vehicle emission behavior by relating emission rates to vehicle operation during a series of short time periods (Wang and Mcglinchy 2009). These models use primarily a traffic simulation model, and an emission model. The traffic simulation model, during this this case, is accountable to deliver the vehicle operation data throughout short time periods. The emission models within the Instantaneous models implement the power-based approach by using the engine power to determine the rate of emissions. An emission factor is assigned for each combination of instantaneous speed and acceleration rate, typically at a one-second interval. Good examples of this kind of transportation emission models are The PHEM (Passenger car and Heavy-duty Emission Model) and MOVES (Motor Vehicle Emissions Simulator) model. This category of traffic emission models needs an amount of detailed data about vehicle operation, the geometry of the road and atmospheric temperature. This data is so far not available and expensive to collect.

2.10 The Role of Digital Elevation Model for Transportation

One powerful technique for generating digital elevation models is interferometric synthetic aperture radar measuring instrument wherever 2 passes of a radar satellite (such as RADARSAT-1 or Terra SAR-X or Cosmo Sky Med), or a single pass if the satellite is equipped with two antennas (like the SRTM instrumentation), collect sufficient data to generate a digital elevation map tens of kilometers on a side with a resolution of around ten meters. Other kinds of stereoscopic pairs will be used the digital image correlation technique, wherever two optical images are acquired with totally different angles taken from an equivalent pass of an airplane or an Earth Observation Satellite (such because the HRS instrument of SPOT5 or the VNIR band of ASTER). The SPOT one satellite (1986) provided the primary usable elevation data for a sizeable portion of the planet's landmass, using two-pass stereoscopic correlation. Later, more data were provided by the European Remote-Sensing Satellite (ERS, 1991) using the same method, the Shuttle Radar Topography Mission (SRTM, 2000) using single-pass SAR and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER, 2000) instrumentation on the Terra satellite using double-pass stereo pairs. The HRS instrument on SPOT five has nonheritable over a hundred million sq. kilometers of stereo pairs.

DEMs can be used to derive topographic attributes, geomorphometric parameters, morphometric variables or terrain information in general. In combination with alternative spatial data, digital elevation models are an important info for topography-related analyses or 3D video animations (e.g. fly-throughs). Different georeferenced 3D products will be derived and complemented by a coordinate system and conferred during a 2D-map projection or as a 3D perspective view.(Digital Elevation Models & their Applications in Geological Studies n.d.)

DEMs are increasingly becoming available in the market today. Many countries already offer elevation grids at course resolutions (> 250 m) and at a commercial price. Free source of elevation data with the world coverage is the global digital elevation map with a horizontal grid spacing of thirty arc seconds, which is approximately 1 x 1 km. It is derived from several raster and vector sources of national topographic information and is available via the website of the US Geological Survey.(Digital Elevation Models & their Applications in Geological Studies n.d.)

A. SRTM DEM

SRTM DEMs are 16bit signed integers, referenced horizontally to the World Geodetic System 1984 (WGS84) and vertically to the Earth Gravitational Model 1996 (EGM96). It is noteworthy that the C-band SAR was employed by the SRTM sensor to measure the height of ground and non-ground features across the Earth's surface. Since C-band wave cannot penetrate dense vegetation or buildings, SRTM DEMs represent elevations between the bare ground and canopy top. The accuracy of the 30 m SRTM DEM is specified as < 16 m absolute vertical elevation error and < 10 m relative vertical elevation error at the 90% confidence level (Farret al., 2007).

B. ASTER DEM

The ASTER DEM version 2 is a global one arc-second elevation dataset that was released in October 2011 by METI, Japan and NASA. The ASTER DEM was generated using optical imagery of 15 m resolution collected in space with the METI ASTER sensor mounted on NASA's Terra satellite (Abrams et al., 2010). Construction of the ASTER DEM depends on the correlation of stereoscopic image pairs. Compared to ASTER DEM version 1, released in June 2009, the version 2 DEM improved spatial resolution, increased horizontal and vertical accuracy, and provided better water body coverage and detection by using 260,000 additional stereo-pairs (Tachikawa et al., 2011). The elevations of ASTER DEMs are 16bit signed integers, referenced horizontally to WGS84 and vertically to EGM96.

C. ALOS DEM

The largest satellite developed in Japan, was launched with HE Advanced Land Observing Satellite (ALOS), which is an H-IIA rocket from the Japanese Space Exploration Agency’s (JAXA) Tanegashima Space Center on January 24, 2006. ALOS carries 3 remote-sensing instruments: the along-track 2.5-m resolution Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM), the 10-m resolution Advanced Visible and also Near-Infrared Radiometer type 2 (AVNIR-2), and the variable resolution polarimetric Phased Array L-band Synthetic Aperture Radar (PALSAR)).(Rosenqvist et al. 2007)

Different authors Namely (Scora, Boriboonsomsin, and Barth 2015),(Tavares et al. 2009),(M. Schröder and Cabral 2019) used ASTER and SRTM DEM to generate Road gradients for transportation routing applications .However (Lightbown, Patsy M., Spada 2013) suggests DEM generated by the Laser Scanner and the UAV are recommended to detailed scales.

2.11 Related Works

The optimization of routes for environmental externalities has been investigated by numerous authors.

In (Andersen et al. 2013) the author tried to assigns eco-weights to a road network based on GPS and fuel consumption data collected from vehicles to enable eco- routing. Given an arbitrary source-destination pair in Denmark, in the study the author neglected gradient effects on fuel consumption, Ecotour returns the shortest route, the fastest route, and the eco-route, along with statistics for the three routes.

In (Pamu et al. 2016) the authors tried to assigned weights of different influencing aspects, such as noise, different pollutants, land use, road inclination, and average speed and applied a multi-criteria method of Weighted Linear Combination. The respective weights are assigned to the road segments of the road network under study to define green routes for city logistics. However, both approaches are not able to estimate fuel consumption and CO2-Emission estimates, allowing only the definition of routes between two points and neglecting the gradient effects on fuel consumption through varying velocities.

In (M. F. Schröder n.d.)the authors tried specifically examined the routing of heavy-duty vehicles (HDV), emphasizing the effects of road inclination in hilly areas and other factors by introducing a Microscale Fuel and Emissions Model for a specific HDV.

In (Zsigraiova, Semiao, and Beijoco 2013) the authors tried to propose a methodology to reduce operating costs and emissions in the collection and transportation routes of waste, in which influencing factors such as varying vehicle speeds and weights are considered by applying an EEM. Nevertheless, instead of optimizing routes for minimized fuel consumption and emissions, the authors merely compared the results in terms of emitted pollutants for the obtained results of routes for the optimization criterions of traveled time (i.e., fastest route) and distance (i.e., shortest route). The effects of road inclination on fuel consumption are neglected in this approach as well.

In (M. Schröder and Cabral 2019) The paper introduced a Geographic Information System (GIS) based 3D-Routing-Model, which incorporates models to estimate vehicle fuel consumption while taking effects, such as road inclination and varying velocities into account. The planned model utilizes a Digital Elevation Model (DEM) to improve a road network with elevation data. The 3D-Routing-Model is applied in different distribution scenarios within the framework of an artificial company in the Lisbon Metropolitan Area, Portugal to evaluate the effects of road inclination on vehicles fuel consumption and its proportional CO2-Emissions

Previous research presented a variety of GIS-based approaches to optimize routes for environmental externalities as fuel consumption and CO2-Emissions. How-ever in Ethiopia transportation sector there are no eco routes identified or managed for the drivers. Developing new tools, methods and practices are becoming a pre-request to reduce emission levels from transportation. This study considers the above issues and solves problems to find environmentally friendly routes from developed road network in the city by considering the effects of road inclination, Vehicle load, and varying velocities.

CHAPTER THREE

3. METHODOLOGY

3.1 Study area description

Addis Ababa is the largest and the capital city of Ethiopia. it is where the African union is headquartered and where its predecessor the organization of African unity (OAU) was based. It also hosts the headquarters of the united nations economic commission for Africa (ECA), as well as various other continental and international organizations. Addis Ababa is therefore often referred to as "the political capital of Africa" for its historical, diplomatic and political significance for the continent. the city lies a few miles west of the east African rift which splits Ethiopia into two, through the Nubian plate and the Somali plate.

3.1.1 Location

The spatial location of the study area has been shown below using a map.

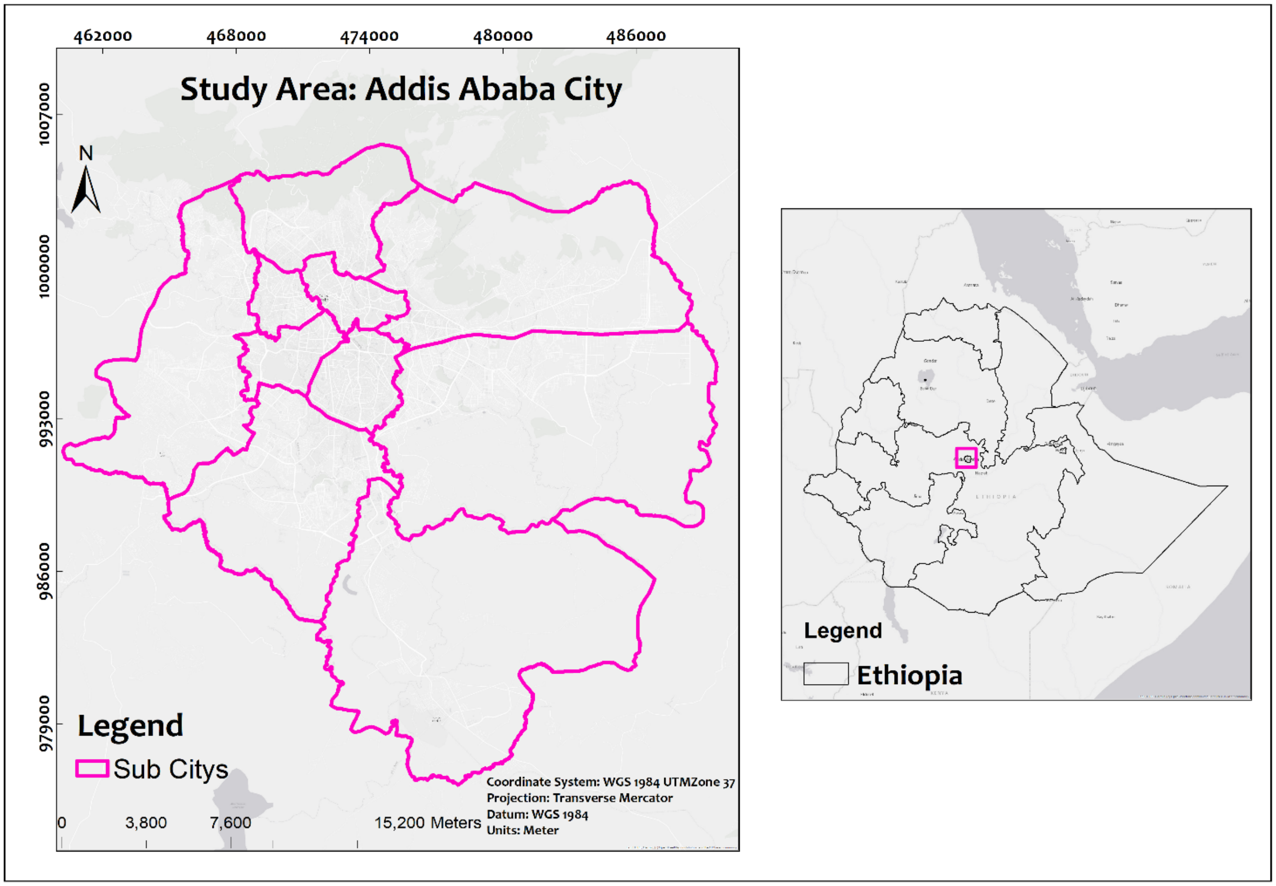

Figure 3.1: Map of the study area

Table 3.1: Location Description

Addis Ababa City	
Coordinates	9°1′48″N 38°44′24″E
Country	Ethiopia
Area(total):	519.482 km^2
Population (Total):	3,384,569 (2007 Census)
Time zone	UTC+3 (East Africa Time)

3.1.2 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 up to June 30, 2011, E.C registration in the city. (“Addis Ababa city Transport Authority 2019”).

3.1.3 Climate

Addis Ababa has a subtropical highland climate. The city has a complex mix of highland climate zones. depending on elevation and prevailing wind patterns. The high elevation moderates’ temperatures year-round, and the city's position near the equator means that temperatures are very constant from month to month. As such, the climate would be maritime if its elevation was not taken into account, as no month is above 20 °C in mean temperatures. (“climate change knowledge portal 2019”)

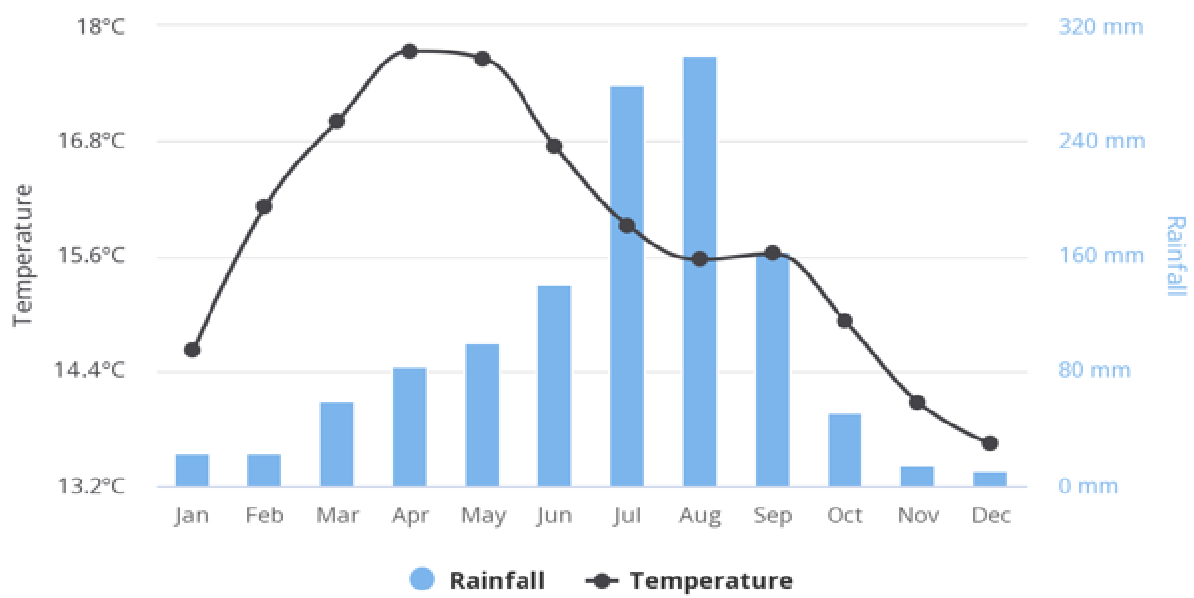

Figure 3.2:Average Monthly temperature and rainfall of Addis Ababa City (1991 -2016) [Source: https://climateknowledgeportal.worldbank.org/]

3.1.4 Topography

The city lies at the foot of Mount Entoto and forms part of the watershed for the Awash. From its lowest point, around Bole International Airport, at 2,326 meters above sea level in the southern periphery, Addis Ababa rises to over 3,000 meters in the Entoto Mountains to the north.

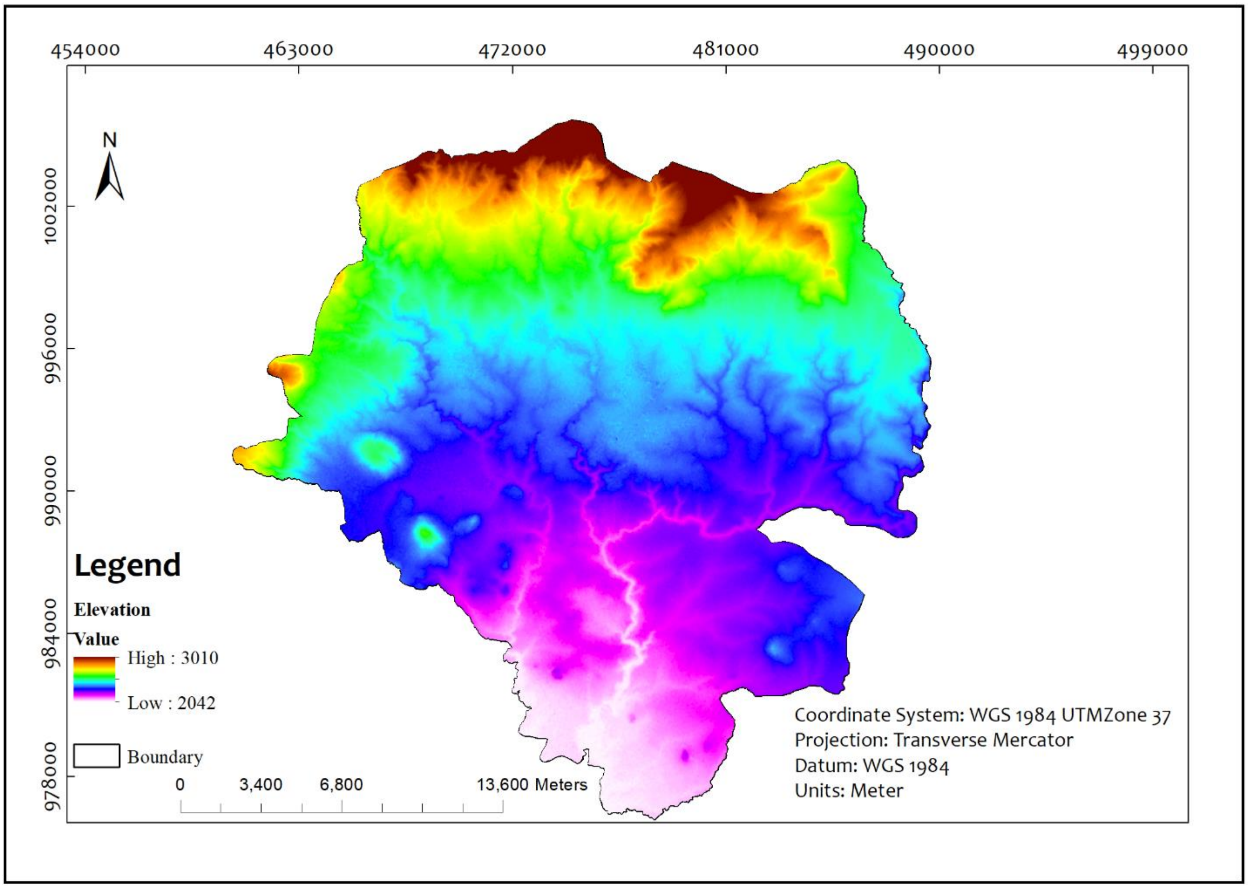

Figure 3.3: Elevation map of Addis Ababa City

3.2 Data and its sources of the study

3.2.1 Primary Data

The overall work of scientific research result and findings depends on the quality of the input data. the primary datasets that used to compile this research work were mostly road network, elevation data, GPS coordinate, google earth images and ortho photo.

3.2.1.1 Road Network

The road network consists of a system of interconnected paved/unpaved carriageways which are designed to carry buses, cars and goods vehicles; the road network generally forms the most basic level of transport infrastructure within urban areas, the function of a road network is to facilitate movement from one area to another. as such, it has an important role to play in the urban environment to facilitate mobility. for this study the road networks are digitized from google image 2019 of 20 m spatial resolution based on vehicle driving direction.

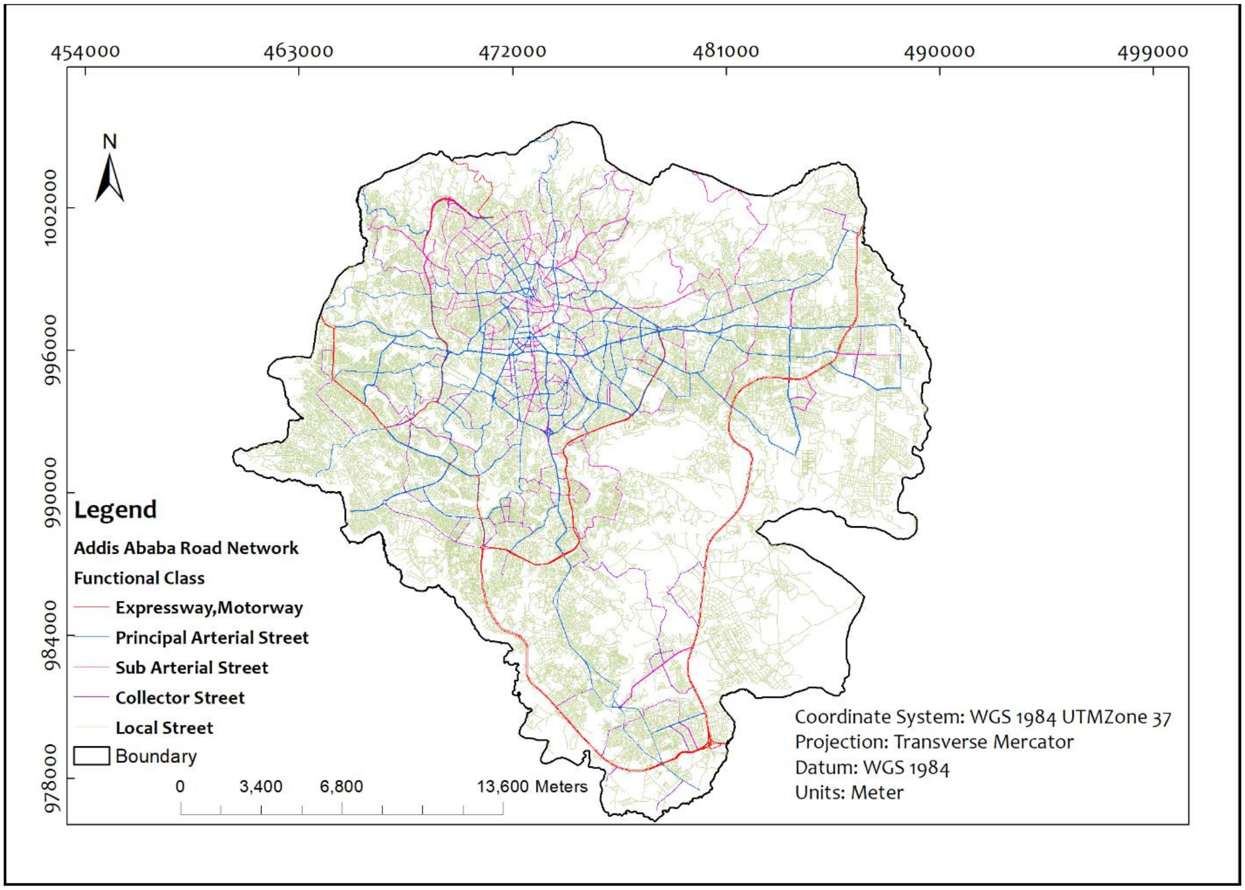

Figure 3.4:Road Network in Addis Ababa City

3.2.1.2 ALOS PALSAR DEM

Advanced Land Observing Satellite -The Phased Array Type L-band Synthetic Aperture Radar (PALSAR) is an active microwave sensor using L-band frequency to achieve cloud-free and day-and-night land observation. It provides higher performance than the JERS-1's synthetic aperture radar (SAR). Fine resolution in a conventional mode, but PALSAR will have another advantageous observation mode. ScanSAR, which will enable us to acquire a 250 to 350km width of SAR images (depending on the number of scans) at the expense of spatial resolution. This swath is three to five times wider than conventional SAR images. The development of the PALSAR is a joint project between JAXA and Japan. for this study digital elevation 12.5m resolution data was downloaded. ("About ALOS - PALSAR 2019".)

3.2.1.3 GPS Coordinates

GPS coordinates are a unique identifier of a precise geographic location on the earth, usually expressed in alphanumeric characters. Coordinates, are points of intersection in a grid system.

GPS(global positioning system) coordinates are usually expressed as the combination of latitude and longitude. Latitude is a measure of degrees of distance from the equator, which is 0 degrees. The north and south poles are at 90 degrees in either direction. The prime meridian is 0 degrees longitude and the locations are measured according to 90 degrees east or west from that point. For this study GPS coordinates of vehicles origin and destinations was collected using hand held GPS of 3m horizontal accuracy level.

3.2.1.4 Google Earth Image

Google Earth is a geo-browser that accesses satellite and aerial imagery, ocean bathymetry, and other geographic data over the internet to represent the Earth as a three-dimensional globe. Geo-browsers are alternatively known as virtual globes or Earth browsers. Google also refers to Google Earth as a "geographic browser." Other examples of geo-browsers are NASA's World Wind, ESRI's ArcGIS Explorer, GeoFusions's Geo-Player, and Earth-Browser by Lunar Software. Google Earth is available on the web for free as well for purchase in more advanced versions. For this study Google earth image was downloaded intended to use for road network extraction.

3.2.1.5 Ortho Photo

An orthophoto, orthophotograph or orthoimage is an aerial photograph or satellite imagery geometrically corrected ("orthorectified") such that the scale is uniform: the photo or image follows a given map projection. Unlike an uncorrected aerial photograph, an orthophoto can be used to measure true distances, because it is an accurate representation of the Earth's surface, having been adjusted for topographic relief, lens distortion, and camera tilt. For this study Orthophoto of 2007 image was obtained to georectify the road network Data.

