Mitigating the Global Warming Potential of Vehicular Emissions in Murree

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Have been found satisfactory for the requirements of the degree of

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DEDICATED TO OUR BELOVED PARENTS,

FAMILY MEMBERS,

AND RESPECTED TEACHERS

Whose constant support and prayers have enabled us to achieve our goals

Abstract

This research focuses on the estimation of vehicular emissions in Murree and the calculation of their Global Warming Potential (GWP) in Carbon Dioxide Equivalent Tonnes which was subsequently used to develop scenarios that reduce the pollutant GWPs through improved modes of transportation. Vehicle surveys were carried out to enquire the type of car, its vehicular kilometres travelled, number of start-ups in a day and the number of occupants. A GPS data logger was installed in cars for 24 hours to store second-by-second data of the vehicle's speed, location along with its starting and stopping pattern. Traffic videos were also recorded to estimate the traffic pattern variation during different times of the day. Data was also obtained from sources at National Highway Authority, Punjab Highway Department for the number of vehicles entering Murree through the major routes for traffic flow analysis on-season and off season. Fleet files were then prepared using the traffic survey data. Vehicle Specific Power bins were also calculated by the method developed by Jimenez (1999) at MIT. This data was then input into the International Vehicles Emission software and the model was run to give us the pollutant emissions in Murree. These emissions were then used to calculate the emission factors in grams per kilometre travelled for each pollutant.

The Global Warming Potential in Carbon Dioxide Equivalent Tonnes for 20 years and 100 years was then calculated. The three scenarios that were then developed consisted of optimizing the occupancy rate by increasing the number of passengers in each vehicle, implementing Euro II standards for vehicles and ensuring compliance with Euro IV standards for vehicles travelling to Murree. The occupancy rate relied on decreasing the number of vehicles travelling to Murree thus, resulting in an overall decrease of the pollutant Carbon Dioxide equivalent emissions by 32%. In the Euro II scenario, the existing fleet was converted to vehicles that comply with Euro II emission standards as a minimum resulting in an overall percentage decrease of Carbon Dioxide equivalent emissions by 46%. For the third scenario, all vehicles in the existing fleet were converted to comply with the Euro IV emission standards according to EU regulations, as a minimum showing an overall percentage decrease of Carbon Dioxide equivalent emissions by 47%. Therefore, the highest GWP decrease was found to occur when vehicles complied with Euro IV standards as a minimum.

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LIST OF ABBREVIATIONS

BC	Black Carbon
BEF	Base Emission Factor
CDA	Capital Development Authority
CH_4	Methane
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPERT	Computer Programme to Calculate Emissions from Road Transport
EF	Emission Factor
EI	Emission Inventory
FTP	Federal Test Procedure
GHGs	Greenhouse Gases
GPS	Global Positioning System
GWP	Global Warming Potential
HC	Hydrocarbons
HDIP	Hydrocarbon Development Institute of Pakistan
I/M	Inspection and Maintenance
ICTA	Islamabad Capital Territory Administration
ISSRC	International Sustainable Systems Research Center
IVE	International Vehicle Emissions (Model)
LDV	Light Duty Vehicles
MOVES	Motor Vehicle Emission Simulator
MPFI	Multi-Point Fuel Injection
N_2O	Nitrous Oxide
NH_3	Ammonia

NHA	National Highway Authorities
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
OTAQ	Office of Transportation and Air Quality
PEMS	Portable Emission Monitoring System
PM	Particulate Matter
PH	Punjab Highway
SO_2	Sulfur Dioxide
SO_x	Sulphur Oxides
US-EPA	United States Environmental Protection Agency
VKT	Vehicle Kilometers Traveled
VOCs	Volatile Organic Compounds
VSP	Vehicle Specific Power

Introduction

1.1 Background:

Atmospheric pollution being harmful to both environment and human health, has an economic impact additionally (Sonawane *et al*., 2012; Franco *et al*., 2013). Considering its impact on human health, 3.7 million premature deaths were reportedly related to outdoor air pollution globally, in 2012 (World Health Organization, 2014). Road traffic emissions are established to be a major part of air pollution (Kanabkaew *et al*., 2013). Many source proportion studies have reported on road transportation sector to be responsible for urban particulate air pollution (Maykut *et al*., 2003 ; Querol *et al*., 2007). Due to increasing number of vehicles emissions are likely to increase in the future (Franco *et al*., 2013).

These vehicular emissions also have severe consequences like formation of tropospheric ozone (Nagpure *et al*., 2011), presence of suspended PM in air (Shah and Shaheen, 2007), acid rain, Greenhouse effect, formation of Ozone precursor pollutants etc. (Yu *et al*., 2009).
With the increase in vehicle numbers worldwide, pollutant emissions are bound to increase in the upcoming years, therefore it is imperative that they be quantified and environmental standards should be established for their decrease in developing countries like Pakistan.

1.2 Emissions from Vehicles:

Emissions from vehicles consist of many toxic air pollutants like Greenhouse Gases and Ozone precursors (Shrestha *et al*., 2013). Greenhouse Gases contribute towards Global Warming are included in Kyoto's protocol (1998) listing Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O) (Lee *et al*., 2013). Vehicles are thought to be responsible for up to 90% emissions from the transport sector (Nakata, 2003). In China, up to 85% Carbon Monoxide, 71% Nitrogen Oxides (NO_x) and 45% Volatile Organic Compounds emissions were present because of vehicular emissions (Zhang *et al*., 2013).

1.3 Emissions in Murree:

Murree is one of the most popular hill stations in Pakistan these days. In the recent years tourism has increased significantly in the Murree region due to improved road networks, pleasant weather and scarcity of recreational areas within cities of Pakistan. Easy availability of cars, better road infrastructure causing people to move with their families while ensuring privacy have also contributed to high vehicle based travelling. Moreover, the lack of alternate modes of transportation such as mass transit or a bus system also encourage high private vehicle based transportation. Vehicular emissions in Murree are also of significant impact since high altitude and temperatures are involved affecting combustion processes in a complex way, as emission rates of Carbon Monoxide and Volatile Organic Compounds also increase with altitude (Nagpure *et al*., 2010). Also, due to the presence of older and poorly maintained vehicles in the fleet, they are likely to emit more greenhouse gases while travelling to Murree. The lack of past studies also signifies the potential impact of the estimation of Vehicular Emissions in the Murree region which will enhance the understanding of pollutant gases from tourist vehicles.

1.4 Main Study Objectives

The research work was designed around the following objectives:

I. Estimation of pollutant emissions in Murree
II. Focusing on GWP pollutants (CO_2, CH_4, N_2O, NOx, VOCs & CO) in particular
III. Predicting the decrease in GWP of vehicular emissions by improved modes of transportation (Alternate scenarios having potential GWP benefits)

Literature Review

2.1 Background

Poor urban air quality has been exacerbated by increasing tourism, particularly in developing nations with the chief contributors being on-road vehicles (Lents *et al.,* 2005; Guo *et al.,* 2007 a; Yu *et al.,* 2009; Zhang *et al.,* 2013). The dynamics between tourism and carbon emissions were investigated revealing that significant technological improvements are required to offset tourism based carbon emissions (Sun Yen, 2016). Emissions from tourism are growing rapidly & policies are least concerned with tourism-related emissions (Stefan G, 2013).

Studying the influence of tourism on Greenhouse gas emissions has shown that tourism has a significantly negative impact on GHG emissions (Lee. *et al.,* 2013). A rise beyond 2°C of global warming may adversely affect tourism activities in areas with colder climates (Manolis *et al.,* 2016). Forecasting emission abatement policies from 2009-2030 discovered that highest emission reduction was under 'increased fuel economy' as compared to 'alternative fuel scenario' (Zhang *et al.,* 2013). Compared to private vehicles, public transportation produces 95% less CO, 45% less CO_2 and 48% less NO_2 than private vehicles (Shapiro, Hassett, & Arnold, 2002).

Heavy element such as Copper, Zinc, and Lead were found to be in high concentrations in suspended dust along the Murree Highway due to high traffic density (Naeem *et al.,* 2013). Petrol vehicles were found to be more polluting than diesel vehicles on the health effects of air pollution on school children in Murree (Pakistan EPA, 2006).

The comparison of transportation parameters for seven cities by IVE model concluded that higher average speed corresponds to lower emission factors while increasing diesel cars result in higher particulate matter emissions (Lents *et al.,* 2004). The lack of necessary resources and previous studies for the quantification of vehicular emissions and their Global Warming Potential emissions in Murree signifies the importance of this research.

2.2 Quantifying Vehicular Emissions

Methods of measuring vehicular emissions include determination of vehicular emission profiles and effect of operational variables (driving conditions/patterns, climatological variations, fuel quality etc.) either under controlled laboratory conditions or real-world conditions. Engine and chassis dynamometer test is undertaken in controlled conditions whereas real world condition tests include tunnel studies, remote sensing measurements, on-road and on-board measurements (Kuhns *et al*., 2004). Another approach of predicting vehicular emissions is the use of prediction models especially developed by USA and Europe. These emission models use factors such as vehicle type, driving pattern, local climatological condition, Inspection and Maintenance (I/M) program, and emission standard, to calculate transportation emissions (Franco *et al*., 2013; CARB, 2014; EEA, 2014; US-EPA, 2014).

Preparation of EI requires precisely calculated Emission Factors (EF) and such an exercise is, most of the time, highly dependent on resources. For example, direct measurement method such as the chassis dynamometer test in laboratories is simple but costly and only fewer vehicles can be tested (Kim Oanh *et al*., 2010). Other direct measurement methods include Portable Emission Measurement System (PEMS) (US-EPA, 2005), remote sensing (Chan *et al*., 2004), and on-road mobile laboratory (Zavala *et al*., 2006). These methods can be adopted in complete real world conditions on a larger number of vehicles, yet they may warrant sufficient resources.

On the other hand, indirect measurement methods include modeling of vehicular emissions which can also examine large number of onroad vehicles in near real world conditions. Generally, emission modeling relies on lesser resources and has been employed in several studies, and for this reason, traffic EI is usually prepared following the emission modeling approach (Davis *et al*., 2005; Kim Oanh *et al*., 2012). In emission modeling, individual vehicle emission measurements are not required thus the costly direct emission measurement tests are averted (Franco *et al*., 2013). Modeling can incorporate high number of default EFs for a larger number of vehicles having differing engine technologies, fuel types and exhaust emission control equipment that is usually observed in every vehicle fleet (Kim Oanh *et al*., 2012). Base Emission Factors (BEFs) used in emission models such as MOBILE (US-EPA, 2015), California Air Resources Board's EMFAC, and IVE model are derived from real measurements and from chassis dynamometer tests conducted in the U.S. (Guo *et al*., 2007 b).

Emissions models are mainly characterized as travel based or fuel based. The later type can use direct measurement methods to determine EFs per unit fuel consumed acquired from governmental records thus creating a fuel based emission inventory such as the COPERT model (EEA, 2000; Pokharel *et al*., 2002). In travel based models, region specific EFs and travel statistics are combined to produce EI such as in MOBILE, EMFAC, and the IVE model. The research trend has been found as moving towards combining emissions models with transportation and simulation models for more accurate estimates (Yu *et al*., 2009).

2.3 Factors Affecting Vehicular Emissions

Although vehicular emission profiles are highly dependent on vehicle technology type, driving pattern, and local geography and climate along with types of fuel used, but among them, the most important is the vehicle technology distribution when analyzing onroad vehicular emissions (Ntziachristos and Samaras, 2000; Huang *et al*., 2005). Vehicle technology type can be categorized by its engine size and air-fuel management technique, emission control method, type of fuel used, vehicle overall use and its age (Lents *et al*., 2004 a). Vehicle age is also considered to be an important factor with old vehicles generating more emissions as compared to newer ones. It is reported in the literature that in developed countries, up to 70 per cent emissions come from only the 10 per cent most polluting vehicles (Pokharel *et al*., 2002; Bishop *et al*., 2003 a; Bishop *et al*., 2003 b). While Guo *et al*. (2006) have attributed 60 per cent of emissions to 20 per cent of the vehicles that are older than 10 years. This also justifies the fact that deteriorating vehicle condition significantly increases pollutant emissions from vehicles as previously reported by Sawyer *et al*. (2000).