3.2.2 Secondary Data

A secondary source of data was collected from a different organization, institution and individual experts were very important to generate the desired result of this research. The most widely used secondary data for this thesis work are Macroscopic Emission Model. Unpublished and published reports, journal articles, and internet sources were also used and to understand the situation; analyze the results and write the final reports.

3.2.2.1 Macroscopic Emission Estimation Model

These models can be used to calculate and develop a national or regional emission inventory, especially in green supply chain management studies. Generally, emission rates are measured for a variety of trips, each with a different average speed. Note that the emissions of CO_2 are directly related to fuel consumption and therefore can be easily calculated if the amount of fuel consumption is known. For this study Methodology for calculating transportation emissions and energy consumption (MEET) which covers several vehicle technologies for different classes of vehicles, such as vehicles weighing less than 3.5 tons, vehicles weighing between 3.5 and 7.5 tons, vehicles weighing between 7.5 and 16 tons, vehicles weighing between 16 and 32 tons and vehicles weighing more than 32 tons. and similar to MEET European Economic Area funded emissions model (Kouridis et al., 2010), which estimates vehicle emissions for a range of vehicles by engine classification and vehicle type used For Gradient correction factors.

3.2.2.2 Study Area Boundary

Political boundaries are frequently defined as borders constructed and imposed on or around a geographic territory in order to distinguish between areas of governance or types (strategies) of political control. Political boundaries can divide not only territory but cultures, languages, ethnicities, and natural resources. For this Study Area Addis Ababa city political Boundary was collected which is used at 2019 in Land Management Offices.

In order to achieve the objectives of this study the following Data used for this study and obtained from their format are clarified in the table below.

Table 3.2: Data Sources

Data type	Format	Spatial Resolution	Source
Road Network	Shape file	-	Extracted from Google Earth Image
ALOS PALSAR DEM	TIFF	12.5m	Alaska Satellite facility https://vertex-retired.daac.asf.alaska.edu/
Emission Data	Numeric	-	MEET Emission Estimation Model
GPS Coordinate	Numeric	-	Field survey (Origin Destination of vehicles)
Google Earth Image	TIFF	20 m	Google Earth
Ortho Photo	TIFF	0.2m	Ethiopian Geospatial Information Institute
Study Area Boundary	Shape file	-	Addis Ababa City Administration Land Management Office
Landsat 8 OLI [B11]	TIFF	30	https://earthexplorer.usgs.gov/

3.3 Materials and Software

The following Software's and materials are used to achieve the proposed objectives.

Table 3.3: Material and Software

Type	Owner	Use
Arc GIS	Environmental Systems Research Institute (ESRI)	Network Analysis, VB Script Calculations and Lay out Preparation
Galileo Handheld GPS	European Space Agency (ESA)	Collects X and Y Coordinates of Origin Destination for vehicles
Computer 8GB Ram	Lenovo	Processing of Raw Data
External Hard Disc	Toshiba	Data Back up
MS-Office	Microsoft	Statistics and Report print outs

3.4 Sampling a Range of Vehicle

For the calculation of emissions of a broad range of vehicles and engine technologies. The parameters and emission factors are obtained by sampling a range of vehicles of a specific category. For this study design, the sample vehicle categories which are selected which have a significant influence on emissions from road transportations are listed in table 3.4.

Table 3.4: Vehicle Sample

Vehicle Type	Engine	Category	Vehicle weight Range [Ton]	Vehicle class
Isuzu Npr 71, Vans	Diesel	Vehicles Carrying goods	3.5-7.5	Heavy - Duty Vehicles
Isuzu FSR 33L, IVECO	Diesel	Vehicles Carrying goods	7.5-16	Heavy-Duty vehicles
IVECO Trucker	Diesel	Vehicle carrying liquid Gas	7.5-32	Heavy-Duty vehicles

Source:("Automotive industry 2019")

3.5 Methodology of the study

This paper proposes a methodology whereby to determine an optimal routing network that minimizes fuel consumption and associated emissions for transporting different types of goods from a network of collection points to a different destination and vice versa. Being entirely implemented in Esri's GIS Environment the model's implementation is distinguished in three phases: (1) generation of a3D-RN by connecting a 2D-RN and a DEM; (2) vehicle specific FC calculation of each direction for each edge within the 3D-RN by implementing a EEM; (3) route optimization for minimum FC and its alternatives for different scenarios simulated in case studies and calculations and attribute manipulations are implemented using the field calculator by utilizing visual basic-Script.

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

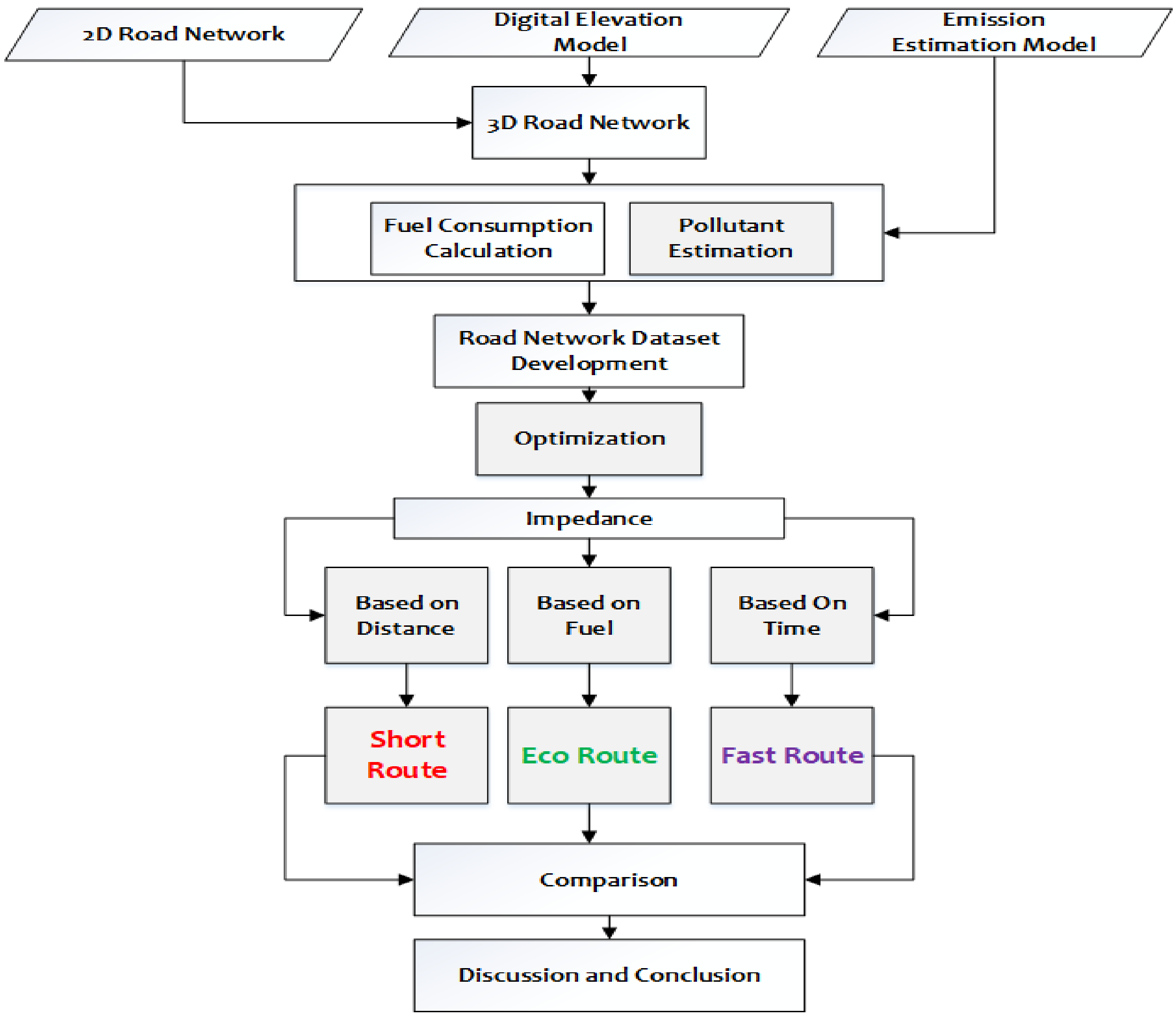

Figure 3.5: General Methodology

CHAPTER FOUR

4. DATA ANALYSIS, RESULT AND DISCUSSION

4.1 Data Analysis

This work presents to apply 3D-Eco Routing-Model to determine most environmentally friendly routes in the domain of different weight ranges of heavy-duty vehicles. Routes are optimized by minimizing vehicle FC and respective CO2-Emissions in an RN, while taking topography (i.e Road Gradient), Vehicle Speed, Vehicle Load and other influencing factors into account. All works Being implemented in Esri's ArcGIS environment, 2D road Network is Digitized from 2019 google earth images[20m Spatial Resolution] in ArcMap and finally rectified to orthophoto image [0.2m Spatial Resolution] to geometrically correct the Road networks and the 3D-RN is created in ArcMap using the 3D-Analyst extension generating Digital elevation model to 2D Road Network and routes are optimized in the Network Analyst extension. Calculations of Fuel Consumption, Carbon Dioxide and Other Pollutants attribute manipulations are implemented using the field calculator for calculations by utilizing Visual Basic-Scripts. The Detailed analysis, which illustrates How the methodology Done for different Scenarios of the 3D-Eco Routing-Model Discussed Below.

4.1.1 2D Road Network

In this stage Road centerlines for lanes of vehicles to travel digitized from google earth images 2019 extracted based on driving direction and rectified to an Orthophoto.

The extracted road in shapefile format then categorized to its functional importance. The hierarchy of roads categorizes road according to their functions and capacities. All road segments were classified and coded based on Esri format and ACCRA Standard. Based on Esri, the basic hierarchy comprises: Primary road, Secondary road, Local road, while ACCRA in Addis Ababa city classifies the hierarchy network edges into a given five levels. Typically, there are three to five levels. For this study A five -level of the hierarchy, which is incorporated in the Esri environment represented by integers:

1. Freeways and Limited-access highways
2. Principal Arterial Street
3. Sub Arterial Street
4. Collector Street
5. Local Street

Performing network analysis using a hierarchy makes use of a heuristic that favors traveling on higher levels of the hierarchy. For instance, with a three-level hierarchy it favors primary roads more than secondary roads and secondary roads more than Local roads. This may result in a solution with a slightly higher cost than if you were to solve the same problem without using the hierarchy.

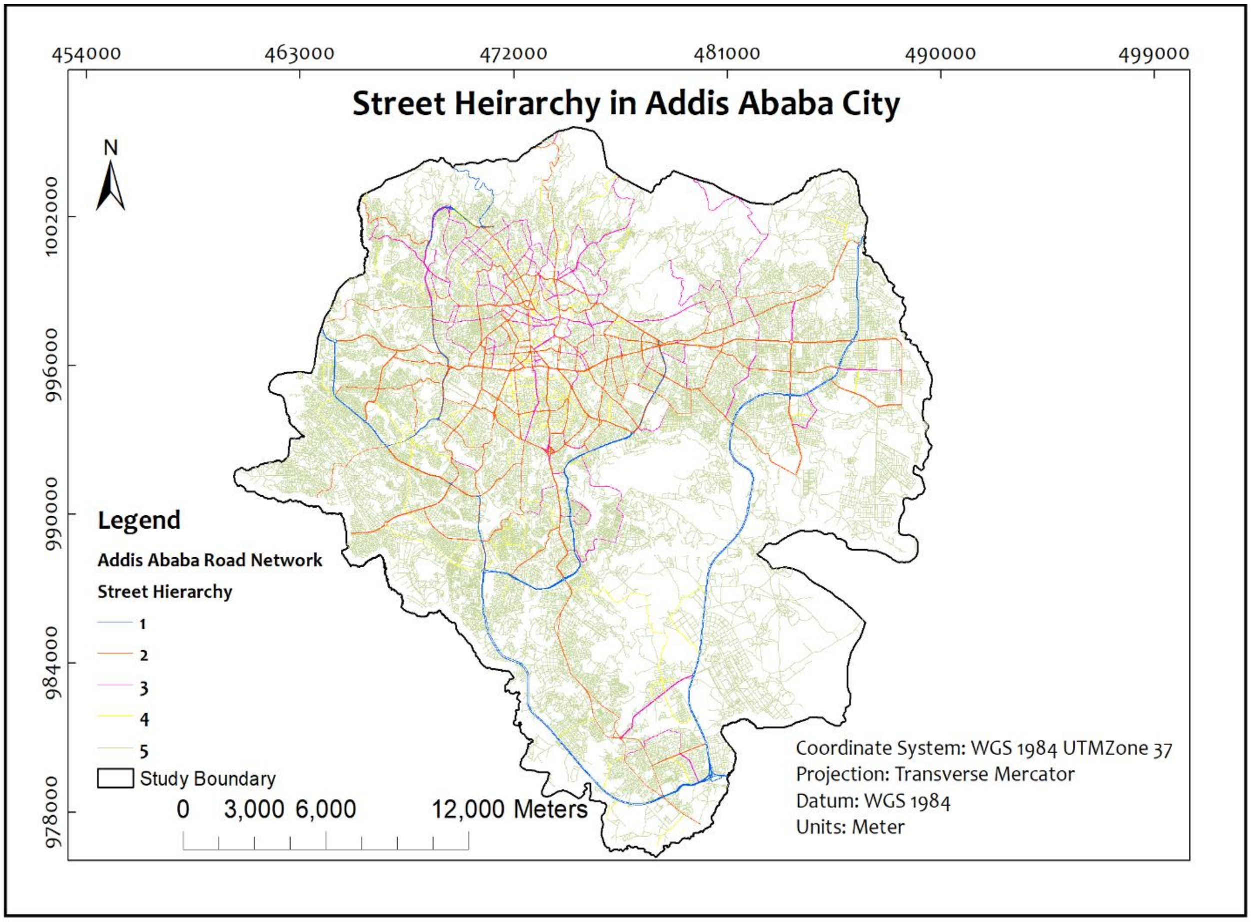

Figure 4.1: Street Hierarchy in Addis Ababa City

After implementing the extracted network with its functional level Geodatabases were created. A geodatabase is an alternate way to store GIS information in one large file, which can contain multiple points, polygon, and/or polyline layers. ESRI is pushing the geodatabase idea, because it is a less "messy" way of organizing data than having multiple shapefiles. in multiple folders. While shapefiles are still very popular and commonly available, you may run into geodatabases in your search for useful data. Here are the basics:

● Geodatabases often appear as single files with the ".gdb" extension or ".mdb" extension.

● In a GDB, "shapefiles" are referred to as "feature classes." Otherwise, they perform the same function when you add them as layers to your map in ArcGIS.

The created geodatabases further used to check the spatial adjacency of street networks which means topological relationship Features that are coincident and share the same location of coordinates, boundaries, or nodes, chances are that geodatabase topology can help to better manage the geographic data. Geodatabase topologies help to ensure data integrity. Using a topology provides a mechanism to perform integrity checks on data and helps to validate and maintain better feature representations in the geodatabase. In addition, topologies are used for modeling numerous spatial relationships between features. These enable support for a variety of analytic operations, such as finding adjacent features, working with coincident boundaries between features, and navigating along with connected features.

One of the primary reasons to develop topology for this study was to provide a rigorous, automated method to clean up data entry errors and verify data. It cleans up slivers, dangles, and under- and overshoots and builds topology again, repeating the clean and build phases as many times as necessary. Because this study areas Road network source file was Manually digitized shape file it has different topological errors and those errors were edited by using different topological rules and applied on this Study.

At the end of fixing topology errors, the networks are free of errors and consequently the network is used to create additional criteria for the property of the street which is turn features ***A turn models*** a movement from one edge element to another. Often turns are created to increase the cost of making the movement, or prohibit the turn entirely. For example, a turn feature representing a left-hand turn at an intersection could be assigned a cost of 30 seconds to model the average time it takes for the left-turn light to change to green. Similarly, a restriction attribute could read a field value from a turn feature to prohibit it. This is useful when the turning movement is posted as illegal (no left turns). Turns can be created at any junction where edges connect. There are n^2 possible turns at every network junction, where n is the number of edges connected at that junction. Even at a junction with a single edge, it is possible to make one U-turn. Turns are store information about a particular turning movement; for instance, a left turn is restricted from one particular edge to another. By creating turn feature class, it is applied to this study to get appropriate traffic movement. The figure 4.2 below shows how the turn feature looks like.

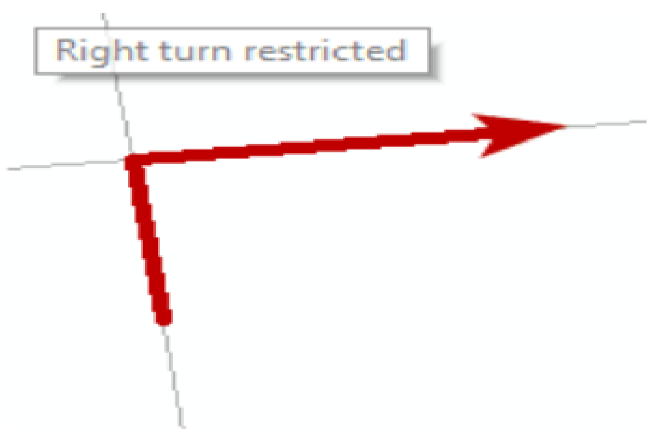

Figure 4.2: Turn feature

After Finishing all the above tasks Know the 2D road network is ready for further processing's.

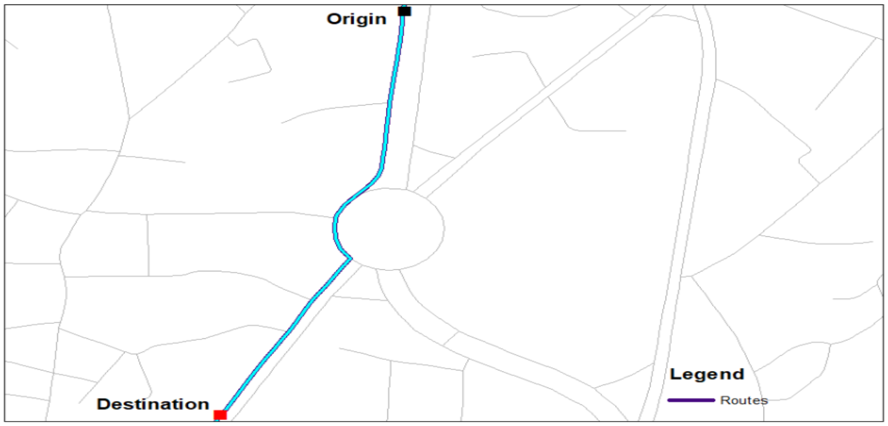

Figure 4.3: Application of Turn

4.1.2 3D Road Network

In this stage the 2D road segment consists of 40886 polyline records with functional class [motorway, principal arterial, sub arterial, collector and local streets] is preprocessed by adding speed attributes to fit study area speed limit based on 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 implemented on 2D Road Network . Finally, the 2D-RN enriched with elevation data, a DEM is used in combination with tools of the ArcMap 3D-Analyst extension and the 2D road Network changed to 3D Road Network. Which used for road network 3D distance and Gradient calculations. more precise absolute gradient values [%] and 3D-Lengths [m] of each edge are added by using the Add Surface Information tool. to determine the direction of the grade (i.e. positive values - uphill & negative values - downhill), start and end points of each edge are extracted (i.e. feature vertices to points) and enriched with their interpolated height. the study area is characterized as irregular with many undulating trains specially on local streets, however the low resolution of DEM leads to unrealistic gradients shown on some part of local streets which leads to inaccurate fuel consumption values. to overcome this gradient values higher than permissible maximum restriction for road slopes reduced according to (Bartlett 2015) however in this study the implemented scenarios cases not exceed the permissible Road Slopes. The obtained 3D distance and Gradient accounts for Terrain consideration to calculate fuel consumptions and to find eco routes. figure 4.4 show how 3D Road Network implemented in ArcMap and figure 4.5 shows how the generated 3D Network Looks in partial view in the city.

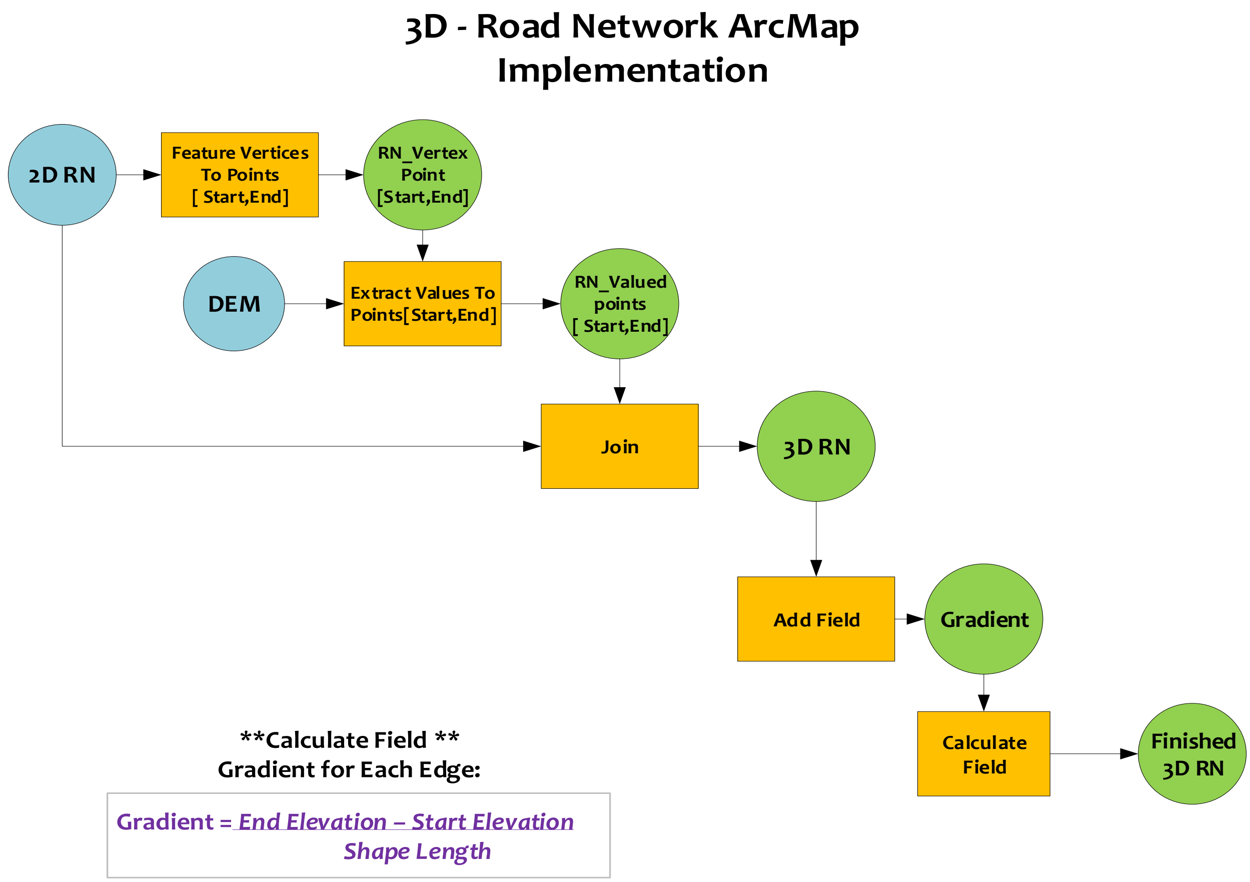

Figure 4.4: 3D Road Network implementation steps

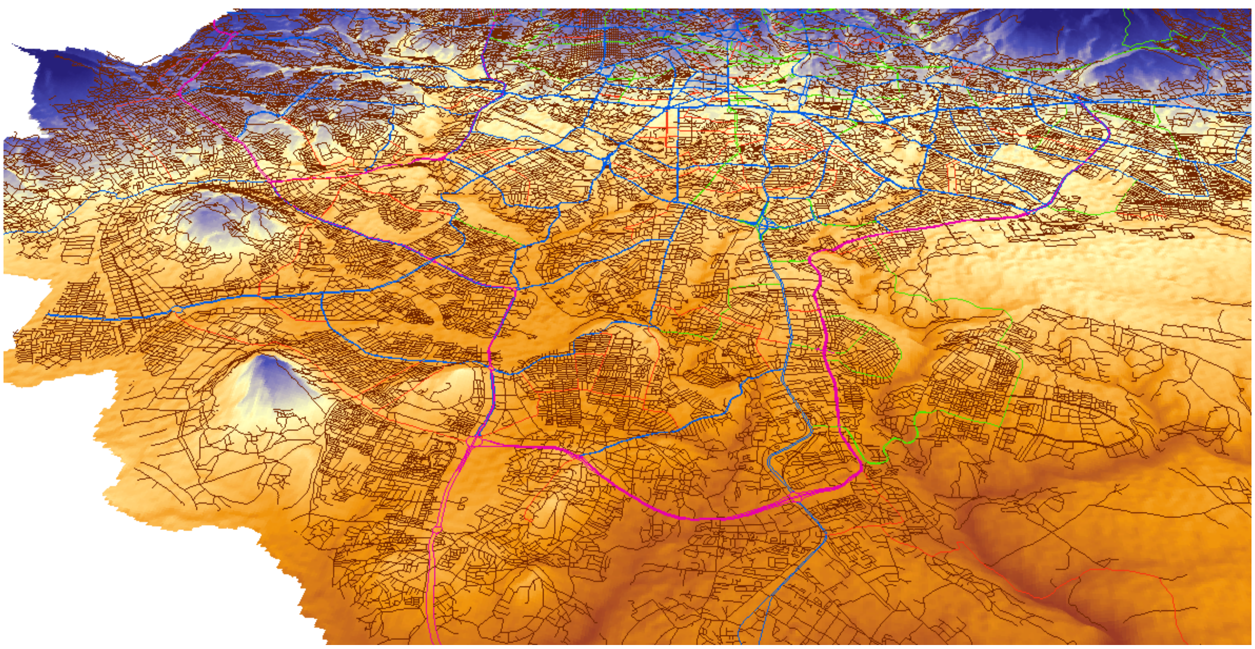

Figure 4.5: 3D Road Network in Addis Ababa City

4.1.3 Fuel Consumption Estimation

The factors influencing fuel consumption have been studied by Ardekani, Hauer, and Jamei (1996), Bigazzi and Bertini (2009), Demir et al. (2011) and Alwakiel (2011). These factors can be divided into five categories vehicle, environment, traffic, driver and operations. Most fuel consumption models concentrate on the vehicle, traffic, and environmental influences, but do not capture driver related issues which are relatively difficult to measure. Moreover, operations related factors are often seen as externalities affecting fuel consumption. summary on various FC models is published by (Demir, Bektaş, and Laporte 2014), where functionalities and usability are exemplified throughout. In this 3D Eco routing model the method proposed in MEET Based on (Demir, Bektaş, and Laporte 2014) and (EEA 1999) was used. MEET is used for calculating transportation emissions and energy consumption for heavy goods vehicles and is based on on-road measurements and all its parameters are extracted from real-life experiments. It covers several vehicle technologies for different classes of vehicles, such as vehicles weighing less than 3.5 tons, vehicles weighing between 3.5 and 7.5 tons, vehicles weighing between 7.5 and 16 tons, vehicles weighing between 16 and 32 tons and vehicles weighing more than 32 tons. This study used the data available to MEET for the category of diesel heavy duty vehicles (from 3.5 to 32 tones) in three scenarios and each scenario tested with three cases.

In All scenarios MEET methodology used with stated adjustments for diesel HDV from 3.5 to 7.5 tons is implemented for scenario (1), Diesel HDV from 7.5 to 16 tons implemented for scenario (2) and lastly Diesel HDV from 16 to 32 ton implemented for scenario (3). FC estimates that are later used as impedance for route optimization and pollutants emissions in the scenarios (one to three), for each direction of each RN edge is calculated.

The basic fuel consumption as a function only of speed, Fcv (g/ km), is expressed for the considered vehicle category by the following equation obtained from MEET Model:

Scenario (1):

$$\text{For } V \quad 5 - 60 \qquad 1425.2V^{-0.7593} \qquad \text{Eq(4.1)}$$

$$\text{For } V \quad 60 - 100 \qquad 0.082V^{2} - 0.0430V + 60.12 \qquad \text{Eq(4.2)}$$

Scenario (2):

$$\text{For } V \quad 5 - 60 \qquad 1068.4V^{-0.4905} \qquad \text{Eq(4.3)}$$

$$\text{For } V \quad 60 - 100 \qquad 0.0126V^{2} - 0.6589V + 141.2 \qquad \text{Eq(4.4)}$$

Scenario (3):

$$\text{For } V \quad 5 - 60 \qquad 1595.1V^{-0.4744} \qquad \text{Eq(4.5)}$$

$$\text{For } V \quad 60 - 100 \qquad 0.0382V^{2} - 5.163V + 399.3 \qquad \text{Eq(4.6)}$$

The emission factors and functions of MEET refer to standard testing conditions (i.e., zero road gradient, empty vehicle, etc.) and are typically calculated as a function of the average vehicle speed. Depending on the vehicle type, a number of corrections may be needed to account for the effects of road gradient and vehicle load on the emissions once a rough estimate has been produced.

A. Road Gradient Influence

The gradient of a road has the effect of increasing or decreasing the resistance of a vehicle to traction. Is obvious that the effect of the slope on emissions and consumption will be highly dependent on the road gradient. For each vehicle weight and gradient class, the gradient correction factor calculated using The MEET methodology provides a formula to calculate a road gradient CF, which increases the FC on positive gradients and vice versa. The given polynomial function is based on different vehicle Weight class, whereas it is valid for road gradients from -6 % to 6 %. As in this study road gradients vary and the formula is given on and adjusted to include abroad range of gradient classes in a city.

The following road gradient correction factor is used to take the effect of road gradient into account fitted to an exponential function. And expressed by the following equation where RG represents the road gradient in percentage.

$$\text{For scenario 1: } G_{CF} = 0.213e^{0.165RG} \qquad Eq(4.7)$$

$$\text{For scenario 2: } G_{CF} = 0.419e^{0.180RG} \qquad Eq\ (4.8)$$

$$\text{For scenario 3: } G_{CF} = 1.0458e^{0.187RG} \qquad Eq\ (4.9)$$

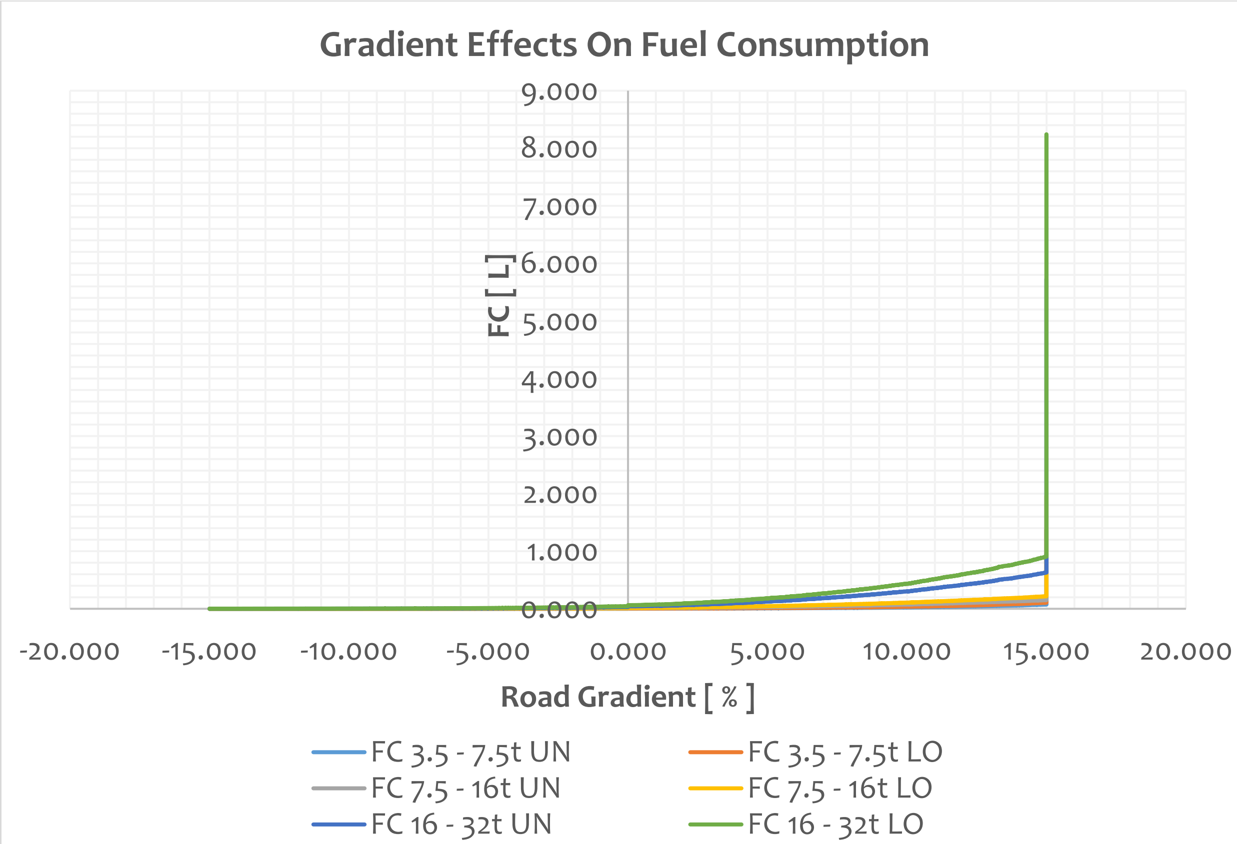

Figure 4.6: Gradient Effects On FC

B. Vehicle Load Effect

It is obvious that the lower the vehicle weight, the less load is demanded from the engine and vice versa. As a result, the consumption as well as the emission rate of the engine change in accordance with the vehicle weight.

To compensate for the different load, the emission factor calculated for a load of 50%, is corrected with the use of the following formula:

$$\mathbf{L_{cf} = [\ 1+2cf\frac{(lp - 50)]}{100}]} \qquad \text{Eq (4.10)}$$

where,

L$_{cf}$ = corrected emission factor of the FC in [g/km] of the vehicle of category

lp = the actual load factor (Expressed as a percentage of the maximum load. That is, lp = 0 denotes an unloaded vehicle and lp = 100 represents a totally laden one)

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 implemented

MEET Suggests the Total Fuel Consumption in **gram** as

$$FC = Fcv * G_{CF} * L_{cf} * D \qquad Eq\ (4.11)$$

Where: Fcv = Speed factor

G_{CF} = Gradient Correction Factor

L_{cf} = Load Correction Factor

D = Distance in km

As FC values in gram are not common, the calculated FC values are converted to Liters [L]

It depends on the density/specific gravity of the fuel. Diesel for automotive use is around 832gm/liter

Therefore: $$Fc_{Liter} = \frac{FC[g]}{832\ [\frac{g}{L}]} \qquad Eq\ (4.12)$$

The calculated FC for each edge and each direction a as impedance for the route optimization, as well as for FC and emission estimates of a route. To compare different routes as eco-Route, fastest and shortest route, the RN is completed by time estimations, T[h], for each edge based on its 3D-Length L [km] and allowed velocity V [km/h] expressed as

$$T\ [h] = \frac{3D\ distance[km]}{Velocity[\frac{km}{hr}]} \text{ used for fast Routes} \qquad Eq\ (4.13)$$

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

4.1.4 Pollutant Estimation

In this stage four different pollutant which is emitted from road transports in the tested scenarios was estimated for each pollutant.

4.1.4.1 Carbon dioxide Emissions

Ultimate CO_2 emissions are estimated on the basis of ***fuel consumption only***, assuming that the carbon content of the fuel is fully oxidized to CO_2. The following formula is applied

mass of CO_2 = 44.011 (mass of fuel/(12.011 + 1.008 . rH/C)) Eq(4.14)

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

4.1.4.2 Other Pollutants Emission Estimation

a) Carbon Monoxide

Carbon monoxide (CO) as a function only of speed, COv (g/ km), is expressed for the considered vehicle category.in carbon monoxide emission estimation MEET suggests the same emission factor for all weight classes by the following equation

For all Scenario

For V 5 – 100 $37.280V^{-0.6945}$ Eq (4.15)

b) Oxides of Nitrogen (NOx)

as a function only of speed, Noxv (g/ km), is expressed for the considered vehicle category.in carbon monoxide emission estimation MEET suggests the emission factor for different weight classes by the following equation

Scenario (1):

For V 5 – 50 $50.305V^{-0.7708}$ Eq (4.16)

For V 50 – 100 $0.0014V^2 - 0.1737V + 7.5506$ Eq (4.17)

Scenario (2):

For V 5 – 60 $92.584V^{-0.7393}$ Eq (4.18)

For V 60 – 100 $0.0006V^2 - 0.0941V + 7.7785$ Eq (4.19)

Scenario (3):

For V 5 – 100 $108.36V^{-0.6061}$ Eq (4.20)

c) Volatile Organic Compounds (VOC)

Volatile Organic Compounds (VOC) as a function only of speed, VOCv (g/ km), is expressed for the considered vehicle category. Emission estimation for VOC MEET suggests the same emission factor for all weight classes by the following equation

For all Scenario

For V 5 – 100 $40.120V^{-0.8774}$ Eq(4.21)

d) Particulate Matter (PM)

Particulate Matter (PM) as a function only of speed, PMv (g/ km), is expressed for the considered vehicle category. Emission estimation of PM MEET suggests the emission factor for different weight classes by the following equation

Scenario (1):

For V 5 – 100 $4.5563V^{-0.707}$ Eq (4.22)

Scenario (2):

For V 5 – 100 $9.6037V^{-0.7259}$ Eq (4.23)

Scenario (3):

For V 5 – 100 $10.890V^{-0.7105}$ Eq (4.24)

A. Gradient Correction Factor for Pollutants

the extracted Pollutant Emission based on speed data is corrected for its respective road inclination in the Study area. MEET suggests for all Pollutants the Gradient correction factor is the same as which applied in Fuel Consumption, the applied Gradient Correction factor for all pollutants is given by the equation below

$$\text{For scenario 1: } G_{CF} = 0.213e^{0.165RG} \qquad \text{Eq (4.25)}$$

$$\text{For scenario 2: } G_{CF} = 0.419e^{0.180RG} \qquad \text{Eq (4.26)}$$

$$\text{For scenario 3: } G_{CF} = 1.0458e^{0.187RG} \qquad \text{Eq (4.27)}$$

B. Vehicle Load Correction Factor for Pollutants

Furthermore, for each complete and empty load data set, Respective emission factors are corrected for their load

To compensate for the different load, the emission factor calculated for a load of 50%, is corrected with the use of the following formula:

$$\boldsymbol{Lcf} = [\ 1+2cf\ ((lp - 50)])/100] \qquad \text{Eq (4.28)}$$

where,

Lcf = corrected emission factor of Pollutant i in [g/km] of the vehicle of category

lp = the actual load factor (Expressed as a percentage of the maximum load. That is, lp = 0 denotes an unloaded vehicle and lp = 100 represents a totally laden one)

cf = load correction factor of Pollutant i

actual Load factor for pollutants are given in MEET and applied for this study are

Table 4.1: Pollutants and its Load factor

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

Therefore, load correction applied for pollutants are given below in the table

Table 4.2: 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

For all pollutants, (i.e. CO, NOx, VOC, PM) MEET Suggests the Total Emission per Road length is calculated as in gram.

$$\textbf{Total Emission of Pollutant} = \mathbf{Pv * GCF * Lcf * D} \qquad \text{Eq (4.29)}$$

Where: Pv = Pollutant Speed factor

GCF = Gradient Correction Factor

Lcf = Load Correction Factor

D = Distance in km

4.1.5 Network Dataset Development

Network datasets are well suited to model transportation networks. They are created from source features, which can include simple features (lines and points) and turns and store the connectivity of the source features. Network datasets are made of network elements. Network elements are generated from the source features used to create the network dataset. The geometry of the source features helps establish connectivity. In addition, network elements have attributes that control navigation over the network. There are three kinds of network elements**:**

Edges — Connect to other elements (junctions) and are the links over which agents travel

Junctions — Connect edges and facilitate navigation from one edge to another
Turns —Store information that can affect movement between two or more edges
Edges and junctions form the basic structure of any network. Connectivity in a network deals with connecting edges and junctions to each other. Network dataset contains different consideration from those some are applied in this Study. Those applied in this Study are:

Network attributes

Network attributes are properties of the network elements that control travers ability over the network. Examples of attributes include the time to travel a given length of the road, which streets are restricted for which vehicles, the speeds along a given road, and which streets are one-way.

- **Restrictions**

Restrictions can be identified for particular elements such that, during an analysis, traversing restricted elements is prohibited entirely, avoided, or even preferred. Choosing which restriction attributes should be respected while solving the analysis. In most cases, restrictions cause roads to be prohibited, but they can also cause them to be avoided or preferred. A restriction attribute, such as One-way, should be used when finding solutions for vehicles that must obey one-way streets (for instance, nonemergency vehicles). in this study, a one-way restriction was applied while solving the analysis.

- **Hierarchy**

Hierarchy is the order or rank assigned to network elements. A street network might have an attribute on the source features that breaks the roads down into three (or more) classes, such as local, secondary, and primary. You can use this attribute on the source features to build a hierarchy attribute on the network dataset. Using a hierarchy tends to reduce the time it takes to solve an analysis across a large network. It also simulates how drivers generally select to travel on highways and interstates because navigating on higher-order roads is more predictable and simpler than on lower-order roads.

- **Connectivity**

To create network dataset choices that determine which edge and junction elements are created from source features. Ensuring that edges and junctions are formed correctly is important for accurate network analysis results. Connectivity in a network dataset is based on geometric coincidences of line endpoints, line vertices, and points and applying connectivity rules that you set as properties of the network dataset. Vertex connectivity method was used in this study.

- **Elevation fields**

Elevation fields are used in the network dataset to refine the connectivity at line endpoints. They contain elevation information derived from fields on a feature class participating in the network. This is different from establishing connectivity based on z-coordinate values, in which the physical elevation information is stored on each vertex of the feature. Elevation fields apply to edge and junction sources. Edge feature sources using elevation fields have two fields to describe elevation (one for each end of the line feature). In the example below, four-line features, EF1, EF2, EF3, and EF4, belong to the same connectivity group and observe endpoint connectivity. The elevation values for EF3 and EF4 are 0; the elevation values for EF1 and EF2 are 1. Hence, at the point of intersection, EF3 is connected to EF4 only (not to EF1 or EF2). Similarly, EF1 connects to EF2 only, not to EF3 or EF4. It is important to understand the elevation fields refine the connectivity; they do not override it. Two edge elements may have the same elevation field value and may be coincident, but if they are placed in two different connectivity groups, they will not be connected.

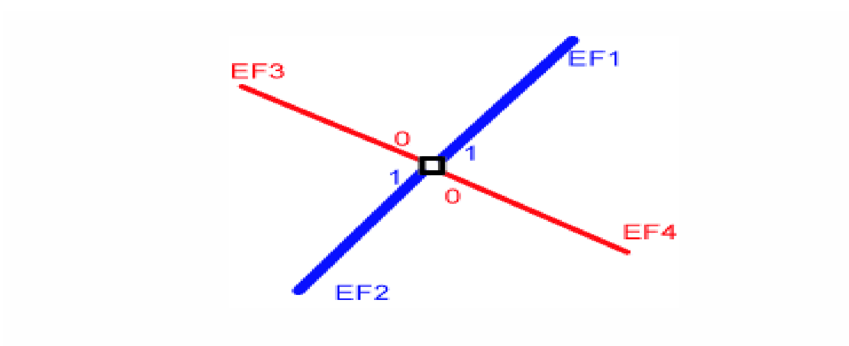

Figure 4.7: Elevation Connectivity

In this study elevation attribute fields filled to consider overpasses, underpasses, and Normal like tabulated below.

Table 4.3: Elevation Attribute Usage

Elevation Start	Elevation End	Usage
1	1	Overpasses
-1	-1	Underpass
0	0	Normal

4.1.6 Optimization

The route optimization was done with ArcMap Network Analyst, which offers different functions for different route optimization settings and parameters. Each route optimization is based on different algorithms, aiming to minimize the total impedance (e.g. FC, time or distance). The route optimization primarily aims to minimize the total FC to determine the eco-route that connects a set of points. when applying optimization in ArcMap cost attributes are used. Certain attributes are used to measure and model ***impedances***, such as travel time (transit time on a street) or demand (the volume of Goods picked up on a street). These attributes are apportionable along an edge; that is, they are divided proportionately along the length of an edge. Network analysis often involves the minimization of a cost (also known as impedance). Impedance is A measure of the amount of resistance, or cost, required to traverse a path in a network or to move from one element in the network to another. Resistance may be a measure of travel distance, time, speed of travel multiplied by distance, and so on during the calculation of a path (also known as finding the best route) for this study Common examples include finding the fastest route (minimizing travel time), the shortest route (minimizing distance) and Eco Route (Minimizing Fuel) are used as cost attributes of the network dataset**.** This study mainly aims to reduce vehicles environmental footprints, therefore, reduction in fuel is not questionable, the applied 3D-Eco Routing model which reduces fuel consumption and emissions were shown below.

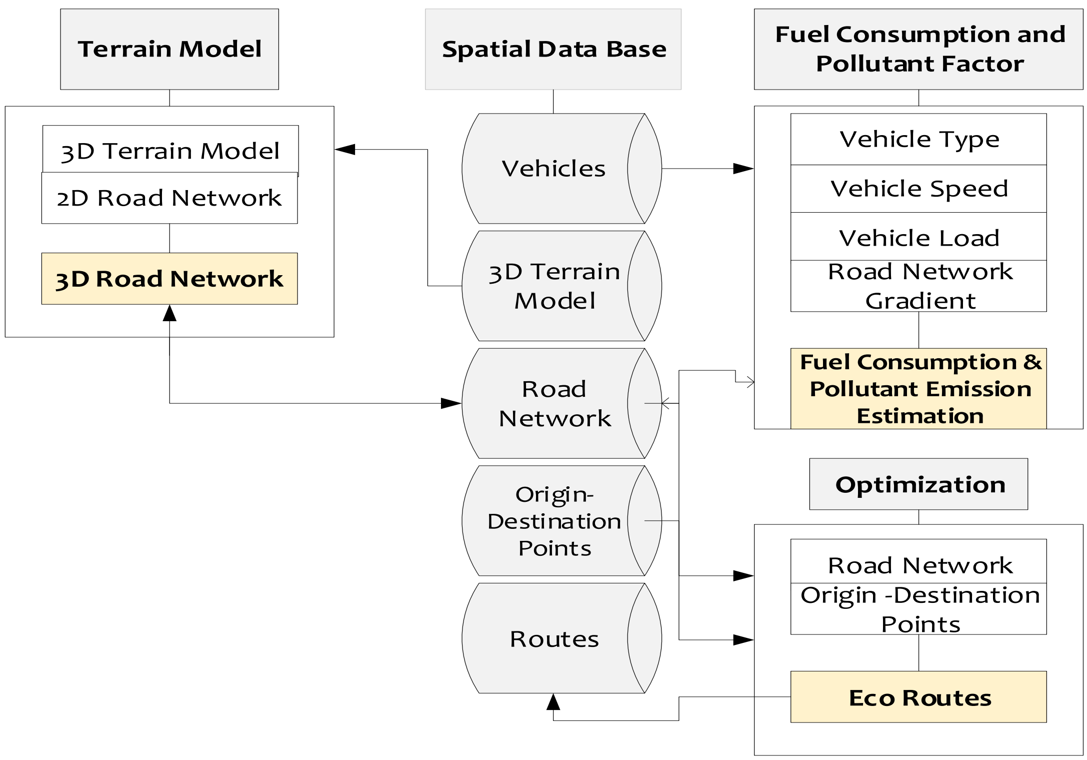

Figure 4.8: Applied 3D Eco Route Model

In this study, three scenarios are implemented to test different routing conditions, which include different ranges of vehicle weight classes which are available in the city of Addis Ababa such that: **Scenario 1**: for Aqua Addis water Distribution Vehicles **Scenario 2**: For Moha soft Drinks Distribution Vehicles. **Scenario 3**: For Oilibya Fuel Distribution Vehicles. Each scenario contains three cases with different loading and routing conditions. the details of how scenarios are implemented in this study were tabulated below.

Table 4.4: Scenario Implementation

Scenarios	Cases	Vehicle Type	Weight Class [Ton]	Loading Condition	Routing	Relationship	Description
1	1	ISUZUNPR, ISUZU VANS Diesel Vehicles	3.5-7.5	Complete Load	Simple	One to One	Loaded Vehicles travels from one origin to one Destination
	2			Complete Load	Full Distribution	One to Many	Loaded Vehicles travels from one origin to Many Destination
	3			Empty Load	Back Haul	Many to One	Unloaded Vehicles travels from Many Destinations to One Origin
2	1	Iveco Truck, ISUZU FSR Diesel Vehicles	7.5 -16	Complete Load	Simple	One to One	Loaded Vehicles travels from one origin to one Destination
	2			Complete Load	Full Distribution	One to Many	Loaded Vehicles travels from one origin to Many Destination
	3			Empty Load	Back Haul	Many to One	Unloaded Vehicles travels from Many Destinations to One Origin
3	1	Iveco Truckker Diesel Vehicles	16 -32	Complete Load	Simple	One to One	Loaded Vehicles travels from one origin to one Destination
	2			Complete Load	Full Distribution	One to Many	Loaded Vehicles travels from one origin to Many Destination
	3			Empty Load	Back Haul	Many to One	Unloaded Vehicles travels from Many Destinations to One Origin

The routes are compared in each scenario and also the routes are compared with respect to economic repercussions this is based on the cost of fuel. the fuel cost is based on Ethiopian diesel prices 16-sep-2019, based on (GlobalPetrolPrices.com n.d.) 1litre diesel in Ethiopia costs **0.64 US Dollar.** Detailed descriptions and their results presented in the results section.