Another important factor is the driving pattern which is defined by a measured velocity profile of the local driving along with the number and times of starting the vehicle and distance traveled each day (Lents *et al*., 2004 a; Yao *et al*., 2007; Fu *et al*., 2013). Vehicles operating in variety of conditions produce a significantly transitory pattern with higher loads (e.g. acceleration and high speeds) giving off considerable amount of emissions (Davis *et al*., 2005; Franco *et al*., 2013). Local conditions affecting vehicular emissions include factors such as fuel characteristics, ambient temperatures and humidity, road elevation and grade along with local travel factors such as its demand and cost, traffic conditions and preference for the public transportation vehicles (Tong *et al*., 2000; Lents *et al*., 2004 b; Hao *et al*., 2011).

2.4 IVE Model & Its Aspects

The IVE model can be used for the estimation of dynamic vehicle fleet emissions based on driving pattern and technology distribution. The IVE model considers various technologies and local conditions prevailing in many developing countries along with their driving patterns. This include factors having a significant effect on tailpipe emissions such as average Vehicle Kilometers Traveled (VKT), Vehicle Specific Power (VSP) developed by Jiménez (1999) and different engine stress modes (Guo *et al*., 2007 a; Zhang *et al*., 2009). VSP is defined as the power required by the engine to operate the vehicle at a given speed and acceleration divided by the mass of the vehicle (Jiménez, 1999; Kuhns *et al*., 2004).

IVE model was designed keeping in view the needs of developing countries by providing a policy making tool (Lents *et al*., 2004 a). IVE model is considered flexible with respect to its application in developing countries (Nicole *et al*., 2005) and has been validated in several countries (Mishra and Goyal, 2014). Method for incorporating local fleet information in IVE model has been found low-cost with a facility of using data from other studies when local data is absent (CAI, 2014). Its application to some of the polluted cities has brought promising results (Kim Oanh *et al*., 2012).

IVE model is a versatile and easy-to-operate standalone Java computer program which is able to project vehicular emissions for any location provided three types of input i.e. (i) vehicle engine technology and exhaust control distribution of a fleet including maintenance, (ii) local driving pattern recorded on different types of vehicles (including vehicle soak distributions), and (iii) local emission factors particular to those vehicles.

(Wang *et al*., 2008). All these factors are considered to have a considerable effect on the exhaust emissions from a hot-stabilized gasoline-run vehicle (Guo *et al*., 2007 b).

Instead of using emission factors derived from average speed, as in MOBILE model, the IVE model is based on driving cycles developed from VSP bin distributions on a per-second level. IVE model consists of default emission factors for 1371 vehicle technology types. IVE model can be considered as the most accurate model for developing countries (Lents *et al*., 2001; Liu *et al*., 2007; Davis and Lents, 2010).

It (IVE model) is also termed as an international version of Motor Vehicle Emission Simulator (MOVES) which was developed by the Office of Transportation and Air Quality (OTAQ) as US-EPA's official model for estimating emissions from cars, trucks and motorcycles (CAI, 2014; US-EPA, 2015).

2.4.1 Emission Factors

Emission of pollutants relative to the activity producing them is given by experimental values termed as EF. These EFs can forecast the amount of a pollutant that will be released relative to the distance travelled, fuel consumed, or energy utilized for operation. IVE application includes the use of default emission factors together with collected local data. However, availability of locally measured emission factors is considered more appropriate and can be used to create adjusted emission factors in the IVE model.

EFs are affected by driving and ambient conditions, fuel characteristics, vehicle technology and emission control equipment (Franco *et al*., 2013). Their accuracy is of utmost importance when estimating vehicular emissions for a given area (Zhang *et al*., 2013).

2.4.2 Vehicle Specific Power

Unlike MOBILE and COPERT which use mean velocities (missing extreme emissions under high engine stress modes), IVE model uses VSP distribution to produce instantaneous emissions on a random driving cycle (Sawyer *et al*., 2000; Wang *et al*., 2008, Goyal *et al*., 2013). Variations in vehicular emissions with respect to variations in driving pattern and speed are best predicted by VSP (Huan *et al*., 2005; Lents *et al*., 2007 a). VSP has been shown to be closely related to vehicular emissions than the acceleration and/or speed (Jiménez, 1999; Kuhns *et al*., 2004; Wang *et al*., 2008). VSP characterizes the driving behavior with respect to the study area and can account for nearly 65 per cent variance in vehicular emissions (GSSR, 2004; Guo *et al*., 2007 b).

IVE model considers 60 VSP bins to account for different driving speeds and patterns. Different driving patterns produce different emissions and this variation is represented by 60 different bins of VSP (Lents *et al*., 2005). Every point of the driving route is assigned to a bin amongst 60 VSP bins which are further divided in 3 engine stress modes of 20 bins each, with each driving bin generating different emission rates. Local driving pattern can be measured by using global positioning System (GPS) which can give second-by-second vehicle location (Latitude, Longitude, and Altitude) and its second-by-second velocity traces (Barth *et al*., 1996; Liu *et al*., 2007). The experiments in the U.S. comparing GPS measured velocity profiles with average traffic velocities have validated the use of GPS for the determination of local driving patterns (Davis *et al*., 2005).

2.4.3 Vehicle Activity & Driving Patterns

Vehicle activity is also determined and subsequently used in IVE modeling, and includes determination of quantity and pattern of driving taking place in an area of interest together with the average number of vehicle start-ups. Vehicle driving patterns are obtained from the use of GPS devices fixed to subject vehicles followed by the determination engine power demand per unit vehicle mass to incorporate impact of driving pattern on exhaust emissions, this power factor (or VSP) is arranged over 60 respective VSP bins (Davis *et al.,* 2004). On the other hand, vehicle starts also contribute significantly towards total exhaust emissions and can be as high as 50 per cent of overall emissions in some cases. While in U.S., start-ups emissions contribute 10 to 30 per cent towards total emissions which underlines the importance of understanding vehicle starting patterns of an area for accurate emission projections (Lents *et al.,* 2004 b; Davis *et al.,* 2005). Cold start-ups are responsible for significant emissions from vehicle start and occur when an engine is completely cooled off (Schifter *et al.,* 2010).

Materials and Methods

3.1 Overall Methodology

For the study period of 4 months starting from November, 2016 and ending in February, 2017, the data was collected in accordance with the guidelines of the IVE supplementary manual "Field Data Collection Activities" (ISSRC, 2014). There were two phases in the data collection process: (i) Primary Data collection and (ii) Secondary Data collection.
The Primary Data collection phase included video recordings of the traffic at different points and vehicular surveys asking the odometer readings, make and models for determining the age of the vehicles, of the roads leading to Murree namely: (i) Old Murree Road (Punjab Highway Authority) and (ii) Murree Expressway (National Highway Authority). It also included GPS Data logging for recording the driving and starting patterns of different vehicles.
The Secondary Data collection phase included obtaining the road lengths, monthly traffic flow of these roads, weather information, fuel characteristics of the type of fuel used in Pakistan (Diesel and Gasoline) by the Punjab Highway Department (PHD), National Highway Authority (NHA), Pakistan Meteorological Department (PMD) and Hydrocarbon Development Institute of Pakistan (HDIP) respectively.

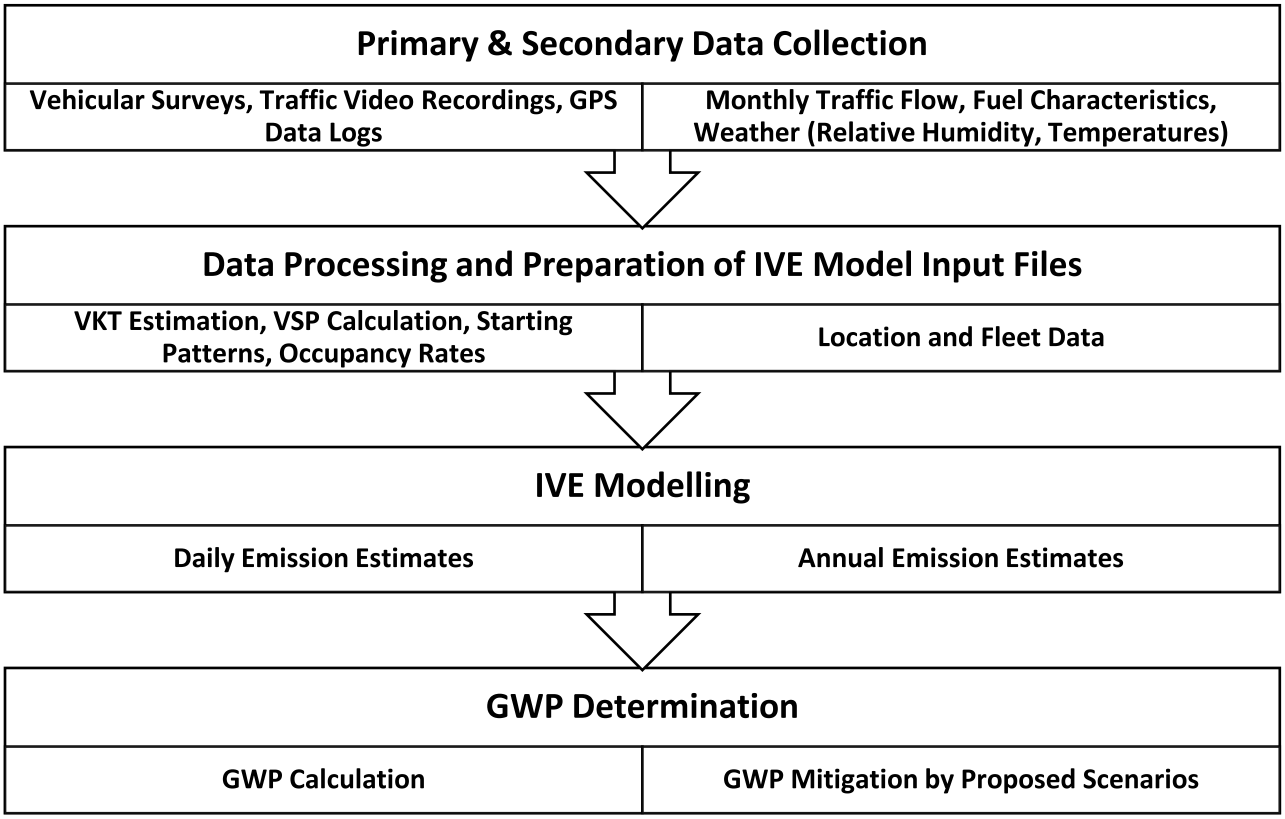


Figure 3.1: An overview of the overall research methodology.

3.2 Vehicle Engine Technology Determination

The engine technologies of the vehicles travelling were determined in a two-step procedure:

(i) Video Recording along the roads leading to Murree at selected locations to estimate per hour flow of different vehicles and their relative share in the overall traffic flow

(ii) (ii) conducting an already prepared questionnaire at certain points having truck stops, food courts or gas stations where people stop for food or filling their fuel tanks. Since all the traffic entering these roads (Old Murree Road and Murree Expressway) had to pass through the whole highway, at any point on a given day, the traffic flow would be exactly the same at another point on the highway, after a certain time.