4.2 Results

This section presents a comparative analysis of the routes considering different criteria, including travel time, Fuel consumption and distance. Additionally, Pollutants Emission Estimation of routes considering a range of different criteria is presented. The parameters are considered along the route Furthermore, the results are monetarily quantified to examine economic repercussions. The purpose of the Scenario case studies is to illustrate the FC and Pollutant-Emission saving potentials, which are enabled through the Application of the 3D Eco Routing-Model. The model is implemented in the following Scenarios with case studies.

4.2.1 Scenario 1

This scenario simulates the supply of a Bottled water to the market, which is utilized by Aqua Addis Bottled water supplier on a demand-based schedule. The vehicle range incorporated in this scenario is HDV 3.5 -7.5tons.

4.2.1.1 Case study 1

This case under scenario 1 implements the supply of a single supermarket with a completely loaded (CFLoad = 1.18). Based on the generated 3D RN, the objective of this case is to determine the eco-friendliest route between the Origin (Bottled Water Store) and a single supermarket, as well as to compare the route to its shortest and fastest alternative. The NAs New Route Solver is set up. And the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting routes are displayed in fig 4.9 below.

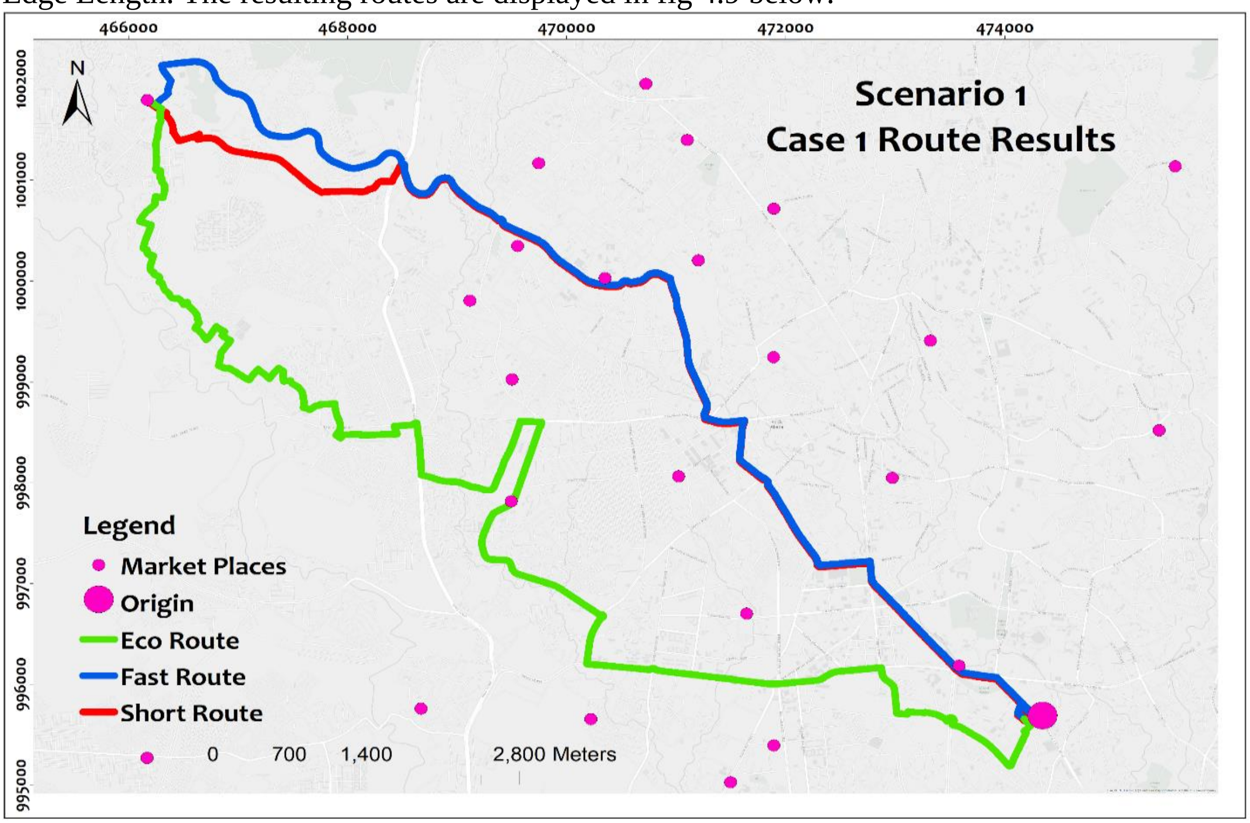

Figure 4.9: Scenario 1 case 1 Route Results

The three generated routes from the Origin to the single market location are displayed in Figure 4.9. Comparing the three routes it can be observed that the shortest and fastest routes, which are not optimized for FC, are partially overlapping as they are mainly utilizing Principal Arterial and Sub arterial streets. The shortest and fastest routes use ascending and descending segments, as the fastest route maximizes the distance in contrast shortest route minimizes the distance towards to the Market place. On the contrary, the eco- route is characterized through preferring descending road-segments, where the FC is minimized.

Table 4.5: Scenario 1 case 1 Parameter Results

Routes	FC [L]	CO_2 [Kg]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	0.928	477.0266	17.232	0.393	0.593
Fast Route	1.542	792.164	12.826	0.196	0.986
Short Route	1.448	743.962	12.786	0.226	0.926

Table 4.5 illustrates the results for different parameters of Case Study 1. Comparing the total FC and CO_2 Emissions, the difference in between the shortest and fastest route are marginal, whereas the eco-route enables significant fuel and CO_2 emission savings of 39.818 % compared to the fastest and 35.911 % to the shortest route further more cost of fuel saving potential of 39.858 % compared to the fastest and 35.961 % to the shortest route. However, the eco-routes distance and time are substantially higher than its alternatives.

4.2.1.2 Case Study 2

This case under scenario 1 implements the supply of bottled water to each market locations with a completely loaded (CFLoad = 1.18). each market place is supplied by a single truck, based on the generated 3D RN, the objective of this case is to determine the eco- route between the Origin (Bottled Water Store) and a Multiple destination Markets, as well as to compare the route to its shortest and fastest alternative. The NAs Closest Facility Solver is set up and the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting a total of 147 routes are displayed below in Figure 4.10.

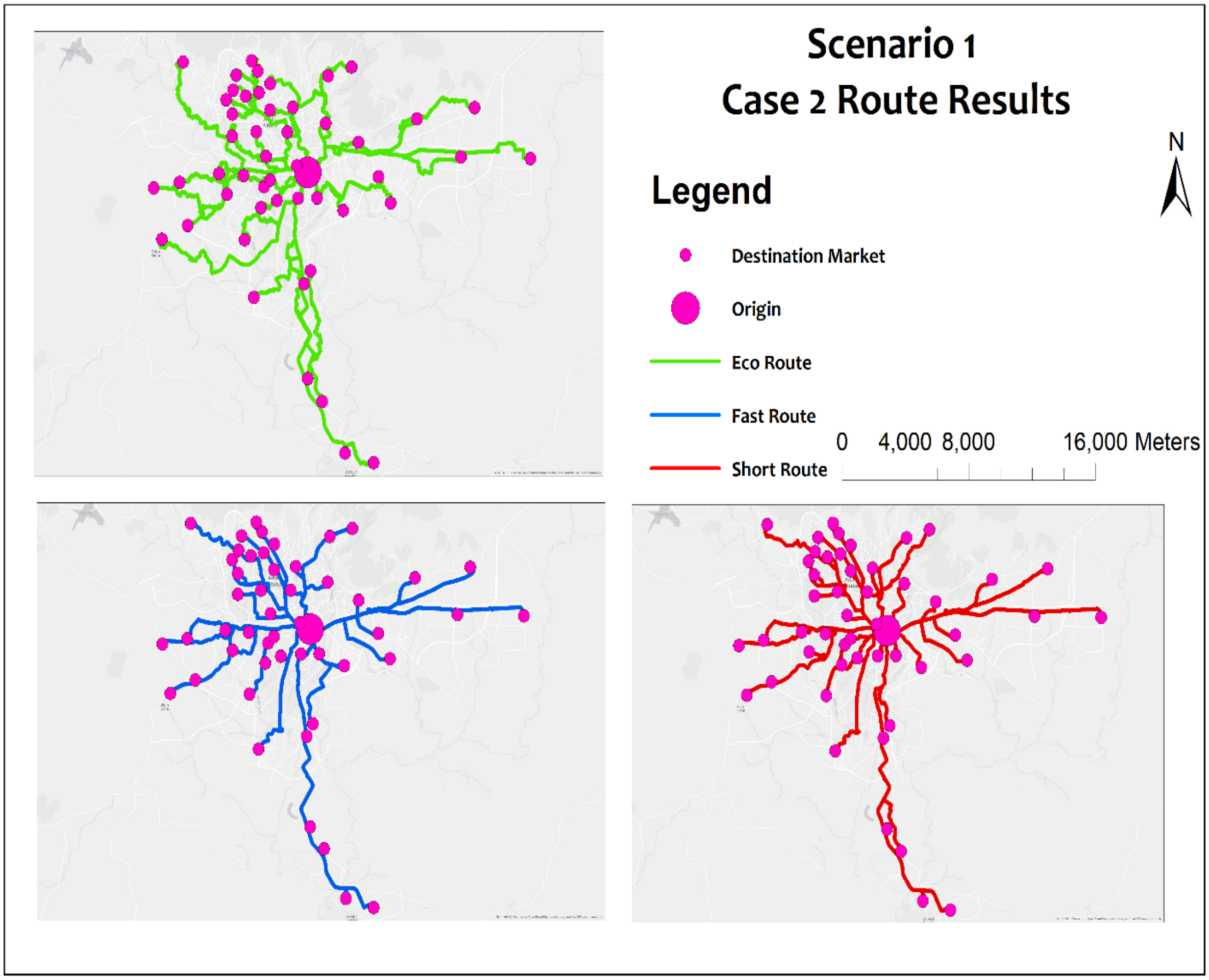

Figure 4.10: scenario 1 cases 2 Route Results

Table 4.6: Scenario 1 Case 2 Parameter Result

Routes	FC [L]	CO_2 [Kg]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	38.168	19604.468	473.624	10.912	24.427
Fast Route	59.118	30364.875	387.587	6.059	37.835
Short Route	54.497	27991.405	378.953	6.489	34.878

The above Table 4.6 illustrates the results for different parameters of Case Study 2. Comparing the total FC and CO_2 Emissions. The same to case study 1 the eco-route in this case 2 enables significant fuel and CO_2 emission savings of 35.437 % compared to the fastest and 29.963 % to the shortest route. furthermore cost of fuel saving potential of 35.438 % compared to the fastest and 29.964 % to the shortest route. However, the eco-routes distance and time are again substantially higher than its alternatives.

4.2.1.3 Case Study 3

The Third case under scenario 1 implements for the backhaul (CFLoad = 0.82) is implemented to account for empty returning trucks. From each supermarket to origin, the eco-route and its alternatives are determined for its return journeys. The NAs Closest Facilty Solver is set up and the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting a total of 147 routes are displayed below in Figure 4.11.

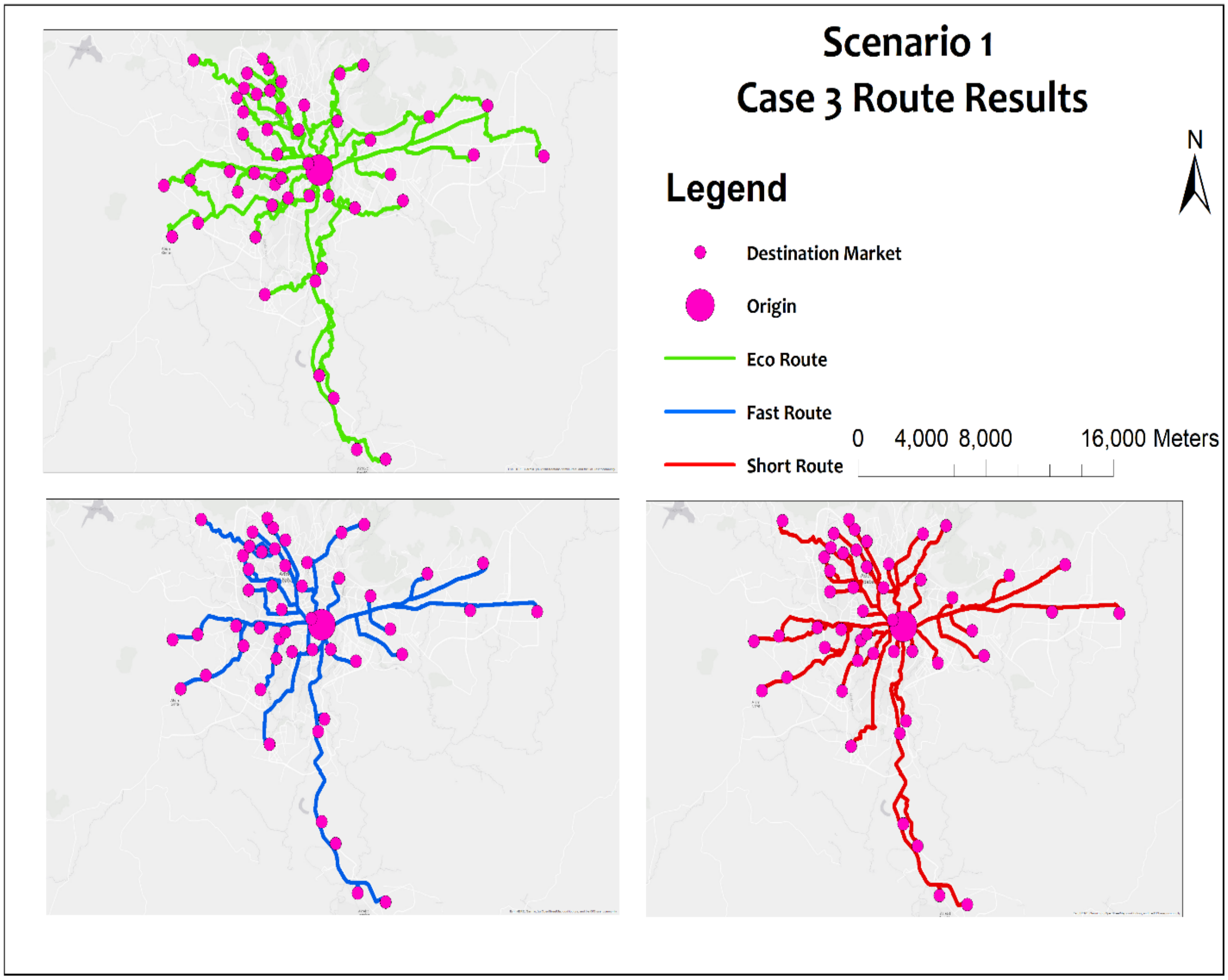

Figure 4.11: Scenario 1 Case 3 Route Results

Table 4.7: Scenario 1 Case 3 Parameter Result

Routes	FC [L]	CO_2 [Kg]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	26.195	13454.662	443.535	9.985	16.764
Fast Route	35.923	18451.502	382.592	6.027	22.990
Short Route	34.439	17689.087	379.066	6.323	22.040

Similar to the above two cases eco routes prefer descending road-segments, leading to significant FC and CO_2 savings of 27.080 % compared to the fastest and 23.937 % compared to the shortest route, further more cost of fuel saving potential of 27.081 % compared to the fastest and 23.938

% to the shortest route However, the travelled eco-routes distance is again higher than the shortest routes distance, as is operation time compared to the fastest route.

4.2.2 Scenario 2

This scenario simulates 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. The vehicle range incorporated in this scenario is HDV 7.5 -16tons**.**

4.2.2.1 Case Study 1

In this scenario 2 of case 1, the same implementation of as that of scenario 1 case 1, as such This case under scenario 2 implements the supply of a single supermarket with a completely loaded (CFLoad = 1.18). therefore, this case determines the eco-friendliest route between the Origin (Soft drink store) and a single supermarket, as well as to compare the route to its shortest and fastest alternative. The NAs New Route Solver is set up. And the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting routes are displayed in fig 4.12 below.

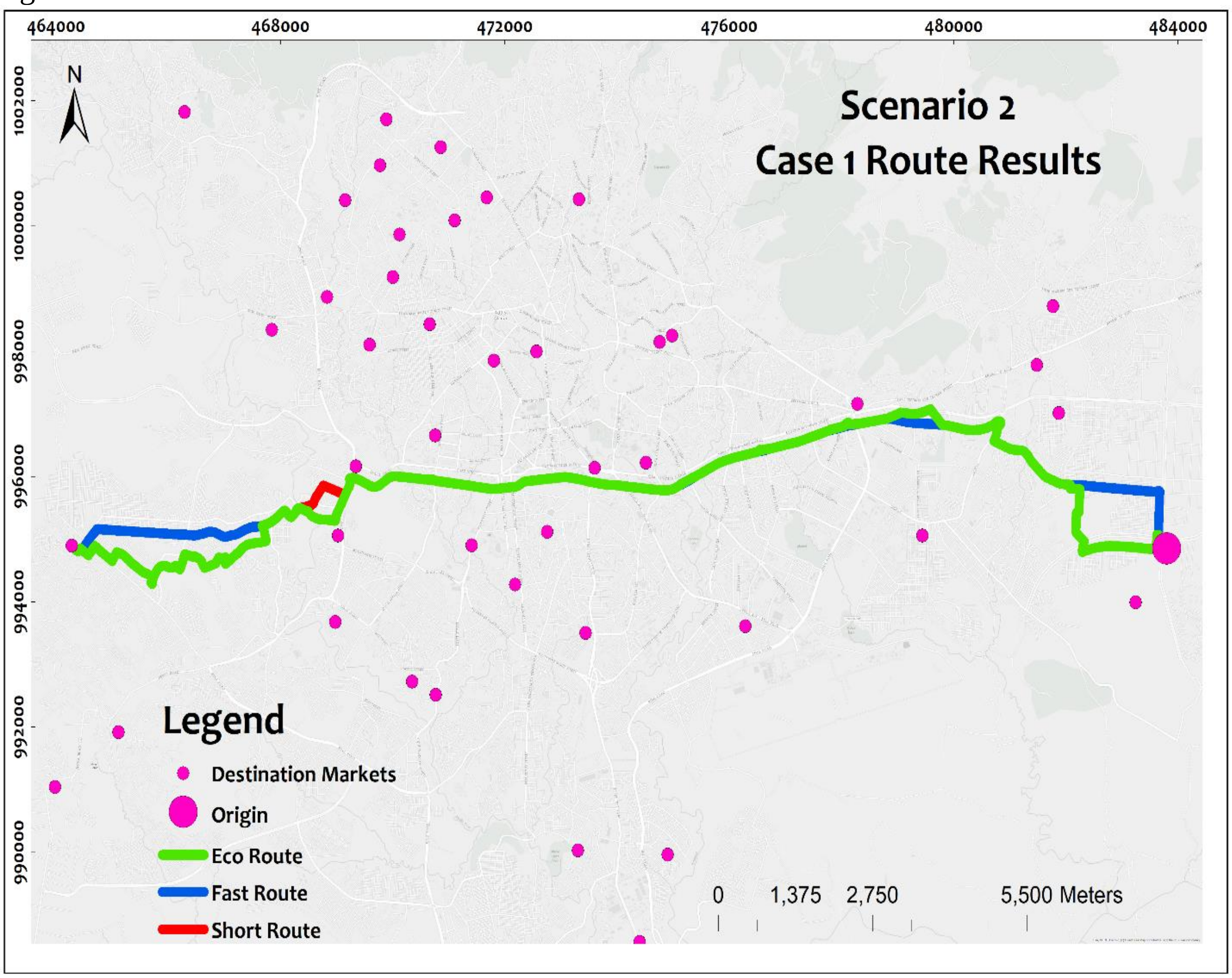

Figure 4.12: Scenario 2 Cases 1 Route Results

Comparing the three routes it can be observed that the shortest and fastest routes, which are not optimized for FC, are overlapping in the initial stage as they are mainly utilizing Principal Arterial and Sub arterial streets which prefers the Summit-Salitemihret road. And as shown in the figure 4.12 all three routes partially overlapping for long kilometers, after that for a few kilometers the shortest and fastest routes use ascending and descending segments, as the Eco route maximizes the distance in contrast shortest route minimizes the distance towards to the Market place. However, the eco- route is characterized through preferring descending road-segments, where the FC is minimized.

Table 4.8: Scenario 2 Case 1 Parameter Result

Routes	FC [L]	CO_2 [Kg]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	2.215	1138.005	24.897	0.461	1.417
Fast Route	2.481	1274.807	22.665	0.323	1.587
Short Route	2.573	1321.690	22.479	0.329	1.646

The above Table 4.8 results shows that eco routes prefer descending road-segments, leading to significant FC and CO_2 savings of 10.721 % compared to the fastest and 13.913 % compared to the shortest route, further more cost of fuel saving potential of 10.712 % compared to the fastest and 13.912 % to the shortest route However, the travelled eco-routes distance is again higher than the shortest routes distance, as is operation time compared to the fastest route.

4.2.2.2 Case Study 2

This case under scenario 2 implements the supply of soft drinks to each market locations with a completely loaded (CFLoad = 1.18). each market place is supplied by a single truck Based on the generated 3D RN, the objective of this case is to determine the eco- route between the Origin (Moha soft drinks Store) and a Multiple destination Markets, as well as to compare the route to its shortest and fastest alternative. The NAs Closest Facility Solver is set up and the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting a total of 150 routes are displayed below in Figure 4.13.

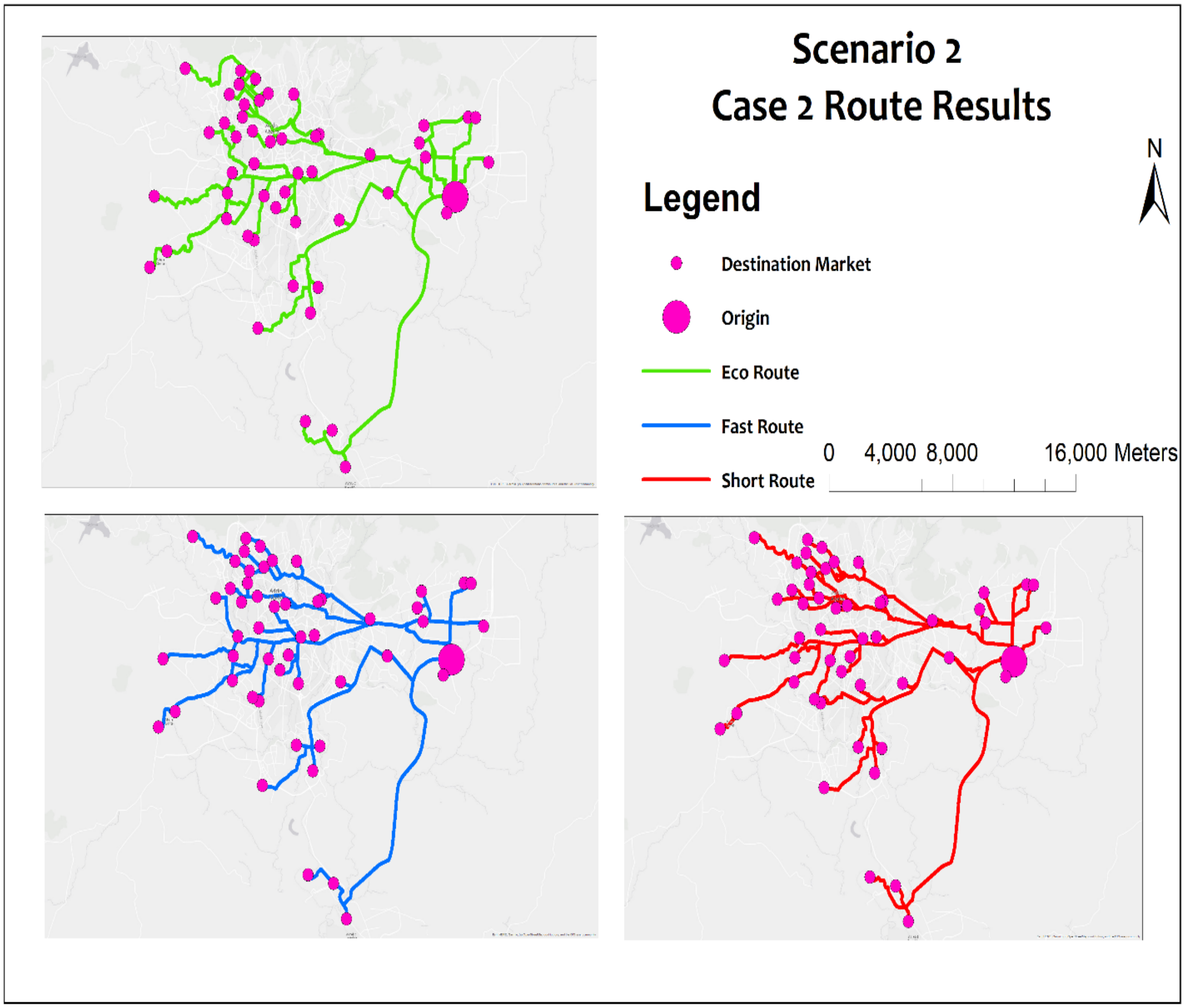

Figure 4.13: Scenario 2 Case2 Route Results

Table 4.9: Scenario 2 Case 2 Parameter Result

Routes	FC [L]	CO_2 [gm]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	72.110	37037.957	816.222	13.933	46.150
Fast Route	83.077	42671.032	750.186	10.715	53.169
Short Route	81.230	41722.138	737.035	11.807	51.987

The above table 4.9 results of case 2 illustrates Eco routes leading to significant FC and CO_2 saving potential of 13.201 % compared to the fastest and 11.227 % compared to the shortest route, further more cost of fuel saving potential of 13.201 % compared to the fastest and 11.227 % to the shortest route However, the travelled eco-routes distance is again higher than the shortest routes distance, as is operation time compared to the fastest route.

4.2.2.3 Case Study 3

The Third case under scenario 2 implements for the backhaul (CFLoad = 0.82) is implemented to account for empty returning trucks. From each market place to the origin, the eco-friendliest route and its alternatives are determined for its return journeys. The NAs Closest Facilty Solver is set up and the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting a total of 150 routes are displayed below in Figure 4.14.

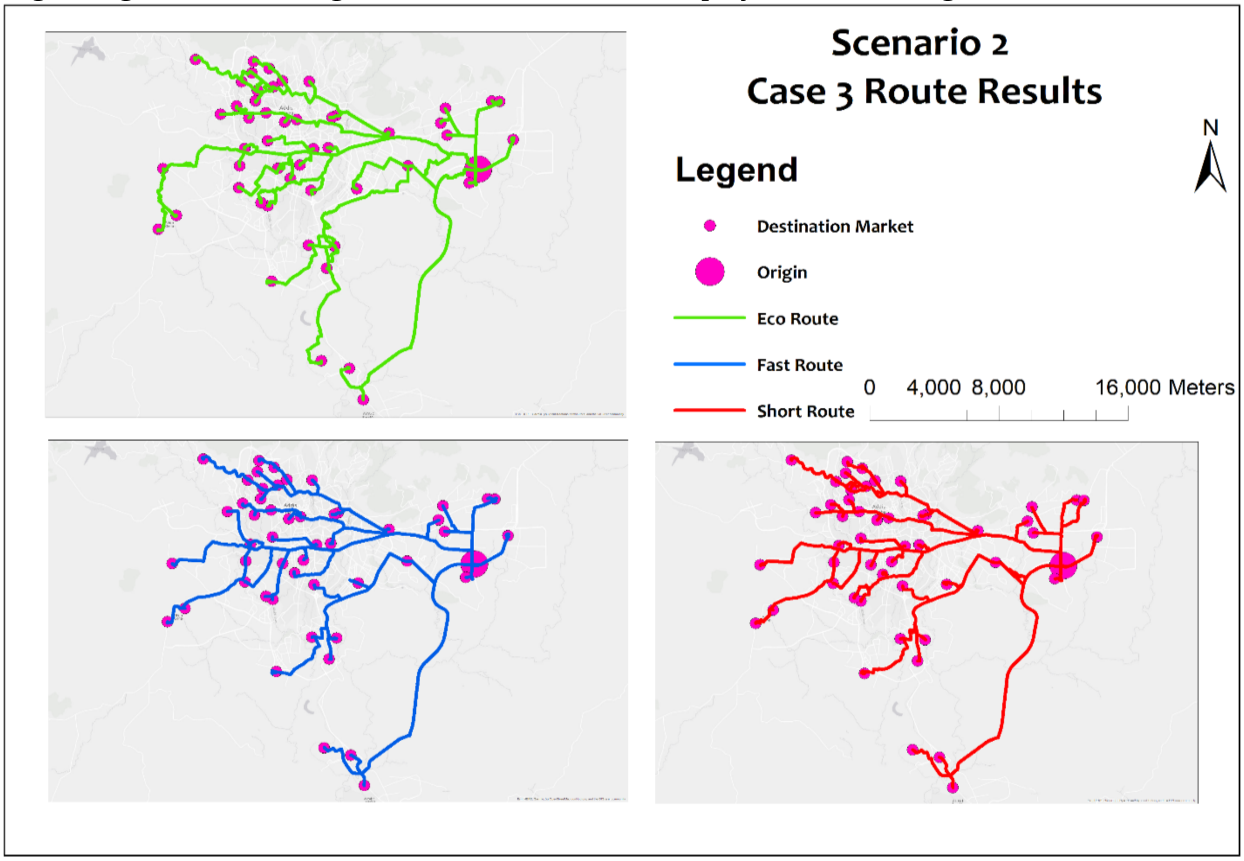

Figure 4.14: Scenario 2 Case 3 Route Results

Table 4.10: Scenario 2 case 3 Parameter Results

Routes	FC [L]	CO_2 [Kg]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	49.095	25216.771	796.291	13.648	31.420
Fast Route	53.931	27700.643	753.619	10.765	34.515
Short Route	54.440	27962.181	746.004	11.123	34.841

Again Similar to the above two cases eco routes prefer descending road-segments, leading to significant FC and CO_2 savings of 8.967 % compared to the fastest and 9.818 % compared to the shortest route, further more cost of fuel saving potential of 8.967 % compared to the fastest and 9.818 % to the shortest route However, the travelled eco-routes distance is again higher than the shortest routes distance, as is operation time compared to the fastest route.

4.2.3 Scenario 3

This scenario simulates the supply of a vehicle Gas (i.e., Diesel and gasoline) to the service station, which are utilized by Oilibiya private limited company. Which distribute 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.

4.2.3.1 Case Study 1

In this scenario 3 of case 1, the same implementation of as that of scenario 1 and 2 of case 1, as such This case under scenario 3 implements the supply of a single supermarket with a completely loaded (CFLoad = 1.18). MEET implements the same correction factor for all ranges of vehicles for loaded and unloaded vehicles, therefore this case determines the eco-friendliest route between the Origin (Depot) and a single service station, as well as to compare the route to its shortest and fastest alternative. The NAs New Route Solver is set up. And the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting routes are displayed in fig 4.15 below.

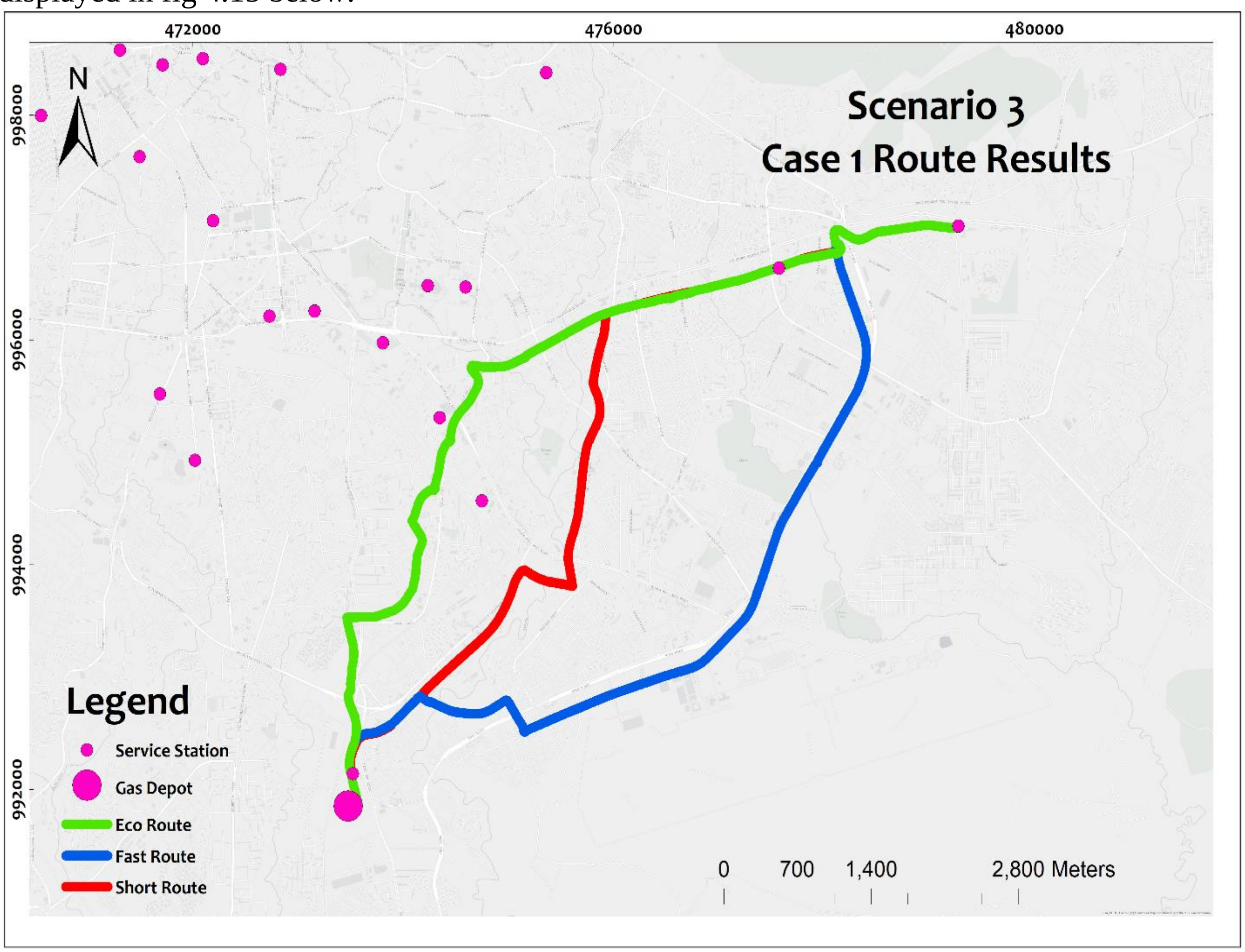

Figure 4.15: Scenario 3 Case 1 Route Results

Comparing the three routes it can be observed that the fastest routes tend to jump on motor ways(ring road) and shortest routes mainly utilizes principal arterial streets which are not optimized for FC, however eco routes utilize initially at gotera masalecha and tends to use sub arterial streets and local streets as shown in figure 4.15 above. all three routes partially overlapping at initial and destination kilometers. The shortest and fastest routes use ascending and descending segments, as the fast route maximizes the distance in contrast shortest route minimizes the distance towards the service station. However, the eco- the route is characterized through preferring descending road-segments, where the FC is minimized.

Table 4.11: Scenario 3 case 1 parameter results

Routes	FC [L]	CO_2 [Kg]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	3.764	1933.619	10.315	0.154	2.408
Fast Route	4.675	2401.623	10.398	0.141	2.992
Short Route	4.496	2309.357	9.976	0.145	2.877

Results of table 4.11 shows that eco routes prefer descending road-segments, leading to significant FC and CO_2 savings of 19.486 % compared to the fastest and 16.281 % compared to the shortest route, further more cost of fuel saving potential of 19.518 % compared to the fastest and 16.301% to the shortest route However, the travelled eco-routes distance is again higher than the shortest routes distance, as is operation time compared to the fastest route.

4.2.3.2 Case Study 2

This case 2 implemented 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 (CFLoad = 1.18). each service station is supplied by a single truck Based on the generated 3D RN, the objective of this case is to determine the eco- route between the depot and a service station, as well as to compare the route to its shortest and fastest alternative. The NAs Closest Facility Solver is set up and the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting a total of 81 routes are displayed below in Figure 4.16.

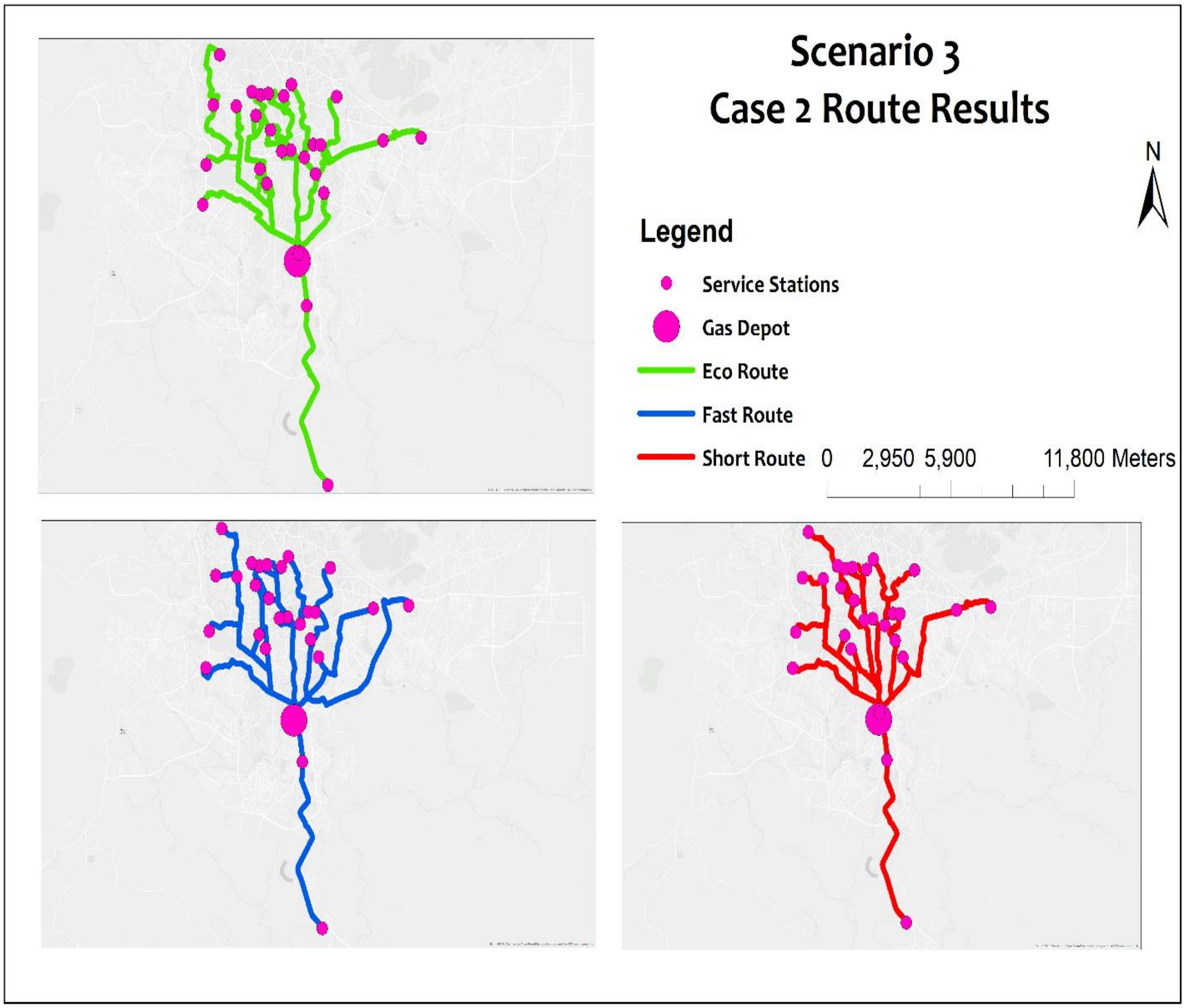

Figure 4.16: Scenario 3 Case 2 Route Results

Table 4.12: Scenario 3 Case 2 Parameter Result

Routes	FC [L]	CO_2 [gm]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	74.255	38139.809	192.833	3.089	47.255
Fast Route	85.149	43735.452	179.716	2.635	54.495
Short Route	92.043	47276.361	176.997	2.846	58.907

With parallel characteristics as in the previous scenarios the eco routes enable FC and CO_2 emission savings of 12.794 % compared to the fastest route and 19.325 % compared to the shortest route. furthermore, the cost of fuel saving potential of 13.285 % compared to the fastest and 19.780 % to the shortest route However, the travelled distance and time are significantly higher compared to its alternatives.

4.2.3.3 Case Study 3

This case implements for the backhaul (CFLoad = 0.82) to account for empty returning trucks. From each Service station to Depot, the eco- route and its alternatives are determined for its return journeys. The NAs Closest Facility Solver is set up and the routes are separately generated for the impedances of FC, 3D-Length and 3D time per Edge Length. The resulting a total of 81 routes are displayed below in Figure 4.17.

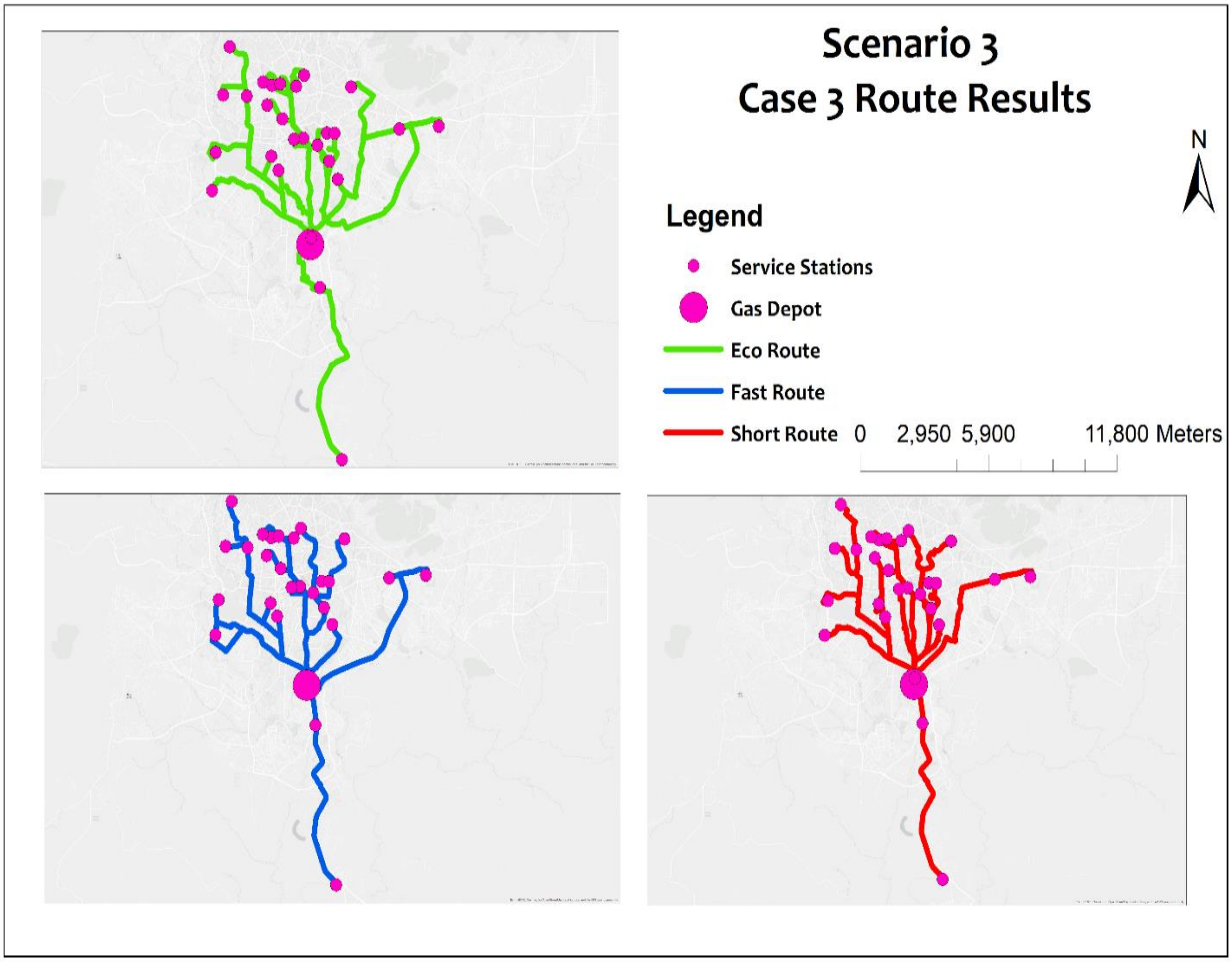

Figure 4.17: Scenario 3 Case 3 Route Results

Table 4.13: Scenario 3 Case 3 Parameter Result

Routes	FC [L]	CO_2 [Kg]	Distance [Km]	Time [Hr.]	Cost [$]
Eco Route	36.211	18599.399	189.506	3.071	23.175
Fast Route	39.528	20303.110	185.266	2.680	25.297
Short Route	41.438	21284.086	180.804	2.895	26.520

With similar characteristics of all the above scenarios, the eco routes enable FC and CO_2 emission saving potential of 8.391 % compared to the fastest route and 12.615 % compared to the shortest route. furthermore, the cost of fuel saving potential of 8.388 % compared to the fastest and 12.613 % to the shortest route However, the travelled distance and time are significantly higher compared to its alternatives.

4.2.4 Other Pollutants Result

Road transport has been identified as a major source of air pollution, especially in urban areas. for this study Emissions of pollutants from generated routes focused on Particulate matters (PM), Volatile organic compounds (VOC), Oxides of nitrogen (NOx) and carbon monoxide (CO). similar to fuel consumption and CO_2 emission on this stage different pollutants obtained from shortest and fastest routes compared with eco routes results are presented below.

4.2.4.1 Scenario 1 Pollutant Result

On this scenario the results are accumulated from scenario 1 which is generated for fuel consumption and CO_2 emissions. Emissions of the tested scenario routes focused on PM, VOC, NOx and CO emissions from Diesel HDV 3.5- 7.5ton results are obtained for each case.

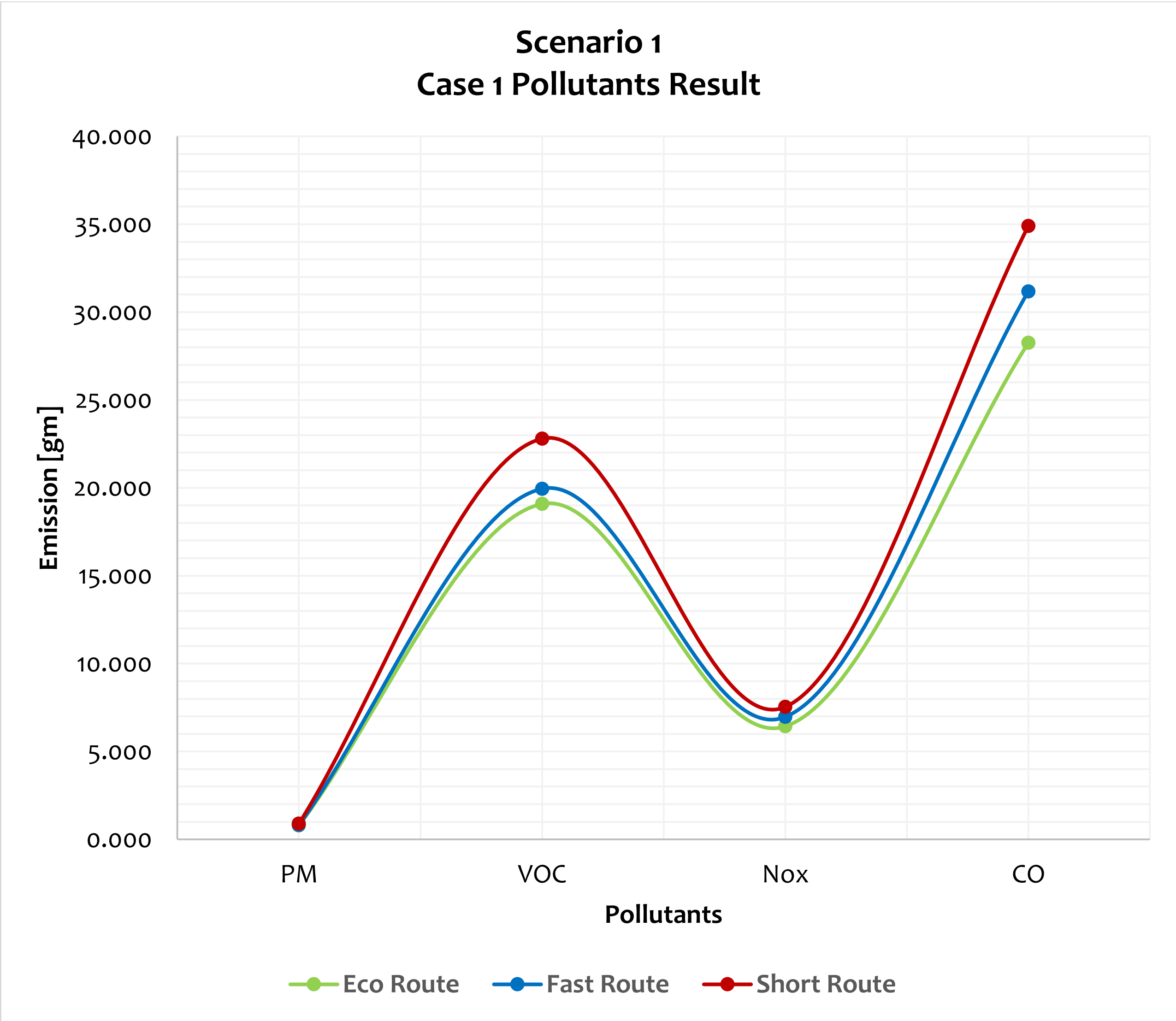

Figure 4.18: Scenario 1 case 1 Pollutant Result

Table 4.14: 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 dramatically use the same trend, in this scenario case 1, no significant changes in PM are observed, however PM has the lowest emissions.

The shortest distance is a strong factor for the total CO emitted. Regarding the trip, the shortest route of CO has high emission, but eco routes show significant emission saving potential therefore eco route is more environmentally friendly with respect to CO emissions.

The analysis of total emissions implies that eco routes have significant emission saving potential with respect to its alternative.