3.2.1 Traffic Video Recording

The traffic at the selected points was video-taped and analyzed later. The hourly vehicular flow was distributed according to the vehicle's engine type and their relative share in the flow. Traffic video was recorded at different points from 8am to 6pm with the ratio of 20 minutes video recording per hour and the total flow per hour was estimated by multiplying the traffic flow (in 20 minutes) with 3. In this way, for one particular day a total of 200 video minutes were generated per day. A total of 1200 video minutes were analyzed during the process.

3.2.2 Vehicular Survey

For a better analysis of the different on-road vehicle types, vehicle surveys were conducted. A total of 1190 vehicles were surveyed, with almost equal fractions of all types of vehicles (530 public transport vans, 40 trucks, 330 private cars, 70 motorcycles and 220 taxis). For this survey, the owners/drivers of the vehicles were asked to fill the already prepared survey questionnaires which asked the year of registration, odometer readings, the types of fuel they used, make and model of the vehicles, assembly (locally manufactured or imported), engine technologies, whether they were equipped with catalytic converters or not, and were they functional, fuel injection system and the mileage of the vehicle. These surveys were conducted at or near the truck stops/gas stations/food courts where the videos were recorded, to have a representative data of the vehicles analyzed by video recording. For the development of a better understanding of the technical specifications of different engine technologies car mechanics, automobile engineers, online sources were consulted. After the survey, the vehicular age and the total annual usage was determined by comparing the total odometer readings with the number of years the car has been registered for.

3.3 Vehicle Driving Patterns

For the determination of the vehicular driving patterns, for different types of vehicles like private cars, public transport vans, taxis, motorcycles a GPS Data Logger (Global Sat DG-200) was used. This GPS Data Logger can store per second instantaneous velocity, location (latitude, longitude and elevation above sea level) and the Global Time of the corresponding Time Zone. The GPS Data Logger was installed in the vehicles for one whole day (24 hours) on the day when they when they traveled from Islamabad to Murree or Murree to Islamabad on both Old Murree Road and Murree Expressway. The vehicles whose driving patterns were recorded were passenger vans, taxis, motorcycles, trucks and private cars. The people who volunteered for this job daily traveled through either the Murree Expressway or Old Murree Road and were either students, public transport drivers, taxi drivers, government/private employees or businessmen. A total of 50,276 seconds of GPS Data was generated and then processed for the development of location Input files for the IVE Model. The GPS data generated was then used to create VSP bins that are required for IVE Modelling, calculated by Jiménez's developed method (1999) whose details are given in the Equation below.

$$\mathrm{VSP} = [1.1\mathrm{a} + \{9.81 \text{ x } \mathrm{atan}(\sin(\mathrm{grade}))\} + 0.132] + 0.000302 \text{ x } v^3$$

Where,

VSP: vehicle specific power (kW/ton)

a: vehicle acceleration (m/s^2)

v: vehicle speed (m/s)

Grade: vertical rise/slope length

The total VSP bins are distributed in three engine stress modes under a total of 60 VSP bins and each vehicular driving point can be attributed to a particular VSP Bin.

3.3.1 Determination of Occupancy and Vacancy Rates using Video Recording Analysis

Occupancy rate is the ratio of number of passengers in the car to the total passenger capacity of the car.

$$\boldsymbol{Occupancy\ Rate} = \frac{\boldsymbol{Number\ of\ Passengers\ in\ the\ Car}}{\boldsymbol{Total\ Passenger\ Capacity\ of\ the\ Car}}$$

Vacancy rate is the difference between maximum occupancy rate i.e. 1 (vehicle being driven at full capacity) and the occupancy rate of the vehicle.

$$\boldsymbol{Vacancy\ Rate = 1 - Occupancy\ Rate}$$

During the video analysis, the total passenger capacity of the vehicle was determined and the number of passengers was divided by the capacity, the occupancy and vacancy rate was determined for each vehicle. The average occupancy and vacancy rate for each vehicle type was determined to get a better overview of the number of passengers travelling per vehicle (according to the capacity) along the roads (Murree Expressway and Old Murree Road).

3.4 Road Lengths

The Road Lengths were obtained from the National Highway Authority and Punjab Highway Department for the Murree Expressway and Old Murree Road and they were 55km and 35km in length respectively.

3.5 Secondary Data Collection

The secondary data for input into the IVE Model location file was acquired from different resources and processed according to the research design. The data included the monthly vehicular flow according to different vehicle classes from both roads for the period of September, 2015 to October, 2016 acquired from the Punjab Highway Department (Old Murree Road) and National Highway Authority (Murree Expressway).

It also included the Fuel Characteristics of the fuel being used in Pakistan (Diesel and Gasoline) from the Hydrocarbon Development Institute of Pakistan (HDPI). The total road lengths were obtained for National Highway Authority (Murree Expressway) and Punjab Highway Authority (Old Murree Road).

The temperature and relative humidity data was obtained from the Pakistan Meteorological Department (PMD). The altitudes were estimated on the basis of GPS Data (obtained from the GPS Data Logger).

3.6 IVE Modeling

After analyzing the data collected, it was processed to prepare two input files for the IVE Model, namely:

(i) location files and

(ii) fleet files.

The fleet files pertain to the Engine Technologies, Vehicle Types and their relative share in the overall fleet and their relative share in the number of vehicles equipped with Air Conditioning Technology and its use, emission controls and their standards, mileage of the vehicles etc. The location files contain the information regarding the vehicle driving patterns, characteristics of the fuels in use, and meteorological factors. All the pollutants provided in IVE Model were calculated with the exception of Lead (Pb) which was phased out in Pakistan since 2005 (Faiz *et al*., 2009) which included criteria pollutants for Global Warming like CO, NOx, SOx, and Particulate Matter. Volatile Organic Compounds (evaporative and exhaust) were also selected as well as toxic pollutants such as 1,3 - Butadiene, Acetaldehyde, Formaldehyde, Ammonia (NH_3) , Benzene and Green House Gases (CO_2, NO_2, and CH_4).

In total, 1 location file and 1 fleet file was prepared for the analyzed vehicles on the selected roads. The total hourly and daily locations were estimated after thorough analysis of the total emissions by selected vehicle and road types, and according to the different times of the day. At the end, total emission factors for starting (g/start) and running emissions (g/km) for the individual vehicle types were estimated and subjected to analysis.

3.7 GWP Determination

3.7.1 Estimation of GWP for the pollutants

The GWP for the IVE pollutants was calculated by first finding the annual emissions in tonnes for each pollutant, followed by multiplying each pollutant with their Global Warming Potential for 20 years and 100 years. The values for the GWP for 20 years and 100 years used were as follows.

Pollutant	GWP 20 year	GWP 100 year
CO_2	1	1
N_2O	268	298
CH_4	72	25
CO	6	2
VOC	14	4.5
NO_x, per kg N	43	28

Table 3.1 GWP values (Kim Oanh *et al*., 2012)

3.7.2 GWP reduction by alternate scenarios

The global warming potential of vehicular emissions can be mitigated by improved modes of transportation which will depend upon designed scenarios that have a potential beneficial effect on GWP mitigation. Through these scenarios, a substantial GWP reduction was obtained.

The three scenarios that were worked upon were:

i. The Occupancy Rate Scenario

This scenario was focused at optimising the current occupancy rate and assuming an occupancy rate of at least 98% for passenger cars, jeeps, vans and hiaces travelling to Murree. This was done by looking at the current occupancy rate and redistributing the same number of people in lesser cars with a new occupancy rate of 98%. As the number of vehicles travelling to Murree decreased significantly this in turn resulted in a noticeable decrease in the GWP of pollutants.

ii. Euro II Scenario

The Euro II Scenario was contingent upon converting the existing fleet into vehicles that comply with the Euro II exhaust emission standards developed as part of the European Union framework for vehicles. The Euro II standards decreased the limit for carbon monoxide emissions as well as reducing the combined limit for unburned hydrocarbons and oxides of nitrogen for both petrol and diesel vehicles. The number of vehicles in the existing fleet remained constant but the models were changed to comply with Euro II emission standards or greater.

iii. Euro IV Scenario

Similarly, the Euro IV Scenario depended upon the conversion of the existing fleet into vehicles that comply with Euro IV exhaust emission standards. Euro IV emission standards are focused on cleaning up emissions from diesel cars, especially reducing particulate matter(PM) and oxides of nitrogen (NOx). As with the Euro II scenario, the number of vehicles travelling to Murree remained the same but the vehicle types were modified to those that complied with Euro IV exhaust emission standards or greater.

Results and Discussions

4.1 Video Recording, Occupancy Rates and Traffic Flow Analysis

4.1.1 Video Recording and Occupancy Rates

Out of the 20 hour videos analyzed, 3 locations belonged to one road (Murree Expressway) and 3 to the other (Old Murree Road). The total hourly average traffic flow was found to be 99 vehicles, as depicted in the table below:

Vehicle Type	Car/Jeep	Van/Hi-ace	Trucks	Bus/Coaster	Motorcycles
Per Hour Average	55	18	8	5	13

Table 4.1: Hourly traffic flow according to the vehicle type.

The occupancy/vacancy rates of vehicles were calculated for the analysed videos for a total sample of 1155 vehicles and the following results were obtained according to the types of vehicles:

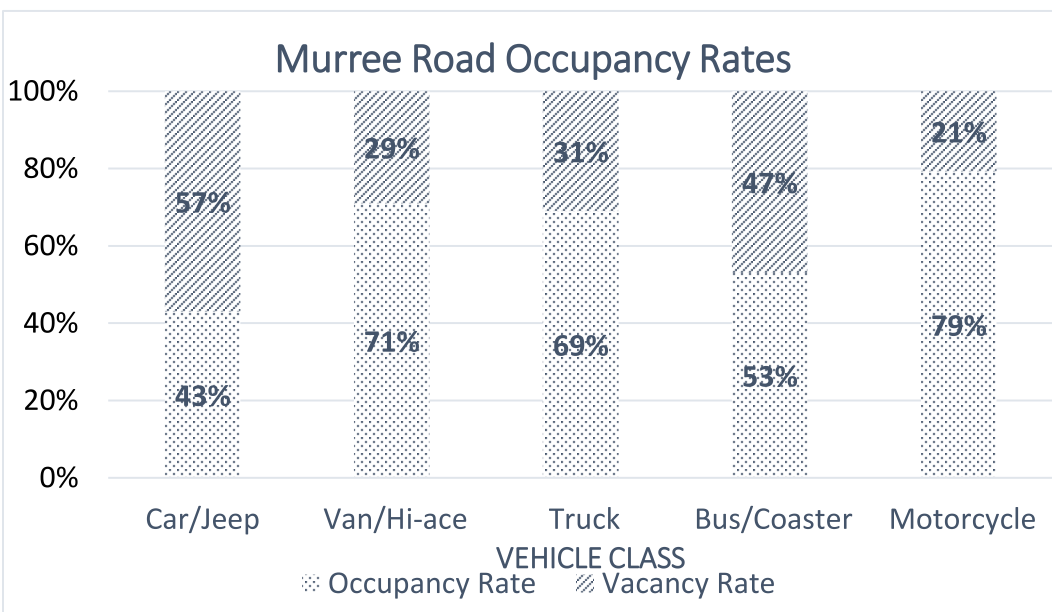


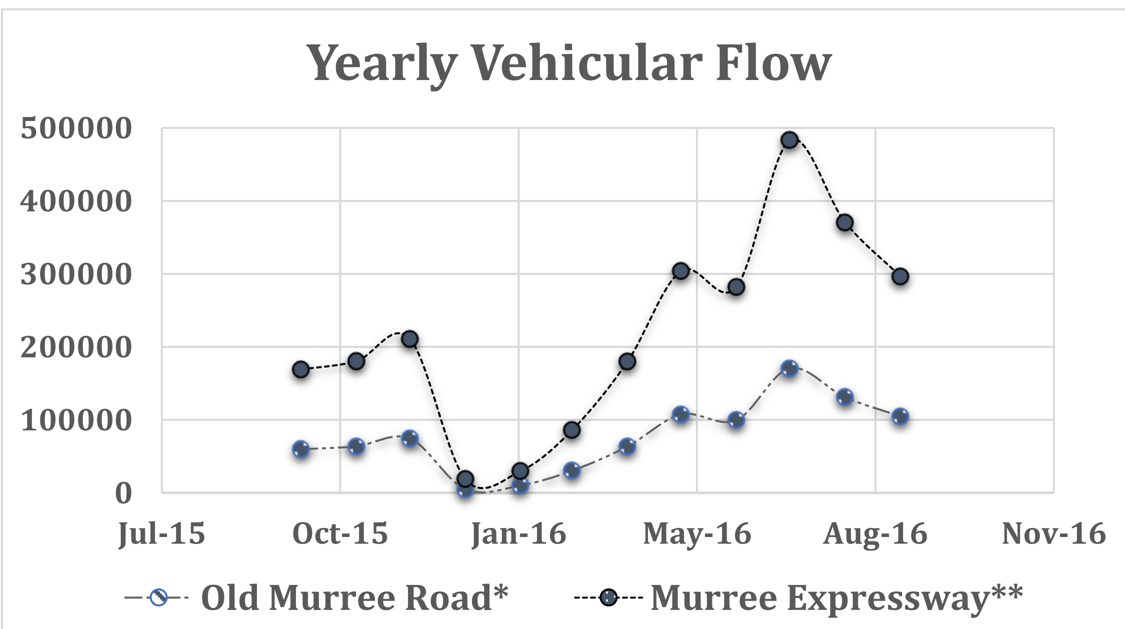
Figure 4.1: Occupancy/vacancy rates of different vehicles according to their types

As shown in the figure cars/jeeps had the highest vacancy rates of 57%, followed by buses/coasters with a vacancy rate of 47%, trucks with a vacancy rate of 31% and vans/hi-aces with a vacancy rate of 29% and motorcycles with the lowest vacancy rate of 21%.

The high vacancy rate of 57% for cars/jeeps and 29% of vans/hi-aces, was the reason these two vehicle categories were selected for change in the occupancy rate scenario. Their occupancy rates, currently 43% for cars/jeeps and 71% of vans/hi-aces were changed to 98% by redistributing the number of people in to lesser cars.

4.1.2 Traffic Flow Analysis from Secondary Data (Annual Flow and Per Month Flow)

After analyzing and processing the raw data obtained for per month traffic flow through Old Murree Road and Murree Expressway (from Punjab Highway Department and National Highway Authority respectively) a graph was plotted as follows:



*Courtesy of Punjab Highway Authorities
**Courtesy of National Highway Authorities

Figure 4.2: Annual traffic flow through Old Murree Road and Murree Expressway

The graph above shows the vehicular flow patterns throughout the year 2015-2016 for Old Murree Road and Murree Expressway obtained courtesy of Punjab Highway Authorities and National Highway Authorities, respectively. This graph clearly depicts that the Murree Expressway is a more popular option with vehicles peaking in the month of July with approximately 48, 400 vehicles in that month.

The traffic flow analysis according to the vehicle type gave us the following results:

Vehicle Type	**Car/Jeep**	**Hiace/Van**	**Bus/Coaster**	**Trucks(all)**	**Motorcycles**
Total	281730	146380	35620	276675	153620
Average (Per month)	23478	12198	2968	23056	12801

Table 4.2: Average traffic flow per month according to vehicle type.

A pie chart was made from the data to compare the relative share of each vehicle class in the fleet.

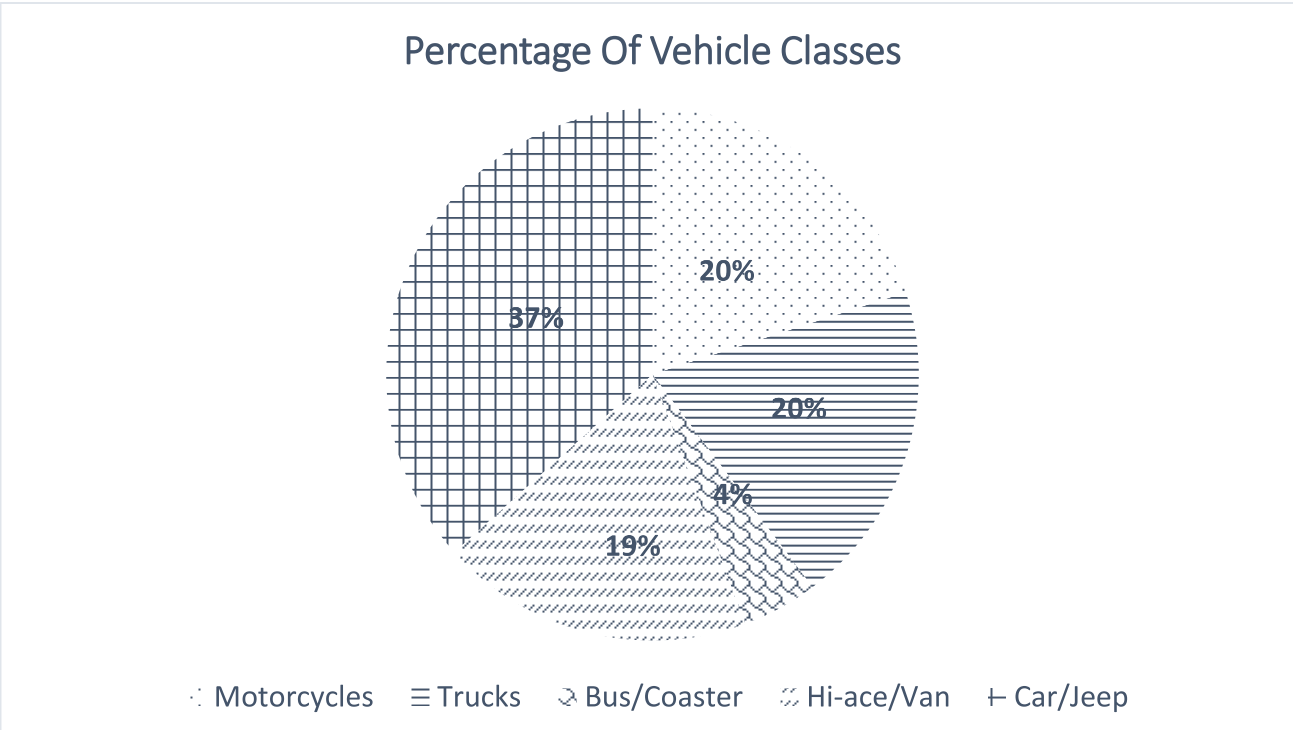


Figure 4.3: Share of different vehicle classes in the average traffic flow

The following pie chart depicts the percentages of vehicles according to the different classes showing that passenger cars have the largest portion of 37%, followed by motorcycles and trucks with a portion of 20 % each, vans/hiace with 19% and buses/coasters with a portion of 4% of road share out of a total of 1155 vehicles.

The share of 37% trucks in the analysed vehicles shows that they are mostly used for hauling supplies (ranging from Construction Material to everyday use items etc.) from the nearby cities of Rawalpindi/Islamabad. It can also be established that Private Cars/Jeeps have a fair share of 20% in the fleet which are mostly tourist owned. Also, the share of Buses/Coasters is very less in the fleet i.e. only 4% from which we can conclude that in the Murree Area, either Private Cars/Jeeps or Hi-ace vans are used for mass transit.

4.2 Vehicle Engine Technologies:

The data obtained by surveys and video recordings was processed and analyzed to determine the different Engine Combustion Technologies being used in the on-road vehicles, they were then matched to their corresponding IVE Index based on odometer readings, Engine Piston Displacement (for determination of Small, Medium or Large Engine Size).

The following are the classifications and the number of vehicles in each class and their relative share in the total sample (1155 vehicles):

Table 4.3: Vehicle classification and share present

IVE Index	Description of Technologies	% Share
0	Pt: Auto/Sm Tk : Lt : Carb : None : PCV : <79K km	0.108
1	Pt: Auto/Sm Tk : Lt : Carb : None : PCV : 80-161K km	0.0242
2	Pt: Auto/Sm Tk : Lt : Carb : None : PCV : >161K km	0.0435
46	Pt: Auto/Sm Tk : Lt : SgPt FI : none : PCV : 80-161K km	0.0416
49	Pt: Auto/Sm Tk : Med : SgPt FI : none : PCV : : 80-161K km	0.0042
50	Pt: Auto/Sm Tk : Med : SgPt FI : none : PCV : >161K km	0.0052
99	Pt: Auto/Sm Tk : Lt : MPFI : none : PCV : <79K km	0.124
100	Pt: Auto/Sm Tk : Lt : MPFI : none : PCV : 80-161K km	0.0381
101	Pt: Auto/Sm Tk : Lt : MPFI : none : PCV : >161K km	0.0069
102	Pt: Auto/Sm Tk : Med : MPFI : none : PCV : <79K km	0.0104
103	Pt: Auto/Sm Tk : Med : MPFI : none : PCV : 80-161K km	0.0075
104	Pt: Auto/Sm Tk : Med : MPFI : none : PCV : >161K km	0.0098
106	Pt: Auto/Sm Tk : Hv : MPFI : none : PCV : 80-161K km	0.0052
180	Pt: Auto/Sm Tk : Lt : MPFI : EuroII : PCV/Tank : <79K km	0.075
181	Pt: Auto/Sm Tk : Lt : MPFI : EuroII : PCV/Tank : 80-161K km	0.0417
198	Pt: Auto/Sm Tk : Lt : MPFI : EuroIV : PCV/Tank : <79K km	0.0085
199	Pt: Auto/Sm Tk : Lt : MPFI : EuroIV : PCV/Tank : 80-161K km	0.016
201	Pt: Auto/Sm Tk : Med : MPFI : EuroIV : PCV/Tank : <79K km	0.0152
202	Pt: Auto/Sm Tk : Med : MPFI : EuroIV : PCV/Tank : 80-161K km	0.007
211	Pt: Auto/Sm Tk : Med : MPFI : Hybrid : PCV/Tank : 80-161K km	0.0026
743	Ds: Auto/Sm Tk : Med : PC : None : None : >161K km	0.0125
759	Ds: Auto/Sm Tk : Med : Dir-Inj : EGR+Improv : None : <79K km	0.0095
760	Ds: Auto/Sm Tk : Med : Dir-Inj : EGR+Improv : None : 80-161K km	0.0281
761	Ds: Auto/Sm Tk : Med : Dir-Inj : EGR+Improv : None : >161K km	0.071
764	Ds: Auto/Sm Tk : Hv : Dir-Inj : EGR+Improv : None : >161K km	0.057
796	Ds: Auto/Sm Tk : Med : FI : EuroII : None : 80-161K km	0.0017
813	Ds: Auto/Sm Tk : Med : FI : EuroIV : None : <79K km	0.0147
1073	Ds: Truck/Bus Tk : Lt : PC : None : None : >161K km	0.0182
1076	Ds: Truck/Bus Tk : Med : PC : None : None : >161K km	0.0149

1079	Ds: Truck/Bus Tk : Hv : PC : None : None : >161K km	0.0195
1082	Ds: Truck/Bus Tk : Lt : Dir-Inj : Improv : None : >161K km	0.0041
1085	Ds: Truck/Bus Tk : Med : Dir-Inj : Improv : None : >161K km	0.007
1088	Ds: Truck/Bus Tk : Hv : Dir-Inj : Improv : None : >161K km	0.018
1207	Pt: SmlEng : Lt : 4Cyc Carb : None : None: 26-50K km	0.0359
1210	Pt: SmlEng : Med : 4Cyc Carb : None : None: 26-50K km	0.0043
1211	Pt: SmlEng : Med : 4Cyc Carb : None : None: >50K km	0.089

Where, Pt: Petrol/Gasoline, Ds: Diesel, SmlEng: Small Engine, Lt: Light. Med: Medium, Hv: Heavy, Carb: Carburetor, PCV: Positive Crankshaft Ventilation, FI: Fuel Injection, SgPt FI: Single Point fuel injection, PC: Pre-Chamber, MPFI: Multi Point Fuel Injection, EGR: Exhaust Gas Recirculation, 3Wy: 3-Way Catalyst, Dir-Inj: Direct Injection, 2Cyc: 2 Cycle, 4Cyc: 4 Cycle

4.3 Vehicle Kilometers Traveled (VKTs)

The total Vehicle Kilometers Travelled were calculated by multiplying the number of vehicles passing through Old Murree Road and Murree Expressway per day with their total lengths, which gave us the average/total Vehicle Kilometers Traveled by a particular class during that day.