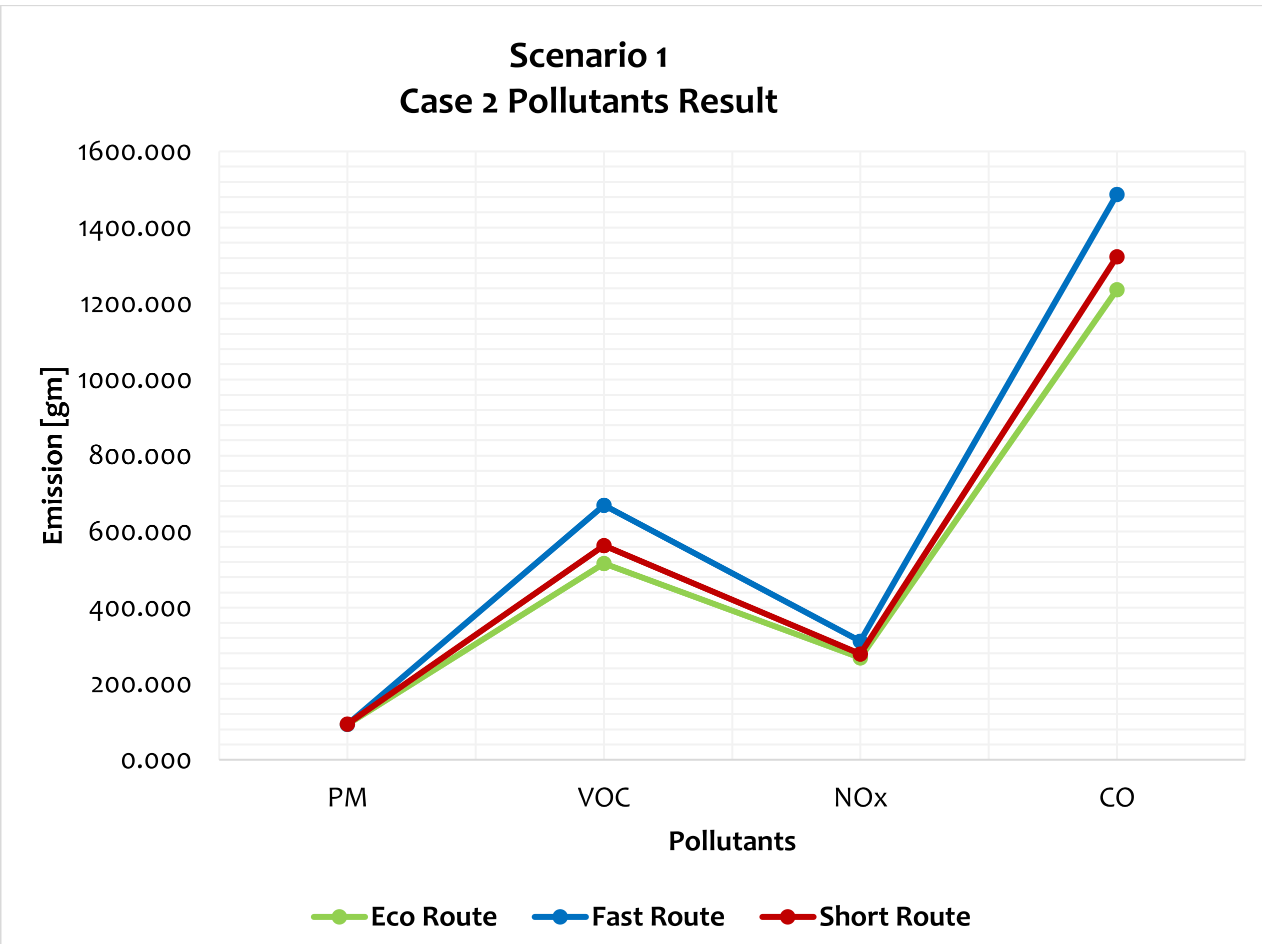

Figure 4.19: Scenario 1 Case 2 Pollutants Result

Table 4.15: 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 show again dramatically uses the same trend, in this scenario case 2, no significant changes in PM are observed, however PM has the lowest emissions.

The Fastest Route is a strong factor for total high emissions. Regarding the trip, Fastest of CO has high emission, but eco routes show significant emission saving potential in VOC therefore eco route are more environmentally friendly with respect to VOC.

The analysis of total emissions implies again eco routes has emission saving potential with respect to its alternative.

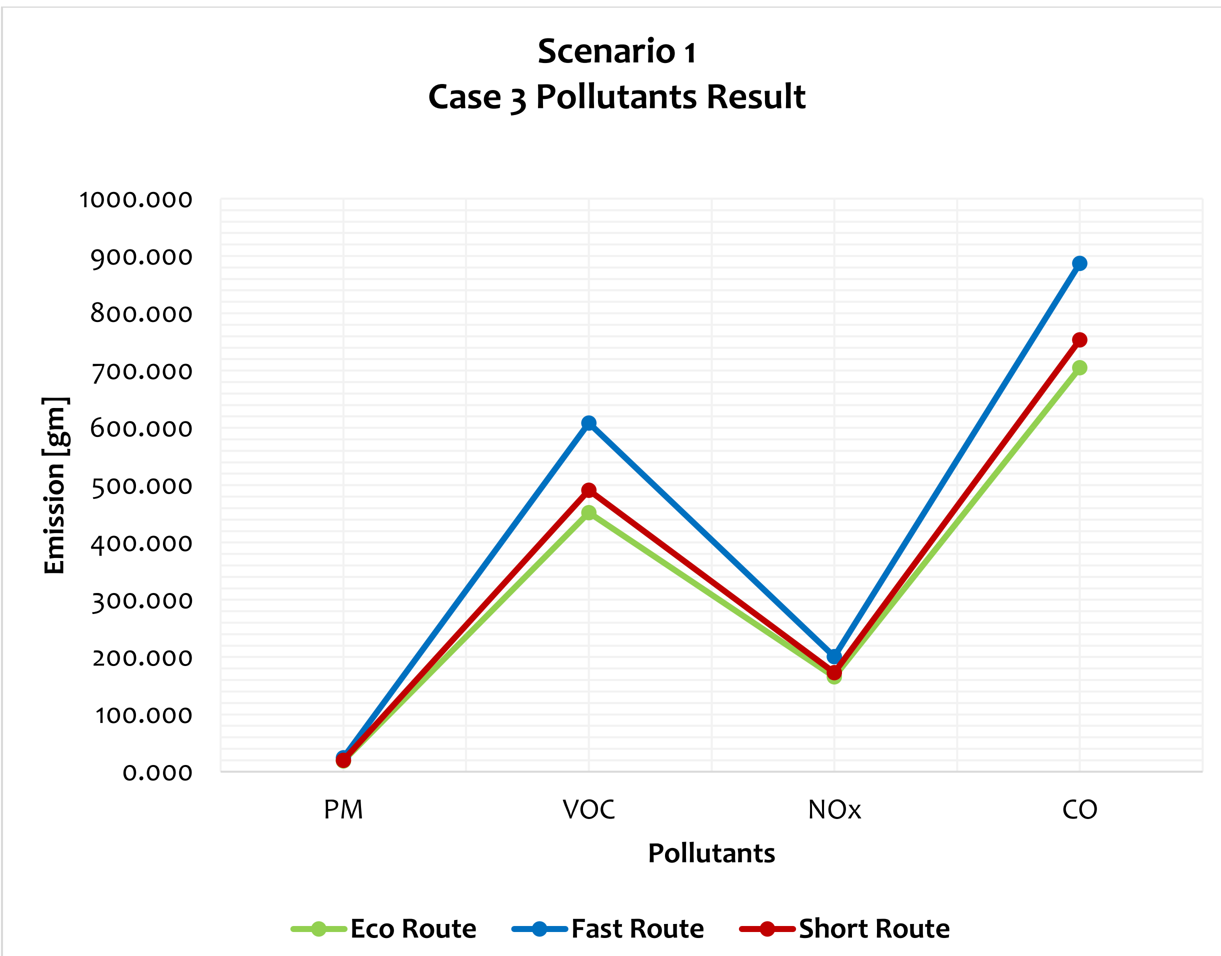

Figure 4.20: Scenario 1 Case 3 Pollutants Result

Table 4.16: 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 this scenario case 3, PM has the lowest emissions with respect to the other three pollutants.

The Fastest Route is a strong factor for total high emissions. Regarding the trip, Fastest of CO has again high emission, but eco routes show significant emission saving potential in VOC with respect to other therefore eco route is more environmentally friendly in VOC.

The analysis of total emissions implies again eco routes has emission saving potential with respect to its alternative.

4.2.4.2 Scenario 2 Pollutants Results

In this scenario the results are accumulated from scenario 2 which is generated for fuel consumption and CO_2 emissions. Emissions of the tested scenario routes focused on PM, VOC, NOx and CO emissions from Diesel HDV 7.5- 16ton, results are obtained for each case.

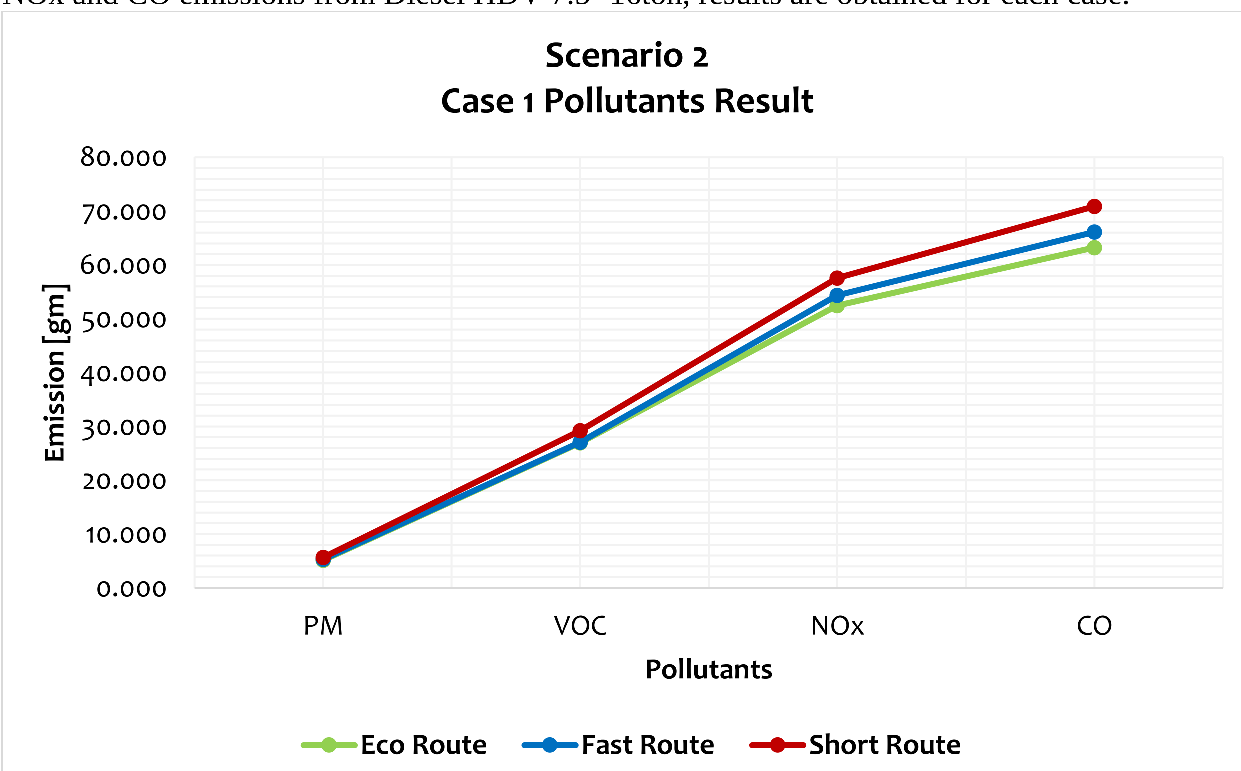

Figure 4.21: Scenario 2 Case 1 Pollutant Result

Table 4.17: Scenario 2 Case 1 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	2.909	0.389	3.547	4.36
From Shortest Route	9.186	7.797	8.897	10.795

In Case 1 of scenario 2 The three route results follow the same trend. From the result PM has the lowest emissions and the highest was CO.

The Shortest Route is a strong factor for total high emissions. Regarding the trip, the shortest route of CO has again high emission, but eco routes show significant emission saving potential in CO compared to others. therefore, the eco route is more environmentally friendly in CO.

The analysis of total emissions in this case implies again eco routes has emission saving potential with respect to its alternative.

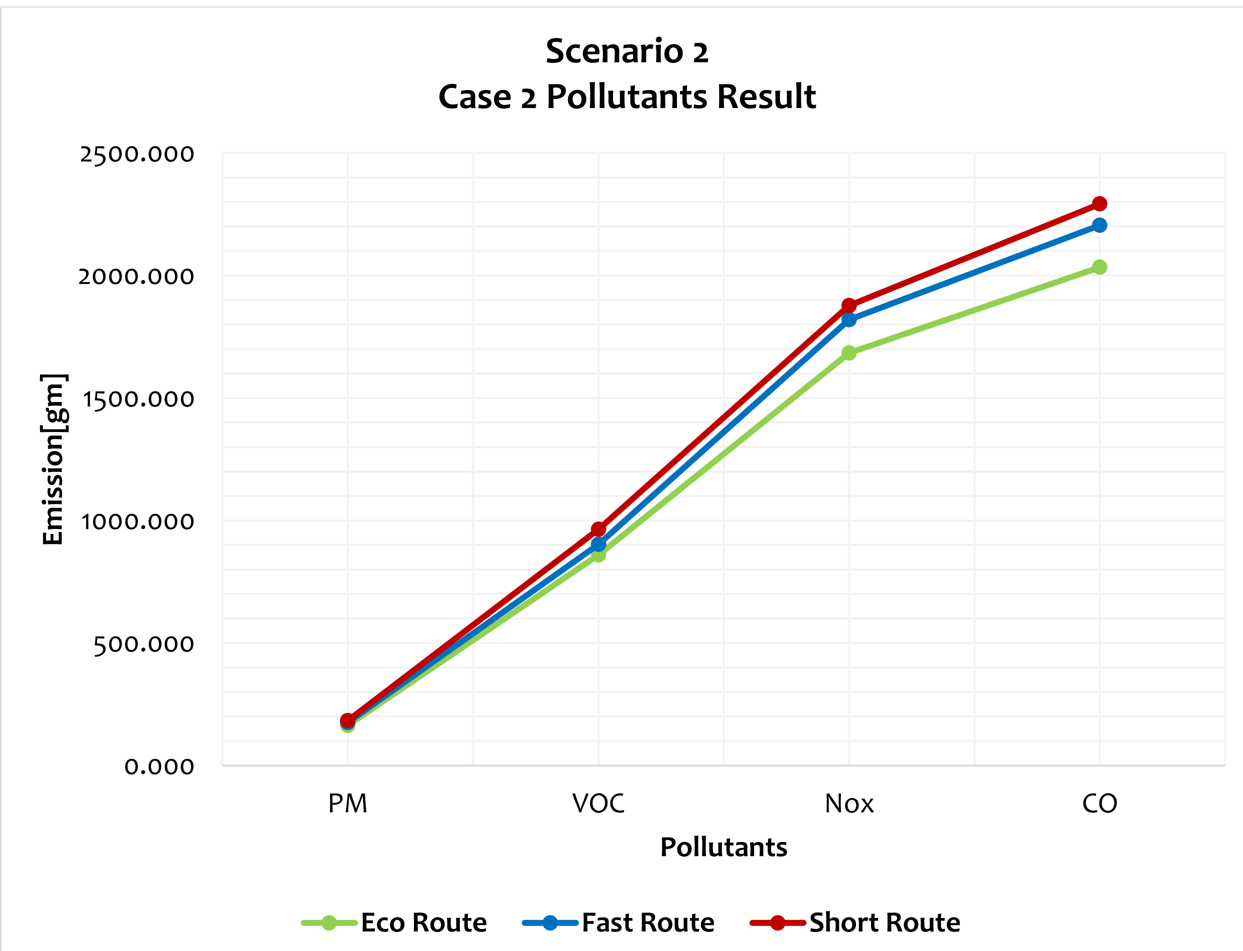

Figure 4.22: Scenario 2 Case 2 Pollutants Result

Table 4.18: Scenario 2 case 2 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	6.468	4.816	7.485	7.782
From Shortest Route	10.256	10.833	10.297	11.279

The three-route results in Case 2 of scenario 2 follow the same trend. From the result PM has the lowest emissions and the highest was CO.

The Shortest Route again in this case a strong factor for total high emissions. Regarding the trip, the shortest route of CO has again high emission, but eco routes show significant emission saving potential in CO compared to others. therefore, the eco route is more environmentally friendly in CO.

The analysis of total emissions in this case implies again eco routes has emission saving potential with respect to its alternative.

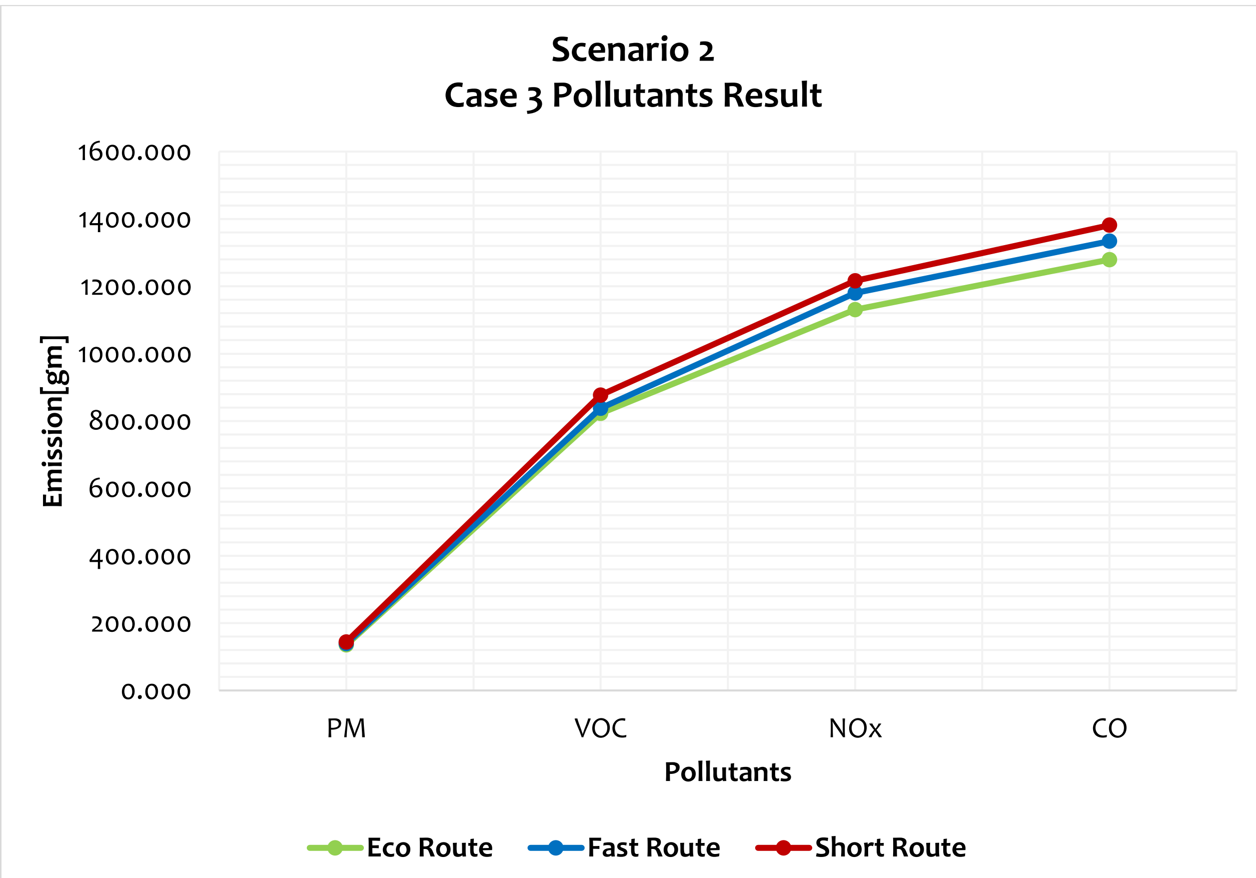

Figure 4.23: Scenario 2 case 3 Pollutants Result

Table 4.19: Scenario 2 Case 3 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	3.019	1.757	4.195	4.100
From Shortest Route	6.348	6.170	7.090	7.393

The three-route results in Case 3 of scenario 2 follow the same trend. From the result PM has the lowest emissions and the highest was CO.

The Shortest Route again in this case a strong factor for total high emissions. Regarding the trip, the shortest route of CO has again high emission, but eco routes show significant emission saving potential in CO compared to others. therefore, the eco route is more environmentally friendly in CO. The analysis of total emissions in this case implies again eco routes has emission saving potential with respect to its alternative.

4.2.4.3 Scenario 3 Pollutants Result

In this scenario the results are accumulated from scenario 3 which is generated for fuel consumption and CO_2 emissions. Emissions of the tested scenario routes focused on PM, VOC, NOx and CO emissions from Diesel HDV 16- 32ton, results are obtained for each case.

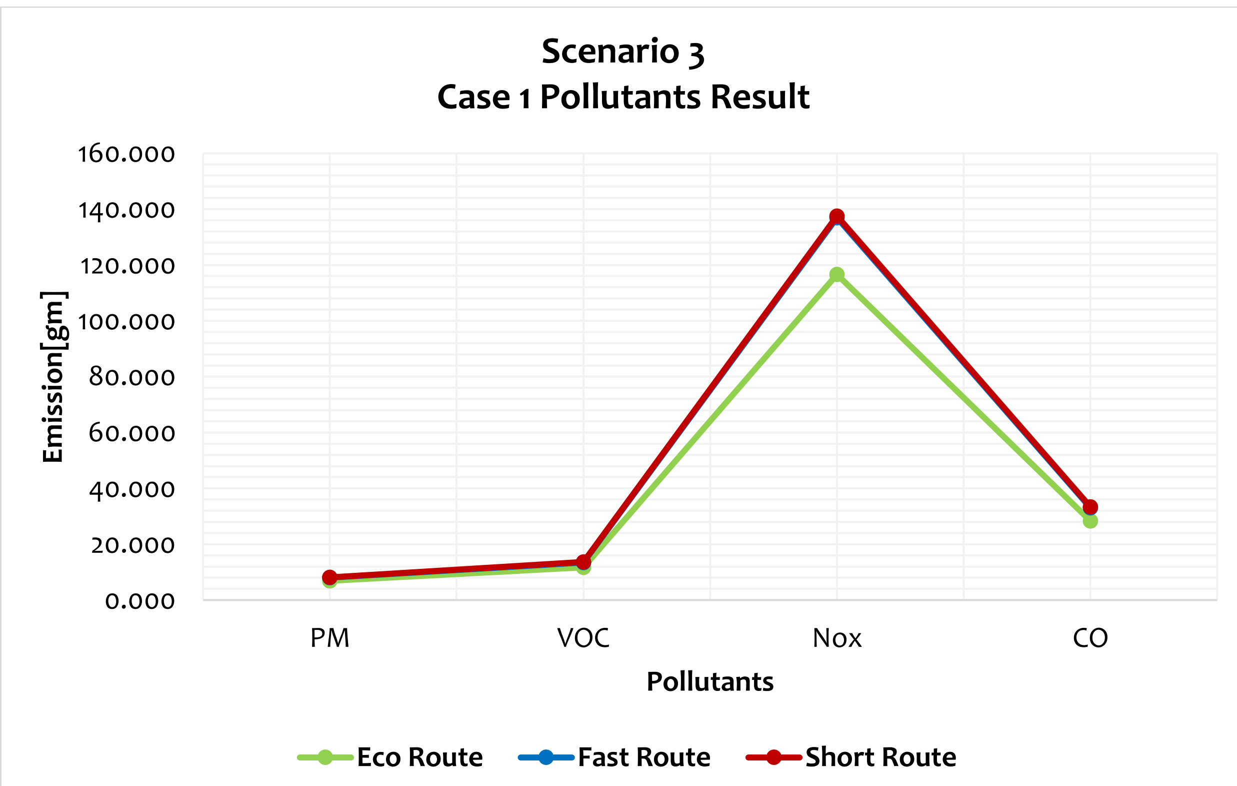

Figure 4.24: Scenario 3 Case 1 Pollutant Result

Table 4.20: Scenario 3 Case 1 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	14.252	13.288	14.853	14.339
From Shortest Route	15.020	14.683	15.229	15.053

The above results follow the same trend. From the result PM has the lowest emissions and the highest was NOx.

The Shortest Route again in this case a strong factor for total high emissions. Regarding the trip, the shortest route of NOx has again high emission, but eco routes show significant emission saving potential in NOx compared to others. therefore, the eco route is more environmentally friendly in NOx. The analysis of total emissions in this case implies again eco routes has emission saving potential with respect to its alternative.

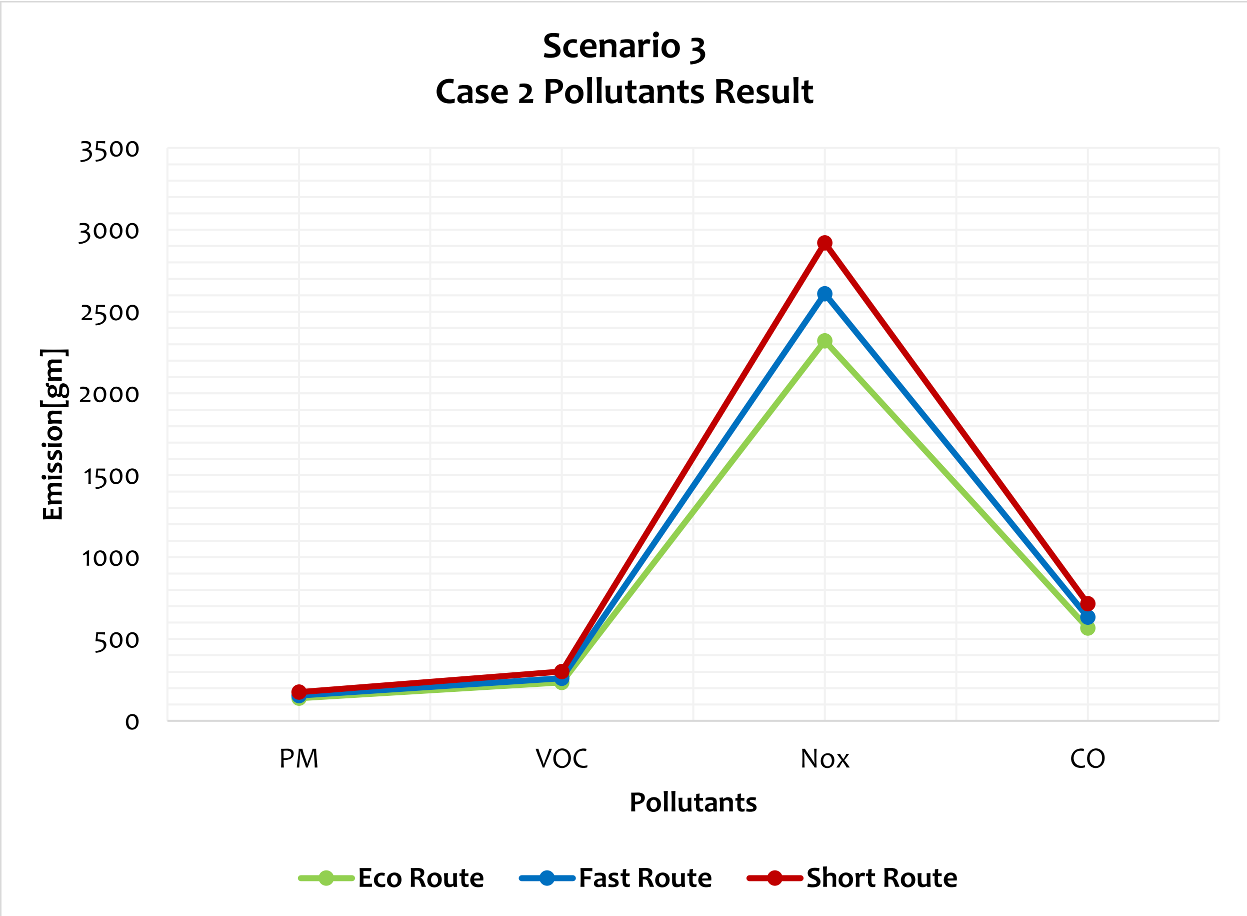

Figure 4.25: Scenario 3 Case 2 Pollutants Result

Table 4.21: Scenario 3 Case 2 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	10.514	9.608	11.042	10.596
From Shortest Route	21.082	22.103	20.488	20.988

The above results again follow the same trend. From the result PM has the lowest emissions and the highest was NOx.

The Shortest Route again in this case a strong factor for total high emissions. Regarding the trip, the shortest route of NOx has again high emission, but eco routes show significant emission saving potential in VOC compared to others. therefore, the eco route is more environmentally friendly in VOC. The analysis of total emissions in this case implies again eco routes has emission saving potential with respect to its alternative.

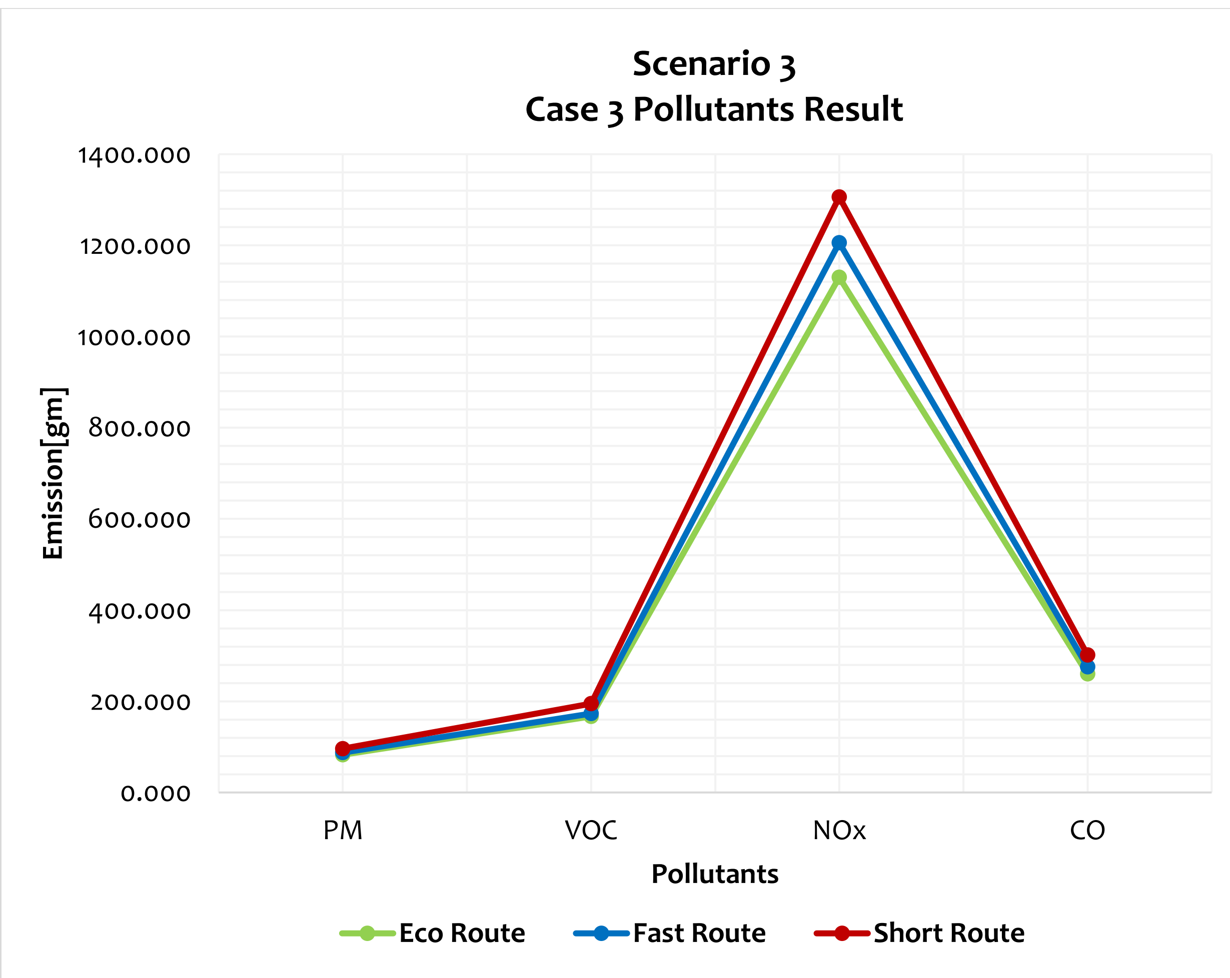

Figure 4.26: Scenario 3 Case 3 Pollutants Result

Table 4.22: Scenario 3 Case 3 Eco Route Emission Saving Potential

Eco Routes Pollutants Emission Saving Potential in %				
	PM	VOC	NOx	CO
From Fastest Route	5.373	3.728	6.308	5.520
From Shortest Route	13.860	14.46	13.504	13.804

This scenario results also shows eco routes having emission saving potentials, results again follow the same trend. From the result PM has the lowest emissions and the highest was NOx. From tested scenarios, shortest route of NOx has again high emission, but eco routes show significant emission saving potential in VOC compared to others. therefore, the eco route is more environmentally friendly in VOC. The analysis of total emissions in this case implies again eco routes has emission saving potential with respect to its alternative.

4.2.5 The correlation of Fuel Consumption and CO_2 Emissions

The correlation statistics of Fuel consumption and Carbon-dioxide Emission calculated per segment length shows the Pearson Correlation Coefficient = 1, this implies Strong Positively Correlated. The highest CO_2 emission occurred where fuel consumption is high and vice versa. The analysis result shown in fig 4.27.

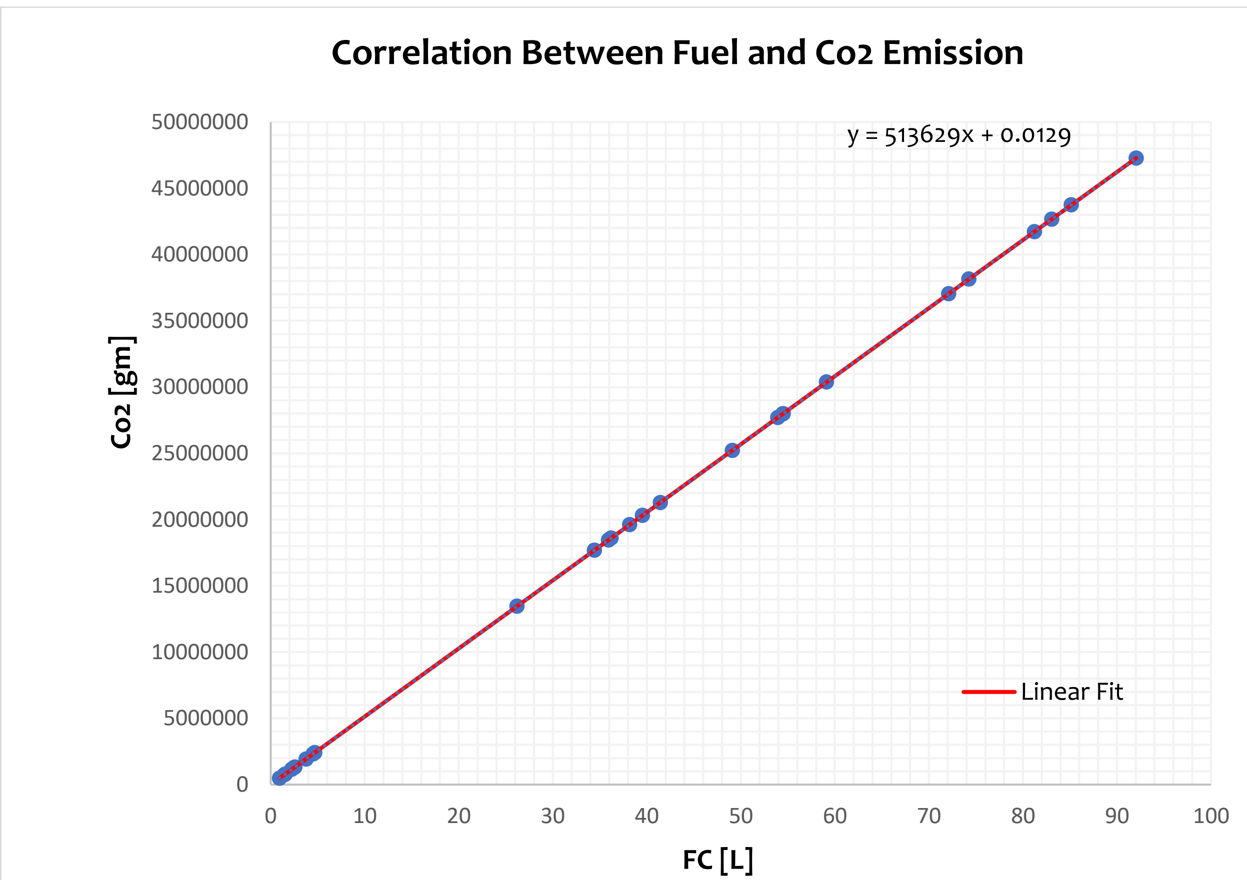

Figure 4.27: Correlation Between Fuel and Co2 Emission

4.2.6 Model validation

4.2.6.1 Gradient Validation

The generated DEM derived Gradients was validated by using 100 Random sample Points were collected from different street classes according to their permissible slope using Handheld GPS of 2m horizontal accuracy level, and then the collected sample tested by correlation analysis to conform the connection between Digital elevation model derived Grade and Actual Gradient on the ground and finally the correlation between them was tested ,and the relationship between them shows strong positive relation and the result shown in fig 4.28 below.

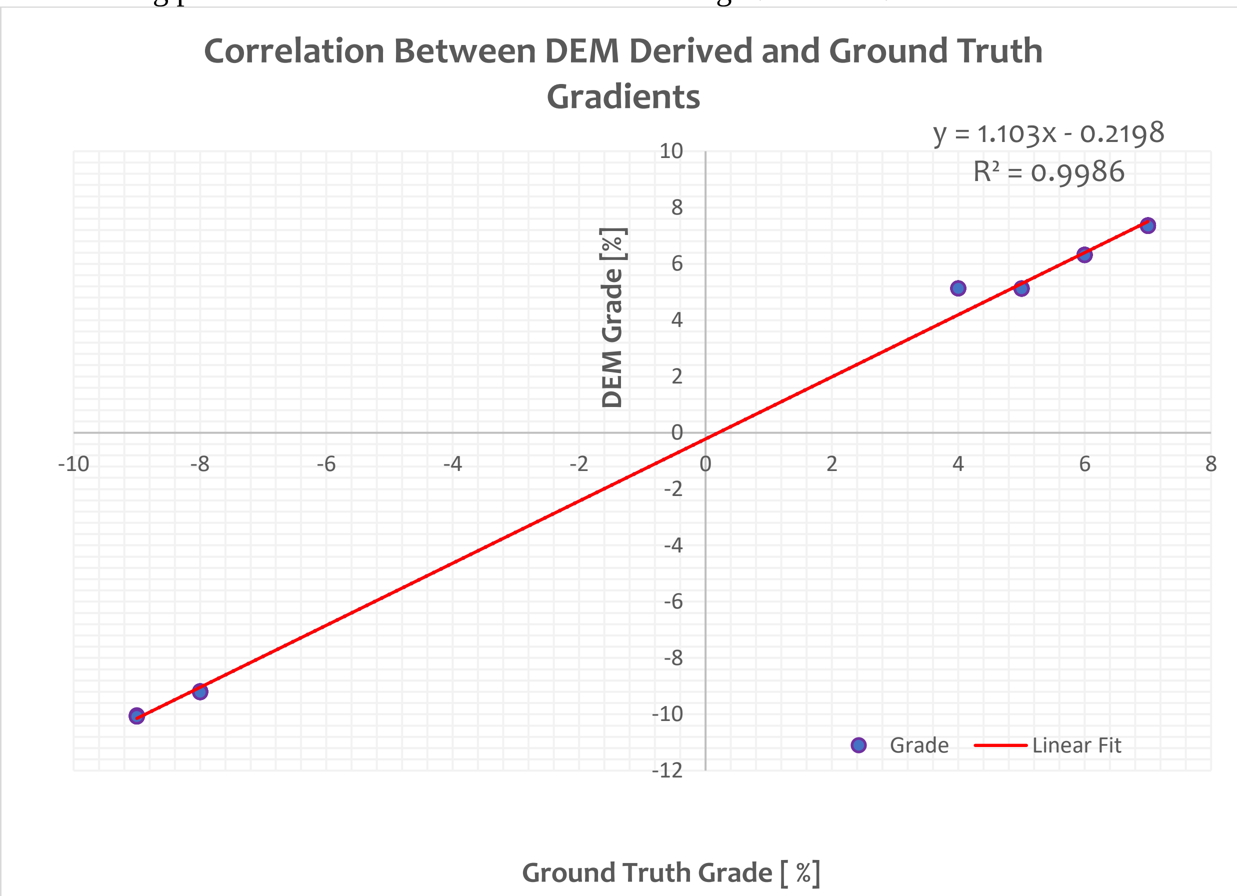

Figure 4.28: Correlation of DEM and Ground Truth Gradients

4.2.6.2 Accuracy Assessment

In addition to validation of gradients accuracy assessment was made to check the degree of reliability of the obtained Route results, Routes were displayed on B11 Retrieved Land surface temperature values to check whether the result was matched or not. this is because Band 11 was highly correlating with CO_2 values because band 11(11.50–12.51 µm) is closer to the 15-micron band of CO_2 (Reddy and Mandla 2016).

For assessment the eco route which has low CO_2 emission, the other two routes having moderate and high CO_2 emissions were displayed on land Surface temperature which having Low, Moderate and High Temperatures. shown on fig 4.29 and the result was validated by Statistical Method.

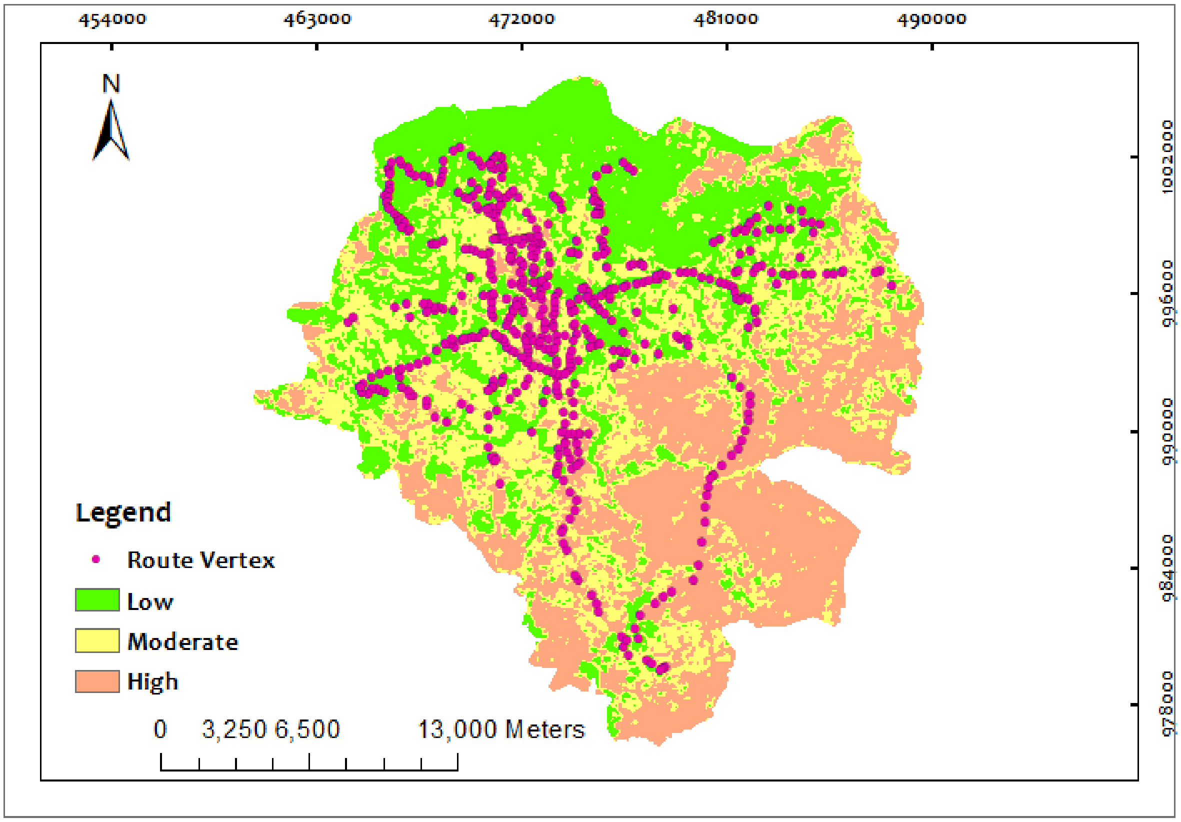

Figure 4.29: Accuracy Assessment

Table 4.23: Confusion Matrix

		Actual LST					
	CO_2 Labels	Low	Moderate	High	Row Total	User Accuracy	Commission Error
Route Result	CO_2 [Low]	258	16	3	277	0.93	0.07
Route Result	CO_2 [Moderate]	8	159	8	175	0.9	0.1
Route Result	CO_2 [High]	1	9	107	117	0.91	0.09
	Column Total	267	184	118	569		
	Producer Accuracy	0.96	0.86	0.9			
	Omission Error	0.04	0.14	0.1			

A. Overall Accuracy

Overall Accuracy is actually telling us out of all of the reference sites what proportion were mapped properly. The overall accuracy is sometimes expressed as a percent, with 100 percent accuracy being a perfect classification where all reference site was classified correctly. Overall accuracy is that the best to calculate and perceive but ultimately solely provides the map user and producer with basic accuracy info.The diagonal parts represent the areas that were properly classified. To calculate the overall accuracy, you add the number of correctly classified sites and divide it by the total number of reference site.

B. Errors of Omission

Errors of omission sit down with reference sites that were not noted (or omitted) from the right category with in the classified map. The real land cover type was not noted or omitted from the classified map. Error of omission is sometime also referred to as a Type I error. An error of omission in one class are going to be counted as an error in commission in another category. Omission errors are calculated by reviewing the reference sites for incorrect classifications. This is done by taking place the columns for every category and adding together the incorrect classifications and dividing them by the total number of reference sites for each class. A separate omission error is mostly calculated for every category. This will permit us to evaluate the classification accuracy and error for each class.

C. Errors of Commission

Errors of omission are in regard to the classified results. These refer sites that are classified as to reference sites that were neglected (or omitted) from the proper class within the classified map. Commission errors are calculated by reviewing the classified sites for incorrect classifications. This is done by going across the rows for every category and adding together the incorrect classifications and dividing them by the total number of classified sites for each class.

D. Producer’s Accuracy

Producer's Accuracy is that the map accuracy from the purpose of the map maker (the producer). This is yet are real features on the ground correctly shown on the classified map or the likelihood that a certain land cover of an area on the ground is classified as such. The Producer's Accuracy is complemented of the Omission Error, Producer's Accuracy = 100% Omission Error. It is also the amount of reference sites classified accurately divided by the total number of reference sites for that class.

E. User’s Accuracy

The User's Accuracy is the accurateness from the point of view of a map user, not the map maker. the User's accuracy essentially tells us how often the class on the map will actually be present on the ground. This is referred to as reliability. The User's Accuracy is complemented of the Commission Error, User's Accuracy = 100%-Commission Error. The User's Accuracy is calculating by taking the total number of correct classifications for a particular class and dividing it by the row total.

From Matrix

Kappa Coefficient = $\frac{N*(\Sigma CP)-\Sigma(RT*CT)}{N^2-\Sigma(RT*CT)} = \frac{178196}{203799}$ = 0.874

Where: N = Total Pixel, CP = Number of correct Pixel, RT = Row Total, CT= Column Total

Table 4.24: Interpretation of Kappa

Kappa	Agreement
< 0	Less than Chance Agreement
0.01 – 0.20	Slight Agreement
0.21 – 0.40	Fair Agreement
0.41 – 0.60	Moderate Agreement
0.61 – 0.80	Substantial Agreement
0.81 – 0.99	Almost Perfect Agreement

According to the kappa gained, 0.874 implies almost perfect Agreement.

The Overall accuracy = $\frac{Number\ of\ Correct\ Pixel}{Total\ Pixel} = \frac{524}{560} =$ **92 %**

From the assessment the route results pass the acceptable kappa agreement and the overall accuracy.

All of the obtained results show that the fastest and shortest route having high fuel consumption and emission. But Eco-Routes in both directions (OD and DO) minimizes FC and Emissions, which is significantly higher on ascending Road-segments. Although the consideration of road inclination effects in the route optimization visibly embodies fuel and emission saving potentials. Pollutant emissions were taken into account this is another important aspect of the present work approaching the obtained results to real-life situations, for the studied case of the Different Distribution Vehicles in Addis Ababa, Ethiopia, it was possible to attain a considerable reduction in Emission due to the reduction of the total collection in fuel consumption and, consequently, reductions of the pollutant emissions (PM, VOC, NOx, and CO) However eco-Routes are longer and take more time, compared to its alternatives (shortest & fastest routes).

But the results show that Eco Routes have Fuel and CO_2 saving Potentials 8.391% to 39.818 % and from other pollutants emission saving potential up to 25.650% with Respect to the corresponding Routes from tested Scenarios, which make them Ecological Solution for More Sustainable Environment. The cost estimation results indicate that eco routes having a reduction of a total Fuel cost up to 39.858 %.

4.3. Discussion

The results of Fuel and Pollutants emission Reduction calculations clearly show the advantage of the proposed methodology. Such potentials are enabled by taking topographic influence as an additional degree of freedom into account.

According to the study objective, the applied model does not claim to calculate exact FC and emission values. Rather, the model aims to show how terrain influence the FC and Pollutants emission rates of different routes in the tested Scenarios. This study used to MEET emissions factors instead of COPERT default emission factors because they better reflect the characteristics of the Addis Ababa diesel fleet. According to the EEA emissions guidebook, FC and Pollutant emissions significantly vary for vehicles of various emission classes.