4.4 Starting Patterns

The average number of daily startups and their time distribution (soakage pattern) was calculated using GPS and survey data. It was noted that, on average, a vehicle is started 5.9 times a day. These startup values were found lesser than Pune (7.02) (GSSR, 2004), Sao Paulo (6.1) (*Lents et al.*, 2004c). For the soakage patterns, soak bin 1 (4-15 minutes) had the highest share followed by soak bin 2, and so on. In this way, Soak bins 8-10 had the lowest share in the overall soakage pattern.

4.5 Vehicle Driving Pattern

4.5.1 Average Speed

The average speed on Murree Expressway was found to be 41.6 kilometer per hour and 44.9 kilometers per hour for downhill and uphill respectively. For Old Murree Road, it was found to be 46.2 kilometers per hour and 43.9 kilometers per hour for downhill and uphill respectively.

4.5.2 Average Trip Duration

The average trip duration was calculated using GPS Data and the average duration for Murree Expressway one sided trip was found to be 1 hour 21 minutes and 1 hour 15 minutes for downhill and uphill respectively. For Old Murree Road it was found to be 46 minutes and 48 minutes for downhill and uphill respectively. This difference average trip duration was because of the different lengths of the two roads.

4.5.3 Vehicle Specific Power Distribution

The lower (engine) stress modes (of the three stress modes) corresponds to the operating conditions where the vehicle is operated within lower speed and acceleration ranges within 20 seconds with low Rotations Per Minute (RPMs), whereas higher (engine) stress mode corresponds to high speed and accelerations of the vehicle for the last 20 seconds with high Rotations Per Minute (RPMs) (ISSRC, 2014).

The vehicle specific power of different vehicles was plotted against their relative share in the following graph:

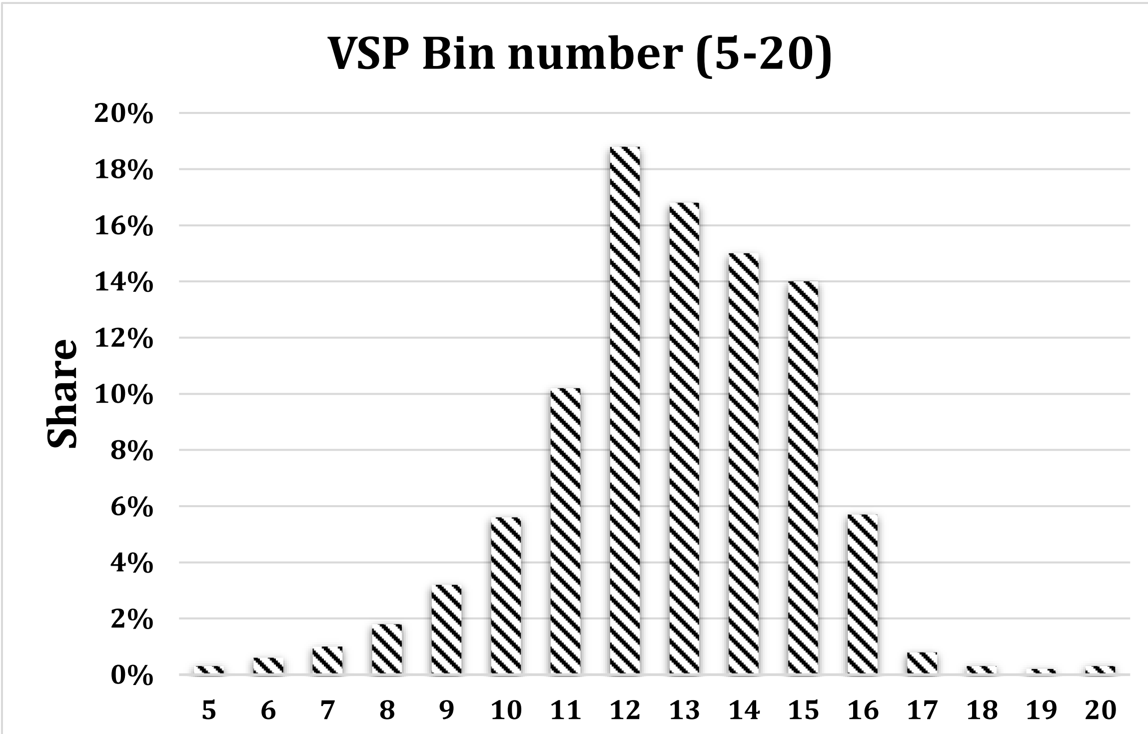


Figure 4.4: VSP distribution of vehicles

A majority of low engine stress modes was observed for the vehicle types in our study. VSP Bin number 12 which is in the range of low (engine) stress modes, had the most share of driving on both the roads. Bin number 1-11 represented conditions of deceleration i.e. stopping, slowing down or idling (due to congestion or traffic lights) or change of grade (slope) of the road etc. The Bin number 12 corresponded to very low power mode i.e. while idling at a traffic light etc. The Bin number 13 and above represented acceleration and more constant speeds etc. (*Lents et al.*,2004 c; Shrestha *et. al*., 2013).

4.6 IVE Model Based Emissions:

4.6.1 Composite Emission Factors

The composite Emission Factors were found to be the following:

Table 4.4: Pollutants and their respective emission factors

Pollutant	**Averaged Running Emission Factors (g per Kg)**
CO	26.467
VOC	2.374
NO_x	2.556
SOx	0.038
PM	0.46
1,3 Butadiene	0.005
Acetaldehydes	0.018
Formaldehydes	0.064
NH_3	0.057
Benzene	0.190
CO_2	214.909
N_2O	0.003
CH_4	0.404

The averaged running Emission Factor for Carbon Monoxide, VOC, NOx, SOx, Particulate Matter, 1,3-Butadiene, Acetaldehydes, Formaldehydes, Ammonia, Benzene, Carbon Dioxide, Nitrous Oxide and Methane were estimated to be 26.467 g/Kg, 2.374 g/Kg, 2.556 g/Kg, 0.038 g/Kg, 0.46 g/Kg, 0.005 g/Kg, 0.018 g/Kg, 0.064 g/Kg, 0.057 g/Kg, 0.19 g/Kg, 214.909 g/Kg, 0.003 g/Kg, and 0.404 g/Kg respectively. This shows that Carbon Dioxide has a major share in the Running Emission Factors.

Emission Factors are experimental values of pollutant emissions corresponding to the activity that produces them. The amount of pollutant emitted relative to the energy utilized for operation, fuel consumed, or distance travelled can be forecasted by these factors and are influenced by emission control equipment, ambient conditions, fuel characteristics, driving behaviors, and vehicle technology (Franco *et al.,* 2013).

4.6.2 Overall Daily Emission Shares (Starting/Running)

The overall Daily Emission shares for starting and running of the engines were the following:

Pollutant	Starting (kgs)	Running (kgs)	Relative Share (%)
CO_2	622.9	54262	86.82
CO	504.5	6254.9	10.69
NO_x	32	620.8	1.03
VOC	47.4	559.2	0.96
PM	17.92	99.54	0.186
CH_4	7.69	95.5	0.16
Benzene	3	45.46	0.077
Formaldehydes	2.11	14.2	0.026
NH_3	0.69	13.74	0.023
SOx	0.14	9.46	0.015
Acetaldehydes	0.58	4.08	0.007
1,3 Butadiene	0.17	1.17	0.002
N_2O	0.04	0.68	0.001

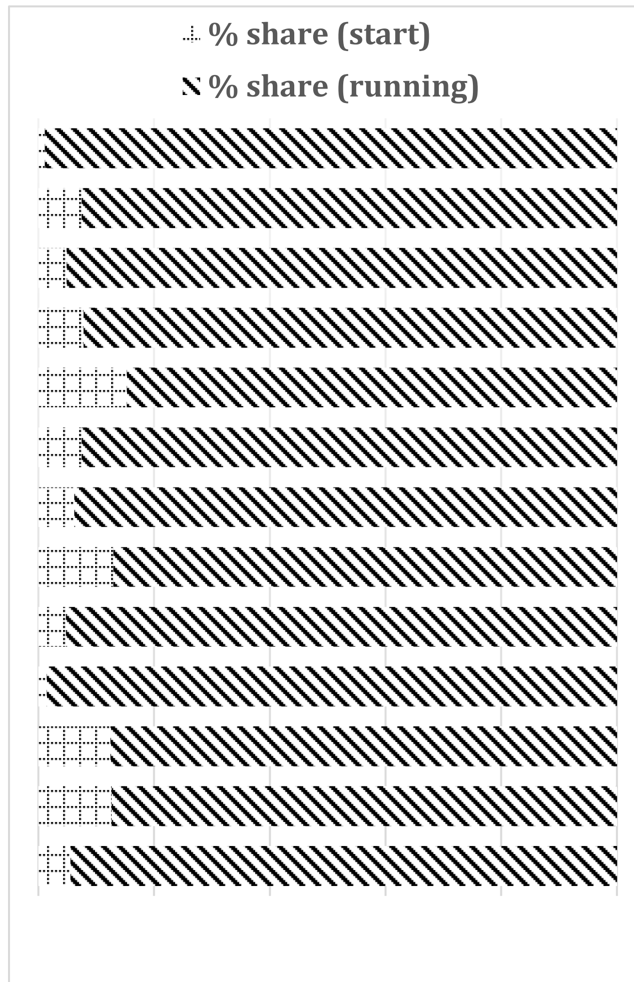


Table 4.5: Daily emission shares for each pollutant

Figure 4.5: Percentage running and start share for pollutants

The above data shows that most of the pollutant emissions are caused by the running of the engines, the emissions caused by the starts are far lesser. It also shows that Carbon Dioxide and Carbon Monoxide have the largest share amongst the pollutants emitted by the vehicles.

4.6.3 Annual Emissions:

The annual emissions were estimated to be the following

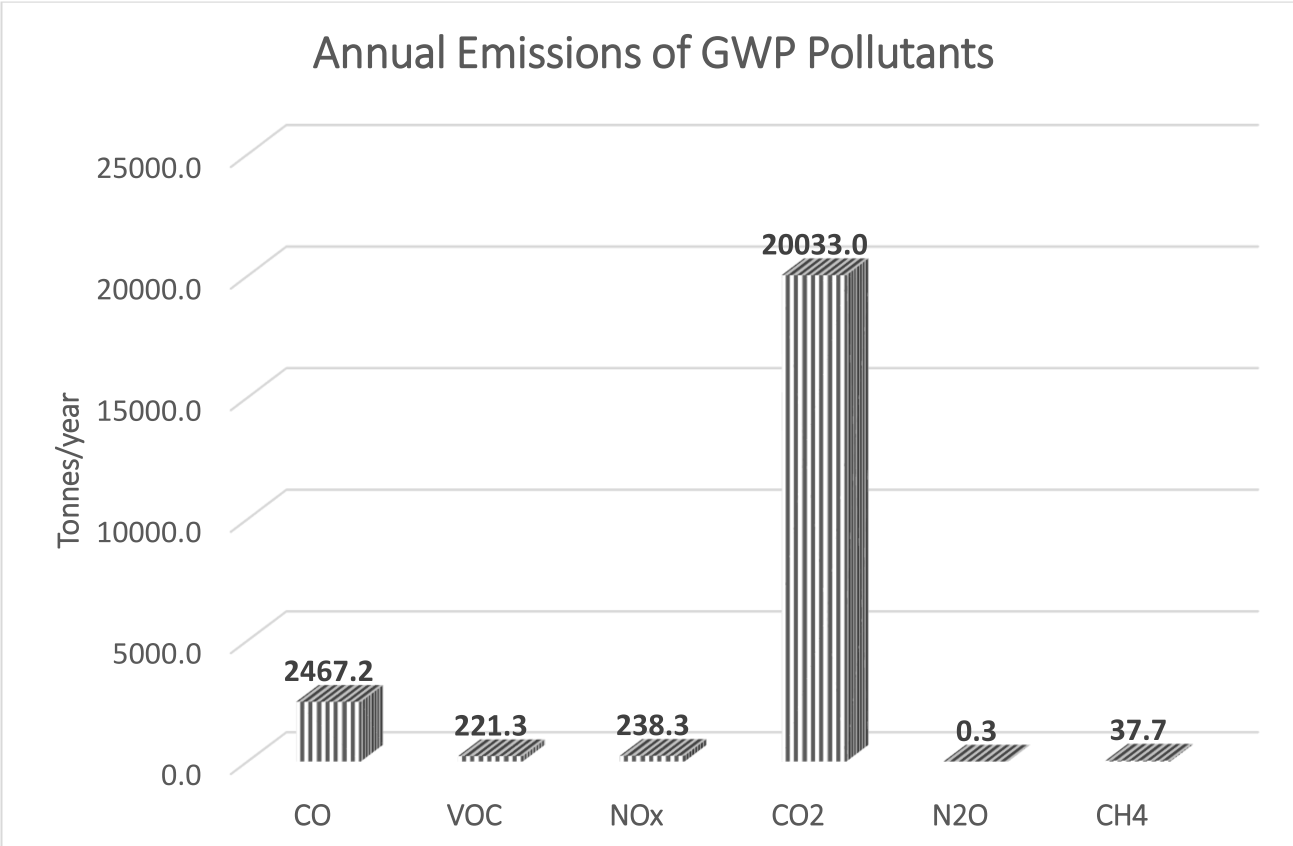
Table 4.6: Annual Pollutant Emissions

Pollutant	Annual Emissions (tonnes)
CO_2	20033.0
CO	2467.2
NO_x	238.3
VOC	221.3
PM	42.9
CH_4	37.7
Benzene	17.7
Formaldehydes	6.0
NH_3	5.3
SOx	3.5
Acetaldehydes	1.7
1,3 Butadiene	0.5
N_2O	0.3

The annual emissions also show that Carbon Dioxide and Carbon Monoxide have the largest share in the overall emissions, amounting to 20033 tonnes or 20 Kilo tonnes and 2467.2 tonnes or 2.467 Kilo tonnes respectively.

The annual Global Warming Emissions in tonnes/year were depicted in the following bar chart.

Figure 4.6: Annual GWP pollutant emissions

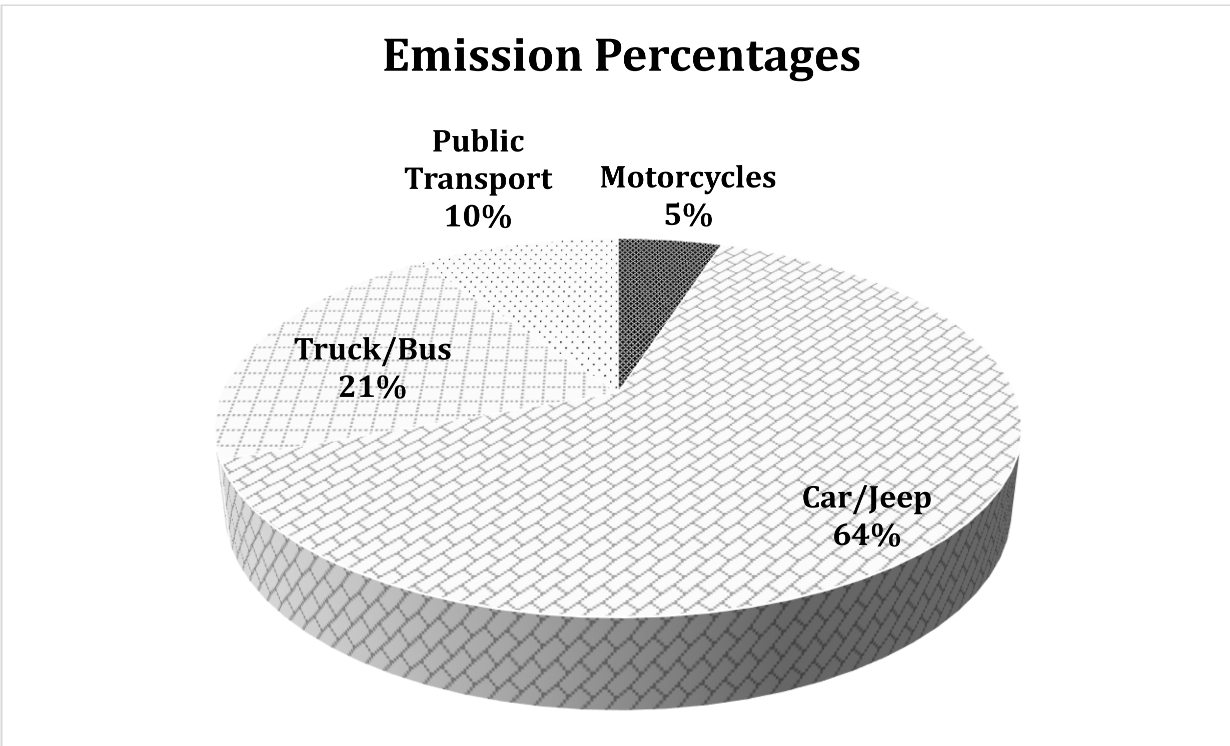


The bar chart clearly shows Carbon Dioxide has the largest share of 20,033 tonnes, followed by Carbon Monoxide with 2467 tonnes, Oxides of Nitrogen with 238 tonnes, Volatile Organic Compounds with 221 tonnes, Methane with approximately 38 tonnes and Nitrous Oxide with 0.3 tonnes of annual emissions.

4.6.3.1 Annual Emissions by Vehicle Type

The annual emissions were then separated by vehicle type showing the percentage of emissions released by each vehicle.

Figure 4.7: Emissions by vehicle type



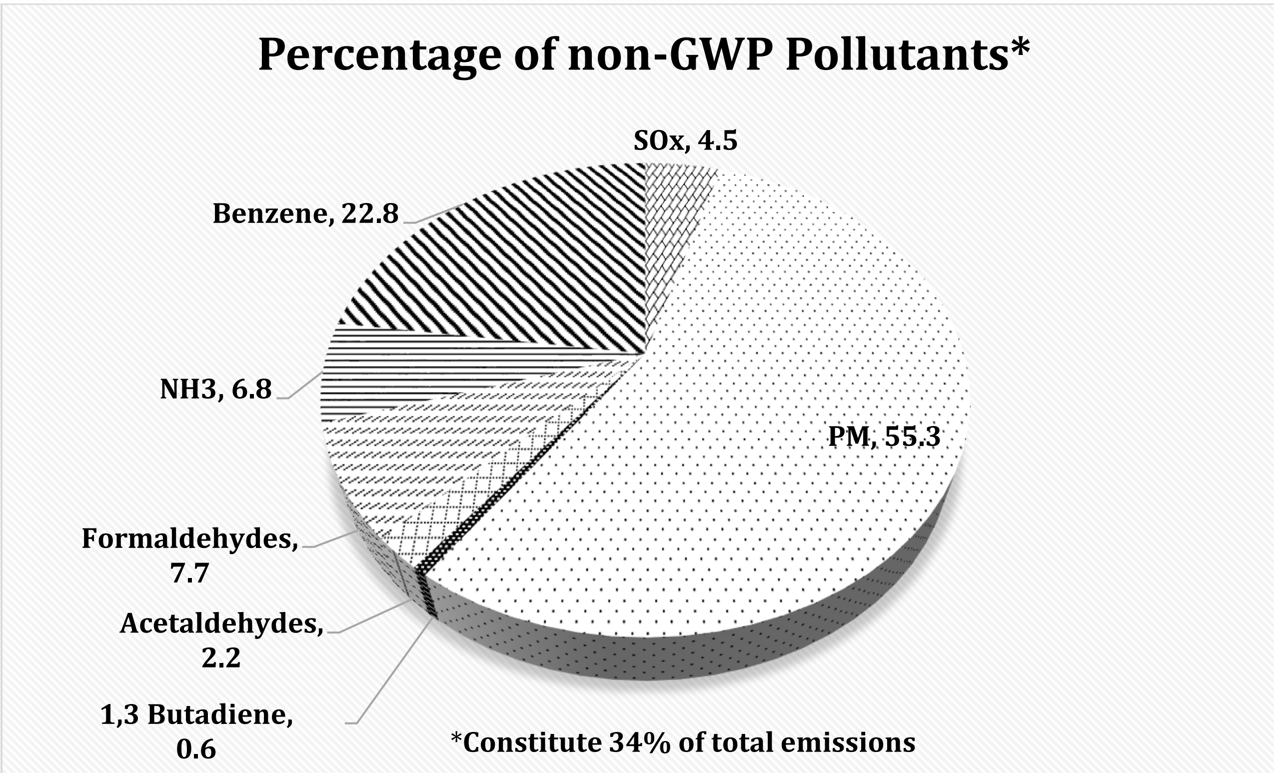
The pie chart clearly illustrates that cars/jeeps are the most polluting category contributing to 64% of overall emissions released, trucks/buses follow with 21% of pollutant emissions, public transport releasing 10% of emissions and motorcycles trailing with a contribution of only 5%.

This justifies the sharp decrease in emissions by decreasing the number of vehicles or moving towards better technology, especially for cars.

4.6.4 Non-Global Warming Potential Pollutant Emissions Distribution

Pollutants other than the Global Warming Potential pollutants were classified into a pie chart to illustrate their various shares.

Figure 4.8: Non-GWP pollutant emission percentages



Of the 34% of non-Global Warming Potential pollutant emissions, Particulate Matter had the highest share of 55.3 %, followed by Benzene with a share of 22.8 %, Formaldehydes with 7.7 %, Ammonia with 6.8 %, Oxides of Sulfur with 4.5 %, Acetaldehydes with 2.2 %, and 1,3 Butadiene with the least share of 0.6 % of total emissions.

4.7 Global Warming Potential Estimation and Reduction

4.7.1 Estimation of Global Warming Potential

The Global Warming Potential of the pollutants was calculated using the method explained earlier to generate the Carbon Dioxide Equivalent emissions in tonnes for 20 years and 100 years.

The existing Carbon Dioxide Equivalent emissions are listed in the figure below.