In this study the applied model, which can be previously presented in the methodology, extends the work of other authors publications in various ways. This work comprises three phases: phase 1 creates a 3D road network by means of the ArcGIS 3D Analyst extension; phase 2 calculates segment-wise fuel consumption and pollutants emission estimation along the entire road network; and phase 3 performs the optimization for different types of Distribution vehicles for minimum fuel consumption, Minimum Distance, and time by applying for the ArcGIS Network Analyst extension and finally the results were compared .

Where as in contraire Zsigraiova, Semiao, and Beijoco (2013) proposed a methodology to reduce operating costs and emissions in the collection and transportation routes of waste. The relevant parameters influencing fuel consumption and pollutant emissions, such as vehicle speed in different roads and loading weight, are taken into consideration Nevertheless, instead of optimizing routes for minimized fuel consumption and emissions, the authors merely compared the results in terms of emitted pollutants for the obtained results of routes for the optimization criterions of traveled time (i.e., fastest route) and distance (i.e., shortest route). The effects of road inclination on fuel consumption are neglected in this approach as well. And also, in Pan, Ballot, and Fontane (2013) proposed logistical mutualization at the strategic level (merging supply chains) was explored from the environmental point of view. With real data offered by two main French retail chains and through an optimization model, the study able to estimate the effect on reducing CO2 emissions by merging supply chains. In addition, two transport modes, road and rail, are considered in this paper. The conclusions arrived at in the paper show that the logistical mutualization proposed in this work is an efficient approach to reducing CO2 emissions, whereas the effect of road inclination was also neglected.

In (M. Schröder and Cabral 2019) The paper introduced a Geographic Information System (GIS) based 3D-Routing-Model, which incorporates models to estimate vehicle fuel consumption while taking effects, such as road inclination and varying velocities into account. The study proposed a model utilizes a Digital Elevation Model (DEM) to enrich a road network with elevation data. The 3D-Routing-Model is applied in different distribution scenarios within the framework of an artificial company in the Lisbon Metropolitan Area, Portugal to evaluate the effects of road inclination on vehicles fuel consumption and its proportional CO2-Emissions. Vehicle ranges incorporated in this study was <16ton and HDV > 32-ton Results indicate that eco-friendly routes can yield significant fuel and emission saving potentials of up to 20% in the tested cases. Where as in (Scora, Boriboonsomsin, and Barth 2015) The paper described the development of an eco-routing and navigation system for heavy-duty trucks, including underlying truck energy and emission model that accounts for vehicle weight, real-time traffic speed, and road grade. The results in this study show that the eco-routing system was able to predict fuel consumption saving 7.5% over the test routes. also in Tavares et al.(2009) The paper proposed the use of geographical information systems (GIS) 3D route modelling software for waste collection and transportation, which adds one more degree of freedom to the system and allows driving routes to be optimized for minimum fuel consumption. The model takes into account the effects of road inclination and vehicle weight. It is applied to two different cases: routing waste collection vehicles in the city of Praia, the capital of Cape Verde, and routing the transport of waste from different municipalities of Santiago Island to an incineration plant. The vehicle range incorporated in this study was HDV 7.5 – 16ton, the results indicate eco routes fuel saving potential up to 12% for a similar total travel distance.

This study resulting in fuel consumption and pollutant emission rates according to the areas of topographic characteristics. Whereas the tested scenario areas in the Addis Ababa road network characterized by a gradient range of around -8% to 8%. Therefore, the average fuel consumption of HDV with 16- 32 tons results in increased fuel consumption and CO_2 emission rate compared to HDV < 16 tons. Although taking the gradients of a road network into account to optimize for eco-routes, As the 3D-road network depicts inaccuracies in slopes values for certain cases as in residential streets which is mainly constructed with cobble stones and gravel road, the utilized ALOS PALSAR DEM (12.5m) used for slope generation. However, Digital terrain model (DTM) for the study areas and also DEM in high resolution is rare to find free of charge. The implementation of varying weight correction factors for loads as in scenarios generated manually in a network, but it is a matter to be addressed in future advancements of the model. In addition, the model can be extended by implementing different vehicle weight ranges which used to identify in which range of vehicles significantly increases fuel consumption and Pollutants emissions. Also, specific restrictions and parameters, according to any given scenario can be implemented via the Network Analyst, 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 companies distribution schedules considered. However as discussed above, several works implemented their models in the domain of a specific range of vehicles, whereas this model is applied to case studies in the domain of Broad vehicle weight ranges of distribution Vehicles.

As a result, this study methodology can calculate FC and 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 Co2 saving the potential of 8.391% to 39.818 % to its alternatives, also Pollutants emission saving potential 0.304 % to 25.650% to its alternatives. The cost calculation is based on fuel costs. therefore, the eco-route in all presented cases resulted in being the most economical route, being up to 39.858% more cheaper than its least cheap alternative. Therefore, a shift to eco-friendliest routes is the only realistic, if companies are forced to reduce their environmental foot print.

Finally, the obtained results are validated, the generated DEM derived Gradients was validated by using 100 Random sample Points were collected from different street classes according to their permissible slope using Handheld GPS of 3m horizontal accuracy level, and then the collected sample tested by correlation analysis to conform the connection between Digital elevation model derived Grade and Actual Gradient on the ground and finally the correlation between them was tested ,and the relationship between them shows strong positive relation therefore the result was acceptable. In addition to checking the degree of reliability of the obtained Route results, Routes were displayed on B11 Retrieved Land surface temperature values to show whether the result was matched or not. this is because Band 11 was highly correlating with CO_2 values because band 11(11.50–12.51 μm) is closer to the 15-micron band of CO2. Reddy and Mandla (2016). From the assessment the route results pass the acceptable kappa agreement and the overall accuracy.

CHAPTER FIVE
5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study provides applying a 3D- Eco Routing Model to Reduce Environmental footprint in the domain of Different Ranges of Heavy-Duty Distribution Vehicles, as well as to show the effects of road inclination on fuel consumption and CO_2 Emissions. The model was applied in three scenarios each scenario contains three case studies. this study confirmed the method used was capable in reduction of environmental footprint of vehicles in Addis Ababa City.

The consideration of road inclination showed how topographic characteristics influence the fuel consumptions and emissions. in the determination of eco- routes and fuel consumption estimations in the tested scenarios minimum fuel consumption and emission gained were the lowest gradient occurred and vice versa.

Emission saving obtained when shifting from the shortest 3D distance and 3D Time criterion to the lowest 3D fuel consumption optimizer. In the tested scenarios, considerable differences were observed between shortest, fastest and eco routes. under the same criteria in the tested scenarios Eco routes Fuel and Co2 emission saving potential observed up to 39.818 % from its alternatives. Moreover, the use of Eco routes can lead pollutants emission saving potential shown in the accumulated results of each scenario, up to 25.650% from its alternative routes.

Eco Routes were found to be a key factor in reducing Fuel consumption and emissions for all pollutants. 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 model for the lowest fuel consumption, when compared to that for the shortest 3D distance and time, resulting in fuel and emission saving even for a travelled distance and time was longer.

This study was importantly provided baseline information on carbon emissions in Addis Ababa City and explores the implications of transportation activities with respect to Emissions in a new manner that has not been previously undertaken. It suggests ways that the transportation sector might adjust its transport investment activities to reduce carbon emissions by utilizing Eco routes while fulfilling its mission to support equitable economic and social development.

5.2 Recommendation

This study mainly needs to recommend in Providing eco-information to road users and implication for upcoming smart technologies.

The study recommends the use of high-resolution digital elevation model and UpToDate road transport emission estimation models to estimate more accurate fuel consumption and emission values if respective direct fuel and emission measuring devices not available.

Due to the advancement of technologies in navigation systems, real time or historical average emissions per link, should be incorporated in routing algorithms to determine the routes with lower emissions. This complete information can be made available on navigation routing systems such as GPS devices and pre-trip planning software. Regarding this all drivers have access to information on emissions and if everyone would choose the most environmentally friendly routes.

This study recommends the use of Eco Routes, rather than Fastest and shortest routes, particularly where significant road gradients exist. When applying Eco route open to drivers traffic jams should be taken into account. It is important to estimate the externalities associated with a significant percentage of vehicles diverting to other roads.

Upcoming research should focus on providing the generated eco-information to travelers and examining their travel selections. It will be also necessary to analyze the route choice impact during peak hours to assess the emissions when the capacity of the infrastructure is limited. Eventually, an integrated platform composed of traffic, emissions and air quality models should be used to gather real time traffic data and deliver accurate eco-information to users.

References

"About ALOS - PALSAR." https://www.eorc.jaxa.jp/ALOS/en/about/palsar.htm (September 20, 2019).

"Addis Ababa city transport programs management office "http://www.tpmo.gov.et/(2019).

Andersen, Ove, Christian S. Jensen, Kristian Torp, and Bin Yang. 2013. "EcoTour: Reducing the Environmental Footprint of Vehicles Using Eco-Routes." *Proceedings - IEEE International Conference on Mobile Data Management* 1: 338–40.

"Automotive Industry | Internal Market, Industry, Entrepreneurship and SMEs." https://ec.europa.eu/growth/sectors/automotive/ (September 20, 2019).

Borge, Rafael et al. 2009. "Comparison of Road Traffic Emission Models in Madrid (Spain)." 2009.

Brief, Evaluation Knowledge. 2010. "Reducing Carbon Emissions from Transport Projects." (July).

"Climate change knowledge portal " https://climateknowledgeportal.worldbank.org (2019).

Demir, Emrah, Tolga Bektaş, and Gilbert Laporte. 2014. "A Review of Recent Research on Green Road Freight Transportation." *European Journal of Operational Research* 237(3): 775–93.

"Digital Elevation Models & Their Applications in Geological Studies." http://www.geol-amu.org/notes/rs12-4-1.htm (October 1, 2019).

EEA. 1999. "Emission Inventory Guidebook: Road Transport."

"Ethiopia Diesel Prices, 16-Sep-2019 | GlobalPetrolPrices.Com." https://www.globalpetrolprices.com/Ethiopia/diesel_prices/ (September 19, 2019).

"Explaining Road Transport Emissions." https://www.transport emission.com/ (September 19, 2019).

Greenhouse, Statewide On-road, Gas Emissions, and Climate Change Assessment. 2018. "Technical Report." (October).

Herzog, Timothy, and Hyacinth Billings.2016. "*Navigating the Numbers*."

"How Will the Future of Transportation Affect the Environment - Earthava." https://www.earthava.com/future-of-transportation-affect-environment/ (September 4, 2019).

Karadimas, Nikolaos V, Maria Kolokathi, and Vassili Loumos. 2007. "municipal waste collection of large items optimized with arc gis network analyst." 4(cd).

LAT/EEA. 2007. "COPERT 4 - Computer Programme to Calculate Emissions from Road Transport." (6): 54.

Lightbown, Patsy M., Spada, Nina. 2013. "Powered by TCPDF (Www.Tcpdf.Org) 1 / 1." *How languages are learned* 12: 27–40.

Minett, Claire F, A Maria Salomons, Winnie Daamen, and Bart Van Arem. 2011. "Eco-Routing:

Comparing the Fuel Consumption of Different Routes between an Origin and Destination Using Field Test Speed Profiles and Synthetic Speed Profiles." (February 2019).

No, E E A Report. 2016. "EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016." (21)

Pamu, Dragan, Ljubomir Gigovi, Ć Goran, and Miodrag Regodi. 2016. "Transport Spatial Model for the Definition of Green Routes for City Logistics Transport Spatial Model for the de Fi Nition of Green Routes for City Logistics Centers." (June).

Pan, Shenle, Eric Ballot, and Frédéric Fontane. 2013. "The Reduction of Greenhouse Gas Emissions from Freight Transport by Pooling Supply Chains." *International Journal of Production Economics* 143(1): 86–94.

Panahi, S, and M R Delavar. 2008. "A GIS-Based Dynamic Shortest Path Determination in Emergency Vehicles." 3(Supple 1): 88–94.

Reddy, Chejarla Venkatesh, and Venkata Ravibabu Mandla. 2016. "Quantification of LST and CO 2 Levels Using Landsat-8 Thermal Bands on Urban Environment." (September 2015).

Rosenqvist, Ake, Masanobu Shimada, Norimasa Ito, and Manabu Watanabe. 2007. "ALOS PALSAR: A Pathfinder Mission for Global-Scale Monitoring of the Environment." *IEEE Transactions on Geoscience and Remote Sensing* 45(11): 3307–16.

Schröder, Marc, and Pedro Cabral. 2019. "Eco-Friendly 3D-Routing: A GIS Based 3D-Routing-Model to Estimate and Reduce CO2-Emissions of Distribution Transports." *Computers, Environment and Urban Systems* 73(July 2018): 40–55. https://doi.org/10.1016/j.compenvurbsys.2018.08.002.

Schröder, Marc Frederic. "A GIS Based 3D-Routing-Model to Estimate And."

Scora, George, Kanok Boriboonsomsin, and Matthew Barth. 2015. "Research in Transportation Economics Value of Eco-Friendly Route Choice for Heavy-Duty Trucks." *Research in Transportation Economics* 52: 3–14. http://dx.doi.org/10.1016/j.retrec.2015.10.002.

Sensing, remote et al. 2015. "proposing a multi-criteria path optimization method in order to." xl: 23–25.

Tavares, G., Z. Zsigraiova, V. Semiao, and M. G. Carvalho. 2009. "Optimisation of MSW Collection Routes for Minimum Fuel Consumption Using 3D GIS Modelling." *Waste Management* 29(3): 1176–85. http://dx.doi.org/10.1016/j.wasman.2008.07.013.

"The Geography of Transport Systems." 2006. : 4–7.

Toro, Eliana, Antonio Hernando, Escobar Zuluaga, and Mauricio Granada-echeverri. 2016. "literature review on the vehicle routing problem in the green." (april 2017).

wang, haobo, and iain mcglinchy. 2009. "review of vehicle emission modelling and the issues for new zealand." (october): 1–13.

Winn, Michael T, and Michael T Winn. 2014. "No Title."

Zsigraiova, Zdena, Viriato Semiao, and Filipa Beijoco. 2013. "Operation Costs and Pollutant Emissions Reduction by Definition of New Collection Scheduling and Optimization of MSW Collection Routes Using GIS . The Case Study of Barreiro , Portugal." 33: 793–806.

Appendices

A. Scenario 1 Origin – Destination Locations

Origin	Company Name	Easting	Northing
1	Aqua Addis Bottled Water PLC	474102	995449

Destinations	Market Place Names	Easting	Northing
1	Habesh Super Market	469355	998842
2	Kolfe Tiwan	468970	999623
3	Juar Mini Market	470204	999845
4	Yeafet Market	471055	1000023
5	Merkato Market Place	470876	997882
6	Hirut Super Market	475262	998338
7	Muscrim Super Market	469347	997634
8	Teshome Super Market	471744	1000534
9	Solsis Super Market	471350	994849
10	Seyifu Super Market	469013	994438
11	Kedroan Kiosk	471742	999064
12	Negash Kiosk	472827	997868
13	Beimnet Kiosk	473174	999227
14	Mukemil Kiosk	469405	1000166
15	Wolela Kiosk	471495	996522
16	Elias Kiosk	470075	995476
17	Senbet Kiosk	468525	995579
18	Addisu Gebeya Market Place	470954	1001218
19	Shola Market Place	477318	997302
20	Asko Kidame Gebeya	466079	1001588
21	Enate Supermarket	473890	989509
22	Arihibu Supermarket	464394	994787
23	Ayu Supermarket	474120	984303
24	Tesfaye Supermarket	476472	980195
25	Wubit Supermarket	478289	979673
26	Hani Supermarket	475040	983042
27	Mohammed Dunkan Supermarket	474300	990222
28	Pharase Supermarket	479371	993954
29	Toyiba Supermarket	483813	996483
30	Wube bayitena Supermarket	488186	996408
31	AU Supermarket	478602	995396
32	Friendship Supermarket	476368	993545
33	Sifen Supermarket	481025	998589
34	Lemelem Supermarket	484663	999198

35	Sara Supermarket	475407	1000957
36	Abdulsemed Supermarket	476901	1001429
37	Seham Supermarket	471162	993692
38	Yabu Market	470128	991930
39	Akinahom Supermarket	470716	988766
40	Lite Supermarket	473506	994209
41	Genet Supermarket	472178	994099
42	Hadiya Supermarket	473435	996005
43	Betselot Supermarket	474711	994227
44	Petram Supermarket	471744	995215
45	Berekamil Supermarket	466546	992724
46	Berhanu Supermarket	464909	991963
47	Ferdos Supermarket	466024	995091
48	Afran Minimarket	469599	1000985
49	Weinshet Supermarket	470577	1001775

B. Scenario 2 Origin – Destination Locations

Origin	Company Name	Easting	Northing
1	Moha Soft Drinks Summit Plant	483791	994858

Destinations	Market Places	Easting	Northing
1	Tsgishet Hotel	469152	1000416
2	Derana Mexic Hotel	470658	998435
3	Embilta Hotel	471102	1000097
4	Umma Hotel	469023	995060
5	Green Vally Hotel	474974	998256
6	Ras Amba Addis View Hotel	474758	998151
7	Eliana Hotel	472558	998002
8	Aselefech Bar	470002	999191
9	Adane Bar	469586	998107
10	Sarem International Hotel and Spa	471676	1000463
11	Rose Hotel	468829	998872
12	Motora Hotel	470119	999871
13	Elily International Hotel	474514	996226
14	Concord Hotel	473437	993505
15	Komboloch Hotel	472180	994281
16	Solomon Hotel	473298	990033
17	Ghion Hotel	473599	996144
18	Rivera International Hotel	470998	987744
19	Bisrat Hotel	468976	993682

20	Ado Barina Restorant	472752	995118
21	Blue Nest Hotel	471406	994906
22	Heaven Hotel	470757	996662
23	Assab Hotel	471804	997856
24	Beacon Hotel	474401	988570
25	Alem Bank Hotel	464281	994901
26	Lidete Hotel	463983	991048
27	Repia Menafesha Hotel	465110	991923
28	Antera Hotel	467847	998348
29	Timetrey Hotel	466290	1001824
30	Ajait Hotel	469341	996168
31	Top view Hotel	478279	997163
32	Liya Hotel	481479	997787
33	Lemlem Hotel	484643	999185
34	Negash Hotel	485119	999164
35	Bayelign Hotel	481764	998725
36	Asidesach Hotel	470767	992518
37	Yilma Hotel	470347	992731
38	Momona Hotel	476283	993615
39	Nigat Hotel	479438	995063
40	Birhanu Hotel	483238	993994
41	Tesfu Hotel	485955	996739
42	Eliyas Hotel	481867	997016
43	Habesha Hotel	474899	989964
44	Eshetu Hotel	475814	982202
45	Akaki Mezinagna Hotel	476678	980206
46	Beza Hotel	474083	982693
47	Damo Hotel	469885	1001709
48	Mastern Hotel	469775	1000973
49	Kalifornin Hotel	470853	1001264
50	Paris Hotel	473320	1000430

C. Scenario 3 Origin – Destination Locations

Origin	Company Name	Easting	Northing
1	Oilibya Ethiopia	473476	991857

Destinations	Service Stations	Easting	Northing
1	OiLibiya Fuel Station Around Gotera	473519	992141
2	OiLibiya Fuel Station Around Estifanos	473805	995978
3	OiLibiya Fuel Station Around Stadium	473156	996260
4	OiLibiya Fuel Station Around Biherawi	472725	996216
5	OiLibiya Fuel Station Around Mexico	471686	995521
6	OiLibiya Fuel Station Around Mexico Orbis	472020	994931
7	OiLibiya Fuel Station Around Teklehayimanot	471493	997634
8	OiLibiya Fuel Station Around Tikur Anbessa	472191	997063
9	OiLibiya Fuel Station Around Around Gojam Verenda	471711	998449
10	OiLibiya Fuel Station Around Atikilt Tera	472093	998505
11	OiLibiya Fuel Station Around GoJam Verenda	471305	998581
12	OiLibiya Fuel Station Around Qebena	475357	998382
13	OiLibiya Fuel Station Around Paulos Medhanialem	469767	100005
14	OiLibiya Fuel Station Around Mesalemia	469468	998055
15	OiLibiya Fuel Station Around Torhayiloch	469119	995676
16	OiLibiya Fuel Station Around Sebategna	470558	997999
17	OiLibiya Fuel Station Around Sost Kuter Mazoria	468953	994100
18	OiLibiya Fuel Station Around Kaliti	474938	982970
19	OiLibiya Fuel Station Around Adey Abeba	473916	990090
20	OiLibiya Fuel Station Around Megenagna	477568	996643
21	OiLibiya Fuel Station Around Ras Mekonen Dildiy	473197	998862
22	OiLibiya Fuel Station Around Hilton Area	474231	996487
23	OiLibiya Fuel Station Around kasanchis sidistegna	474591	996474
24	OiLibiya Fuel Station Around Olompiya	474345	995312
25	OiLibiya Fuel Station Around Gurdshola	479272	997016
26	OiLibiya Fuel Station Around Piyassa	472832	998411
27	OiLibiya Fuel Station Around Wollo Sefer	474744	994570

D. Eco Route Driving Directions sample from scenario 1 case 1

Begin route Location 1 – specific market location

1: Start at aqua Addis water store 2: Go north Drive 31 m ~ < 1 min 3: Turn left Drive 95 m ~ < 1 min 4: Make sharp right Drive 241 m ~ < 1 min 5: Turn right on Africa Avenue / Bole Road Drive 235 m ~ < 1 min 6: Continue Drive 27 m ~ < 1 min 7: Bear left at Menelik II Avenue / Drive 375 m ~ < 1 min 8: Turn right on Ras Desta Damtew Street Drive 158 m ~ < 1 min 9: Turn left Drive 138 m ~ < 1 min 10: Turn right on Ras Mekonnen Avenue and immediately turn right Drive 191 m ~ < 1 min 11: Turn right on Ras Mekonnen Avenue Drive 1.3 km ~ 1 min 12: Continue on Chad Street Drive 1.1 km ~ < 1 min 13: Continue Drive 47 m ~ < 1 min 14: Bear right on Smuts Av Drive 592 m ~ < 1 min 15: Turn right on Dejazmach Balcha Aba Nefso Street Drive 492 m ~ < 1 min 16: Continue Drive 59 m ~ < 1 min 17: Turn right Drive 2.8 km ~ 3 min 18: Turn left at Fitawrari Habte Giorgis Street Drive 190 m ~ < 1 min 19: Turn left Drive 1.4 km ~ 1min

20: Turn right Drive 385 m ~ < 1 min 21: Bear right on Ring Road Drive 133 m ~ < 1 min 22: Turn left Drive 56 m ~ < 1 min 23: Bear right on New Ambo Road Drive 155 m ~ < 1 min 24: Turn left Drive 81 m ~ < 1 min 25: Turn right Drive 336 m ~ < 1 min 26: Turn right and immediately turn left Drive 213 m ~ < 1 min 27: Turn right and immediately turn right Drive 383 m ~ < 1 min

28: Turn left Drive 133 m ~ < 1 min 29: Turn left and immediately turn right Drive 179 m ~ < 1 min 30: Turn right Drive 317 m ~ < 1 min 31: Turn left Drive 65 m ~ < 1 min 32: Turn right Drive 102 m ~ < 1 min 33: Turn left and immediately turn left Drive 186 m ~ < 1 min 34: Turn right Drive 139 m ~ < 1 min 35: Turn left Drive 136 m ~ < 1 min 36: Turn right Drive 320 m ~ < 1 min 37: Turn right Drive 282 m ~ < 1 min 38: Turn left Drive 93 m ~ < 1 min 39: Turn right Drive 44 m ~ < 1 min 40: Turn left Drive 91 m ~ < 1 min 41: Turn left Drive 164 m ~ < 1 min 42: Turn right Drive 156 m ~ < 1 min 43: Turn right Drive 66 m ~ < 1 min 44: Turn left Drive 246 m ~ < 1 min 45: Make sharp left and immediately turn right Drive 392 m ~ < 1 min 46: Make sharp right Drive 131 m ~ < 1 min

47: Turn left Drive 184 m ~ < 1 min 48: Turn left Drive 99 m ~ < 1 min 49: Turn left Drive 285 m ~ < 1 min 50: Turn left Drive 110 m ~ < 1 min 51: Turn right Drive 225 m ~ < 1 min 52: Turn left Drive 77 m ~ < 1 min 53: Turn right Drive 69 m ~ < 1 min 54: Turn left Drive 152 m ~ < 1 min 55: Turn right and immediately turn left Drive 23 m ~ < 1 min 56: Turn right and immediately turn left

Drive 51 m ~ < 1 min 57: Turn right Drive 74 m ~ < 1 min 58: Turn left and immediately turn right Drive 288 m ~ < 1 min 59: Turn left and immediately turn right Drive 380 m ~ < 1 min 60: Turn left Drive 358 m ~ < 1 min 61: Turn right on Old Ambo Road Drive 113 m ~ < 1 min 62: Turn right Drive 70 m ~ < 1 min 63: Turn left and immediately turn right Drive 150 m ~ < 1 min 64: Finish at specific market location , on the left.

Total time: 23 min, Total distance: **17.2 km** End of route Location