Table 4.7: The Carbon Dioxide Equivalent emissions for 20 years and 100 years

Pollutant	Global Warming Potential (20 years)	Global Warming Potential (100 years)	CO_2 Equivalent Tons (20 years)	CO_2 Equivalent Tons (100 years)
CO_2	1	1	20033	20033
N_2O	268	298	71.4	79.4
CH_4	72	25	2712.4	941.8
CO	6	2	14803.1	4934.4
VOC	14	4.5	3098.3	995.9
NO_x	43	28	10246	6671.8
Total	-	-	50964.1	33656.2

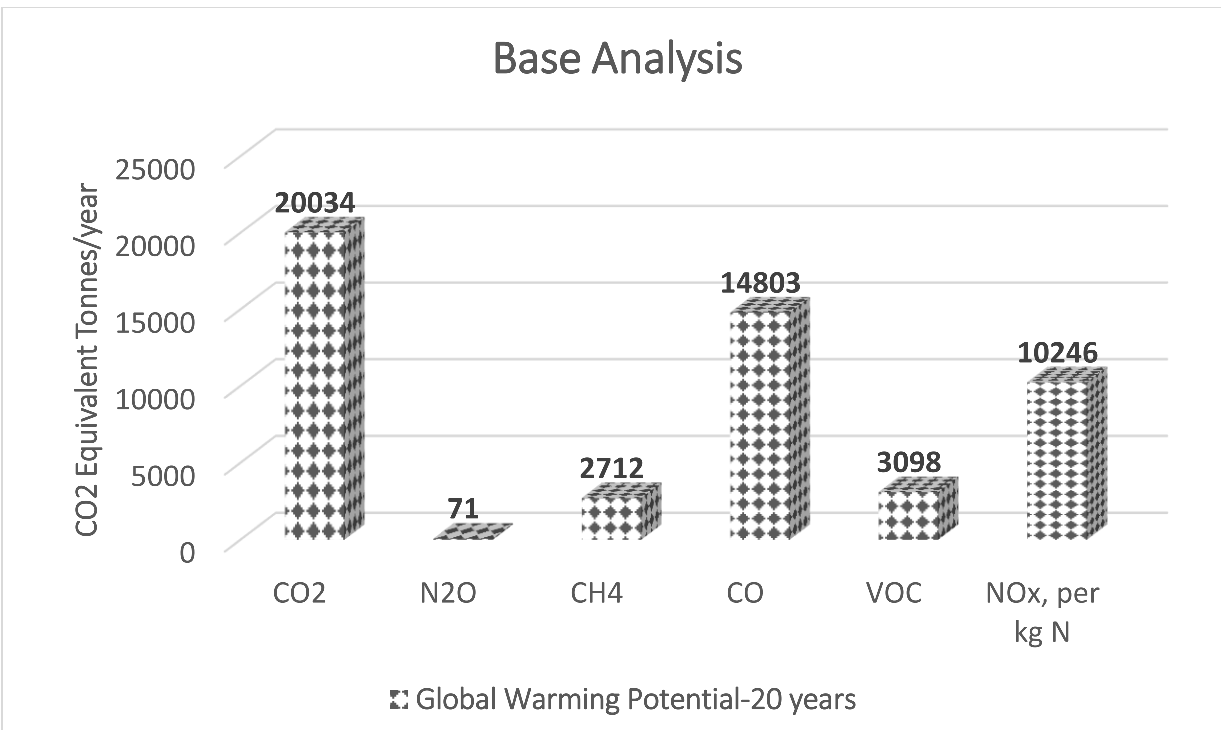
The existing situation yields a total of 50,964 Carbon Dioxide Equivalent Tonnes for 20 years and 33, 656 Carbon Dioxide Equivalent Tonnes for 100 years where the highest share of Carbon Dioxide Equivalent Tonnes for 20 years is 20,033 tonnes of Carbon Dioxide, followed by Carbon

Monoxide with 14,803 tonnes, Oxides of Nitrogen with 10,246 tonnes, Volatile Organic Compounds with 3098 tonnes, Methane with 2712 tonnes and Nitrous Oxide with 71 tonnes.

Similarly, in the Carbon Dioxide Equivalent Tonnes for 100 years the highest share of Carbon Dioxide Equivalent Tonnes for 100 years is 20,033 tonnes of Carbon Dioxide, followed by Oxides of Nitrogen with 6672 tonnes, Carbon Monoxide with 4934 tonnes, Volatile Organic Compounds with 996 tonnes, Methane with 942 tonnes and Nitrous Oxide with 79 tonnes.

The following chart displays the GWP pollutant emissions.

Figure 4.9: Carbon Dioxide Equivalent Tonnes per year for different GWP pollutants



4.7.1.1 Occupancy Rate Scenario

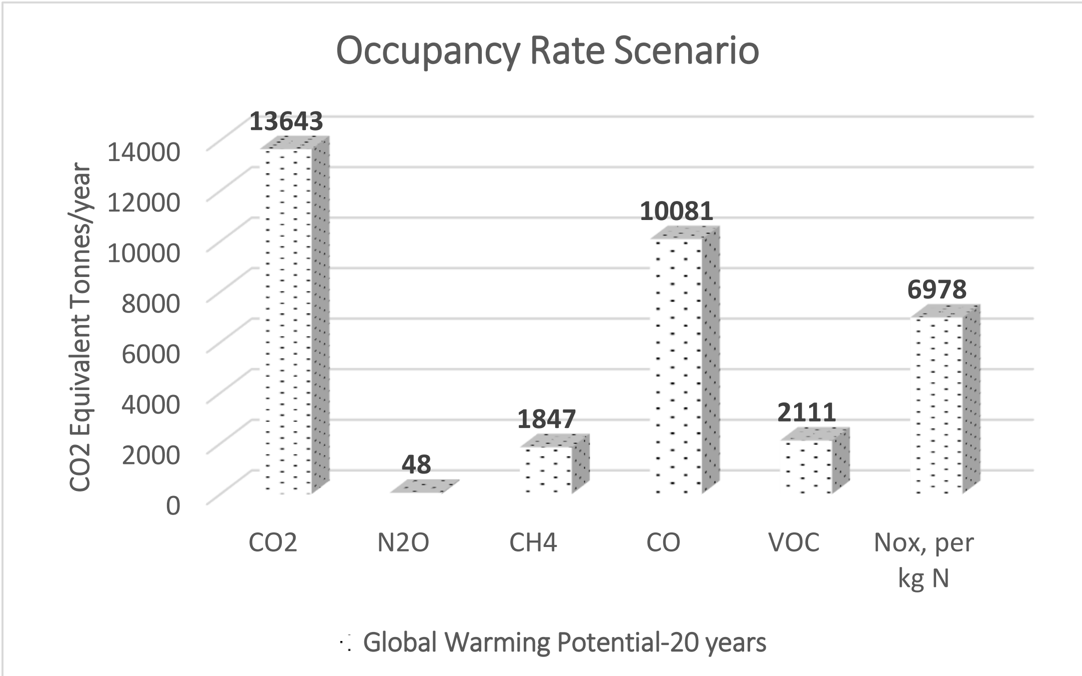
To decrease the number of vehicles on road the occupancy rate was increased from the existing value to 98 % for cars/jeeps and vans/hi-aces thus decreasing the number of vehicles travelling to Murree. Therefore, the existing fleet of 5119 was decreased to 3486 vehicles with a decreased startup value of 14498 as well. This resulted in a significant GWP reduction as evidenced in the table below.

Table 4.8: The Carbon Dioxide Equivalent emissions for 20 years and 100 years for Occupancy Rate Scenario

Pollutant	CO_2 Equivalent Tons (20 years)	CO_2 Equivalent Tons (100 years)	Percentage Reduction (%)
CO_2	13642.97	13642.97	31.90
N_2O	47.93	53.30	32.88
CH_4	1847.22	641.4	31.90
CO	10081.23	3360.41	31.90
VOC	2110.74	678.45	31.87
NO_x	6977.68	4543.61	31.90
Total	34707.77	22920.13	31.90

As the on-road vehicles were decreased by a specific number, the percentage reduction was also observed to be approximately 32 % and 33 % for all with an overall percentage reduction of 32%.

Figure 4.10: Carbon Dioxide Equivalent Tonnes for Occupancy Rate Scenario



The bar chart shows that Carbon Dioxide has the highest CO_2 Equivalent Emissions of 13643 tonnes, followed by Carbon Monoxide with 10081 tonnes, Oxides of Nitrogen with 6978 tonnes, Volatile Organic Compounds with 2111 tonnes, Methane with 1847 tonnes and Nitrous Oxide with 48 tonnes.

4.7.1.2 Euro II Scenario

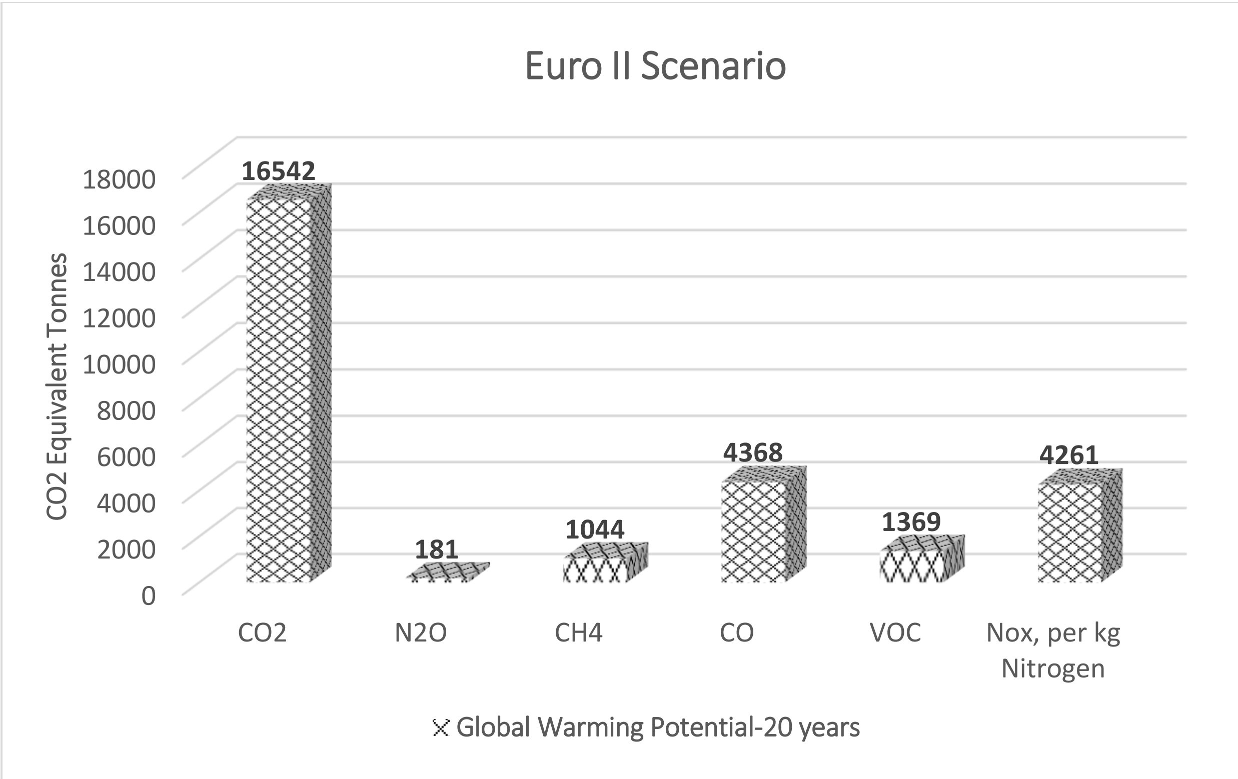
In the second scenario, all existing vehicles were upgraded to comply with Euro II standards as a minimum. This means that cars should meet Euro II standards at least while trucks should meet Euro III standards. This showed a substantially greater GWP reduction than the Occupancy Rate Scenario.

Table 4.9: The Carbon Dioxide Equivalent emissions for 20 years and 100 years for Euro II Scenario

Pollutant	CO_2 Equivalent Tons (20 years)	CO_2 Equivalent Tons (100 years)	Percentage Reduction (%)
CO_2	16542.01	16542.01	17.43
N_2O	180.97	201.22	-153.42
CH_4	1043.58	362.35	61.53
CO	4368	1456	70.49
VOC	1368.76	439.96	55.82
NO_x	4260.88	2774.53	58.41
Total	27764.2	21776.07	45.52

The table shows that the highest percentage reduction was observed in Carbon Monoxide, followed by Methane, Oxides of Nitrogen, Volatile Organic Compounds, and Carbon Dioxide while Nitrous Oxide increased due to complete combustion. An overall percentage decrease of 46% was observed which is significantly greater than the 32% decrease obtained in the Occupancy Rate Scenario.

Figure 4.11: Carbon Dioxide Equivalent Tonnes for Euro II Scenario



The bar chart clearly shows Carbon Dioxide has the highest CO_2 Equivalent Emissions of 16542 tonnes, followed by Carbon Monoxide with 4368 tonnes, Oxides of Nitrogen with 4261 tonnes, Volatile Organic Compounds with 1369 tonnes, Methane with 1044 tonnes and Nitrous Oxide with 181 tonnes. The slightly higher Carbon Dioxide and Nitrous Oxide values are due to the better technology being used which assumes better combustion and conversion of pollutants.

4.7.1.3 Euro IV Scenario

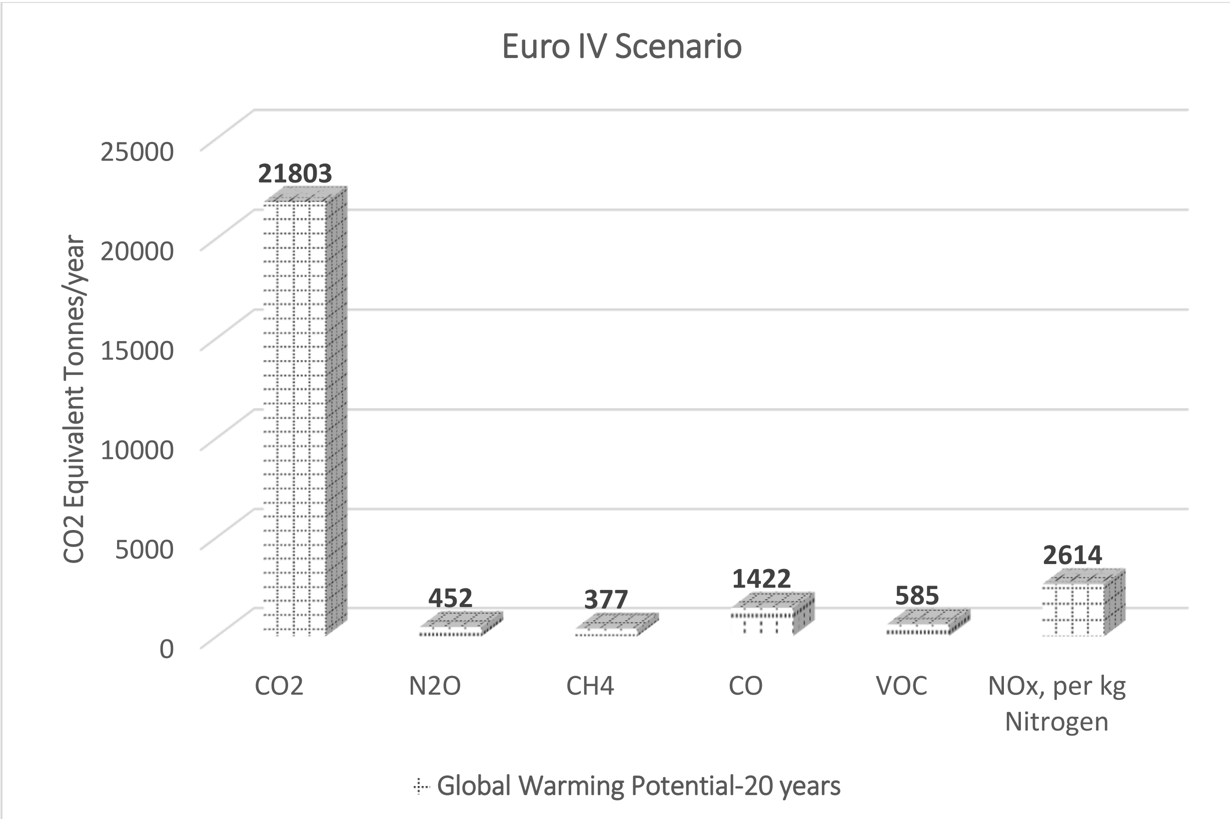
All existing vehicles were upgraded to comply with Euro IV standards as a minimum while the number of on road vehicles remained the same. This means that cars should meet Euro IV standards at least while trucks should meet Euro V standards. This showed a greater GWP reduction than the Occupancy Rate Scenario or Euro II scenario.

Table 4.10: The Carbon Dioxide Equivalent emissions for 20 years and 100 years for Euro IV Scenario

Pollutant	CO_2 Equivalent Tons (20 years)	CO_2 Equivalent Tons (100 years)	Percentage Reduction (%)
CO_2	21802.96	21802.96	-8.84
N_2O	451.93	502.52	-532.88
CH_4	376.86	130.85	86.11
CO	1422.43	474.14	90.39
VOC	584.53	187.89	81.13
NO_x	2614.47	1702.45	74.48
Total	27253.17	24800.80	46.52

The table shows that the highest percentage reduction was observed in Carbon Monoxide, followed by Methane, Volatile Organic Compounds, and Oxides of Nitrogen, while Carbon Dioxide and Nitrous Oxide increased due to the assumption that complete combustion occurs along with the catalytic converters used that work at high efficiencies. An overall percentage decrease of 47% was observed which is greater than the 32% decrease obtained in the Occupancy Rate Scenario and 46% obtained in Euro II scenario.

Figure 4.12: Carbon Dioxide Equivalent Tonnes for Euro IV Scenario

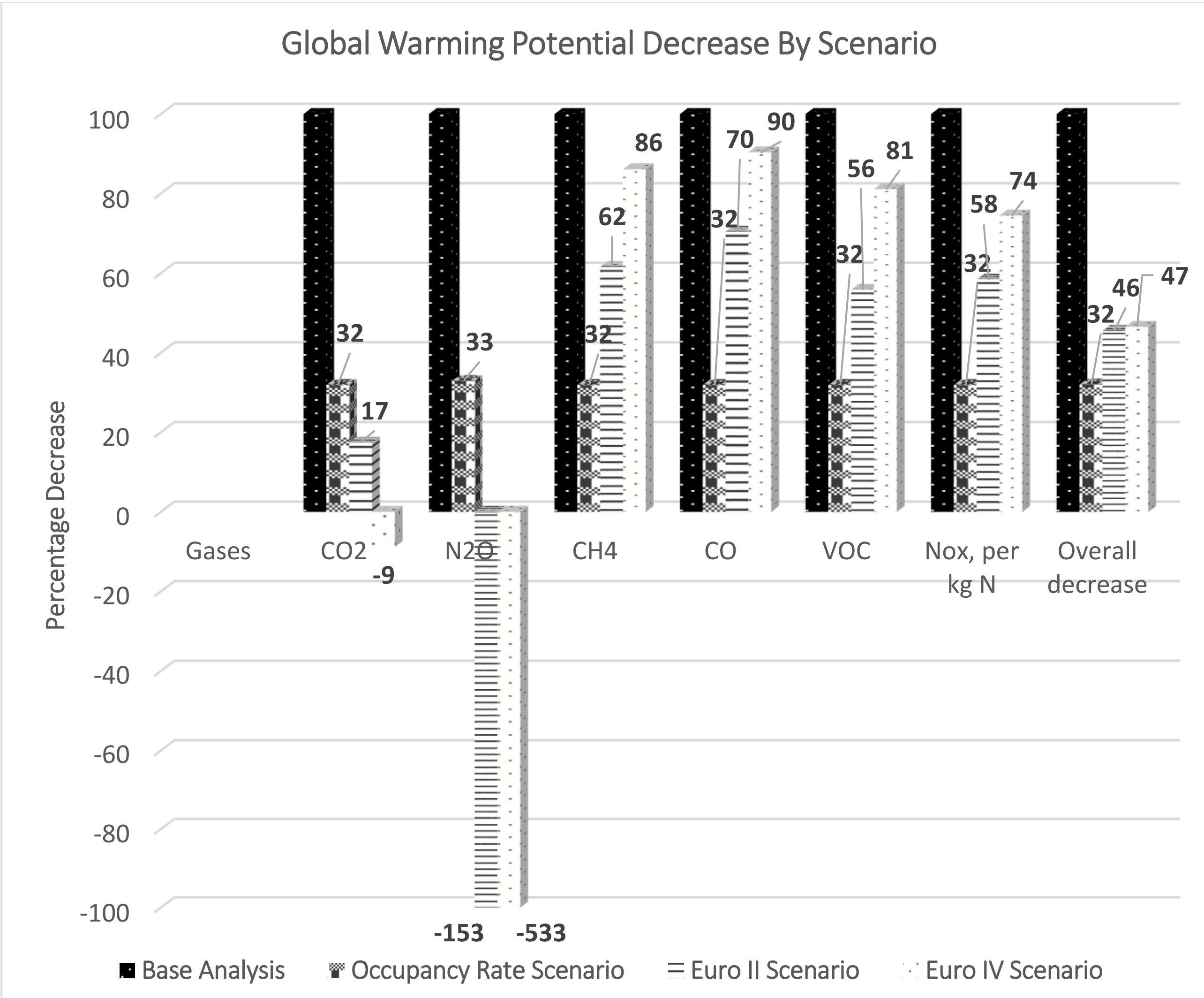


The bar chart clearly shows Carbon Dioxide has the highest CO_2 Equivalent Emissions of 21803 tonnes, Oxides of Nitrogen with 2614 tonnes, followed by Carbon Monoxide with 1422 tonnes, Volatile Organic Compounds with 585 tonnes, Nitrous Oxide with 452 tonnes and Methane with 377 tonnes.

4.7.1.4 GWP Percentage Decrease by Scenario

The GWP percentage decrease in each scenario were then compared for all pollutants resulting in the following bar chart.

Figure 4.13: GWP decrease by scenario



This bar chart illustrates the pollutant decrease in each scenario followed by the overall decrease. Carbon Dioxide and Nitrous Oxide showed the greatest decrease when the occupancy rate was optimized while Methane, Carbon Monoxide, Volatile Organic Compounds, and Nitrogen Oxides decreased the most when complying with Euro 4 standards. The greatest overall decrease was therefore found to occur in the Euro 4 scenario.

Conclusions and Recommendations

5.1 Conclusions

The greatest decrease in Nitrous Oxide & Carbon Dioxide emissions was found to be in the Occupancy Rate Scenario with a 33% and 32% decrease in the CO_2 Equivalent emissions, respectively as compared to business as usual scenario.

For Methane, Carbon Monoxide, Volatile Organic Compounds & Oxides of Nitrogen: All four pollutants showed the greatest decrease in emissions in the Euro IV implementation scenario with a percentage decrease of 86%, 90%, 81% and 74% respectively.

5.2 Recommendations

To decrease Carbon Dioxide and Nitrous Oxide emissions, steps must be taken to improve occupancy rates for tourists travelling to Murree by introducing methods such as High Occupancy Vehicle Lanes to decrease the number of vehicles on road.

To significantly reduce emissions of Methane, Carbon Monoxide, Volatile Organic Compounds and Oxides of Nitrogen, strict compliance with Euro IV emission standards is recommended.

Furthers studies exploring the role of mass transit such as a better bus network, or tour buses are also recommended.

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